THERMAL CONSTRAINTS ON THE TIME AND DURATION OF ACCRETION OF THE H-CHONDRITE PARENT BODY. M. Monnereau[1], M.J. Toplis[1], D. Baratoux[1], J. Guignard[1]. [1]Institut de Recherche en Astrophysique et Planétologie, Observatoire Midi-Pyrénées, 14, Av. E. Belin, 31400, Toulouse, France. (mtoplis@irap.omp.eu).

Introduction: The meteorite collection would appear to be dominated by samples coming from relatively small, compositionally diverse parent bodies that escaped accretion into planetary-sized objects. As such, these samples provide a precious window into the earliest stages of the planet building process. Critical information on the extent and time-scales of internal differentiation is provided by geochemical studies, but the challenge remains to integrate these data into a self-consistent time-temperature scenario involving well identified heat sources. In this respect, there is an increasing consensus that short-lived radio-isotopes such as ^{26}Al and ^{60}Fe may have been the principal driving force for internal differentiation in the early solar system. However, even for the simple case of a body which has not partially melted (i.e. for which internal material transport is negligible), a huge range of thermal histories is possible as a function of the exact time of accretion [1], the extent to which accretion was spread-out over time [2], and the presence of an insulating regolith [3].

Thermochronological data such as metallographic cooling rates or age determinations at well defined closure temperatures [4], provide critical constraints with which to assess thermal models, in particular for the favourable case of ordinary chondrites that have experienced extensive thermal metamorphism, but not partial melting. The H-chondrite parent body has been the subject of many analytical and theoretical studies (e.g. [4, 5]), with the broad conclusion that thermo-chronological data are consistent with a body heated by ^{26}Al [4, 6]. However, the recent increase in the number and precision of geochemical constraints for the H-chondrites makes it of interest to confront the latest data-set with predictions of thermal models.

Furthermore, in contrast to most previous work, we systematically explore, quantify and illustrate the parameter space that is consistent with available thermochronological data, rather than restricting discussion to optimal solutions. Secondly, we focus on the effects of non-instantaneous accretion, assessing to what extent the available thermochronological data constrain the time interval of accretion of the H-chondrite parent body, an issue of interest in the light of recent theoretical work in this field [7].

Methods. Thermal evolution of the H-chondrite parent body is modelled using the spherical 1-D conduction equation including a heat-source term [6]. Temperature dependent heat conductivity was described by the equation $k(T) = k_e(T_e/T)^a$ [8], where k is conductivity, k_e is the conductivty at the surface of the body, T is absolute temperature, T_e is temperature at the surface of the body, and a is an exponent assumed to have a value of 0, 0.5, or 1. The method adopted to handle progressive accretion considers non-dimensional radius r' (defined as r/R) of a body of time dependent total radius $R(t)$. This operation transforms the moving boundary problem of a growing body into a fixed boundary problem [9].

For the H-chondrite parent body there are well over one hundred potential thermochronological constraints [6], but of these we have focussed attention on cases for which multiple data points exist for single samples (constituting series of time-temperature coordinates for that sample). Such data exist for 8 H-chondrites, including two H4 (Forest Vale, Sainte Marguerite), three H5 (Richardton, Nadiabondi, Allegan) and three H6 (Estacado, Guareña, Kernouvé), thus covering the major part of the H-chondrite parent body. In total, twenty eight useful individual dates exist for these samples covering systems with closure temperatures from 390 to ~900K.

In this work we have systematically explored the influence of body size and accretion time, all other parameters held fixed or varying in a given way (e.g. conductivity, duration of accretion etc.). Each series consists in a set of around 9,000 models that cover a range of final radius (from 70 km to 200 km in steps of 2 km) and the time of accretion since CAI formation (from 0 Myr to 2.8 Myr in steps of 0.02 Myr). Each body is modelled using 300 radial mesh points and 2×10^5 time steps. The temperature equation was solved by a classical finite difference method, based on a control volume discretisation. The quality of fit was quantified for each 'body-size'-'accretion time' coordinate through calculation of the distance between the model and experimental constraints (i.e. an RMS).

