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Article

Rock Varnish: Nature's Shield

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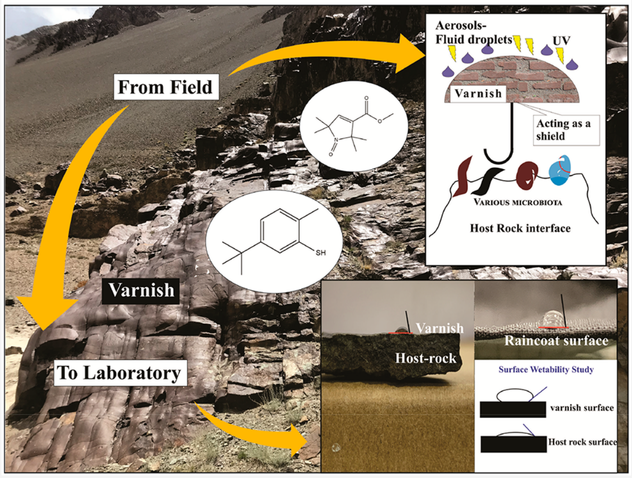
ABSTRACT: Bare rock surfaces in dry to semiarid places of the world often host a black-brown accretion rich in Mn and Fe known as rock varnish. The varnish surface presents an ideal environment for microbial development. A burgeoning interdisciplinary arena of scholarship focuses on the biogeochemical fingerprints of life in severe settings. Given that a large number of researchers hypothesize that varnish formation is a key process by microorganisms, the high altitude Ladakh remains a largely unexplored research setting. Thus, as one of the world's harshest dry deserts, we selected Ladakh as the focus for this investigation into the nature of organic biomarkers found in subaerial rock varnish in this severe climate. Microbial fingerprinting using organic biomarkers and isotopic analyses in conjunction with electron microscopy reveals the presence of organic metabolites such as fatty acids, alkyl benzenes, oxime, amide, and fatty acids that we interpret as resulting from mineral−microbial interactions. We hypothesize that a newly discovered change in surface wettability characteristics from hydrophilic (in host rock) to hydrophobic (in varnish) might be important in facilitating the development of microbial processes that could be related to varnish formation.



KEYWORDS: *rock varnish, surface wettability, extreme environment, Ladakh, mineral−microbe interaction, organic molecules, isotopic studies*

1. INTRODUCTION

Rock varnish exists as a thin, dark, lustrous coating frequently seen on exposed rock surfaces worldwide in desert environments,[1] including its accretion on top of ancient petroglyphs.[2,3] Rock varnish hosts range of microorganisms,[4,5] with a composition dominated by clay minerals cemented to rock surfaces by iron and manganese oxides and hydroxides.[6−9] Depending on different factors, varnish coatings range in thickness from ≤1 μm to several 100 μm. The rate of accretion varies tremendously, ranging from a few micron per millennia in harsh warm deserts to microns per century in wetter settings.[10−13] Scholars have proposed a host of alternative competing hypotheses to explain the tremendous concentration of manganese found in varnish. These are particularly grouped into abiotic geochemical processes,[14,15] and microbial processes.[16] No consensus, however, exists on exactly how this rock coating forms. The current trend in research favors the importance of microbial processes in rock varnish development, focusing on microbial explanations for the enhancement of manganese.[17]

Some have argued that the Mn and Fe in rock varnish act as a shield from the intense UV irradiation and extreme temperatures.[18] Some of the motivation for this research rests in the possibility that terrestrial varnish is an analog for Mn-rich coatings found on Mars[19,20] and that the presence of varnish on Mars might infer the presence of life on that planet, since microbial processes might be a key in varnish genesis.[21−25]

Microbial life finds a complex network of niches within exposed rock surfaces and assists in the formation of microbial biofilms, which are eventually preserved on rock surfaces and serve as crucial life indicators.[26] Researchers are constantly seeking to discover the interactions and factors that drive the formation of these microbial-driven biofilms.[27] In general, hydrophobic solid surfaces promote a positive association between bacterial retention and hydrophobicity.[28] In the context of bacterial adhesion, the majority of the existing literature has focused on the effect of surface properties on the

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