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RESEARCH PAPER

Charnockite microstructures: From magmatic to metamorphic

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Abstract Charnockites sensu lato (charnockite-enderbite series) are lower crustal felsic rocks typically characterised by the presence of anhydrous minerals including orthopyroxene and garnet. They either represent dry (H_2O-poor) felsic magmas that are emplaced in the lower crust or granitic intrusions that have been dehydrated during a subsequent granulite facies metamorphic event. In the first case, post-magmatic high-temperature recrystallisation may result in widespread metamorphic granulite microstructures, superimposed or replacing the magmatic microstructures. Despite recrystallisation, magmatic remnants may still be found, notably in the form of melt-related microstructures such as melt inclusions. For both magmatic charnockites and dehydrated granites, subsequent fluid-mineral interaction at inter-grain boundaries during retrogradation are documented by microstructures including K-feldspar micro-veins and myrmekites. They indicate that a large quantity of low-H_2O activity salt-rich brines, were present (together with CO_2 under immiscible conditions) in the lower crust.

1. Introduction

At the end of the 19th century, Sir Thomas Holland, the head of the Geological Survey of India, suggested the name of "charnockite" for a massive, equigranular dark-greenish rock forming the Saint-Thomas Mount, a small hill located at Pallavaram, a suburb of Chennai (formerly Madras) in the Tamil Nadu State. Most authors refer to the paper published in 1900, but according to an article published in The Hindu (national newspaper in India) on 27 May 2002, the name was already given earlier in an address entitled "The petrology of Job Charnock's tombstone", which was delivered to the Asiatic Society of Bengal in 1893: "As this is a new type of rock… I would suggest for it the name of Charnockite, in honour of the founder of Calcutta, who was the

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unconscious means of bringing, perhaps, the first specimen of this interesting rock to our capital."

Holland's definition of charnockites was refined in a subsequent paper published eight years later (Holland, 1908), in which it was given as "a quartz-feldspar-hypersthene-iron minerals-bearing rock", of a blue-grey to greenish colour (later referred to in the French literature as "couleur malgachitique", e.g. Lacroix, 1922). Holland was convinced that the charnockites in southern India were magmatic in origin. Further, he also recognised that at the type locality charnockite occurred together with a series of other contemporaneous rock types, ranging from acid (charnockites) to basic (norites or ultrabasic pyroxenites). The fact that the charnockites in southern India have later been reinterpreted to be metamorphic rocks (Cooray, 1969) has resulted in a more general redefinition of charnockites by Pichamuthu (1969) as being a quartzo-feldspathic rock with orthopyroxene. Since then, charnockites have been described in the literature, amongst others, as orthopyroxene-bearing lower crustal rocks that occur mostly in granulite facies terrains as igneous plutons, gneisses, charnockitised amphibolitic gneisses (i.e., incipient charnockites), pegmatites, and migmatites (Newton, 1992). Considering the variety of these descriptions, it is no surprise that there is some confusion about charnockites (e.g., Newton, 1992; Frost and Frost, 2008). In context with the occurrences mentioned by Newton (1992), charnockites can essentially be considered to be either igneous (crystallisation product of an anhydrous melt) or metamorphic (granite dehydration during granulite facies metamorphism) in origin.

The topic of this paper is to review and introduce some new aspects of the study of microstructures in igneous and metamorphic charnockites. Fortunately, substantial advances have recently been made in this too often disregarded field (e.g., Vernon, 2004; Holness et al., 2011). This study may serve as a guide to petrographically distinguish igneous from metamorphic charnockites and establish a mineral chronology, which is indispensable for geochronological studies and in particular fluid inclusion studies. Fluid inclusions are sometimes extraordinarily abundant in charnockites and of critical importance for understanding the formation of these rocks.

