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Fossils on Mars? A "Cambrian Explosion" and "Burgess Shale" in Gale Crater?

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Abstract

An array of formations resembling the fossilized remains of Ediacaran and Cambrian fauna and other marine organisms have been observed embedded atop sediments in the dried lake beds of Gale Crater, Mars. Specimens similar and diverse in morphology have been found together and upon adjacent and nearby rocks and mudstone. These include forms morphologically similar to polychaete and segmented annelids, tube worms, "*Kimberella*," crustaceans, lobopods, chelicerates, *Haplophrentis carinatus*, and the "ice-cream-cone-shaped" "*Namacalathus*" and "Lophophorates" and other biomineralized metazoans. All specimens may have dwelled in a large body of water and fossilized/mineralized following the rapid receding of these waters. Statistical quantitative micro- and macro- morphological comparisons with analog organisms from Earth support the fossil-hypothesis. It is not likely so many similar and diverse specimens, side by side, oriented differently, some on top of each other, were fashioned via abiogenic forces such as wind, mineralization, crystallization, dried mud, or water-erosion scenarios as there are no terrestrial abiogenic analogs. Interplanetary transfer of life may explain the parallels with Earth. Collectively these putative fossils may represent the equivalent of a "Cambrian Explosion" and the remnants of Martian organisms that long ago flourished in the lakes and inland seas of Gale Crater.

Keywords: Mars • Martians • Life on mars • Fossils on mars • Burgess shale on mars

Introduction

Fossils in the Dried Lake Beds of Gale Crater?

In this report we present a vast array of forms, many resembling the fossilized remains of Ediacaran and Cambrian fauna, embedded atop the surface of sediments in the dried lake beds of Gale Crater, Mars. These include specimens similar to "*Kimberella*" and the "ice-cream-cone-shaped" "Lophophorates," and "*Namacalathus*" as well as polychaete and segmented annelids, tube worms, crustaceans, lobopods (e.g. *Hallucigenia*, *Marrella splendes*) chelicerates, and possibly *Haplophrentis carinatus* and others that first evolved, on Earth, during the Ediacaran and Cambrian Epochs. Gale Crater specimens resembling fossilized concentric stromatolites [1-3], sponges and corals [4,5] and tubular formations interpreted as possible tube worm ichnofossils [6-8] have also been previously reported. If most of these fossil-like specimens are biological these assemblages could represent veritable "Burgess Shale" in Gale Crater which provided an environment conducive to the formation of fossils [9-10].

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Are these in fact, fossils? It is possible that several or all these formations are abiogenic, perhaps formed via the movement of fluidized sediment coupled with water-erosion [11]. Gale Crater rocks may be more resistant to erosion than overlying, albeit embedded deposits that may include mud that upon drying has formed unusual elevated concentric and eccentric layers and patterns [11,12]. The buildup of minerals, metals, crystals, may also take unusual shapes. Therefore, it could be argued that the fossil-like structures reported here and in earlier reports, including those interpreted as concentric stromatolites similar to those of Lake Thetis Australia [1,13] are evidence of abiogenic and aqueous processes that have played a major role in the surface geology of Mars. However, there are no abiogenic terrestrial analogs and thus, the abiogenic explanation must be classified as speculation.

What appear to be "fossils" could be illusions, much like seeing familiar shapes in overhead clouds. The problem with the "imaginative cloud" interpretation is so many diverse and nearly identical forms are morphologically similar to those of Earth, and most appear within a few cm of each other and on substrates located in multiple locations in Gale Crater and other areas of Mars. For example, what may be tube worm and worm tube ichnofossils have been observed upon the dried lake bottom of not just Gale Crater [5-8] but Meridiani Planum [13] and Endurance Crater which may have hosted a lake or sea heated by thermal vents [14,15]. Likewise, specimens resembling microbialites and stromatolites have been observed in Gale Crater and other areas of Mars [16-21].

Regardless of their shifting shapes, clouds also contain moisture. Water would also sustain life. Likewise, the fossil-like forms depicted in this and in earlier reports, appear to be similar to water dwelling organisms that flourished during the Ediacaran and Cambrian epochs on Earth. That Gale Crater has hosted lakes and large bodies of water is accepted by most investigators

[14,15,22-24]; waters that may have rapidly receded at some later date [4,25]; perhaps when axial tilting waned to below a critical tipping point [26-28]. Rampe EB, et al. [29] has argued that Gale Crater may have last hosted a lake relatively recently, though when that was, is unknown.

There is considerable evidence that because Mars does not have a stabilizing moon, the axial tilt of the Red Planet can periodically exceed 60 to 80 degrees [26-29,30]. This increase in axial orientation is believed to be responsible for raising temperatures and atmospheric pressure and the melting of polar and surface/subsurface glaciers such that massive bodies of water flooded across the surface--and forming rivers, lakes, and oceans that may have endured for hundreds of thousands to hundreds of millions of years [4,31-33]. A conservative estimate is that the last episode came to a close as recently as 110,000 to 400,000 years ago [27,28].

A large body of published evidence by over 30 investigators supports the hypothesis that a variety of organisms flourished and evolved in those waters [1-7,13-18,20,21,25,34-36]. It is our hypothesis that the fossil-like forms reported here may include bottom dwelling (benthic) and free-swimming (nectonic) organisms that likely survived by filter feeding or upon the organic content drifting down and accumulating on the floor of Gale Crater lake, or via predation or the scavenging of dead organisms.

Possibly, as the axial tilt of Mars diminished and the critical tipping point was reversed these large bodies of surface water suddenly retreated, evaporated and reformed surface and subsurface glaciers [4,27-28]. And then the cycle would repeat [27,28,37-39]. In consequence, rocks and sediments may have broken apart and/or were carried great distances by storm surges and receding floods, whereas any organisms dwelling in these rapidly receding and falling levels of water would have been deposited upon rapidly drying lake, river and ocean bottoms where they decomposed or became covered with mud and debris and were then fossilized/mineralized. These catastrophic conditions would have also triggered the mass extinction of most marine organisms.

A Mars' Cambrian Explosion?

McKay CP [40] may have been the first to propose the hypothesis that life on Mars evolved and experienced a "Cambrian Explosion." According to Hartman and Mckay CP [41] "Given the similarity of the environments on the early Mars and early Earth it is plausible that life originated on Mars and oxygenic photosynthesis also began there at a very early stage through the action of photochemically produced oxidants." McKay CP [40] then proposed that "after the origin of life the key evolutionary steps could have occurred much more rapidly on Mars than on Earth" and that over a billion years ago, Mars may have "experienced the range of biological evolution that would be duplicated on the Earth only with the start of the Cambrian."

The array of fossil-like specimens that were photographed by NASA's Mars rover Curiosity in Gale Crater on Sols 0302, 0553, 0808, 0809, 0869, 0880, 0905, 1032, 1921 provide strong support for the hypothesis put forward by McKay CP [40], Grotzinger JP, et al. [9-10]. Many are strikingly similar to fossils embedded in the Burgess Shale which formed during the Cambrian Era, over 500,000,000 years ago.

A Sample: Gale Crater Specimens from Sols 302, 553, 808, 809, 869, 880, 905, 1032, 1921

Some of the array of fossil-like forms in photographs presented here lack an ideal resolution, but are included for illustrative purpose. Fortunately, the specimens in the majority of photographs are clearly visible thanks, in part, to Fotor image enhancement software which enabled the authors to magnify these images, and alter color and contrast to sharpen detail. All specimens were photographed in Gale Crater.

Because of depth of field and angle and distance from the camera the inclusion of "scale bars" would be deceptive and misleading. The graphic scale in mastcam images cannot be obtained from information NASA makes available. We estimate that the size of the majority of these specimens range

I. The Putative Fossils of Sol 0553MR0022370010303889E01_DXXX

Figure 1. Sol 0553. An assemblage of fossils like forms ranging from 1-5 mm in size as also depicted in Figures 2-6.

Figure 2. Sol 0553. Magnified section of Figure 1. An assemblage of fossils like forms ranging from 1-5 mm in size.

Figure 3. Sol 0553. Magnified section of Figure 1. An assemblage of fossils like forms ranging from 1-5 mm in size.

Figure 4. Sol 0553. Magnified section of Figure 1. An assemblage of fossils like forms ranging from 1-5 mm in size.

Figure 5. Sol 0553. Magnified section of Figure 1. An assemblage of fossils like forms ranging from 1-5 mm in size.

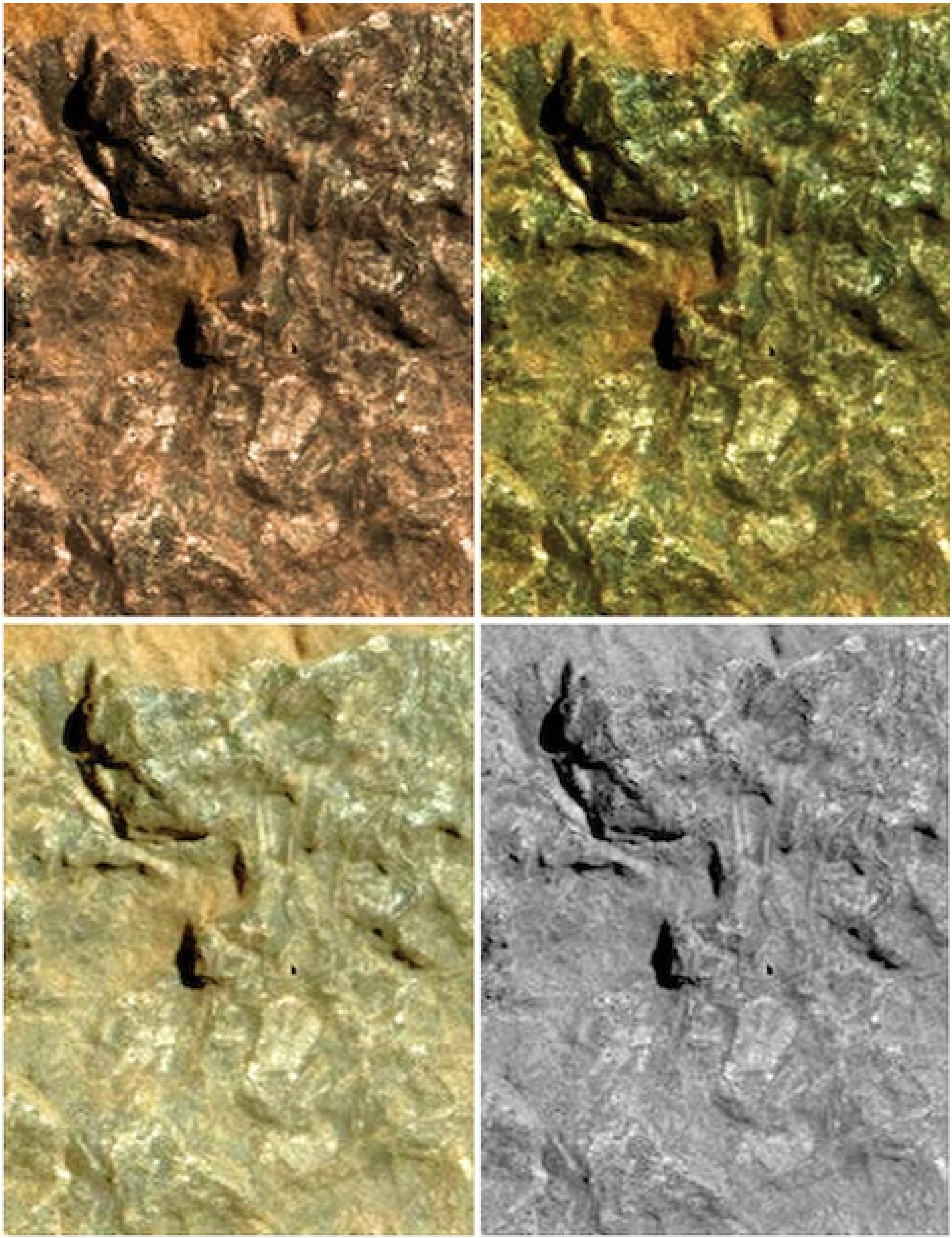

Figure 6. Sol 0553. Magnified color saturated/desaturated section of Figure 1. An assemblage of fossils?.

II. Morphological Comparisons: Gale Crater, Sols 553, 809, 869, 880, 905

Figure 7. (Mars left): Gale Crater. Sol 809. (Earth center): Namacalathus. (Mars right): Gale Crater Sol 869. Arrows indicate open apertures.

Figure 8. "Ice-cream cone" fossil-like formations. Middle Left: 0880MH0004620000302350R00_DXXX. Middle Right: 0553MR0022370010303889E01_DXXX. Bottom Row: 0880MH0004620000302350R00_DXXX / 0553MR0022370010303889E01_DXXX.

Figure 9. Sol 0809. An assemblage of fossils like forms ranging from 1-5 mm in size.

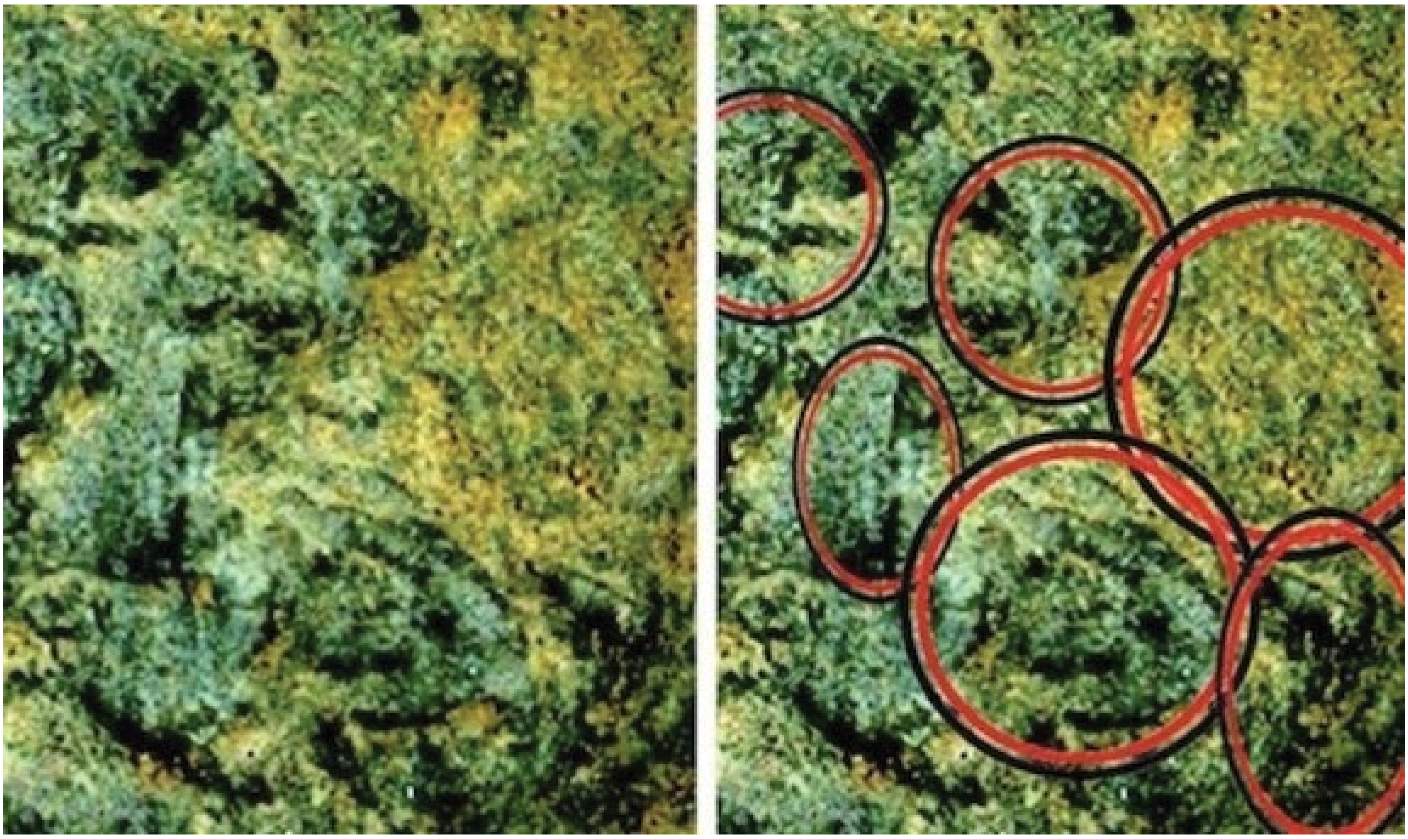

Figure 10. Sol 0809. An assemblage of fossils like forms ranging from 1-5 mm in size.

