Mid-Archean low geothermal gradient metamorphism: constraints from phase relationships in metamorphosed BIF from the Inyoni shear zone of the Barberton granite-greenstone belt, South Africa

*Kazumasa Aoki[1], Shinji Yamamoto[2], Yusuke Sawaki[3], Hisashi Asanuma[3], Tsuyoshi Komiya[4]

1. Department of Applied Science Okayama University of Science, 2. Graduate School of Environment and Information Sciences, Yokohama National University, 3. Department of Earth and Planetary Sciences, Tokyo Institute of Technology, 4. Graduate School of Arts and Sciences, The University of Tokyo

The Barberton granite-greenstone belt is one of the oldest and best-preserved examples of Archean geology in the world. High-P amphibolitic rocks associated with ca. 3.23 Ga subduction-collisional event were reported from the Inyoni shear zone situated south of the Barberton belt (Dziggel et al., 2002; Moyen et al., 2006; Nédélec et al., 2012; Cutts et al., 2013). According to those studies, the high-P rocks formed under geothermal gradients of ca. 12–30°C/km, which is similar to those found in the Phanerozoic subduction and collision zones. Therefore, other metamorphic rocks exposed in the Inyoni shear zone must preserve mineralogical and petrological evidences showing such a low geothermal gradient metamorphism. In this study, in order to verify the low geothermal gradients at the mid-Achearn subduction-collision zone, quartz-rich layers in metamorphosed BIF from the Inyoni shear zone have been examined for the metamorphic P-T conditions, based on the phase relationships combined with microscopic observation, mineral compositions and thermodynamic calculations.
Studied samples (BF152 and BF153) are composed mainly of quartz, garnet, grunerite, amphibole, clinopyroxene and magnetite. Taking into account the microscopic observation and EPMA analyses (WDS mode) of each mineral, equilibrium mineral assemblage during the metamorphism are shown as follows; assemblage 1 (A1): Grt+Cpx+Gru+Mag+Qtz --> assemblage 2 (A2): Grt+Cpx+Gru+Hbl+Mag+Qtz --> assembalge3 (A3): Act+Mag+Qtz+Gru or Hbl.
To provide a framework for understanding the change of mineral assemblages and to constrain the metamorphic P-T conditions, P-T pseudosection and isopleth calculations have been performed by forward modeling with a computer program PERPLEX ver. 6.6.6 (Connolly, 2005 and its update) with an internally consistent dataset of Holland & Powell (1998 and its update). Moreover, garnet-hornblende geothermometer (Graham & Powell, 1984 and Perchuk et al., 1985) using the program THERMOBAROMETRY ver. 2.1 (Spear & Kohn, 1999) and the average P-T calculations of THERMOCALC ver. 3.33 with the computer program AX2 (Holland and Powell, 1998 and its update) were carried out as necessary. The bulk rock composition was confirmed by XRF analysis. The chemical states of iron and their relative abundances in the sample were measured by using ^{57}Fe Mössbauer spectroscopy. The effective bulk compositions of each assemblage were calculated by volume estimates combined with chemical analysis and abundance ratio of the minerals.
The calculated pseudosection diagrams show that the stability filed of each assemblage are about over 10 kbar and 580-690°C (A1), over 4 kbar and 500–600°C (A2) and lower than 4 kbar and 530°C (A3), respectively. These results are consistent with the change of mineral assemblage inferred by the petrography for the samples. These results lead us to that the samples record a series of metamorphism from peak to retrograde conditions. The P-T conditions of A2 given in combination with average P calculation and Grt-Hbl geothermometry are P = ca. 10 kbar and T = ca. 512–538 °C. These results correspond with both the equilibrium phase diagrams and isopleth results. On the other hand, the isopleth result of A1 is not consistent with the stability filed of A1 in the pseudosection diagram. This suggests that the chemical compositions of minerals that up the A1 were modified at a late stage where A2 formed. Thus, we cannot constrain the specific P-T conditions of A1, but we may say at least that A1

underwent higher-grade metamorphism than A2.
The estimated P-T conditions indicate that the A2 formed under geothermal gradients of ca. 15–20°C/km, This gradient corresponds to previous works for the highest-grade rocks in the same area (Dziggel et al., 2002; Moyen et al., 2006). Furthermore, our study suggests that the metamorphism that A1 underwent was higher P-T conditions than that of A2. Hence, it is possible that the geothermal gradients along the subduction-collisional zone when A1 formed were almost as much as or lower than ca. 15-20°C/km. Such gradient gives close agreement with that of subduction zone like Japan and of collision zone such as Himalaya and Kokchetav Massif. These features suggest the possibility that the mid-Archean crust was sufficiently cool and rigid as already mentioned by Moyen et al. (2006), and some of the crustal materials were subducted into much deeper depths than previously considered.