COMMENT

Progressive charnockitization of a leptynite-khondalite suite from Kerala, India—Evidence for formation of charnockites through decrease in fluid pressure?

(A comment on the paper by C. Srikantappa, M. Raith and B. Spiering published in the Journal of the Geological Society of India, Vol. 26, No. 12, 1985).

The description of progressive charnockite formation in the south of Kerala, recently published by Srikantappa *et al.* (1985), is very impressive and the work is an admirable extension of the preliminary statement of Kumar *et al.* (1985). The discovery of arrested charnockite formation of a different age from that of the Archaean transition zone in southern Karnataka and northern Tamil Nadu is extremely interesting. Compelling evidence is presented that the fluid inclusion systems at Ponmudi are similar in both the amphibolite and granulite facies host gneisses and the charnockite veins and patches (Klatt and Raith, 1985). This is not, however, the case at Kabbaldurga, where there is extensive documentation that CO_2-rich fluid inclusions are limited to the charnockite veins and patches, while H_2O-rich inclusions dominate the amphibolite facies rocks (Hansen *et al.*, 1984a, b). Further, it is evident that, since there was no partial melting taking place, the structural and metamorphic setting of the Ponmudi charnockites are quite different from the Kabbaldurga occurrence, where partial melting is an important process (Friend, 1981, 1983). Here, active shear zones have in several instances controlled the development of charnockite (Friend, 1985).

Since the Ponmudi area is in a distinctly different tectonic unit of southern India, these differences could be readily accepted and, quite reasonably, could lead to the formulation of a new hypothesis for charnockite formation. A startling similarity are the PT conditions under which the two different events occurred. Srikantappa *et al.* (1985) suggest c. 750°C and 6 ± 1 kbar, which is in the middle of the range of suggested conditions for the southern Karnataka transition, though Kabbaldurga appears to be slightly lower at 5.5 kbar (Hansen *et al.*, 1984a). However, overlap through experimental error cannot be ruled out owing to the assemblages at Kabbaldurga only poorly constraining the conditions (Janardhan *et al.*, 1982).

There are several points raised by the authors in two particular paragraphs which need clarification. A main argument I have with the contribution is the discussion of the position of the Closepet granite in relation to the charnockite event.

1) Srikantappa *et al.* (1985) state on p. 868 :

'It has been proposed that . . . H_2O-rich fluids were flushed out . . . causing *in situ* granitization . . . by potassium metasomatism, and formation of granite magmas by partial anatexis.'

A body the size of the Closepet granite is unlikely to have originated by potassium metasomatism. Some workers have suggested that this happened (e. g. Divakara Rao *et al.*, 1969) but on the basis of the data they presented this is considered to be dubious (Friend, 1984). In the southern portion of the Closepet granite, partial melting of the country gneisses can be demonstrated to have been the major

