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# Högbomite of unusual composition from Reedy Creek, South Australia

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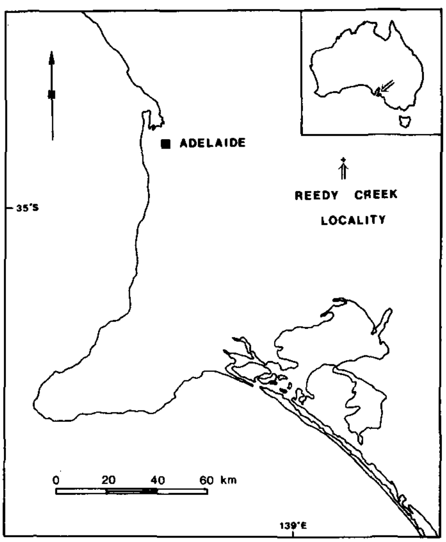
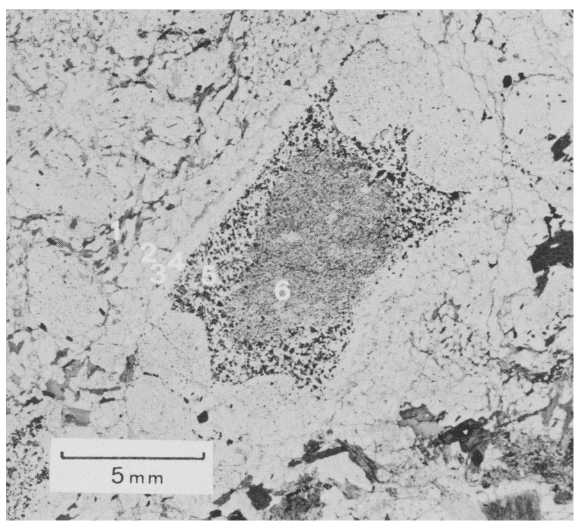
ABSTRACT. Högbomite from Reedy Creek, South Australia, is of a composition outside the previously reported range. It contains less Ti and Mg and more Al and total Fe, with a total Fe/(total Fe + Mg) value between 0.69 and 0.72. The högbomite occurs in unusual cordierite-sillimanite aggregates containing minor magnetite, ilmenite, hematite, corundum, and hercynite.

HÖGBOMITE occurs in aluminous segregations within laminated metaarkoses of the Cambrian Kanmantoo Group in Reedy Creek, 70 km east of Adelaide, South Australia (fig. 1). The location lies within the highest-grade migmatite zone of the regional metamorphism which affected the Adelaide Fold Belt (White, 1966; Mancktelow, 1979). Mineral assemblages within this zone suggest peak metamorphic conditions of approximately 3.7 kb and 640 °C (Mancktelow, 1979). Aluminous segregations from this locality were first described by Sando (1957) and later by Whitehead (1975), but högbomite was not recognized.

*Assemblage.* The unusual aluminous segregations consist of a groundmass of albite ($An_{04}$), cordierite, quartz, phlogopite, magnetite, ilmenite-hematite, minor retrogressive chlorite, and rare retrogressive andalusite and staurolite (Table I). Ilmenite and hematite occur only as composite grains showing exsolution of one component in the other. Through this matrix are scattered occasional large cordierite aggregates (fig. 2), which may once have been single crystals but now form an interlocking mosaic of small cordierite grains. These aggregates have a characteristic geometry, with a




FIGS. 1 and 2. FIG. 1 (*left*). Location diagram. FIG. 2 (*right*). Photomicrograph of a typical cordierite-rich aggregate. 1—external matrix; 2—plagioclase-rich corona; 3—vermicular intergrowth at contact between plagioclase of zone 2 and cordierite of zone 4; 4—inclusion-poor cordierite rim; 5—inclusion-rich zone; 6—core of cordierite sieved with oriented sillimanite prisms.

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central core and succeeding diffuse rings. The core consists of cordierite sieved with oriented coarse sillimanite prisms; the sillimanite is largely in optical continuity and may occupy more than 60% of this central area (figs. 2, 3). This core is surrounded by a zone rich in magnetite, ilmenite-hematite, corundum, hercynite, högbomite, and occasional phlogopite inclusions within the cordierite, which in turn is surrounded by an outer, inclusion-poor rim of cordierite. These large aggregates are surrounded by a plagioclase-rich corona, without quartz, and with very little phlogopite compared with the general matrix. Vermicular intergrowths of cordierite and plagioclase often occur at the boundary of the cordierite aggregates (fig. 4). The origin of these aggregates is still unresolved.

