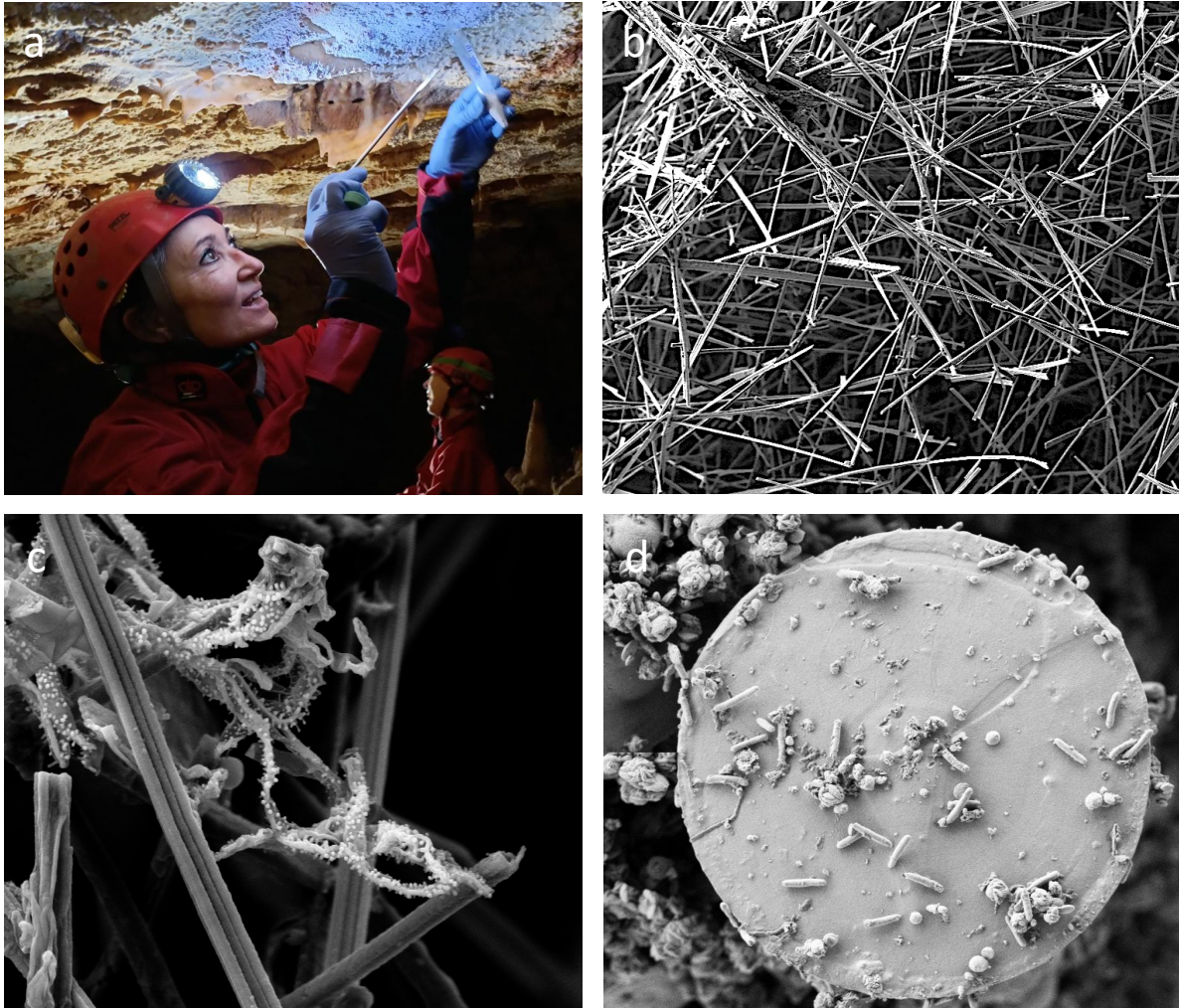


The Amazingly Curious Microbial Phenomena Gallery

Moonmilk and the micro builders of calcium carbonate

(Teresa Rinaldi)



Moonmilk. a: sampling of Moonmilk in the Lamalunga cave in Puglia. b: nanofibers of the Moonmilk observed with Scanning Electron Microscopy (SEM), sampled in the Tomba degli Scudi, in the ancient Etruscan Necropolis, Tarquinia. c: the same Moonmilk as in b, a bacterium living among the nanofibers of calcium carbonate. d: a semi sphere of calcium carbonate, produced in the laboratory, by carbonatogenic bacteria, which are visible on the surface. The bacteria are 1 micrometer in length.

