Högbomite from the Aldan Shield, Eastern Siberia, USSR

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Högbomite, a complex oxide of Al, Fe, Mg, and Ti, is an important constituent of some iron ores and emery deposits as well as an infrequent accessory in aluminous high-grade rocks (e.g. Grew et al., 1987). The recent increase in reports of new localities (e.g. Rammlmair et al., 1988) suggests that högbomite may be more widespread than is generally perceived. We report here högbomite from the Aldan Shield, Eastern Siberia. This högbomite is remarkable for the wide variation in composition measured in a single thin section. Our report is only the second from the USSR of högbomite for which chemical data are given. Reports of högbomite other than Moleva and Myasnikova’s (1952) well-documented description of högbomite from the Urals are based only on optical properties (Bobrovnik, 1955; Sinitsa, 1957; Sudovikov et al., 1962); the third citation includes mentions of högbomite in pelitic gneisses from unspecified localities in the Aldan Shield. In the present paper we present details of the paragenesis and chemistry of högbomite and several associated minerals; the reader is referred to Drugova et al. (in press) for a general account of the högbomite-bearing rock and its geological and geochemical significance.

Högbomite is found in a biotite-plagioclase-corundum-spinel schist cropping out 2 km east of the Aldan River at a point 1 km north of its tributary Ayyannaakh Creek (approximately 120 km
The nodules generally have a core of corundum and the nodule-bearing rocks are apatite, zircon, allanite, and others pale brown or green. Other minerals in the nodule have a corona of fine-grained pale biotite. The oxide nodules constitute up to 30 or 40% of the rock and are found over an area of 20 or 30 m² in outcrop. The matrix to the nodules is a medium-grained rock (mostly 0.5–3 mm) consisting of dark biotite, plagioclase, subordinate magnetite, rare clinzoisite, and minor secondary muscovite. The plagioclase (An 40–46 in the section analysed with the microprobe, Drugova et al., in press) is locally zoned. The nodules generally have a core of corundum up to 12 mm across, surrounded by a mantle of spinel, magnetite, and corundum. Adjacent to the corundum core is an inner rim of magnetite. Spinel is commonly dominant in the remainder of the mantle; magnetite, rarely in association with ilmenite, occurs as isolated grains. The spinel also contains abundant blebs of exsolved magnetite in distinct planar arrays. Towards the margin of the mantle are biotite and patches of corundum riddled with magnetite. This corundum is in places dichroic in blue. In the analysed section, the oxide nodule has a corona of fine-grained pale biotite. Discrete biotite flakes near this corona are in places pale brown or green. Other minerals in the nodule-bearing rocks areapatite, zircon, allanite, monazite, pyrrhotite, and rutile (Drugova et al., in press); of these, only zircon was found in the analysed section.

Högbomite is found in both the matrix and in the nodules; its distribution is irregular. Grains are mostly 0.05 to 0.2 mm across, locally up to 0.35 mm, and range from nearly equant to planar. In the matrix, högbomite is closely associated with magnetite and forms aggregates contiguous to irregular magnetite grains; in some cases, högbomite appears to have replaced magnetite; in others, textural relations are ambiguous. Near some högbomite, magnetite appears to have replaced by a fine-grained mineral resembling rutile (leucocene?). In the nodules, högbomite occurs mostly in and near spinel and locally with magnetite or corundum and, in places, touches biotite. Högbomite is moderate brown (nodule) to dark brown (matrix) and is dichroic.

One grain of the nodule högbomite and three grains (in two aggregates) of the matrix högbomite, together with spinel (in two spots) and associated minerals, were analysed in a single thin section within a 1 × 1.5 cm area with a Cameca ‘Camebax-micro’ electron microprobe at the Institute of Geology, Yakutsk (selected analyses listed Table 1). The nodule and matrix högbomite differ most in Ti, total Fe, and Mg. Matrix högbomites also vary in composition from grain to grain and within a grain (e.g. TiO₂, 4.6–5.6%; ZnO, 0.8–1.8%), and the nodule högbomite grain also appears to be zoned in Ti. In formulae recalculated assuming 22 cations, 30 oxygens and 2 hydroxyls (Gatehouse and Grey, 1982; Grew et al., 1987), most of the Fe in the matrix högbomite is Fe³⁺ and that in the nodule högbomite, Fe³⁺, and the two compositions can be related by the substitutions Ti + Fe²⁺ = 2 Fe³⁺ (TiFe₇₋₄, ilmenite-hematite type) and Mg = Fe (MgFe₋₄₋₁); Al contents in the formulae are nearly identical. However, these formulae were calculated assuming the 8H polytype, apparently a rare polytype (Beukes et al., 1986), and thus may not be valid for either or both of the Aldan högbomites. Indeed, the excessively high analytical totals calculated for the nodule högbomites (e.g. 102.4%, Table 1) indicate that this calculation results in an excessive estimate of Fe³⁺ content. On the other hand, the Zakrzewski (1977) formula for recasting högbomite analyses yields Fe³⁺/Total Fe ratios of 0.07 and 0.08 for the matrix högbomite and <0 and 0.05 for the nodule högbomite. These values seem too low, because the corresponding ratios in spinel are calculated to be 0.10 to 0.13. In the absence of detailed crystallographic studies of different högbomite polytypes, it is not possible to reliably recast analyses and estimate Fe³⁺/Fe²⁺ ratios, nor is it possible to determine water contents. We have calculated a value of H₂O using the Gatehouse and Grey (1982) formula in order to call attention to this potentially critical component of högbomite.

