

δ D in lunar volcanic glasses and melt inclusions: A Carbonaceous chondrite heritage revealed

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Water is perhaps the most significant molecule in the solar system, and determining its origin and distribution in planetary interiors has important implications for understanding the evolution of planetary bodies. Here we present the isotopic composition of hydrogen dissolved in lunar volcanic glasses and in their olivine-hosted melt inclusions to establish the source of the lunar magmatic water. These volcanic glasses, returned by the Apollo 15 and 17 missions, represent some of the best-studied and most primitive magmas generated within the Moon. The D/H ratios and H₂O contents were measured simultaneously in the center of the exposed interiors of individual lunar volcanic glass beads and olivine-hosted melt inclusions, using a Cameca NanoSIMS 50L multicollector ion microprobe. We examined very-low Ti and low-Ti glasses from Apollo 15 15426/27 and high-Ti glasses from Apollo 17 74220. The Apollo 17 high-Ti glasses contain olivine-hosted melt inclusions, small samples of magma trapped within the olivine that grew in the magma before eruption. By virtue of their enclosure within their host crystals, melt inclusions are protected from loss of volatiles by degassing during eruption. After consideration of cosmic ray spallation and degassing processes our results demonstrate that lunar magmatic water has an isotopic composition that is indistinguishable from the bulk water in carbonaceous chondrites and similar to terrestrial water, implying a common origin for the water contained in the interiors of the Earth and Moon. The Moon must have received its water during or shortly after its accretion, before the formation of a robust lunar lithosphere ≤ 100 My. Data for highly siderophile elements [1] suggest that a late veneer of meteoritic material delivered to the Moon was too small to be responsible for the lunar volatile budget. Therefore, the simplest scenario consistent with our observations is that the Earth was wet at the time of the Moon-forming event, as predicted by dynamic models [2,3], and that the water was not completely lost during this giant impact.

[1] Day, J. M. D. *et al.* (2007) *Science* **315**, 217-219. [2] Morbidelli, A. *et al.* (2000) *Meteor. Planet. Sci.* **35**, 1309. [3] Walsh, K.J. *et al.* (2012) *Meteor. Planet. Sci.* **47**, 1941.

Fluid-mineral reactions during CO₂-based geothermal energy extraction

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Geothermal energy extraction with groundwater as the subsurface heat extraction fluid can result in substantial scaling (mineral precipitation) in pipes, heat exchangers, power conversion equipment, and the subsurface reservoir. A potential solution to this problem is to utilize carbon dioxide (CO₂) as the subsurface heat extraction fluid. During this approach, CO₂ from an emitter, such as a coal-fired power plant, biofuel plant, or concrete factory, is injected into a geothermal reservoir such as a sedimentary basin or a hydrofractured rock. In the case of the sedimentary basin approach, large amounts of CO₂ are permanently stored underground in the form of a CO₂ plume while a small portion of the geothermally heated CO₂ is circulated back to the surface for power production before reinjection into the reservoir along with the main CO₂ stream. This is referred to as a CO₂-Plume Geothermal (CPG) system.

When CO₂ is injected into deep saline aquifers, the CO₂ largely displaces the brine although there is a small degree of dissolution at the CO₂-brine interface. The result is a multicomponent-multiphase plume environment that ranges from virtually pure CO₂ in the center of the plume to CO₂ with dissolved water on the CO₂ side of the CO₂-water interface, to brine with dissolved CO₂ on the brine side of the interface, to brine with no CO₂ away from the plume.

Here, we present results on the reactions of some of the above described fluid components with various reservoir minerals that are based on flow-through reaction cell experiments under realistic T and P conditions. Pre- and post-experiment X-Ray Computed Tomography analyses provide 3D images of pore-space geometry changes due to the reactions. The 3D images are then used as input in lattice-Boltzmann fluid flow simulations to determine permeability field changes due to the fluid-mineral reactions. The ultimate objective of this work is a parameterization of permeability changes as a function of fluid and mineral chemistry for typical host rocks and T-P conditions which can be included into geothermal reservoir simulators such as TOUGH2.