SHORT COMMUNICATIONS

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A grandidierite–sapphirine association from India

GRANDIDIERITE is a rare accessory borosilicate in thermally and regionally metamorphosed rocks, and in pegmatites and aplites (van Bergen, 1980). This communication reports the first association of grandidierite and sapphirine, and the first occurrence of grandidierite in India.

Grandidierite occurs in two sapphirine–sillimanite rocks collected by C. S. Middlemiss from the granulite-facies terrain near Paderu (18° 05′ N., 82° 40′ E., Vishakhapatnam district, Andhra Pradesh). These rocks are Royal Ontario Museum specimens E2724 and E2730, corresponding to the register numbers 16/171 and 16/191 given in Walker and Collins (1907), who described the sapphirine-bearing rocks from Paderu. The Royal Ontario Museum labels give the localities of E2724 and E2730 as Jeypore Zamindari and Vishakhapatnam district, respectively. However, Middlemiss (1903) and Walker and Collins (1907) report that Middlemiss's sapphirine-bearing samples, including E2724 and E2730, were collected from a band some 30 miles in extent and lying entirely within the Vishakhapatnam district.

The major components of E2724 and E2730 are sapphirine, sillimanite, biotite, and kornerupine; spinel, hemo-ilmenite, and corundum are minor (Higgins *et al.*, 1979; Grew, 1982). Sapphirine, in grains over 1 cm across, is nearly black in hand specimen and pleochroic blue to light brown in thin section. Sillimanite, in prisms approaching 4 mm long and 1.5 mm across, is in part colourless and in part chatoyant and light brown from abundant acicular inclusions. A few of the inclusion-rich patches are pleochroic in brown. Kornerupine is olive-green in hand specimen and very pale blue in thin section, while corundum is pale pink in hand specimen.

Grandidierite forms rare prisms or grains generally 0.1–0.15 mm across; a few are as much as 0.4 mm long. It is found enclosed in sillimanite or between sillimanite and other minerals and rarely as inclusions in grains of opaque adjacent to sillimanite. These opaque grains also enclose sillimanite that extinguishes simultaneously with sillimanite outside the opaque, suggesting that the sillimanite is continuous outside the plane of the thin section. The enclosed grandidierite may thus have had a contact with sillimanite, also outside the thin section plane. Grandidierite is in contact with hemo-ilmenite, biotite, sillimanite, spinel, and sapphirine, but not with kornerupine. The grandidierite is pleochroic in blue (with a hint of green), and the absorption scheme is $\alpha \gg \gamma > \beta$. Its birefringence is markedly higher than that of sillimanite.

Optical identification of grandidierite was confirmed by electron microprobe analyses of two grains in E2724 (Table I), and identification of the only grandidierite grain found in E2730, by an element scan with the electron microprobe, in which only Al, Si, Mg, and Fe were found in significant amounts. Ion microprobe analyses of grandidierite and kornerupine in E2724 indicate that substantial amounts of boron are present in these two minerals (Grew and Hinthorne, in prep.). Li, Be, F, Na, K, Ca, Ti, V, and elements with atomic number greater than Fe were either not detected or were found in only trace amounts in grandidierite (E2724) in scans with the electron and ion microprobes.

The composition of sapphirine and kornerupine in E2724 (Table I) are similar to the compositions of these minerals in E2730 (Grew, 1982). Sapphirine and kornerupine have relatively high Fe/Mg ratios and the sapphirine and sillimanite contain small amounts of boron (Grew and Hinthorne, in prep.). These rocks are relatively oxidized, as ilmenite contains exsolution lamellae of hematite and 1.3 wt. % Fe_2O_3 is present in the sillimanite.

Metamorphic temperatures and pressures for the belt of granulite-facies rocks passing through Paderu are estimated to have been 800–850 °C and 7–8 kbar (Grew, 1982). R. K. Herd (pers. comm. to Newton, 1978) confirmed the report by Walker and Collins (1907) of the sillimanite–orthopyroxene–quartz association in granulites from the Paderu area, and granulites containing the sapphirine–quartz association occur near Paderu (Grew, 1982). Both assemblages are indicative of low water fugacities during metamorphism (Newton *et al.*, 1974).

Grandidierite may be more widespread in high-grade regionally metamorphic rocks than is generally realized. For example, the present author found small grains (0.01 × 0.05 to 0.04 × 0.18 mm) of grandidierite (Table I) associated with sillimanite,

TABLE I. *Electron microprobe analyses of grandidierite, kornerupine, sapphirine, and cordierite (in wt. %)*

Mineral	India (E2724) Sapphirine	India (E2724) Kornerupine	India (E2724) Grandidierite	Canada (ON/WP-109-77) Grandidierite	Cordierite Average*	Cordierite Range*
SiO_2	13.55	30.10	20.65	20.88	49.86	—
Al_2O_3	58.92	42.66	51.15	51.89	34.20	—
Cr_2O_3	0.12	0.01	0.03	< 0.01	0.02	—
FeO	13.59	8.28	4.58	6.10	4.88	4.57–5.28
MnO	0.09	0.07	0.01	< 0.01	0.04	—
MgO	15.10	15.12	11.58	10.79	10.94	10.70–11.08
Total	101.38†	96.24‡	88.01‡	89.66	99.93	

All Fe as FeO.
* Four analyses of two grains of cordierite near analysed grandidierite grain.
† Small amounts of boron present (ion microprobe analysis).
‡ Large amounts of boron present (ion microprobe analysis).

