Kutolin V.A., Shirokikh V.A. Kinetics of olivine and pyroxene dissolution in basalts: experimental basis for the upper mantle websterite model.

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**Key words:** [olivine, pyroxenes, dissolution kinetics in basalts, mantle]

Kinetics of olivine and pyroxene dissolution in basalt melts was studied at atmospheric pressure [1] and also at pressures from 5 to 30 kbar [2,3]. These experiments showed that olivine is dissolved in basalt melts 1.5-72 slower than orthopyroxene and 1.3-53 slower than clinopyroxene at pressure up to 20 kbar and faster than both pyroxenes at pressure of 30 kbar (Table 1).

Based on the experimental data Kutolin and Agafonov [1] came to a conclusion that high contents of peridotites among the mantle nodules in basalts are due to higher stability of dunites and herzolites compared to websterites and pyroxenites during the xenolith transportation to the surface by basalt magma, but not due to the abundance of these rocks in the mantle. Taking into account this fact the upper mantle composition calculated by corrected relative content of the various mantle nodules will correspond to olivine websterite (Table 2) but not to pyrolite [4]. This conclusion is supported by up-to-date geophysical data according to which the olivine content in mantle must be 30-40 % but not 50-60 % as in pyrolite model [5,6,7].

Table 1. Relative stability of olivine and pyroxenes during the dissolution in basalts.

<table>
<thead>
<tr>
<th>P</th>
<th>1 bar</th>
<th>5 kbar</th>
<th>12 bar</th>
<th>12.5 kbar</th>
<th>14 kbar</th>
<th>20 kbar</th>
<th>30 kbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>T°C</td>
<td>1150</td>
<td>1200</td>
<td>1250</td>
<td>1300</td>
<td>1300</td>
<td>1350</td>
<td>1400</td>
</tr>
<tr>
<td>Ol/Opx</td>
<td>10.90</td>
<td>5.40</td>
<td>3.70</td>
<td>1.50</td>
<td>72.20</td>
<td>2.60</td>
<td>0.90</td>
</tr>
<tr>
<td>Ol/Cpx</td>
<td>20.90</td>
<td>12.30</td>
<td>7.40</td>
<td>4.70</td>
<td>53.10</td>
<td>5.70</td>
<td>0.30</td>
</tr>
<tr>
<td>Source</td>
<td>[1]</td>
<td>[3]</td>
<td>[2]</td>
<td>[3]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Analyses of the websterite mantle xenoliths and estimate of the upper mantle composition.

<table>
<thead>
<tr>
<th>NN sa.</th>
<th>KA</th>
<th>NK-66</th>
<th>5736-2</th>
<th>4/92</th>
<th>SP 1068</th>
<th>4/56</th>
<th>66SAL-1</th>
<th>BG-03</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>47.6</td>
<td>48.02</td>
<td>46.92</td>
<td>44.21</td>
<td>44.23</td>
<td>52.98</td>
<td>44.82</td>
<td>47.12</td>
</tr>
<tr>
<td>TiO2</td>
<td>0.25</td>
<td>0.22</td>
<td>0.52</td>
<td>0.33</td>
<td>0.08</td>
<td>0.14</td>
<td>0.52</td>
<td>0.26</td>
</tr>
<tr>
<td>Al2O3</td>
<td>5.35</td>
<td>4.88</td>
<td>5.7</td>
<td>4.93</td>
<td>3.04</td>
<td>3.55</td>
<td>8.21</td>
<td>9.13</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>2.20</td>
<td></td>
<td>9.9</td>
<td>4.82</td>
<td>2.03</td>
<td>2.56</td>
<td>3.42</td>
<td>2.07</td>
</tr>
<tr>
<td>FeO</td>
<td>5.80</td>
<td></td>
<td>5.39</td>
<td>8.87</td>
<td>5.86</td>
<td>5.39</td>
<td>7.91</td>
<td>6.67</td>
</tr>
<tr>
<td>MnO</td>
<td>0.15</td>
<td>0.14</td>
<td>0.15</td>
<td>0.18</td>
<td>0.09</td>
<td>0.17</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>MgO</td>
<td>31.70</td>
<td>32.35</td>
<td>30.90</td>
<td>31.31</td>
<td>34.51</td>
<td>29.70</td>
<td>26.53</td>
<td>28.39</td>
</tr>
<tr>
<td>CaO</td>
<td>6.4</td>
<td>2.97</td>
<td>3.4</td>
<td>6.62</td>
<td>4.73</td>
<td>2.22</td>
<td>8.12</td>
<td>7.06</td>
</tr>
<tr>
<td>Na2O</td>
<td>0.40</td>
<td>0.66</td>
<td>0.71</td>
<td>0.44</td>
<td>0.27</td>
<td>0.05</td>
<td>0.89</td>
<td>0.35</td>
</tr>
<tr>
<td>K2O</td>
<td>0.15</td>
<td>0.07</td>
<td>0.01</td>
<td>0.02</td>
<td>0.07</td>
<td>0.06</td>
<td>0.03</td>
<td>0.04</td>
</tr>
</tbody>
</table>


