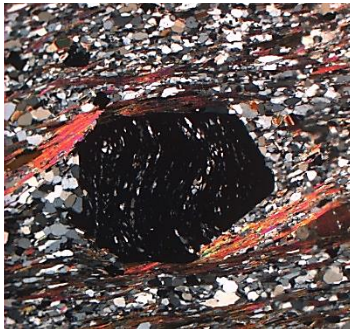
Petrogenesis of Granulites

M.Sc. Semester II



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Granulites

As per the recommendations by the IUGS Subcommission on the Systematics of Metamorphic Rocks (2007):

Granulite is a high-grade metamorphic rock in which Fe-Mg-silicates are dominantly hydroxyl-free; the presence of feldspar and the absence of primary muscovite are critical, cordierite may also be present.

The mineral composition is to be indicated by prefixing the major constituents. The rocks with >30% mafic minerals (dominantly pyroxene) may be called mafic granulites, those with <30% mafic minerals (dominantly pyroxene) may be called felsic granulites.

The term should not be applied to ultramafic rocks, calc-silicate rocks, marbles, ironstones or quartzites.
Detailed names and subdivisions may be given using mineral-root names, for example, garnet-clinopyroxene-plagioclase granulite.

Factors controlling petrogenesis of granulites

(i) **Facies:** Granulites belong to the granulite facies that consists of high temperature (~ 700 as lower limit of temperature) and moderate to high pressure (3 – 15 kbar ≈ 10 – 50 km depth) mineral assemblages. The granulite facies corresponds with the upper parts of the Barrovian sillimanite zone and – at still higher temperature – the cordierite- garnet zone. With decreasing pressure, the low pressure field of granulite facies metamorphism grades into the pyroxene and sanidinite hornfels facies. As progressively higher temperature conditions develop within orogenic belts, migmatites of the granulite facies are produced.

Factors controlling petrogenesis of granulites

(ii) **Mineral Assemblages:** Granulite facies minerals are predominantly anhydrous, due to dehydration reactions at high temperatures. Hydrous minerals hornblende and biotite, but not muscovite, can occur in the lower part of the granulite facies, sometimes referred to as granulite I. The upper part of the granulite facies, sometimes referred to as granulite II, is characterized entirely by anhydrous minerals. Amphibole minerals (tremolite, anthophyllite, hornblende) dehydrate to pyroxene minerals (enstatite, diopside, hypersthene), and phyllosilicate minerals (such as muscovite) dehydrate to anhydrous minerals (orthoclase) in response to high temperatures. Such reactions are completed either in the transition from amphibolite to granulite facies or in the transition from granulite I to granulite II. The common mineral assemblages in this facies include plagioclase, K-feldspar, Al_2O_3 rich pyroxenes.

Factors controlling petrogenesis of granulites

(iii) **Tectonic Setting:** Granulite facies metamorphism occurs in the highest temperature dynamothermal metamorphism region at (1) convergent plate boundaries, (2) at the base of thick continental crust, and (3) in the uppermost part of the mantle. Some basic granulites may represent the refractory residual rock material following partial melting at the base of continental lithosphere. Granulites occur in rocks of all ages, but are especially common in Precambrian shields and associated anorthosite complexes where long - term erosion has exposed rock formed deep below the surface. Granulite facies rocks are found to occur in ancient deep to middle continental crust that have been highly dehydrated.

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Petrogenesis of granulites

A problem in dealing with this topic in a concise way is that granulite terrains vary widely in character, and granulite-facies rocks present many different sorts of phenomena to be explained. The basic petrological problem is that typical granulite-facies assemblages require $P_{H2O} << P_{total}$ for their stability, and debate has centred around how this low P_{H2O} is achieved. There are three distinguishable models:

1. Melting occurs, water from intergranular fluid and hydrous phases is partitioned into the melt, and the melt may be removed, taking the water with it.

2. CO_2-rich vapour from some external source passes through the rocks, driving dehydration reactions and diluting or flushing out the resulting aqueous fluid.

3. In certain terrains the precursor rocks were already rather dry (e.g. water-deficient magmatic rocks and their dehydrated thermal aureoles) so that their subsequent high-grade metamorphism does not require a special mechanism to generate granulite-facies assemblages.

Petrogenesis of granulites

Other features of granulite terrains which need to be explained are:

1. Depletion in large-ion lithophile elements (LILE).

This was regarded as a major issue in the 1970's when the focus was on the Lewisian gneisses, and it was ascribed either to melt extraction or to deep-seated fluid metasomatism. It is now realised that the Lewisian is atypical, being exceptionally depleted in LILE, whereas many granulite terrains show rather small depletions.

2. CO_2-rich fluid inclusions.

A classic study by Touret in southern Norway established that a change from water-rich to CO_2-rich fluid inclusions coincided with the regional orthopyroxene isograd. This has been found to be generally true, though granulite terrains form a spectrum from those in which fluid inclusions are ubiquitous and abundant to those in which they are rare and small.

Petrogenesis of granulites

3. "Arrested charnockitisation"

A strange phenomenon first described from south India and Sri Lanka, where in acid to intermediate rocks granulite-facies assemblages (charnockite) are found in vein-like arrays superimposed over amphibolite-facies gneisses. These features are now known, on a less conspicuous scale, from a number of other terrains. They have been attributed to CO_2 streaming. Other explanations may be possible, but at the very least this phenomenon draws attention to the fact that the amphibolite-granulite transition cannot depend on changes in T or P alone.

Petrogenetic models of granulites

Three possible petrogenetic models of granulites are given below:

Model 1: Melting and melt extraction

The original reference given for this model is usually Fyfe (1973), who suggested that granulites could be regarded as restites after removal of relatively large amounts of partial melt. The model has been suggested for the Lewisian Complex.

A substantial boost for the model came from the realisation that dehydration melting, i.e. vapour-absent incongruent melting of assemblages containing hydrous phases (Ms, Bt, Hbl) is likely to be an important process in high-grade metamorphism.

Dehydration melting was applied to natural examples in Broken Hill, Australia (Phillips, 1980), New England (Tracy and Robinson, 1983) and Namaqualand, S. Africa (Waters and Whales, 1984; Waters, 1988). Notice, however, that these more recent accounts don't necessarily envisage the extraction of large volumes of melt.

Petrogenetic models of granulites

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Model 2: Influx of CO_2-rich vapour

The type locality for this model is in south India, at classic exposures in stone quarries, e.g. at Kabbaldurga in the Late Archaean amphibolite-granulite transition zone, and further south in the Kerala "khondalite belt" where the phenomena are probably of Pan-African age (550 Ma). The model has been championed by R.C. Newton at Chicago.

Petrogenetic models of granulites

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Model 3: Metamorphism of dry precursors

The type area for this model is the Adirondack Highlands of upstate New York, where much of the terrain consisted of pre-orogenic pyroxene-bearing igneous rocks and their high-grade thermal aureoles, subsequently metamorphosed to give Grenville age (1000 Ma) granulite-facies assemblages.

Thank You

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