TABLE I. *Electron-microprobe analyses of associated minerals from the högbomite-bearing assemblage*

| | Cordierite | Phlogopite | Plagioclase | Ilmenite |
|---|---|---|---|---|
| $SiO_2$ | 47.78 | 37.35 | 65.57 | — |
| $TiO_2$ | — | 2.00 | — | 49.48 |
| $Al_2O_3$ | 34.35 | 17.27 | 21.74 | — |
| FeO | 4.04 | 11.50 | — | 49.05 |
| MgO | 11.28 | 17.18 | — | 0.36 |
| MnO | 0.08 | — | — | 0.54 |
| CaO | — | — | 0.92 | — |
| $Na_2O$ | 0.24 | 0.43 | 11.21 | — |
| $K_2O$ | — | 8.74 | 0.05 | — |
| Total | 97.77 | 94.47 | 99.49 | 99.43 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| O | 18 | O | 20 | O | 8 | O | 3 |
| Si | 4.862 | OH | 4 | Si | 2.890 | $Fe^{3+}$ | 0.041 |
| Al | 1.138 | Si | 5.493 | Al | 1.130 | Ti | 0.959 |
| Al | 2.984 | Al | 2.507 | Na | 0.958 | Mg | 0.014 |
| $Fe^{3+}$ | 0.016 | Al | 0.488 | Ca | 0.043 | $Fe^{2+}$ | 1.016 |
| Mg | 1.712 | Ti | 0.221 | K | 0.003 | Mn | 0.012 |
| $Fe^{2+}$ | 0.328 | Fe | 1.415 | | | | |
| Mn | 0.007 | Mg | 3.769 | | | | |
| Na | 0.048 | Na | 0.122 | | | | |
| | | K | 1.640 | | | | |

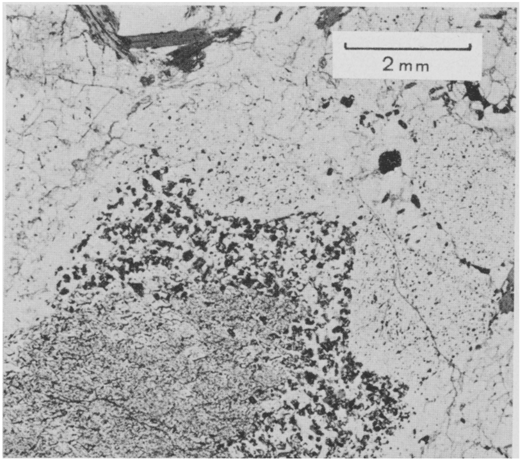
| | Magnetite | Corundum | Hercynite | Hercynite |
|---|---|---|---|---|
| $SiO_2$ | 0.15 | — | 0.13 | 0.09 |
| $Al_2O_3$ | 0.38 | 99.30 | 59.64 | 59.58 |
| $Cr_2O_3$ | — | — | 0.20 | 0.11 |
| FeO | 90.77 | 1.10 | 28.43 | 30.13 |
| MgO | — | — | 7.54 | 7.44 |
| MnO | — | — | 0.17 | 0.22 |
| ZnO | — | — | 3.49 | 1.69 |
| NiO | 0.11 | — | 0.18 | 0.14 |
| Total | 91.41 | 100.40 | 99.78 | 99.38 |

