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129

## NATURE AND ORIGIN OF FLUIDS IN GRANULITE FACIES

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Orthopyroxene, the definitive mineral of the granulite facies, may originate in prograde dehydration reactions in rock systems open to fluids or may be a premetamorphic relic of igneous intrusions or their contact aureoles which persisted through fluid-deficient metamorphism. Terrains showing evidence of open-system orthopyroxene-forming reactions are those of South India and southern Norway. An example of fluid-deficient granulite facies metamorphism is the Adirondack Highlands of New York, where metamorphic pyroxene commonly resulted from dry recrystallization of pyroxenes of plutonic charnockites and anorthosites. The metamorphism recorded by the presence of orthopyroxene in different terrains may thus have been conservative or may have involved fluids of different origins pervasive on various length-scales.

Metamorphism with pervasive metasomatism is signaled by monotonous  $H_2O$ ,  $CO_2$  and  $O_2$  fugacities over large areas, nearly independent of lithology, by scarcity of relict textures, and by pronounced depletion of Rb and other large ion lithophile (LILE) elements in the highest grade areas, such as the southernmost part of the Bamble, South Norway, terrain (1). Primary hornblende is rare or absent in quartzofeldspathic gneisses and orthopyroxene is ubiquitous in acid and basic rocks in the charnockitic terrains. Pronounced major and minor element redistributions took place during metasomatic charnockitization of amphibole gneiss at Kabbaldurga, Karnataka (2).

Conservative metamorphism of originally dry rocks in the Adirondacks is evidenced by incipient grain-boundary garnet-forming reaction zones between plagioclase and interstitial pyroxene in anorthosites, implying lack of a pervasive flux, by elevated  $^{18}O$  of paragneisses, reflecting preservation of low-temperature processes in the protoliths, by strong lateral gradients in  $^{18}O$  (3) and in apparent volatile fugacities, especially  $f(O_2)$ , implying lack of a large oxygen source in the form of pervasive  $H_2O$  or  $CO_2$ , and by common preservation of upper-crustal, premetamorphic textures, such as chilled margins of dikes, rapakivi texture, and thermal aureoles around intrusions. Lack of LILE depletion in high-grade granulites indicates fluid-deficient metamorphism.

The origin of fluids is a key issue in high-grade metamorphism. Such fluids must have been low in  $H_2O$  to coexist with orthopyroxene. Dense  $CO_2$ -rich fluid inclusions in Bamble (4) and the Nilgiri Hills (5) suggest that fluids were dominantly carbonic in metamorphism of the charnockitic terrains. Such fluids could have resulted from: A) alteration of resident pore fluids by absorption of  $H_2O$  into anatectic melts (6); B) exsolution from crystallization of deep-crustal mafic (4) or intermediate (7) magma bodies; C) decarbonation of crustal limestones and dolomites (8); D) an outgassing mantle hot spot (9); E) reaction of hydrous minerals and graphite in uplift and decompression of granulite-facies (10); or F) release of  $CO_2$  from deep crustal fluid inclusions by deformation during a metamorphic episode (2). Occurrence of orthopyroxene in migmatitic leucosomes in Namaqualand, South Africa (11) is evidence for A); charnockitic margins on acid dikes in the Wind River Range of Wyoming (12) is evidence for B); massive charnockite grading upward to patchy charnockite in hornblende gneiss overlying a massive marble bed in Sri Lanka is evidence for C) (13); the large length-scales and high paleotemperatures nearly

## ORIGIN OF GRANULITE FLUIDS

Newton, R.C.

independent of paleopressures in the South India terrain suggest a subcrustal origin of heat-transporting fluids in accord with D) (9); apparent fracture control of charnockitic alteration of paragneisses in Kerala suggest E) (10); and late Archaean charnockitic veins around the margins of possibly older granulites in southern Karnataka suggest F) (2).

It is likely that different kinds of fluids of different origins and in varying amounts were instrumental in different granulite terrains. Resolution of the nature and extent of the operation of fluids in granulite metamorphism will be provided by detailed studies of oxygen isotopes, oxidation states of iron oxides and silicates, apparent paleofugacities of H<sub>2</sub>O and CO<sub>2</sub> indicated by mineral assemblages, and by open-system versus closed-system behavior indicated by metamorphic patterns of major and trace elements.

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