# GARNET-SILLIMANITE GNEISSES FROM THE LÜTZOW-HOLM BAY REGION, EAST ANTARCTICA

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***Abstract:*** This paper presents the regional distribution and petrographical features of garnet-sillimanite gneisses in the Lützow-Holm Bay region, East Antarctica. In addition to sillimanite, such aluminous silicate and oxide minerals as kyanite, staurolite, sapphirine and spinel occur in the gneisses. Among them, sapphirine is the first report in a pelitic rock from the region. From their microscopic textures, it is inferred that the rocks in the region suffered the prograde metamorphism of kyanite-sillimanite type as those in the Prince Olav Coast did. Thus, it is clarified that the rocks in the present region and the Prince Olav Coast have the same metamorphic history and possibly belong to the same geological unit. The metamorphic grade is expected to increase progressively towards the southern part of the Lützow-Holm Bay region.

## 1. Introduction

The Lützow-Holm Bay region, East Antarctica, is underlain by Precambrian high-grade metamorphic rocks associated with various kinds of plutonic rocks. Among them, aluminous metapelite which is referred to as garnet-sillimanite gneiss in this paper, occurs at several localities in the region. It is mostly interbedded with surrounding metamorphic rocks and is characterized to the naked eye by large crystals of garnet and sillimanite as main constituents. In addition, kyanite, staurolite, sapphirine and spinel are present as inclusions within garnet in the gneisses. HIROI *et al.* (1983a) have reported the regional distribution of staurolite and three polymorphs of $Al_2SiO_5$ mineral in the Prince Olav Coast including Langhovde, but the modes of occurrence of these diagnostic minerals have not been described in detail in the Lützow-Holm Bay region.

This paper presents the regional distribution and textural characteristics of such aluminous silicate and oxide minerals in the garnet-sillimanite gneisses from the region. On the basis of the petrographical evidence, metamorphic facies series and recrystallization history of the rocks in the Lützow-Holm Bay region will be discussed.

## 2. Geological and Petrological Outlines of the Lützow-Holm Bay Region

The Lützow-Holm Bay region is underlain largely by well-layered pelitic and intermediate gneisses with subordinate amounts of basic to ultrabasic rocks and calc-silicate rocks. Granitic and migmatitic rocks occur occasionally.

The pelitic rock comprises biotite gneiss, garnet-biotite gneiss and several kinds of sillimanite-bearing gneiss as described in this paper. The intermediate rock is represented by hornblende gneiss and pyroxene gneiss (charnockitic rock). The Lützow-Holm Bay region is characterized by the wide occurrence of pyroxene gneiss. Basic to ultrabasic rocks occur as thin layers, boudinaged pods or as isolated blocks in the pyroxene gneiss. Granitic and pegmatitic rocks are commonly observed in the region. Whole rock and mineral ages by K-Ar, Rb-Sr and U-Pb methods are mostly concentrated around 500 Ma (NICOLAYSEN *et al.*, 1961; MAEGOYA *et al.*, 1968; SAITO and SATO, 1964; YANAI and UEDA, 1974), which is considered to be coeval with their plutonic activities.

Since the 1st Japanese Antarctic Research Expedition, geological survey around the Lützow-Holm Bay region has been carried out by many Japanese geologists, and a great volume of data have been accumulated up to the present. On the basis of these data, petrological and mineralogical outlines of the metamorphic rocks in the region are summarized as follows.

(1) The Lützow-Holm Bay region is a granulite-facies terrain as revealed by BANNO *et al.* (1964) and SUWA (1968).

(2) Sillimanite is the stable aluminum silicate in the region (YOSHIDA *et al.*, 1976; YOSHIDA, 1978, 1979a, b). However, kyanite has also been discovered recently as a metastable relic in sillimanite-bearing gneisses from Langhovde (HIROI *et al.*, 1983a), Skallen (HIROI, personal communication) and Rundvågshetta (MOTOYOSHI *et al.*, 1984), respectively.

(3) Cordierite has been described from some localities in the Prince Olav Coast (HIROI *et al.*, 1983a; SUZUKI, 1984), but it has not been reported from the Lützow-Holm Bay region so far.

(4) KATSUSHIMA (1985) recently discovered an Fe-rich orthopyroxene ($X_{Fe}>0.9$) in pyroxene gneiss from Sigaren, west of Langhovde. On the basis of the experimental data by BOHLEN *et al.* (1980) and BOHLEN and BOETTCHER (1981), he estimated the pressure condition above 9 kbars at 800°C.

Thus, several lines of evidence suggest that the pressure condition of the regional metamorphism of the Lützow-Holm Bay region is higher than those previously estimated.

