DISCOVERY OF COPPER SULFIDE IN LUNAR VESICULAR BASALT 15556: EVIDENCE FOR LATE-STAGE MAGMATIC AQUEOUS LIQUID

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Introduction: Previous reports of water originating from volcanic activity on the Moon were limited to OH bound within minerals or glasses. Now, our latest findings reveal the presence of liquid water, giving rise to the formation of copper sulfide ($Cu_{1.4-1.8}S$), in pristine Apollo vesicular basalt 15556 [1].

Results and discussions: This copper sulfide is observed as multiple coatings, fine-grained in nature, which drape over troilite grains on the walls of vesicles or cover fracture surfaces surrounding troilite within the rock (Fig. 1). Massive aggregates of small euhedral grains, smaller than 0.5 μm, are often present on top of the coatings. Additionally, copper sulfide rosettes, composed of bladed crystals measuring approximately 1 μm in size, occur at the periphery of the coatings in some occurrences (Fig. 2). Troilite grains underneath copper sulfide coatings show no signs of alteration. Cross sections of trolitie grains on the vesicle wall, exposed in polished thin sections, also show no sign of alteration. The major and minor element chemistry of troilite grains, despite their locations in the sample, are similar.

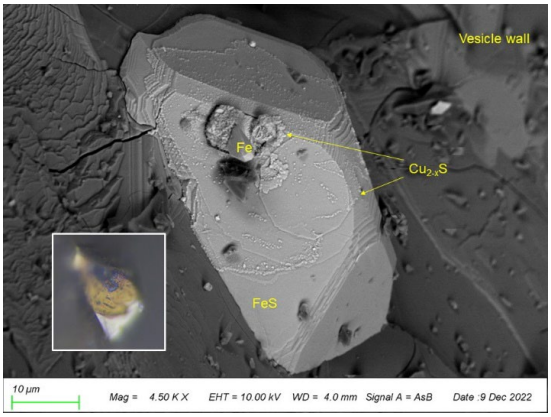

Fig. 1. An example of copper sulfide coating and massive clusters on the surface of an troilite (FeS) grain on the vesicle wall in Apollo 15556.

Copper sulfide is free of Fe, Ni, and Co, the more abundant elements in mare basalt. Cu, Ni, and Co are chalcophile (sulfur loving) when metal is absent, but Ni and Co prefer Fe metal when Fe and FeS are both present. The Fe metal chemistry in Apollo 15556 shows a clear correlation with the petrographic context. Fe metal inside troilite in the mesostasis contains the lowest Ni, whereas Fe metal inside troilite on the wall contains the highest Ni.

Collectively, the manner in which the coatings drape over the surfaces, along with their distinct geochemical characteristics, strongly suggest that the copper sulfide precipitated from aqueous liquids containing copper (Cu) and sulfur (S). These aqueous solutions likely originated deeper within the lava flow, as a result of the late-stage crystallization of magma. Pressure differentials forced these aqueous sulfide liquids upward, where they came into contact with the vesicles of Apollo 15556. Subsequently, due to exposure to the high vacuum of space and extensive vesicle connectivity, the liquids evaporated, resulting in the saturation and subsequent precipitation of copper sulfide.

Implications: This discovery provides compelling evidence that extensive magma crystallization on the Moon can give rise to aqueous liquids, some of which may still be contained within intrusive igneous rocks. The presence of such aqueous solutions expands our understanding of lunar geology and the potential availability of water resources on the Moon.

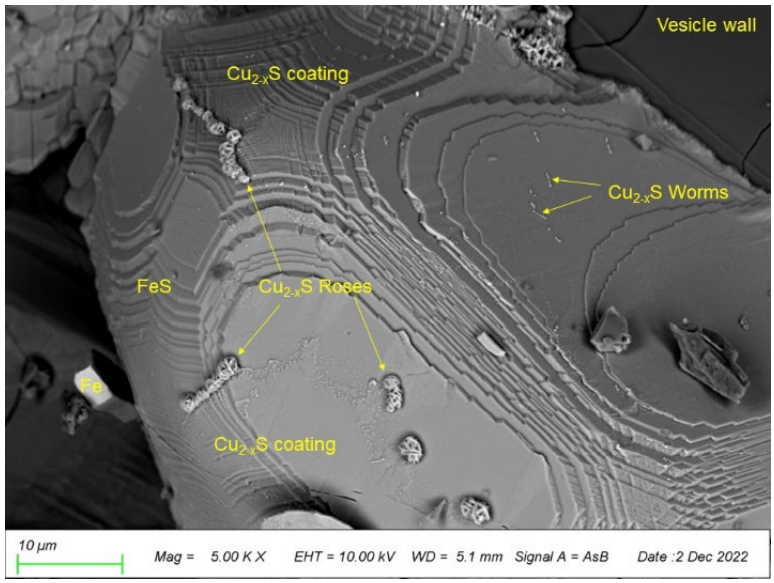

Fig. 2. An example of copper sulfide coatings and rosettes on the surface of an troilite (FeS) grain on the vesicle wall in Apollo 15556.

References: [1] Liu Y. et al. (2023) Nature Geoscience, in review. https://www.researchsquare.com/article/rs-2649595/v1