Figure 11. (First row): Sol 809 and Sol 869. (Second row) Sol 905 and Sol 905. Specimens photographed in Gale Crater and that are quantitatively and statistically significantly similar to Ediacaran fossils of Namacalathus (Earth, Bottom Row) Cambrian fossils of Lophotrochozoa (three bottom right). Photos of Namacalathus reproduced from and courtesy of Kontorovich A E, et al. [42]. Photos of Lophotrochozoa reproduced from and courtesy of Zhang ZF, et al. [43]

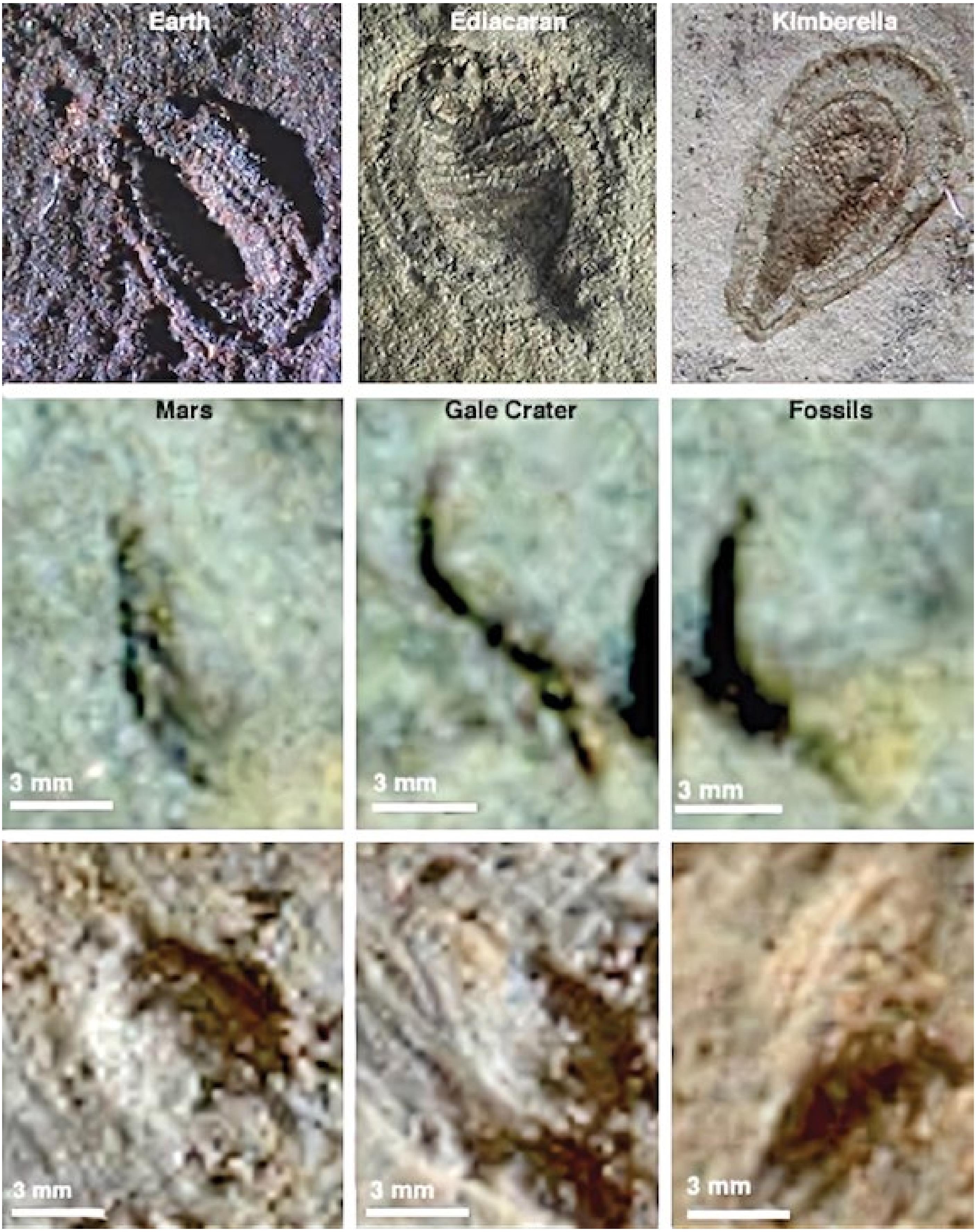

Figure 12. Earth (First row) fossilized remains of Ediacaran Kimberella. (Mars, Bottom two rows): Specimens photographed in Gale Crater, quantitatively and statistically indistinguishable from Ediacaran fossils of *Kimberella*. Sol 809, Sol 809, Sol 809; Sol 880, Sol 905, Sol 905. Note proboscis and pleopod appendages.

III. The Fossils of SOL 0808MH0004460020300780C00_DXXX

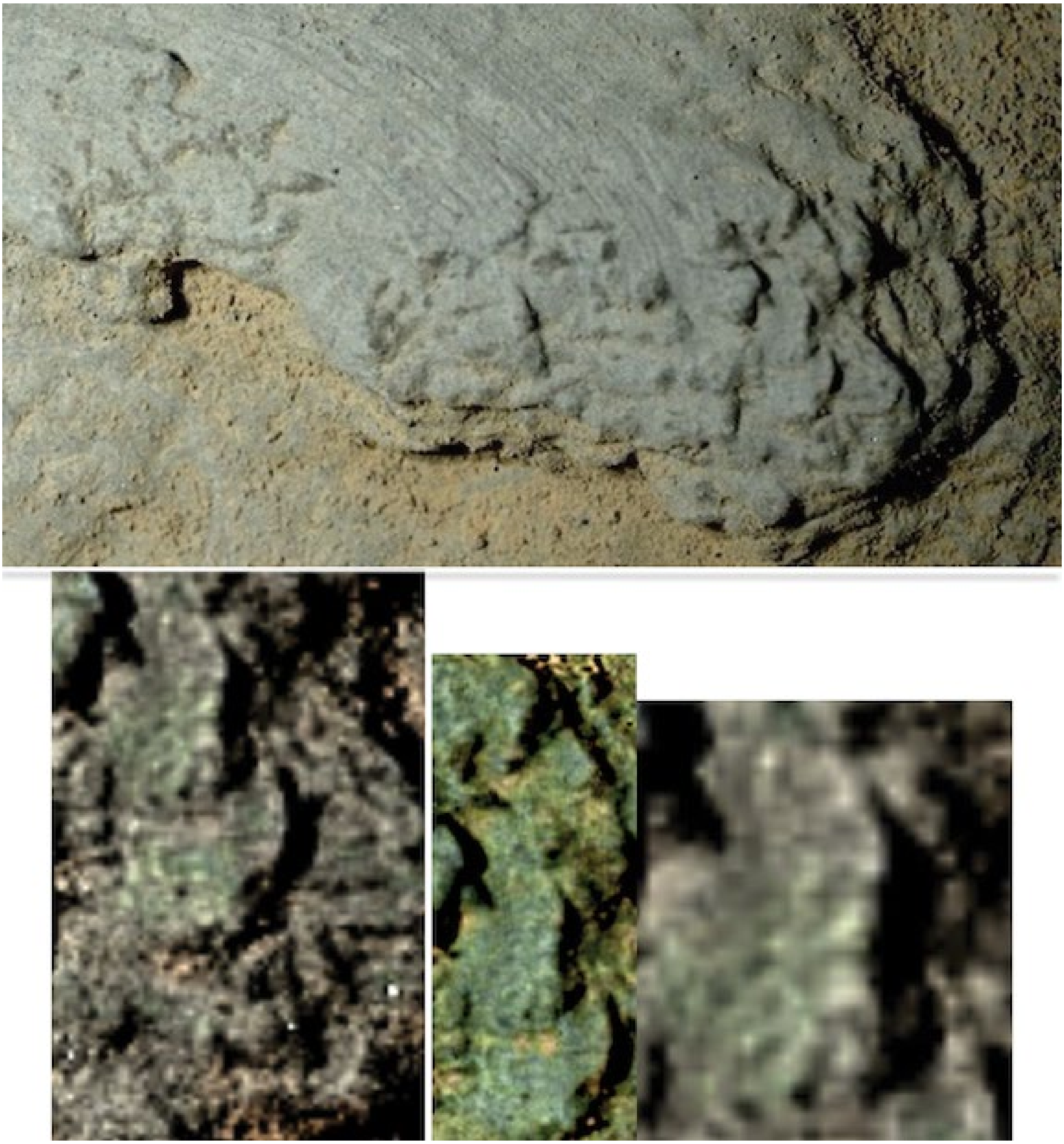

Figure 13. Sol 808. Fossil like specimens approximately 1-2 mm in length (808MH0004460020300780C00_DXXX).

IV. The Putative Fossils of SOL 809MH0001710000300846R00_DXXX

Figure 14. Sol 809. An assemblage of fossil-like forms that resemble several "Kimberella," and the "ice-cream-cone-shaped" specimens.

Figure 15. Sol 809. An assemblage of fossil-like forms that resemble segmented worms, and several "*Kimberella,*" and "ice-cream-cone-shaped" specimens (809MH0001710000300846R00_DXXX).

Figure 16. Sol 809. An assemblage of fossil-like forms that resemble segmented "*Kimberella,*" and other organisms (809MH0001710000300846R00_DXXX).

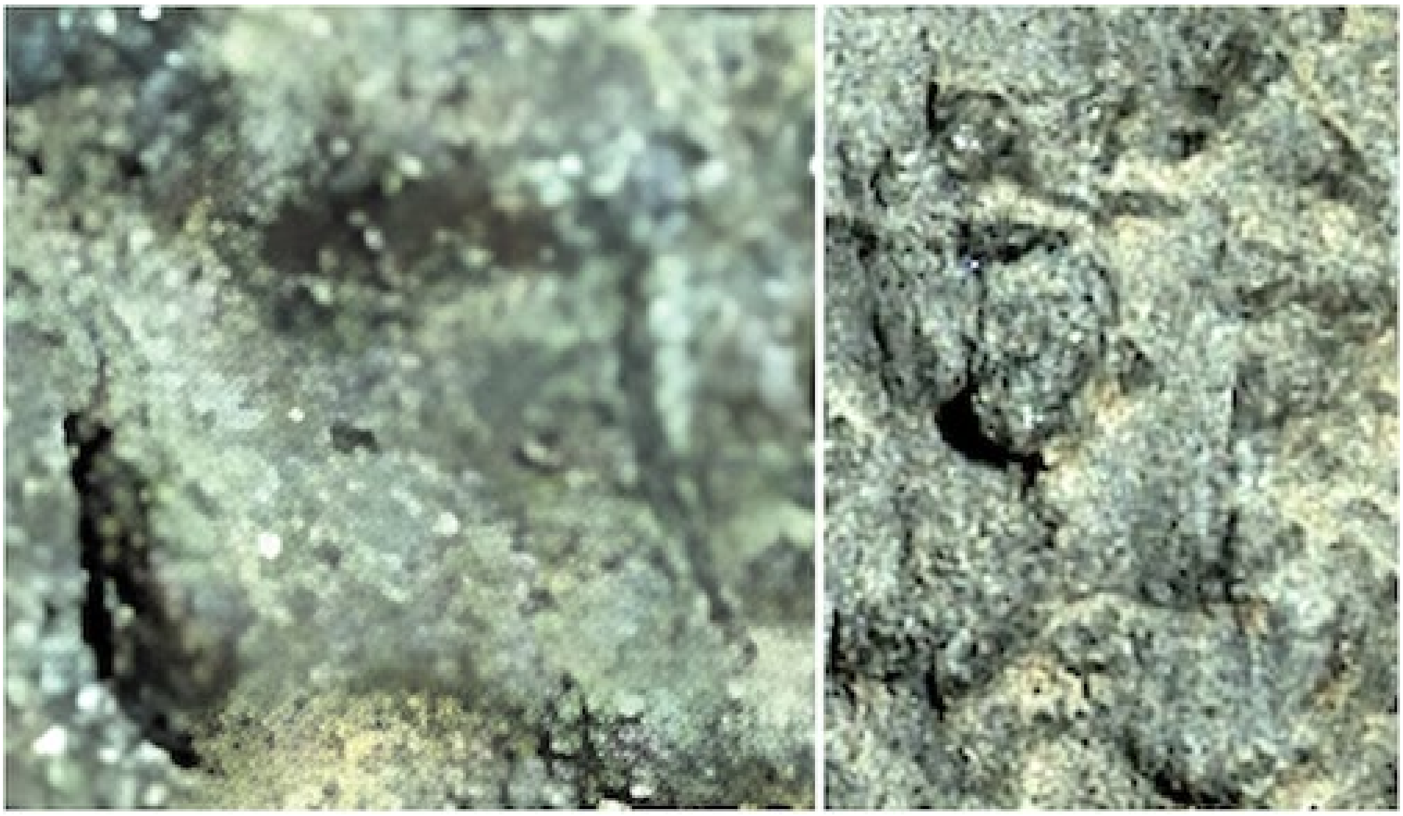

Figure 17. Sol 809. An assemblage of fossils like forms ranging from 1-2 mm in size 0809MH0001710000300846R00_DXXX.

