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Preparing for Mars Sample Return: Non-destructive Mapping of Hydrous Phases in Ancient Martian Crust

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The return of crustal samples from Mars, such as the extraordinarily diverse suite currently being collected in Jezero crater as part of the Mars Sample Return efforts [1,2,3], represents the next major step towards understanding the geological, environmental, and hydrological evolution of Mars. A crucial preparation for the return is the development of analytical techniques that maximize the scientific yield of studying these invaluable samples. Non-destructive methods have the advantage of providing critical information about a sample's interior in three dimensions, without jeopardizing its pristine state, making them ideal for early-stage sample characterisation.

We investigate a non-destructive, multimodal approach using highly complementary X-ray and neutron Computed Tomography (CT). These techniques differ in elemental sensitivity, and the strong interaction between neutrons and hydrogen enables a sample-wide mapping of hydrous phases and, possibly, organic material [4,5]. As an analogue to Martian surface material, we analyse the water-rich NWA 7034 meteorite, the only known meteorite sampling ancient crustal rocks from Mars [6].

Hydrous material occurs as highly localised neutron-attenuating hotspots, identified as Fe-oxyhydroxides through combined X-ray diffraction and CT. Interestingly, these hydrogen-rich phases are hosted within igneous clasts (Figure 1), which generally have ancient crystallisation ages up to 4.48 Ga [7,8]. Fe-oxyhydroxides are also among hydrated alteration phases in samples collected by the Perseverance rover, suggesting that similar hydrated phases may represent a widespread surficial water reservoir on early Mars.

The precise mineralogical carrier of hydration remains uncertain, though multiple lines of evidence point to a nanophase Fe-hydroxide (Figure 2). Transmission electron microscopy analyses have yielded high-resolution images, chemical, and electron diffraction data that, together with planned hydrogen isotopic measurements, will constrain the formation pathway for the water-bearing Fe-oxyhydroxides and the conditions at the time of their formation.

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