CHEMICAL-PETROLOGICAL STUDIES OF INDIVIDUAL CHONDRULES
FROM THE RICHARDTON METEORITE


Individual chondrules have been separated from the H5 chondrite Richardton and analyzed for major elements, rare-earth elements (REE), Rb, Sr and $^{87}\text{Sr}/^{86}\text{Sr}$. This chemical study has been integrated with petrographic observations and phase-chemical studies of the same chondrules. Previous investigations of chondrules include studies of phase chemistry (e.g., 2, 3), and major and trace element analyses (e.g., 4, 5), but none have combined petrological and chemical analyses.

Richardton contains chondrules ranging in size from a few mg up to 50 mg (see also [5]). The degree of chondrule integration with the matrix is variable from one portion of the meteorite to another and is independent of chondrule size. The present study was made on a number of poorly integrated and easily separable chondrules which are characterised by a phase assemblage consisting of olivine, orthopyroxene and plagioclase.

Eight chondrules have been analysed for REE and four of these together with two others have been studied petrologically. The technique employed involves initial splitting of the chondrules into two halves, one of which is mounted for electron-probe study. The second half is finely ground and an aliquot fused into a glass which is subsequently analysed for Si, Ti, Cr, Al, Fe, Mn, Mg, Ca, Na and K by electron-probe. The remaining powdered chondrule is analysed by mass spectrometry for $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and for REE, Rb and Sr contents by low-blank isotope dilution techniques. The samples used for this part of the study range from 0.7 to 4.5 mg. The mass spectrometric analysis of the REE was performed using a Daly scintillation detector and ion-counting. Where $^{87}\text{Sr}/^{86}\text{Sr}$ ratios could be measured with reasonable precision (+1%) model Rb-Sr ages have been calculated. Total procedural blanks for the trace element analyses, where measurable, are given in Table 1.

The six chondrules studied petrologically are variable in texture and modal mineralogy. Typically a single major phase (olivine or orthopyroxene) is present as barred, radiating or blocky crystals in a fine-grained groundmass containing olivine, orthopyroxene, plagioclase and occasionally other minor phases. Despite the wide variation in modal mineralogy, major element compositions of the bulk chondrules show surprisingly little variation (Table 2). If the major phase compositions also shown on Table 2 are characteristic of the given chondrules, the chondrule groundmass must display complementary variation to produce the relative constancy of Si, Fe and Mg contents.

Si contents are in excellent agreement with the neutron activation data of Osborn et al. (5) for Richardton chondrules; Fe and Al average somewhat lower than their data, but are within the range reported. The relative constancy of Si and Mg is reflected in the limited range of Mg/Si (Table 3). Figure 2 demonstrates that Mg/Si ratios of the chondrules are distinctly lower than those of H-group chondrites, principally due to the higher Si of the chondrules. The depletion of Fe/Si is even more marked, in general agreement with the chondrule averages of Osborn et al. (5). The lower Fe/Si of chondrules in this case reflects Fe depletion as well as Si enrichment, due at
least in part to the paucity of metallic Fe in the chondrules. Ca/Si (Table 3, Fig. 2) is extremely variable, as is Ca/Al. Ca shows no correlation with Sr or divalent Eu, as inferred from Eu anomalies (Table 3, Fig. 2).

Rb and Sr contents vary by factors of 2-3 (Table 3) and show no correlation, so that Rb/Sr varies by a factor of 4. Despite this spread in Rb/Sr, the 87Sr/86Sr ratios, when determinable with sufficient accuracy, yield T<sub>SB</sub> model ages of ~4.55 Ga (Table 3). This suggests that these chondrules have been closed systems since that time, though whether it is prior or subsequent to their incorporation into the meteorite cannot be determined.

REE analyses of eight chondrules are shown in Fig. 2, normalized to average CI chondrite abundances (6). Chondrule A was a large (47 mg) chondrule not examined petrologically. Its V-shaped pattern and depleted abundances are reminiscent of the pattern obtained by Masuda et al. (7) for olivine from the Brenham pallasite. The remaining patterns have much higher REE abundances, and uniformly display some degree of heavy REE enrichment. Schmitt et al. (8) analyzed a composite of 50 Richardton chondrules for REE and obtained a pattern very similar to chondrule E (Fig. 3), with somewhat lower absolute abundances. Other chondrules on this study differ from E in having negative (B) or non-existent (C,F,G) Eu anomalies, or in displaying light REE enrichment (F,K,M). Blank corrections for light REE are ca. 10% in some cases, but are far from being able to account for the observed upturn, nor could they explain the negative Eu anomalies. A whole rock analysis from the same portion of Richardton from which the chondrules in this study were separated shows a slight light REE enrichment (6).

In summary the chondrules studied exhibit a variety of textural and chemical features, probably originating at a time close to the origin of the solar system. In both major and trace element characteristics (e.g., Si content, Mg/Si, Fe/Si, Rb/Sr, elevated REE abundances and fractionated patterns) they are considerably more evolved than average chondritic material. However, this combination of characteristics cannot be readily accounted for by fractionation of the phases present in the chondrules themselves. This implies that either more complex parent-body processes have occurred, or that the chondrules predate parent-body formation, in which case this may result from fractional condensation of the nebula.

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RICHARDTON CHONDRULES

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Table 3

<table>
<thead>
<tr>
<th>Chondrule</th>
<th>Sample Size (kg)</th>
<th>Mg/Si (atomic)</th>
<th>Ca/Si (atomic)</th>
<th>Rb (ppm)</th>
<th>Sr (ppm)</th>
<th>Model Age $T_{BARI}$ (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>4.36</td>
<td>0.73</td>
<td>0.066</td>
<td>2.40</td>
<td>8.78</td>
<td>4.50±8</td>
</tr>
<tr>
<td>G</td>
<td>4.34</td>
<td>0.69</td>
<td>0.096</td>
<td>3.61</td>
<td>6.96</td>
<td>4.53±8</td>
</tr>
<tr>
<td>I</td>
<td>3.49</td>
<td>0.74</td>
<td>0.031</td>
<td>3.24</td>
<td>16.83</td>
<td>—</td>
</tr>
<tr>
<td>K</td>
<td>1.26</td>
<td>0.72</td>
<td>0.060</td>
<td>6.02</td>
<td>18.99</td>
<td>—</td>
</tr>
<tr>
<td>L</td>
<td>0.72</td>
<td>0.79</td>
<td>0.051</td>
<td>5.60</td>
<td>6.97</td>
<td>—</td>
</tr>
<tr>
<td>M</td>
<td>3.17</td>
<td>0.62</td>
<td>0.15</td>
<td>3.36</td>
<td>11.50</td>
<td>4.59±8</td>
</tr>
</tbody>
</table>

* Errors quoted are for 2σ. Assumed value for initial $^{87}\text{Sr}/^{86}\text{Sr}$ = 0.69698(1), $\lambda = 1.42 \times 10^{-11}$ y$^{-1}$.

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