

THE FORMATION TIME AND THERMAL HISTORY OF THE UREILITE PARENT BODY. L. Wilson¹ and C. A. Goodrich² ¹Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, U.K. (l.wilson@lancaster.ac.uk) ²Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston TX 77058 USA. (goodrich@lpi.usra.edu).

Introduction: Budde et al. [1] recently argued that the ureilite parent body (UPB) accreted at ~1.6 Ma after CAI formation. We have previously argued for UPB accretion at ~0.55 Ma [2] to ~0.58 Ma [3] after CAIs. Here we review the factors bearing on the estimation of the UPB accretion time and the importance of uncertainties in the values adopted for input parameters to asteroid thermal modeling. We underline the key role played by melt migration in controlling the evolution of differentiated asteroids and update our previous estimate of the early UPB accretion time. Our latest estimate lies in the range 0.61-0.64 Ma after CAIs, about 1 Ma earlier than the Budde et al. [1] estimate, essentially entirely because they do not include melt migration in their analysis.

Modeling assumptions: It is now well-established that ²⁶Al was by far the major heat source controlling the early histories of asteroids, dominating over contributions from ⁶⁰Fe [4] and numerous other short-lived isotopes [5]. The key parameters needed in modeling asteroid thermal histories are the mass fraction of total Al in the accreted asteroid, dictated by its assumed bulk composition, the canonical initial ratio of ²⁶Al to ²⁷Al = 5×10^{-5} [6] and the specific decay energy of ²⁶Al = 0.355 W/kg [7]. Also critical are the asteroid accretion time (or time interval if not essentially instantaneous), and the mass fraction of ice in the body as it forms. As the temperature inside an asteroid increases the mineral components progress through a series of potential stages: ice melting, mineral hydration and dehydration (all of which of course require some ice to be initially present), and then thermal metamorphism, formation of an Fe,Ni-FeS liquid, and silicate melting.

The final key factor in asteroid thermal models is the fate of the melts produced. FeNi-FeS liquid may segregate downward to form a core, may remain as isolated droplets trapped by surface tension forces [8, 9], or in extreme cases be driven upward by trapped bubbles of released gas to erupt at the surface [10]. Similarly silicate liquids may remain in the mantle or may migrate upward. Whether they migrate or stay in place is critical because Al, taking the ²⁶Al heat source with it, partitions preferentially into the basaltic melts produced by asteroid mantle melting [11]. Many models assume that the silicate melts remain in place to form an internal magma ocean [12-17]. Others infer silicate melt migration, either slowly as a result of per-

colation between unmelted grains [18-21], more quickly during mantle convection [15, 21], or very rapidly as a result of the formation of a complex hierarchical network of interconnected small veins, larger veins, and dikes [22, 23], which efficiently transfer melt to the base of the crust to form a series of magma reservoirs or even a global sill [22]. Surface eruptions may subsequently take place as the melt in the intrusions evolves thermally and chemically [23]. We regard the UPB as exemplifying this latter mode of melt transfer, because there is strong geochemical evidence [24] that negligible chemical interactions took place between ascending melts and mantle residues in the UPB. Silicate melt migration may have been aided on the UPB by the presence of copious CO produced by smelting reactions between graphite and iron oxide [24], but even without this process [25] melt removal is highly efficient [3, 26].

UPB formation time: The errors in the thermal parameters listed above have now become small enough that the chief uncertainties in modeling the formation time of the UPB are its ice content and its bulk silicate composition, and hence total Al content. We continue to assume a range a possible ice contents in the range zero to 25% by mass [22] and an initial temperature range of 150-250 K [3]. However, we have modified our earlier assumed value of the initial bulk Al content of the asteroid from ~1.38 wt.% to a value in the range 1.1 to 1.2 wt.%. This change is due to the recognition that the chemical composition of at least the silicate portion of ureilite precursor materials must have been more like that of ordinary chondrites than carbonaceous chondrites [27, 28]. The Al contents we now assume are based on chondritic compositions from [29].

We have added to our original model some details such as the net water loss during dehydration reactions and now find a formation time-window in the range 0.61-0.64 Ma after CAIs. This formation time is about 1 Ma earlier than the Budde et al. [1] estimate. The difference arises as a result of a combination of two factors: (a) Budde et al. [1] do not include melt migration out of the mantle in their analysis, whereas we [3, 22, 24] regard this is critical in the case of the UPB, and (b) they assume a bulk Al content of 1.75 wt.%, which we consider much too large.

History of the UPB: To summarize our interpretation of the history of the UPB (all times are measured from CAI formation): accretion sometime in the inter-

val 0.61-0.64 Ma; onset of silicate melting and melt migration at ~0.9 Ma; peak melt production at ~1.0 Ma with rapid growth of a global sill or multiple intrusive bodies at the base of the ~10 km thick crust; peak mantle temperature of ~1550 K [30] reached at ~4 Ma; slow cooling of melts in intrusions until disruption of the UPB by a major impact at ~5.4 Ma [31, 32, 33].

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