APATITE CRYSTALS WITH COLORED CORES IN VICTORIAN GRANITIC ROCKS

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ABSTRACT

Some of the small apatite crystals in granitic rocks occasionally contain colored cores showing pleochroism. Because of their minuteness and scarcity, they can only be studied by optical means. A small proportion of the colored cores show optical properties comparable with those of hornblende, biotite and chlorite. The larger number of the cores show pleochroic color changes in shades of blue and brown, but cannot be conclusively identified with any particular mineral species. They appear to represent finely dispersed, partially resorbed ferromagnesian mineral matter, and to have had a contamination mode of origin, because the majority are associated with Victorian granitic rocks that have assimilated considerable amounts of foreign material.

INTRODUCTION

Attempts to determine the nature of the material composing the colored cores in certain apatite crystals have not been wholly successful. Chemical tests have so far proved unsuccessful (3, p. 7), and optical investigations have indicated the nature of only a few of the colored cores. Thus, in the granite of Brittany, some colored cores are considered to be chloritic and others composed of biotite (4, p. 94). The color effects resembling pleochroism in these cores are regarded as due to the reflection and transmission of light by numerous small included particles, the ranges of pleochroism depending upon the size and arrangement of these particles. Similar pleochroic cores in apatite crystals from the Eskdale granite in England, are regarded, despite the different colors, as due to finely divided chloritic inclusions around which the apatite crystallized (6, p. 375).

In the Victorian occurrences a small number of the colored cores can be identified with certainty as consisting of hornblende, chlorite and biotite, but there exists a larger group (later referred to as group *a*) with cores characteristically pleochroic from blue to brown tints, whose nature cannot be conclusively determined. In view of their scarcity and minuteness, it has been found impracticable to apply chemical tests, and optical investigations with the polarization microscope were the only tests resorted to.

Colored cores similar to those found in apatite crystals have not been observed in other minerals occurring in granitic rocks, even though many thousands of crystals in heavy mineral assemblages have been examined.

