Article

Evidence of travertine and microbe life on Mars

火星上泉华石和微生物存在的证据

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Abstract

The travertine stone is a rock formed by chemical precipitation of minerals around a spring mouth. It can be mushroom-like or cylindrical, and often has mold holes derived from filamentous microbes. In this study a travertine stone with filamentous mold holes is identified in a microphotograph of Mars's surface taken by NASA rover Curiosity. The analysis revealed that it was formed in at least six steps: (1) High-pressure hot springs of water supersaturated with carbonate ion and calcium ion flowed from the spring to the surface of Mars, (2) Filamentous microbes or microalgae grew upward or radially around the spring mouth, (3) The carbonate minerals (probably calcite) precipitated on the filaments and eventually filled the interspace between the filaments to form a travertine stone, (4) The mold holes formed from the death and degradation of the filaments, (5) The spring water channel was filled by some white minerals, and (6) The travertine stone underwent weathering. The smooth surface, the presence of mold holes, the shape of big head and small feet, and the fissure-like passage of the spring water filled with white minerals are the key features for identifying this kind of travertine stone. The discovery of this travertine stone indicates that there were once spring and microbes on Mars.

Key words: Mars, travertine stone, mold hole, microbe, life.

1. Introduction

Mars is the planet similar to Earth in many aspects, and is most likely to have similar layered struc-

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ture and life. Determining whether there is life on Mars is one of the important contents of the study of the origin and evolution of the universe and life.

At present, the main means of seeking the evidence of life on Mars include: (1) analysis of the photos of the Martian surface taken by rovers, (2) analysis of the chemical composition data of the Martian surface obtained by the instrument of the rovers, and (3) analysis of samples collected from the Martian surface and brought back to the Earth in the future.

The Curiosity and Perseverance rovers launched by NASA and the Zhurong rover launched by the China Space Administration have taken hundreds of thousands of photos of the Martian surface, including a lot of close-up photos, providing rich original materials for analyzing the rock composition of Mars and searching for evidence of life on Mars.

Although China and the United States have plans to collect rock samples from Mars and bring them to Earth for study, both are many years away. Prior to the return of samples from Mars to Earth, the analysis of the already obtained photographs is the main research mean. It is very meaningful to determine whether there is life on Mars as early as possible, not only to gain important scientific understanding, but also to establish a basis for future search for life on Mars.

In this paper a photograph of the Martian surface taken by NASA's Curiosity rover is analyzed to determine whether life exists or existed on Mars.

2. Previous research works

Many researchers have did studies to search for evidence of life on Mars. Important works include those by Rizzo and Cantasano (2011), who made a comparison of the laminated fabrics of a outcrop on Mars to the laminated fabrics of some terrestrial stromatolites, Rizzo and Cantasano (2017) , who compared microfabrics of some Martian rocks in photos with those of terrestrial microbialites, Rizzo (2020), who compared a mound-like structure on Mars to some similar mound-like microbial structures on Earth, Bianciardi et al. (2014, 2015), who performed a quantitative image analysis to compare some terrestrial images of microbialites with the images photographed by the Opportunity Rover and interpreted the latter as the presumptive evidence of microbialites in the Martian, Noffke (2015), who identified some structures in Curiosity rover mission image to be like the terrestrial microbially induced sedimentary structures, Joseph et al. (2019, 2021), who studied the same photo we study in this paper, interpreted them as microbial mat, and interpreted the white substance as calcium and/or calcium oxalate.

Microbialites and MISS are both evidence of life. Previous studies have proposed that Mars may have microbialites and MISS, both of which are considered have an origin related to microbes. Even thought so many studies have been performed, however, to date, there is no agreement about presence of life on Mars. So, the research to search for evidence of life on Mars is still on way. And new study using new method or new thought is needed.

3. Research method

Evidence of life on Earth includes living organisms, remains or relics of organisms, various fossils of organisms, rocks formed by organisms (called bioliths; Wu, et al., 2021, Wu, Y.S., 2023) including reef rocks, non-reef rocks, and microbioliths formed by microbes, mold holes (Wu, et al., 2021) referring to the holes in carbonate rocks, ferric rocks, manganese rocks, and fine-grained clastic sedimentary rocks formed by organisms and originally having the same size and shape as the organisms. The hot spring on Earth is a water flowing from the deep part of the Earth through a fractural passage formed by tectonic activities. The mold holes and travertines on Earth provide a basis for interpreting similar phenomena on Mars.

