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Highlights and Breakthroughs

Revisiting the importance of clay minerals in rock varnish

Ronald I. Dorn[1,]*

[1]School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, Arizona 85281, U.S.A.

Rock varnish is a natural coating that contains three main ingredients: manganese oxyhydroxides, iron oxyhydroxides, and the largest component—clay minerals. In the nearly half-century since George Rossman and his Ph.D. student Russ Potter discovered the importance of clay minerals in the formation of varnish (Potter and Rossman 1977; Potter 1979), only a few (e.g., Chaddha et al. 2021) have conducted research on varnish clay minerals. In this issue of *American Mineralogist*, Qian Fang et al. are the first in 48 years to provide substantive new insights into this dominant component of rock varnish.

In "Formation and transformation of clay minerals in Mars-analog rock varnish," Fang et al. (2025, this issue) use X-ray diffraction, high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM), and transmission electron microscopy (TEM) examination of focused ion beam (FIB) milled lamella and clay-fraction powders, as well as visible- and near-infrared spectroscopy to analyze clay minerals in rock varnish. Unlike most in varnish research, they did not restrict themselves to hot, dry deserts, but selected varnishes from different climatic regions in China, discovering that illite and chlorite dominate clays in deserts, whereas kaolinite increases in wetter settings. Unlike many others who limit their analyses to exposed surfaces, Fang et al. also analyzed varnish that had migrated downward into fractures within the underlying weathering rind. However, Fang et al. emphasize that their STEM observations reveal that rock varnish does not originate from the underlying rocks but is externally applied as a coating.

Digging deeper into the texture of clays using high-resolution TEM, Fang et al. (2025) discovered that illite thickness influences not only nanoscale chemical variability, but also that much of the interaction with Fe- and Mn-oxyhydroxides occurs with thin, likely authigenic, illite. This explains the "feathering" of authigenic illite associated with the insertion of nanoscale Mn-Fe granules into illite's outer edges next to microbial casts (Dorn 2024). Fang et al. (2025) also stress the importance of thin (<7 nm) illite particles in creating the lamellate texture of nanoscale rock varnish.

Prior to his passing (Mahaney et al. 2018), Dave Krinsley and I collaborated on a paper regarding Dual-Beam FIB/TEM and HAADF-SEM analysis of varnish clays. I am pleased that we were "scooped" by Fang et al. (2025), as this now allows me to report that we have replicated their findings for our North American samples. The only difference was that we found substantial amounts of mixed-layered illite-smectite, a similar finding to Potter and Rossman (1977). What remains could easily explain the dominance of illite and chlorite in China are regional variations in desert dust mineralogy (e.g., Gonçalves Ageitos et al. 2023).

Terrestrial rock varnish research has had an (almost) exclusive focus on manganese: how it is enhanced (Dorn 2024); how it informs on Quaternary climatic change and dating surfaces (Liu and Broecker 2013); its complex mineralogy (McKeown and Post 2001); and more. A similar focus on manganese dominates varnish research related to Mars, with rare consideration of its two other major components: iron and clays. In contrast, Fang et al. (2025) take on both constituents. For example, they point out that observed transformations from chlorite within illite could explain some of the iron enrichment in varnish.

By Fang et al. (2025) reemphasizing the importance of clay minerals in terrestrial varnish, I hope that martian varnish researchers refocus attention on this largest component of rock varnish. Fang et al. additionally draw attention to transformations of illite to chlorite that occur within the center of illite particles instead of along edges, as well as through the development of interstratified structures between illite and chlorite. The paucity of water on Mars highlights the role of Mg^{2+} in retaining interlayer water, which is compatible with the illite-to-chlorite transformation on Mars.

I have two wishes as it relates to clay minerals for scholars like Fang and colleagues who are thinking about rock varnish on Mars. Please focus future research on particularly cold and dry terrestrial sites, such as Antarctica (Dorn 2024) and Ladakh (Chaddha et al. 2023, 2024), which are far superior terrestrial analogs compared to warm deserts.

Terrestrial rock varnish forms on both subaerial exposures and within rock joints (Dorn 2024). I think that the same could occur on Mars (Fig. 1a). Terrestrial fracture varnish is exposed by spalling of the overlying rock (Fig. 1b). Fang et al. (2025) speculate that the illite-to-chlorite transformation on Mars might be aided by the long exposure times to solar radiation for rock faces. My second wish for varnish clay scholars is to test this important idea on Earth by analyzing varnishes found within joint fractures and comparing them to varnishes nearby that have been exposed to solar radiation.

* Corresponding author E-mail: ronald.dorn@asu.edu Orcid https://orcid.org/0000-0003-1343-4556

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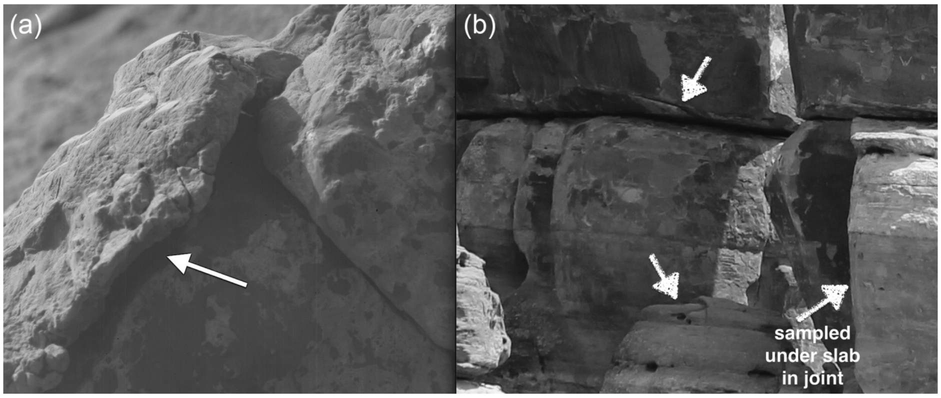

Figure 1. Rock varnish formed in joint fractures. (**a**) NASA's rover Curiosity acquired this image using the Mars Hand Lens Imager on June 4, 2024 (Sol 4205, details of image capture at https://mars.nasa.gov/raw_images/1358365/?site=msl). For scale, the lens was between 20–25 cm from the target. The white arrow identifies what looks to be a dark rock coating similar in appearance to rock varnish within a rock joint. What looks to be varnish also occurs on exposed rock faces in the same area as this image. (**b**) At Garden of the Gods, Colorado, white arrows identify rock varnish that formed within sandstone joint faces, sampled with permission. The rock face is about 1.5 m from top to bottom. Photo by R. Dorn.

In the end, I return to my gratitude to Fang and colleagues for, finally—almost half a century after Potter and Rossman (1977)—making a substantial contribution to new insight into the largest component of rock varnish: clay minerals.

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