HIGH-TEMPERATURE CHEMICAL PROCESSING ON ASTEROIDS: AN OXYGEN ISOTOPE PERSPECTIVE.
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Introduction: Small planetary bodies accreted within 2.4 Myr of solar system formation [1]. The primitive materials (CAIs, chondrules, matrix) incorporated into these asteroids were altered by a variety of secondary processes, including aqueous alteration, shock metamorphism, thermal metamorphism and melting. Here we look primarily at the role played by thermal metamorphism and melting in altering the oxygen isotope systematics of asteroidal materials.

Metamorphism and melting: Peak temperatures recorded by meteorites range from 400ºC in the least altered type 3 chondrites [2], to over 1500ºC for achondrites formed during large scale planetary melting [3]. This range can be subdivided as follows: i) thermal metamorphism (400ºC to 950ºC), ii) limited partial melting (950ºC to 1250ºC), and iii) extensive partial melting (1250ºC to >1500ºC). These divisions loosely correspond to the thermal regimes experienced by i) chondrites, ii) primitive achondrites, and iii) differentiated achondrites.

Chondrites (400ºC to 950ºC): Slow rates of oxygen diffusion in the solid state mean that, where thermal metamorphism was essentially dry, only limited disturbance of primary oxygen isotope signatures took place. Consequently, chondrites preserve important information about nebular processes [4]. However, chondrites are not pristine materials. Recent studies of the ordinary chondrites demonstrate that they have complex histories with low-temperature hydrothermal assemblages being progressively obliterated by later thermal metamorphism [5]. Systematic shifts in oxygen isotopes have been recognized in the CO3 chondrites, with a subtle increase in Δ^{17}O values from grades 3.1 to 3.4 indicating that an aqueous fluid phase was present during metamorphism [6]. In contrast, a systematic increase in δ^{18}O values in the enstatite chondrites from type 3 to type 6 is not the result of any simple parent body process [7]. In the carbonaceous chondrites significant difficulties exist in establishing genetic links between unequilibrated (type 3) and equilibrated (type 4 to 6) groups. A genetic relationship has been proposed for the CV3 and CK groups [8], which display a trend of decreasing oxygen isotope variation with increasing grade.

Primitive achondrites (950ºC to 1250ºC): Eutectic melting occurs at about 950ºC in the Fe-FeS system, with silicate partial melting commencing at ~1170ºC. Asteroidal materials that experienced these conditions show complete recrystallisation followed by progressive loss of Fe-Ni-S and silicate partial melts [9]. Termed primitive achondrites, these meteorites include the ureilites, acapulcoites and lodranites, aubrites, brachintes, winonaites and associated IAB and IIICD irons. In terms of oxygen isotope systematics they show less heterogeneity than chondrites, but still retain significant levels of variability [10]. Thus, acapulcoites and lodranites display textures indicative of about 1% to 20% partial melting of a single parent body [11]. Their Δ^{17}O values (-0.99‰ to –1.49‰) display a significantly greater range than seen in the differentiated achondrites [10]. Likewise, ureilites display major oxygen isotope variation and scatter about the slope 1 line defined by primitive chondrites [10].

Differentiated achondrites (1250 to >1500ºC) At relatively high degrees of partial melting complete isotopic homogenisation takes place, with subsequent mass-dependent fractionation resulting in variation along lines with slope 0.52 on δ^{17}O v. δ^{18}O diagrams [10]. Examples of differentiated achondrites include the HEDs and angrites**.** Pallasites, mesosideites and IIIAB irons show similar oxygen isotope variation to the HEDs and may be fragments from the same parent body [9].

Conclusions: Meteorites provide clear evidence of widely varying thermal conditions within asteroids in the early solar system. With increasing temperature there is a progressive loss of primary oxygen isotope variation, complete homogenization occurring at high degrees of partial melting.

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