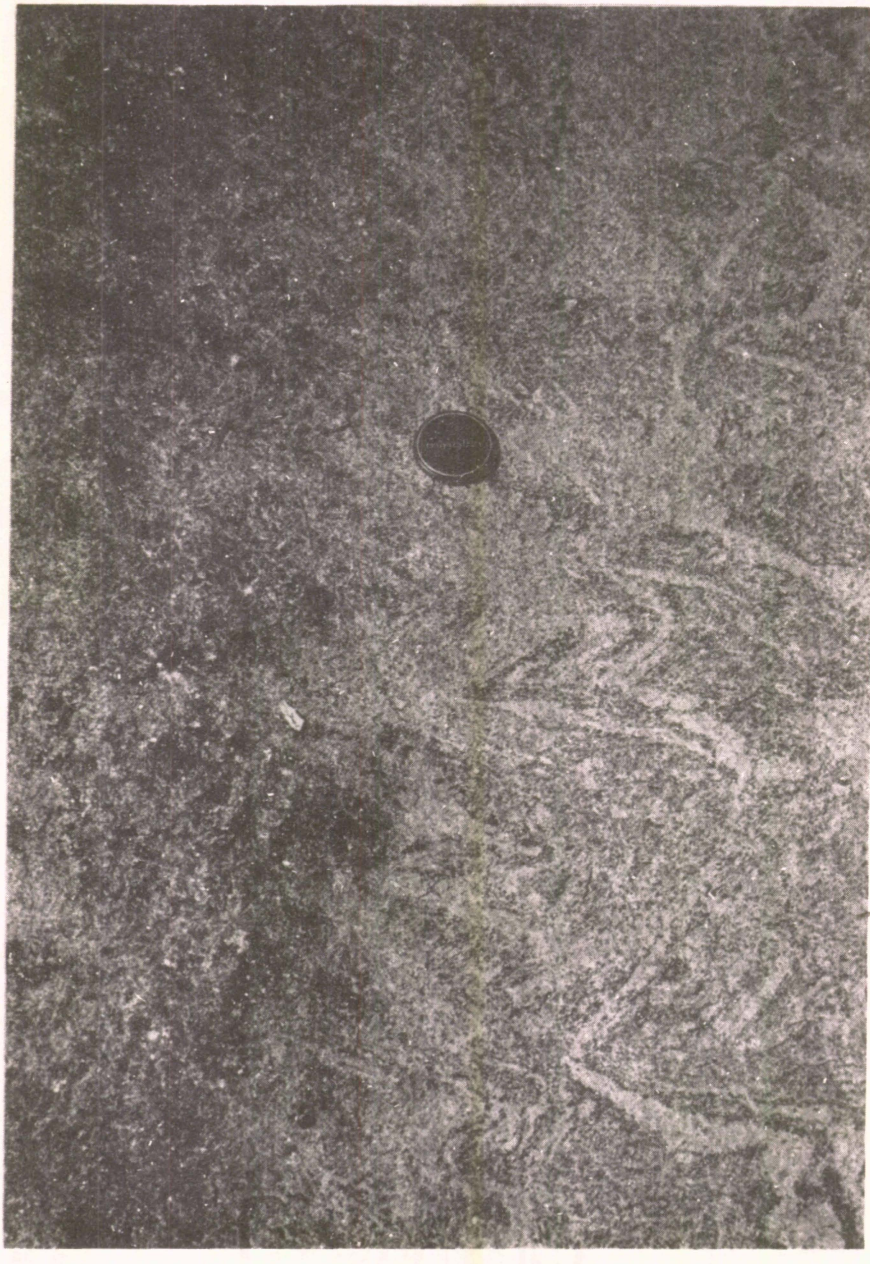

Figure 1. Charnockite (left) overprinting diffuse grey gneiss (right) penetrated by thin pink veins of granite. In some instances (lower right) biotite-rich selvedges occur along the granite contact suggesting the onset of partial melting. Kabbal Durga Quarry.

Figure 2. Large sheet of granite (left) cutting grey gneiss (upper right). Along the contact of the granite sheet there is a zone of incipient charnockite in which veins-rich in orthopyroxene and biotite occur. Again, clear evidence of the overprint of granite by charnockite is shown.

granite-forming process. Fluids associated with that process and crystallisation are likely to have mobilized some potash. In the granite, this leads to redistribution of the potash and the growth of megacrysts. Some metasomatic growth of K-feldspar megacrysts has taken place in rafts of gneiss engulfed in the granite, e.g., to the west of Ramanagaram. Additionally, there are small areas of K-rich rocks which could only have arisen by extensive metasomatism (for example near Timmasandra, where rocks containing 9.54% K_2O outcrop (K. A. Oak, pers. comm.), but such occurrences are very limited.

2) Their statement is then followed by:

'The genetic relations . . . were inferred from the coincidence of these two processes at Kabbaldurga . . .'

The inference that the processes of granite production and charnockite formation were taking place at the same time was made NOT from the coincidence of the two processes but that the granite cross-cut the charnockite and that, at the same time, charnockite was clearly overprinting the granite (Friend, 1981, 1983). At Kabbaldurga it is certainly not the case that there is small-scale granitisation prior to charnockite formation (Srikantappa *et al.*, 1985 p. 869) since there are many examples of granite overprinted by charnockite and these were explained by Friend (1983, Figs 3, 6 and 8). For further clarification two illustrations are included (Figs. 1 and 2).

3) Srikantappa *et al.* (1985) p. 869 further conclude that:

'. . a close inspection of the field relations at Kabbaldurga indicates that the Closepet-type granites intruded only after the charnockitization of the gneisses.'

Given reference to Figs. 1 and 2 which show charnockite overprinting granite, and previous data (Friend, 1981, 1983, 1985; Hansen *et al.*, 1984a, b; Janardhan *et al.*, 1982), this statement is considered to be incorrect. A considerable body of data has been obtained from the Kabbaldurga area concerning the timing of the events, particularly the melting of the Peninsula gneiss and formation of charnockite. These relationships have also been successfully used to explain similar occurrences to the east in Tamil Nadu (Condie *et al.*, 1982). The writers do dot present any detailed evidence to support their contention.

