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## Artificial colouration of fluorite by electron bombardment

THE artificial colouration of fluorite by irradiation or electron bombardment has long been known (Blount and Sequira, 1919; Gobel, 1930; Przibram, 1954; Feltham and Ghosh, 1968; MacKenzie and Green, 1971; and Galwey et al., 1979). This colouration has had something of a curiosity interest and has been discussed in connection with the natural purple colour of Blue John, However, if a simple inexpensive method can be found to turn fluorite a distinctive colour, then this can be used as a staining technique. With this in mind, uncapped, polished thin sections mounted in epoxy resin were irradiated in a diffractometer. The specimens were positioned normal to the X-ray beam;  $Cu-K\alpha$ radiation was used with no divergence slit. After 1 hour at 40 kV and 20 mA a pale blue colouration developed. Several hours of treatment intensified the colour but, unfortunately, the whole irradiated area blackened. The diffractometer was used because of its wide availability, but the method is of limited use because insufficient intensity of colour is produced and this fades completely within a few hours.

A second method was tried involving a cathodoluminescence chamber. The sections used in the diffractometer experiment were repolished and placed in the electron beam produced from a cold aluminium cathode to which 30 kV was supplied with a beam current of 800  $\mu$ A. After 1 hour an intense, purple surface colouration developed with no blackening of the fluorite. Thin sections of colourless, blue, green, yellow, and purple transparent fluorite crystals all produced the same purple colouration after 1 hour's treatment. The intensity of colour developed on the specimens over an identical exposure time was different. The over-all colour differed, not only between specimens but also within individual crystals, some of which showed delicate colour zoning (fig. 1). One feature of the purple colour is that it is polarized. Thin sections rotated in plane polarized light show a distinctive change in colour from mauve to blue. The colour fades over a period of weeks. Detailed microscopy is best undertaken using a conventional petrological microscope, in preference to the microscope which bears the cathodo-luminescence chamber, since the latter is restricted to low-power objectives with long working distances.

The electron beam in the cathodo-luminescence chamber which produces the semi-permanent purple colour in fluorite also excites the fluorite to emit a strong blue luminescent light. This luminescent light fades over a few hours' exposure, which is either due to masking of the luminescence as the surface purple colouration develops, or because the activator(s) in the fluorite which causes the luminescence is slowly quenched by the electron beam. A comparison between the features shown by the semi-permanent purple colouration and those displayed in luminescent light reveals only one difference; the luminescent light is not strongly polarized.

The utility of this technique as a means of identifying fluorite depends on its specificity. In a recent review, Nickel (1978) records the luminescence properties of over fifty minerals, including the blue luminescence of fluorite (Mariano and Ring, 1975) but no mention of semi-permanent colouration is made. Przibram (1954) records yellow and blue semi-permanent colouration of halite when subjected to X-radiation. The author also investigated halite which behaves in a similar manner to fluorite



FIG. 1. Photomicrographs from one colourless fluorite crystal, Alston, Cumbria. (a and c), polished section before treatment. (b, d, e, and f), polished section after 1 hour under electron beam. (b and d), same areas as (a) and (c) respectively. (b) gives appearance of sectorial zoning but this is due to differing colour (mauve and blue) on the three crystal faces. (b) also shows thin fracture, left of fig., filled with white fluorite. (e), enlargement of upper centre of (b) showing edge with subcrystals between two faces. (f), apparent 'faults' caused by stepping of growth zones. There is no break in zones; continuity of zones across steps is best seen near top of fig. Surface of crystal during this stage of growth probably exhibited mosaic structure. Irregular, recrystallized patches (white) follow the steps in lower centre of fig.

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 KCI 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  $\mu$ 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. I (b, d, e, and f). Irregularities in growth along crystal edges shown in fig. I(e) and the mosaic structure shown in fig. I(f) are invisible in the untreated crystals. Secondary periods of growth may also be identified. Fig. I(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. I(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) Al<sub>3</sub>B SiO<sub>9</sub>, 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° 47<sup>1</sup>/<sub>2</sub> S, 32° 48' 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 mediumgrained quartz-muscovite schists with opaque iron oxides and sporadic tourmaline. Sillimanite occurs locally, but without alkali feldspar. The finegrained, banded hornfelses 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 coarsergrained bands, up to 2 mm wide, of quartz and microperthite, and plates of biotite cut across the