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The K-Ar age of schists in Gibbs Island, Antarctica

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남극 깁스 섬에 분포하는 편암의 K-Ar 연대

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Abstract: The K-Ar ages of muscovite and actinolite were determined for metamorphic rocks around The Spit and Toss Bay in the southern part of Gibbs Island, Antarctica. The study area primarily consists of muscovite schist together with subordinate mafic schist. Muscovite ages of four muscovite schists are 26.1±0.6 Ma, whilst the actinolite age of mafic schist is 25.3±0.8 Ma. These results together with those of earlier studies suggest that Gibbs Island has experienced greenschist (± amphibolite) facies metamorphism during Paleogene. Metamorphism is probably related to the opening of Drake Passage and/or the subduction of Shekleton Fracture Zone beneath the western margin of Antarctic Peninsula.

Key words: Gibbs Island, K-Ar age, Drake Passage, Shekleton Fracture Zone

요약. 남극 깁스 섬(Gibbs Island)의 스핏(The Spit)과 토스 만(Toss Bay) 주변에 분포하는 변성암류에 대하여 K-Ar 광물연대를 측정하였다. 변성암류는 백운모 편암으로 구성되어 있으며 부분적으로 염기성 편암이 협재한다. 네 개의 백운모 편암시료에서 26.1±0.6 Ma의 백운모 연대와, 한 개의 염기성 편암시료에서 25.3±0.8 Ma의 양기석 연대를 얻었다. 이러한 결과는 이전의 연구와 함께 고 제3기(Paleogene)의 녹색편암상(± 각섬암상)의 변성작용을 나타낸다. 변성작용은 드레이크 해협(Drake Passage)의 형성 또는 쉐클톤 파쇄대(Shekleton Fracture Zone)가 남극반도의 서쪽 주변부 아래로 서브덕션하는 지구조 운동에 관련된 것으로 생각된다.

주요어: 깁스 섬, K-Ar 연대, 드레이크 해협, 쉐클톤 파쇄대

INTRODUCTION

The Scotia Metamorphic Complex (SMC; Tanner *et al.*, 1982) represents an accretionary wedge related to the subduction at the western margin of the Gondwana supercontinent. Radiometric datings of SMC rocks have yielded ages ranging from late Paleozoic to Cenozoic (Miller, 1960; Dalziel, 1972; Rex, 1976; Tanner *et al.*, 1982; Hervé *et al.*, 1984, 1990, 1991; Trouw *et al.*, 1990; Grunow *et al.*, 1992). Until Tanner *et al.* (1982)

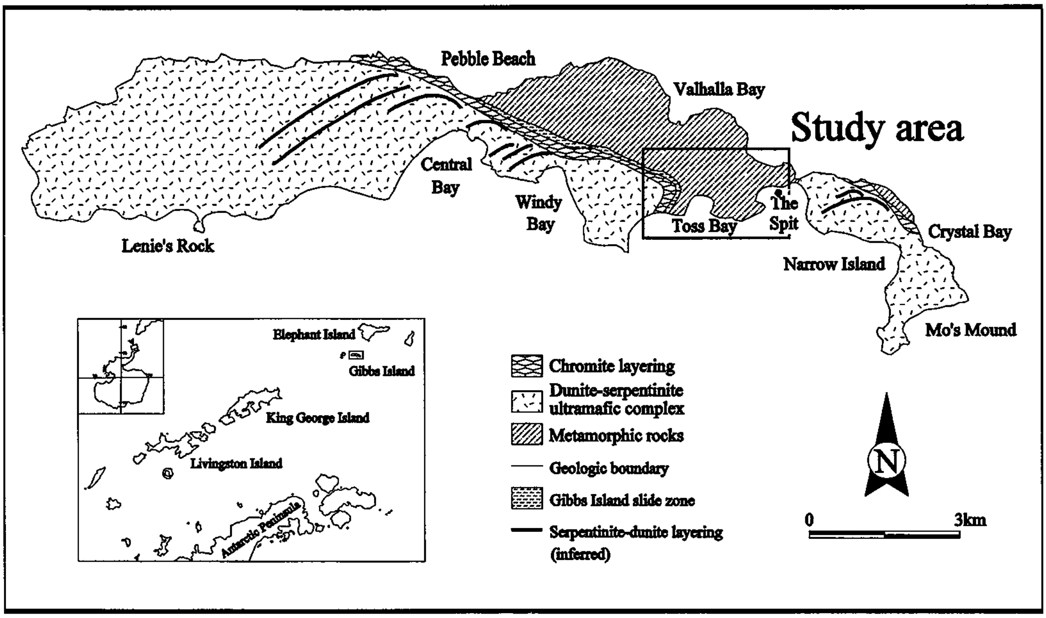

Fig. 1. Simplified geologic map of Gibbs Island after De Wit *et al.* (1977).

obtained the late Cenozoic age in the O'Brien Island, the SMC was considered to be upper Paleozoic to lower Mesozoic. The wide range of radiometric ages suggests that the SMC may have experienced polyphase deformation and metamorphism.