Högbomite (5 analyses) in the matrix and nodules contain 0.2–0.3% Cr₂O₃ and 0–0.2% TiO₂, Al₂O₃, MnO, MgO, and ZnO (for example, Table 1), with the exception of one spot with 3.1% Al₂O₃ in the matrix. The averaged spinel analyses in Table 1 are representative of the 4 analyses in Cr₂O₃ contents (0.08–0.12%) and X(Fe)/Ti(0.35–0.36), while ZnO in the unlisted analyses reaches 1.68%. Corundum (4 analyses) in the spinel mantle contains 0.37–0.99% Fe₅O₇ and 0.18–0.24% Cr₂O₃. The dark biotites of the matrix (4 flakes analysed; average of 2 in Table 1) are titanian (2.8–3.1% TiO₂), and relatively
Table 1. Composition of Minerals in Sample 02069, Ayyannaakh Stream, Aldan Shield, USSR

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Biotite</th>
<th>Corona</th>
<th>Nélogite</th>
<th>Nodule</th>
<th>Spinel</th>
<th>Nodule</th>
<th>Magnetite</th>
<th>Nodule</th>
<th>Corundum</th>
<th>Nodule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Analyses</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>35.82</td>
<td>37.16</td>
<td>38.48</td>
<td>0.0</td>
<td>0.05</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>TiO₂</td>
<td>3.13</td>
<td>0.38</td>
<td>0.26</td>
<td>5.30</td>
<td>5.55</td>
<td>2.93</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>17.57</td>
<td>21.52</td>
<td>19.10</td>
<td>61.20</td>
<td>60.74</td>
<td>64.67</td>
<td>65.40</td>
<td>0.23</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>0.06</td>
<td>0.07</td>
<td>0.06</td>
<td>0.25</td>
<td>0.29</td>
<td>0.17</td>
<td>0.10</td>
<td>0.18</td>
<td>0.29</td>
<td></td>
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<tr>
<td>FeO</td>
<td>13.74</td>
<td>7.22</td>
<td>7.45</td>
<td>24.56</td>
<td>25.50</td>
<td>17.10</td>
<td>17.29</td>
<td>87.88</td>
<td>87.74</td>
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</tr>
<tr>
<td>MnO</td>
<td>0.11</td>
<td>0.12</td>
<td>0.06</td>
<td>0.15</td>
<td>0.34</td>
<td>0.27</td>
<td>0.39</td>
<td>0.0</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>13.65</td>
<td>19.45</td>
<td>20.48</td>
<td>5.97</td>
<td>5.47</td>
<td>13.14</td>
<td>17.57</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>ZnO</td>
<td>1.35</td>
<td>0.83</td>
<td>0.94</td>
<td>0.63</td>
<td>0.15</td>
<td>0.02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
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<tr>
<td>CaO</td>
<td>0.0</td>
<td>0.03</td>
<td>0.02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.15</td>
<td>0.16</td>
<td>0.15</td>
<td>0.37</td>
<td>0.02</td>
<td>0.02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>K₂O</td>
<td>3.04</td>
<td>3.24</td>
<td>3.35</td>
<td>0.24</td>
<td>0.26</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.38</td>
<td>0.52</td>
<td>0.55</td>
<td>0.22</td>
<td>0.26</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Total SiO₂</td>
<td>98.36</td>
<td>100.61</td>
<td>100.27</td>
<td>100.10</td>
<td>100.01</td>
<td>100.82</td>
<td>101.41</td>
<td>88.52</td>
<td>88.24</td>
<td></td>
</tr>
</tbody>
</table>