For the purpose of this paper, we would like to comment on the charnockite definition introduced by Frost and Frost (2008). Frost and Frost (2008) define charnockites as (p. 41): "…an orthopyroxene (or fayalite)-bearing granitic rock that is clearly of igneous origin or that is present as an orthogneiss within a granulite terrane." Our first remark on this definition is that we would prefer to add garnet to orthopyroxene/fayalite, as garnet and orthopyroxene charnockite varieties are so narrowly connected in many regional occurrences (e.g., Ansignan charnockites, Agly Massif, French Pyrenees, Fig. 1). Note that, in general, garnet-bearing charnockites do not show the "malgachitic" colour, which only occurs in orthopyroxene-bearing garnet-absent varieties. Further, the second part of the definition by Frost and Frost (2008) indicates that gneissic charnockites (referred to as "orthogneiss", a name that we would like to change to "charnockitic augen gneisses") only occur in granulite terranes. This is not entirely true; for example, in southern Norway (i.e., the Bamble Province, e.g. Touret and Nijland, 2012), elongated bodies of charnockitic augen gneisses (i.e., Hovdefjell and Ubergsmoen augen gneisses) occur outside of the granulite domain, north of the regional amphibolite/granulite boundary. Conversely, many igneous charnockites that occur within granulite terrains have been subjected to a metamorphic granulite facies overprint, which can obliterate the original igneous structures. Finally, we would regret the elimination all other terms of the "charnockites" series (i.e., QAP classification as proposed by LeMaitre in 1989) as suggested by Frost and Frost (2008). Charnockite series are the lower crustal equivalents from the granite series in granulite facies terrains and the fact that these rocks are consistently ignored by the granite specialists (charnockite is not even mentioned in recent books on granites, e.g. Bouchez and Nédelec, 2011) does not circumvent the fact that they should be studied in parallel. We agree that terms including opdalite and jotunite are not frequently used and could easily be excluded, but a rock like mangerite is extremely important in the well known anorthosites-mangerites-charnockite-granite (AMCG) complexes (Emslie et al., 1994) and the "charno-enderbite" labelled as a "terminological monstrosity" by Frost and Frost (2008) is in our opinion as useful as and not much more complicated than "granodiorite".

1.1. Metamorphic vs. igneous charnockites

Initially, the idea that orthopyroxene could not crystallise directly from a granitic magma (Howie, 1955) was used as evidence that charnockites had to be granitic rocks dehydrated during

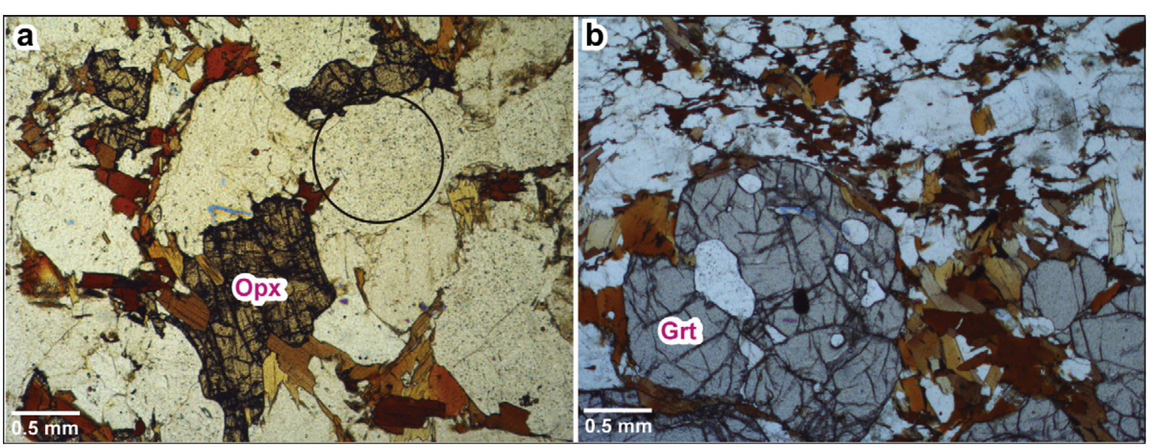

Figure 1 Microphotographs of two types of Ansignan charnockites (Agly Massif, French Pyrenees) in plane polarised light (thin sections courtesy M. Demange). a: orthopyroxene-bearing charnockite, b: garnet-bearing charnockite. The garnet-bearing variety is more deformed (charnockitic augen gneiss). In both cases biotite crystals are partly bent and tend to occur along feldspar intergrain boundaries. Feldspar in the orthopyroxene-bearing charnockite comprises CO_2 dominated fluid and empty inclusions (a). Quartz blebs in garnet comprise brine inclusions (not visible in the microphotograph).