The Gibbs Island schist, a member of SMC, is composed of upper Paleozoic to lower Mesozoic meta-sedimentary rocks formed near the active front of the accretionary wedge. Hervé *et al.* (1991) obtained the Rb-Sr whole rock isochron age of 287±48 Ma, and interpreted this result representing the metamorphic episode during late Carboniferous to early Triassic times (De Wit, 1977). On the other hand, Grunow *et al.* (1992) have recently reported 32±0.5 Ma for the ^{40}Ar-^{39}Ar muscovite age in muscovite garnet schist. In this study, we report on the Cenozoic metamorphic event and its tectonic implication on the evolution of the SMC.

GEOLOGICAL SETTING

Gibbs Island is located 30 km southwest of Elephant Island in a tectonically complex region where the Shakleton Fracture Zone (SFZ) intersects the Antarctic plate margin. In Gibbs Island, dunite-serpentinite complex is associated with chromite layer as well as other metamorphic rocks (Fig. 1). This ultramafic complex probably represents an obducted and disrupted segment of oceanic lithosphere (Moores, 1973). Layerings in the ultramafic complex are entirely tectonic in origin (De Wit *et al.*, 1977). Metamorphic rocks are composed mainly of muscovite schist intercalated with subordinate mafic schist. These metamorphic rocks are in fault-contact with the ultramafic complex (De Wit *et al.*, 1977). Quartz veins ranging 0.1-2 cm in width occur commonly normal to the foliation. Fault zone is filled with serpentine or illite. Detailed geology and structure of the Gibbs Island are available in De Wit *et al.* (1977).

The study area is located in The Spit and Toss Bay areas corresponding to the southeastern part of the Gibbs Island (Fig. 1). Muscovite schist predominates in the study area, and consists of garnet, epidote, muscovite, sphene, calcite, plagioclase, quartz, and opaque mineral. Pale to pink garnet-rich layers are often conspicuous in the calcite-rich matrix (De Wit *et al.*, 1977). The mafic layers occur sporadically in muscovite schist and their thicknesses range up to 1 m. These layers consist of hornblende, actinolite, epidote, plagioclase, chlorite, muscovite, and calcite. The dunite-serpentinite complex consists mainly of serpentines (antigorite,

Table 1. K-Ar age data for muscovite and actinolite.

Sample no.	Mineral	Grain size (μm)	Sample Weight (mg)	K[1] (wt.%)	^{36}Ar (10^{-10}cc/g)	^{40}Ar$_{rad}$ (10^{-8}cc/g)	Air[2] (%)	Age (Ma)
Muscovite schist								
G1	Mus	63-125	30.9	8.45	107.812	890.355	26.39	27.0±0.6
G4	Mus	63-125	28.6	7.96	139.993	765.393	35.14	24.6±0.6
G6	Mus	63-125	28.1	8.10	133.580	834.106	32.17	26.3±0.6
G10	Mus	63-125	26.8	6.53	110.245	673.405	32.67	26.4±0.6
Mafic schist								
G11	Act	63-125	59.5	0.63	22.030	61.963	51.35	25.3±0.8

Mineral abbreviations: Act, actinolite; Mus, muscovite.

1) Experimental uncertainty for determining the K concentration by atomic absorption method is estimated to be ±3%.

2) Air fraction.

crysotile, and lizardite), calcite, talc, and magnetite, and preserves primary olivine and pyroxene. This complex is strongly serpentinized especially near the Gibbs Island slide zone (De Wit *et al.*, 1977) (Fig. 1).

Three deformation events (early-D_E, main-D_M, and late-D_L) were recognized in the study area (De Wit *et al.*, 1977; Dalziel, 1984). D_E is restricted to the ultramafic complex (De Wit *et al.*, 1977). D_M governs the major structure of the island, and defines the penetrative foliation in both ultramafic complex and metamorphic rocks. D_L locally develops as tight to open folds, but is recognizable in the whole rock units. Tight folds related to D_L are well observed in the eastern part of the Toss Bay. Lower greenschist facies metamorphism is associated with D_M, whereas upper greenschist-lower amphibolite facies metamorphism is attributed to D_L (De Wit *et al.*, 1977).