A photo of the Martian surface taken by the Curiosity rover's ChemCam camera was downloaded from NASA's website and was analyzed.

The sharpness of the photo was enhanced (Fig. 1), the content in the photo was analyzed, and it was found that the subject in the photo was a stone formed by hot spring, called travertine stone, with dense mold holes in its surface. The characteristics of the travertine stone and mold holes are analyzed, and their formation models are established.

4. Phenomena in the photo

The image in the photo (Fig.1) can be divided into five parts: A (darker in color, in the middle, within the orange line), B (the upper and upper right corner of the image, between the orange and yellow lines), C and D (to the left and lower parts of A, respectively, between the yellow and orange lines), E (the light-colored left part of the image, on the left of the yellow line), and F (the lower right part of the image).

Part A has a white irregular area (W) and has many black nearly circular or oval holes. Part B is a smooth surface sloping toward the upper right corner, with dense longitudinal stripes (LS), many black nearly circular holes (CS), and some oval holes (OS). The stripes extend roughly toward the upper right corner and are more or less radially arranged. Some circular holes are concentrically arranged (CO). Part C is a light-colored inclined surface. Part D is a dark, steep, uneven surface. Part E has a lot of small round holes. Part F consists of some kind of grains.

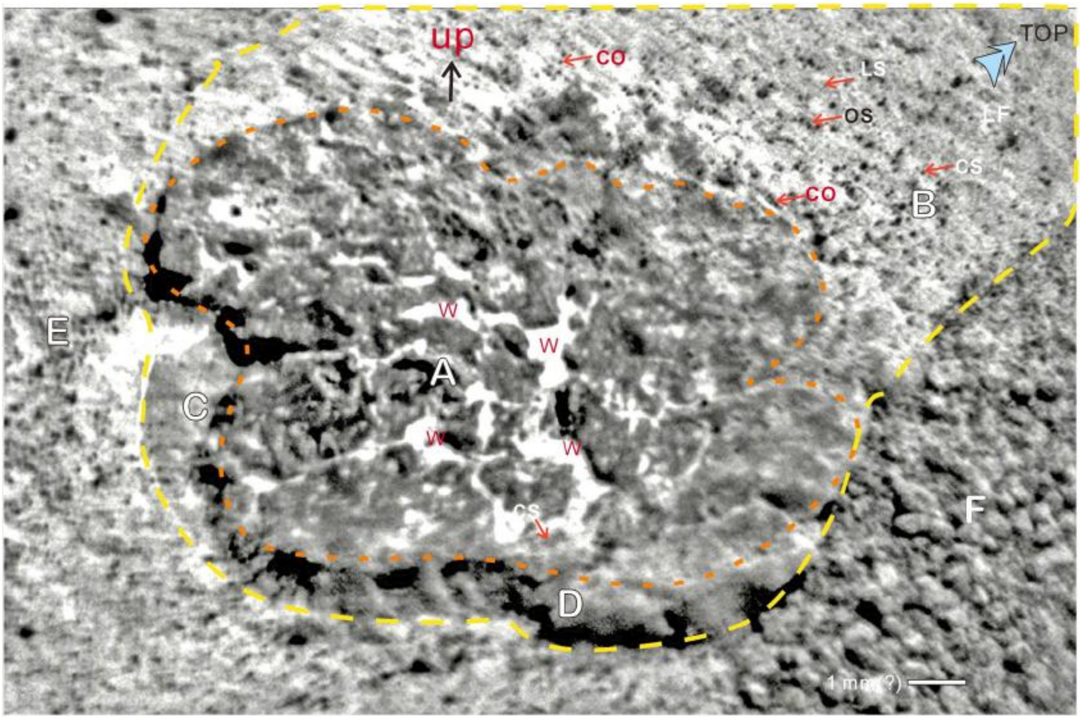

Fig. 1 One of the photos of the Martian surface taken by the Curiosity Rover (Sol 890), downloaded from NASA's website. The sharpness of the photo has been enhanced and annotations (lines, arrows, letters) added by the authors of this paper.

