Abstract: Small anomalies in the isotopic abundance of $^{142}\text{Nd}$ have been measured for two A17 high-Ti basalts, ilmenite basalt 12056, olivine-pigeonite basalt 12039, feldspathic basalt 12038, and two KREEP basalts. These anomalies correlate with $^{147}\text{Sm}/^{144}\text{Nd}$ for the basalt source regions as calculated from initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratios in the basalts, and are interpreted to be from decay of $^{147}\text{Sm}$ ($t_1/2 = 103$ Ma) in distinct lunar mantle reservoirs. A three-stage model for evolution of $^{143}\text{Nd}/^{144}\text{Nd}$ and $^{142}\text{Nd}/^{144}\text{Nd}$ yields reservoir $^{147}\text{Sm}/^{144}\text{Nd}$ ratios which, with the $^{142}\text{Nd}/^{144}\text{Nd}$ ratios in the basalts, form a "mantle isochron" giving a lunar mantle formation interval of 94-98 Ma (2σ). Calculated reservoir $\text{Sm}/\text{Nd}$ ratios are in the range expected from some earlier models of basalts petrogenesis. The isochron value of $^{142}\text{Nd}/^{144}\text{Nd}$ at $^{147}\text{Sm}/^{144}\text{Nd}_{\text{CHUR}} = 0.1967$ is within error limits of the average $^{142}\text{Nd}/^{144}\text{Nd}$ measured for an L6 chondrite, an H5 chondrite, and the Orgueil carbonaceous chondrite. Evolution of $^{143}\text{Nd}$ and $^{142}\text{Nd}$ for high-Ti basalt 70135 was modelled precisely, starting from chondritic relative REE and Nd-isotopic abundances and using the initial $^{146}\text{Sm}/^{144}\text{Sm}_{0}$ ratio inferred from a previous study of angrite LEW86010 as the initial solar system value of this parameter. We infer that the initial $\text{Sm}/\text{Nd}$ ratio in precursor lunar materials was very nearly chondritic (within -8%) prior to lunar differentiation.

Reservoir $^{147}\text{Sm}/^{144}\text{Nd}$ and the Mantle Formation Interval: Table 1 gives Nd-isotopic data for seven lunar basalts and the average $^{142}\text{Nd}$ for three chondrites. For the lunar basalts, values of $^{142}\text{Nd}$ roughly correlate with values of $^{143}\text{Nd}$, in spite of differences in crystallization ages ($T_c$). Reservoir values of $^{147}\text{Sm}/^{144}\text{Nd}$ were calculated from a three stage model

$$I_{143} = I_{141} + \mu_{147}(e^{\lambda_{147}t_{143}} - e^{-\lambda_{147}t_{0}}) + \mu_{147}(e^{\lambda_{147}t_{143}} - e^{-\lambda_{147}t_{0}}) + \mu_{147}(e^{\lambda_{147}t_{143}} - e^{-\lambda_{147}t_{0}}) \tag{1}$$

where $I_{143}$ = present-day $^{143}\text{Nd}/^{144}\text{Nd}$, $t_1$ = lunar formation age, $t_2$ = lunar differentiation age, and $t_3$ = basalt age. Also, $\mu_{147}$ = present-day value of $^{147}\text{Sm}/^{144}\text{Nd}$ in the magma ocean at $t_2$, $\mu_{147}$ = present-day value of $^{147}\text{Sm}/^{144}\text{Nd}$ in the basalt source region at $t_3$, $\mu_{147}$ = present-day $^{147}\text{Sm}/^{144}\text{Nd}$, and $\lambda_{147}$ is the $^{147}\text{Sm}$ decay constant. Eq. (1) was solved for $\mu_{147}$ to get

$$\mu_{147} = \frac{I_{143} - I_{141} - \mu_{147}(e^{\lambda_{147}t_{0}} - e^{-\lambda_{147}t_{0}})}{(e^{\lambda_{147}t_{0}} - e^{-\lambda_{147}t_{0}})} - \frac{\mu_{147}(e^{\lambda_{147}t_{0}} - e^{-\lambda_{147}t_{0}})}{(e^{\lambda_{147}t_{0}} - e^{-\lambda_{147}t_{0}})} \tag{2}$$

To a good approximation, evolution of $^{142}\text{Nd}/^{144}\text{Nd}$ can be expressed by

$$e_{142} = e_{142} + 1801(^{146}\text{Sm}^{144}\text{Sm})_0 \mu_{147} e^{-\lambda_{147}t_{0}} \tag{3}$$

in $\epsilon$-notation, where $^{146}\text{Sm}/^{144}\text{Sm}_{0}$ is the solar system initial value. Systems having the same formation interval ($t_1-t_2$) and second stage $e_{142}$ will determine an isochron whose slope, $m$, gives the formation interval

$$t_1-t_2 = -\lambda_{147}^{-1} \ln((5.55)10^{-4})/(^{146}\text{Sm}^{144}\text{Sm})_0 \tag{4}$$

