$^{26}Al/^{27}Al$ record in UOC chondrules: Possible effect of parent body thermal metamorphism

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Introduction

Refractory Ca-Al-rich Inclusions (CAIs) and Chondrules present in meteorites are considered as products of high temperature processes taking place in the solar nebula, the gas and dust cloud surrounding the early sun.

Chondrules from Unequilibrated Ordinary Chondrites (UOCs) having petrologic grades 3.0 to 3.4 display a range of initial $^{26}Al/^{27}Al$ varying from $<10^{-6}$ to ~ 2×10^{-5} [Russell et al., 1996, Kita et al., 2000, Huss et al., 2001, Mostefaoui et al., 2002, Rudraswami and Goswami., 2007]

These UOCs are expected to experience temperatures of ~250°C (3.0) to ~450°C (3.4) in their parent bodies. Such temperatures are not sufficient to disturb Al-Mg isotope systematics in Al-rich phases (plagioclase) present in UOC chondrules even if they sustain for about 10 Ma [LaTourette and Wasserburg, 1998]. Thus, the above variation in initial $^{26}Al/^{27}Al$ would suggest a very long duration of close to three million years for chondrule formation.

The main objective of this work are:

To infer the exact duration of chondrules formation in the solar nebula from studies of chondrule of low metamorphic grade (≲3.3)

Investigate the possibility of parent body thermal processes that may have affected the Al-Mg isotopic systematics in UOC chondrules of low metamorphic grades.

Samples selection

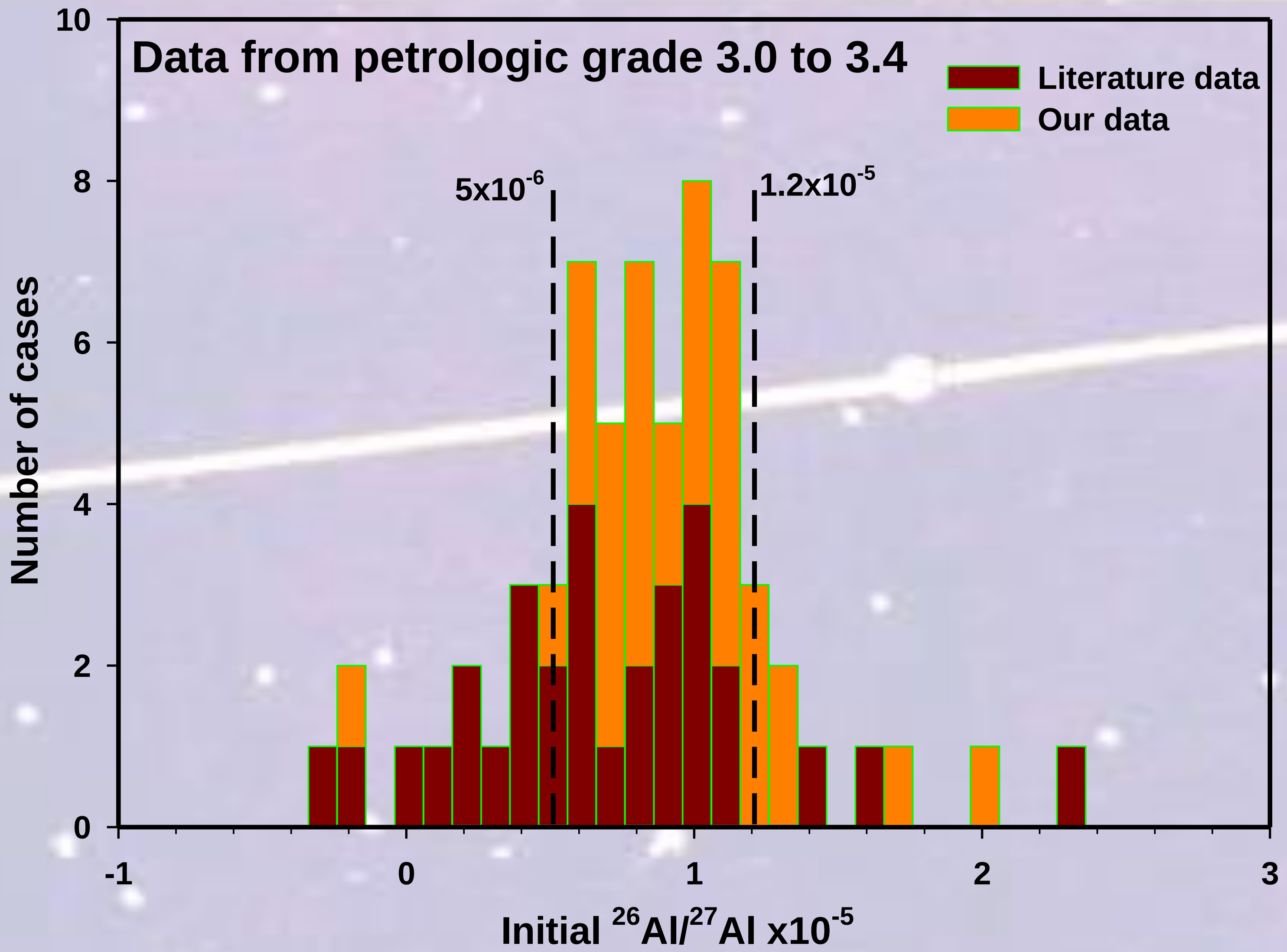
Thermal metamorphism is an important parameter in our choice of samples. Nine Unequilibrated Ordinary Chondrites (UOCs) were selected for the present work are among the least metamorphosed chondritic meteorites; we have excluded petrologic grade 3.4 in our study as earlier data suggest possible evidence of thermal metamorphism in chondrules from these UOCs [Huss et al., 2001].