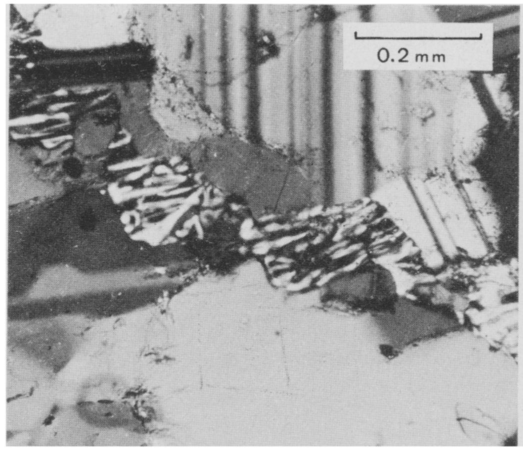
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| O | 32 | O | 3 | O | 32 | O | 32 |
| Si | 0.064 | Al | 1.990 | Si | 0.029 | Si | 0.021 |
| Al | 0.184 | $Fe^{2+}$ | 0.016 | Al | 15.640 | Al | 15.663 |
| $Fe^{3+}$ | 15.752 | | | Cr | 0.035 | Cr | 0.019 |
| $Fe^{2+}$ | 7.728 | | | $Fe^{3+}$ | 0.296 | $Fe^{3+}$ | 0.298 |
| Ni | 0.040 | | | Mg | 2.501 | Mg | 2.473 |
| | | | | $Fe^{2+}$ | 4.994 | $Fe^{2+}$ | 5.321 |
| | | | | Zn | 0.574 | Zn | 0.278 |
| | | | | Mn | 0.032 | Mn | 0.042 |
| | | | | Ni | 0.031 | Ni | 0.025 |

Each analysis is representative of 8-10 grain microprobe analyses, except for the opaques where only two grains of each phase were analysed. Compositional variation of the component minerals is slight except for Zn in hercynite. Two hercynite analyses covering the range of Zn values are given. There is no significant compositional difference between cordierite grains from the matrix and those from the larger aggregates. Corundum, hercynite, and högbomite only occur within the cordierite aggregates.

Högbomite occurs as medium- to light-brown grains, both as separate inclusions within the cordierite and intergrown with green hercynite, magnetite, and ilmenite-hematite. No clear replacement relationship is discernible between högbomite and hercynite (cf. McKie, 1963; Zakrzewski, 1977; Teale, 1980), hercynite often abutting magnetite, ilmenite-hematite, and corundum without any intervening högbomite. Högbomite commonly also occurs as isolated grains, and appears to be a stable member of this upper amphibolite-facies mineral assemblage, with no evidence of breakdown or alteration.

*Composition.* McKie (1963) considered the range of högbomite compositions to be $R^{2+}_{1.0-1.6}Ti^{4+}_{0.2-0.4}R^{3+}_{3.7-4.3}O^{2-}_{7.6-8.0}OH^{-}_{0-0.4}$. Zakrzewski (1977) demonstrated from the infra-red spectra of Liganga högbomites that they contain no $OH^-$ or $H_2O$ groups. Of all the complete analyses of högbomite which have been published (see summaries in Wilson, 1977, and McKie, 1963, and the recent analyses of Teale, 1980), only those of Nel (1949) report any structural $H_2O$, and Nel considered that this may have been due to chlorite contamination. The Reedy Creek högbomite has a composition outside this range of previously published analyses (Table II). Ti is lower (0.084–0.172), Al higher (3.920–4.039), Mg lower (0.482–0.534), and total Fe higher (1.189–1.262). The ratio of total Fe to total Fe + Mg varies between 0.69 and 0.72, higher than the range of previous analyses (0.020–0.62). Analysis by electron microprobe does not allow distinction between $Fe^{2+}$ and $Fe^{3+}$ or the determination of $H_2O$, and the small grain size (< 70 microns), and very limited quantity of Reedy Creek högbomite precludes successful separation for chemical analysis. Zakrzewski (1977) proposed a formula for högbomite analogous to that of nigerite, namely $R^{2+}_{2-2x}Ti_xR^{3+}_4O_8$, and assumed the correctness of this formula to divide the total Fe from his microprobe analyses into $Fe^{2+}$ and $Fe^{3+}$ components. The analyses for Reedy Creek högbomite would fit this formula moderately well (Table II), but because of the high values for $Al^{3+}$, the predicted $Fe^{3+}$ values seem unrealistically low




FIGS. 3 and 4. FIG. 3 (*left*). Photomicrograph of the cordierite-rich aggregate of fig. 2 at a higher magnification showing the zone rich in inclusions of opaque magnetite, ilmenite, and hematite, and translucent hercynite and högbomite. FIG. 4 (*right*). Photomicrograph of the vermicular intergrowth between cordierite and plagioclase developed at the rim of the cordierite-rich aggregates.

