WHY ASTEROIDAL ALTERATION WAS ISOCHIMICAL: HIGH POROSITY ≠ HIGH PERMEABILITY

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Carbonaceous chondrites (CCs) are amongst the most primitive materials available to us. However, it has become clear that their mineralogy is highly altered. A range of evidence indicates that alteration occurred within CC parent asteroids (e.g. [1,2]). Solar abundances for soluble elements show that aqueous alteration was isochemical, with negligible fluid flow (even over sub-mm distances [3,4]). Hydration models (which assume zero flow) based on O-isotopes indicate that water:rock ratios were high [5].

Numerous studies have modelled asteroidal aqueous and thermal alteration [6-12]. In each case, large-scale fluid flow was observed, frequently over 10's km [6-9,12]. But whether flow is observed as a single pass ‘exhalation’ [8], or in convecting cells [6,12], the movement of liquid water through rock would fractionate aqueous species. The modelling results directly contradict the meteorite data – the one indicates that alteration occurred in an open system with large-scale fluid-flow; the other that alteration was isochemical, with minimal flow.

How to resolve this paradox? Permeability is fundamental to flow. Initial permeability estimates of 10⁻¹¹–10⁻¹³m² for chondritic asteroids [6] (based on suggested terrestrial and lunar analogs), were adopted in all subsequent studies [7-12]. But is this permeability appropriate for CC precursors? Matrix grain size in the least altered CCs is ~200nm [13,14], far lower than in the analog materials. Using the Blake-Kozeny-Carman equation [15] to predict permeability for grain sizes of this order (given reasonable estimates of the hydraulic tortuosity coefficient), yields values ranging from 10⁻¹⁶-10⁻¹⁹m², even in high-porosity matrix. Matrix grain size dictates mean pore-throat diameter, so is a key control on permeability (which scales as grain size squared). This observation may reconcile compositional data indicating minimal fluid flow and oxygen isotope studies suggesting high water:rock ratios. Preliminary modelling using lower permeability [16] now appears consistent with the meteorite data.