cordierite, opaque oxide, K-feldspar, and biotite in a pelitic gneiss (sample no. ON/WP-109-77) collected by Lonker in the Westport Quadrangle, Ontario, Canada (locality 109, 44° 33′ N., 76° 20′ W., Lonker, 1980, and pers. comm., 1982), which is located in the Grenville Province. The atomic Fe/(Mg + Fe) ratio of the analysed grandidierite grain (0.24) is only slightly higher than the average Fe/(Mg + Fe) ratio of nearby cordierite (0.20) (Table I). Quartz, plagioclase, kornerupine, tourmaline, and garnet are also present in the gneiss, but not in direct contact with grandidierite. D. M. Carmichael (pers. comm., 1982) and Carmichael, Haase, Jaffe, and Robinson (in prep.) have found grandidierite in several localities in the nearby Gananoque area of Ontario. These are the first reports of grandidierite in North America. Metamorphic conditions in these two areas are estimated to be 675–800 °C and 4–6 kbar (Lonker, 1980).

Grandidierite is restricted to metamorphic and a few plutonic rocks crystallizing at temperatures above the breakdown of muscovite + quartz, that is 600–900 °C, and at pressures ranging from less than 0.3 kbar to over 8 kbar, as summarized by van Bergen (1980). Moreover, van Bergen (1980) suggests that in high-temperature contact aureoles and granulite-facies terrains, grandidierite takes the place of tourmaline, which is the characteristic accessory borosilicate mineral in muscovite-bearing metapelitic rocks and granitic pegmatites. Dumortierite also occurs in these muscovite-bearing rocks, but is much less common. Equilibrium associations of grandidierite with tourmaline or dumortierite are rarely reported. In most cases, tourmaline and dumortierite have either formed after grandidierite or replace grandidierite during a post-crystallization event, one that probably involved reintroduction of water (Vrána, 1979; Huijsmans *et al.*, 1982). Kornerupine is an infrequent accessory borosilicate mineral in high-grade pelitic or Mg-Al-rich metamorphic rocks or in veins and pegmatites associated with high-grade rocks; association with primary muscovite is very rare. In contrast to grandidierite, kornerupine is found only in regional terrains metamorphosed at pressures of 4 kbar or more. In addition to the assemblages described here, grandidierite–kornerupine associations are reported from Natal (de Villiers, 1940) and Zambia (Vrána, 1979), where kornerupine formed after grandidierite. In the pelitic gneiss from the Westport quadrangle, kornerupine is found in a layer free of sillimanite except for rare sillimanite inclusions in garnet (see also Lonker, 1980, Table I), while grandidierite is found sparingly with sillimanite in a contiguous layer. Tourmaline occurs in both layers. There is no textural evidence for reactions among the three borosilicates, and differences in mineralogy between the two layers may reflect differences in bulk chemical composition. In the two Indian rocks, grandidierite and sillimanite are intimately associated, a feature characteristic of several other grandidierite parageneses (van Bergen, 1980; Huijsmans *et al.*, 1982). Sillimanite may be a suitable site for grandidierite to nucleate, for the crystal structures of the two minerals are similar in the *c*-axis translation, which is parallel to edge-linked AlO_6 octahedral chains (Stephenson and Moore, 1968). During granulite-facies metamorphism in the Indian rocks, grandidierite may have formed from a B_2O_3-rich, H_2O-poor intergranular fluid (as suggested by Werding and Schreyer, 1978) that remained in the rock after crystallization of the coarse-grained sillimanite-kornerupine-biotite-sapphirine assemblage.

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Prehnite from the Ilimaussaq alkaline intrusion

THE Ilimaussaq alkaline intrusion situated approximately 30 km NE of Julianehåb, South Greenland is renowned for its unique assemblage of rare ultramafic rocks and nepheline syenites containing abundant rare earth, beryllium, and radioactive minerals. During field work in the summer of 1968 at Laksetværelv, Kangerdluarssuk, on the eastern border of the intrusion, the author collected some large spherulitic specimens of a yellow-green mineral. Recently this mineral has been analysed by infra-red spectrophotometry and X-ray powder diffraction and identified as prehnite.

Occurrence. At Laksetværelv the prehnite occurs as large spherulitic incrustations on altered lava xenoliths, associated with aegirine, albite, microcline, yellow-green natrolite (with which it was at first confused), and sparce blue fluorite. Prehnite has been found at various other localities in Greenland. Bøggild (1953) summarizes seven localities; an eighth is Mikis Fjord, East Greenland (O. V. Petersen, pers. comm.). At most of these localities prehnite occurs as spherulitic aggregates in association with zeolites in volcanic rocks. Flink (1898) mentions prehnite from Nunarssuatsiag but this proved later to be apatite (Bøggild, 1953). The occurrence of prehnite in the peralcaline rocks of the Ilimaussaq intrusion is remarkable and a description of the mineral is given below.

Physical and optical properties. The spherulitic fan-shaped hand specimens measuring up to 15 cm in size consist of exceedingly fine confocal fibrils producing gem-quality, translucent, pale green or yellow-green, sometimes white aggregates with a pearly lustre on fracture surfaces.

In thin section the prehnite appears colourless with a moderate birefringence. Euhedral to anhedral grains of aegirine, albite, and microcline are embedded in and partly altered by the later prehnite. Spherulites sectioned parallel to the fibril axis display subparallel oriented fibrils, arranged in radiating bundles. The bundles are fan-shaped and may be continuous; in the latter case bundles have nucleated in succession, forming composite spherulites with a flamboyant texture.

Close to the extinction position the bundles exhibit a peculiar herring-bone pattern oblique to the fibrils. In thicker parts of the section the pattern is very pronounced but tends to disappear in the thinner parts. Since anomalous blue interference colours are also encountered in the thicker parts of