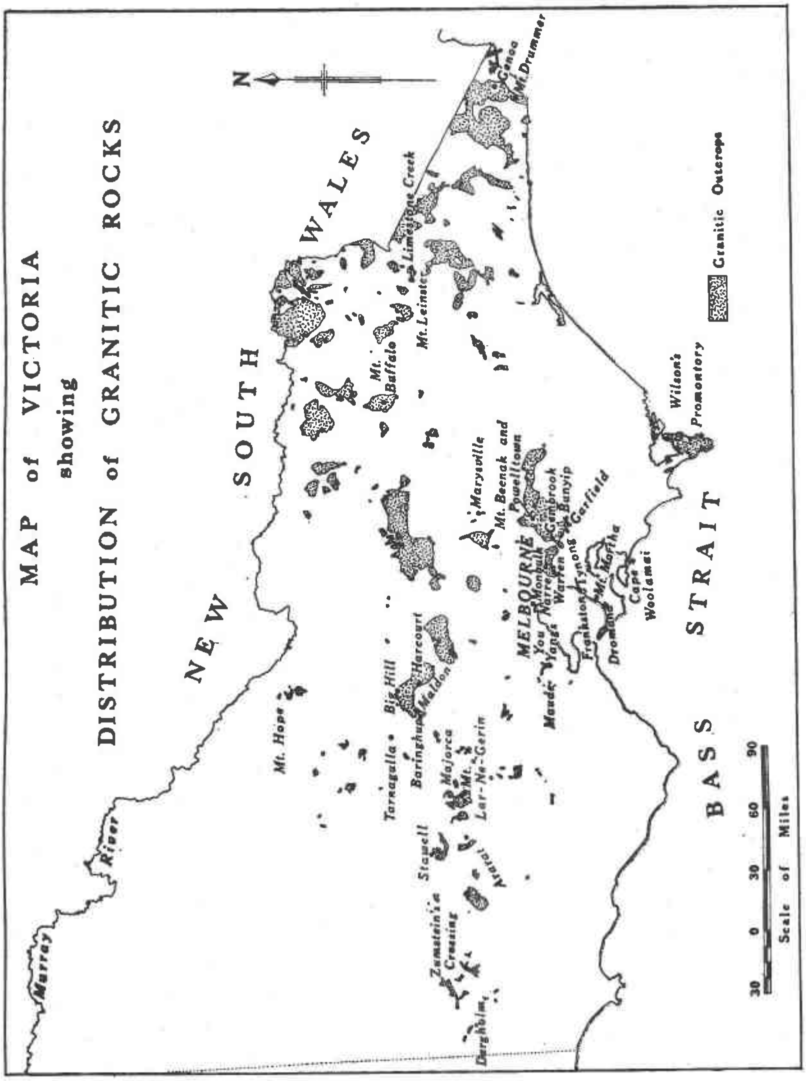

FIG. 1. Map of Victoria showing distribution of granitic rocks and localities mentioned in the text.

Occurrences

Apatite crystals with colored, pleochroic cores were first noticed by the author in heavy mineral concentrates from the Dromana granite (1), but mention had been previously made of apatite crystals with carbonaceous cores in the granodiorite from Marysville (5). Examination of these crystals in the heavy mineral assemblages from the Marysville rock, shows that the cores display a color change as in other apatite crystals with pleochroic cores, and since no pleochroic effects have been observed for carbonaceous inclusions in minerals like chiastolite and andalusite, it is concluded that the material producing the coloration of the inner portions of these apatite crystals is not carbonaceous.

The study of over one hundred heavy mineral assemblages of Victorian granitic rocks, has revealed the presence of apatite crystals with colored cores in thirty-six of the assemblages, namely:

Granites—Cape Woolamai, Dromana, Mt. Buffalo, Dergholm, Mt. Lar-Ne-Gerin, Stawell, Bunyip, Mt. Hope, Powelltown, Mt. Beenak, Wilson's Promontory, Maude, You Yangs, Tynong, Garfield, Genoa and Gembrook.

Adamellite—Marysville.

Granodiorites—Maldon, Mt. Martha, Mt. Leinster, Harcourt, Zumstein's Crossing in the Grampians, Majorca, Oliver's Hill near Frankston, Limestone Creek, Mt. Eliza south of Frankston, Big Hill near Bendigo, Ararat, Narre Warren, Baringhup, Mt. Drummer, Tarnagulla, Powelltown, Marysville and Monbulk Creek in the Dandenongs.

The distribution of these occurrences is shown on the accompanying map (Fig 1.)

The apatite crystals with colored cores are not abundantly developed in these rocks. They are more frequent in varieties containing hornblende and also occur in hornblende diorite schlieren at Dromana (1). In individual heavy mineral assemblages they are most common from Dergholm, Tarnagulla and Big Hill, where some 30 to 40 crystals occur in each slide mount consisting of approximately 2,000 grains of the heavy minerals. In several of the granitic rocks, however, generally only one or two and seldom more than half a dozen crystals with colored cores are present in any one slide mount. In all of the heavy mineral assemblages, apatite crystals with colored cores are subordinate in amount to clear, colorless or pale yellowish-green apatites. None of the minute, needle-like crystals of apatite have been observed to contain colored cores.

Nature and Properties of the Colored Cores

The length of the crystals with the colored cores varies from 0.05 mm. to 0.1 mm. in most examples. Larger ones in the granite from Mt. Lar-Ne-Gerin are up to 0.35 mm. in length. The coloring matter forming the cores may be brown, blue, purplish-blue, greenish, grayish or almost