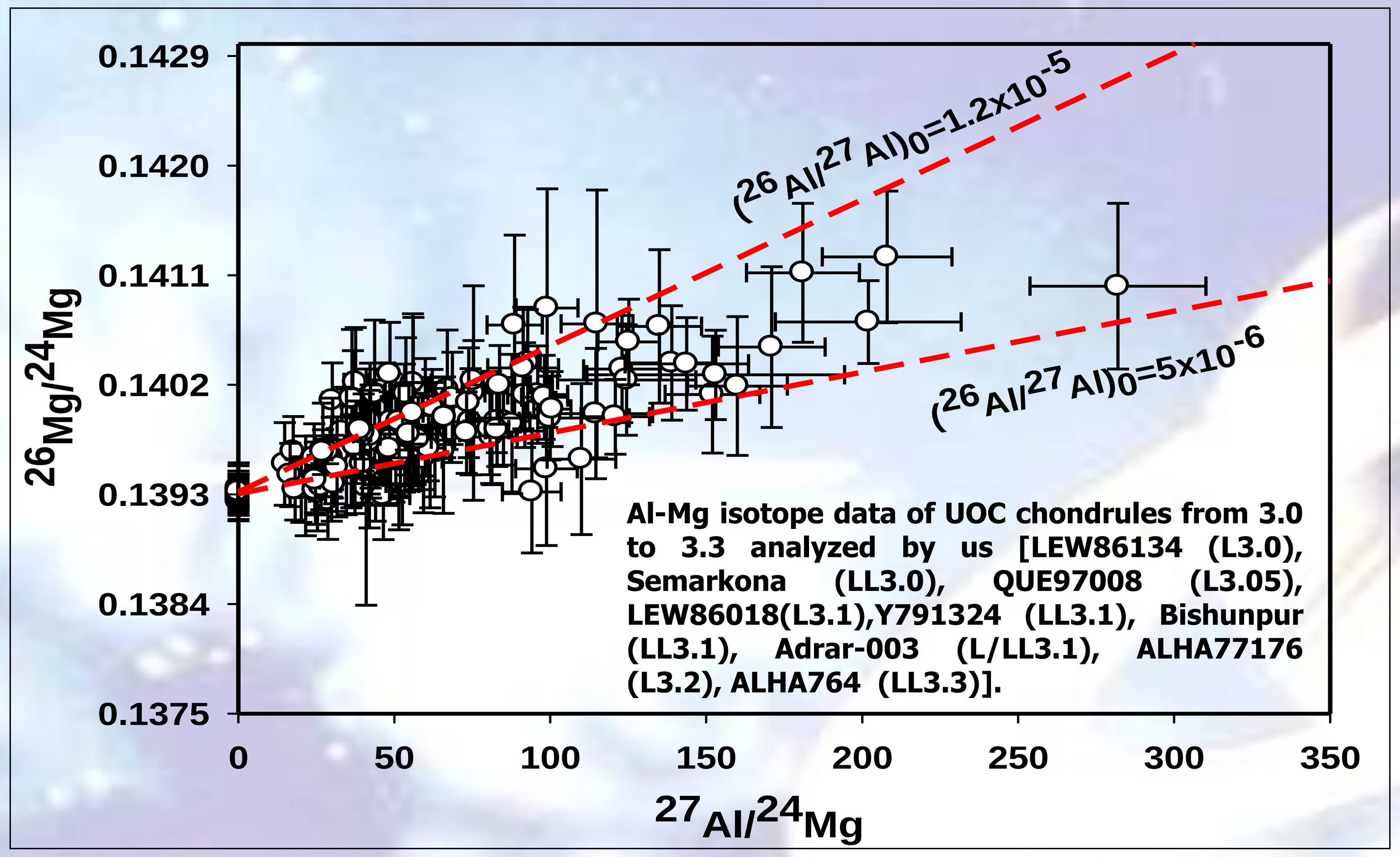
Experimental approach

- Thin sections mapped using a scanning electron microscope equipped with an energy dispersive X-ray analyzer.
- Phases with high Al/Mg ratio present within the chondrules were identified from backscattered electron images of the sections.
- Identified areas, typically tens of microns across, were analyzed to determine their mineralogical composition using electron microprobe (EPMA; Cameca SX-100).
- Such phases, were analyzed for Al-Mg isotope systematics using a Cameca ims-4f secondary ion mass spectrometer (SIMS) [Goswami et al., 1994].

