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Characterizing ancient, deep-seated copper from beneath the Keweenaw Peninsula (U.S.A.) to inform barrier performance of deep geologic repositories

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Canada's Nuclear Waste Management Organization (NWMO) deep geological repository (DGR) plans include enclosing used fuel in copper-coated containers. Evaluating the long-term corrosion behaviour of copper under evolving underground conditions is inherently challenging. The DGR lifetime prediction of copper resilience can be informed by examining the condition and properties of natural copper that has been subjected to analogous upper crustal environments over geologic timescales. We have located such material with the U.S. National Parks Service (NPS) in historical drill core and logs that the NPS have archived from the world-renowned copper deposits of the Keweenaw Peninsula, located along the southern shore of Lake Superior in Michigan, U.S.A.. This copper was introduced along fractures and into pore spaces by metamorphic fluids ~1.1 billion years ago (Bornhorst et al., 1988) late in the formation of a kilometres-thick package of volcanics and sediments in the Mid-Continental Rift. We confirmed through core retrieval and re-examination that commercial drilling in 1946 intersected a copper-bearing volcanic unit at 432 metres depth below surface, 112 meters beneath the nearby floor of Lake Superior. Laboratory analysis by optical, X-ray MicroCT, and electron microscopy reveals remarkable copper preservation within veins of secondary calcite and prehnite. Microstructural analysis of a 6 mm long and 2 mm wide copper vein by Electron Backscatter Diffraction indicates coarse grain sizes ranging from ~0.5mm to 5 mm in width on the polished surface. Each grain shows several types of microstructure. Several localized, elongate, and discontinuous Σ3 twin domains and lamellae occur up to 0.45 mm in length within grains. Individual grains can also display distributed plastic deformation adding up to as much as 15° of misorientation. Despite these textures, and the sample's subsurface position in the crust for hundreds of millions of years, the copper is free of alteration internally or at contacts with the matrix minerals. The preservation and stability of this natural copper deposit over a billion-year timescale at depths comparable to those selected for a DGR provide natural analogue evidence supporting the performance assessment of copper as a corrosion barrier material in used nuclear fuel containers.