Formulae

| O               | 22      | 22     | 22       | 31     | 31     | 31     | 31        | 31     | 31       |
| Si              | 5.398   | 5.278  | 5.478    | 0.0    | 0.0    | 0.0    | 0.0       | 0.0    | 0.0      |
| Al Eleventh     | 2.602   | 2.722  | 2.522    | 0.0    | 0.0    | 0.0    | 0.0       | 0.0    | 0.0      |
| Cr              | 0.618   | 0.880  | 0.663    | 0.0    | 0.0    | 0.0    | 0.0       | 0.0    | 0.0      |
| Ti              | 0.088   | 0.007  | 0.007    | 0.0    | 0.0    | 0.0    | 0.0       | 0.0    | 0.0      |
| Fe²⁺            | 1.706   | 0.858  | 0.885    | 0.738  | 0.988  | 0.452  | 0.317     | 0.976  | 0.998    |
| Fe³⁺            | 1.461   | 1.381  | 1.598    | 2.323  | 2.048  | 1.908  | 1.984     | 1.984  | 0.012    |
| Mn              | 0.014   | 0.014  | 0.010    | 0.044  | 0.060  | 0.044  | 0.008     | 0.000  | 0.001    |
| Mg              | 0.29    | 0.414  | 0.436    | 1.335  | 1.690  | 3.860  | 3.663     | 0.000  | 0.000    |
| Total Si        | 3.067   | 4.114  | 4.346    | 1.835  | 1.690  | 3.860  | 3.663     | 0.000  | 0.000    |

Notes.

1. All Fe as FeO, except for corundum, for which all Fe as Fe₂O₃. In formulae, Fe²⁺ and Fe³⁺ calculated from stoichiometry.
2. Calculated assuming ideal hydroxyl contents for Nélogite (2(OH) and 22 cations, Gatehouse and Grey, 1982) and for biotite.
3-8. Calculated weight %: 3- FeO=15.88, Fe₂O₃=9.31; Total=100.03, 4- FeO=17.24, Fe₂O₃=8.76, Total=100.91; 5- FeO=2.78, Fe₂O₃=15.91, Total=102.43; 6- FeO=15.00, Fe₂O₃=2.24, Total=101.64; 7-FeO = 29.36, Fe₂O₃ = 65.04, Total = 95.04; 8- FeO = 29.37, Fe₂O₃ = 64.87, Total = 94.74.
9. X(Fe)T = total Fe/(Mg + Total Fe)

Microprobe Operating Conditions: 20 kV, 40 nA.
iron rich \((X_{Fe} = 0.35-0.37)\), while the fine-grained biotites in the corona (7 analyses) are almost free of Ti (0-0.4% \(\text{TiO}_2\)), aluminous (19-23% \(\text{Al}_2\text{O}_3\)) and magnesian \((X_{Fe} = 0.15-0.17)\).

The present mineralogy and chemistry of the högbomite-bearing rocks is due to a complex metamorphic history to which Drugova et al. (in press) assigned 3 stages. The \(X_{Fe}\)'s of the matrix biotite, which is interpreted to have formed during the granulite-facies event, and spinel are approximately equal, that is \(K_D = [\text{Fe}/\text{Mg(Sp1)}]/[\text{Fe}/\text{Mg(Bt)}] = 0.91-1.00\), in marked contrast to equilibrium spinel-biotite pairs, for which \(K_D \geq 3.7\) (Lal et al., 1978; Waters and Moore, 1985). Consequently, the analysed spinel probably did not equilibrate with the matrix biotite, whose rather constant composition from grain to grain is presumed to be little changed since original crystallization in the granulite facies. The spinel–magnetite–corundum intergrowths in the mantles of the nodules could have resulted from exsolution, breakdown, and possibly oxidation of a homogeneous hercynite-rich member of the spinel group that had equilibrated with the matrix biotite. Högbomite in the nodule probably formed during this breakdown, drawing on Ti and Zn in the original homogeneous spinel. By analogy with other högbomite occurrences (e.g. Grew et al., 1987), appearance of högbomite suggests interaction of the secondary spinel, magnetite, and corundum with hydrous fluids. Alternatively Ti for högbomite could have originated from the recrystallization (and oxidation?) of a pre-existing Fe–Mg–Ti–Al ± Zn spinel phase (+ ilmenite?). In any case, given its different composition, the matrix högbomite must have formed from a different mix of oxide phases from those in the nodule, thereby implying that compositional factors, including oxygen fugacity, rather than pressure and temperature, are the main controls on högbomite chemistry.

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**References**


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