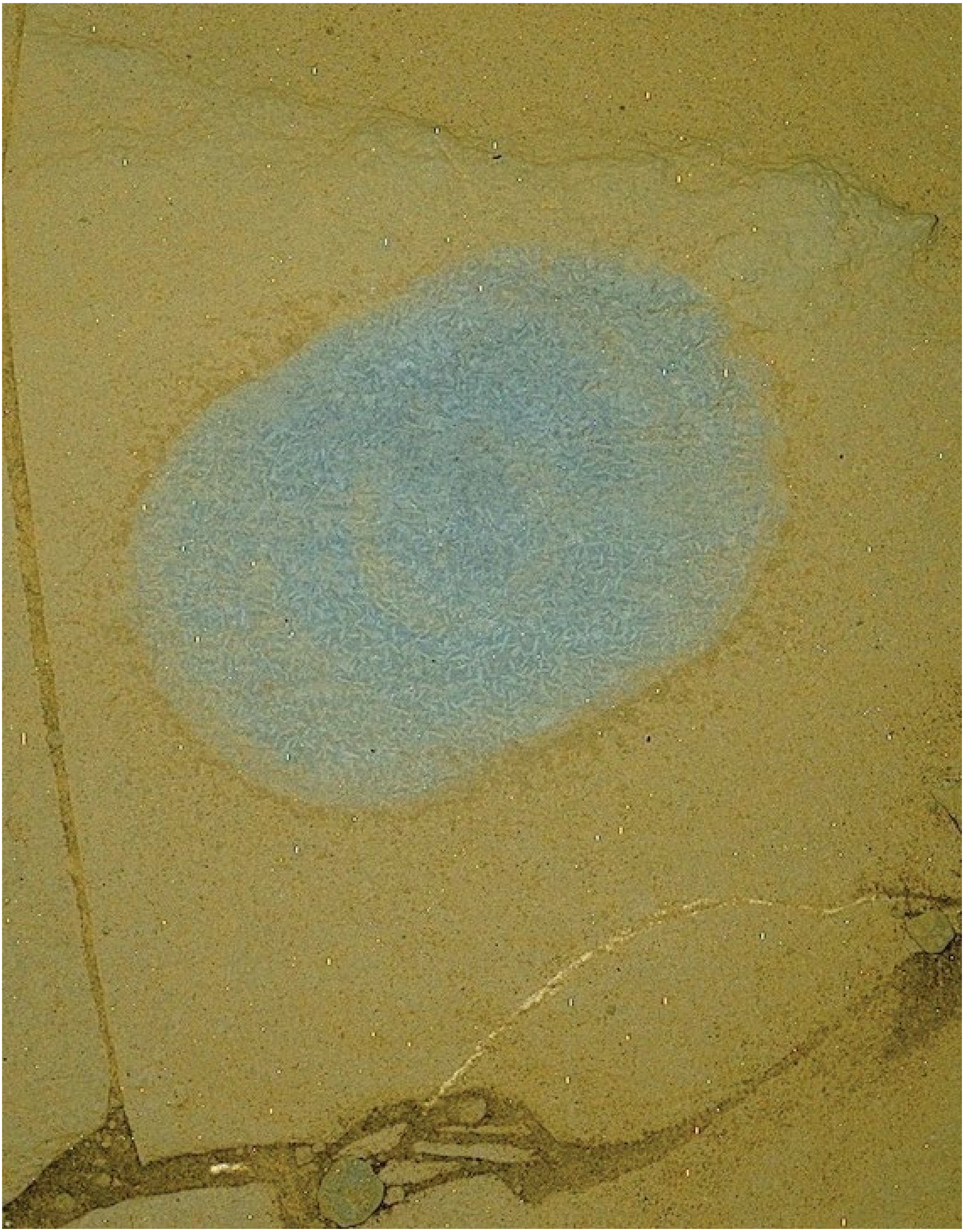

Figure 18. Sol 809. As assemblage of light colored elongated and globular forms that had been revealed when the Curiosity's brush tool clear away overlying sand and soil. There are two, not mutually exclusive explanations: these are minerals and crystal, or they are the remnants of organism that have been mineralized. 0809MH0004440010300853C00_DXXX. Magnification of sections of this area swept of debris, can be viewed in Figure 19.

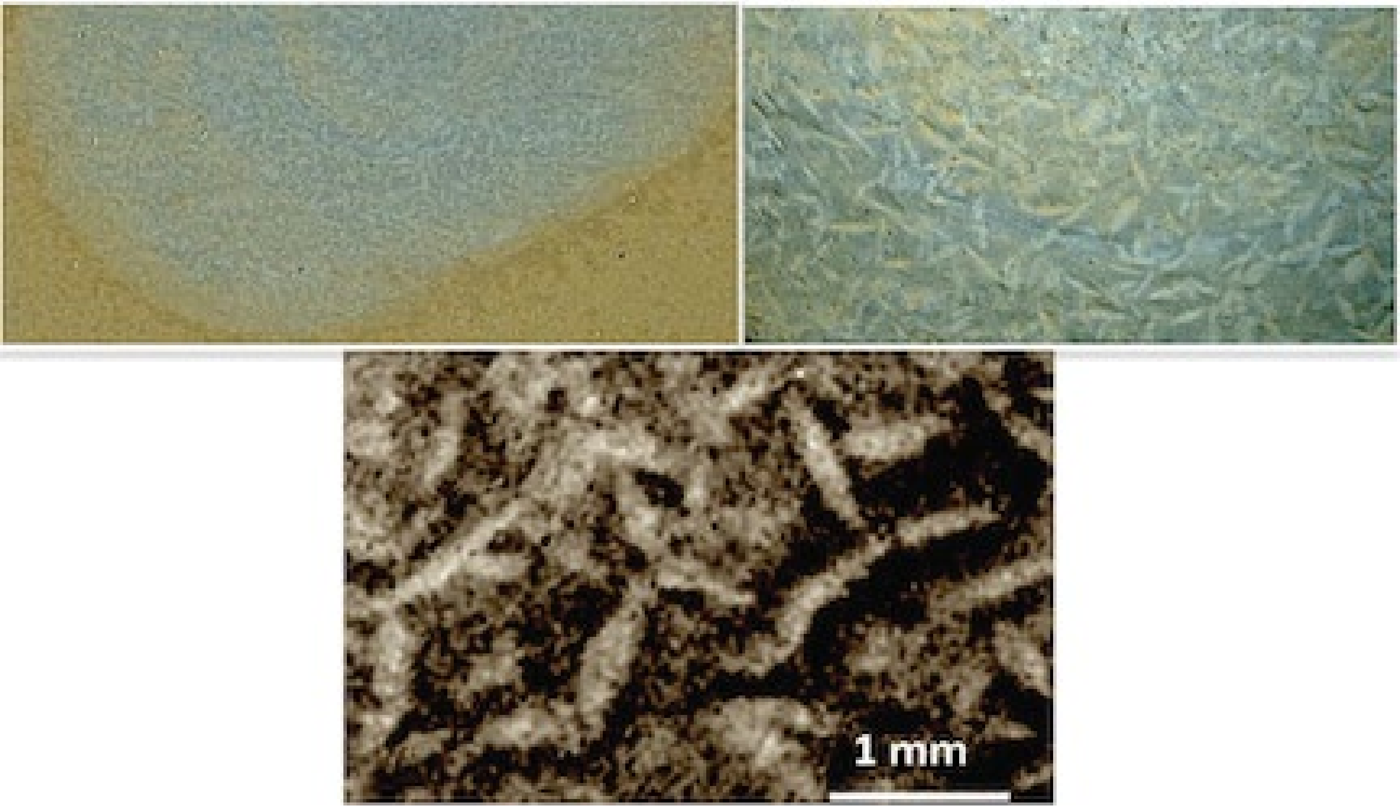

Figure 19. Sol 809: (Bottom enlarged, desaturated). These specimens resemble mineralized trace fossils possibly created by colonies of unknown organisms that may have been mineralized. The orientation of the spindle-like, whitish structures are not organized like mineral structures. Quantitative morphological analysis by Rizzo et al. (2021) supports the hypothesis that these may be biological in origin.

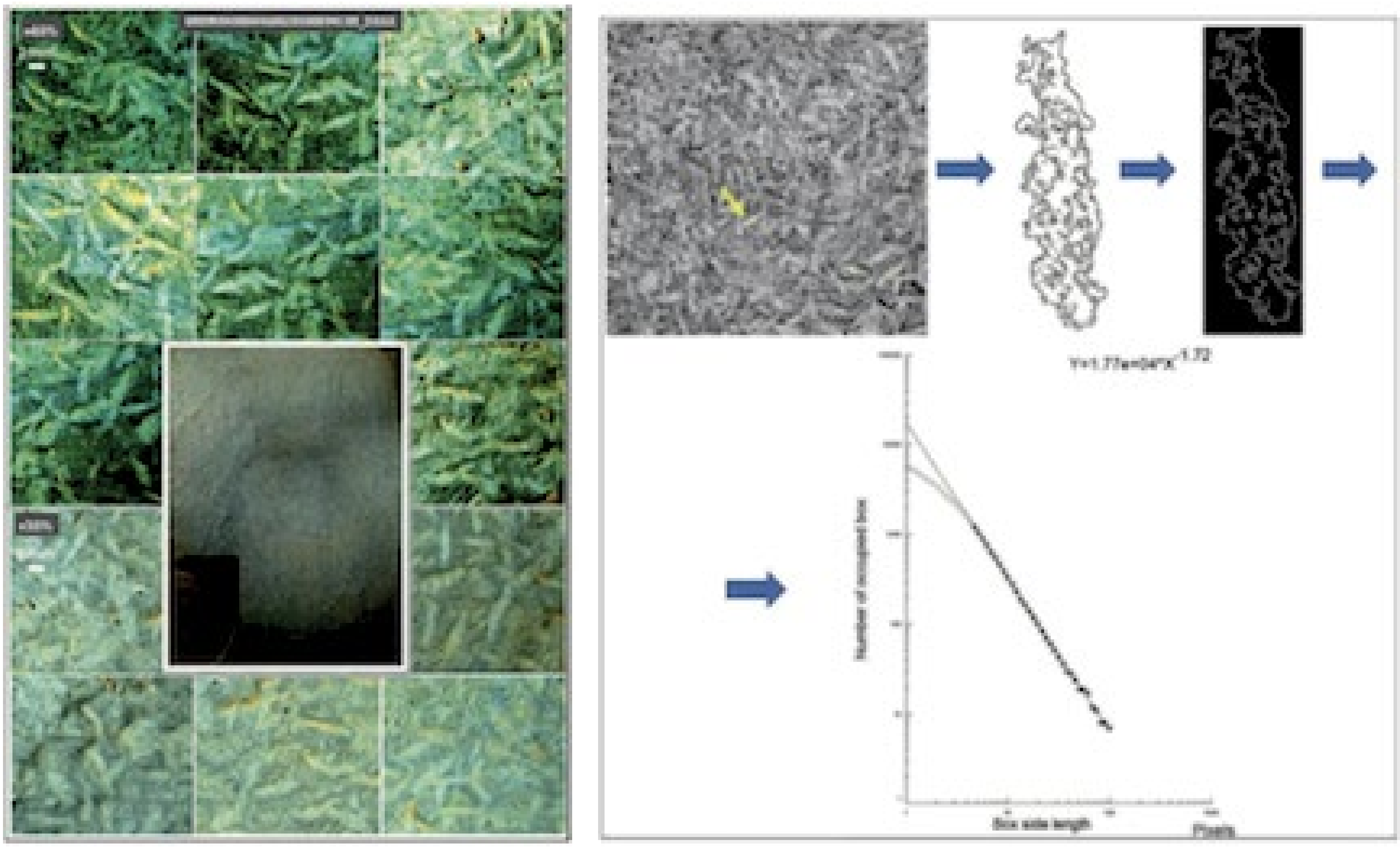

Figure 20. Sol 809 depicting elongated fusiform shaped formations. A canny filter was used to create negative images for the purpose of fractal analysis (Rizzo, et al. 2021). The log plot is a strangth line (p, 0.01) indicating that the vast majority of these light-colored elongated structures have a fractal structure of self-similiairty; its exponent the fractal dimension. These findings are compatible with biology, but not crystalization.

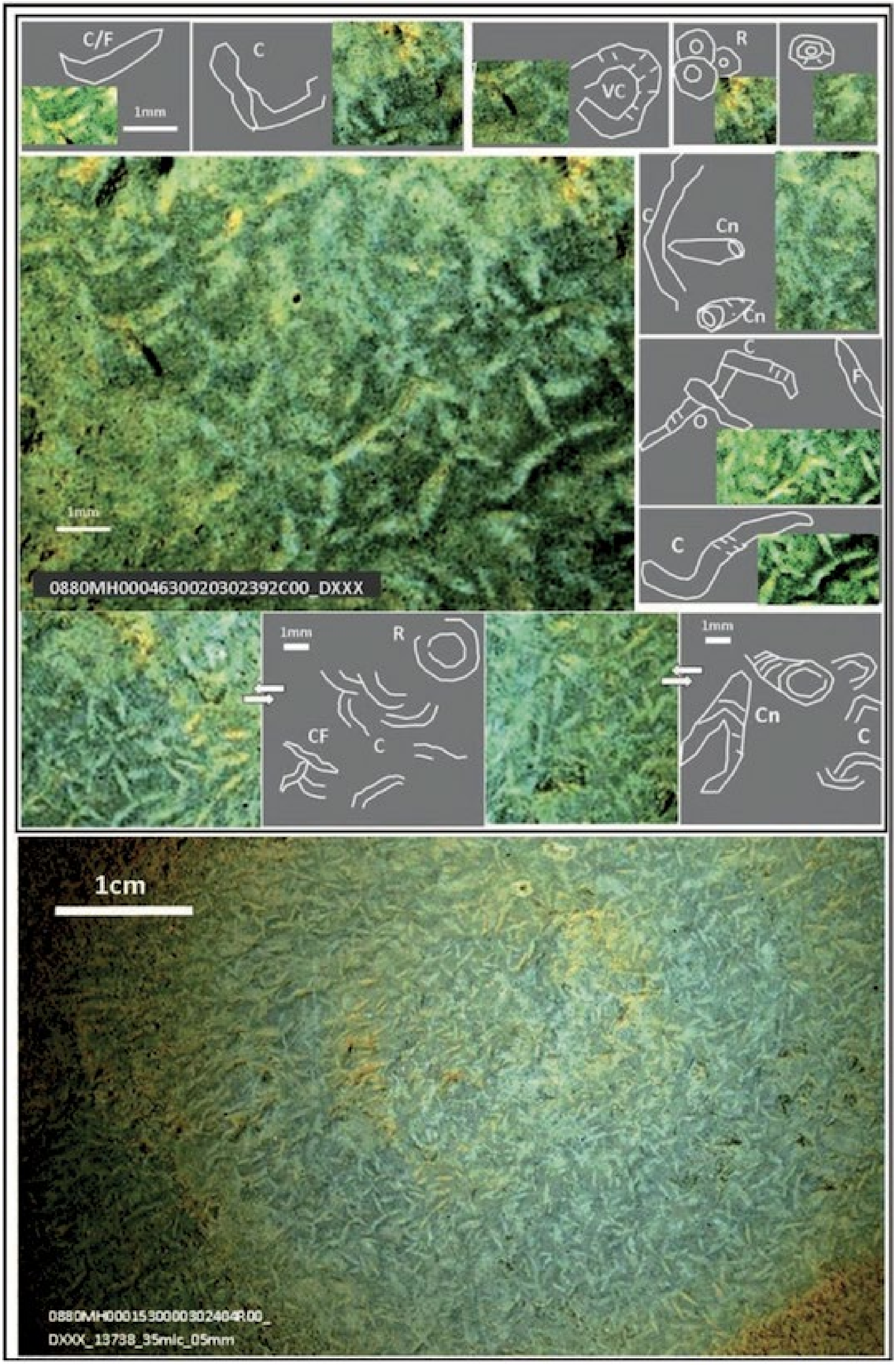

Figure 21. Sol 809, 880. Morphological analysis of the elongated and globular light colored specimens depicted in Sol 809 and Sol 880. It is evident there are repetitive (C), overlapping (O), conical (Cn) very curved (VC) ring-shaped (R) curved fusiform (C/F) shapes. These patterns and shapes are not what would be expected if these were embedded crystals (Rizzo et al. 2021). Compare with Figure 21.