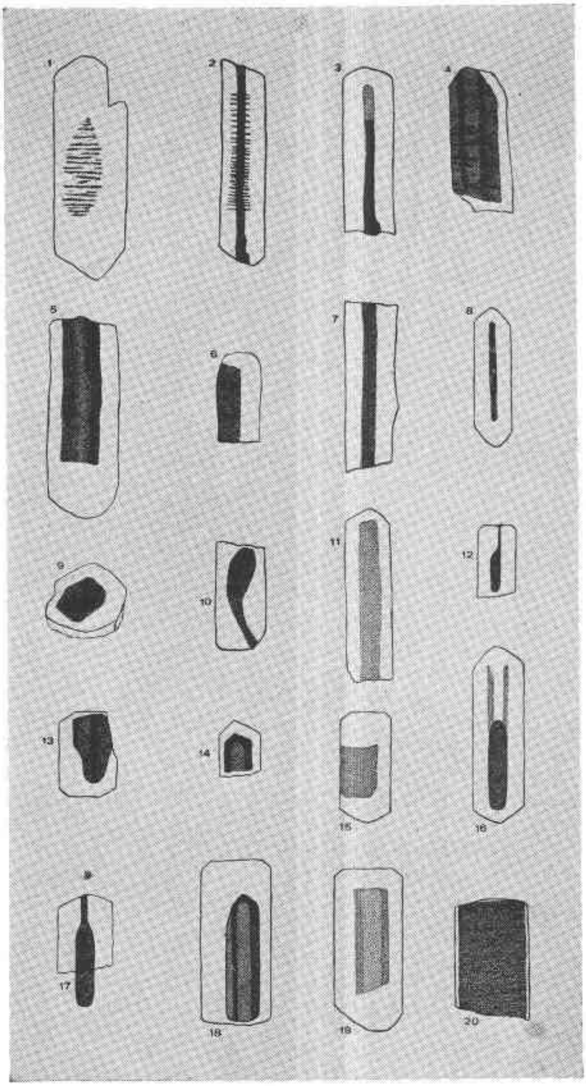

Fig. 2. The dots in the diagram do not indicate individual particles, but are shadings representing variations in density of coloration. Letters refer to the pleochroic group to which each crystal belongs, and figures (0.1 mm.), refer to the natural sizes.

Apatite crystals with colored cores from:

1. Powelltown granodiorite (*a*, 0.15 mm.).
2. Dergholm granite (*a* and *c*, 0.2 mm.).
3. Mt. Beenak granite (*c*, 0.1 mm.).
4. Zumstein's Crossing granite (*a*, 0.1 mm.).

black. At times this material is confined to the central portions of the crystals, and shows clear cut divisions from the colorless outer zones of apatite (Figs. 3, 7, 8, 11 and 19), but it may be evenly distributed throughout (Fig. 20), situated towards one side (Figs. 6 and 15) or one end, or somewhat irregular and bulbous (Figs. 10, 12 and 17). In some of the central cores a greater concentration of the coloring matter parallel to the long axis of the crystal has produced a marked banding effect, in which the darkest portions may be situated centrally (Fig. 7), laterally (Figs. 5 and 19), in a kind of zonal arrangement (Figs. 14 and 18), or in strips of alternating lighter and darker colors (Figs. 4 and 13).

Where apatite crystals with colored cores have fractured parallel to the basal pinacoid during the crushing treatment for heavy mineral separation, it is observed that some of the dark centers are more or less hexagonal in outline, and arranged parallel to the external form of the crystals (Fig. 9); similarly shaped occurrences noted from Irish granites are regarded as having been produced by the crystallization of colorless apatite around the dark central portions (8, p. 14).

In some crystals, the coloring material in the cores appears to consist of cloud-like suspensions of minute particles which vary in intensity of aggregation, and are almost sub-microscopic in size. In others, the material is so extremely fine as to be non-resolvable under the highest magnifications of the microscope, and an even coloration is then imparted to the central portions of the crystals, appearing merely as a faint stain, and only visible in some instances when the high power condenser is inserted. Sometimes the rather larger particles are arranged in a series of lines parallel to the short axis (Figs. 1, 2 and 20), and they appear to be confined to structural planes in the crystals. In one example, such lines of

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5. Tarnagulla granodiorite (*a*, 0.15 mm.).
6. Tarnagulla granodiorite (*a*, 0.1 mm.).
7. Mt. Hope granite (*a*, 0.125 mm.).
8. Stawell granite (*a*, 0.1 mm.).
9. Dergholm granite (*a*, 0.1 mm.).
10. Powelltown granite (*c*, 0.1 mm.).
11. Big Hill granodiorite (*a*, 0.2 mm.).
12. Mt. Martha granodiorite (*c*, 0.15 mm.).
13. Mt. Martha granodiorite (*a*, 0.1 mm.).
14. Big Hill granodiorite (*a*, 0.08 mm.).
15. Mt. Drummer granodiorite (*a*, 0.06 mm.).
16. Maldon granodiorite (*a* and *c*, 0.175 mm.).
17. Tynong granite (*c*, 0.06 mm.).
18. Limestone Creek granodiorite (*a*, 0.075 mm.).
19. Mt. Lar-Ne-Gerin granite (*a*, 0.1 mm.).
20. Genoa granite (*a*, 0.125 mm.).

denser aggregation traverse banded portions of the core (Fig. 4). The rounded darker parts in the central hexagonal core shown in Fig. 9 suggest that dark strips such as are indicated in Fig. 4, trending parallel to the long axis of the crystal, are cylindrical in habit.

