THE CARBON MEASUREMENTS IN THE UPPER MANTLE MINERALS BY THE
$^{12}$C(d,n)$^{13}$N NUCLEAR REACTION: A.A.Kadik, S.N. Shilobreeva  V.I.Vernadsky Institute of
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The knowledge of carbon solubility in minerals of deep origin by participating in point defect equilibria \(^{5,6}\) could be critical to understanding the carbon contents in the mantle rocks and magmas. The carbon
measurements in the mantle olivine (Ol), orthopyroxene (OPx) and garnet (Gar) minerals by \(^{12}C(d,n)^{13}N\)
reaction show that carbon is dissolved in this crystals in content of 5-100 ppm. The average the carbon content
in the orthopyroxenes is higher than in olivines and garnets. The partial melting of carbon-bearing minerals
in the absence of free carbon and fluid phase was shown to lead to formation of 300-400 ppm C or 0.1-0.15 wt
% CO\(_2\) in melt. This carbon content is consistent with CO\(_2\) content observed in basaltic magmas.

PROBLEMS. It is expected that redox state of the mantle and the carbon solubility in minerals under mantle
conditions by participating in point defect equilibrium plays a important role in the formation of carbon species
in the mantle and the terrestrial basalts\(^{2,3,4,5}\). Over the past fifteen years most attention has been focused on
the formation of carbon species in terrestrial magmas as a result of CO\(_2\) solubility in melts. This model
proposes melting of the upper mantle in the presence of some amount of fluid phase or carbonates in depth. In
contrast to this model it is assumed that accretional degassing, melting and vaporization of the solid at impact
leads to a depletion of the original volatiles of the Earth and the presence of primary fluid phase in the mantle
is rather doubtful \(^{1,2}\). In this case the knowledge of carbon solubility in minerals (Ol, Px, Gar) by
participating in point defect equilibria\(^{5,6}\) could be critical to understanding the carbon contents in magmas. It is assumed
that the formation of the carbon species of melt in this case is fractionation of carbon between melt and
carbon-bearing crystals. Mechanism and scale of this process is poorly understood. In this study we provide:
1) the carbon measurements in the mantle olivine, orthopyroxene and garnet minerals by \(^{12}C(d,n)^{13}N\)
nuclear reaction, 2) the estimation of carbon species formation in magmas during fluid-absent melting of
the carbon-bearing mantle.

SAMPLES. The spinel and garnet Iherzolite nodules from the alkaline basalt of Mongolia are rather close in
composition to the primitive upper mantle\(^1\). The olivine, pyroxene and garnet crystals are of pure gem quality
and free from fluid or other inclusions. The main part of slightly depleted Iherzolites are moderately reduced
(around WM and WM-2). The range of oxygen fugacities (fo\(_2\)) at 900-1100 °C, 10-25 kbar corresponds to the
graphite stability in the C-O-H system\(^8\). This conclusion is confirmed by the presence of rare and extremely
fine-grained crystals in minerals. Raman spectroscopy indicates that graphite is fully crystalline with a well
defined peak at 1581 cm\(^{-1}\).

METHOD OF APPROACH. The \(^{12}C(d,p)^{13}N\) nuclear reaction has been applied to the measurement of carbon
contents in natural and synthetic silicate glasses and crystals\(^5,10,11\). The beam surface ranges from 5 to 50 μm
and the analyzed depth is up to 10 μm, depending on sample composition. However, the problem of carbon
surface contaminant determination remains during the analysis of such sample depths. In this study we use
the \(^{12}C(d,n)^{13}N\) nuclear reaction for determining the carbon content in natural crystals of the mantle origin\(^{11}\).
Detection limits and accuracy of activation analysis depend on surface effects arising during preparation
and irradiation of the sample. This method let us reach a detection limit of the order of 10~\(^{-6}\).

The crystals were mounted in Wood's alloy and ground. The prepared surfaces of the crystals were
irradiated by a 1.7 me deuteron beam for 10 minutes in a cyclotron. The current density was no more than 5
μA/cm\(^2\) to prevent radiation and thermal effects of the deuteron beam on surface layers of the samples. After
the irradiation, polishing for 20 seconds with a finely dispersed powder of chromium oxide was used to
remove the surface layer and then the crystal was melted from the metallic alloy. Etching with mineral acids
(25 ml H\(_2\)O + 25 ml H\(_2\)SO\(_4\) 25 ml HNO\(_3\) + 5 ml HF) at 50 - 90 °C for 6 - 15 minutes was used to remove the
surface layers. The thickness of the removed layer was controlled on decreasing the activity of \(^{26}Mg\).
Radionuclide \(^{26}Mg\) has sufficient activity, therefore it was used as internal monitor for the irradiation dose.
The activity of \(^{26}Mg\) was recorded by \(\gamma\)-scintillation spectrometry using a NaI(T1) detector and was used to
pinpoint the thickness of the removed layer. As the cross section of the nuclear reaction \(^{26}Mg(d,p)^{27}Mg\) is
unknown, the curve of relative output of Mg radionuclide with subsequent removal of layers was measured
during the activation of pure metallic magnesium. The layers of activated magnesium were removed by
etching with nitric acid in ethanol (4%). Thickness of the removed layer was measured by the weight method
with an accuracy of 0.01 mg/cm\(^2\). The carbon concentration in the samples was estimated from the equation\(^{11}\)
C = Cs* Ax/As* Am/Amx * Rs/Rm * Wm / K, where C - the carbon concentration in crystals and Cs - the
carbon concentration in standard sample (steel with 0.24 wt.% C); Ax and As - the activities of \(^{14}N\)

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RESULTS. The carbon measurements in the mantle minerals by $^{12}\text{C}(d,n)\text{^3N}$ nuclear reactions show that carbon is dissolved in olivines, pyroxenes and garnets at a concentration of 5 - 100 ppm (Table 1). This concentration is below or very close to carbon saturation of minerals at high pressure. The average carbon contents in the orthopyroxenes are higher than in olivines and garnets. Several measurements have shown the crystal sections where the carbon contents are higher in order than the the average contents of carbon in crystals. This may be attributed the presence of small inclusions containing carbon.

ACKNOWLEDGMENTS. This research is supported by grant number MA 8300 of International Sciences Foundation.


Table 1. The carbon contents in minerals of the lherzolite xenoliths (Mongolia).

<table>
<thead>
<tr>
<th>Mineral</th>
<th>N</th>
<th>-log fO2</th>
<th>C, ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ol</td>
<td></td>
<td>12.5</td>
<td>14±6</td>
</tr>
<tr>
<td>314-56</td>
<td>n.d</td>
<td>70±8</td>
<td></td>
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<tr>
<td>4334-11</td>
<td></td>
<td>65±25</td>
<td></td>
</tr>
<tr>
<td>8505/2</td>
<td>n.d</td>
<td>25±5</td>
<td></td>
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<tr>
<td>OpX</td>
<td>Z-2</td>
<td>13.0</td>
<td>168±80</td>
</tr>
<tr>
<td>79/1</td>
<td></td>
<td>75±15</td>
<td></td>
</tr>
<tr>
<td>Gar</td>
<td>8531/10</td>
<td>n.d</td>
<td>97±63</td>
</tr>
</tbody>
</table>