V. The Fossil-Like Forms of Sol 869MH0004600020302294C00_DXXX

Figure 22. Sol 869. Sediment to the middle and upper left includes elongated and globular light colored specimens similar to those depicted in Sol 809 and Sol 880. Mudstone/sediment in the lower right (see Figure 22) reveals the presence of elevated and elongated forms that resemble worm-like (segmented and unsegmented) and other fossil-like organisms, some with open apertures. 869MH0004600020302294C00_DXXX.

Figure 23. Top and bottom right: Segmented worm-like shapes that appear to be mineralized and embedded in a mud-covered coral-like matrix. Sol 869MH0004600020302294C00_DXXX. Bottom left: Sol 1905. These specimens are approximately 1 to 5 mm in length on average. Several of these "worm-like" specimens have an open aperture at one end. However, in comparing Sol 1905 to Sol 869, note: the dimensions are very different and the shape of 1905 is flat, not segmented. The only thing in common is the curvilinear shape. Hence, they may represent two species of "worm" (e.g. annelids *vs.* nematodes).

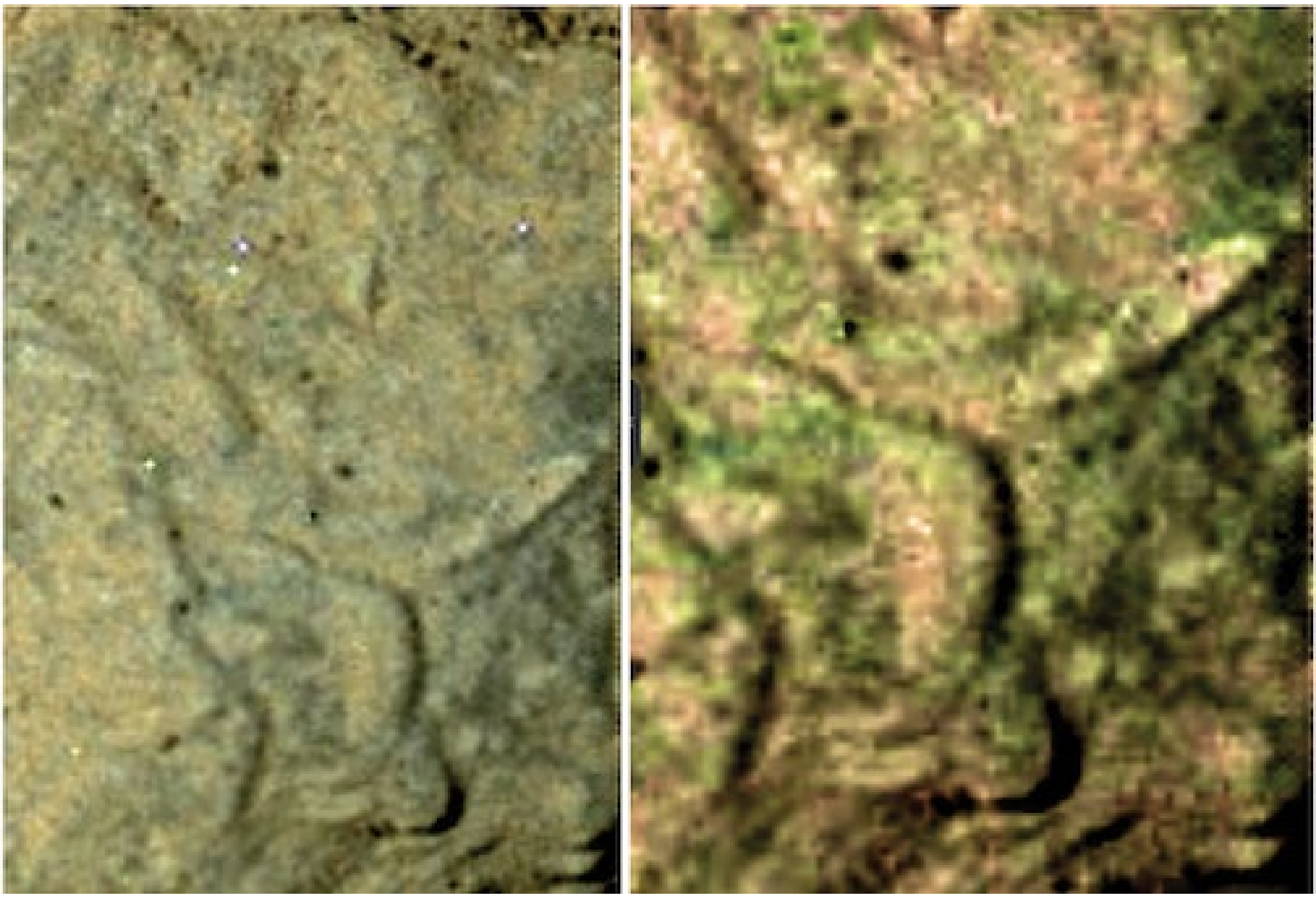

Figure 24. Sol 869. worm-like specimens embedded atop mudstone/sandstone. Approximately 1-3 mm in length. 869MH0004600020302294C00_DXXX.

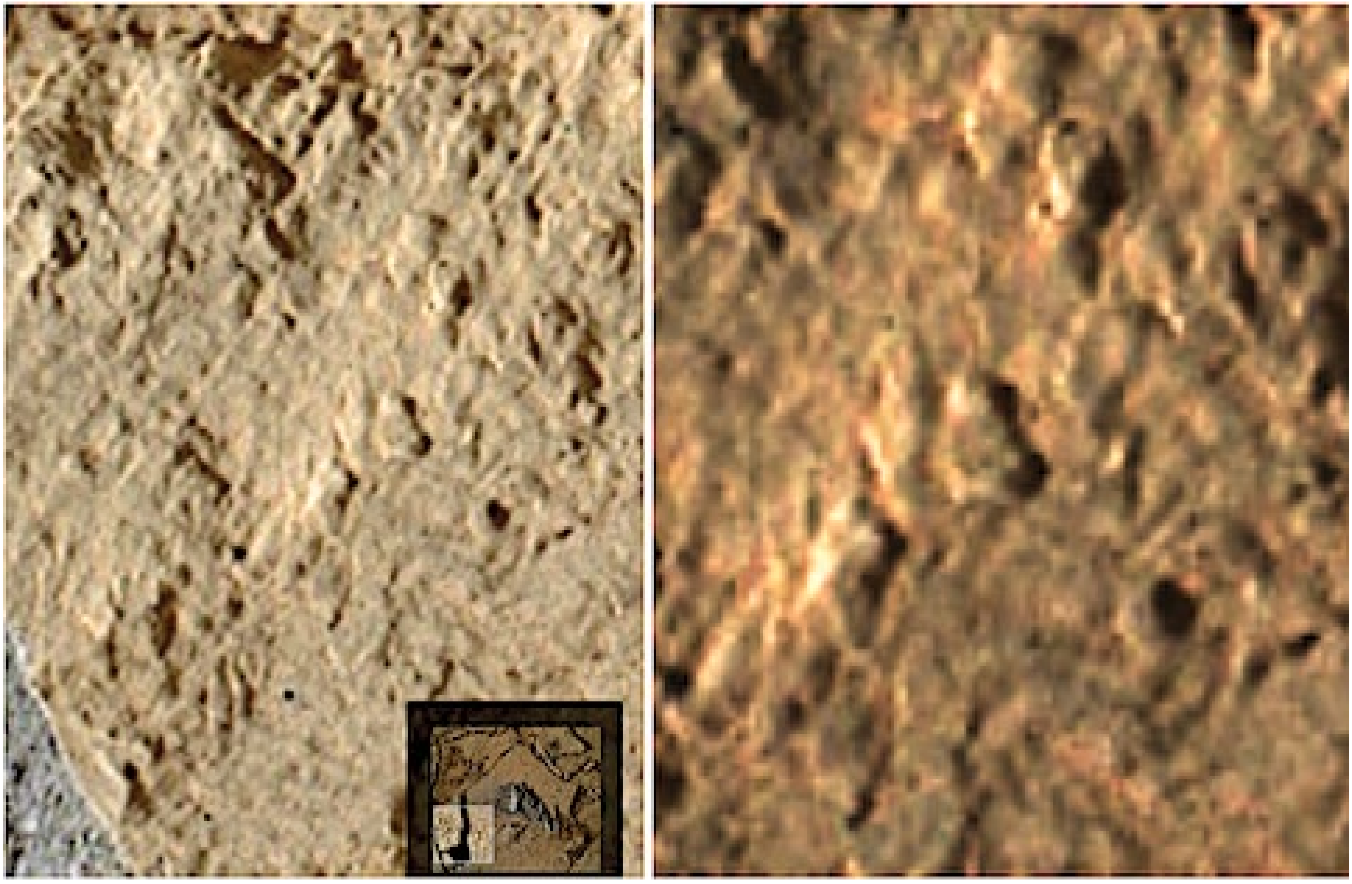

Figure 25. Sol 869. Fossil-like specimens resembling a variety of organisms. 0869MH0002650000302304R00_DXXX.

VI. The Fossil like Forms of SOL 880

Figure 26: Bottom Left: Rover Curiosity's Dust Removal Tool revealed an assemblage of fossil-like forms that resemble "*Kimberella,*" and "ice-cream-cone-shaped" and other specimens. Bottom right: Magnified, 0880MH0004620000302350R00_DXXX.

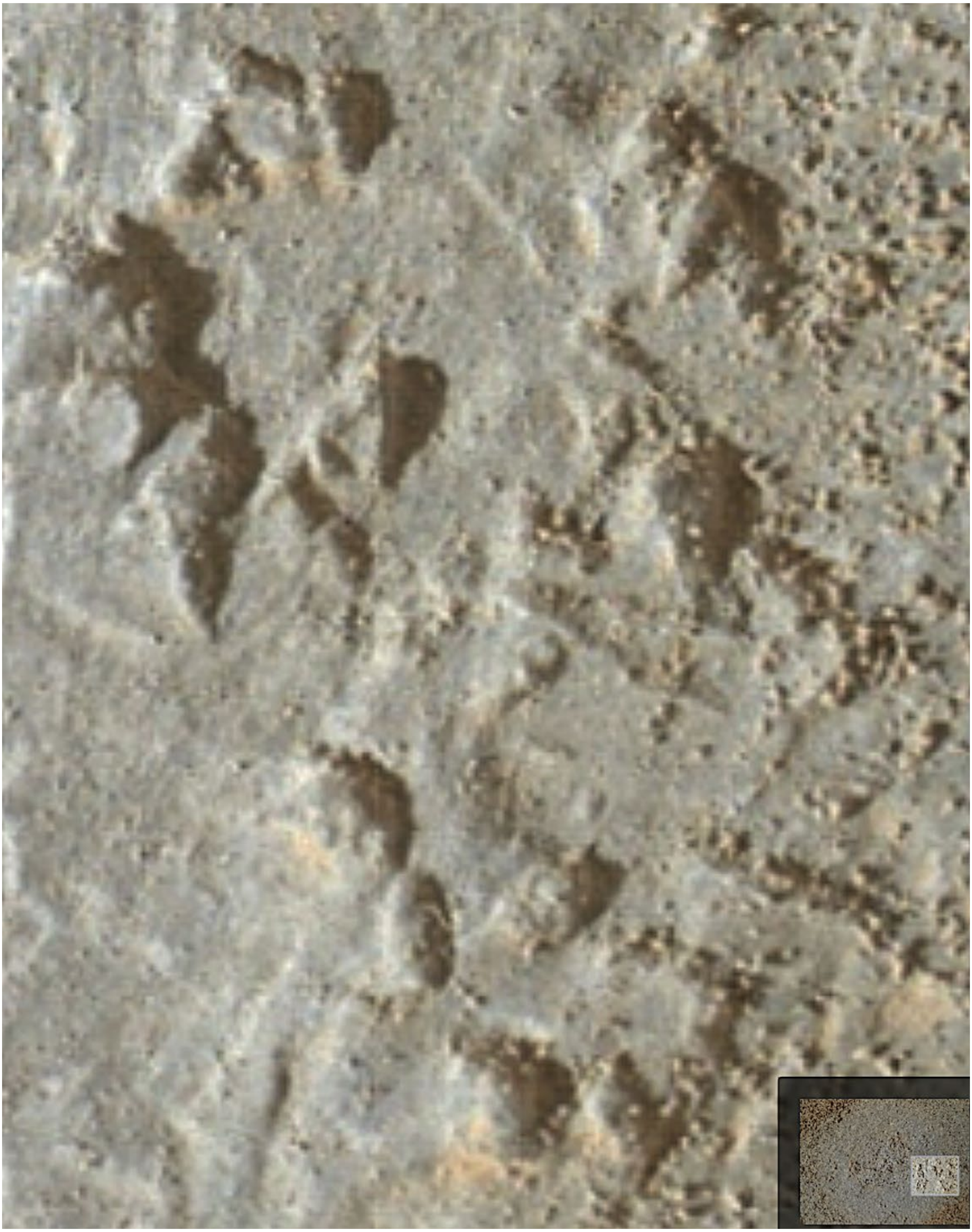

Figure 27. An assemblage of fossil-like forms that resemble "*Kimberella,*" and "ice-cream-cone-shaped" and other specimens. Bottom: Magnified, 0880MH0004620000302350R00_ DXXX.

Figure 28. Magnification of a section of Figure 25. An assemblage of fossil-like forms that resemble "ice-cream-cone-shaped" and other specimens. 0880MH0004620000302350R00_DXXX.

Figure 29. Sol 880. An assemblage of fossil-like structures one of which could be mistaken for an elasmobranch, but is more likely one organism atop another. 0880MH0004620000302350R00_DXXX.