TABLE II. *Electron-microprobe analyses of högbomites from Reedy Creek*

| | | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | — | — | 0.09 | 0.13 | — | 0.13 | 0.14 | 0.11 | 0.08 |
| $TiO_2$ | 2.03 | 2.93 | 4.11 | 2.80 | 3.58 | 2.23 | 3.85 | 3.38 | 3.11 |
| $Al_2O_3$ | 62.38 | 61.76 | 60.04 | 61.49 | 60.01 | 62.64 | 61.24 | 62.04 | 61.45 |
| $Cr_2O_3$ | 0.10 | — | — | 0.14 | 0.09 | 0.06 | — | 0.10 | 0.06 |
| FeO (tot.) | 26.64 | 26.77 | 25.83 | 25.81 | 26.45 | 27.80 | 25.51 | 25.61 | 26.30 |
| MnO | 0.14 | 0.19 | 0.12 | 0.09 | 0.16 | 0.17 | 0.15 | 0.19 | 0.15 |
| NiO | 0.10 | 0.13 | — | — | 0.15 | — | 0.17 | 0.10 | 0.08 |
| MgO | 6.29 | 6.39 | 5.80 | 6.45 | 6.46 | 6.16 | 5.67 | 6.58 | 6.23 |
| ZnO | 0.34 | 0.89 | 0.93 | 0.76 | 0.83 | 0.34 | 0.65 | 0.44 | 0.65 |
| Total | 98.09 | 99.19 | 97.03 | 97.78 | 97.84 | 99.65 | 97.44 | 98.68 | 98.21 |
| Si | — | — | 0.005 | 0.007 | — | 0.007 | 0.008 | 0.006 | 0.004 |
| Ti | 0.084 | 0.120 | 0.172 | 0.116 | 0.149 | 0.091 | 0.160 | 0.142 | 0.129 |
| Al | 4.039 | 3.972 | 3.941 | 3.992 | 3.920 | 4.009 | 3.985 | 3.987 | 3.981 |
| Cr | 0.004 | — | — | 0.006 | 0.004 | 0.003 | — | 0.004 | 0.003 |
| $\Sigma Fe^{2+}$ | 1.224 | 1.222 | 1.203 | 1.189 | 1.226 | 1.262 | 1.178 | 1.165 | 1.209 |
| Mn | 0.006 | 0.009 | 0.006 | 0.004 | 0.008 | 0.008 | 0.007 | 0.009 | 0.007 |
| Zn | 0.014 | 0.036 | 0.038 | 0.031 | 0.034 | 0.014 | 0.026 | 0.018 | 0.026 |
| Ni | 0.005 | 0.006 | — | — | 0.006 | — | 0.007 | 0.005 | 0.004 |
| Mg | 0.515 | 0.519 | 0.482 | 0.530 | 0.534 | 0.498 | 0.466 | 0.534 | 0.510 |
| $\Sigma R$ | 5.891 | 5.884 | 5.851 | 5.878 | 5.885 | 5.897 | 5.839 | 5.861 | 5.872 |
| $\Sigma R^{3+}$ | 4.043 | 3.972 | 3.941 | 3.998 | 3.924 | 4.012 | 3.985 | 3.982 | 3.982 |
| $\Sigma R^{2+} + 2Ti^{4+}$ | 1.932 | 2.004 | 2.014 | 1.984 | 2.030 | 1.964 | 1.989 | 1.997 | 1.989 |
| $\Sigma R^{3+} + \Sigma R^{2+} + 2Ti^{4+}$ | 5.975 | 5.976 | 5.955 | 5.982 | 5.954 | 5.976 | 5.974 | 5.979 | 5.971 |
| $\Sigma Fe^{2+}/(\Sigma Fe^{2+} + Mg^{2+})$ | 0.70 | 0.70 | 0.71 | 0.69 | 0.70 | 0.72 | 0.72 | 0.69 | 0.70 |

Number of cations calculated on the basis of eight oxygens.
The final column is the mean of the eight analyses.

in comparison with previously published analyses in which $Fe^{2+}$ and $Fe^{3+}$ were determined independently (see Wilson, 1977). Until further complete analyses are available for högbomite, the applicability of the structural formula proposed by Zakrzewski (1977) remains unproven.

*Conclusion.* The microprobe analyses of högbomite from Reedy Creek extend the range of known compositions to considerably higher values of total Fe/(total Fe + Mg). The discovery of högbomite of this composition as a stable component of an upper amphibolite-facies mineral assemblage is of some significance in the context of Moore's (1971) suggestion that iron högbomite is unstable and dissociates to form corundum and ilmenite.

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