The gneiss complex at Kabbaldurga comprises an intimate mixture of unmodified grey gneisses, metatexites, both inhomogeneous and homogeneous diatexites and granite. The relationships were first mapped by Suryanarayana (1960), although not, of course, described in the nomenclature of Mehnert (1971). It is the case that throughout the area of Kabbaldurga to Kanakapura (some 15 km to the east) and towards Channapatna (some 20 km to the north) the gneisses were undergoing partial melting to produce granite and that all stages from migmatite production to the accumulation of melt into individual sheets may be observed. In Kabbaldurga quarry, many of these stages are preserved. It is across these textures and structures that the charnockite veins and patches have developed (Figs. 1 and 2). At the same time, occasional sheets of granite, having been produced elsewhere in the melting zone, may be found that cut the charnockite.

Previously, charnockite was found to occur as far north as Yelachipaliyam (Janardhan *et al.*, 1982), though no outcrops were known in between. Now, several other localities where arrested charnockite formation occurs have been discovered between Yelachipaliyam and Kabbaldurga (K. A. Oak, unpub. data). At all of these occurrences charnockite has developed over Closepet granite and the stages of partial melting. It is therefore considered that: a) the charnockite event can be conclusively demonstrated to have occurred syn- and post-granite production i.e. it is penecontemporaneous; b) partial melting and the formation of charnockite were related and were controlled by a change in the fluid phase composition.

The mechanisms whereby charnockite formed at Ponmudi, as described by Srikantappa *et al.* (1985) and Kabbaldurga (Janardhan *et al.*, 1982) would thus appear to be different. Because graphite does not occur at Kabbaldurga the reaction buffering the influx of CO_2 was different to that suggested for Ponmudi. R. C. Newton (pers. comm.) considers that at Kabbaldurga O_2 is controlled by:

3 ferrosilite + O_2 = magnetite + 3 quartz. Indeed, the section on buffering of the Ponmudi rocks presented by Srikantappa *et al.* (1985) is not clear since they themselves state that the leptynites, for example, have not been strictly O_2-buffered. If this is the case, how are they certain of the fluid conditions in the other rock types?

As the influx of CO_2 may be either oxidizing or reducing, it is insufficient to state that CO_2 influx would increase O_2 without documenting the relevant conditions and reactions. More precise fluid conditions have to be investigated.

To investigate crack propagation at these levels of the crust is itself an interesting point. Considering the data of Hansen *et al.* (1984a, Fig. 5) and the required PT conditions for the metamorphism and melting, c. 750°C at 6 kbar, it would appear difficult to produce the required effect on the fluids. From evidence in the Kabbaldurga area, it is clear that the rocks were in at least a semi-ductile state, with magma being produced and emplaced relatively locally. It would seem unlikely that the rocks would have been in a brittle state. It is not easy to judge from the data presented by Srikantappa *et al.* (1985) what deformation could be expected if a 5 km crack were to have opened. Isothermally, changing P_{fluid} by decompressing the fluid system in the rocks would, as explained by the writers, be capable or producing the required effect. However, accomplishing it by opening up a 5 km crack at these crustal levels would seem to be rather difficult. A reduction of 1 kbar at 750°C from c. 6 to 5 kbar is within the bracket between the two curves for ideal and non-ideal mixing of H_2O-CO_2. To produce the required dehydration, a greater decrease would be needed, evidence for which is not seen in the data given by Srikantappa *et al.* (1985). Indeed, in their conclusions, they suggest that they cannot decode which of the two models (infiltrational or non-infiltrational) operated.

Department of Geology and Physical Sciences
Oxford Polytechnique, Oxford OX3 OBP

C. R. L. FRIEND

References

CONDIE, K. C., ALLEN, P. and NARAYANA, B. L., (1982) Geochemistry of the Archaean low- to high-grade transition zone, southern India. Contrib. Mineral. Petrol., v. 81, pp. 157-167.

DIVAKARA RAO, V., QUERESHY, M. N. and ASWATHANARAYANA, U., (1969) Major element geochemistry of parts of the Closepet granite pluton, Mysore State, India. Bull. Nat. Geophys. Res. Inst., v. 7, pp. 145-157.

