

The Origin of Desert Varnish



Photo: Hieroglyphs carved into rock varnish from Israel's Negev Desert.

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Abstract

The slowest accumulating terrestrial sedimentary deposit known, desert varnish is usually dark brown to black in color depending on the relative abundance of MnO_2 . Archaeologists often utilize desert varnish for relative age determinations. Although this application has proven unreliable, recent studies suggest that the chemical microstratigraphy in desert varnish can provide valuable information about past environmental fluctuations. Other applications of desert varnish have also been found.

While some varnish deposits are uniform and continuous, most desert varnish appears in discontinuous patches of variable thickness and texture (Staley et al., 1991). The primary components which make up desert varnish are clays and iron and manganese oxides that are derived from air-borne dust and other sources external to the underlying rock. Clay minerals, such as montmorillonite and illite, comprise more than 70 percent of the varnish and are involved in manganese fixation. Iron (predominantly ferric) and manganese oxides constitute the bulk of the remainder (~30%) and are dispersed throughout the clay layer.

Since detailed studies of desert varnish began, the mechanism of varnish formation was not well understood. The idea that desert varnish formed via physiochemical precipitation was accepted for some time. Recent studies propose that desert varnish is a product of microbial activity. It is likely that physical, biological, and chemical processes are all involved with varnish formation to some extent.

Introduction

Desert varnish has been around for nearly 100,000 years, and can be found worldwide in arid to semiarid environments. For centuries, desert varnish has invoked scientific curiosity. Alexander von Humboldt first noticed desert varnish in the early nineteenth century while traveling through South America (Liu and Broecker, 2000); Charles Darwin observed it on his early expeditions as well (Staley et al., 1991). Defined as a distinct morphological entity which appears naturally as a thin, dark coating, desert varnish has an abrupt boundary with the underlying rock (Fig. 1). The morphological demarcation of varnish from rock suggests that varnish material is derived from external sources (Potter and Rossman, 1977).



Figure 1: Archaeological artifact carved into desert varnish from the Negev Desert of southern Israel. Photo taken on a geological expedition in June of 2007.

A particular type of rock coating, desert varnish is the slowest accumulating terrestrial sedimentary deposit known. Rock coatings occur at the interface between air, organisms, and mineral matter. These coatings form as moisture from rain, fog, dew, and snow interacts with detrital materials on rock surfaces (Perry et al., 2006); analogous sedimentary coatings appear in more humid environments as silica veneers. Although

numerous laboratory experiments have been conducted to simulate the growth of desert varnish, the exact cause(s) of its origin remain unclear.

Most desert varnish is dark brown to black in color. In some cases, the varnish may also be orange to brick-red. This color difference may be attributed to a lower abundance of the black MnO_2 that masks the color of iron. Further, these varnishes tend to have a higher relative abundance of the mineral hematite. Iron-rich orange varnishes are typically associated with arid, alkaline environments; manganese-rich black varnishes are characteristic of moderately arid, near-neutral environments (Staley et al., 1991).

Uses of Desert Varnish

Desert varnish is often used by archaeologists for the purpose of relative age determinations. Recently, this application has proven to be unreliable. Because varnish is an open system, it is continuously interacting with the surrounding environment – this continuous interaction yields ages that are highly variable, depending on the amount of wear and tear that the sample has undergone (Staley et al., 1991).

While desert varnish may be a poor relative dating tool, the chemical microstratigraphy in rock varnish can provide valuable information about past environmental fluctuations. Alternations between black and orange microlaminations likely correspond to the fluctuations of moisture conditions: Mn-rich orange layers typically develop under wetter conditions (Nash, 2001). The slowly accumulating varnish offers a long term climate recorder in deserts of up to 250,000 years (Liu and Broecker, 2000).

Other applications of desert varnish include: paleo-environmental research, geochemical prospecting, and studies of the biogeochemical cycling of manganese (Dorn and Oberlander, 1981). Interestingly, there has been little study of the mechanism responsible for the concentration of iron in desert varnish (Staley et al., 1991). The ubiquity of varnish in harsh arid environments has led to speculation that varnishes may have Martian analogues (Thiagarajan and Lee, 2004), which could prove useful in the search for life on other planets (Perry et al., 2006).