5. Interpretation of the phenomena

According to the perspective principle, the parts A, B and D in Figure 1 are the different faces of an object. A is its bottom surface, B and D are its two side surfaces. B is facing the upper right; D is facing away from us. The extension directions of D and B surfaces indicate that the top of the object is several times larger than its bottom surface. The higher the height of the object, the larger the top surface. The D side is dark because it is steep and backlit. The light was at above the photo when the photo was taken.

Based on four key features, we believe that the object is a travertine stone. The four key features are: (1) the shape of a small foot (part A) and a large head (on upper right), (2) The irregularly shaped white material may be some kind of mineral filling the channel of the hot spring, (3) The longitudinal strips and nearly round, oval holes may be the mold holes formed by precursor filamentous microbes or microalgae, and (4) The smooth surface may be the weathered surface of a carbonate rock.

Travertine stone is a common structure on Earth, formed when hot spring water flows from the Earth's crust to the ground. At normal temperature and pressure, the solubility of carbonate minerals in water is very small, 0.00015 mol/L. However, in the deep part of Earth's crust, the solubility of carbonate minerals in the high-pressure water is much greater and water is generally supersaturated with carbonate minerals. When this kind of water flows to the ground through a channel formed by tectonic activities, it forms a hot spring, and much of the carbonate minerals in the water precipitate around the mouth of the spring because of decline in pressure and the resultant reduced solubility of the carbonate minerals in the water.

If the flow rate of the hot spring is fast, the carbonate minerals are carried out and deposited at places away from the spring mouth, forming large area of travertine rocks, such as the cases of Wucaichi in Huanglong, China (Url1) and the travertine in Yellowstone Park (Url2), United States. On the contrary, if the flow rate is very slow, the carbonate minerals will be deposited around the spring mouth, forming a small-scale travertine rock commonly in in spherical, or cylindrical, or mushroom shape.

Because the spring water near the mouth is warm and contains abundant minerals, filamentous microbes often grow around the mouth, which extend in the flowing direction of the spring water. Carbonate minerals tend to precipitate on the surface of the filaments and at the space between the filaments, eventually bury the filaments and cause them to die. The holes formed by the degraded filaments are called mold holes.

There are many mushroom-shaped, nearly spherical, and hill-shaped travertine stones (Fig. 2) in Lake Pavilion, Canada (Omelona, et al., 2013), all of which have many spring water channels extending upward (Fig. 3, SWP). There are many nodular protrudes at the top (Fig. 2) of the living travertine stones. Dense green living filaments of microbes or microalgae are vertically growing on the surfaces of the nodules (Fig. 2: FA), and white carbonate minerals are forming in the space between the filaments (Fig. 2: Ca). On the cross section of the travertine stones, there are dense mold holes (Fig. 3), whose longitudinal sections are long, and cross sections are rounded, and oblique sections are elliptic. The mold holes have similar diameters and certain arrangement (sch as radial, parallel, and concentric). On the edges of the travertine stones, the filamentous mold holes are generally radially arranged. The surfaces of the travertine stones are rough or smooth.

The white substance in the bottom of the travertine stone in the photo may represent a kind of mineral filling the channel of the spring. The most common white minerals on Earth include calcite and gypsum, but gypsum is whiter in color. Some researchers have identified some white mineral on Mars as gypsum (Url 3). Thus, the white mineral in the travertine stone might be gypsum. This Travertine stone has a small foot (i.e., the beginning part) and a large head (i.e., the end part), the shape of a mushroom-like travertine stone formed by a slowly flowing hot spring.

The travertine stone has dense mold holes, and the mold holes are similar in diameter and arranged along the extension direction of the travertine stone. The arrange of the mold hoes are consistent with the characteristics of filamentous microbes or microalgae extending in the flow direction of a slow-flowing spring water.

On Earth, some algae (such as *Spirogyra*, a common green alga in fresh water) have a diameter up to 170 microns. It is estimated that the diameter of the mold holes in this travertine stone can reach 0.8-1.7 mm, being within the acceptable range.

The most common rocks on Earth composed of carbonate minerals are limestone and dolomite. There are many types of limestones, one of which is composed of calcite micrites. The limestone composed of calcite micrites has a fine, even and smooth surface after weathering. In addition to carbonate rocks on Earth, there are magmatic rocks and clastic sedimentary rocks, but their fresh and weathered surfaces are rough and unsmooth. The surface of the travertine stone in this photo is fine and smooth, a feature characteristic of the weathered surface of limestone, indicating that it may also be composed of calcite micrites.