FRIEND, C. R. L., (1981) Charnockite and granite formation and influx of CO_2 at Kabbaldurga Nature v. 294, pp. 550-551.

——— (1983) The link between charnockite formation and granite production: evidence from Kabbaldurga, Karnataka, southern India. *In:* M. P. Atherton and C. D. Gribble (Eds), Migmatites, Melting and Metamorphism, Shiva, Nantwich, pp. 264-276.

Friend, C. R. L., (1984) The origins of the Closepet granites and the implications for the crustal evolution of southern Karnataka. Jour. Geol. Soc. India. v. 25, 73-84.

—— (1985) Evidence for fluid pathways through Archaean crust and the generation of the Closepet granite, Karnataka, South India. Precamb. Res., v. 27, 239-250.

Hansen, E. C., Newton, R. C. and Janardhan, A. S., (1984a) Fluid inclusions in rocks from the amphibolite-facies to charnockite progression in southern Karnataka, India: direct evidence concerning the fluids of granulite facies metamorphism. Jour. Metamorphic Geol., v. 2, pp. 249-264.

—— (1984b) Pressures, temperatures and metamorphic fluids across an unbroken amphibolite-facies to granulite-facies transition in southern Karnataka. *In:* A. Kroner, A. M. Goodwin and G. N. Hansen (Eds.), Archaean Geochemistry, Springer-Verlag, Berlin, pp. 359-373.

Janardhan, A. S., Newton, R. C. and Hansen, E. C., (1982) The transformation of amphibolite facies gneiss to charnockite in southern Karnataka and northern Tamil Nadu. Contrib. Mineral. Petrol., v. 79, pp. 130-149.

Klatt, E. and Raith, M., (1985) Microthermometrical investigation of the prograde charnockitization of garnet-biotite metatexites from Kerala, southern India. European current research on fluid inclusions. Symposium, University of Gottingen, Abstracts, v. 8, pp. 82-83.

Kumar, G. R. R., Srikantappa, C. and Hansen, E., (1985) Charnockite formation at Ponmudi in southern India. Nature, v. 313, 207-209.

Mehnert, K. R., (1971) Migmatites and the Origin of Granitic Rocks. Elsevier, Amsterdam, 2nd. edn., 405 pp.

Srikantappa, C, Raith, M. and Spiering, B., (1985) Progressive charnockitization of a leptynite-khondalite suite from Kerala, India – Evidence for formation of charnockites through decrease in fluid pressure? Jour. Geol. Soc. India, v. 26, pp. 849-872.

Suryanarayana, K. V., (1986) The Closepet Granite and associated rocks. Indian Mineral., v. 1, pp. 86-100.

REPLY

The comments made by C. R. L. Friend on our paper entitled 'Progressive charnockitization of a leptynite-khondalite suite from Kerala, India—Evidence for formation of charnockites through decrease in fluid pressure?' are mainly confined to the relationship between formation and emplacement of Closepet-type granites and the process of charnockitization at Kabbaldurga. In fact, since Weaver (1980) suggested that K-rich rocks in the Madras granulite terrane were formed by fluid metasomatism and partial fusion prior to their inversion to charnockite by the advance of a CO_2 front, this idea has strongly influenced most of the recent models of 'Kabbaldurga-type arrested charnockitization'. Janardhan *et al.* (1982), Holt and Wightman (1983), Condie *et al.* (1982), Friend (1983) argue that K-metasomatism of Archaean gneisses and anatectic development of granite in southern Karnataka were caused by a wave of aqueous fluids pushed upwards by an ascending front of 'charnockitizing' carbonic fluids of deep-seated origin. This point has been briefly discussed in our paper to emphasize that the imperative connection between potash metasomatism, granite formation and 'Kabbaldurga-type' charnockitization as propagated by these workers did not exist in the case of southern Kerala and is also questionable in the case of Kabbaldurga as evidenced by recent investigations (Hansen *et al.*, 1987; Stahle *et al.*, 1987; Raith *et al.*, 1987). In this context, some of the comments raised by C. R. L. Friend are examined.

1) Nowhere in our paper did we imply formation of granites in the Closepet plutonic belt by potassium metasomatism. We fully agree with the concept that these granites were generated by partial melting of tonalitic to granodioritic gneisses during upper amphibolite facies metamorphism 2.5 b.y. ago. As indicated by