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Evolution of the Highest-grade Metamorphic Rocks from Central Highland Complex, Sri Lanka

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Introduction

The Sri Lankan Precambrian basement has been subdivided into four major lithotectonic units (Kröner et al., 1991; Cooray, 1994). These units are the Vijayan Complex (VC) in the east, the Highland Complex (HC) in the central part and the Wanni Complex (WC) in the west. The fourth one is at the area towards the northwest part of Kandy previously known as the "Arena rocks", renamed as the Kaduganawa Complex (KC) by Kröner et al. (1991) and Cooray (1994). The KC is now considered to be part of the WC (Kehelpannala, 1997). In the present study we discuss the evolution and geochronology of ultrahigh-temperature (UHT) mafic granulites from the central Highland Complex and attempt to correlate with the other known UHT-granulite occurrences in the complex.

Geology of UHT-Granulites in the Highland Complex

The central Highland Complex consists mainly of granulite-facies metamorphic rocks with minor UHT-granulites. The first finding of UHT-granulites (sapphirine-quartz and sapphirine-garnet-orthopyroxene bearing) at Talatu Oya, ~6.5 km SE of Kandy was reported by Osanai (1986). Later, various localities in the surrounding area have also been well studied by several works to substantiate the UHT metamorphism (e.g. Kriegsman and Schumaker, 1999; Osanai et al., 2000; Sajeev and Osanai, 2002). The occurrence of sapphirine-forming prograde reaction textures in pelitic granulite from the Highland Complex was also reported from a nearby locality (Hiroi et al., 1994).

The central Highland Complex consists of inter-layered mafic and pelitic granulites, foliated granites, quartzite and intercalated calc-silicates and marbles. The present samples (UHT-mafic granulite) discussed in this study were collected from a roadside exposure, near to the Victoria Dam towards the southeastern part of Kandy. The exposure consists of mafic granulite intercalated with calc-silicates and thin layers of highly migmatised pelitic granulites. From the hand specimen of mafic granulite, coarse porphyroblasts of garnet and clinopyroxene can be perceived by naked eye. The general foliation varies from N 50° W to N 5° E with a dip of 75 - 85° S.

The other known UHT-granulites are high Al-Mg pelitic granulites. The sapphirine-bearing granulite at Talatu Oya (Osanai, 1986; Osanai et al., 2000) is exposed as blocks within marbles. Mafic granulites are also identified from the same location as boudins. The exposure near Gampola (Sajeev and Osanai, 2002) consists of thin disrupted layers of garnet-sapphirine-quartz-orthopyroxene-sillimanite granulite intercalated with garnet-cordierite-sillimanite-biotite gneiss and garnet-bioptite gneiss. At the exposure elucidated by Kriegsman and Schumaker (1999) from Hakurutale, the sapphirine-bearing granulite occurs as lenses within a quartzite matrix.

Petrographical Features

UHT-mafic granulites from the Highland Complex

The major textural features exhibited by the granulites studied are the porphyroblasts, symplectites and moat. The major porphyroblasts are garnet (Grt), clinopyroxene (Cpx) and quartz (Qtz) (Fig. 1a) with grain sizes varying from 3 mm to 5 mm for Grt, 1 mm to 7 mm for Cpx and 1 mm to 5 mm for Qtz. Opx and plagioclase (Pl) are present only as retrograde phases forming symplectites. Orthopyroxene (Opx) moat along the grain boundary of quartz