According to the interrelationship between the different parts of the photo, the travertine stone is buried in the rock of areas E and F. The rock of areas E and F are similar to the travertine stone, which lead to the explanation that the head of the travertine stone was buried by a later-formed rock of the same type (i.e., a carbonate with mold holes). The granular material in area F is the grains of some fine-grained clastic sediments, such as clay, covering the surface of the carbonate rock.

6. Formation model of the Martian travertine stone

According to the above analysis, the formation of this Martian travertine stone may be formed in the following steps: (1) Some tectonic activities formed a long and thin vertical passage from the deep part of the Mars' crust to the Mars' ground, and hot water mineral-rich water flew out of the passage to form a hot spring; The mineral-rich hot water enabled filamentous microbes or microalgae to grow around the spring mouth; The upward flowing of the spring water made the filaments extend in the flowing direction of the spring water; (2) Because of decline in the pressure of the spring water around the spring mouth, the solubility of carbonate minerals in the water declined, and calcium ions, and carbonate ions in the water combined to precipitate on the surface of the filaments and filled the interspace between the filaments; (3) Carbonate minerals continued to form and eventually filled all the space between the filaments, causing the filaments die because they were enclosed in carbonate minerals and could not perform photosynthesis, degrade, and form mold holes; (4) Because of some factors, the spring water stopped flowing, the water pool dried up, the travertine stone was exposed to the air, subjected to weathering, which made the mold hole exposed and the surface of the travertine stone become smooth; (5) The travertine stone became upside down because of weathering, wind or water, and later its head was buried by the later-formed microbial rocks; (6) The travertine stone was captured by the Curiosity Rover ChemCam camera.

7. Future research directions

The Curiosity Rover has taken at least 650,000 images of the Martian surface. Only one of them has a travertine stone, and it is used in this study. This shows that travertines stone is not common or not widely distributed on the surface of Mars. The mission to collect rock samples from Mars and return them to Earth has high hope of finding evidence of life on Mars. However, the chance to collect a sample with evidence of life is very small, because the number of the samples is limited, and the probabil-