The Nature of Desert Varnish

There is a common misconception that varnish occurs as a uniform deposit that totally obscures the underlying rock. While some varnish deposits are uniform and continuous, most desert varnish appears in discontinuous patches of variable thickness and texture (Staley et al., 1991). In fact, the nature of desert varnish makes it texturally variable, ranging from thin subparallel layers to highly diverse botryoidal (resembling a bunch of grapes) and pinnate structures (Fig. 2). Botryoidal morphologies can likely be attributed to drying and shrinking processes associated with formation (Perry et al., 2006). Desert varnish surface morphology can be seen most clearly on quartz (Fig. 2), where dendritic growths of varnish have abrupt, easily visible boundaries (Potter and Rossman, 1977).

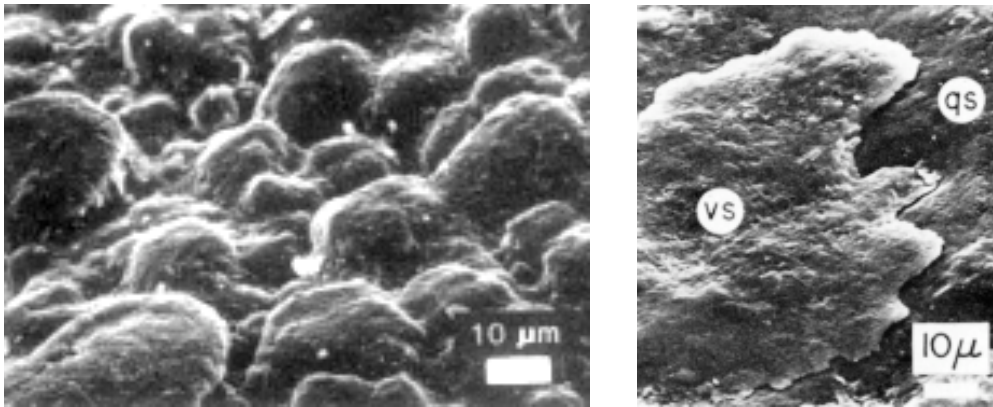


Figure 2: Left: photomicrograph of natural black varnish from Phoenix, Arizona. Modified from Dorn and Oberlander, 1981, Fig. 2C. Note the semi-botryoidal crystalline structure. Right: dendritic growth of desert varnish (vs) over uncoated quartz (qs). Modified from Potter and Rossman, 1977, Fig. 2B.

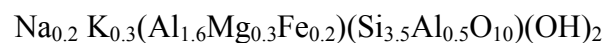
Varnishes occur on nearly all rock types, including quartzites, which have little or no iron, manganese, and clay minerals (Thiagarajan and Lee, 2004); however, varnishes are less common on limestone than on the less calcareous rocks (Hunt, 1954).

Manganese-rich varnishes are found in both wet and dry environments. The term “desert varnish” refers specifically to varnishes which form in arid or semi-arid regions. Coated and polished surfaces found in alpine regions, glacial moraines, and in streams and intertidal marine environments are usually referred to by the general term “rock varnish.” These varnishes may appear superficially similar to desert varnish, but differ mineralogically (Staley et al., 1991).

Desert varnishes begin as microscopic black flecks that grow both laterally and vertically into a uniform dark coating (Dorn and Oberlander, 1981). The growth rates of rock varnish vary from <1 to $40\ \mu\text{m}$ per thousand years on subaerially exposed rock surfaces and rarely reach thicknesses $>200\ \mu\text{m}$, regardless of age. Postdepositional modifications such as spalling, chemical leaching, compaction, and diagenesis may reduce the original varnish thickness (Liu and Broecker, 2000).

The primary components which make up desert varnish are clays and iron and manganese oxides that are derived from air-borne dust and other sources external to the underlying rock. Although these varnishes are widespread, no comprehensive global comparisons of their occurrences and properties have been conducted. Most work on desert varnish has been directed towards its characterization and understanding its origin (Staley et al., 1991).

