THE STRUCTURE AND ACCRETIONARY HISTORY OF THE CV_{OX} PARENT BODY CONSTRAINED FROM THE MAGNETIZATION OF KABA. K. H. Dodds[1], J. F. J. Bryson[2], J. A. Neufeld[1,3,4] and R. J. Harrison[1], [1]Department of Earth Sciences, University of Cambridge, Cambridge, UK, [2]Department of Earth Sciences, University of Oxford, Oxford, UK, [3]BP Institute, University of Cambridge, Cambridge, UK, [4]Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge, UK.

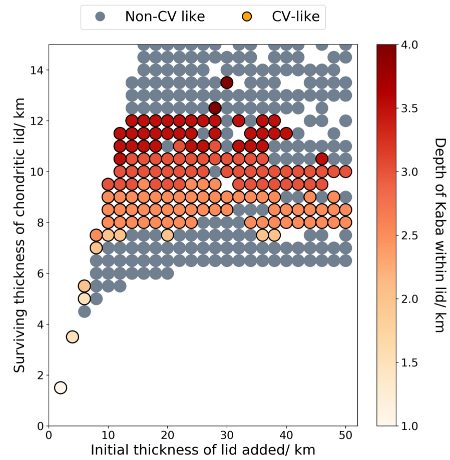
Introduction: The observed magnetization of multiple CV_{Ox} meteorites such as Kaba [1] and Allende [2] at >4 Myr after the formation of calcium-aluminium-rich inclusions (CAIs) has been used to argue that the CV_{Ox} parent body (PB) was partially differentiated i.e. it consisted of a liquid metal core capable of generating a dynamo field overlain by a differentiated silicate mantle and an undifferentiated chondritic crust [1-4]. This has led to proposed accretionary scenarios for such bodies as well as estimates of the physical properties of the CV_{Ox} PB [3,4] based on the condition that the CV_{Ox} dynamo is driven solely by thermal convection in its core. Here we use the magnetization of Kaba to further explore the structure and accretionary history of the CV_{Ox} parent body. We focus on Kaba specifically because its thermal history and magnetization are more straightforward than those of other CV meteorites (e.g Allende [2,5]), providing new and reliable insights into its PB.

Kaba's thermal and magnetic history: Kaba's magnetization has two non-terrestrial components: a non-unidirectional HT component that unblocks from 520 K to 860 K and corresponds to a paleointensity of <0.3 μT; and a stable unidirectional MT component that unblocks from room temperature to 520 K and corresponds to a paleointensity of ~3 μT [1]. Kaba has an estimated peak metamorphic temperature (PMT) of 560-680 K [6,7]. The HT component has been interpreted as the absence of magnetic fields on the CV_{Ox} PB while Kaba cooled from its PMT down to ~420 K (converting the 520 K laboratory unblocking temperature to a likely blocking temperature experienced by Kaba on its PB) [1]. This interpretation also implies that there was no field present for the aqueous alteration episode at ~4 Myr after CAI formation during which magnetite and pyrrhotite formed in this meteorite [1,4]. Once Kaba had cooled to ~420 K, a magnetic field seemingly switched on and it recorded its MT component. The unmagnetized nature of Kaba's HT component and the formation age of its secondary mineralogy at ~4 Myr [8,9] after CAI formation provides an upper constraint on the age of the magnetization of the MT component and the field source. Given this upper age limit, Kaba's most likely source of magnetization is an internally generated dynamo field because the solar nebula field had seemingly decayed by this time [10] and the solar wind intensity was likely too low to be responsible for the magnitude of the remanence without significant pile-up [11] and very rapid formation of the magnetic mineralogy [12]. We assume this dynamo is driven by thermal convection in the core alone, given its likely old age [4].

Model description: Our model consists of a convecting differentiated silicate magma ocean overlain by a chondritic crust that accreted instantaneously to the surface at some time between 2 and 4.8 Myr after CAI formation. We calculate the thermal profile across this lid, which is first heated internally by the decay of ^{26}Al at early times (<3 Myr after CAI formation) and subsequently from below by the convecting magma ocean. During the initial phase of heating, if the base of the lid becomes sufficiently hot and molten, it may delaminate. This leads to erosion of the chondritic lid. The lid reaches thermal equilibrium and starts to cool. We terminate our calculations once magma ocean convection ceases since subsequent thermal dynamo generation is highly unlikely [3,4,13]. We identify depths within the chondritic lid that reproduce Kaba's thermal history (reaching a PMT of 560-680 K >4 Myr after CAI formation then cooling to ~ 300 K within ~35 Myr after CAI formation). The start time of the CV_{Ox} dynamo corresponds to the time at which this depth cools to ~420 K and its earliest end time corresponds to the time at which it cools to ~ 300K. We then compare these timings to predicted thermal dynamo timings [13] in differentiated planetesimals to elucidate the complete structure and potential accretionary history of the CV_{Ox} PB. This comparison is only possible for thin chondritic lids (<50 km), the presence of which do not qualitatively change the results of these more detailed thermal models.