Results. Twenty five series of simulations have been performed, exploring the thermal influences of accretion length (τ_{acc}), temperature dependent conductivity, insulation due to surface regolith, and temperature and age of the solar nebula. For each series, accretion time t_{acc} and body size R have been systematically explored. In each case, a broad minimum in overall RMS can be identified, allowing identification of the best fitting model of that series (*e.g.* Fig. 1). We find that if accretion occurs over a time span of <0.2Myr, the most plausible solutions are restricted to accretion occurring in the time window ~2.2±0.1Myr after CAI formation, and body radius on the order of 130±10km. The dramatic increase in RMS for earlier accretion (Fig. 1) is a consequence of the fact that local temperature was constrained to be less than 1273K. For accretion spread out over >0.2Myr, this cut-off is less and less apparent, but the minimum overall RMS tends to increase.

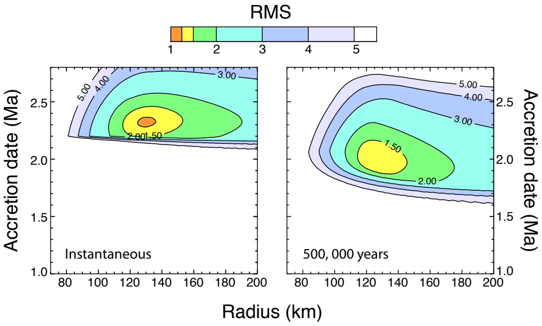

Figure 1. Global RMS Maps obtained with a thermal conductivity proportional to the inverse of the temperature and for τ_{acc} =0 (left) and 0.5 Mys (right).

Comparison of the models and thermo-chronological data shows that for all cases for which the total RMS is <1.25, a minimum of 27 of the 28 individual data points is fitted. On the other hand, for RMS>1.25, less than 27 data points are systematically accounted for by the model. When all the relevant series of calculations are considered, it is found that at fixed a, the RMS of the optimal solution of each series (RMS_{min}) varies in a systematic way as a function of τ_{acc} with a shallow minimum in the range 0.1-0.2 Myr, and a rapid increase for τ_{acc} > 0.5 Myr (Fig. 2).

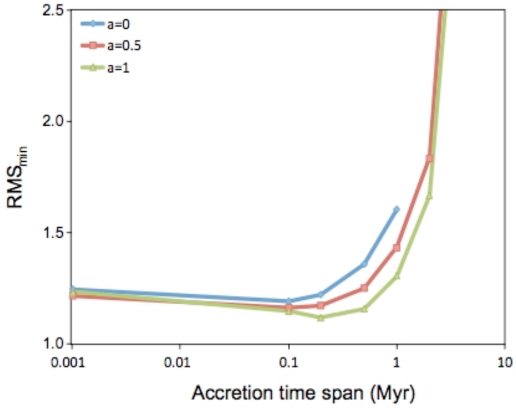

Figure 2. Minimum RMS for each series of thermal models plotted as a function of the accretion length of the body. Three different laws for thermal conductivity are considered.

Another important result of our models is that they may be used to constrain the depth of individual samples within the original parent body. Considering this issue, it is found that for all bulk solutions with RMS<1.25, deepest samples systematically come from depths of at least 50% of the radius. The presence of a regolith layer is found to have dramatic effects on predicted temperature-time paths and sample depths, but values of global RMS are well above those of the regolith-free case, arguing against the need for a regolith layer to account for thermochronological data.

Overall, the results of this modelling clearly point to accretion times that are relatively short, unlikely to be more than 0.5 Myr (Fig. 2). Furthermore, irrespective of τ_{acc}, samples would appear to come from a wide range of depths, potentially reaching the centre of the original parent body.

Discussion and conclusions. The self-consistent thermal models presented here may be used to constrain issues such as the maximum temperature experienced at the centre of the parent body, and the values of maximum temperature experienced by samples of different metamorphic grade (H4, 5, 6). The results also constrain the size of the original parent body to be on the order of 260 km in diameter, but the fact that the samples are inferred to come from an extended depth range would argue against that body having survived intact to the present day. This does not discount 6 Hebe as the parent-body of the H-chondrites [10], but it does infer that if this were the case, Hebe has not preserved an onion-shell structure. The other important conclusion of this study is that accretion of the H-chondrite body would appear to have occurred on short time-scales, most probably somewhere in the range 0.1 to 0.2 Mys, and in any case less than 0.5 Mys. These time-scales are consistent with independent estimates based on modelling of the dynamics of the solar nebular and early asteroid belt [7, 11], pointing to extremely rapid planetisimal formation in the early solar system. This is an important result, as rapid accretion is necessary to form differentiated asteroids such as 4-Vesta, if ^{26}Al is to be the principal heat source.

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