SAMPLE PREPARATION AND EXPERIMENTAL METHODS

Mineral samples for the K-Ar age determination were selected from both muscovite schist and mafic schist. The sample locations are shown in Fig. 2. Mineral assemblages (+plagioclase, quartz, and oxide mineral) of muscovite schist and mafic schist are epidote+sphene+muscovite+chlorite±garnet and epidote+sphene+actinolite+chlorite+muscovite, respectively. The analyzed samples are deformed by D_L after the formation of metamorphic minerals such as garnet, epidote, actinolite, and muscovite. Garnet and/or epidote appear as the scattered grains within the folded actinolite or muscovite layer. No neoblasts grew during D_L.

Muscovite and actinolite used for the K-Ar analysis were separated using an isodynamic separator after crushing, sieving, and cleaning of rock specimens. Mineral separates were finally prepared by hand picking. Minerals with the size 63-125 μm were used to determine the potassium concentration and argon isotopic ratio.Quantitative analysis of potassium was carried out by using the atomic absorption method with the Varian Spectra AA20 at Polar Research Center, Korea Ocean Research and Development Institute. Experimental uncertainty is estimated to be ±3% based on multiple measurements of standard sample (JR-1).

As details on the Ar analysis will be reported by Nagao *et al.* (in prep.), only an outline of the procedure is described here. Quantitative analysis of argon was performed on a modified VG5400 noble gas mass spectrometer, using the isotopic dilution method at the Institute for Study of the Earth's Interior, Okayama University. The weight of each sample varied from 27 mg to 60 mg, depending on the potassium concentration of the separated mineral (Table 1). Samples were wrapped in Al-foil (10 μm thick), then pre-heated at 180°C for a day in a sample holder connected to an ultra-high vacuum Ar extraction and purification system to remove an atmospheric Ar. Argon was extracted by fusing the sample at about 1600°C for 15 minutes in an elec-

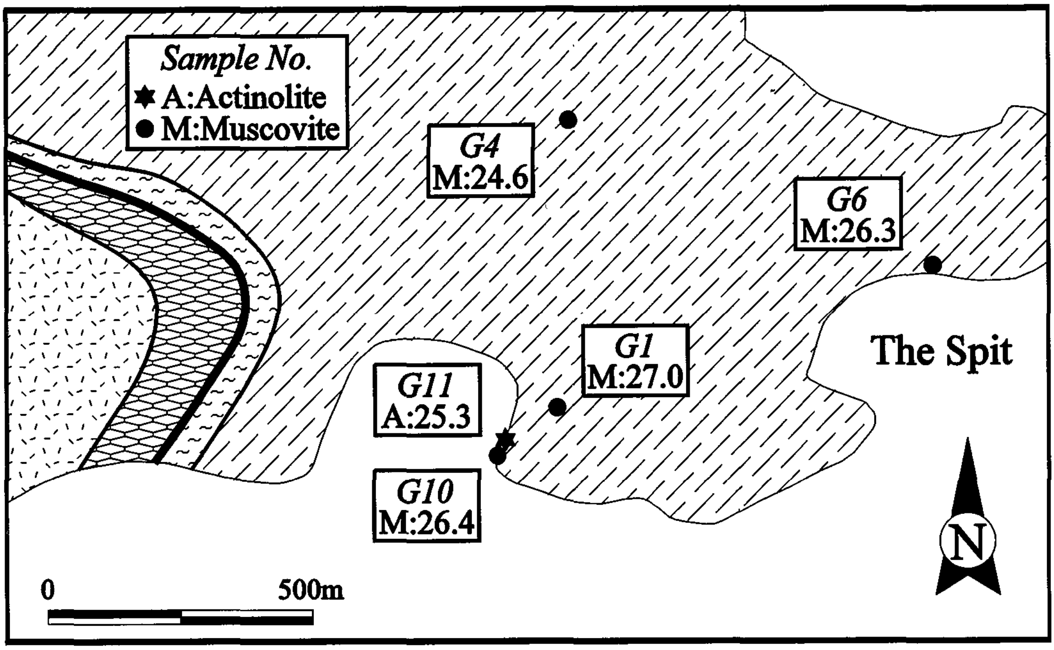

Fig. 2. Geologic map of the study area. Symbols of solid circles and star denote the sample locations.

tric furnace, then spiked by ^{38}Ar and purified by two Ti-Zr getters heated at 800°C.

RESULT AND DISCUSSION

Results of the isotopic analysis for muscovite and actinolite are listed in Table 1, and also shown in Fig. 2.

Muscovite: The K-Ar ages of four muscovite schists range from 24.6±0.6 Ma to 27.0±0.6 Ma (Table 1). These ages are slightly younger than those of Grunow *et al.* (1992) who reported an ^{40}Ar-^{39}Ar muscovite age of 32±0.5 Ma from muscovite garnet schist. The apparent discrepancy is probably due to the difference in the grain size of muscovite seperates or in the closure temperature of two isotopic systems (Itaya and Takasugi, 1988).