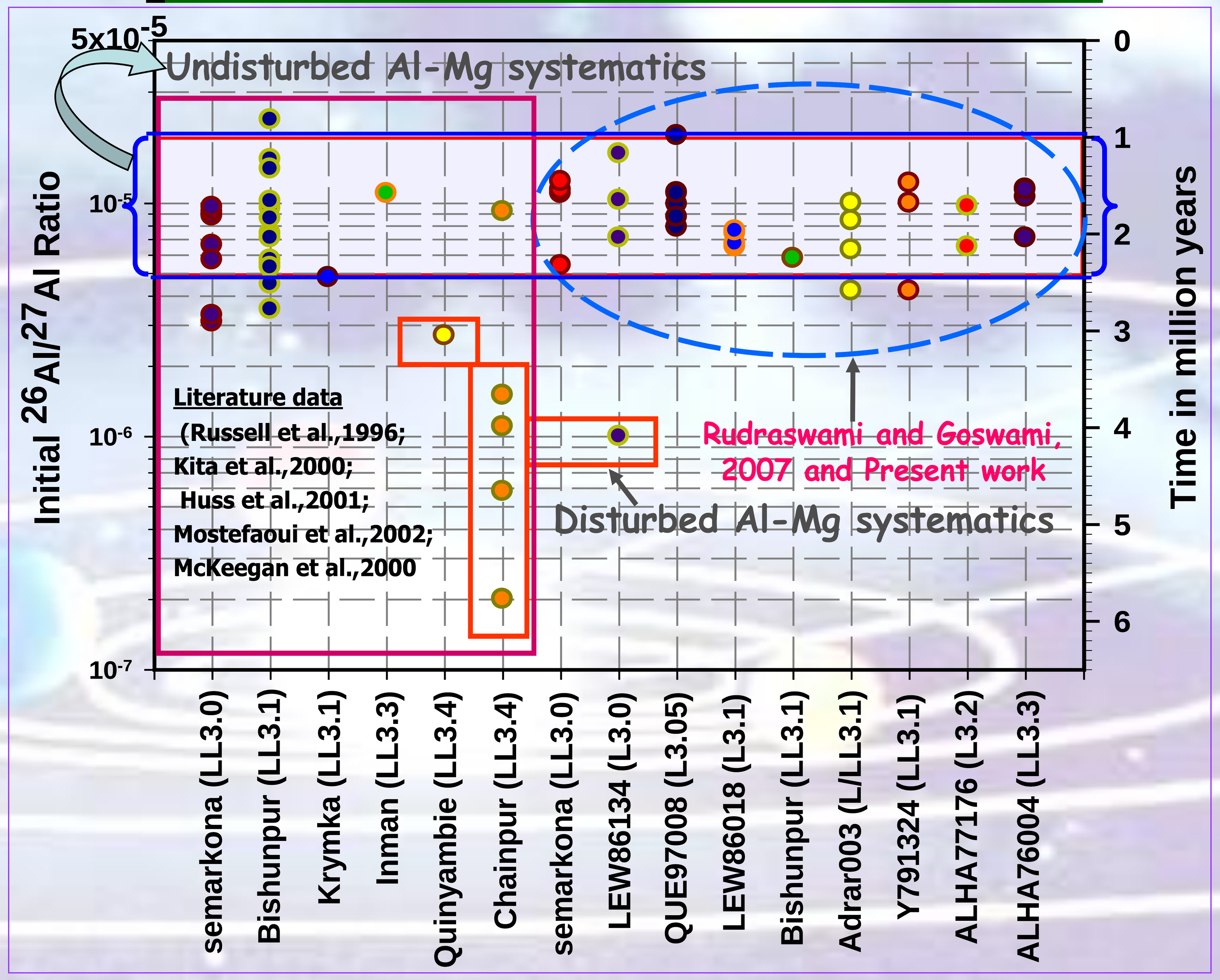
Results

- The range of initial $^{26}Al/^{27}Al$ ratios in the analyzed chondrules varies from ***1.95×10^{-5} to 5×10^{-6}*** with a sole exception that has an initial value of $<10^{-6}$.
- *A majority of them (~ 85%) lie in the range of 5×10^{-6} to 1.2×10^{-5}.*
- Absence of resolved ^{26}Mg excess in one chondrules from LEW86134, belonging to low petrologic grade L3.0.





Data on Initial $^{26}Al/^{27}Al$ at the time of Chondrule formation



- The initial $^{26}Al/^{27}Al$ values in UOC (3.0-3.3) chondrules vary from :~2×10^{-5} to ≤10^{-6}.
- **Onset of the chondrule formation: ~1Ma after CAI.**
- **An intense chondrule formation epoch ~1.5 Ma after CAI formation and lasted ≤1Ma.**

[Most of the chondrules have $^{26}Al/^{27}Al$ ratio between (5-12) x 10^{-6}]

