
Michael P. Lucas¹, Nick Dygert¹, Allan D. Patchen¹, Nathaniel R. Miller², and Harry Y. McSween¹
(1) Department of Earth & Planetary Sciences, University of Tennessee, 1621 Cumberland Ave., 602 Strong Hall, Knoxville, TN 37996, mlp@utk.edu
(2) Department of Geological Sciences, University of Texas, Austin, TX 78712

Introduction

Thermal evolution models of asteroids are ground-truthed by estimates of temperatures and cooling rates from meteorite cosmochemical data [e.g., 1]. However, traditional geothermometers used to constrain the thermal evolution of meteorite parent bodies typically record blocking temperatures during cooling rather than peak or magmatic temperatures. Recently, a REE-in-two pyroxene thermometer was developed [2] that relies on the relatively slow diffusive exchange of REEs between co-existing pyroxenes. This method has been shown to record near-peak or magmatic temperatures for samples from a variety of geologic settings in the Earth's mantle and crust, and some samples from planetary environments [2-5]. Here, we apply the REE-in-two pyroxene thermometer to six H ordinary chondrites to provide key near-peak temp data. These data, accompanied by major element geothermometry, furnish new insights into the thermal histories of H chondrites. Accurate thermal histories in turn help to discriminate between competing models (e.g., onion-shell vs. diabase) regarding the geologic evolution of the H chondrite parent body.

H Chondrite (H6) Characterization

Peekskill (H6)

(a) X-ray map

(b) Reflective Light (RL)

(c) BSE

(a) False-color X-ray map of the Peekskill H chondrite; phases characterized are cpx (yellow), opx (light green), olivine (blue-green), FeNi metal (blue), and phosphates (red). (b) RL photomicrograph (grains selected for LA-ICP-MS analysis outlined). (c) BSE image of dashed region in (a).

Major Element Mineral Chemistry

<table>
<thead>
<tr>
<th>Sample</th>
<th>TiO²</th>
<th>CaO</th>
<th>Al₂O₃</th>
<th>Mg#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queen's Mercy</td>
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<td></td>
<td></td>
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<tr>
<td>Mulga</td>
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<tr>
<td>Kernouve</td>
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<td>Guarea</td>
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<tr>
<td>Estacado</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>LL chondrites</td>
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<td></td>
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<tr>
<td>Mantle xenoliths</td>
<td></td>
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<tr>
<td>Ophiolitic peridotites</td>
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</tbody>
</table>

Takeaway: Homogeneous compositions suggest thermally equilibrated samples.

Methods

(Left) TRE inversion diagram for Mulga (90a). A linear regression through REEs vs. (REE+Y) defines TRE. TRE cannot be determined in cases where REE+Y fail to align linearly.

(Right) In pyroxene, REE (3+ cation) diffusion is one to two orders of magnitude slower than for major elements (2+ cation).

Trace Element Mineral Chemistry

<table>
<thead>
<tr>
<th>Sample</th>
<th>Chondrite Normalized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queen's Mercy</td>
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<td>Guarea</td>
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<td>Estacado</td>
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</table>

Chondrite normalized REE+Y abundance in cpx (solid lines) and ox (dotted lines). Error bars are 1σ SD of replicate analyses. Shown for comparison are the range of values in four LL chondrites [6] (light gray lines).

Takeaway: Trace elements are homogeneous and reproducible among px grain pairs.

Competing Parent Body Models

Onion-Shell

Internal heating due to ⁵⁷⁷Al decay


Fragmentation — Reassembly

A proposed five stage fragmentation—reassembly model for the thermal evolution of the H chondrite parent body (numerical modeling forthcoming).

Stages:

1. Radially symmetric evolution of the initial asteroid due to heating by ⁴⁰³Al decay
2. Collisional break-up of fragments follow scaling laws for collisional populations
3. Short cooling period (<1 yr) for collisional fragments => random reassembly
4. Post-reassembly thermal evolution and coalescence of rubble pile asteroids
5. Further reassembly of small rubble piles into a larger rubble pile parent body

Conclusions

- Samples have equilibrated major+trace element compositions; suitable for our method.
- REE-in-two-pyroxene method provides key near-peak temperature data.
- TRE, TREE, and CaO temperatures suggest fast cooling rates (see below).
- Our results suggest an early fragmentation—reassembly event, rather than in situ cooling at different depths in an onion-shell parent asteroid.

References & Funding


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Temperature (°C) vs. Cooling Rate (°C/yr)

Cooling Rates for Six H Chondrites

REE温情 Thermometry (This study)

REE温情 Thermometry (This study)

Cooling Rate (°C/yr)

Temperature (°C)

PEa: Meteoric and Petroleum fluids (data are cobbled at 82°C)

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