Actinolite: An actinolite sample seperated from mafic schist produced the K-Ar age of 25.3±0.8 Ma. This result is compatible with Tanner *et al.* (1982) who have obtained K-Ar hornblende age of 29 Ma from the O'Brien Island schists. The K-Ar actinolite age is identical to or slightly younger than K-Ar muscovite ages, although the closure temperature of actinolite is higher than that of muscovite. Similar result was obtained by Grunow *et al.* (1992) who have attributed identical hornblende and muscovite ages to rapid cooling of high-temperature schists from Rowett Island, Elephant Island Group. In the study area, however, actinolite is closely associated with fine-grained muscovite (smaller than 100 μm in the maximum dimension) and retrograde chlorite. Because the grain size of our actinolite separate is in the range of 63-125 μm (Table 1), it would be implausible to remove completely the fine-grained impurities solely by hand picking technique. Thus our actinolite separate may contain small amounts of muscovite and chlorite (Sisson and Onstott, 1986; Baldwin and Harrison, 1989). These impurities may account for the identical actinolite and muscovite ages, because the potassium content of actinolite is very low (Table 1).

The Rb-Sr whole rock isochron age of 287±48 Ma reported in Gibbs Island (Hervé *et al.*, 1991) is older than not only the K-Ar ages of this study but also the ^{40}Ar-^{39}Ar muscovite age of Grunow *et al.* (1992). These age differences suggest that later metamorphic event has occurred at low temperatures not to reset the Rb-Sr whole rock isotope system. This suggestion is consistent with the lack of neoblasts accompanying D_L. Hence, in contrast to the previous result by early workers (De Wit *et al.*, 1977; Grunow *et al.*, 1992), it is unlikely that the highest grade of metamorphism in Gibbs Island was achieved during late-stage deformation (D_L).

Both muscovite and actinolite have experienced after their formation various deformational, metmorphic, and uplifting processes. These processes may cause the Ar-loss in the analyzed minerals. The extent of argon depletion in muscovite depends on not only the grain size but also the severity and duration of low-temperature deformation (Itaya and Takasugi, 1988). Thus, K-Ar ages of this study may not correspond to the cooling ages of muscovite and actinolite but the deformation ages related to D_L and/or uplift process. Because the relationship between D_L and uplift process is still ambiguous, resolution for the Ar-loss problem awaits for further studies.

Grunow *et al.* (1992) suggested that Miocene opening of Drake Passage and initiation of the SFZ may account for the emplacement of the ultramafic complex in Gibbs Island. The emplacement of ultramafic complex into the country rock schists has accompanied local deformation (D_L) and upper greenschist to lower amphibolite facies metamorphism in the schists. Their suggestion, however, contrasts with the development of foliation in the ultramafic complex. Alternatively, De Wit *et al.* (1977) proposed that the ultramafic complex was emplaced within the schists prior to or during the main phase deformation (D_M). Both rock units are in fault-contact, and there is no evidence for the contact metamorphism resulting from the emplacement of dunite-serpentinite complex.

Extensional joints are present in both ultramafic complex and metamorphic rocks, and filled with serpentine and quartz, respectively. These joints are propably formed by the uplift process that may be related to the initiation of Drake Passage. Joints in both ultramafic complex and metamorphic rocks have identical attitude of NW strike and SW dip. It is thus likely that the uplifting has occurred after D_M and/or D_L.

Upper Cenozoic metamorphism in southern South America and Antarctic Peninsula has been reported by previous studies (Allen, 1982; Tanner *et al.*, 1982; Grunow *et al.*, 1992). Opening of Drake Passage and Powell Basin and initiation of the SFZ result from the left-lateral transform motion along both the SFZ and the South Scotia Ridge (Barker, 1982; Dalziel and Brown, 1989; Pelayo and Wiens, 1989; Cunningham *et al.*, 1995). It was about 80 Ma that Antarctic Peninsula began to rotate clockwise relative to southern South America (Cunningham *et al.*, 1995). Dalziel and Brown (1989) and Grunow *et al.* (1992) suggested that tectonic denudation of the Cordillera Darwin core complex occurred at 70-78 Ma. Grunow *et al.* (1992) also interpreted the ^{40}Ar-^{39}Ar age of 32 Ma corresponding to the uplifting stage of metamorphic rocks in Gibbs Island. Thus late Paleogene ages of this study from Gibbs Island may represent the timing of the uplift of an upper Paleozoic to lower Mesozoic subduction complex, initiated probably by the opening of Drake Passage and/or the subduction of Shakleton Fracture Zone beneath the Antarctic Peninsula margin.

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