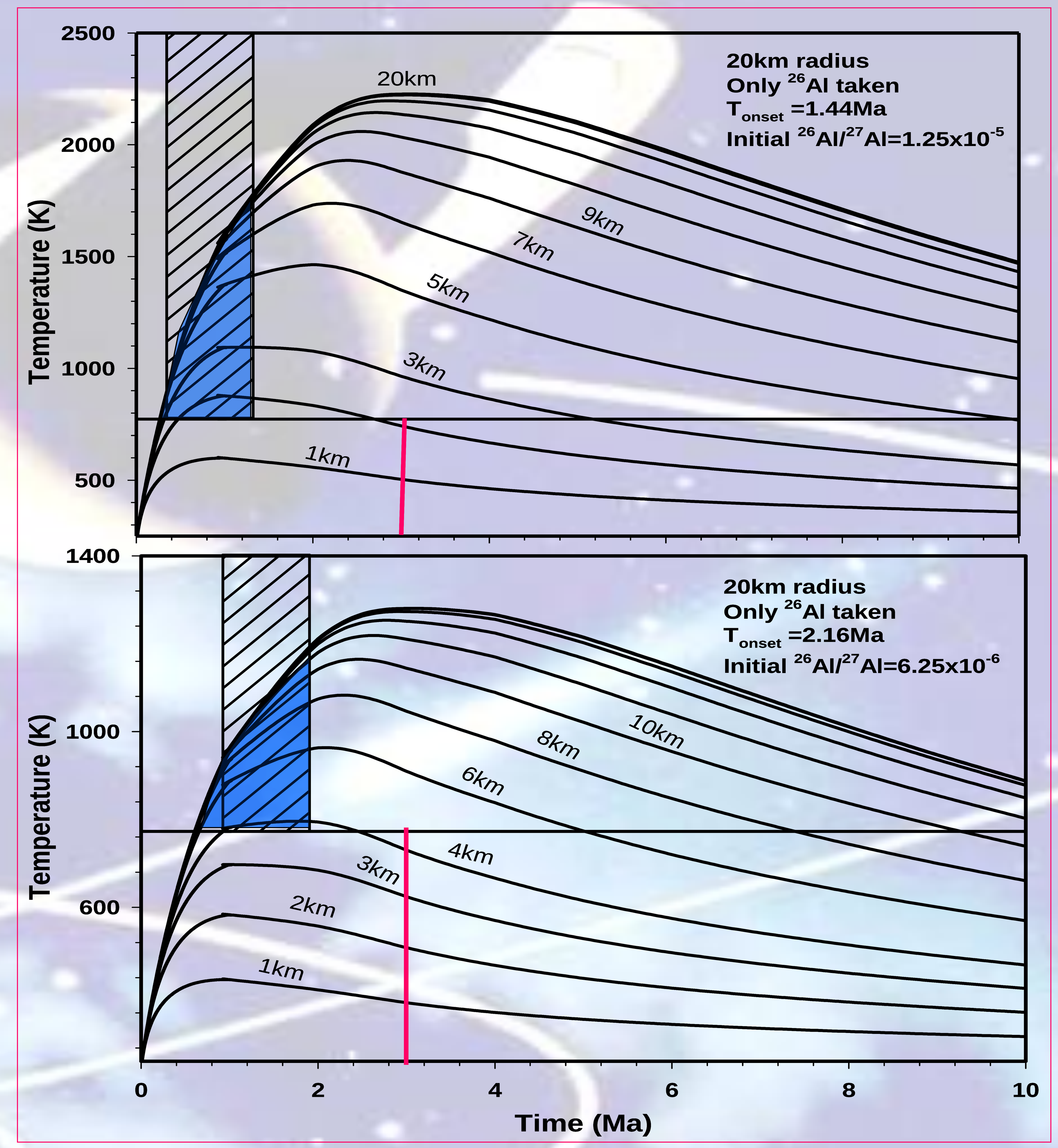
The absence of radiogenic ^{26}Mg in a chondrule from LEW86134 (3.0) and also in Krymka (L3.1) [Huss et al., 2001] is not expected because of the low temperature thermal history of the parent bodies of these UOCs. We model thermal evolution by solving the heat conduction equation numerically using finite difference method and using standard values for the various parameters such as density, decay constant, initial temperature, thermal conductivity, thermal diffusivity and heat capacity [Yomogida and Matsui, 1983] to further investigate this issue.

Laboratory studies suggest that Mg isotope records in plagioclase over scale length of tens of micron, typical size of the analyzed phases in UOCs, can be thermally reset at a temperature of ~500°C within a time period of about 1Ma [LaTourette and Wasserburg, 1998].

Calculations were carried out for meteorite parent bodies ≥20km in size and of chondritic composition, with initial $^{26}Al/^{27}Al$ of 1.25×10^{-5} (formation time 1.44 Ma after CAI) and of 6.25×10^{-6} (formation time 2.16 Ma after CAI), respectively, and considering instantaneous accretion.

Our calculations show that the time temperature regime (>1Ma, 500°C) will be experienced by an object residing at ≥2km below the surface in such bodies. Note that the temperature for resetting Al-Mg isotope records in glassy phases (mesostasis) will be lower than plagioclase and hence their isotopic records may be reset even at shallower depths.

Further, if we include contribution from the other heat source, ^{60}Fe as well (initial $^{60}Fe/^{56}Fe$ ~10^{-6}), and also consider an extended regolith surface (with poor thermal conductivity), resetting of Al-Mg isotope records in the above cases can take place for chondrules residing even closer to the surface, nominally between 1 and 2 km.



We, therefore, propose that the occasional chondrules with low initial $^{26}Al/^{27}Al$ ratio (having $<5\times10^{-6}$) present in UOCs of petrologic grades 3.0 to 3.2, and whose number increases significantly in UOCs of petrologic grades >3.3, experienced such a thermal episode as an independent entity, perhaps due to impact related dynamic mixing on the parent body, prior to their final incorporation into the host meteorite.

Conclusion: Parent body thermal processes can explain presence of chondrules with low initial $^{26}Al/^{27}Al$ in UOC of various petrologic grades.

Reference

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