The majority of the colored cores are pleochroic, some of them only weakly so, and a small number display no pleochroism whatsoever. The pleochroic changes are grouped thus: (*a*) from almost black, dark purple, paler purple, purplish-blue, blue, grayish-blue and gray to lighter or darker shades of brown, grayish-brown and purplish-brown; (*b*) from darker to lighter greenish-brown or from bluish-green to greenish-brown; and (*c*) from dark brown or black to lighter brown. The faint stain-like colorations in some of the cores of group (*a*) are only weakly pleochroic in contrast to examples from the hornblende diorite schlieren at Dromana (1), in which the whole of the strongly colored crystals are pleochroic from a deep azure-blue to brown. In rare examples from Maldon (Fig. 16) and Dergholm (Fig. 2), material of groups (*a*) and (*c*) are associated together in the same crystal.

The presence of the purple and blue to brown pleochoric matter of group (*a*) does not affect the birefringence of the apatite crystals. Cores of group (*b*) do, and the polarization colors which show above the low order colors of apatite, together with the value of the extinction angle, indicate that this type of included material is comparable with hornblende. Colored cores of group (*c*) are also birefringent; the polarization colors, the pleochroic colors and the positions of maximum absorption in plane polarized light, correspond to those of biotite. This determination was confirmed from a bleb of biotite which protrudes through the broken end of an apatite crystal in the Tynong granite (Fig. 17). Dark greenish colored, non-pleochroic cores are rare, one occurring at Mt. Martha (Fig. 12) and one at Baringhup. These are probably chloritic in nature, and in view of their rarity, have not been assigned to a special group.

In groups (*b*) and (*c*), the material composing the cores is lath-, bleb- or rod-like in shape, and can be correlated with definite mineral species like hornblende, biotite or chlorite. Such cores form a minority among the colored pleochoric apatites, the bulk of the cores occurring in group (*a*). Colored cores of groups (*b*) and (*c*) occur in the granitic rocks from the You Yangs, Garfield, Cape Woolamai, Powelltown (granite), Gembrook and Mt. Beenak. None of these rocks contain apatite crystals with cores of group (*a*), and in them the biotite group is of most frequent occurrence. In some rocks, apatites with cores of groups (*a*), (*c*) and sometimes (*b*) are all represented in the same heavy mineral assemblage, as at Oliver's Hill, Mt. Eliza, Monbulk Creek, Mt. Martha, Maldon, Baringhup, Marysville (granodiorite), Tynong, Dergholm, Bunyip, and Genoa. In the remaining nineteen granitic rocks from which pleochroic apatites are recorded, the colored cores belong exclusively to group (*a*).

The types of color changes in the cores of group (*a*) are comparable with those of certain varieties of tourmaline, but the positions of maximum absorption are similar to those for hornblende and biotite, agreeing with Smithson's determinations for occurrences in the Leinster (Ireland) granite, where the colors are darkest for the fast ray (9, p. 469). The fact that the directions of the color changes in this group of pleochroic cores are not comparable with those for tourmaline or for other colored pleochroic minerals of similar genesis, eliminates the possibility of the containing apatites having developed from processes of pneumatolysis.

The coloring material in the cores of group (*a*), is no doubt due to finely dispersed mineral particles. These obviously crystallized earlier than the apatite in the cooling history of the magma. It is to be expected that the first formed portions of the growing crystal of apatite would separate out slowly from the magma, as the earlier-formed mineral substance, acting as a nucleus to the crystallizing apatite, gradually became incorporated and partially resorbed. Further crystallization of the apatite in the clear rim was probably more rapid. The interior portions of the crystals would thus be unable to eliminate the impure residuum, which would remain confined to the inner portions, with a sharp line of demarcation between it and the clear outer rim. In some instances the coloring matter becomes relegated to structural planes in the internal portions of the crystals, and the density of coloration depends upon the degree to which resorption occurred. This process of formation conforms to the theory that the included particles were incorporated in later formed apatite crystals (6), rather than being products of simultaneous crystallization formed by rhythmic precipitation (4), where an inner zone of clear apatite would be expected within the colored cores as explained by Simpson (6, p. 377). No such crystals with clear inner zones have been observed in the Eskdale granites (6) or in Victorian occurrences.

