

The story of Mars's early atmosphere is told in carbonate rocks

Newly found iron-rich minerals suggest that carbon dioxide cycled in and out of the planet's ancient atmosphere.

Mars's atmosphere, compared with Earth's, is thin and wispy. Some of it was lost to space after the planet's magnetosphere failed some 4 billion years ago (see the Quick Study by Bruce Jakosky, *PHYSICS TODAY*, April 2022, page 62). The current air pressure—only 0.6% that of Earth's—ensures that the Martian surface stays cold and dry. Mars's current atmosphere has roughly 6 millibars of carbon dioxide, but if the past atmosphere had at least tens of millibars of CO₂, as models suggest, the climate could have been warm enough to support liquid water (see the article by Bruce Jakosky and Michael Mellon, *PHYSICS TODAY*, April 2004, page 71).

For several decades, researchers studying Mars have used rovers and orbiters to search its sediments for evidence of CO₂. The gas, after being emitted from volcanic eruptions, may have reacted with liquid water to form sedimentary carbonate rocks. Yet despite many remote-sensing observations, not enough carbonates have been found on the Martian surface to support an at-

mosphere rich with CO₂. Now Benjamin Tutolo (University of Calgary) and colleagues have found a large carbonate reserve in the subsurface, in an iron-rich mineral not seen before on Mars. Called siderite, the mineral was found to have a nearly pure iron composition.

In 2022, NASA's *Curiosity* rover reached Mount Sharp, a 5-kilometer-tall stack of sediments in Gale Crater, which is thought to have once been a lake. There, the rover drilled four samples. Tutolo and colleagues' analysis identified not just siderite but also several other minerals, including sulfates and iron oxides. The finding of all the minerals together suggests that siderite, with its especially pure composition, precipitated out of an aqueous solution underground. Later, infiltrating fluids partially dissolved the siderite to form iron oxides. If the released carbon made its way to the atmosphere, it would have contributed to a Martian carbon cycle and potentially prolonged the duration of liquid water on the surface because of continued greenhouse warming.

Tutolo and colleagues speculate that the sulfate minerals masked the siderite from the reflectance and thermal emission spectroscopy approaches of remote-sensing instruments. Various sources would have added CO₂ to Mars's ancient atmosphere. Using a

broad estimate for the amount of siderite that may be in the planet's subsurface, the researchers predict that the carbonate-rich sediments contributed 2.6–36 millibars of CO₂ to the total. The higher end of the range would offer enough atmospheric pressure to stabilize liquid water on the surface. But more CO₂—potentially lost through other means such as atmospheric escape—would have been required to raise temperatures to habitable conditions.

The finding of siderite and its partial dissolution suggests a planetary carbon cycle. When atmospheric CO₂ was plentiful, some was sequestered to form siderite, and then subsequent rock-water interactions released some CO₂ back into the atmosphere. Now that the mineral has been found with sulfates, reanalysis of existing remote-sensing data could help determine whether large siderite deposits exist elsewhere. On the ground, other Mars rovers—*Perseverance* and *Spirit*, before it lost contact with Earth—spotted iron-rich oxides close to sulfates in various locations. The samples that *Perseverance* has collected, and that NASA hopes to bring back by 2040, will likely yield new clues about the planet's ancient atmosphere. (B. M. Tutolo et al., *Science* 388, 292, 2025.)

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PILES OF ROCKS, which could have formed from floods of water, are seen in this 180° panorama of a channel in Gale Crater, captured by NASA's *Curiosity* Mars rover on 31 March 2024. (Image by NASA/JPL-Caltech/MSSS.)