THE HYDROLOGY OF ICY PLANETESIMALS INFERRED FROM CARBONACEOUS CHONDRITE OXYGEN ISOTOPE RATIOS . E. D. Young[1] and R.D. Ash[1], [1]Department of Earth Sciences, University of Oxford, Parks Road, Oxford, OX1 3PR, UK (ed.young@earth.ox.ac.uk).

Introduction: The diversity of mineralogy and oxygen isotope ratios among carbonaceous chondrites is spanned by the CV, CM, and CI groups. Calculations are presented showing that this diversity can be explained by down-temperature flow of aqueous fluid at temperatures near 273 K within icy, internally-heated asteroidal parent bodies. It is suggested that if water-rich ices co-accreted with carbonceous chondrite rock in the early solar system, that fluid flow caused by internal heating in these icy planetesimals would lead to the patterns of oxygen isotope ratios and mineralogies exhibited by the carbonaceous chondrites.

Motivation: Ultraviolet laser ablation/fluorination measurements of $^{17}O/^{16}O$ and $^{18}O/^{16}O$ in chondrules and a CAI from the Allende meteorite [1,2] suggest that shifts in these ratios attending aqueous alteration occurred along a mass fractionation curve with a $\Delta^{17}O$ of –2.7 (Allende mass fractionation curve, AMF, Fig. 1). Previous models for the isotopic and mineralogical evolution of carbonaceous chondrites during aqueous fluid-rock exchange are based on fluid-rock ratios and assume motionless water [3]. These models can not account for shifts in rock $^{18}O/^{16}O$ at constant $\Delta^{17}O$ by interaction with water-rich fluid. Instead, the observation that $^{18}O/^{16}O$ increased at constant $\Delta^{17}O$ requires that the water moved down a temperature gradient while exchanging with the host rock.

Phyllosilicate mineral separates from CM carbonaceous chondrites with relatively low $^{18}O/^{16}O$ lie on the AMF while isotopically heavier hydrous minerals exhibit $\Delta^{17}O$ ranging up to values comparable to the CI group (Fig. 2). This pattern of phyllosilicate $^{18}O/^{16}O$ and $\Delta^{17}O$ ranging from the AMF to the CI field (lower right in Fig. 2) suggests a potential link between alteration in the CV, CM, and CI groups.

Model: Our previous models for aqueous fluid flow in icy planetesimals [4] have been improved by smearing discontinuous temperature-dependent properties with error functions. This procedure eliminates numerical artifacts that contribute spurious changes in $\Delta^{17}O$ adjacent fluid-rock exchange fronts.

The models depict the evolution of a fictive chondritic planetesimal by solving conservation equations for CO_2, ^{18}O, and ^{17}O in the fluid phase together with the conductive heat transfer equation. The heat source is ^{26}Al distributed uniformly throughout the rock portion of the spherical body. The conservation equations include the effects of oxygen isotopic exchange, redistribution of oxygen isotopes due to mineral-mineral equilibration, and progress of the reaction

$$4Mg_2SiO_4 + 5CO_2 + H_2O = 5MgCO_3 + Mg_3Si_4O_{10}(OH)_2$$

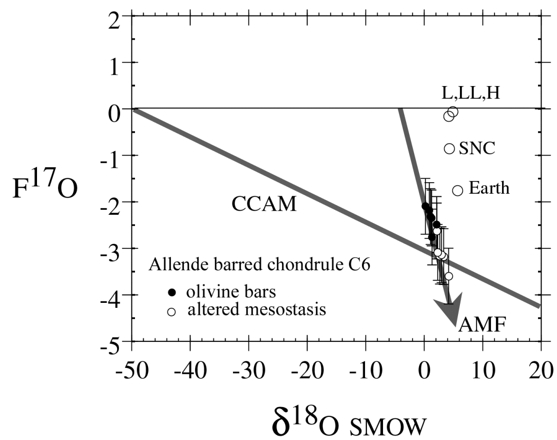

Fig. 1 Oxygen isotope ratios in an Allende chondrule obtained by laser ablation. Ordinate shows deviations from the slope-1.00 line on the conventional three-isotope plot.

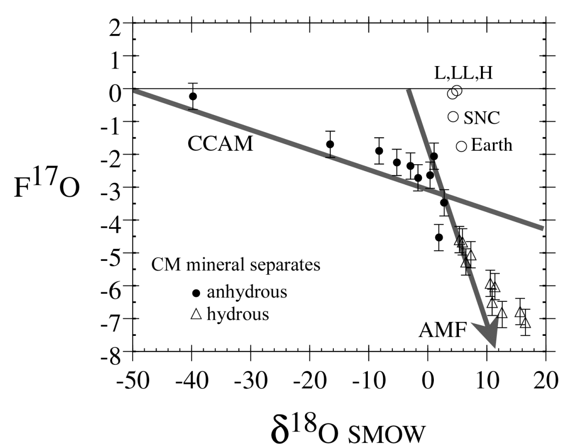

Fig. 2 Conventional mineral separate data for CMs from the literature [5,6] showing hydrous phases both on and off the AMF.

The net-transfer reaction serves as an analogue for the conversion of anhydrous minerals (represented by forsterite) to hydrous phases like saponite and serpentine (represented by talc) and carbonates (represented by magnesite). The reaction is driven by introduction of CO_2 into the pore liquid during melting of ice.