The apatites with colored cores in granitic rocks differ from the dusky apatite crystals described from volcanic rocks at Kerguelen (2, p. 89) and from trachyte in the Macedon District, Victoria (7), in being more definitely colored and more pronouncedly pleochroic, less fibrous in appearance and less crowded with dark colored inclusions.

With respect to their position in the order of crystallization, only the cores of the group (*a*) type have been observed in association with the other minerals in the rocks. In thin sections of the Dromana and Marysville (granodiorite) rocks they occur as inclusions in biotite plates, and must therefore have crystallized prior to the main crop of biotite. Crystals with pleochroic cores assignable to biotite, however, indicate that small blebs and plates of biotite had formed before the appearance of the apatite, for which they acted as centers of crystallization. The apatites with colored cores also crystallized earlier than clear colorless apatites, as instanced by an occurrence from Mt. Leinster in Victoria, where a blue to brown pleochroic crystal is included in a larger colorless apatite (Fig 18).

The relationship between the blue to brown pleochroic material of group (*a*) and biotite cores of group (*c*) is provided by an occurrence from the Dergholm granite. In the same crystal, a central rod-like core of biotite is traversed by parallel lines of the blue to brown pleochroic material (Fig. 2) in such a manner as to suggest that the biotite portion of the core was the first to develop.

Conclusions

Pleochroic cores of groups (*b*) and (*c*) in apatite crystals present no difficulties of identification. The material forming cores of the group (*a*) type, cannot be identified with any particular mineral species with certainty, but the evidence available suggests that it is partially resorbed ferro-magnesian material. The degree of fineness of dispersal of residual particles is responsible for the differences in the pleochroic color effects occurring within this group.

The occurrence in the heavy residues of hornblende diorite schlieren from Dromana, of rare altered hornblende crystals containing purplish-blue to brownish pleochroic material along cleavage directions, comparable in color change with the pleochroic material in the cores of group (*a*) in apatite crystals, suggests that altered hornblende may be responsible for this type of pleochroic core in the apatite crystals of this rock. The altered hornblende would become included in the apatite crystals during the process of breaking down of the hornblende, the apatite probably being produced during a reaction involving the removal of lime from the hornblende, and the supply of P_2O_5 from the magma. The incorporated hornblende would thus become impoverished in lime, and the residual material would have a composition somewhat analogous to that of riebeckite, which shows pleochroic color changes comparable with those of the colored apatite cores of group (*a*).

The intimate association of apatite crystals having blue to brown pleochroic cores, with clots of ferro-magnesian minerals in contaminated portions of the Marysville granodiorite, may provide some indication of one of the sources of colored apatites. The clots, which consist of hornblende and biotite with associated sillimanite, are derived from incorporated sedimentary rocks (5), and although the crystals with colored cores are not observed within the xenoliths contained in this granodiorite, they have probably developed as a consequence of contamination by assimilation, as they are confined to those parts of the granodiorite in which evidence of xenolithic digestion is most pronounced. On the other hand, pleochroic apatite crystals at Maldon, are more common in biotite-rich xenoliths than in the granodiorite host rock. Crystals with similar pleochroic cores in the granite at Dromana were derived from the assimilation of hornblende diorite schlieren, and as these crystals were formed in the schlieren during the period of instability of the hornblende, when granitization was in progress, they would be xenocrystal when occurring in the granite.

Although apatite crystals with colored pleochroic cores are wanting in several Victorian granitic rocks which provide evidence of contamination by the assimilation of foreign rocks, and although a small number of examples occur in rocks showing little evidence of the effects of contamination, the general conclusion from the above investigations, is that as the majority of apatite crystals with pleochroic cores in Victoria are frequently closely associated with granitic rocks showing indisputable signs of having assimilated foreign rocks, and as most of the lesser contaminated granitic rocks are free from pleochroic apatites, such apatite crystals have a contamination mode of origin.

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