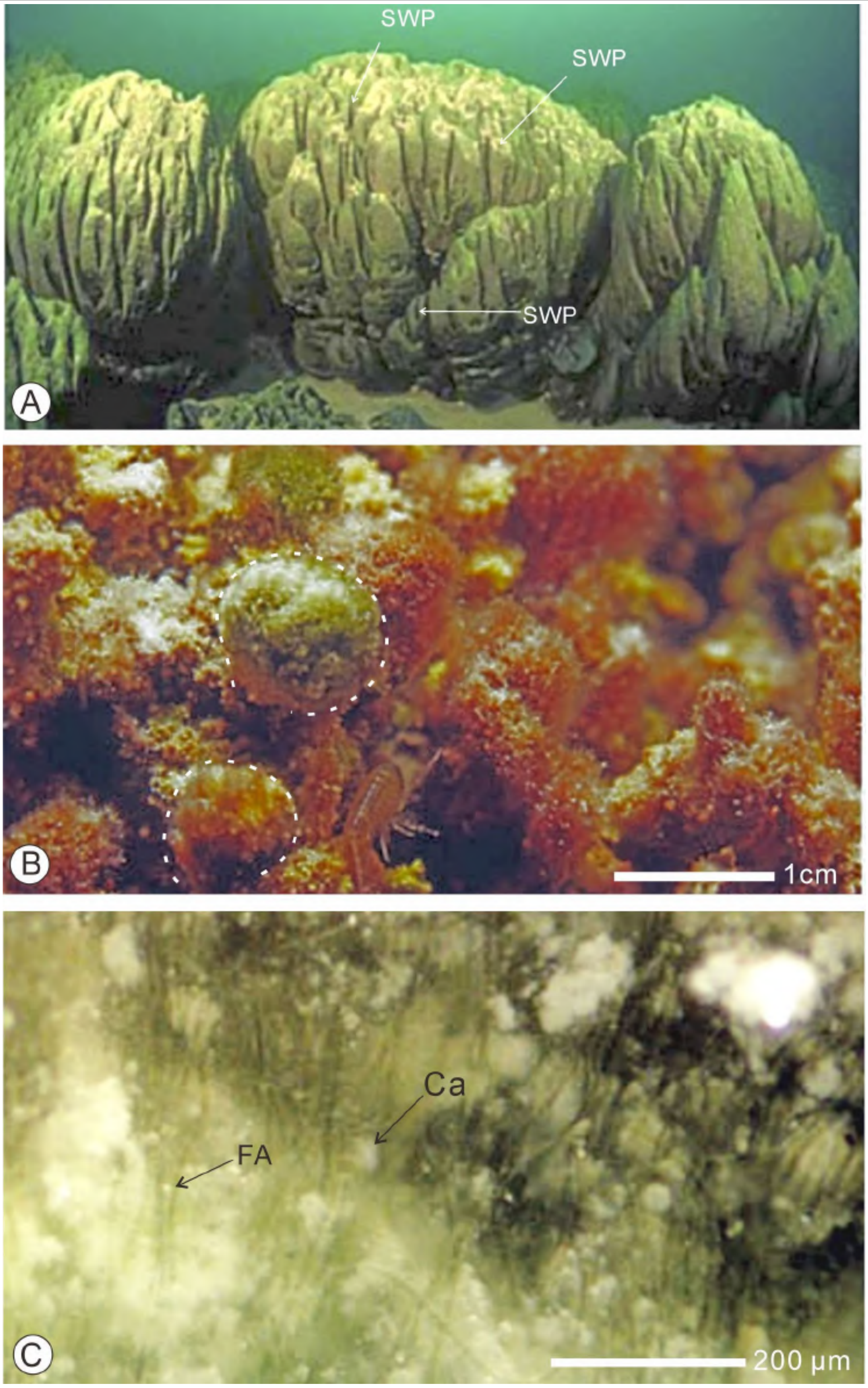

Fig. 2 Travertine stones in Pavilion Lake, Canada (Omelon et al., 2013). A: Dead travertine stones in spherical, mushroom-like, and high-cone shapes, which all have channels for upwelling water (SWP). B: a close-up photograph of the top of a living travertine stone having many nodules (two of which are inside the white dotted lines). If the spring water stops flowing, the travertine stones will die and be subjected to weathering, and the nodules can tumble to the ground. C: a close-up photograph of the surface of a living travertine stone showing microbial or microalgal filaments and white calcite crystals on their surface and in the space between the filaments.

