CARBONACEOUS CHONDRITE PARENT BODIES, II: RESULTS AND IMPLICATIONS OF THERMAL MODELS, Robert E. Grimm, Department of Geological Sciences, Southern Methodist University, Dallas, TX 75275, and Harry Y. McSween, Jr., Department of Geological Sciences, University of Tennessee, Knoxville, TN 37996.

Many carbonaceous chondrites have been aqueously altered within their parent bodies, although such alteration has not been quantitatively related to a thermal driving mechanism. This abstract describes the results of thermal models for carbonaceous chondrite parent bodies formulated in a companion abstract [1]. From chemical and textural data on these meteorites and from studies of collision mechanics, we pose two hypotheses for the aqueous alteration environment. In the first model, alteration occurs uniformly throughout the parent body interior; in the second, alteration occurs in a post-accretional surface regolith. Both models are based on the assumptions of an initially homogeneous mixture of ice and rock and heating by decay of ^{26}Al and long-lived radionuclides.

Interior-alteration model. In order to study the primary effects of water on thermal evolution, we consider models in which the pore volume is saturated with H_2O; because this simplification easily leads to hydraulic fracturing at modest temperatures, venting of water is not included. H_2O loss due to aqueous alteration and degassing are also neglected for purposes of this illustration. The remaining variables are parent object diameter, water volume fraction, and initial $^{26}Al/^{27}Al$ ratio. In terms of these quantities, the problem may be formulated to find limits to the radionuclide abundance at specified size and ice:rock ratio; this upper limit to ^{26}Al is constrained by the peak temperature for each group. In order to estimate this bound conservatively for the homogeneous model, the volume-averaged peak temperature is used; core temperatures may be somewhat higher. When hydrothermal convection is included, more efficient heat transfer allows a greater initial proportion of ^{26}Al.

These calculations have been carried out over a range of ice:rock compositions and object sizes. We find that initial $^{26}Al/^{27}Al$ ratios up to several parts per million are allowed for CI parent bodies a few hundred km in diameter and containing 10%-40% H_2O by volume. Calculations for CO chondrites, which are anhydrous but experienced higher peak temperatures, give similar results. The similarity of inferred radionuclide abundances between CI and CO chondrites suggests that water may have played an important role in controlling their different thermal evolutions; that is, water in CI chondrites may have acted as a thermal buffer to prevent the metamorphism experienced by CO chondrites. Moreover, the required initial $^{26}Al/^{27}Al$ ratios are within the observational upper limit of $8x10^{-6}$ established for one ordinary chondrite [2], and in reasonable agreement with the value of $5x10^{-6}$ inferred from thermal modeling of ordinary chondrite parent bodies [3]. These arguments are more difficult to apply to CM chondrites, however, as their low inferred peak temperatures limit the initial $^{26}Al/^{27}Al$ ratios to a factor of 2-3 below CI parent bodies of the same diameter. More ^{26}Al can be accommodated if CM parent objects are smaller, but at the expense of a smaller altered fraction of the interior. If, say, at least half of interior rocks must be exposed to liquid water so that delivered samples are representative of the later-disrupted parent body, then homogeneous interior-alteration models may be constrained to parent bodies a few hundred kilometers in diameter and larger for CM chondrites and several tens of kilometers in diameter and larger for CI chondrites.

These models explicitly satisfy peak temperature constraints only. It is also possible to consider qualitatively the water:rock ratio derived from oxygen isotope data. The low peak temperature inferred for CM chondrites suggests that temperature gradients within a homogeneous parent body are insufficient to develop hydrothermal convection; therefore the bulk water content must be at least 50% by volume. Under the temperature range allowed for CI chondrites, however, hydrothermal circulation is more likely, and hence it is possible that the time-integrated water:rock ratio for some samples could be large.

Because aqueous alteration can occur rapidly, models that explicitly include consumption of water and release of the latent heat of reaction immediately exhaust available H_2O and show a marked increase in internal temperatures. Such thermal histories are not inconsistent with observations, as long as temperatures do not exceed the dehydration interval. However, since alteration is assumed to occur immediately, but only after the total melting of ice, water is never free to circulate. Consequently, there is no opportunity to satisfy constraints on water:rock ratios. In reality, melting and alteration might be contemporaneous, and heterogeneity in alteration reactions could allow water to circulate without reacting.

Regolith-alteration model. Water may be introduced into the regolith by internal heating in three ways: by direct melting of local ice, which may lead to H_2O circulation and replenishment from below, by venting of liquid or vapor along fractures caused by failure under high pore pressure, or by vapor diffusion through existing pores and cracks. Following the arguments given earlier that regolith-derived carbonaceous chondrites require a large parent body, several models at 300 km-diameter were calculated to illustrate these mechanisms. We find that, under different conditions, all three mechanisms can supply H_2O to within a few kilometers of the surface.

Regolith alteration can also qualitatively resolve some of the inconsistencies found under the internal-alteration model. Water can be introduced to the regolith from below in great quantities by venting or vapor diffusion, but probably at irregular intervals. Condensation there would provide a low-temperature environment for aqueous alteration, and removal of reaction heat is more easily accomplished from a near-surface location. Alteration by local melting of ice still fails to satisfy observed water:rock ratios, unless hydrothermal circulation extends into the regolith. Aqueous alteration by impact heating faces a similar problem, in that there is no H_2O enhancement over the bulk composition of the regolith and the projectile population, unless impactors become progressively more ice-rich with time, or else the parent body accreted sufficiently far from the sun that near-cosmic proportions of ice were condensed.

Conclusions. (1) Mixtures of anhydrous silicates and ice are suitable starting compositions for carbonaceous chondrite parent bodies that have experienced aqueous alteration. (2) Aqueous alteration may have occurred either within asteroidal interiors or surficial regoliths. Chemical, textural, and mechanical arguments support a petrologically homogeneous interior for the interior-alteration model and a large parent body for the regolith-alteration model. (3) The fusion heat of ice, the high heat capacity of water, and the ability of circulating water to enhance rates of heat loss may all significantly contribute to thermal buffering of primordial heat sources for carbonaceous chondrite parent bodies. (4) The short duration of both plausible primordial heat sources and relevent chemical reactions easily allows aqueous alteration to occur within time constraints imposed by radionuclide chronometers. In fact, exothermic hydration reactions probably require that water was gradually introduced into reaction sites to maintain low temperatures. Because the reverse reaction is endothermic, it is a thermal barrier, which may explain why little dehydration is observed in carbonaceous chondrites. (5) For the interior-alteration model, bounds on initial $^{26}Al/^{27}Al$ ratios for CI chondrites are found comparable to those inferred or observed for both CO and ordinary chondrites. Model CI objects must be greater than several tens of kilometers in diameter to satisfy the interior homogeneity condition. CM chondrites require lower $^{26}Al/^{27}Al$ ratios, and model objects of this group do not develop the hydrothermal circulation that is probably necessary to satisfy water:rock ratios implied by oxygen isotope data. (6) Regolith alteration may be driven by impacts or by internally- generated heat sources. In internally-heated models, temperatures at depth may reach higher levels than allowed for interior-alteration models. Large quantities of water may be supplied to the regolith from below by hydrothermal circulation, vapor diffusion, or venting. Impacts can provide sufficient heat after parent bodies have accreted but must be ice-rich in order to deliver the required water volumes.

References. [1] H.Y. McSween and R.E. Grimm, this volume; [2] I.D. Hutcheon et al., *LPSC XIX*, 523, 1988; [3] M. Miyamoto et al., *PLPSC, 12B*, 1145, 1981.