Clay minerals, such as montmorillonite and illite, comprise more than 70 percent of the varnish and are involved in manganese fixation. Illite in particular is known to fix Mn under pH and oxidation-reduction conditions at which varnish forms. Small amounts of kaolinite and chlorite are present in some samples (Potter and Rossman, 1977). The average composition of the complex clay mixture in extracted varnish was determined by electron microprobe analysis to be as follows:



Iron (predominantly ferric) and manganese oxides constitute the bulk of the remainder (~30%) and are dispersed throughout the clay layer. These oxides are likely present as external coatings on the clay particles. It has been suggested that the clay and oxide phases in desert varnish may be mutually dependent: the clay depends on oxides for resistance to erosion, and oxides depend on clay for transport and deposition (Potter and Rossman, 1977).

How Desert Varnish Forms

Since detailed studies of desert varnish began in the 1950s, the mechanism of varnish formation was not well understood. As Hunt noted in 1954 (p. 183), “such

widespread deposits in such heterogeneous environments assuredly have heterogeneous origins.” He proposed that the staining originated from a variety of sources, both physiochemical and biochemical. For a long time, physiochemical precipitation was proposed as the more likely explanation.

In 1981, Dorn and Oberlander observed that manganese-rich varnish is often present in places where water intermittently streams over rock surfaces. These moistened surfaces are favorable for microbial colonization and development. Based on these observations, they suggested that natural desert varnish and other manganese-rich rock varnishes in nondesert environments are products of microbial activity in which microorganisms concentrate ambient manganese that becomes greatly enhanced in brown to black varnish.

Thiagarajan and Lee (2004) outline the three main models that are currently used to explain desert varnish formation. The first proposed model suggests that varnishes form by direct leaching of the underlying rock substrate, followed by re-precipitation of the rock surface. This process predicts that varnish grows from the inside out via accretion from within. The second model attributes varnish formation to slow diagenesis of detrital dust particles after accretion to the underlying rock substrate, which may take over 1,000 years. Each of these models (Fig. 3) has been rejected by the authors (Thiagarajan and Lee, 2004).

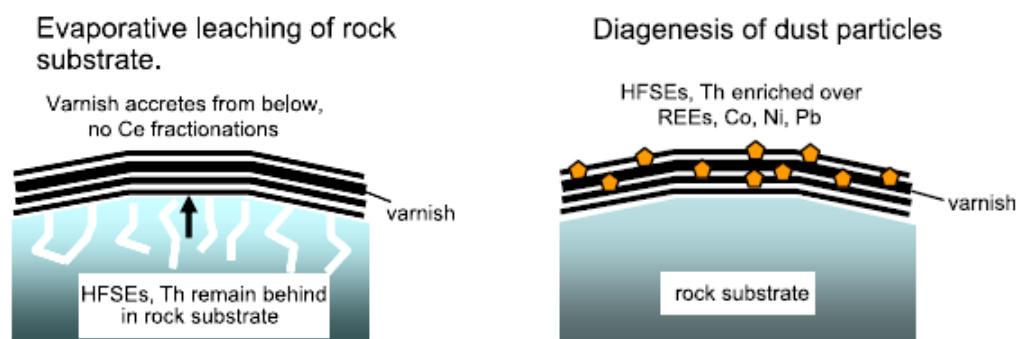


Figure 3: Schematic diagrams showing models for varnish precipitation. Left: leaching of the rock substrate, followed by precipitation at the rock surface. Right: post-depositional diagenesis. Modified from Thiagarajan and Lee, 2004, Fig. 4a and 4b.

The third model suggests that varnishes form by direct chemical precipitation of dissolved atmospheric components in rain water, fog droplets or aerosols. The leaching of dust particles in the atmosphere allows for the residual dust particles and aqueous components to be physically removed before or during deposition as a varnish (Fig. 4). This is the model endorsed by the authors (Thiagarajan and Lee, 2004).