As seen from Table 1 the data of [1,2,3] are consistent. Despite this fact, the authors of [2,3] rejected the idea of re-estimating the upper mantle composition [1] and advanced the two objections. The first one is that the influence of the basaltic melt is limited by the deep xenoliths’ envelope preventing penetration to the central parts [2]. This objection is easy to decline since the xenoliths’ dissolution and disintegration in melts occurs through destruction of the thin concentric incrustations at the xenolith’s surface and their further desquamation, whereas the xenolith’s central part remains almost unmodified [8,9,10].

The second objection belongs to Brearly and Skarfe [3] who calculated the rates of peridotite and pyroxenite dissolution in basalt melt. These calculations showed that the predominant disintegration of the pyroxenite xenoliths would occur at pressure of 10 kbar, unlike the peridotite nodules due to high dissolution rate of pyroxenes compared to olivine. Changing relative content of xenoliths of various compositions is not confirmed by calculations for magmas being under pressure of 20 and

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19
30 kbar. This was the reason to reject the idea of re-
estimating the upper mantle composition [1]. However, 
the basalt magma uplift rate was taken extremely high 
(5 and 10 km/h) in these calculations, whereas 0.4 km/h 
estimate is more reliable [11]. If we take this value the 
predominant disintegration of pyroxenites compared to 
peridotites occurs at pressure of 20 kbar as well. 
Moreover, the convection of magmatic melt is not con-
considered though it strongly accelerates xenolith’s disso-
lution [12], which is also acknowledged by the authors 
[3].

Thus, papers [2,3] do not give reasons to reject the 
conclusion [1] on predominant disintegration of pyrox-
enites compared to peridotites during the xenoliths’ 
transportation by basalt magma, though it should be 
acknowledged that this process occurs only at pressures 
below 20 kbars. It is known that both petrographic ob-
servations and laboratory experiments on heating peri-
dotite xenoliths [14] give evidence on more rapid dis-
solution of pyroxenes compared to olivine. Arzi [15] 
showed that stability of partially molten rock dramati-
cally decreases when the melt portion exceeds 26 %. 
Thus, the websterite and lherzolite xenoliths containing 
more than 26 % of pyroxenes are less likely to survive 
than dunites and peridotites during their transportation 
to the surface. The upper mantle probing by basalts oc-
curs with decreasing fraction of fertile xenoliths and 
increasing fraction of restites. Most of those peridotites 
nodules, the analyses of which were used for estimating 
the upper mantle composition [16] and exhibited a good 
convergence with the pyrolite model [4], are those res-
tites. 

As follows from [5,6] the analyses of the deep xe-
noliths with olivine content of about 30-40 % give a real 
estimate of the upper mantle composition. The analyses 
of such xenoliths are presented in Table 2. They all are 
represented by websterites by classification [17], thus, 
the websterite model [1] is preferred to the pyrolite one 
for the upper mantle [4]. The latter model confirms the 
geophysical data [5,6,7] and, besides, considers those 
changes occurred during the upper mantle probing by 
the basalt magma. Basalts and komatites can be melted 
from the websterite upper mantle [18]. By composition, 
olivine websterites are similar to a silicate part of chon-
drites [1], that’s why the websterite model is in accor-
dance with cosmogonic data. Moreover, analogy be-
tween the Earth and the Moon’s upper mantles appears 
as the pyroxenite composition is predicted for the 
Moon’s mantle [19].

References:

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