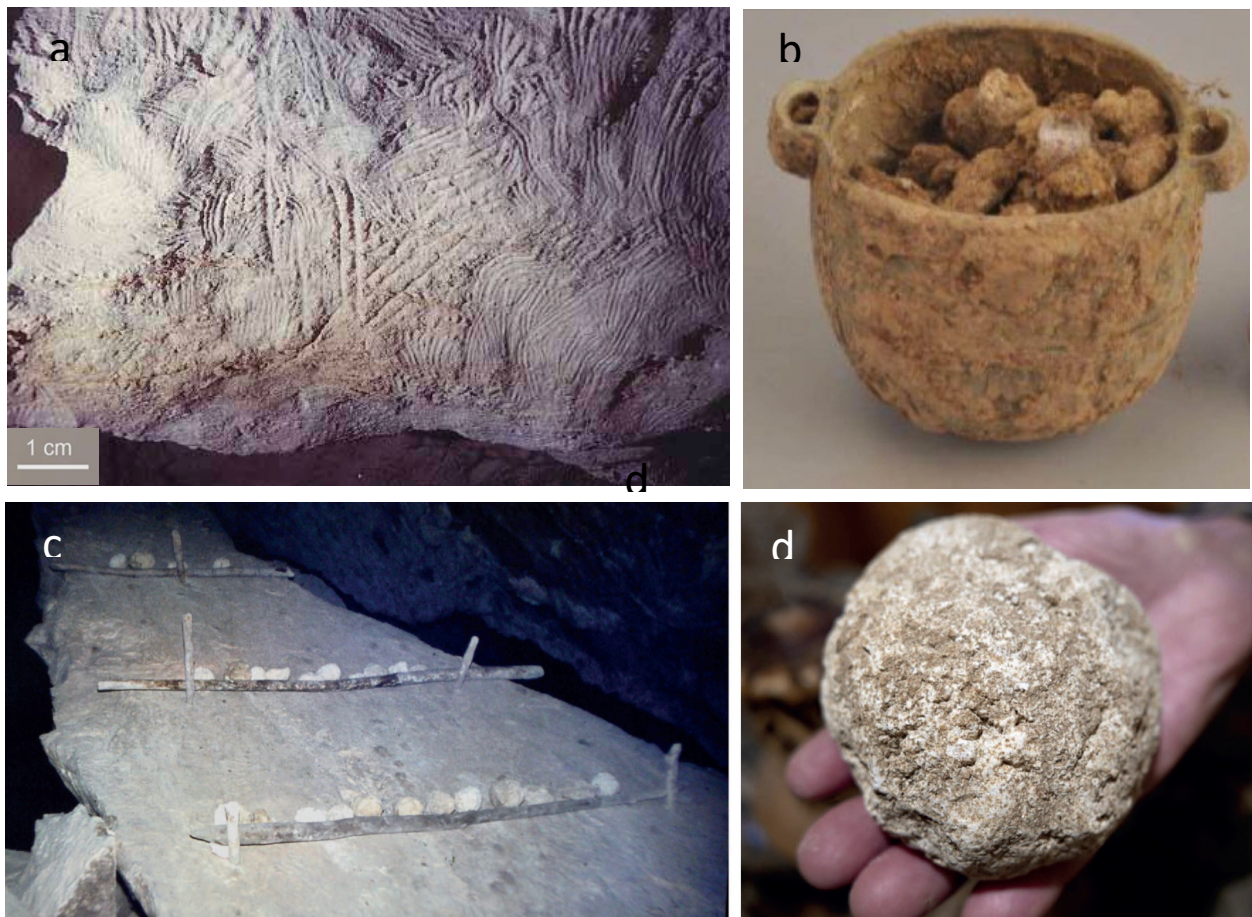
...The microbiologist was very worried; she was not a speleologist (someone who studies caves, or who climbs in them for sport) and the idea of being lowered into a karst (limestone) cave to take environmental samples was not at the top in her list of things to do. Nevertheless, the black hole near her shoes was the entrance of a special cave, of great archaeological value, into which just a few people can enter, and only for assessment of environmental conditions to preserve the site. Thus, she took a breath and said to the speleologists: “I’m ready”. Ten meters below the ground, she lit up the permanent dark environment with a torch, and the cave revealed the beauty of a hidden world, full of hidden life. When she saw the white patina on the ceiling, fluffy and soft, among stalagmites, she said: “wow, I was sure I would find the Moonmilk!”.