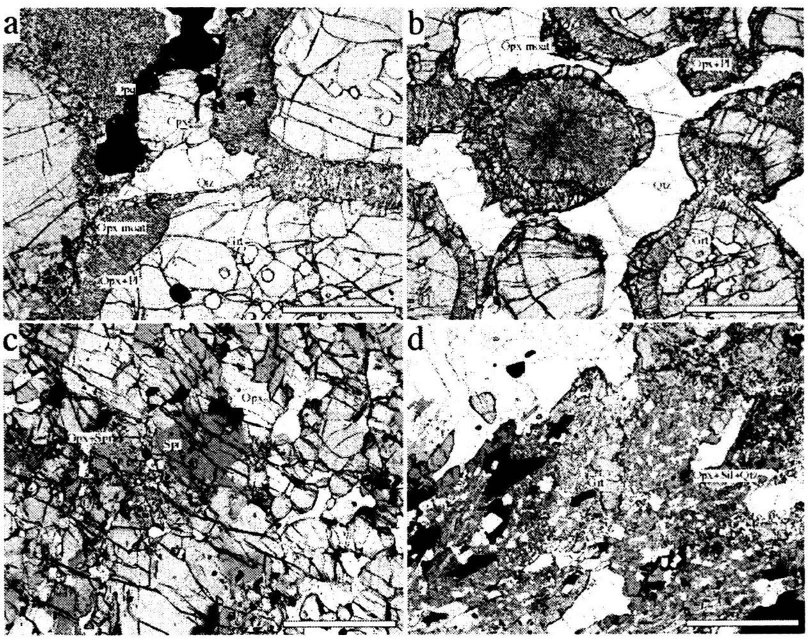

Figure 1. (a) Photomicrograph of Grt-Cpx-Qtz granulite. Grt-Cpx porphyroblast associated with Qtz. Note the fine rim of Opx-Pl symplectite at the grain boundary of porphyroblasts. (b) Complete consumption of Grt, replaced by Opx-Pl symplectite. Note the orthopyroxene moat on the quartz rim. (c) Spr-Opx symplectite in Grt-Spr-Opx granulite from Talatu Oya (d) Opx-Sil-Qtz assemblage after break down of Spr and Grt from Gampola. Scale bar represents 1 mm.

can also be identified in some of the thin sections. In some samples complete consumption of Grt produces pod-like texture of Opx-Pl symplectite (Fig. 1b). The major mineral inclusion in Grt and Cpx is Qtz with minor amount of opaque minerals and rutile. No plagioclase inclusions can be identified as initial minerals. Fine lamellae of Opx were found in Cpx during the microprobe analysis, which may indicate an exsolution from pigeonitic pyroxene (inverted pigeonite). It is notable that hydrous mafic minerals such as hornblende (Hbl) and biotite (Bt) are completely absent in this rock type. From the above textural features the following reaction can be assumed where Grt, Cpx and Qtz are consumed to produce Opx and Pl.

$$\text{Grt} + \text{Cpx} + \text{Qtz} = \text{Opx} + \text{Pl}$$

The garnet composition varies and has pyrope 32.5-34.7%, almandine 46.7-47.7% and grossular 16.1-19.3%. Cpx has X_{Mg} values ranging from 0.681 to 0.709 in the core and from 0.768 to 0.780 at the rim. The Opx lamellae in Cpx preserve the highest Al_2O_3 (3.80 wt%) and X_{Mg} (0.575) contents. However, the Opx of symplectite phases as well as moat consists of 2.15-2.4 wt% of Al_2O_3 with an X_{Mg} values from 0.530 to 0.564. Pl in all samples studied has very similar compositions; An% being 91.5-84.1 and Ab% being 8.5-14.2.

Other UHT-Granulites from the Highland Complex

As described earlier petrographical studies on the highest-grade UHT-pelitic granulites from the Highland Complex have been carried out by various workers. Osanai et al. (2000) describes the evolution of Spr-Opx-Grt and Spr-Opx-Qtz granulites from Talatu Oya, in which the fO_2 condition varies from domain to domain. The major textural feature is the Spr-Opx-Crd±Spl symplectite forming reactions after garnet, which is, indeed, an FMAS reaction at UHT conditions during the near isothermal decompression (Fig. 1c) as part of the clockwise evolution. Krn is also found as a retrograde phase in this type of rocks. Kriegsman and Schumacher (1999) also explained a clock-wise evolution path for their sapphirine-bearing granulites from Hakurutale and Munwatte. Sajeev and Osanai (2001) described another Grt-Opx-Sil granulite from Gampola, SSW of Kandy. The major textural evidences of the sample are primary Grt containing Spr and Qtz inclusions and coexistence of Opx-Sil-Qtz in the matrix, a feature observed in the matrix of the same sample (Fig. 1d) that could indicate isobaric cooling profile as part of counter-clockwise evolution.

