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Surinamite in pseudomorphs after cordierite in polymetamorphic granulites from Zambia

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Abstract

The rare Be–Mg–Al silicate surinamite occurs in biotite–kyanite ± garnet pseudomorphs after—apparently beryllian—cordierite in granulites from E Zambia. The surinamite-bearing assemblage was formed by a relatively high-pressure regional metamorphism transitional between amphibolite and granulite facies. In general surinamite seems to be restricted to granulites of a polymetamorphic (Zambia, Australia) or polyphase (Suriname, Antarctica?) character. In these rocks apparently two factors essential for the formation of surinamite are fulfilled: (1) an Mg–Al-rich beryllium source, provided by NaBe cordierite (Be-rich minerals are rarely found with surinamite); (2) a relatively high-pressure metamorphism in the upper amphibolite or granulite facies.

Introduction

Surinamite is a Be–Mg–Al silicate optically similar to sapphirine, with the approximate composition $(Mg,Fe)_3Al_4BeSi_3O_{16}$ (de Roever et al., 1981). It was first found in a mesoperthite gneiss from the Bakhuis Mountains, western Suriname, associated with charnockitic granulites (de Roever et al., 1976), and later in granulite-facies rocks from central Australia (Woodford and Wilson, 1976) and Antarctica (Grew, 1981). Vavrda and Vrána (1972) had recognized a blue pleochroic mineral in E Zambia which they tentatively identified as sapphirine. After the discovery of surinamite in Suriname the second author realized the possible identity of the mineral. Reexamination of samples received from Zambia by the first author proved the mineral to be surinamite. Its occurrence will be described in some detail here because of the clear textural evidence for its origin.

Occurrence

Surinamite was found in two samples from the Chimwala area near the Malawi border, about 40 km NE from Chipata, in the Eastern Province of Zambia. A large part of the province is occupied by polymetamorphic granulite and upper amphibolite facies rocks. According to Vavrda and Vrána (1972) an early phase of folding and metamorphism led to widespread formation of granulite-facies rocks, including spinel, hypersthene, and sillimanite granulites (± garnet and cordierite). At numerous localities granulites alternate intimately with amphibolite-facies rocks and migmatitic gneiss. The cordierite present in many granulites, and some hornblende granulite-facies assemblages are assigned to a late (lower-pressure) stage of the granulite-facies metamorphism. Numerous granite bodies with a marginal charnockitic facies intruded the complex during this later stage.

A major phase of deformation and metamorphism (M_3) was superimposed on the high-grade rocks. The deformation resulted mostly in open folding and shearing. The metamorphism is characterized by (1) Breakdown of cordierite to aggregates of kyanite and biotite/phlogopite (± garnet + quartz), (2) kyanite formation from older sillimanite, and (3) kyanite–quartz formation from de-alkalized potash feldspar.

Surinamite occurs in vaguely banded or streaky cordierite granulites consisting of medium-grained (about 1 mm) quartz, perthitic potash feldspar, antiperthitic plagioclase, altered cordierite, an altered sillimanite-like mineral and magnetite. Cordierite is altered either to a brown pinitic mass or to a fine-grained (about 50 μm) assemblage of unoriented biotite, kyanite, surinamite and quartz. The amount of surinamite is small, it appears to be an accessory component. Part of the fine-grained assemblage has been replaced by coarser garnet poikiloblasts, accompanied by symplectitic biotite and rarely coarse surinamite. The garnet poikiloblasts contain inclusions of the fine-grained assemblage, such as kyanite and surinamite. The sillimanite-like crystals and a part of the potash feldspar have been replaced by kyanite and biotite.

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Surinamite characteristics

The surinamite forms thin, platy crystals 20–100 μm in diameter. They have a pleochroism *X* pale yellow, *Y* bluish and *Z* bright green-blue, and a very weak birefrigence with anomalous interference colors. Since these optical characteristics match both surinamite and sapphirine, the electron microprobe was used to ensure positive identification. Analysis with a Geoscan Mark 9 microprobe at 20 kV with pyrope as the main standard gave 32.3% SiO_2, 34.3% Al_2O_3, 10.8% FeO (total iron oxide as FeO), 0.7% MnO and 17.3% MgO, and no alkalies or CaO. Assuming about 4.5% BeO to be present (see de Roever et al., 1981), this would give

$$(Mg_{2.39}Mn_{0.06}Fe_{0.55})_3(Al_{3.74}Fe_{0.28})_{4.02}BeSi_{2.99}O_{16}$$

which closely resembles the compositions of surinamite from Suriname, Australia and Antarctica.