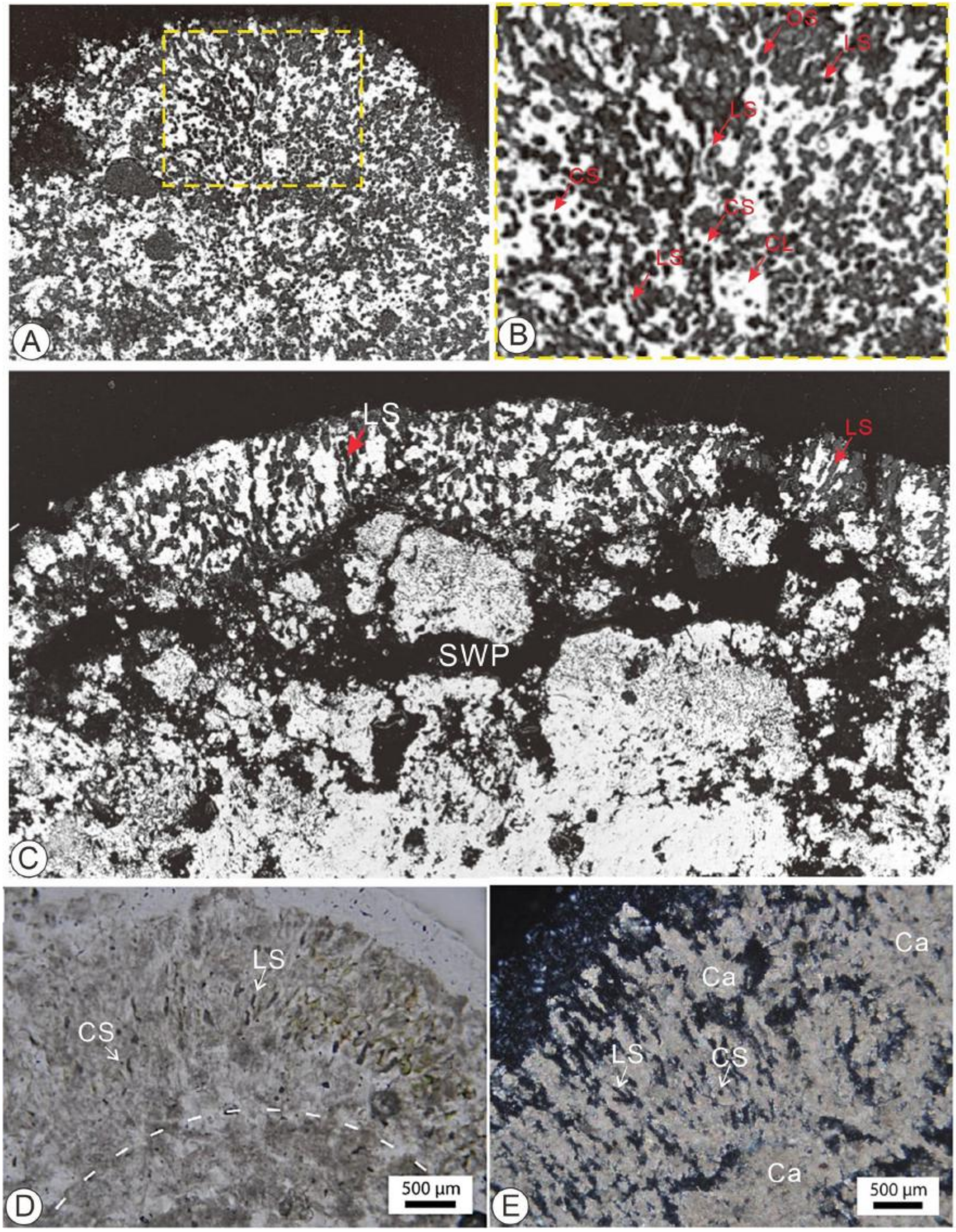

Fig. 3 Microphotographs of some thin sections of the travertine stones in Pavilion, Canada (t), showing the characteristics of mold holes. A: Part of a cross section of a travertine stone, showing dense circular cross sections of mold holes. B: Local amplification of A. C: Part of a cross section of a travertine stone, showing irregular passage of spring water (SWP), dense mold holes of bacteria in the interior, and circular and elongate mold holes (LS) of larger filamentous microbes or microalgae. D: Part of a cross section of a travertine stone, showing circular cross sections of mold holes (CS) of microbes or microalgae in the interior and the elongate longitudinal sections of mold holes (LS) in the edge. E: Part of a cross section of a travertine stone under orthogonal light, showing many elongate longitudinal sections of mold holes (LS) and circular cross sections (CS), and the white interference color characteristic of calcite.