P-T Condition of UHT-Mafic Granulite

Temperature for the plagioclase-absent initial assemblage is calculated by using the garnet and clinopyroxene Fe-Mg exchange thermometer for the representative core compositions. For pressure estimation, it is clear that the condition was in the 'plagioclase-out' field of the experimental results by Green and Ringwood (1967) (Fig. 2). To estimate the retrograde conditions, we then followed the Grt-Opx exchange thermometer for the rim composition of garnet and orthopyroxene moat. The retrograde pressure was calculated by using Grt-Opx-Pl-Qtz net-transfer reaction thermobarometry.

Temperature estimates using core compositions of coexisting Grt-Cpx pairs give a maximum temperature of 1006°C by the calibration of Ellis and Green (1974), which gives the highest values. The estimations based on the thermometric calculations suggested by Powell (1985) and Krogh (1988) also give similar temperatures of 995°C and 990°C, respectively. The calculations using the method of Ai (1999) and Krogh (2000) indicate slightly lower temperatures of 947°C and 939°C, respectively. The pressure for the initial assemblage was determined to be above 13 kbar using these temperatures, which is in the 'plagioclase-out' field in the P-T space. Calibrations using Grt-rim and Opx-moat for Grt-Opx exchange thermometer by Lee and Ganguly (1988)

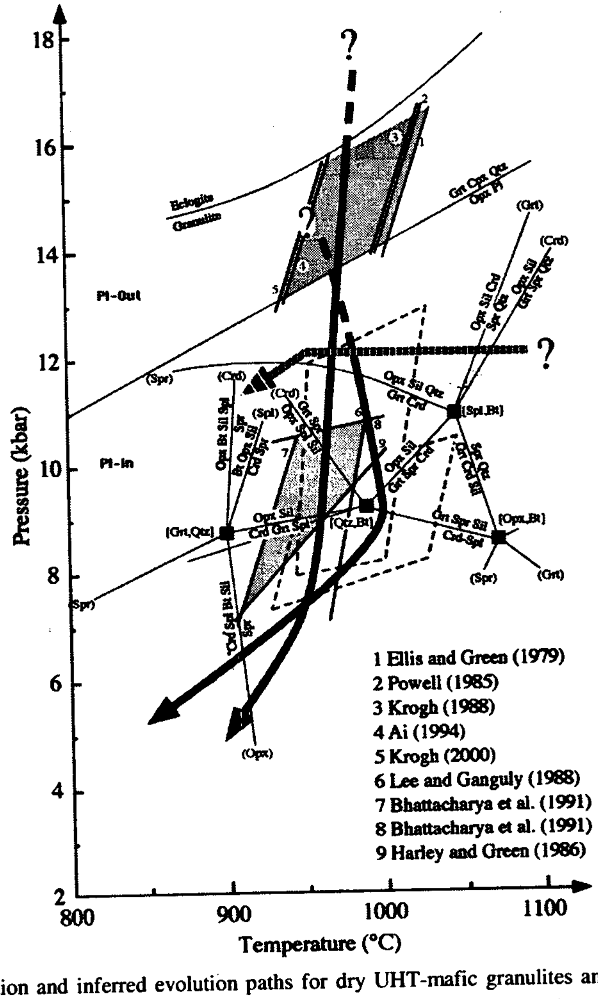

Figure 2. P-T estimation and inferred evolution paths for dry UHT-mafic granulites and related sapphirine-bearing granulites from the central Highland Complex. Shaded rectangles are estimated P-T conditions of mafic granulites and broken-line rectangles are those of sapphirine-bearing granulites. The univariant Opx-Pl forming reaction curve and the eclogite-granulite transition line are taken from Green and Ringwood (1967). Petrogenetic grid for sapphirine-bearing granulites is after McDade and Harley (2002).

give temperature of 982°C, while T estimation based on Battacharya et al. (1991) is 938°C. More lower temperature of 875°C is yielded by the method of Lal et al. (1993). Pressures were calculated using rim compositions of coexisting Grt-Opx-Pl-Qtz (GOPS) and also from

Grt-Opx pairs. Based on barometers of Harley and Green (1982) and Wood (1974), the estimated pressures are 10.8 kbar and 10.5 kbar, respectively. The result from the barometer by Bhattacharaya et al. (1991) gives a higher value of ca.11 kbar. GOPS barometer by Newton and Perkins (1982) yields pressures between 9.1 kbar and 10.7 kbar, while that of Bohlen et al. (1983) gives the lowest values of 8.5-9.5 kbar.

