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論 文 内 容 要 旨

In the south western part of Greenland, huge, exposures of the Archean rocks have been recognized in more than 200×200km area. It is comprised of gneisses called the Amitsoq gneisses (largest volume), dotted small areas containing supracrustal rocks which are divided into three sequences (the Akilia association, the Malene supracrusts, and the Isua supracrustal belt), and dykes of later age. The Amitsoq gneisses are classified into five main lithologic units:gray gneisses, white gneisses, late gray gneisses, pegmatitic gneisses, and banded gneisses in the order of the intrusion (Moorbath et al., 1973; Bridgwater et al., 1986; McGregor, 1979; Nutmam, 1982a).

The Isua supracrustal belt studied in here is located at the northern end (65°10′N, 50°W) of the Archean terrain and occurs as a U-shaped strip and lens included in the Amitsoq gneisses. The northwestern edge of the belt is cut by the Ataneq Fault which is 50-100m wide and proterozoic in age (McGregor, 1979), and the northwestern edge is covered by ice sheets. Many field investigations have carried out in this region (e.g. McGregor, 1979; Bridgwater and McGregor, 1974; Nutman et al., 1983, 1984a). The rocks in the Isua supracrustal belt are usually classified into two sequences (A and B) and ultramafic intrusions. Sequence A consists of 6 formations (A1-A6) and sequence B of 2 formations (B1 Felsic Formation and B2 Mica Schist Formation). Most areas (~80%) of the Isua supracrustal belt are comprised of Sequence A while Sequence B occurs only in the northeastern edge of the Isua supracrustal belt, and its relationship with Sequence A is not yet understood.

Previous works on metamorphic rocks in the Isua district included field investigations, bulk rock chemical analyses (major element, trace element and rare earth elements), geochronology,and P-T estimations (Appel, 1977; Boak et al., 1983; Bridgwater and McGregor, 1974; Jacobsen and Dymek, 1988; Nutman et al., 1984a; Rosing, 1983; Shimizu et al., 1990). However , many problems concerning the metamorphism and crustal evolution in the early Earth still remain unresolved.

Previous works on the metamorphic history in the Isua supracrustal belt and the adjacent Amitsoq gneisses have identified polymetamorphic features of this region. However, it has been uncertain on to the number of metamorphic events, and the ages and extents of each metamorphic events. This study attempts to put constraints on these problems through dating on the 11 samples of separated minerals (hornblende, biotite, and Cr mica) from this region.

The K-Ar ages obtained in this study show a wide variation, from 3620 to 1890 Ma for the Isua supracrustal belt and 3380 to 1960 Ma for the Amitsoq gneisses. From a comparison of our K-Ar ages with the reported radiometric ages (U-Pb, Pb-Pb, Rb-Sr, Sm-Nd, K-Ar and Lu-Hf) on a variety of rocks from the Isua and Amitsoq districts, the following suggestions are made:(1)Nutman (1986) has suggested five cycles of metamorphic (first:3750-3700 Ma, second:~3600 Ma, third:3400-3200, fourth:3100-2600 Ma, and fifth:2100-1600 Ma) and that the metamorphism of 3100-2600 Ma was the main metamorphism. However, the effects of this metamorphism were not as extensive as suggested by Nutman. (2)There were probably four metamorphic events:3700-3400 Ma, second:3400-2900 Ma, third:2800-2400 Ma, and fourth:2000-1600 Ma. (3)The rocks with K-A ages greater than 3200 Ma are likely to have retained the chemical and mineralogical characteristics of the earlier metamorphism, but some rocks from this region were certainly affected by later metamorphism(s). (4)Consideration of the effects of later metamorphism is required in reconstructing the P-T-t history of the Isua supracrustal belt from data from various geothermometries and geobarometries.

The results of K-Ar dating of hornblende and biotite separates from the Isua district (Chapter 1) have revealed that the main metamorphism occurred ~3600 Ma, and that the~3300 Ma metamorphism did not completely destroyed the P-T records of the earlier metamorphism. The second objective of this study was therefore to identify the relative abundances of minerals formed by each metamorphic event, and its P-T conditions. The effects of each metamorphism are still retained in the chemical composition of garnet crystals.

The temperature and pressure conditions during the metamorphism in the Isua supracrustal belt were estimated by applying some new and old geothermometries and geobarometries. The maximum P-T conditions of the first cycle metamorphism were:P=10.0-7.5 kbar, and T=850-600℃. These conditions lie near the solidus of hornblende under water saturated conditions, and agree with the partial melting phenomena described in Nutman (1986). The peak metamorphic condition was probably reached ~3600 Ma indicated by the U-Pb ages of the Amitsoq gneiss. The retrograde phase of this metamorphism passed through P-T conditions of P=4.6 kbar, and T =410℃. The P-T conditions during the retrograde phase of the second metamorphism (~3200Ma) was estimated to be:P=5.3 kbar, and T=~380℃. The P-T conditions during the retrograde phase of the third (~2600Ma), and the fourth (~1800Ma) metamorphism were also estimated as:T=390℃, P=4.8 kbar for the third and T=410℃ for the fourth.

