

overestimates its own effects on the evolution of the interior. However, we find that the regolith can act either as a thermal blanket or a thermal sink, depending on the initial setup. Second, we include solar nebula temperature evolution [3] to determine the initial asteroid temperature as well as the surface equilibrium temperature; at 10^7 yr after nebula collapse, the nebula dissipates and the surface is assumed to be in thermal equilibrium with the solar flux. This produces a substantial difference between our models, because many material properties are dependent on temperature and the nebula at 3 AU drops to ~ 20 K before it dissipates. Third, we vary the time between nebular collapse and the accretion of the asteroid. This is similar to varying the amount of live ^{26}Al as in [1], but has wider implications because of the solar nebula model discussed above. Fourth, we consider a broad set of alteration reactions and use a finite rate of reaction. This allows us to track effects of mineral alteration on water salinity, pH, and freezing-point depression. The choice of alteration reaction determines the amount of heat released during alteration, and this is found to have a large effect on the duration of liquid water. The choice of reaction also has volumetric consequences; we suggest that examination of altered matrix for expansion textures might constrain the mode of alteration.

Although highly dependent on the choice of alteration reaction, our preliminary results show that the interior of a 100-km-diameter body can reach temperatures high enough to produce liquid water for significant times ($>10^6$ yr). Some scenarios allow the complete melting of ice in the deep interior, with a subsequent temperature rise ($T_{\text{max}} = 400$ K). We produce a nonuniform distribution where liquid water persists longest in the deepest zones and the regolith never sees conditions appropriate to aqueous alteration. The nonuniform liquid distribution produces a radially dependent amount of alteration products. It has been suggested [4] that both CI- and CM-type material could be formed by progressively altering the same initial assemblage, perhaps by this kind of parent-body history.

References: [1] Grimm R. E. and McSween H. Y. (1989) *Icarus*, 82, 244–280. [2] Anders E. and Ebihara M. (1982) *GCA*, 46, 2363–2380. [3] Cassen P. (1994) *Icarus*, 112, 405–429. [4] Zolensky M. E. et al. (1989) *Icarus*, 78, 411–425.

RECYCLING (?): RELICT SPINELS (?) IN TYPE B CALCIUM-ALUMINUM-RICH INCLUSIONS. H. C. Connolly Jr. and D. S. Burnett, Division of Geological and Planetary Sciences, Mail Code 100-23, California Institute of Technology, Pasadena CA 91125, USA.

Type B calcium-aluminum-rich inclusions (CAIs) can be thought of as a type of chondrule despite obvious differences in size, composition, and texture. Nevertheless, igneous CAIs likely experienced similar thermal histories. A major constraint on the thermal history of chondrules is that they have been recycled, mainly supported by the presence relict grains. Although well known that igneous CAIs experienced at least two melting events (counting Wark-Lovering rims), the identification of relict grains has been problematic.

The best candidate for relict grains within type B CAIs is spinel. Spinel is the liquidus phase with complete melting at approximately 150°C above type B peak melting temperatures ($\sim 1400^\circ\text{C}$). Consequently, relict spinels, either from a previous generation of CAIs or direct nebular condensate spinels, are stable at the inferred maximum heating temperature of type B CAIs. Minor- and trace-element concentrations can be used to distinguish relict grains from those that crystallized from an initially homogeneous liquid.

We measured minor-element concentrations in spinels from two type B CAIs, Allende TS-23 and Leoville 3537-2 (6). Our results show that Ti and V are positively correlated, but their concentrations vary as a function of the petrologic location and context. Grains located in the edge areas form a separate population from grains in the center. Edge areas are richer in V than Ti (~ 0.16 – 0.44 wt% and ~ 0.06 – 0.25 respectively). Spinels enclosed within melilite define a different pattern from those enclosed by fassaite (overall range ~ 0.09 – 0.33 wt% V and ~ 0.06 – 0.40 wt% Ti). Experiments show that spinel crystallization effectively ceases before 40–50% total crystallization. As Ti is highly incompatible in this part of the crystallization sequence, at most a factor of 2 range

within spinel is expected from fractional crystallization. Our data show a range from 3 (TS-23) to 6 (Leoville) in Ti concentrations, inconsistent with fractional crystallization.