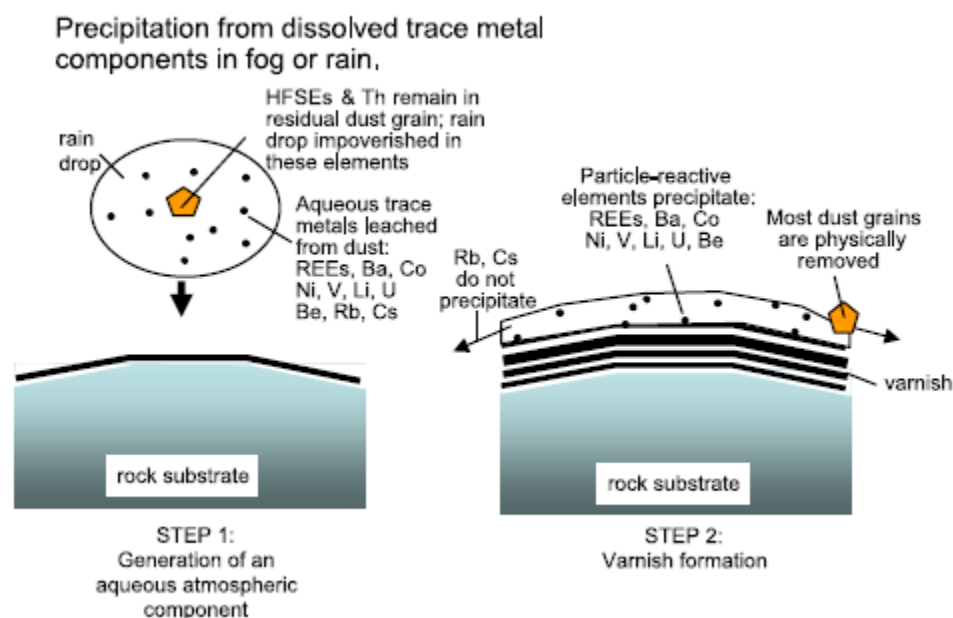


Figure 4: Schematic diagram for varnish formation showing direct aqueous atmospheric deposition. Fe, Mn, and other trace elements are leached from dust grains into rain/fog

droplets, and residual dust/clay grains are physically separated from the aqueous component by water runoff or by wind. Modified from Thiagarajan and Lee, 2004, Fig. 4c.

In 1981, Dorn and Oberlander noted that Mn-rich varnish is often conspicuous where water intermittently streams over rock faces, creating moist surfaces which are favorable for microbial colonization and development. Today, varnish is being actively formed along the Colorado River and other areas which are wetted frequently. Such deposits suggest that the moisture requirements for deposition of desert varnish are considerable (Hunt, 1954).

While these observations make a good case in favor of a microbial origin for desert varnish, the distinct processes associated with varnish formation are still uncertain. Perry et al. (2006) rejected the idea that microbes and bacteria play a key role in the formation of desert varnish and proposed instead that these microorganisms have been “passively entombed” in rock coatings. It seems likely that physical, biological, and chemical processes are all involved with varnish formation to some extent – the degree to which has yet to be determined.

Summary and Conclusions

Desert varnish has been an object of scientific wonder for hundreds of years, and has useful applications as a relative dating tool. The fact that this varnish forms in some of the harshest environments on Earth could prove useful in the search for life on other planets, particularly Mars (Perry et al., 2006). The chemical microstratigraphy in rock varnish may also provide valuable information about past environmental fluctuations.

The growth rates of rock varnish vary from <1 to $40\text{ }\mu\text{m}$ per thousand years on subaerially exposed rock surfaces and rarely reach thicknesses $>200\text{ }\mu\text{m}$, regardless of age. The primary components which make up desert varnish are clays (nearly 70%) and iron and manganese oxides that are derived from air-borne dust and other sources external to the underlying rock.

Since detailed studies of desert varnish began in the 1950s, the mechanism of varnish formation was not well understood. Initially, it was thought that desert varnish was precipitated physiochemically. Recent studies have noted the close association between microorganisms and varnish formation, but a causal role of this biological activity has yet to be affirmed. While the remarkably slow growth rate of desert varnish obscures our understanding of its formation, it does provide a valuable proxy for comparing past climates and the conditions necessary to sustain life.

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