A third objectives of this research is to understand the roles of fluids in each cycle of metamorphism by analyzing oxygen isotopic characteristics of garnet growth zones and adjacent minerals (biotite, chlorite, quartz, and ilmenite).

The oxygen isotope analyses were performed on 22 samples of bulk-rocks and mineral separates using the conventional analytical technique, and also on 300(?) spots on mineral grains using a newly developed in-situ laser ablation method.

The oxygen isotope temperatures based on the bulk-mineral $\delta^{18}O$ values or those based on the spot $\delta^{18}O$ values of neighboring minerals give reasonable metamorphic temperatures (~200°-~800℃) only about 30 percent(?) of 50(?) pairs. This suggests that the oxygen isotopic disequilibrium not attained among the coexisting minerals in the Isua metamorphic rocks. When the oxygen isotope temperatures fall within a reasonable temperature range, their temperatures are generally higher than those estimated from cationgeothermometries, such as the garnet-biotite geothermometry based on the partitions of Fe and Mg. These differences may reflect the differences in the closure temperatures arising from the differences in the diffusion coefficients of oxygen atoms and cations in minerals.

Three types of $\delta^{18}O$ zoning patterns are recognized in garnet crystals:(1)flat type where the difference in the $\delta^{18}O$ values between the rims and core is less than 0.5‰, (2)concave type where the rims have higher $\delta^{18}O$ values than the core by 0.7 to 1.5‰, and (3)convex type where the rims have lower $\delta^{18}O$ values than the core by 1.5 to 4.9‰. The convex type is most common. The convex type $\delta^{18}O$ profile was interpreted to reflect the decreases in the $\delta^{18}O$ values of later stages, from ca. +10‰ for stage 1, ca. +6‰ for stage 2, ca. 3‰ for stage 3, and ca. −2‰ for stage 4. Because each garnet crystal retains only one to three stages of garnet growth, rather than the entire four stages, the observed decreasesin the $\delta^{18}O$ values from the core to rims are less than 5‰.

Four mechanisms were evaluated to explain the observed $\delta^{18}O$ profiles of garnet. They are: (a)isotope exchange with surrounding minerals during cooling, (b)isotope zoning caused by the Rayleigh crystallization process during growth of new minerals from precursor minerals, (c) isotope zoning caused by reactions with high temperature water during prograde stages of polymetamorphic processes, and (d)isotope zoning caused by reactions with low temperature water during retrograde stages of polymetamorphic processes. The results of evaluation suggests that the mechanism (d)was most likely to produce the observed concave type $\delta^{18}O$ profiles.

According to this model, outer of garnet 1 crystals were converted back to chlorite + quartz assemblage by reactions with externally derived water with $\delta^{18}O$ values around + 6 ‰ at temperatures ~200℃ during the retrograde phase of the first metamorphic cycle (t=~3600Ma);this chlorite + quartz assemblage was converted to garnet 2 at temperatures~500 ℃ during the prograde phase of the second cycle metamorphism (t=~3200

Ma). Portions of stage 2 garnet were subsequently converted to chlorite + quartz by reactions with externally derived water with $\delta^{18}O = \sim 0‰$ during the retrograde phase of the second cycle metamorphism, and then converted to garnet 3 during the prograde phase of the third metamorphic cycle (t=~2600 Ma). Portions of stage 3 garnets were subsequently converted to chlorite + quartz by reactions with the externally derived water of $\delta^{18}O = \sim -4‰$ during the retrograde phase of the third cycle metamorphism and finally to garnet 4. The externally derived water involved in the first cycle retrograde reactions may have been derived from dewatering of metamorphic minerals at deeper depths, those involved in the second cycle retrograde reactions may have been seawater, and the those involved in the third cycle retrograde reactions may have been meteoric water.

The involvement of a large amount of meteoric water during retrograde phases of polymetamorphism is also suggested from $\delta^{18}O$ zonings of quartz pebbles in some metamorphic rocks from the Isua district.

論文審査の結果の要旨

グリーンランド・イスア地域は，残存する世界最古の大陸地殻である。大竹真紀子は，本地域の地質調査を行い，採集した多量の岩石試料について，岩石学的，鉱物学的および地球化学的な様々な特性（K-Ar年代，各種元素比，酸素同位体比など）を多角的，かつミクロレベルで測定し，この地域の岩石が経た温度，圧力，環境（地殻深度）の歴史および溶液との反応の歴史を明らかにし，大陸地殻の生長プロセスについての新しい知見を生み出した。

本研究により，イスア地殻は，38〜18億年前の期間において，200℃以下の低温・２km以浅の環境から，500℃以上の高温・15km以深の深度環境へと約４億年の周期で変遷したことが明らかとなった。

このことは，38億年前には，すでに現在とほぼ同じ厚さの大陸地殻が形成されており，プレートテクトニクスがすでに開始されていたことを示唆する。本研究結果は，「初期地球における大陸地殻は非常に小さく，地質時代と共に増大した」という従来の学説を打ち砕き，新しい地球観の創生につながる画期的な研究であると高く評価できる。

本論文の成果は，大竹真紀子が自立して研究活動を行うに必要な高度の研究能力と学識を有することを示している。したがって，大竹真紀子提出の学位論文は，博士（理学）の学位論文として合格と認める。