Conditions of formation

Surinamite forms part of an assemblage with kyanite–biotite±garnet formed at the expense of cordierite and potash feldspar. In the region affected by the metamorphic overprint (M_3) causing these replacements, various domains can be mapped, as shown in Figure 1. The boundary between domains 1 and 2 represents the kyanite-in isograd and corresponds to cordierite transformation into kyanite-bearing pseudomorphs. The typical pseudomorph assemblage biotite-kyanite±garnet in cordierite granulites is widespread over an area of more than 3000 km^2; M_3 recrystallization in mafic and acid rocks produced assemblages with green hornblende, garnet and biotite. These mineral assemblages are typical of the amphibolite facies. However, in the subarea 2A near the Malawi border, where surinamite was found, several samples carrying orthopyroxene in the biotite-kyanite pseudomorphs after cordierite were collected. This information was obtained after the article by Vavrda and Vrána (1972) was in press. Granulite-facies conditions were, at least locally, attained in domain 2A during the M_3 overprint, perhaps depending on the local activity of H_2O. It is, therefore, uncertain whether surinamite crystallized in the (upper) amphibolite facies or in the granulite facies.

Other surinamite occurrences

Only in the two Antarctic occurrences is surinamite accompanied by typical granulite-facies minerals, in assemblages such as quartz–sillimanite–surinamite–biotite–orthopyroxene–garnet and sillimanite–garnet–biotite–surinamite–taaffeite–sapphirine (Grew, 1981). These are primary metamorphic assemblages formed at 800–900° C and 7–8 kbar (Grew, 1981) or at slightly higher pressure (Sandiford and Wilson, 1983).

The origin of the surinamite, however, may be less simple than suggested because of the large difference in grain size of the minerals. At the Christmas Point occurrence (see description by Grew, 1981) grains of quartz, feldspar and oriented sillimanite are several cm across;

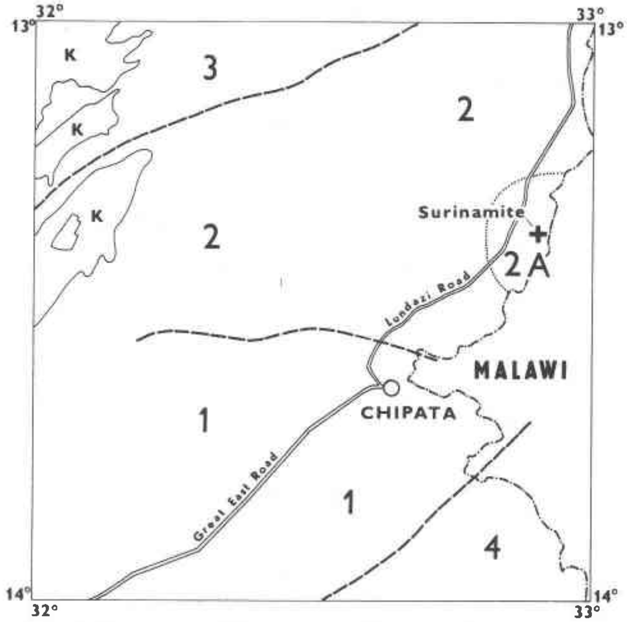

Fig. 1. Domains of M_3 metamorphism superimposed on the granulite complex of the Eastern Province, Zambia. 1—persisting granulite facies rocks essentially free of M_3 imprint, 2—domain of distinct M_3 recrystallization in amphibolite facies, 2A—domain of M_3 recrystallization in granulite facies (tentative domain boundary), 3—intense F_3 deformation and M_3 recrystallization in amphibolite facies, 4—distinct F_3(?) deformation and M_3(?) recrystallization in greenschist facies. K—Karroo and alluvium. Simplified after Vavrda and Vrána (1972). Surinamite localities lie in the vicinity of the cross.

dense mafic segregations in the form of irregular veins, masses and stringers in the pegmatoid rocks are also several cm in size. The segregations are fine- to medium-grained and contain, e.g., surinamite crystals of 50–500 μm, bundles of sillimanite prisms 50–200 μm across, and orthopyroxene grains of 70–400 μm in size. Inclusions of surinamite, biotite and sillimanite of 20–100 μm occur in garnet (observations by de R. on a sample provided by Grew). Further complications are tectonic deformation and younger or retrograde metamorphism witnessed by cordierite and biotite microveinlets cutting the older minerals, and the formation of kyanite (Grew, 1981).

The size difference of the Antarctic minerals and their mode of occurrence suggests to the present authors that the segregations are pseudomorphs after a coarse-grained primary mineral such as cordierite. This would explain the conspicuous absence of cordierite at Enderby Land, whereas another generally lower-pressure mineral, osumilite, is fairly common. Whatever the origin of the surinamite-bearing segregations, surinamite is accompanied by orthopyroxene (of comparable size) and taaffeite.