Structure of chondritic lid: We find that Kaba originates from a depth of ~2-4 km within a chondritic lid with a surviving thickness of ~7-12 km (Fig. 1). This final lid is thick enough to allow sufficient insulation for a depth to heat up to Kaba's PMT but thin enough to allow cooling of this depth to room temperature within ~35 Myr after CAI formation. The timing of accretion of this lid and its initial thickness are not uniquely constrained due to a trade-off between these two properties because thick chondritic lids that accreted <3 Myr were significantly heated by ^{26}Al, resulting in differentiation of the bottom tens of km and a ~10 km surviving thickness.

Fig. 1. Thickness of chondritic crust on the CV_{Ox} parent body and depth of Kaba within this crust. The grey circles denote model simulations that do not result in Kaba-like behaviour whereas the coloured ones do.



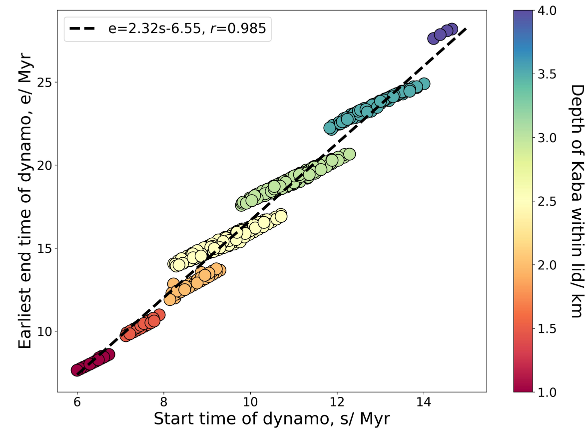


Fig. 2. Predicted CV_{Ox} thermal dynamo start and earliest end times constrained by the unblocking temperatures of the MT component of Kaba's magnetization. The main control on these timings is the depth of Kaba within the ~10 km chondritic lid as this depth controls how quickly the meteorite cooled.

Thermal dynamo timings: The predicted dynamo start, *s*, and earliest end, *e*, times range from 6-15 Myr and 8-28 Myr after CAI formation respectively, depending on the exact depth of Kaba (Fig. 2) within the lid. The relationship between start and end times is linear and can be approximated by

$$e=2.32s-6.55.$$

Properties of differentiated interior: We compare the timings predicted for the CV_{Ox} thermal dynamo by our chondritic lid model to the timings predicted from a detailed model of thermal dynamo generation in planetesimals [13]. The ability for a planetesimal to drive a thermal dynamo may be sensitive to its accretion duration and rate [13] as these control whether a strong stable thermal stratification can develop in its core. This comparison constrains the duration of accretion of the differentiated portion of the CV_{Ox} PB to 100-1000 kyr, growing from an initial radius of <250 km to a final radius of >420 km during this period.

A compositionally driven CV_{Ox} dynamo? So far we have assumed that the dynamo field responsible for Kaba's magnetization is purely thermally driven and therefore can only exist during the first 35 Myr after CAI formation [3,4,13]. However none of the direct dating constraints on Kaba require it to have stopped acquiring its magnetization by 35 Myr after CAI formation. Modelling of the release of Xe from Allende suggests that the last disturbance to this system occurred ~40 Myr after CAI formation [2]. If the CV dynamo was still active at this time, it is likely that it was then driven by compositional convection generated during core crystallization.

Furthermore, planetesimal dynamo generation within the first 35 Myr after CAI formation may not uniquely be due to thermal convection. In addition to the core's size, a dominant control on the timing and duration of a compositional field is the light element concentration of the core, especially its sulfur content [4,13]. The S content of an iron-sulfur core vastly alters its liquidus temperature and thus the time at which it starts to solidify. For sulfur contents < ~15 wt%, this leads to the start of core crystallization and potential compositional dynamo activity within the thermal dynamo activity window. Core S content may also have consequences for the mode and direction of crystallization [14] and thus dynamo driving mechanism [15]. Further modelling of both the evolution of the sulfur content of planetesimal cores during differentiation and solidification of these cores is required to evaluate whether the CV_{Ox} dynamo is more likely to be thermally or compositionally driven.

Conclusions: We find that Kaba's observed magnetization is best explained by a partially differentiated CV_{Ox} parent body with of a >420 km radius differentiated interior that includes a >210 km radius core, overlain by a ~7-12 km undifferentiated chondritic crust. This assumes that the CV_{Ox} dynamo was thermally driven, existing within the first 35 Myr after CAI formation. We highlight that a compositionally driven dynamo could also be responsible for the observed magnetization of the CV_{Ox} meteorites and that further study is needed in this area to identify the origin of this remanence and the effect that this would have on our understanding of the structure and history of the CV_{Ox} PB.

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