The derived pressures are certainly lower than the pressure determined for the initial assemblages. However, the temperature estimates for both initial and retrograde assemblages are similar, and thus this can be interpreted as a result of evolving in a near isothermal decompression manner (Fig. 2). The absence of hydrous minerals even in the retrograde stage could be explained in two ways. Firstly, this could be the result of the bulk chemical control and secondly, the rock could not have declined to the lower temperature side, i.e. into the hornblende stable field (Spear, 1993), before the mineral reactions freezed. Estimated P-T conditions of sapphirine-bearing UHT granulites and their evolutionary paths are also shown in Figure 2, which have already reported by Osanai et al. (2000) and Sajeev and Osanai (2002).

Geochronology of UHT-Granulites

The Sm-Nd internal isochron plotted using the resulting composition gives an age of 532±9 Ma. The Pan-African granulite facies metamorphism is estimated to have taken place ~610-550 Ma ago (Kröner an Williams, 1993). However, geochronological studies on UHT granulites of the Highland Complex have not been undertaken on a wide extent. The only known work is from Osanai et al. (1996) and Sajeev et al. (submitted). Osanai et al. (1996) obtained a slightly older metamorphic age (~670 Ma) using Sm-Nd whole rock isochron for sapphirine-bearing granulites from Talatu Oya. They also reported the age of retrogression of these granulites as ~500 Ma using whole rock biotite internal isochron. Sajeev et al. (2003) obtained even an older age of ca. 1447 Ma for Grt-Opx-Sil granulite from Gampola by the internal isochron of garnet-whole rock-felsic fraction (Qtz+Pl) in Sm-Nd system with a reference retrograde age of 550 Ma. These results may indicate that the metamorphic evolution with isothermal decompression under UHT-conditions had taken place during Pan-African related to the Gondwana assembly, while the evolution with isobaric cooling process probably had taken place in relation with supercontinet Columbia (Rogers and Santosh, 2002; Kehelpannala, 2003).

Conclusion

Grt-Cpx-Qtz granulites are identified and studied in detail for the first time in Sri Lanka. The textural relations indicate a clear break-down of garnet and clinopyroxene with quartz for the production of plagioclase and orthopyroxene symplectites. Schumacher and Faulhaber (1994) concluded that the near peak metamorphic conditions of mafic granulites from the Highland Complex around 760-830°C and 8-10 kbar. However, in the present study the thermobarometric results show that the metamorphic conditions were significantly high with temperature and pressure of 939-1006°C and >13 kbar, respectively. These results are derived by using the core compositions of coexisting Grt-Cpx pairs and considering the stability field of the initial assemblage in the 'plagioclase-out' field. The Grt-Opx thermometric results give a similar temperature of 900-975°C at 10-11 kbar pressure. The total absence of hydrous minerals shows that the present samples is unique, indicating a completely dry condition from the initial stage through out its evolution. The observed reaction textures and the mineral chemical data indicate a near isothermal decompression under UHT conditions.

The geochronological results from internal isochron (~532 Ma) for the UHT-mafic granulites may represent a cooling age slightly younger than the initial granulite metamorphism. Plotting of the isochron using initial Grt-Cpx as well as later Opx and felsic fraction with whole rock forms a single straight isochron, indicating that the uplift could have taken place in a short period of time. Similar Pan-African ages are also determined from sapphirine-bearing UHT-granulites. indicating an isothermal decompression. The internal isochron age from the Grt-Opx-Sil granulite, which shows an early isobaric cooling, may represent a possible Pre-Grenvillian metamorphic event in relation to supercontinent Columbia.

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