Petrographic data for the Australian occurrence are rather limited. The area where surinamite was found, underwent two distinct periods of granulite-facies metamorphism, an older, lower-pressure one (M_1) with abundant cordierite, and a younger one (M_2) with waning stages into the upper amphibolite facies. During this metamorphic period cordierite was replaced partly by sillimanite–orthopyroxene–quartz, and locally assemblages with rare minerals such as surinamite were formed (Woodford and Wilson, 1976).

The surinamite-bearing rock contains quartz, spinel, sapphirine, phlogopite, orthopyroxene, kyanite, sillimanite and cordierite. Surinamite occurs as rare grains in cordierite. Lacking more data, the presence of surinamite as grains in M_1 cordierite and the alleged production of surinamite by the M_2 overprint imply that surinamite was formed at the expense of cordierite. This took place under conditions of the granulite facies (around 850–900°C and 9–11½ kbar, Woodford and Wilson, 1976) or of the upper amphibolite facies, during which the kyanite was formed.

At the type locality in the Bakhuis Mountains in Suriname surinamite occurs in a rather coarse mylonitic mesoperthite gneiss, in streaky, deformed aggregates of fine-grained biotite, kyanite and some sillimanite (de Roever et al., 1976). Surinamite is present in most of the aggregates, in minor amount. The aggregates are interpreted as pseudomorphs after cordierite, because in the Bakhuis Mountains undeformed aggregates of fine-grained biotite, hypersthene, sillimanite and kyanite were formed by replacement of cordierite, of which relics are commonly present in the aggregates.

Surinamite at the type locality is not accompanied by any typical high-grade mineral. The gneiss contains a few relics of sillimanite of an earlier, coarser assemblage. Biotite in the aggregates is greenish brown in contrast with the orange brown biotite commonly found. Its formation may be related to the mylonitization of the gneiss.

The common occurrence of the assemblage hypersthene $\pm$ biotite + Al_2SiO_5 in the aggregates in the Bakhuis Mountains indicates cordierite replacement under higher-pressure granulite-facies conditions. Aggregates without hypersthene, such as the surinamite-bearing ones, are locally present. They probably formed under identical conditions, but the possibility of formation after the main stage of cordierite replacement, under lower-grade conditions, cannot be ruled out.

Conclusions

The surinamite occurrences known thus far have many things in common:

1. The metamorphic history of all occurrences is complex, showing at least two high-grade metamorphic phases. In Zambia, Suriname and Australia (and possibly Antarctica) surinamite was formed during a younger high-grade phase by recrystallization of cordierite.

2. The beryllium necessary for surinamite formation (4.5% BeO) is—apparently—derived for most occurrences from beryllian cordierite, i.e., the formation of surinamite is not the result of Be metasomatism. Only the "Zircon Point" occurrence in Antarctica shows Be-rich minerals, chrysoberyl and taaffeite. The origin of the BeO content of the cordierite may be entrapment and enrichment of BeO in cordierite during its formation. BeO contents of 0.9, 1.4 and 1.8% BeO in cordierite have been reported (Černý and Povondra, 1966; Povondra and Čech, 1978; and Schreyer et al., 1979).

3. The main type of surinamite formation in Zambia was by hydrous breakdown of cordierite. Cordierite breakdown on a regional scale went according to the reaction:

$$3 \text{ cordierite} + 2 \text{ potash feldspar} + H_2O \rightarrow 2 \text{ biotite} + 6 \text{ kyanite} + 9 \text{ quartz}$$

For beryllian cordierite the reaction was:

$$\text{NaBe-cordierite} + \text{potash feldspar} + H_2O \rightarrow \text{biotite} + \text{kyanite} + \text{surinamite} + \text{quartz} + \text{albite}$$

The amount of surinamite produced and the stoichiometry of the reaction depends on the Be content of the cordierite. The reaction might occur for BeO contents such as reported for beryllian cordierite, around 1–2% (see above). A cordierite of higher BeO content, around 2½%, might break down to an Al_2SiO_5–surinamite assemblage without an associated Mg,Fe mineral.

4. Antarctic surinamite, accompanied by hypersthene, was formed by metamorphism in the granulite facies. Surinamite from Surinam probably was formed under conditions of this facies, as well. Surinamite from Australia was formed under granulite- or amphibolite-facies conditions. The Zambian occurrence shows surinamite in a very fine-grained, amphibolite-facies-like assemblage formed under conditions transitional to the granulite facies.

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