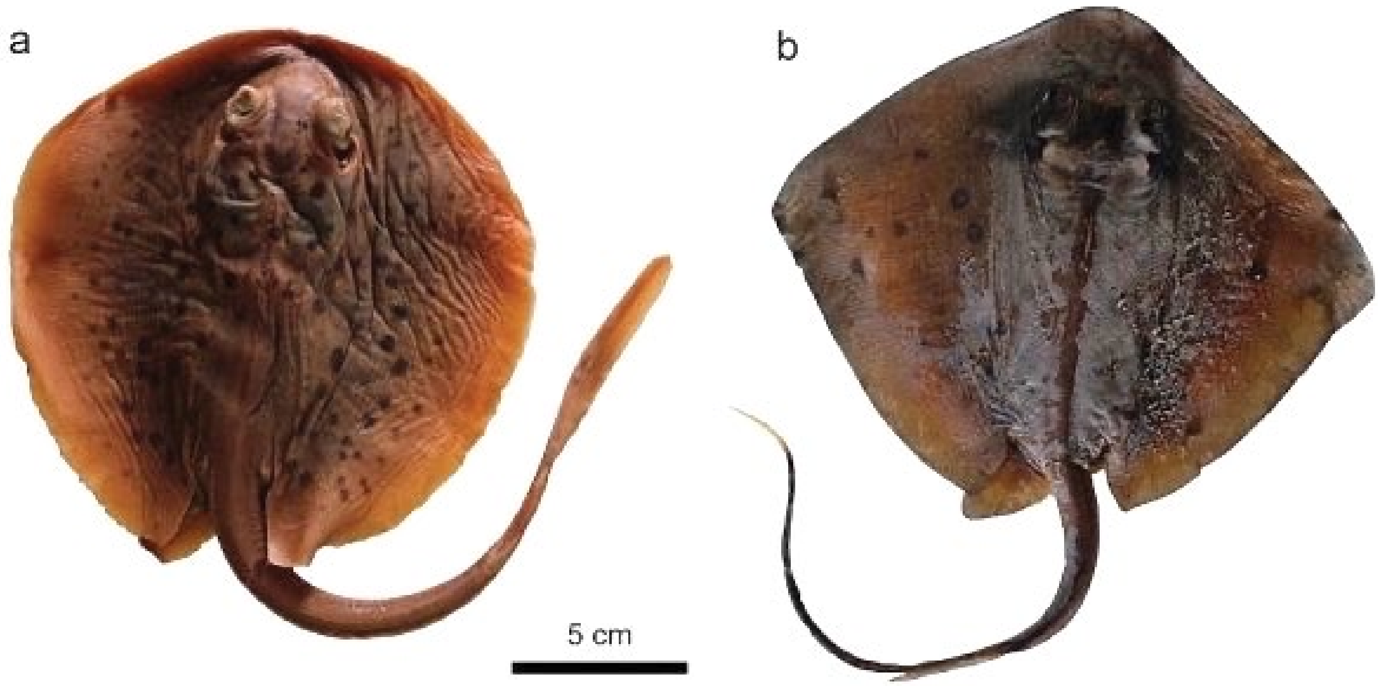

Figure 30. a) Taeniura lymma; b) Neotrygon sp. From a collection at the Institute of Paleontology of the University of Vienna. CREDIT: Giuseppe Marrama.

VII. The Fossil-like Forms of Sol 905

Figure 31. Sol 905 (left half of entire photo. Figure 34 displays right half). An assemblage of fossil like forms ranging from 1-3 mm in length and width. The dark groove to the center left was created when the Curiosity brush instrument swept away the soil to the right, revealing numerous specimens that had been buried just beneath the soil. MH0001930000302862R00_DXXX.

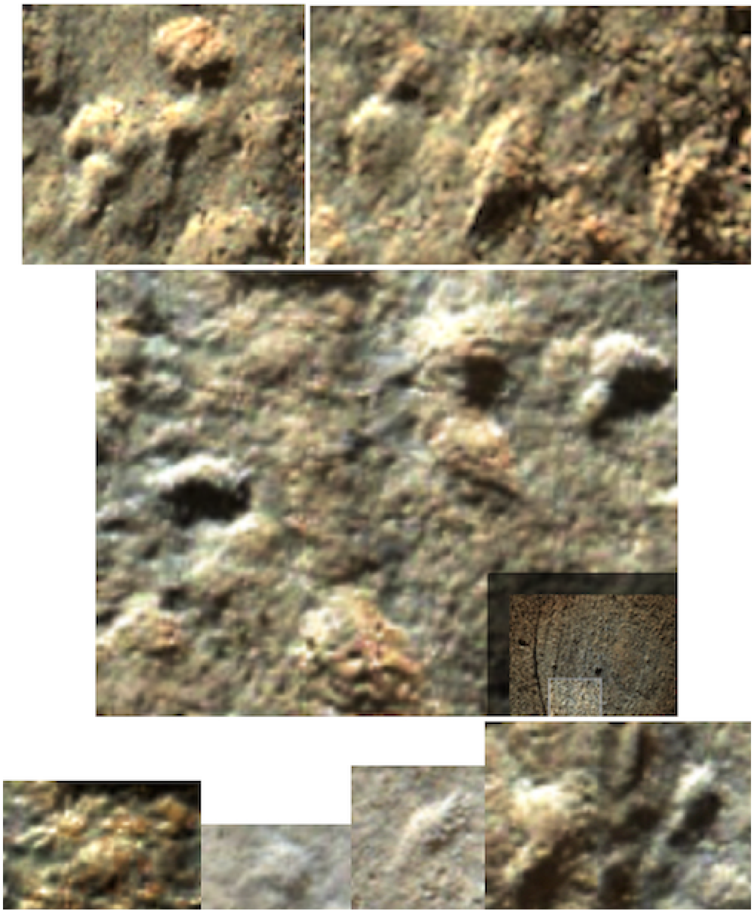

Figure 32. Sol 0553. An assemblage of fossils like forms ranging from 1-5 mm in size as also depicted in Figure 31.

VIII. Worm-like Tubular Forms Photographed on Sol 1032

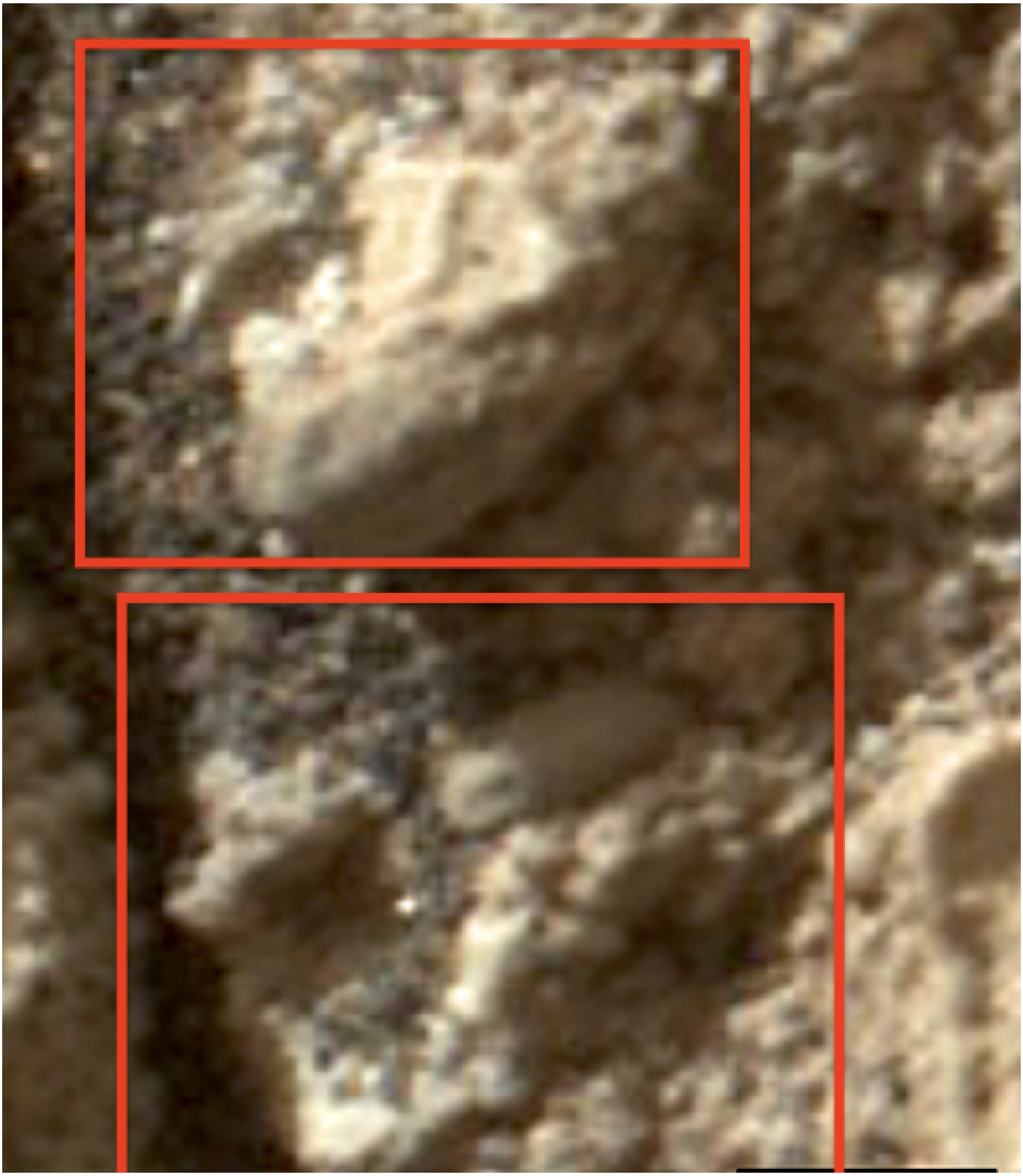

Figure 33. Sol 1032. Tubular forms segmented (top) and with open orifices (bottom) 1032MH0005070010400164C00_DXXX.

Figure 34. A variety of worm-like forms photographed on Sol 1032. MH0005070010400164C00_DXXX.

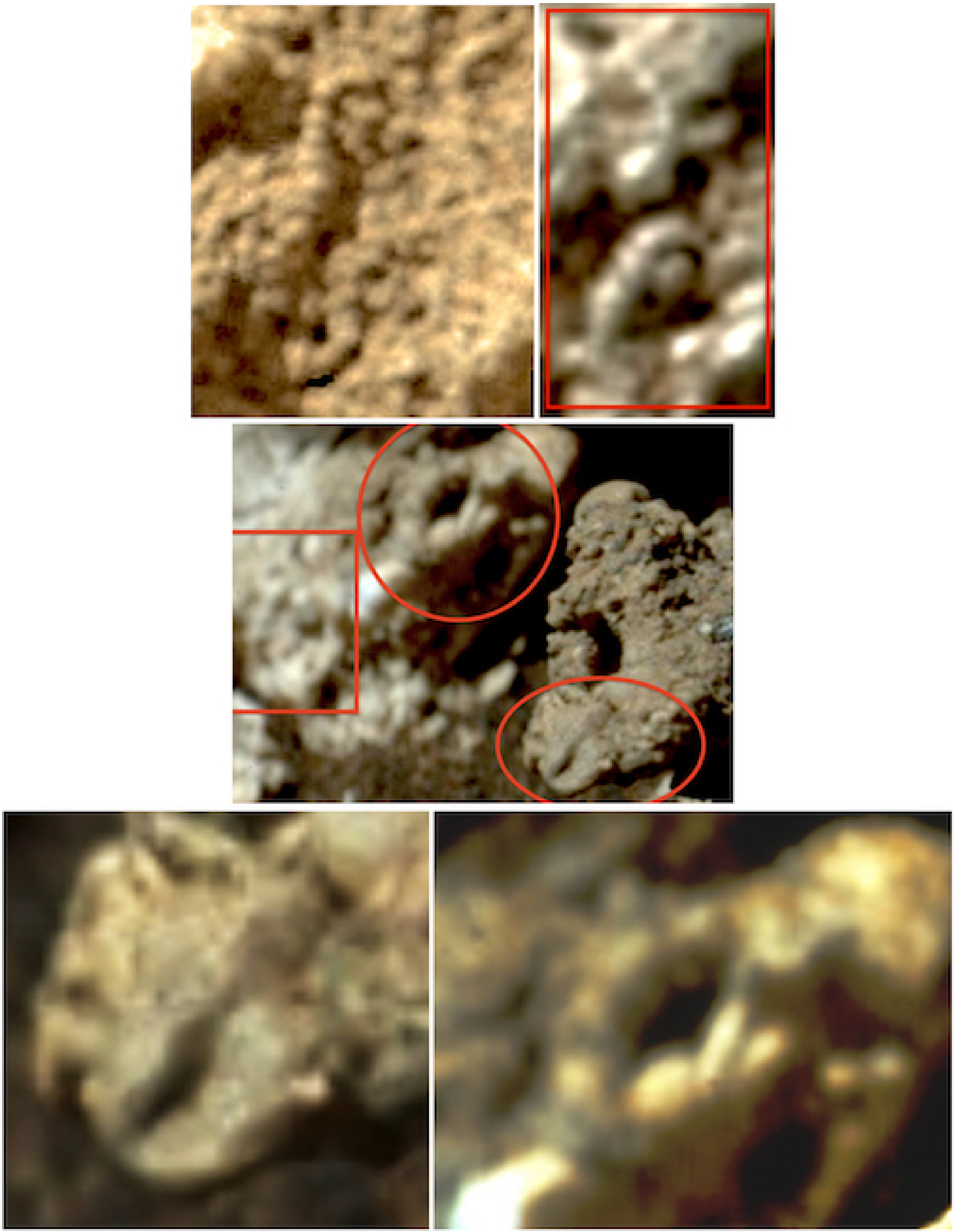

Figure 35. Worm-like forms photographed on Sol 1032. MH0005070010400164C00_DXXX.

IX. Segmented Tubular Forms Photographed on Sol 302

Figure 36. Segmented worm-like tubular forms oriented in different directions including upwards on a mound of soil. 0302MR0012570170203809E01_DXXX.

