

Plotting  $a$  vs.  $c$  for a large number of apatites showed a surprising separation of genetic types. This plot is shown in fig. 2 and its use is recommended as a test to substantiate suspicions of 'interesting' apatite from thin section study. The fields for other hydrothermal systems in which apatite plays an indicator role are included for interest.

All apatites studied were examined in the UV and, without exception, all fluoresced a bright orange. The reaction is brighter in short wavelength but clearly visible at long wavelength. Further experimentation showed an increase in intensity of the excited radiation linked with increasing degree of development of the porphyry system. The reaction is faint in low-grade, immature porphyries but the colour is still distinctive.

Many apatites of other origin were examined but none showed the characteristic orange fluorescence.<sup>1</sup> Apatites from other occurrences gave varied reactions, mostly negative. At this writing, the nature of the activator in porphyry copper apatites is unknown.

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*Phelps Dodge Corporation*  
*Douglas, Arizona, U.S.A.*

SIDNEY A. WILLIAMS  
FABIEN P. CESBRON

<sup>1</sup> All apatites from tin and molybdenum porphyries examined fluoresced in a pale buttery yellow colour.

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## Petrogenesis of migmatites in the Huntly-Portsoy area, north-east Scotland—a discussion

IN a recent paper on the migmatites of the Huntly-Portsoy area, Ashworth (1976) has advocated an anatectic origin for all the migmatite types found, i.e. at relatively low grades veined 'trondhjemitoid' and 'muscovite-granitoid' migmatites, and at higher grades 'cordierite-granitoid' and 'noritoid' types. However, the results presented from the trondhjemitoid and muscovite-granitoid migmatites appear to be incompatible with the anatectic model, and to indicate an origin by metamorphic segregation via an aqueous fluid phase.

Both metamorphic segregation and anatexis fulfill the requirement that migmatization took

place in a closed system. Anatexis involves penetrative partial melting along grain boundaries within a layer of suitable composition, followed by accumulation of the melt phase into pods or veins and crystallization from the melt. Thus the amount of fluid or melt phase present varies considerably during the process, and the crystallized material in the leucosomes is of virtually the same composition as the melt phase formerly present. In contrast, metamorphic segregation may take place in the presence of a very small and constant amount of aqueous fluid phase, in response to chemical potential gradients between groundmass mineral grains and lower energy (e.g. unstrained) grains of the same minerals growing at preferred sites such as fractures. Material is continuously dissolved in the host rock, transported by diffusion or fluid circulation down chemical potential gradients, and precipitated on the recrystallized grains. The composition of the material in the leucosome reflects the host rock composition and the chemical potential differences driving segregation; it does not reflect the composition of material dissolved in the fluid phase.

An anatectic origin is most unlikely for the trondhjemitoid migmatites. These consist of leucosomes of quartz and plagioclase with minor biotite, developed in quartz-plagioclase-biotite-garnet schists, lacking both muscovite and K-feldspar. Trondhjemite magmas may be developed by fractionation of wet basalt, or by partial melting of hydrous basic rocks (Barker and Arth, 1976); however, experimental studies of melting in biotite-quartz-plagioclase-water systems (von Platen, 1965; Hoschek, 1976) have invariably produced truly granitic melts as a result of the breakdown of biotite to cordierite or amphibole+K-feldspar component of the melt. Clearly, at very high  $P_{H_2O}$  biotite *might* remain stable during melting; however, biotite breakdown in such moderately high variance assemblages has several degrees of freedom, and there should be a broad range of melting conditions over which biotite breaks down in part while the residue changes composition. At 4 kb  $P_{H_2O}$ , Hoschek (1976) found that a wide range of biotites broke down at the onset of melting, and, since the sillimanite grade aureole of the Huntly-Portsoy intrusions is superimposed on andalusite zone country rocks (Ashworth, 1975), it is unlikely that  $P_{H_2O}$  was appreciably higher than this during the migmatization. The suggestion that the trondhjemitoid migmatites were produced by anatexis is therefore contrary to all the available experimental evidence (*cf.* Misch, 1968). On the other hand there are a number of examples described in detail in the literature of quartz-plagioclase or quartz-albite veins formed by metamorphic segregation at sub-solidus temperatures (Ramberg, 1961; Vidale, 1974; Yardley, 1975).

An anatectic origin for plagioclase-bearing veins can be ruled out if the plagioclase has the same composition (*i.e.* within about 5 % An) in both vein and restite (Vernon, 1975). It has been known since the study by Bowen (1913) that, on melting, the albite component of plagioclase is strongly fractionated into the melt. This remains true of more complex plagioclase-bearing systems (Yoder *et al.*, 1957; Piwinski, 1968; Drake, 1976). During anatexis, albite should be fractionated into the melt leaving a restite enriched in anorthite: Piwinski (1968) monitored the composition of residual plagioclase after varying amounts of partial melting of granodiorite, tonalite, and granite and observed precisely this phenomenon, although it may have been somewhat inhibited in his experiments by failure to attain equilibrium (Drake, 1976). If migmatite leucosomes represent anatectic melts, their plagioclases should be appreciably more sodic (*i.e.* by 10 % Ab or more) than those in the restite. Furthermore, since crystallization does not exactly reverse melting processes, plagioclases in anatectic leucosomes might show zoning to still more sodic compositions. It would conceivably be possible for sub-solidus processes to re-equilibrate plagioclases in leucosomes and restites, but this can be ruled out for the Huntly-Portsoy rocks because sharp differences in plagioclase composition remain between palaeosomes and leucosomes.

The muscovite-granitoid migmatites have leucosomes that superficially appear to represent possible melt compositions; however, the similarity of plagioclase compositions in leucosomes and melanosomes suggests that these migmatites too were formed by metamorphic segregation.

Ashworth has advocated an origin by anatexis for the trondhjemitoid migmatites firstly because 'no dehydration reactions occurred that could produce segregable quantities of this [aqueous gas] phase'. It is, however, clear from the preceding discussion that no specially large amounts of fluid are required for segregation to take place. The occurrence of these migmatites in the upper sillimanite zone might be associated with the extensive dehydration accompanying muscovite breakdown. The very large quantities of water liberated by this reaction may lead to local fluid overpressures and hence hydraulic fracturing permitting escape of fluid; however, the fluids must pass out through all the rocks of the complex, not simply those in which they were generated. Secondly, Ashworth has pointed to the close scatter of trondhjemite leucosome compositions about the cotectic in the quartz-plagioclase system. In the absence of comparable data for hydrothermal systems it is difficult to take this as proof of anatexis, a similar scatter could result from metamorphic segregation, and indeed the muscovite-granitoid leucosomes show 'no convincing agreement with the cotectic curves' (Ashworth, 1976, p. 674).

Although the temperature of metamorphism of these rocks may have been above the water-saturated granite solidus, even small amounts of other components (*e.g.* CO<sub>2</sub>) in the metamorphic fluid may have a large effect on the temperature for initial melting; with natural fluid compositions, temperatures well in excess of 700 °C may be required for anatexis. Possibly the different, and more complex, character of the higher-grade migmatites may result from their being truly the products of melting?

*Department of Geology  
University of Manchester  
Manchester M13 9PL*

BRUCE W. D. YARDLEY

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