

in the cathodo-luminescence chamber; strong blue luminescence is exhibited which fades over a few hours' exposure. Fluorite and halite are readily distinguished, however, because halite develops a yellow semi-permanent colouration. Feltham and Ghosh (1968) record green, blue, and mustard colours for SrF_2 , BaF_2 , and SrO respectively and Froehlich and Grau (1965) a purple colour for KCl on X-radiation treatment.

Coarsely crystalline fluorite is easy to identify petrographically without recourse to staining, but for the examination of crystals less than $30\text{ }\mu\text{m}$ in diameter intergrown with anisotropic, colourless minerals the use of an artificial colouring technique is a valuable aid to identification. However, caution is needed when using the method for this purpose, for, as already pointed out, fluorites have a variable susceptibility to developing the purple colouration.

The most immediately significant result of these experiments is the display of internal features revealed within single crystals; particularly the extremely delicate growth zonation shown in fig. 1 (*b*, *d*, *e*, and *f*). Irregularities in growth along crystal edges shown in fig. 1(*e*) and the mosaic structure shown in fig. 1(*f*) are invisible in the untreated crystals. Secondary periods of growth may also be identified. Fig. 1(*f*) shows white irregular patches of fluorite which cut across, and must post-date, growth zones. The same patches, probably caused by some form of recrystallization, do follow the mosaic structure. Fig. 1(*b*) shows a late vein fill of white fluorite which cuts all other structures. The identification of all these internal features may be

useful in the interpretation of fluid inclusion data, especially in anhedral fluorites. The positions of lines and groups of inclusions can be related to these internal features and the inclusions may then be designated as primary, pseudo-secondary, or secondary. The examination and distribution of the fluid inclusions must be made and recorded (photographically or by relation to cleavage etc.) before the samples are treated, since the specimen surface attains a high temperature in the electron beam which may cause inclusions to decrepitate.

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Grandidierite from a metamorphic aureole near Mchinji, Malawi

SINCE the first record of grandidierite (Mg,Fe) $\text{Al}_3\text{B SiO}_9$, as a metamorphic mineral by Black (1970) several more occurrences have been described, as reviewed by van Bergen (1980). The presence of grandidierite in the aureole of a small intrusion of hypersthene granodiorite in the Kachebere Hills, in the Mchinji District of Malawi, was noted by Brewer *et al.* (1979). The locality ($13^\circ 47\frac{1}{2}'\text{ S}$, $32^\circ 48'\text{ E}$) is close to the Zambian border about 10 km west of Mchinji in west-central Malawi. Outside the aureole the metasediments (assigned to the Precambrian Kachebere Formation of the Mchinji Group, which is equivalent to the Mwami Group

of Zambia) are quartzites and fine to medium-grained quartz-muscovite schists with opaque iron oxides and sporadic tourmaline. Sillimanite occurs locally, but without alkali feldspar. The fine-grained, banded hornfels of the aureole contain fine needles of sillimanite, together with quartz, potash feldspar, and opaque iron oxides, while muscovite occurs as a late-stage replacement mineral. Cordierite occurs rarely, but probable pseudomorphs after cordierite are more widespread. Close to the granodiorite there are coarser-grained bands, up to 2 mm wide, of quartz and microperthite, and plates of biotite cut across the

TABLE I. *Electron microprobe analyses of two grandierite crystals in specimen HH 202*

	I 2		Number of cations to 7.5 oxygens ($\frac{1}{4}$ unit cell)		
			I	2	
SiO ₂	20.08	20.04			
TiO ₂	0.01	0.02			
Al ₂ O ₃	50.65	49.54	Si	1.01	1.02
FeO	8.37	9.03	Al	2.99	2.96
MnO	0.31	0.37	Fe	0.35	0.38
MgO	8.55	8.18	Mn	0.01	0.02
CaO	0.01	0.00	Mg	0.64	0.62
Na ₂ O	0.00	0.00	Fe		
K ₂ O	0.01	0.00		0.35	0.38
Cr ₂ O ₃	0.01	0.00	Fe + Mg		
V ₂ O ₃	0.02	0.01			
NiO	0.00	0.00			
Total	88.02 ¹	87.19 ¹			

Analyses carried out using the techniques and standards described by Bowles (1975).

¹ B₂O₃, which normally constitutes about 11% of grandierite, was not determined.

banding. The banding might be due to partial melting, though metamorphic differentiation and, near the igneous contact, magmatic injection are other possible causes. Both tourmaline and grandierite are found in the aureole. Tourmaline occurs in rocks rich in muscovite. Some muscovite-poor assemblages contain grandierite while others contain tourmaline; in one slide the two minerals occur in adjacent areas of otherwise similar assemblages.

Specimen HH 202 (see Table I) is mostly fine- to medium-grained, containing quartz and abundant small needles of sillimanite, together with microcline microperthite, cordierite (mostly replaced, some by a sericitic aggregate and some by a yellowish to brownish isotropic substance), hematite, magnetite, ilmenite, accessory grandierite, and local cross-cutting crystals of biotite. There are coarser-grained bands of quartz and microcline microperthite with minor oligoclase, altered cordierite, and iron oxides.

The grandierite occurs as very small crystals (generally < 0.1 mm). Most grains are anhedral, but some sections show prismatic habit and some hexagonal basal sections are seen. It shows the usual pleochroism (α blue, β colourless, γ pale greenish blue). Compared with other published analyses, the two analysed grains (Table I) are rich in iron, with Fe/(Fe + Mg) higher than that of the Mt. Amiata specimen (van Bergen, 1980), and in manganese, with MnO contents as high as that of the Blanket Bay specimen (Black, 1970). In common with most grandierite analyses, Al is slightly lower than in the stoichiometric composition and in one analysis (Fe + Mn + Mg) is slightly higher.

Discussion. The widespread presence of tourmaline in the surrounding metasediments indicates that boron was present in the sediments and was not derived from the granodiorite magma. Grandierite has only been observed in assemblages above the sillimanite-K-feldspar isograd, and is not associated with tourmaline. This supports the suggestion (van Bergen, 1980) that grandierite is the natural high-temperature breakdown product of tourmaline. Tourmaline associated with muscovite in specimens bearing sillimanite and alkali feldspar may be due to retrograde reaction, but the presence of tourmaline in certain muscovite-poor sillimanite-K-feldspar assemblages suggests that the boundary between the stability field of tourmaline and that of grandierite is at a slightly higher temperature than the reaction muscovite + quartz = sillimanite + K-feldspar + H₂O at the prevailing conditions. The metamorphic conditions in the aureole cannot be accurately determined from the present data, but comparison of the mineralogy with experimental data (e.g. Kerrick, 1972) suggests pressures of around 3–6 kb and temperatures of about 600–670 °C. The presence of grandierite and tourmaline in adjacent fields of a single slide might be due to a temperature gradient but could alternatively be attributed to differences in chemical composition, e.g. Fe/(Fe + Mg).

The high quartz contents of the host rocks at Mchinji show that silica-deficiency is not an essential condition for the formation of grandierite, as suggested by Semroud *et al.* (1976). However, the lower stability limit of grandierite appears to be close to the minimum melting curve of granite, and van Bergen (1980) has pointed out that grandierite is often associated with partial melting. The removal of such a melt could, in certain rocks, lead to silica-deficiency, and this might account for the fact that several grandierite-bearing assemblages are quartz-free.

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