If a population of spinels were truly “relict,” because they were produced in some other generation of CAIs that was broken and spinels then reaccrated into the precursor of the two studied objects, their apparent correlations between minor-element contents and host mineral should not exist. Their distribution within the CAIs should be random. The presence of a petrologic correlation suggests that another process dominated. It may be that the various populations of spinels were generated in a remelting event(s).

If the objects were remelted to temperatures between 1200° and 1250°C , a liquid dominated by melted cpx would be produced. This cpx-rich liquid would be enriched in Ti over the bulk composition. Such a Ti-rich liquid could introduce Ti into existing spinels through diffusion. It is also possible that the new liquid (pyx-rich and/or pyx + an-rich) would not be spinel saturated. Upon cooling, these liquid pockets would first produce spinels, containing a higher Ti concentration than existing spinels trapped in melilite, as observed in our dataset.

Edge spinels have V and Ti concentrations different from the middle and center regions as well as lower Cr and higher Fe abundances. Although the high Fe may reflect some secondary alteration process, the other elements appear unaffected. Furthermore, the Fe and Cr concentrations do not match predictions (Ebel and Grossman, personal communication), so they are apparently not condensates. We suggest that these grains are a later generation due to the melting of mantle melilite. It is possible that the Wark-Lovering rim-forming process was more extensive than previously believed.

In summary, it appears that remelting occurred in more than one generation of spinels for both CAIs studied. We have no evidence for any true “relict” spinels.

METAMORPHISM, SHOCK, AND POROSITY: WHY ARE THERE METEORITES? G. J. Consolmagno^{1,2}, D. T. Britt², and C. P. Stoll³, ¹Vatican Observatory, Steward Observatory, University of Arizona, Tucson AZ 85721, USA (gjc@as.arizona.edu), ²Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721, USA, ³6270 Colby, Oakland CA 94628, USA.

Introduction: Most carbonaceous chondrites appear to have relatively large porosities, in the range of 20–38% [1,2] (a handful of CVs are exceptions). Most ordinary chondrites, after correcting for terrestrial weathering, have porosities between 8% and 12% [1]. Porosity is not a function of petrographic grade [1,3]. The average porosity is about 12% for shock state S1 chondrites, and 10% for all other shock states [1,4]. But a relatively small number of lightly shocked ordinary chondrites have porosities ranging up to 30%; the maximum value of this range appears to decrease linearly with increasing shock state — ordinary chondrites of shock state S3 can still range in porosity up to 20%, but the highest porosity of an S6 meteorite is only 10% [1].

Chondrites resemble terrestrial sandstones in that they were formed by the physical accumulation of unrelated grains, followed by a lithification process. Tectonics and the simple weight of overlying layers provide the conditions for lithification of sandstones on Earth. What role does this play on meteorite parent bodies? Why do ordinary chondrites exist as well-compacted rocks? Why are carbonaceous chondrites less well compacted?

Porosity and Pressures: Sandstones have porosities ranging from 15% to 30%. Experiments [5] show that confining pressures of 0.3–0.4 GPa are required to fill their pore spaces with comminuted rock; such material is still filled with microcracks and still has a significant porosity. By comparison, the central pressure of the largest asteroid, Ceres, is about 0.2 GPa. We conclude that the lack of correlation between metamorphic state and porosity is not surprising; no asteroid is large enough for burial depth to change porosity.

Hirata et al. [6] found that mineral powders (initial porosity 30–35%) shocked to 2.5 GPa reduce their porosity to about 10%. Increasing the shock pressure only slightly decreases porosity from this point. These