X. Fossil-like Tubular Forms Photographed on Sols 1921 / 1922

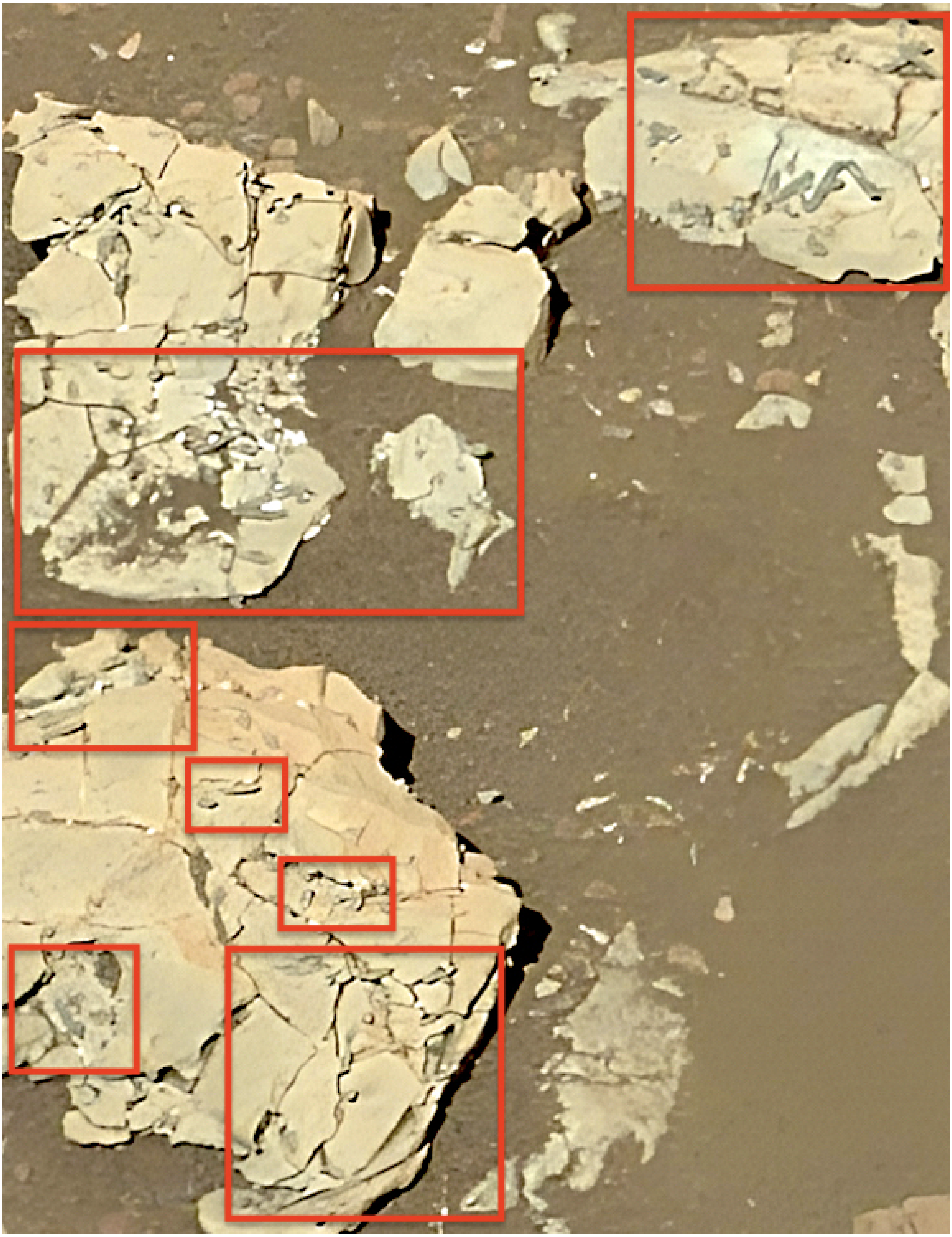

Figure 37. Sol 1921. Numerous tubular formations laying upon different rocks. Supporting the hypothesis these were living organisms, the tableau vivant is compatible with mineralization following the rapid receding of the waters. 1921MR0100290000900414E01_DXXX.

Figure 38. Sol 1922. Note open aperture. These Gale Crater tubular specimens are distinct in color and texture from the host-rock surface. If these are the highly mineralized remnants of tubular organisms, they may have dwelled upon these rocks within a lake or inland sea that quite suddenly receded. These may be the trace fossils of the tunneling and burrowing systems made by worms, or they may depict worms and other organism that became fossilized and embedded atop sandstone and mudstone. These specimens resemble the trace fossils of treptichnids, priapulid worms, and their burrowing curved branching beneath and along the mud of the seafloor on Earth, circa 545 mya and which filled with sediment and mineralized. They are distinct from those photographed upon the surface of Endurance Crater that may have host a large body of water heated by thermal vents. (1922MH0001520010703174C00_DXXX).

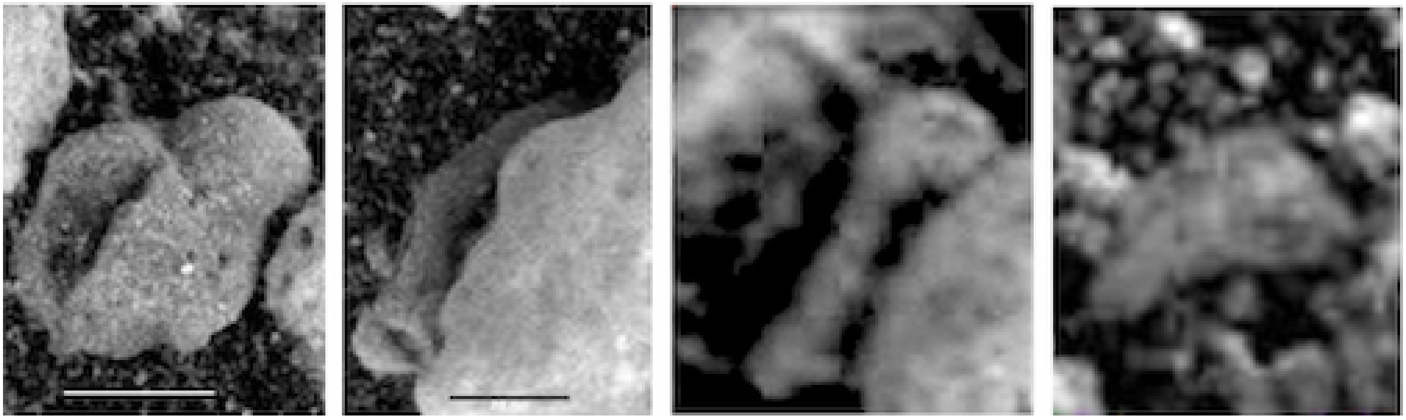

Figure 39. Endurance Crater. Tubular forms photographed in an ancient lake bottom adjacent to holes in the ground that may have been thermal vents [14]. 1M145852648EFF3505P2957M2M1.

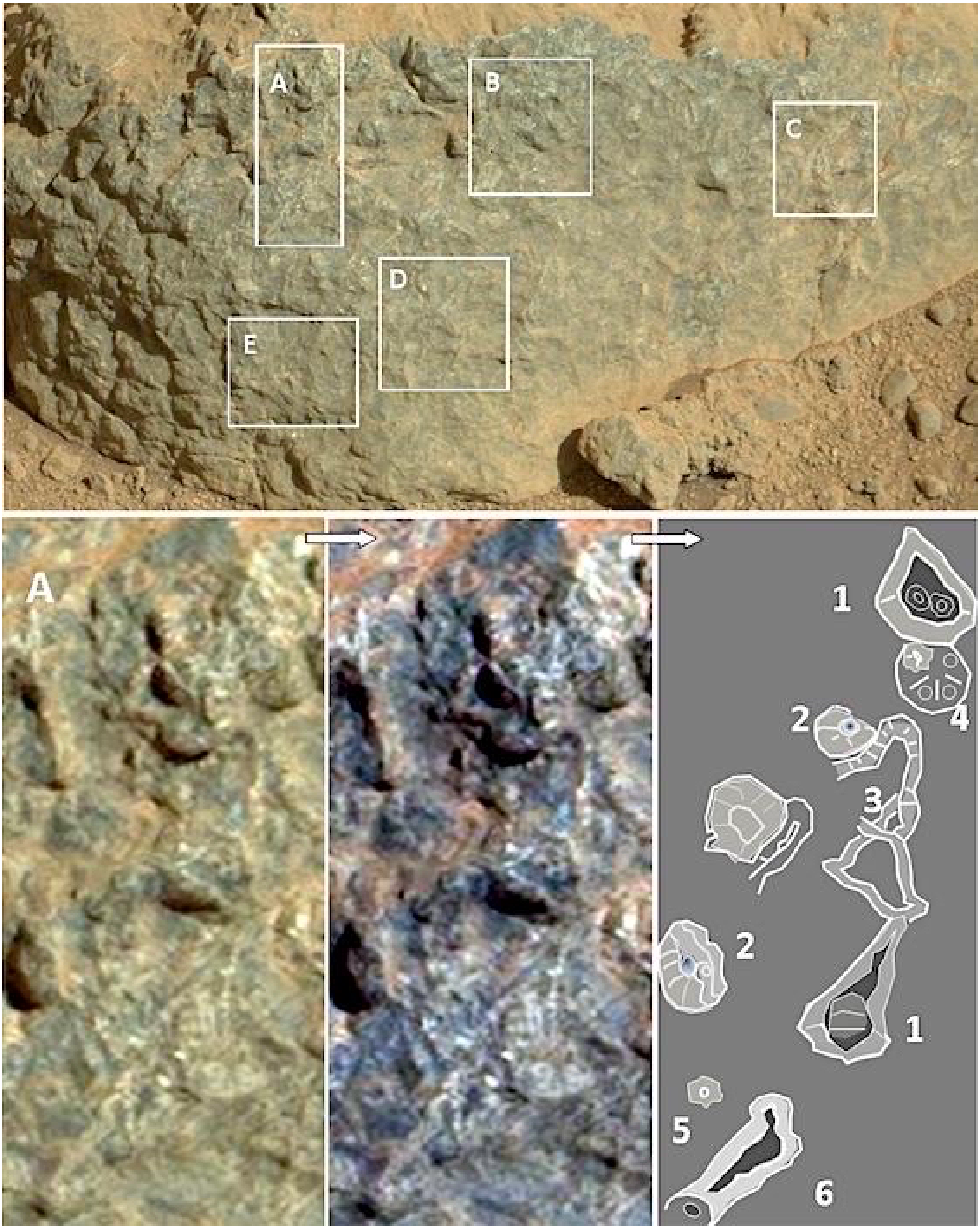

Figure 40. Microanalysis analysis of Sol 553, sharpened and amplified via Paint net. Chaotic microstructures, similar to possible microfossils are evident as based on their istinct shapes as defined by color, roughness and relief, elevation, which indicate individuality including those that are 1 conical, 2 rolled, 3 elongated and overlapping, 4 globular, 5 tubular and possibly hollow. These individual forms are distinct from the underlying sediment which may be a fragment of a coral reef. Additional micro-analysis of Sol 552 is presented in Figure 41.

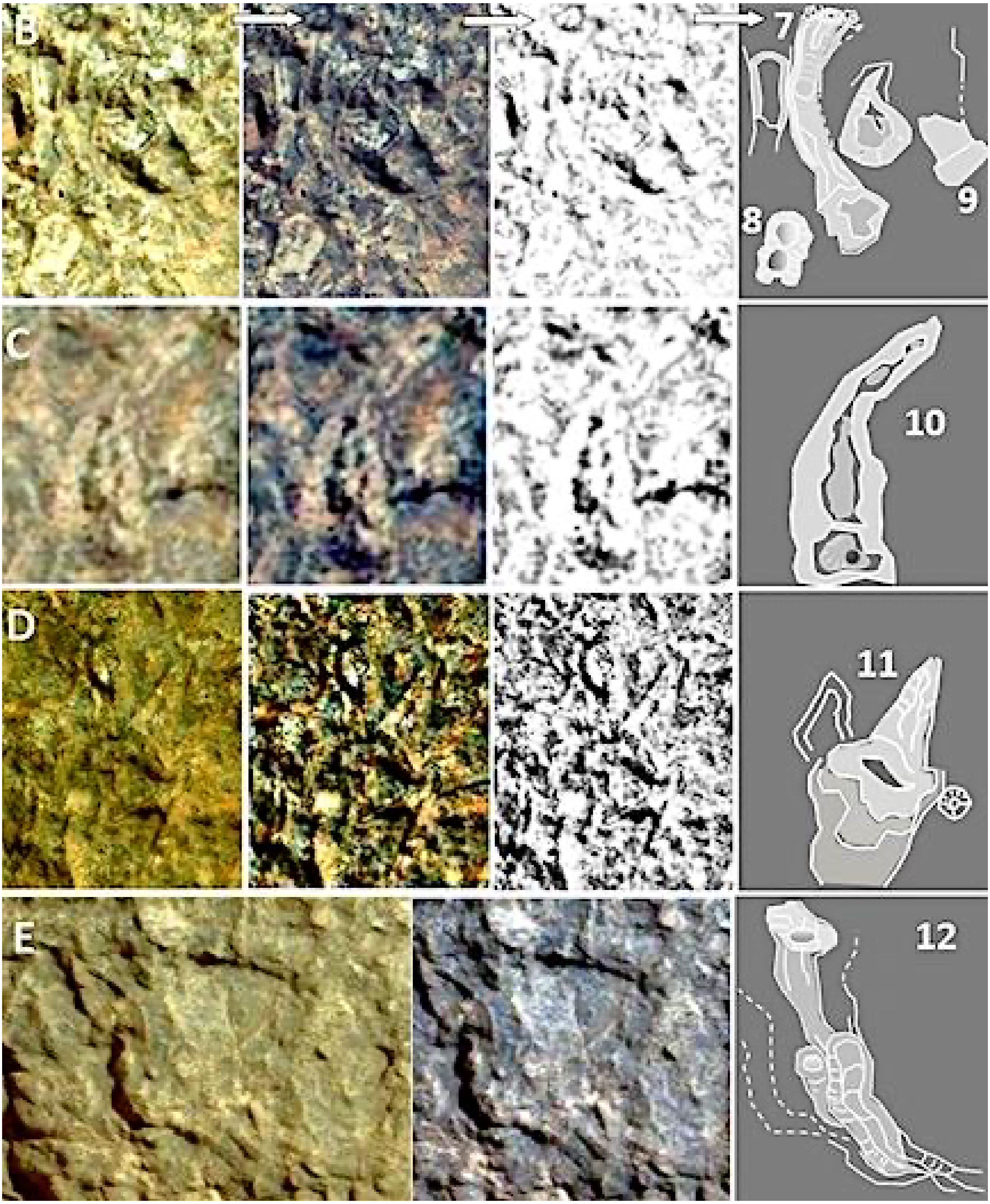

Figure 41. Microanalysis of Sol 553. B-E are also identified in Figure 41 and include paint-net processing with black and white highlighting of the most salient features. 7-9 reveals forms that are hollow, branched, fusal structure, and 7 with an internal cavity that widen towards the two ends whereas. in 10 one end is narrow the other wide. 8 includes structures with two smooth lobes side by side and joined together by a clear, knurled frame, which together constitute a single and distinct structure.10 has a conical and curved shape with a central cavity rising irregularly upwards with walls forming a radial system at the top. In box D a clear conical shape which becomes enlarged in a shapeless flaring and which may overlap with another structure In box E irregular conical shapes include those that are hollow and with set walls, some of which develop within a branched system starting from a vertex (bottom). 3 is suggestive of microspheres and laminae that wrap either in a chaotic way or in a regular way, whereas in 11 they form overlapping structures with cones or tubular shapes (1,6,7,10,11,12). The overall chaotic pattern is similar to what might be expected of numerous organisms that were oriented differently when fossilized.