A child-centric microbiology education framework

The biologist opened the sampling kit, took samples under the supervision of the archeologists (panel a), and then said: “let’s go into the lab and start the analysis!”. (the author)

Would you like to know the secrets of Moonmilk and know why the biologist wants to do experiments in the lab? Let’s read its story below.

What is moonmilk? Moonmilk (panel b above) is formed of nanofibers (tiny fibers) of calcium carbonate. Nobody knows how exactly the fibers are formed, but two “ingredients” are fundamental: bacteria and rocks. Microorganisms and rocks have been *friends* for billions of years but sometimes rocks contain too much calcium ion, which stresses the bacteria. The clever bacteria respond by *neutralizing* this ion by locking it up in molecules of calcium carbonate (panel c). This is the reason why Moonmilk is not rare – everyone can find it, especially in karst caves that are formed of limestone (calcium carbonate). In caves, a huge number of microbial species form a microbial community adapted to live *in* and *on* the rock in the cave environment, with darkness, silence, humidity, and a constant temperature. In one word, a paradise for the bacteria!



Moonmilk in art and medicine in the past. a: Finger flutings in Koonalda Cave, Nullarbor Plain, Australia, probably between 15,000 and 31,000 years old (Bednarik, R.G. 2014. *Arts*, 3, 156-174; b: agglomeration of yellowish white lumps inside the bronze jar, found in a 2700-year-old tomb in China, that correspond to Moonmilk mixed with animal fat (Han, B. 2021. *Archaeometry*, 63,5, 1042-1058); c: View of the drying facility in a cave in Austria, in use until the beginning of the 19th century, showing a series of ball-shaped moonmilk chunks left by the miners. Width of image about 2 m; d: One of the very few remaining original moonmilk balls (Spötl, C. 2018. *International Journal of Speleology*, 47,2, 2).

A child-centric microbiology education framework

Moonmilk was a canvas for art. Moonmilk fascinated humans already 30,000 years ago in the Paleolithic period. In addition to painting rocks in caves, the most famous being in the Altamira, Lascaux and Chauvet caves, ancient humans used their fingers to trace shapes and create drawings on Moonmilk (see panel a in the second collage).

Moonmilk is a bioprotectant. While microorganisms are often responsible for biodeterioration of all manner of materials, from food, to cotton, steel and stone, our studies have shown that Moonmilk acts as a protective agent preventing the damage of the ancient mural paintings in underground environments. Moonmilk is perhaps a unique example of protection of cultural heritage. So moonmilk bioprotects both the bacteria that produce it, and cultural heritage that it may form on.

Moonmilk was used in traditional medicines and personal care preparations. Moonmilk was also used in ancient times as a cosmetic for face and hands, and has been recently found mixed with animal fat in a perfectly preserved container in a tomb in China dated 2,700 years ago (panel b).

Moonmilk was used in veterinary and human medicine. The first document mentioning moonmilk, published in 1555, reports that it was extracted by local people in Switzerland and used as a remedy. Moonmilk was also extracted from an Austrian cave until the beginning of the 19th century (panels c and d) and used by farmers as a cattle-feed additive to cure intestinal diseases in cattle. It was even used as a cure for poorly lactating cows and humans. It was the first antacid and cure for ulcers, treatment for broken bones, remedy for dysentery, and agent to dry bleeding wounds.

In fact, the microbial community of Moonmilk hosts many species of bacteria that produce molecules of pharmaceutical interest, including antibiotics. Thus, it is of great interest to study the Moonmilk microbial community because producers of new antibiotics can be obtained from it. Moonmilk and its microbial community have biotechnological applications.

Application potential of moonmilk and the microbes that produce it. There are a number of potential applications of both the moonmilk microbial community and single bacterial strains isolated from it, including biorestitution of monuments, the capture of carbon dioxide from the atmosphere, production of self-healing concrete, production of biobricks, discovery of new molecules of pharmaceutical interest, and the production of pure calcium carbonate (e.g. see panel d in cover image).

A sustainable Earth needs a new generation of geomicrobiologists... we are waiting for you...

Moonmilk formation is an amazingly curious microbial phenomenon with important applications!