Pressure-temperature estimates of selected regions of the Lützow-Holm Complex utilizing Zr-in-rutile geothermometer

Kota Suzuki[1], Tetsuo Kawakami[1] and Yohei Igami[1, 2]

[1]*Department of Geology and Mineralogy, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan*

[2]*Institute of Materials and Systems for Sustainability, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan*

Metamorphic zone mapping of the Lützow-Holm Complex by Hiroi et al. (1991) divided the complex into three zones, upper amphibolite facies zone, transitional zone and granulite facies zone. Recent studies have found that high-*T* conditions above 850 ºC are common even in the transitional zone and such temperatures are attained under kyanite stability field (Kawasaki et al., 2011; Iwamura et al. 2013; Kawakami et al., 2016). Our aim of this study is to re-examine the peak *P-T* conditions and *P-T* paths of selected regions of the Lützow-Holm Complex utilizing Zr-in-rutile geothermometer that is more robust than the traditional Fe-Mg exchange type geothermometers during high-*T* metamorphism.

Chemical zoning of garnet in high-*T* metamorphic rocks in terms of major elements (Fe, Mg, Ca and Mn) are commonly obscured by the diffusion under high-temperatures. On the other hand, chemical zoning of garnet in terms of P is less affected by the later diffusion, and commonly preserves sharp growth zoning (e.g., Hiroi et al. 1997; Kawakami and Motoyoshi, 2004). Utilizing the sharp P zoning as a contemporaneous surface during garnet growth to define cores and rims of garnet, and utilizing relic mineral inclusions in garnet such as Al_2SiO_5 minerals and rutile to estimate the *P-T* conditions of each metamorphic stage (e.g., Kawakami and Hokada, 2010), we estimated *P-T* conditions recorded in pelitic gneisses from Rundvågshetta, Skallen, Skarvsnes and Akarui Point (Lützow-Holm Complex, East Antarctica), and obtained *P-T* paths from Skallen and Skarvsnes.

In the course of this study, sillimanite with a characteristic Raman peak around 420 cm^{-1} which is not listed as a sillimanite peak in the Lyon database (http://www.geologie-lyon.fr/Raman/) were found from Rundvågshetta, Skallen and Skarvsnes samples. Sillimanite with 420 cm^{-1} peak was found as inclusions in garnet and as matrix minerals. In order to examine whether such a peak is related to the phase transition from kyanite to sillimanite or mullite to sillimanite, we observed them in detail by TEM. However, no evidence for such transition was found. Therefore, sillimanite with 420 cm^{-1} peak is dealt as normal sillimanite in the following description and discussion.

In Skallen, garnet porphyroblasts in a Crn-Spl-Sil-Grt gneiss (sample TK2003011203) were originally coarse-grained up to ~5 cm in diameter, and presently disaggregated into smaller garnet fragments of ~5 mm. The intervening matrix between the smaller garnet fragments consist of plagioclase, K-feldspar and quartz. When reconstructed, the ~5 cm-sized garnet porphyroblast has P-rich patches in the center where kyanite are included, which are further rimmed by P-poor garnet including kyanite and sillimanite. Applying Zr-in-rutile geothermometer (Tomkins et al., 2007) to rutile included in the P-rich patches and P-poor rims, and taking into account the presence of kyanite in the P-rich patches and the coexistence of kyanite and sillimanite in the P-poor rims, the *P-T* conditions of the P-rich patches and P-poor rims were estimated at >11.3 kbar and 877 ±14 ºC (average ±2σ ºC hereafter), and 10.0 kbar and 813 ±34 ºC, respectively. Rutile in the rock matrix yielded 853 ±2 ºC at 7.7 ±1.0 kbar, applying Zr-in-rutile geothermometer (Tomkins et al., 2007) and GASP geobarometry (Hodges and Spear., 1982) to the P-poor (Ca-poor) rims of garnet and Ca-rich rims of plagioclase in the rock matrix containing sillimanite. Combining these stages, an isothermal decompression *P-T* path at ~880-810 ºC is obtained for the Skallen sample.

In Skarvsnes, garnet porphyroblasts in a Grt-Sil gneiss (sample TK2003012803) that fills boudin necks of the Grt-Bt gneiss are studied in detail. Garnet in the Grt-Sil gneiss has P-poor cores that include kyanite, and P-rich rims that include kyanite and sillimanite. Utilizing the same geothermobarometry as in Skallen, *P-T* path of the Grt-Sil gneiss was constructed. The *P-T* condition of the kyanite-bearing P-poor core was estimated at >10.6 kbar and 845 ±24 ºC, and the matrix rutile, garnet rim and plagioclase rim coexisting with sillimanite yielded 7.9 ±1.0 kbar and 828 ±33 ºC. The P-rich rim was probably formed at 10.7 kbar and 849 ºC, judging from the coexistence of kyanite and sillimanite in the P-rich rim of garnet. Combining these stages, an isothermal decompression *P-T* path at ~845-830 ºC is obtained for the Skarvsnes sample.