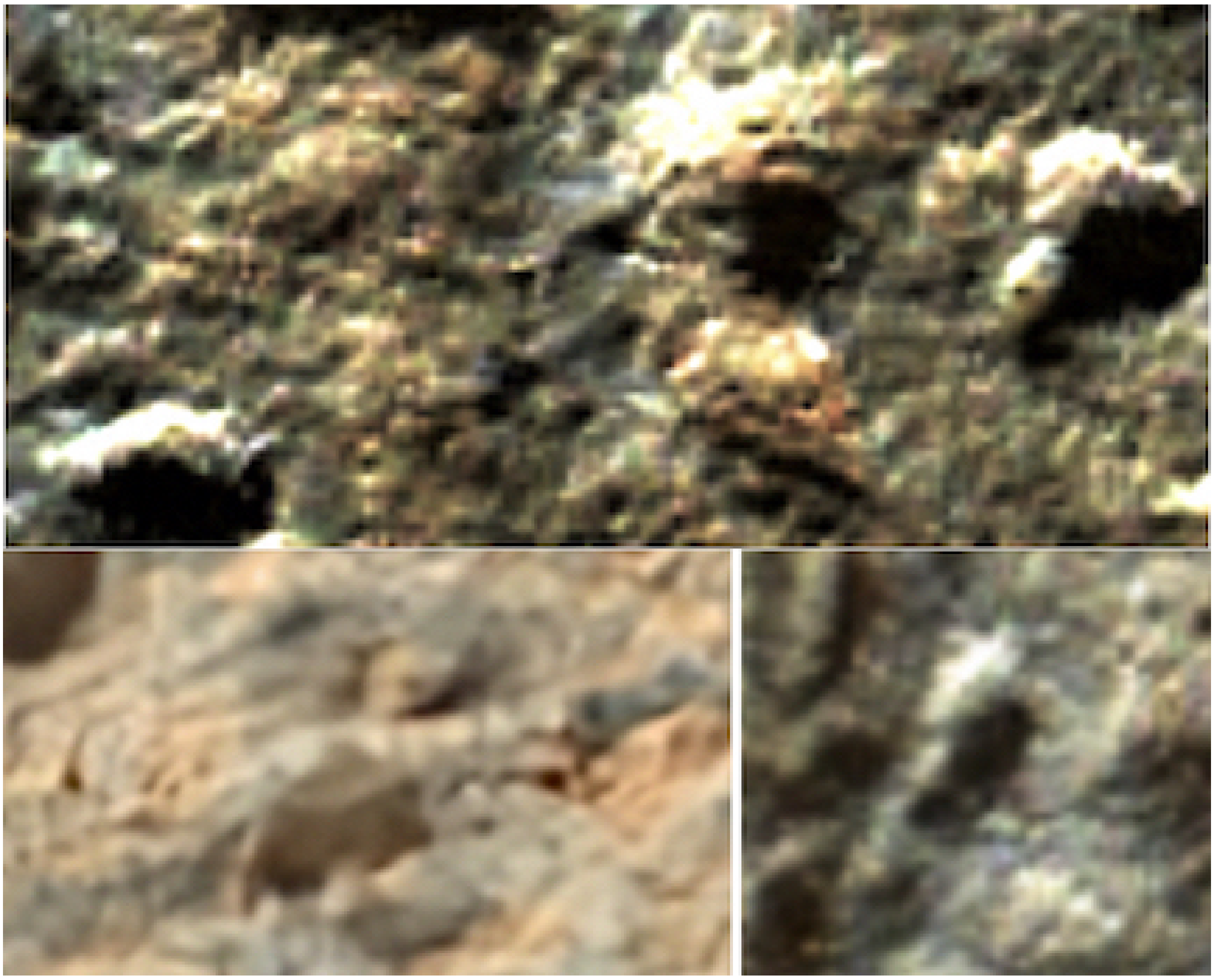

Figure 42. Sol 0905. A sea bottom *Tableau vivant* of life? (top)MH0001930000302862R00_DXXX.
Bottom (Left)132MH0001580010101221C00_DXXX. (Right) 905MH0001930000302862R00_DXXX.

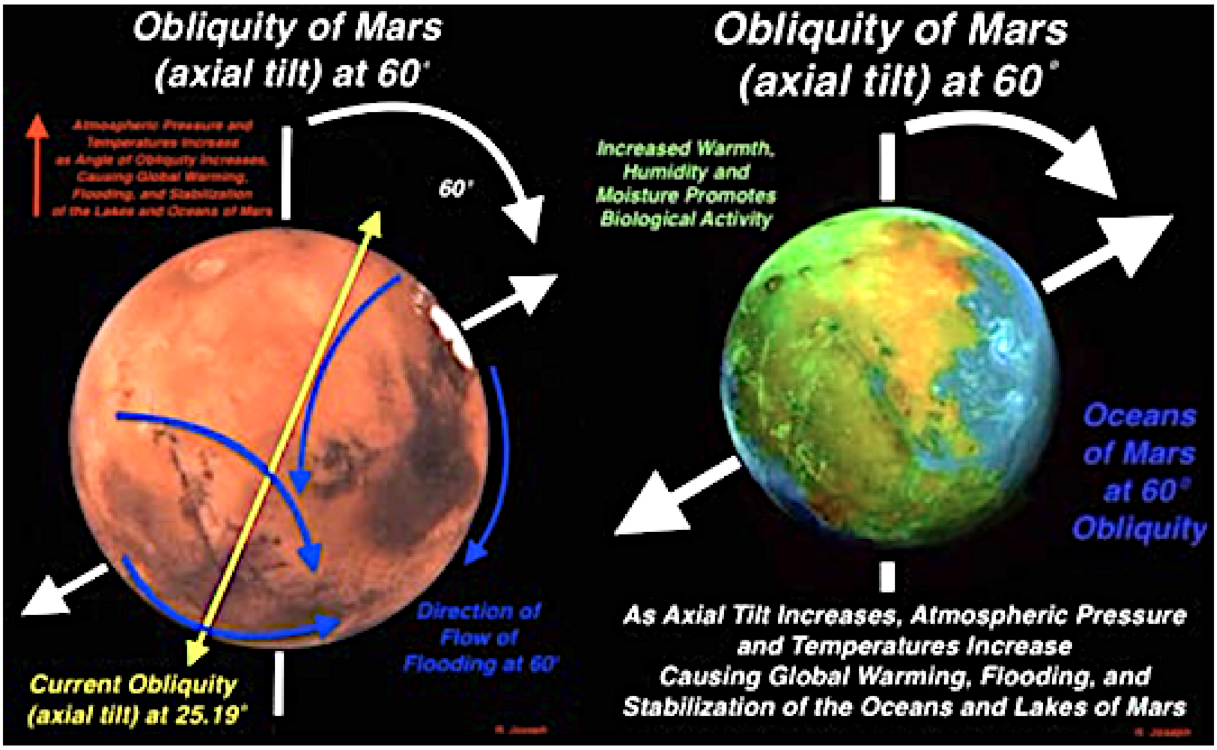

Figure 43. The obliquity of Mars can range up to 82 degrees.

from 1 mm to 5 mm, though, admittedly, their actual length, width, and diameter are unknown.

We have presented these photos/specimens in different sections based on the (1) date in which they were photographed; (2) morphological comparisons with each other and terrestrial fossils, and (3) results from comparative micro- and macro- morphological statistical analysis. The following should be viewed as just a sample of the numerous fossil-like structures that have been observed in Gale Crater (Figures 1-37).

Statistical Support for Tube Worms / Ichnofossil Hypothesis (Sols 1921 / 1922)

Mineralized/fossilized elongated forms resembling ichnofossils have been observed upon rocks along the dried lake bottom of Vera Rubin Ridge Gale Crater [6-8,44,45]. Some of these "tubes" appear hollow and/or have an open aperture at one end, and resemble mineralized tube worms. Detailed quantitative, comparative, morphological and statistical analysis of these tubular formations [6,8,44] have provided evidence contrary to any abiogenic crystal / mineral or rock erosion scenarios [12] and instead are supportive of the ichnofossil hypothesis [7] (Figures 38-40).

For example, Baucon A, et al. [8] conducted a morphological comparative quantitative study and determined that crystals and erosional geological processes do not share the morphological and topological features of the Vera Rubin Ridge tubes. In order to test for biogenicity Baucon A, et al. [8] examined the width, length and angle and performed a comparative analysis and determined the colors are different and that tubular structure contact with the host rock is sharp, distinct, and well-defined indicating they are not coextensive as might be expected if due to weathering and erosion. In addition, although the morphology resembles the horizontal burrows of terrestrial worm-like organisms they may actually be the mineralized remains of tubular worms.

These findings are similar to the comparative statistical data published by Joseph RG, et al. [6] and Armstrong CP [44]. Although the likelihood these are fossils of worms or their burrow has been challenged [12] numerous worm-like features are also common on adjacent rocks in Vera Rubin Ridge (Figure 36). Specimens similar to these hypothetical tube worms are also abundant in other areas of Gale Crater [46] and have also been observed in other areas of Mars including Endurance Crater [14,15]. However, in contrast to the putative tubular organisms that may have dwelled in the lakes of Gale Crater Vera Rubin Ridge, those from Endurance Crater (Figure 36,37) may have flourished in heated waters adjacent to a thermal vent [14,15]. What many of the Endurance Crater, Gale Crater, and Vera Rubin Ridge Gale Crater "tubes" have in common are open apertures at one end, and which may have served as a "mouth" for the filter feeding, scavenging, or predation (Figures 38,39).

Discussion

Burgess Shale Analogy

The fossil-like forms reported here were photographed on mudstone or slabs of sediment in the dried lake bottom of Gale Crater on Sol 0553, 808, 809, 869, 880, 0905, 1921, 1922. These samples include those that resemble *Kimberella*," "Lophophorates" and annelid worms, tube worms, multi-limbed lobopods (e.g. *Hallucigenia*, *Marrella splendes*) as well as multi-tentacled chelicerates, cheliceromorphs, chasmataspididas, Eurypterida and the tapered cone-shaped anterior-tentacled *Haplophrentis carinatus* which on Earth is ancestral to an extinct group of mollusks. Hence, based on morphology many are structurally similar to Ediacarans and those embedded in the Burgess Shale (located in the Canadian rockies) which may have been first discovered in 1886 by Richard McConnell of the Geological Survey of Canada. Palaeontologist Charles Walcott apparently rediscovered the Burgess Shale in 1909; and who, along with family members, excavated over 60,000 specimens [46].

The "Burgess Shale" is approximately 510 million years in age [47,48]. However, if McKay's [40] hypothesis is correct, then these putative Martian "Cambrian" fossils may be the remnants of creatures that evolved over a billion years ago.

The "Burgess Shale" may have formed in the presence of large bodies of water and the surging and ebbing of great floods and storms [49] such that sediments and reefs broke apart and were transported via flood waters to great distances [47-49]. The Martian sediments hosting these putative fossils may have also been part of larger structures that broke apart perhaps in response to catastrophic flooding or a surge of receding flood waters.

Ediacaran and Cambrian fauna were marine organisms and we hypothesize that these putative Martian organisms were also sea and lake dwellers. Likewise, catastrophic changes in the environment and water levels --secondary to reductions in axial tilt-- may have led to the preservation and rapid fossilization of these hypothetical Martian water-dwellers. When water levels rapidly receded this may have caused a cessation of surrounding microbial activity when these presumptive marine metazoans and associated microbes were buried in mud, e.g. lack of oxygen, inability to respire sulfates. The buildup and layering of mud and minerals would have also created protective entombing coats thereby forming casts and molds that preserved morphology even as these organisms decayed and dissolved. Many of the specimens in this report were covered by several mm of dirt, sand, and dust, which was swept away by the rover Curiosity's metal-brush instrument (Figures 18-20,23,34). If these Martian specimens are fossilized marine metazoans, it is probable that most became extinct.

A Cambrian Explosion on Earth and Mars? Interplanetary Transfer?

Assuming these Martian specimens are genuine fossils, it is reasonable to ask why they are similar to organisms that evolved during the Ediacaran era and the "Cambrian Explosion" on Earth. How could similar species evolve, in parallel, on two different worlds?

Svante Arrhenius, Chandra Wickramasinghe and R. Gabriel Joseph have proposed theories based on the interplanetary transfer of life that could account for these putative parallels [20,50-56]. As first formally theorized by Nobel Laureate Svante Arrhenius in 1908, life on Earth and life on Mars may have common origins, having arrived in this solar system from other more ancient worlds in other solar systems [56]. Therefore, beginning around 4 billion years ago life on both planets may have had identical genomes which were inherited from organisms that first evolved on other worlds; and from these foundation genes evolved similar forms of life [50,51,55].

Arrhenius S [56] also theorized that life may have been repeatedly transferred between Earth and Mars; and there is now considerable evidence in support of this theory [20,52-54,57]; i.e. millions of tons of life-bearing soil, rock, and water ejected and splashed into space following the impact of meteors, asteroids and comets, over the course of the last 4 billion years. Organisms that survived ejection into space and the crashing landing on Earth or Mars, would have engaged in horizontal gene transfer with native-life forms; and they may have also served as founding stock from which similar species evolved on both planets [20,50-52]. Furthermore, as first proposed by Hoyle and Wickramasinghe [54,55] extraterrestrial viral organisms may have inserted their genes into the genomes of numerous species thereby triggering explosive episodes of what Stephen Jay Gould and Niles Eldredge [58] described as punctuated equilibrium; i.e. that new species suddenly evolve after long periods of stasis.

Joseph extended these theories to include the genomes of bacteria and eukaryotes encased in meteors, asteroids, and comets and which were repeatedly deposited on Earth and Mars beginning over 4 billion years ago, and which subsequently, via horizontal gene transfer, also affected the trajectory of evolution [50-52]. Joseph in 2000 also proposed complex organisms, including metazoans, may have been repeatedly transferred between these two planets thereby triggering a Cambrian Explosion on Earth, a function of masses of life-bearing soil, rock, and water ejected into space following bolide impacts [50]. This would also account for why many bizarre organisms suddenly evolved and then became extinct during the Cambrian explosion [50], i.e. they originated on Mars. In 2018, Wickramasinghe and colleagues published a full length article that also proposed the Cambrian Explosion had extraterrestrial origins and provided a detailed genetic explanation in support [59]. Moreover, microscopic structures recovered from meteorites and recent stratospheric samplings that revealed forms with similar morphologies; and this suggests that viable organisms may be continually raining down upon this (and other planets) from space [60].

Therefore, based on these interplanetary genetic-evolutionary theories it could be predicted that life would have evolved on Mars and Earth in parallel--at least to the level of metazoan invertebrates--so long as the environments on both planets were similar-- because life on both planets have common genetic origins. In addition similar extraterrestrial viruses, prokaryotes, and simple eukaryotes encased in extraterrestrial debris may have been subsequently and repeatedly transferred between and deposited on both worlds. Those that survived interplanetary transfer would have engaged in horizontal gene transfer and their progeny might have also evolved--again, in parallel on both worlds.