The values of $\mu_{147}$ and $\mu_{147}$ differ only slightly due to radioactive decay of $^{147}\text{Sm}$ between $t_2$ and $t_3$. Thus, $\mu_{147}$ in Eq. (3) can be approximated by $\mu_{147}$ from Eq. (2), coupling the two Sm-Nd chronometers. Assuming $\mu_{147} = 0.2027$, the CHUR [1] value at $t_1 = 4.56$ Ga ago, substituting the basalt age for $t_3$, and setting $t_1 = t_2$ in Eq. (2) yields a two-stage approximation to $\mu_{147}$. $e_{142}$ for the basalts can be plotted versus $\mu_{147}$ as in Fig. 1, to obtain an approximation to the source region.
Table 1. Nd isotopic anomalies and source region 147Sm/144Nd for lunar basalts.

<table>
<thead>
<tr>
<th>Basalt</th>
<th>142Nd</th>
<th>143Nd</th>
<th>Tc(Ga)</th>
<th>147Sm/144Nd</th>
<th>(\mu_{2,3}^\text{CHUR})</th>
</tr>
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<tbody>
<tr>
<td>70135</td>
<td>0.25±0.17</td>
<td>7.60±0.33</td>
<td>3.77</td>
<td>0.380</td>
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<tr>
<td>75076</td>
<td>0.33±0.15</td>
<td>7.56±0.52</td>
<td>3.70</td>
<td>0.371</td>
<td></td>
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<tr>
<td>12056</td>
<td>0.21±0.20</td>
<td>12.31±0.7</td>
<td>3.00</td>
<td>0.371</td>
<td></td>
</tr>
<tr>
<td>12038</td>
<td>-0.36±0.12</td>
<td>1.73±0.38</td>
<td>3.33</td>
<td>0.308</td>
<td></td>
</tr>
<tr>
<td>12039</td>
<td>-0.16±0.12</td>
<td>4.80±0.56</td>
<td>3.20</td>
<td>0.225</td>
<td></td>
</tr>
<tr>
<td>14078</td>
<td>-0.30±0.13</td>
<td>-</td>
<td>3.89</td>
<td>0.181</td>
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<tr>
<td>15386</td>
<td>-0.36±0.20</td>
<td>-1.30±0.3</td>
<td>3.85</td>
<td>0.181</td>
<td></td>
</tr>
<tr>
<td>CHUR</td>
<td>-0.35±0.08</td>
<td>0</td>
<td>4.558</td>
<td>0.1967</td>
<td></td>
</tr>
</tbody>
</table>

Mantle Formation Interval (Ma) 94±23

147Sm/144Nd in source if established at 4446 Ma ago.

of Apollo 17 basalts is in the range -0.24 to -0.29 for model values [4,5,6,7]. Similarly, \(\mu_{2,3}^\text{CHUR} = -0.27\) and -0.21 for the sources of ilmenite basalt 12056 and feldspathic basalt 12038 in satisfactory agreement with model values of -0.26 and -0.215, resp. [4,5,8], and \(\mu_{2,3}^\text{CHUR} = -0.22\) for ol-pig basalt 12039 is in the model range -0.21-0.23 [4,5,9].

Comparison of 142Nd and 147Sm/144Nd: The weighted average 142Nd for the three chondrites gives 142Nd = -0.35±0.08, nearly identical with the lunar isochron value of 142Nd = -0.31±0.06 (2σ) at 147Sm/144NdCHUR = 0.1967. Thus, evolution of 142Nd in the bulk moon appears to have been the same as in a chondritic reservoir. Fig. 2 shows the evolution of 142Nd and 143Nd for high-Ti basalt 70135 as modelled from CHUR parameters starting at 142Nd = 143Nd = 0 at 4.558 Ga ago [10]. The model includes Nd evolution in a chondritic reservoir for 94 Ma, after which 142Nd increases in a chondritic reservoir for 94 Ma, after which 142Nd increases by -0.66 difference from present-day 142Nd and 143Nd. Growth in a chondritic reservoir would have led to 142Nd = +2.67, explaining the -0.66 difference between present-day 142Nd for 70135 and chondrites (Table 1).

The modelled values of 142Nd/144Nd and 143Nd/144Nd agree exactly with measured values (Fig. 2). Significant departures from chondritic evolution within the interval (t = t), during which 38% of the total growth in 142Nd/144Nd occurred, should be detectable as a difference between calculated and measured 142Nd/144Nd ratios. Calculated growth in 142Nd/144Nd from t to t = -126 ppm, and (143Nd-142Nd) = +10 ppm. Thus, the 147Sm/144Nd ratio is suggested to be within ~8% of the CHUR value between lunar formation and differentiation.