In Rundvågshetta, garnet porphyroblasts in a Grt-Sil gneiss (sample TK2003010307) have P-poor cores in which no Al_2SiO_5 mineral is included, and P-rich rims which include sillimanite. Applying Zr-in-rutile geothermometer (Tomkins et al., 2007) to rutile included in the P-poor cores of garnet yielded 852-935±16 ºC (at 0.5-14 kbar), although pressure condition could not be constrained. On the other hand, rutile in the rock matrix yielded 848 ±18 ºC at 7.9 ±1.0 kbar, applying Zr-in-rutile geothermometer (Tomkins et al., 2007) and GASP geobarometry (Hodges and Spear., 1982) to the P-poor (Ca-poor) rims of garnet and Ca-rich rims of plagioclase in the rock matrix containing sillimanite.

In Akarui Point, garnet porphyroblasts in a Grt-Bt gneiss (sample TK2002122305) have P-poor cores and P-rich rims. Pressure conditions could not be constrained because Al_2SiO_5 mineral was absent in this sample. However, by applying Zr-in-rutile geothermometer (Tomkins et al., 2007) to rutile included in the P-poor core of garnet, temperature of the garnet core formation may be estimated at 780-855 ±18 ºC (at 1-14 kbar). This is consistent with the temperature estimate of recent studies from Akarui Point using ternary feldspar thermometry (Nakamura et al., 2013) and slightly lower than Iwamura et al. (2013) that reported temperature around 900 ºC.

Comparing inferred *P-T* paths of the high-*T* pelitic gneisses from Skallen and Skarvsnes, both of them indicate isothermal decompression path that start from the kyanite stability field at temperature above ~850 ºC. This type of *P-T* path was recently reported from Rundvågshetta (Kawasaki et al., 2011), Skallevikshalsen (Kawakami et al., 2016) and Akarui Point (Iwamura et al., 2013) in the Lützow-Holm Complex. Our result indicates that the high-*T* pelitic gneisses from Skallen and Skarvsnes also experienced such a *P-T* path, and may suggests that the 'transitional zone' and 'granulite facies zone' of the Lützow-Holm Complex record similar isothermal decompression *P-T* paths starting from the kyanite stability field at temperatures above ~850 ºC.

References

Iwamura, S., Tsunogae, T., Kato, M., Koizumi, T., and Dunkley, D. J., Petrology and phase equilibrium modeling of spinel-sapphirine-bearing mafic granulite from Akarui Point, Lützow-Holm Complex, East Antarctica: Implications for the *P-T* path. Journal of Mineralogical and Petrological Sciences, 108(6), 345-350, 2013

Hiroi, Y., Shiraishi, K. and Motoyoshi, Y., Late Proterozoic paired metamorphic complexes in East Antarctica, with special reference to the tectonic significance of ultramafic rocks. In Geological Evolution of Antarctica (Thomson, M.R.A., Crane, J.A. and Thomson, J.W. Eds.). Cambridge University Press, Cambridge, 83–87, 1991

Hiroi, Y., Motoyoshi, Y., Ellis, D. J., Shiraishi, K., and Kondo, Y., The significance of phosphorus zonation in garnet from high grade pelitic rocks: A new indicator of partial melting. In The Antarctic Region: Geological Evolution and Processes (Ricci, CA Ed.). Proceedings of the VII International Symposium on Antarctic Earth Sciences, Siena, Terra Antarctica (Vol. 73, p. 77), 1997

Hodges, K. V., and Spear, F. S., Geothermometry, geobarometry and the Al_2SiO_5 triple point at Mt. Moosilauke, New Hampshire. American mineralogist, 67, 1118-1134, 1982

Kawakami, T., and Motoyoshi, Y., Timing of attainment of the spinel + quartz coexistence in garnet-sillimanite leucogneiss from Skallevikshalsen, Lützow-Holm Complex, East Antarctica. Journal of Mineralogical and Petrological Sciences, 99(5), 311-319, 2004

Kawakami, T., and Hokada, T., Linking *P-T* path with development of discontinuous phosphorus zoning in garnet during high-temperature metamorphism — an example from Lützow-Holm Complex, East Antarctica. Journal of Mineralogical and Petrological Sciences, 105(4), 175-186, 2010

Kawakami, T., Hokada, T., Sakata, S., and Hirata, T., Possible polymetamorphism and brine infiltration recorded in the garnet–sillimanite gneiss, Skallevikshalsen, Lützow–Holm Complex, East Antarctica. Journal of Mineralogical and Petrological Sciences, 111(2), 129-143., 2016

Kawasaki, T., Nakano, N., and Osanai, Y., Osumilite and a spinel + quartz association in garnet–sillimanite gneiss from Rundvågshetta, Lützow-Holm Complex, East Antarctica. Gondwana Research, 19(2), 430-445, 2011

Nakamura, A., Kitamura, M., and Kawakami, T., Microstructural records of multiple retrograde local H_2O supplement in the pelitic gneiss, Lützow-Holm Complex at Akarui Point, East Antarctica. Mineralogy and Petrology, 108(2), 177-186, 2013

Tomkins, H.S., Powell, R. and Ellis, D.J., The pressure dependence of the zirconium–in–rutile thermometer. Journal of Metamorphic Geology, 25, 703–713, 2007