That there may have been an extraterrestrial-in-origin Cambrian Explosion on Mars as well as Earth, is supported by the discovery that mosquito larvae, fish eggs and embryos from crustaceans, the majority of seeds from a variety of plants, develop and reproduce normally after 7 to 13 months exposure to space outside the ISS and could travel between these two planets and survive [61]. In fact over 40 species including bacteria, fungi, plants, insects, crustaceans, and marine organisms, including daphnia embryos, diapausing larvae of dipterans, and eggs of fish, of shrimps, copepods and ostracods, can also survive outside the ISS and in Mars-like environments, despite long term exposure to gamma, microwave and ultraviolet radiation and a wide range of high and low temperatures [62].

In 1880 and 1882, it was reported that “zoological formations belonging to different classes of sponges, corals, and crinoids” were discovered deep within fragments of a meteorite and that “lived in water that never froze entirely” [63,64]. Specifically, Hahn O [63] a professor of zoology, mineralogy and geology at the University of Tübingen, Germany, sliced samples from 547 pounds of meteorites that fell at Knyahinya, Hungary in 1866 and published 142 photographs of what he believed to be fossilized organisms including corals, crinoids and sponges. Hahn O [63] emphasized the samples “contain no life of higher construction; rather, all are lower life forms — the same ones which prevail in the Silurian strata — sponges, corals, and crinoids.” As reported by Birgham F [64] a “noted zoologist Dr. Weinland” confirmed “that a large number of the formations in question are without doubt remains of coral belonging to the class of the favositines, which on earth are now to be found only in a fossil state, and then only in the oldest or palaeolithic stratum.... we must, therefore, accept this fact as important evidence that an organic evolution of great similarity to that on our own earth has taken place on whatever planet from which these meteorites originated.”

Hahn O [63] also considered and rejected the possibility these meteorites and their fossilized cargo originated on Earth, perhaps ejected hundreds of millions of years ago following bolide impact: “...the rock of the chondrites is not a type of sedimentary rock as on Earth, in which fossils are embedded, that it is not a conglomerate formation; but rather, its whole mass is entirely formed of organic beings, like our coral rocks... plant-animals! The whole stone is life.” Hahn also noted what he believed to be an evolutionary progression in the fossilized assemblage that corresponds to and parallels the evolution of life on Earth: “Anyone who even superficially surveys the forms will soon find that they provide an actual historical development. All the transitions... are present.” Hahn [63] was puzzled by his findings of what he believed to be parallel evolution and asks: “how could evolution coincide on different planets?”

If there was a Martian “Cambrian Explosion” is as yet unproven. However, if a “Cambrian Explosion” occurred on Mars over a billion years ago [40,52], and given the similarity between the fossils presented here and the Burgess Shale, then it is possible life-bearing meteors, asteroids, comets and frozen bodies of water ejected from Mars via bolide impact may have repeatedly fallen into the oceans of Earth and caused the Cambrian Explosion of life over 500 million years ago [20,52]. Interplanetary transfer of complex life could help explain the “explosion” of life in every ocean of Earth with every major phyla appearing in a period of 5 to 20 million years in the absence of any intermediate forms; and the fact that numerous species bizarre in appearance also suddenly appeared on Earth only to become extinct [65]. This scenario would also account for why the Martian fossils presented in this report are strikingly similar to fossils from Earth.

There are many well founded explanations for the Cambrian Explosion on Earth that do not require interplanetary transfer. Furthermore, at this juncture, there is no absolute proof that these Martian fossil-like specimens are genuine fossils or that a “Cambrian Explosion” of life took place on Mars. Without extraction and detailed genetic and microscopic examination, we can only speculate.

Abiogenic Scenarios

It is possible these fossil-like forms are illusions? Might they consist entirely of minerals, metals, oddly shaped clumps of mud and/or formed via water seepage and fluidized sediment followed by mineralization then geophysical-wind- and water-erosion? NASA has dismissed some fossil like specimens as consisting of pseudomorphic minerals (NASA.gov/jpl/msl/pia19077). That various minerals are abundant on Mars and in Gale Crater is well established and often protrude atop the surface of rock and mudstone [66,67].

As discussed by Rubin DM, et al. [11] water-sediment-mineral interactions can play a significant role in the fashioning of complex concentric and twisting linear shapes, creating elevated mounds, knobs, ridges, cylinders, and irregular layers of eccentric deformations due to the flow of subsurface fluids or fluidized sediment. Rubin DM, et al. [11] also argued that some Gale Crater rocks may be more resistant to erosion than soft-sedimentary structures and overlying deposits of surface material that may include mud.

The problem with these abiogenic Earth-analog scenarios is that mud, minerals, and water, are typically contaminated with microbes including fungi--as also pointed out by Rubin and colleagues [11]. Moreover, many of these Martian specimens are similar or nearly identical to one another, differing only in width, length and diameter and can be observed in close proximity or on adjacent rocks or slabs far distant from one another. Particularly abundant are those with an ice-cream-cone shape (similar to "*Namacalathus*" and "Lophophorates") and those with an ovoid-proboscis-shape coupled with zipper-like appendages on the outer-body, i.e. “*Kimberella*.” which are often found together creating what appears to be a fossilized tableau of diverse marine life.

Microanalysis of Sol 553: Abiogenic vs Biological Scenarios

A major focus of this report is a fragment of sediment (Sol 553), resembling a carbonate rock, which, on the basis of the observable texture and the large amount of allochems could be part of or related to a coral reef (Figures 1,41)--and in other areas of Mars what may be the remnants of coral reefs have been detected [4]. A microanalysis analysis of the image, sharpened and amplified in size via Paint net program (Figures 41,42), shows a chaotic set of microstructures, similar to possible microfossils.

When processed with Paint net color balance option, then based on the identification of shapes, by color, roughness and relief, elevated structures characterized by their individuality, extraneous to the matrix of the sediment that contains them can be readily defined. The structures (1-6) in (Figure 41), includes those that are conical (1), rolled (2), overlapping (3), globular (4), tubular (5) shapes. Conical and tubular, some with cavities sometimes filled with allochems. Those that resemble shells looks to be septed. The rolled shapes (2) are marked by their shadows and have smoother surfaces, a central depression and possibly a septed body. The globular body also seems to be regularly septed. The filamentous bodies are open, tortuous structures, which in some cases overlap; they look like rows of spheres, resembling septate bodies. Hence, in all respects, the elevated forms upon this rock, have all the hallmarks of biological organisms that may have colonized a fragment of coral reefs.

If abiogenic, if for example, formed by drying mud or generated by meteoritic impacts and seismic waves (Shutter coins) the structures should be uniformly cone-like in structure and consisting of the same material as the bedroom. They should also be sequential, formed by wave-like sequences of uniformly directional energy, thereby causing plane-coned fractures. Instead, the elevated fossil-like forms are of a different composition from the underlying much harder bedrock, and often from each other, displaying irregular curvatures and shapes and different orientations--patterns that are inexplicable if abiogenic, but are to be expected if biological and consisting of a variety of organisms oriented in different directions when they were fossilized.

If these forms were created by abiogenic forces, including, for example, meteor impact, seismic waves, water, volcanic or mud flow, then sequences of the same forms should line up in a series of rows and columns, and the repeating patterns should have same widths, lengths, curvatures. Instead, a variety of forms similar to terrestrial biota appear mixed together, sometimes on top of one another; and even those similar to and different from one another differ in size, length, width and distribution; which is what might be expected of colonies of organisms of varying age and having undergone differential degrees of degradation and decomposition.

What is the likelihood numerous specimens nearly identical to one another and to analog fossils from Earth would be photographed next to one another, on rocks and mudstone near and at great distances from one another and chaotically oriented in different directions and of different size, if fashioned via abiogenic processes? There are no abiogenic terrestrial analogs for the majority of specimens. Abiogenic factors, however, should not be ruled out.

Gross Morphology: Statistical Quantitative Comparative Analysis Supports Biology

In a previous report, nine of those metazoan-like ("ice-cream-cone" shaped) specimens that morphologically resemble "*Namacalathus*" and "Lophophorates," and six (ovoid-proboscis-shaped) specimens resembling "*Kimberella*," were subjected to a computerized quantitative morphological analysis comparing these forms with analog fossils from Earth [6] (Figures 11,12). It was determined that these putative metazoan fossils resembling *Namacalathus* were statistically indistinguishable from fossils of the Ediacaran *Namacalathus* [6]. Likewise, based on a quantitative analysis of the height, length, width, slope of the heads and tails, the presumptive Martian lophophorates were determined to be statistically nearly identical to terrestrial lophophorates with the only significant difference involving the ratio of tail length which is significantly proportionately longer in the terrestrial fossils of lophophorates. In addition, morphologically, the putative Martian *Kimberella* not only posses the characteristic probosci and zipper-like appendages, but were found to be statistically nearly identical to terrestrial fossils of the Ediacaran *Kimberella* and exhibit statistically similar L/W ratios, degree of 'curvature' and 'roundness.'

Micro-Morphology: Statistical Quantitative Comparative Analysis of Supports Biology

Rizzo V, et al. [2] and Joseph SC et al. [45] have both offered biological interpretations of what appear to be the light-toned lozenge- and oval-shaped microstructures clustered together and embedded in the surface of Pahrump Hill (Mojave and Mojave 2 targets, at Sols 809 and 880, (Figures 20, 38)). NASA dismissed these clusters as pseudomorphic sulfate crystals resulting from the evaporation of water. Similar abiogenic claims published by a NASA-controlled journal have been made regarding the tube-worm-like forms photographed in Vera Rubin Ridge [12]. However, the abiogenic explanations for the putative tube worm fossils are not compatible with the results from complex comparative morphological analysis performed by Armstrong CP [44], Joseph RG, et al. [6] and Baucon A, et al. [8].

Rizzo V, et al. [2] have published evidence documenting that these lozenge-shaped forms have patterns and shapes are characteristic of biology and not crystals as based on a statistical comparative quantitative micro-structural analysis (Figure 38). Specifically, Rizzo V, et al. [2] compared the morphology of these microstructures with the microstructures of stromatolites/microbialites, microfossils and algae, and microstructures of sulphate crystals (gypsum, jarosite). Morphological analysis of MAHLI images at sols 809 and 889 reveal that the "lozenge-shaped" formations have distinct fusiform/filiform, septate, and curved shapes characteristic of colonies of microorganisms (e.g. terrestrial microalgae, filamentous cyanobacteria, euglenoids). Based on comparative quantitative measures it was determined that these patterns and shapes do not resemble crystal-type organization or structure.

The metric data reported by Rizzo V, et al. [2] indicates a significant degree of uniformity in distribution--as might be expected of colonies of microorganisms-- whereas variation in length and width and length/width ratios and orientation specificity were statistically distinct from the terrestrial crystal samples but similar to microorganisms. The gypsum crystals, for example, were found to form distinct clusters significantly different from the Mars sample. Neither feldspar phenocrysts nor jarosite crystals are closely related to the Mars sample as based on a metrics. Correlations between factor loadings and the various metrics indicate that Mars sample profile widths and profiles with the fusiform and curved shape of terrestrial microorganisms are significantly correlated but statistically distinct from mineral deposits.

It should be stressed, however, that it is impossible to determine the identity of these organisms based on statistics or shape. Likewise, the crystal or mineral hypothesis cannot be ruled out as minerals are abundant in Gale Crater. However, mineralization is also a major contributor to fossilization.

Conclusion

A vast array of forms resembling the fossilized remains of various marine organisms including Ediacaran and Cambrian fauna have been photographed embedded atop various sediments within the dried lake beds of Gale Crater including what may be a fragment of a coral reef. These include those resembling "*Kimberella*" and the "ice-cream-cone-shaped" "Lophophorates," and "*Namacalathus*" as well as polychaete and segmented annelids, tube worms, chelicerates, lobopods and forms reminiscent of a variety of terrestrial marine biota.

Are these true fossils? Comparative quantitative analysis of gross, overall morphology has documented that samples of these putative Martian fossils are statistically nearly identical to those of Earth [6,44]. Microanalysis published by Rizzo et al. [2] indicates that some of these specimens statistically resemble colonies of microorganisms and are distinct from gypsum, jarosite, or feldspar crystals. Microanalysis also reveals that these specimens are oriented in different directions with no sequential repetitive patterns; and these findings are not compatible with any abiotic scenario. Detailed quantitative, comparative, morphological and statistical analysis of photos depicting tubular formations in the dried lake beds of Gale Crater [6,8,44] are also supportive of biology.

Have we in fact identified Martian analogs to specific terrestrial species? We cannot state with certainty the name or identity of all the specimens presented. The diversity is too great and without extraction and direct examination it is impossible to draw conclusions as to identity or biogenicity. We can only make reasonable deductions based on morphological similarities, and the fact that in some respects, these assemblages are reminiscent of a sea bottom *Tableau vivant* of life.

Admittedly, we have not proven these are true fossils. Conversely, consider the alternative: What is the probability that Mars is and was a "lifeless desert" that was and is completely sterile? Given the ability of "life" to adapt and flourish in the most extreme environments including long term direct exposure to space outside the ISS [60,61], coupled with the fact that despite "sterilization" even NASA "clean rooms" and Mars-bound equipment are crawling with bacteria, fungi, and other microorganisms [53], and as there is so much published evidence supportive of current and past life on Mars [1-7,13-21, 25, 34-36], then the probability of sterility is zero. Certainly it is possible that some of the fossil-like specimens presented here are abiogenic. However, given the lack of abiogenic analogs, whereas so many diverse forms are oriented differently yet remain morphologically similar to each other and to fossilized marine biota of Earth, an abiogenic explanation is unlikely but can't be ruled out without extraction and detailed microscopic examination.

Obviously, the current biosphere of Mars is so unlike Earth it seems inconceivable that similar species could have evolved, or that metazoans could survive. However, because Mars does not have a stabilizing moon this causes periods of extreme axial obliquity. In consequence, there have been repeated episodes in which the Red Planet may have become Earth-like, such that temperatures and atmospheric pressure have risen causing the melting of the polar ice caps and surface and subsurface glaciers, thereby flooding the planet with rivers, lakes, and oceans of water that remain stable for hundreds of thousands and perhaps hundreds of millions of years (Figure 43). However, even when obliquity declines below a critical tipping point, thereby triggering the recession and freezing of waters and mass extinctions, it is highly probable that various organisms, or their eggs, may have become dormant. On Earth rivers run dry and remain so even for dozens or hundreds of years and then suddenly become flush with marine vertebrates and invertebrates when rivers and lakes reappear. Hence, it is not inconceivable that dormant organisms or their eggs, may also repopulate the Red Planet when obliquity again, and again, and again, exceeds 40 degrees thereby flooding Mars with warmth and oceans of water. What impact might repeated episodes of extreme obliquity have on the evolution of life? The answer is unknown. Given these limiting parameters and periodic catastrophic conditions, and as there is, at present, no evidence to suggest otherwise, it is likely that life on Mars may have evolved only to the level of metazoan invertebrates.

In conclusion, based on the evidence presented in this and other reports, we hypothesize and believe that the majority of these specimens could be true fossils of Martian organisms that long ago flourished in the lakes and inland seas of Gale Crater.

Conflict of Interest

The authors declare that there is no conflict of interest associated with this research and this manuscript.

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