Results: Results show that fluid flux within the fictive planetesimal is maximized where water ice and liquid coexist (near the 273 K isotherm at any given time interval). This maximum in fluid flux is typical of cryohydrological systems in terrestrial environments [7]. An alteration front in which new minerals grow with fluid-like $\Delta^{17}O$ forms deep within the interior of the fictive planetesimal as a consequence of the maximum in fluid flux and protracted exchange of oxygen between fluid and rock. The width and radial extent of the alteration front depends upon the rate of ice melting (and hence fluid flux) relative to reaction rates.

An example result is shown in Figs. 3 and 4. The body in this model has a radius of 25 km. Results are shown after 1Ma of heating by ^{26}Al (initial $^{26}Al/^{27}Al$ = 2.3e-6), yielding a maximum core temperature of 330 K. Data from the literature are shown in Fig. 3 for comparison. Each model datum in Fig. 3 represents the isotopic composition of the indicated mineral (phyllosilicate, anhydrous, or carbonate) as sampled at approximately 300-meter intervals. Fig. 4 shows that growth of hydrous and carbonate minerals is concentrated in the alteration front where $\Delta^{17}O$ is highest. Appreciable growth of secondary minerals also occurs upstream of the front. CM phyllosilicates and carbonates correspond to model hydrous and carbonate phases in the interior of the fictive planetesimal upstream of the alteration front. CI phyllosilicates match the model hydrous phases within the alteration front. The increase in $^{18}O/^{16}O$ at the initial rock $\Delta^{17}O$ (the AMF), as exhibited by altered components of the Allende CV meteorite (Fig. 1), occurs downstream of the front where temperature gradients are the greatest as a result of either simple exchange (gray dots) or incipient new mineral growth (gray triangles mixed with gray dots).

Discussion: Our fluid flow models reproduce the salient mineralogical and oxygen isotopic features of three major carbonaceous chondrite groups. The implication is that melting of co-accreted water-rich ice and ensuing down-temperature fluid flow may have been a global process that affected numerous carbonaceous chondrite parent bodies in the early solar system. It is not necessary to appeal to a single parent body to link the carbonaceous chondrite groups by this process. Instead, the modeling is interpreted to mean that initial rock $\Delta^{17}O$ values for many carbonaceous chondrite bodies as a whole were in the vicinity of –3 per mil and that co-accreted ices had considerably higher $\Delta^{17}O$ well above the terrestrial mass fractionation curve (TMF).

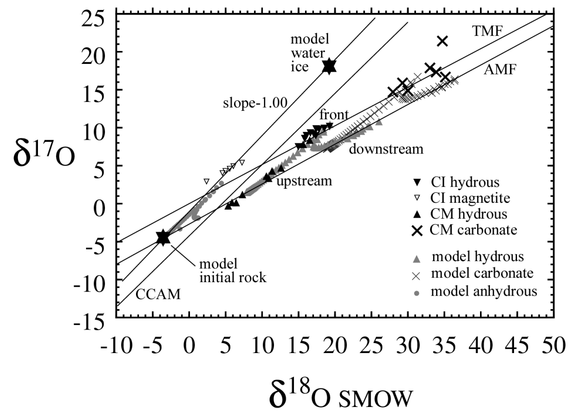

Fig. 3 Three-isotope plot showing model calculations depicting oxygen isotope ratios in an icy planetesimal. CI and CM meteorite data are shown for comparison [5,6,8].

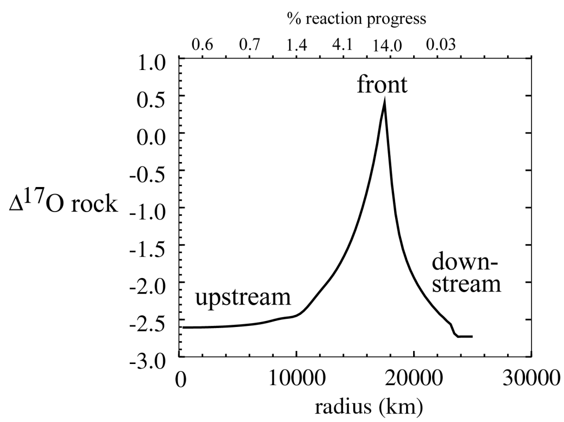

Fig. 4 Plot of radius vs. $\Delta^{17}O$ for model planetesimal. Per cent values refer to mole per cent new mineral growth.

References: [1] Young E.D. and Russell S.S. (1998) *Science, 282*, 452. [2] Ash R.D. et al. (1999) *LPSC XXX*, CD-ROM. [3] Clayton R.N. and Mayeda T.K. (1999) *GCA, 63*, 2089. [4] Young E.D. et al. (1999) *Science, 286*, 1331. [5] Clayton R.N. and Mayeda T.K. (1984) *EPSL, 67*, 151. [6] Rowe M.W. et al. (1994) *GCA, 58*, 5341. [7] Oliphant J.L. et al. (1983) *Permafrost Fourth Int. Conf.*, 951. [8] Brearley A.J. et al. (1999) *LPSC XXX*, CD-ROM.