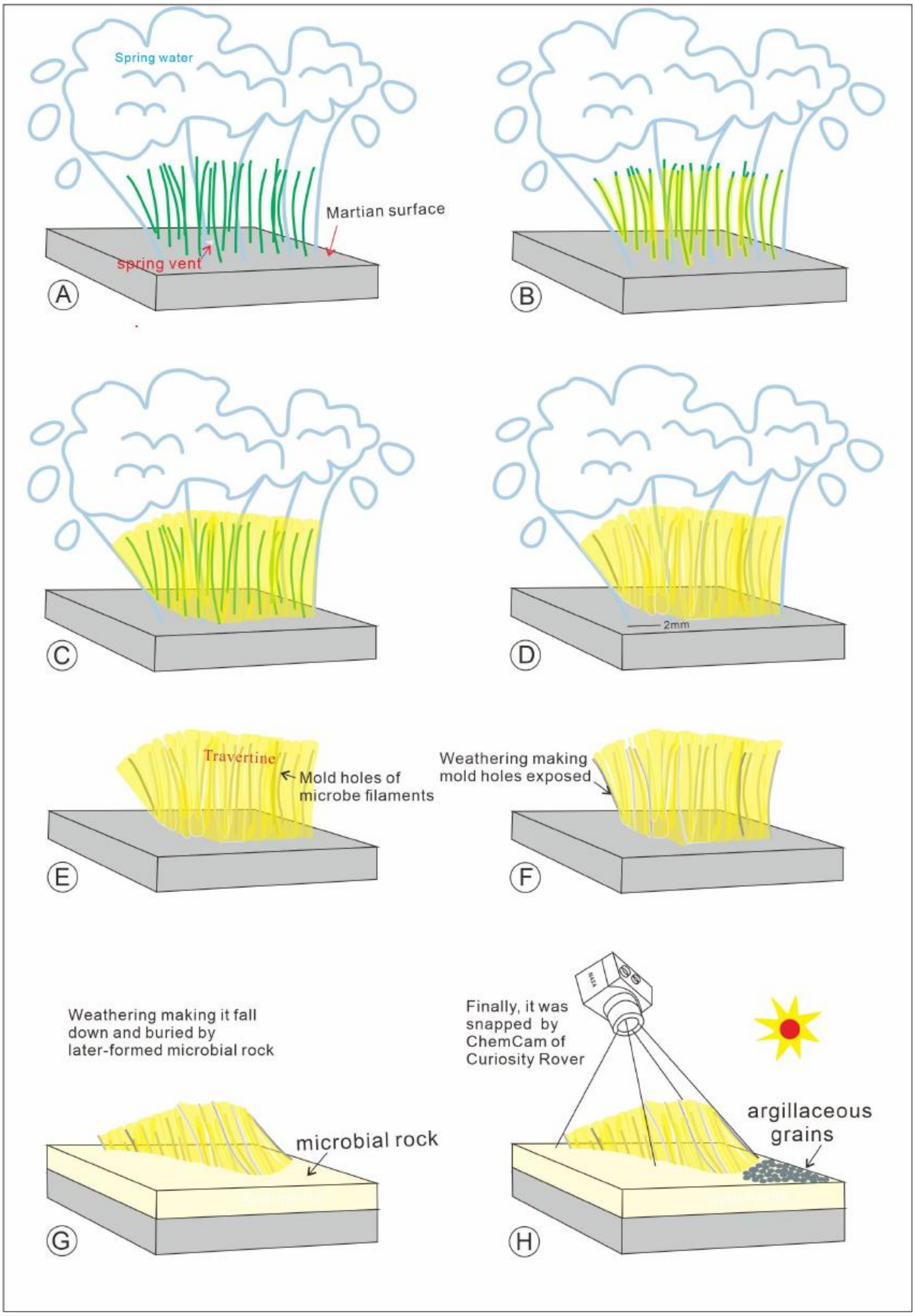

Fig. 4 Formation model of the Martian travertine stone in Fig. 1. A: Filamentous microbes (green) grew in the slowly flowing spring water, and extended in the flowing direction of the water. B: The surfaces of the filaments were coated with carbonate minerals (yellow). C: The space between the filaments was filled by carbonate minerals (yellow) and a travertine stone formed. D: The filaments died. E: The filaments decayed out, and mold holes formed. F: Because of weathering, the mold holes became

exposed in the surface and the travertine stone surface became smooth. G: Weathering, as well as wind or water flow, made the travertine stone to became upside-down, and its big end was buried by later-formed microbial rock. H: The travertine stone and the surrounding rocks and sediments were photographed by the ChemCam camera of NASA's Curiosity Rover.

ity that the sampling locality is right at a travertine stone is very small. The most effective and promising method is to find the site of the travertine stone studied here, collect it and bring it back to Earth for study.

8. Conclusions

The rock in a photo of Martian surface taken by NASA's rover Curiosity has smooth surfaces formed from weathering of limestone, a shape with a big top and a small base, a channel penetrating the internal of the stone, and dense mold holes in its surface, and is identified as a travertine stone formed around a hot spring mouth with water slowly flowing from the interior of Mars' crust. The mold holes were formed by filamentous microbes growing around the spring mouth. The formation of the travertine stone needs the condition that the spring water was supersaturated with Calcium and bicarbonate ions.

The characteristics of the travertine stone indicate that: (1) Mars has a structure and tectonic movements similar to those on Earth, (2) Filamentous microbes once grew in the water of the hot springs, (3) A travertine stone formed in some ancient time, and (4) Chemical weathering was once precent on Mars.

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