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NATURE AND INTERPRETATION OF FLUID INCLUSIONS IN GRANULITES

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Many granulites contain CO_2 rich high density fluid inclusions (carbonic fluids). This observation has led to the concept of "carbonic metamorphism", (1) the dry character of granulites being less explained by the absence of water ("vapor absent metamorphism") than by the presence of a CO_2-rich fluid phase which dilutes the water and lowers considerably its partial pressure. Recent observations have indicated however that the situation is much more complicated than initially assumed and that any interpretation must be carefully evaluated and discussed against other, independent evidence.

NATURE OF FLUID INCLUSIONS: Carbonic fluids are dominant in granulites, but their abundance vary greatly from a sample to another. Perfect "granulitic texture" (equant crystals with straight boundaries and many triple junctions at 120°) are normally devoid of fluid inclusions, which are destroyed during the solid state recrystallization inherent to this texture. In other rocks, fluid inclusion abundance vary from astonishing heights (at least 10 to 20% in volume in garnet of some Indian charnockites) to a few tens of inclusions in a 10 cm^2 double polished plate. Even if it is not possible to link the abundance of fluid inclusions and the absolute fluid quantity present at the time of their formation, this must indicate a very unequal fluid distribution during and after granulite metamorphism.

Most important, carbonic fluids are not the only fluids occurring in granulites. Other gaz components, notably CH_4 and N_2, have been observed, mixed or not with CO_2. Pure CH_4 and/or N_2 have always a very low density and they are obviously generated or reequilibrated at a very late stage of the rock history. This poses a serious problem for N_2, which, from its occurrence (most abundant in or near metasediments), seems to be inherited from a premetamorphic stage and must therefore have gone through the whole range of P.T. conditions.

Aqueous inclusions, present in variable amounts in many granulites, were initially assumed to be late and related to the partial retromorphosis shown by almost any granulites. This is certainly correct for late, low salinity, high density H_2O inclusions (homogenisation temperature below 200°C), but not obvious for high salinity, NaCl bearing brines which, in some granulites, are far more abundant than CO_2 inclusions. They are essentially related to specific lithotypes (metapelites, skarns, meta acid volcanics) and their distribution indicate that they may have coexisted with CO_2 (immiscible fluids) during and after peak metamorphism. (2)

INTERPRETATION OF FLUID INCLUSIONS DENSITY (ISOCHORES). This is a very complicated problem which can best be attempted for pure CO_2. Note that the maximum CO_2 density presently recorded with certainty is 1.176 g/cm^3, corresponding to a homogenization temperature (liquid) of -56.6°C (CO_2 triple point). All inclusions which homogenize at lower temperatures ("metastable extension of the liquid-vapor curve") precisely investigated so far are CO_2-N_2 mixtures. (3).

High density CO_2 inclusions tend to reequilibrate easily to changes in external P-T conditions. This is shown e.g. by many decrepitation features and extensive transposition of former inclusion trails along new directions. In some cases, a careful observation establishes a sequence of inclusion formation, from primary to several generations of secondary ones. Primary inclusions are especially abundant in some minerals, notably garnet and plagioclase, but they may also be found in unstrained minerals (e.g. quartz) totally enclosed and protected in another larger mineral grain (e.g. quartz in garnet or plagioclase). Contrary to earlier hypothesis (4), it has been found that successive generations do not systematically correspond to a decrease of inclusion density. This complicates obviously the interpretation of fluid inclusion data (highest density inclusions cannot be longer considered as closest to peak metamorphic conditions) and, in order to characterize a synmetamorphic fluid, several conditions must be fulfilled:

1) *A well defined isochore, corresponding to a precisely identified generation of fluid inclusions, must be consistent with a set of P.T. conditions derived from coexisting minerals (Intersection of the isochore and the P.T. "box" of a given metamorphic assemblage).*

2) *Later inclusions in the same sample must fall on isochores differing significantly from the one corresponding to early inclusions.*

The trend of variation (evolution towards higher or lower densities) defines 2 major types of possible post metamorphic P.T. trajectories:

i) "Adiabatic uplift path", in which pressure decreases faster than temperature (essentially vertical movements, decrease of density with time). (4)

ii) "Isobaric cooling path" showing an opposite trend and an increase of CO_2 density in younger inclusions. (2)

Two examples are discussed in some detail: West Uusimaa Complex (Finland), a low pressure granulite dome illustrating the first trend (isobaric uplift) and a mylonitic charnokite of Dodda Betta, India, in which 3 successive generations of CO_2 inclusions in garnet, plagioclase and quartz show a density increase from 0.96 g/cm^3 in garnet to 1.12 g/cm^3 in quartz. It is suggested that the isobaric cooling trend can be due, either to the intrusion at depth of deep seated, synmetamorphic intrusive masses, or to large scale horizontal thrusting.

3) *The nature of the fluid must correspond to the theoretical composition predicted from heterogeneous mineral equilibrium.*

At a time where thermodynamics and the theory of mineral equilibria allow the prediction of many fluids, this condition may seem obvious. It must be recognized, however, that it has up to now met with a limited success and that, in many cases, the observed composition differs grossly from the expected one: CO_2 in wollastonite skarns (Willesboro, New Jersey), CO_2 in rocks where the combination of fO_2, P and T should indicate more reduced species, etc. (5)

Each case must be discussed seperately, but there are at least some possible answers for many observed discrepancies:

i) In the lower crust, fluid composition may be locally buffered and vary markedly on short distance. This may result in apparently immiscible mixtures of e.g. brines and CO_2, a situation which has been obscured in many metalimestones and skarn related occurrences (2). It is possible that the CO_2 observed in Willesboro samples represent an externally derived droplet in the real metamorphic fluid, a brine.

ii) Many systems are not internally buffered for fluid composition. This is the case e.g. for charnockites, in which CO_2 was most probably introduced in the magmatic stage, either as dissolved gazes or from the breakdown of carbonate melts (2,6). If oxygen fugacity is buffered by the QMF assemblage CO_2 is the dominant species at 7 kb total pressure for temperatures above 600°C (Fig. 10, in 5). Lower fO_2 will drastically decrease the CO_2 content, and at QMF-2 log units, for instance, CO_2 is only dominant at temperature above 900°C. Many fO_2 recorded by opaque assemblages correspond to the CO_2 absent field, but only at temperature well below any possible peak metamorphic temperature. Conversely, the few results which correspond to peak temperatures (about 800°C) are frequently above the graphite stability line and hence consistent with a CO_2 fluid.

In conclusion the interpretation of fluid inclusions in granulites is a difficult problem which requires several conditions:
- Favourable samples: Possibility to establish inclusion chronology, lack of obvious perturbation and recrystallization.
- Very careful observation and comparison of fluid and solid mineral data at the scale of the hand specimen. P-T solid estimates and fluid inclusion investigations must be done in the same specimen and, ideally, in the same thin section.
- Absolute necessity to discuss the fluid inclusion information against other independent evidences. It must be remembered, however, that any solid assemblage may evolve after its crystallization and that fluid inclusions are not a priori more sensitive to external perturbation than rock forming minerals.

Once these limitations and difficulties are accepted, it becomes evident that the potential information contained in fluid inclusions and in the associated minerals is of prime importance for the interpretation of the rock history. Analytical techniques and theoretical background are now sufficiently well established. Only the multiplication of precisely studied cases will help to understand fully their message.

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