## 3. Petrography of the Garnet-Sillimanite Gneisses

The regional distribution of garnet-sillimanite gneisses in the Lützow-Holm Bay region is shown in Fig. 1. The rocks are leucocratic and coarse-grained, and generally occur as concordant thin layers up to about 1 m thick within the surrounding metamorphic rocks.

The mineral assemblages of the gneisses are summarized in Table 1, and the

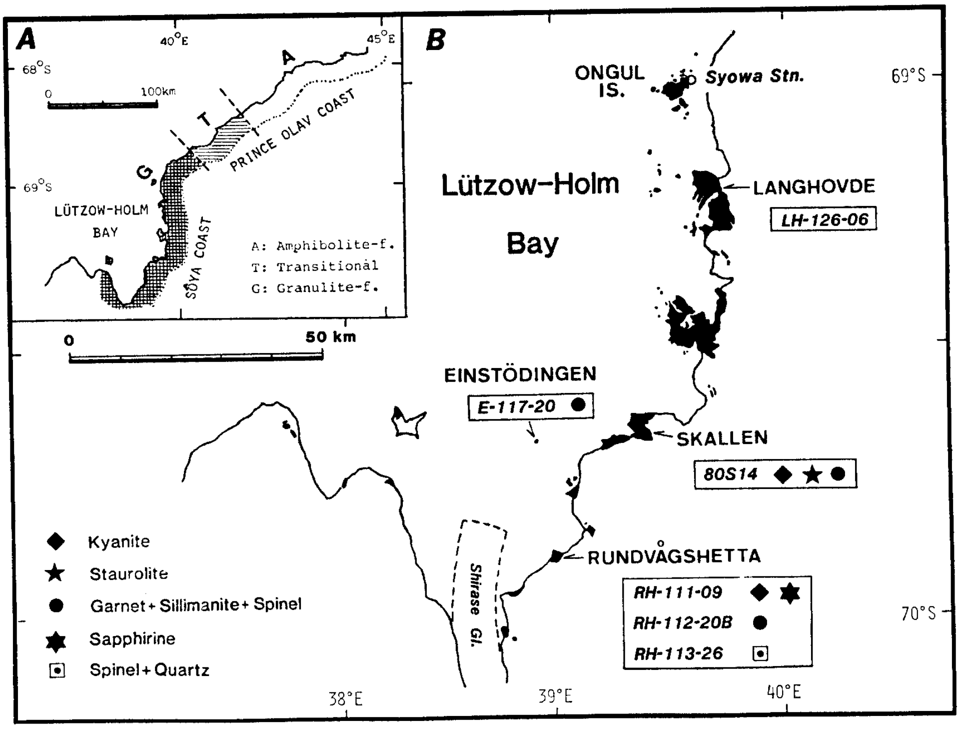


*Fig. 1. A: Metamorphic facies along the Prince Olav and Sôya Coasts (after HIROI et al., 1983a). B: Occurrence of diagnostic minerals and mineral asssociations in garnet-sillimanite gneisses (with specimen no.) in the Lützow-Holm Bay region.*

*Table 1. Mineral assemblages in the garnet-sillimanite gneiss.*

| Specimen No. | Gar | Sill | Ky | St | Sa | Sp | Bt | Pl | Kf | Qz | Ru | Il | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LH-126-06 | + | + | | | | | — | + | + | + | + | + | Zr |
| 80 S 14 | + | + | (—) | (—) | | + | — | + | + | + | + | + | |
| E-117-20 | + | + | | | | (+) | — | + | + | + | + | | Zr |
| RH-111-09 | + | + | (—) | | (—) | — | — | + | + | + | + | + | |
| RH-112-20B | + | — | | | | (—) | + | + | | + | | + | Zr |
| RH-113-26 | | + | | | | + | + | | + | + | + | | Zr, Ap |

Abbreviations: Ap–apatite, Il–ilmenite, Pl–plagioclase, Sa–sapphirine, St–staurolite, Bt–biotite, Kf–K-feldspar, Qz–quartz, Sill–sillimanite, Zr–zircon, Gar–garnet, Ky–kyanite, Ru–rutile, Sp–spinel; + common, — rare, ( ) as inclusion

microscopic textures of constituent minerals are shown in Figs. 2 through 6. The petrographical descriptions of each mineral are briefly given below.

Garnet is generally rounded and coarse-grained up to 5 mm in diameter. Porphyroblastic grains frequently include other minerals such as quartz, plagioclase, sillimanite, kyanite, staurolite, spinel, sapphirine, ilmenite, rutile and biotite (Figs. 2A, 2B, 3B, 3C, 4B, 5A, 5B, 5C and 6A). Garnet and K-feldspar are often in direct contact (Figs. 4C and 5C). Garnets from Einstödingen and Rundvågshetta are pyrope-rich with $X_{Mg}$ up to 0.56 in maximum.

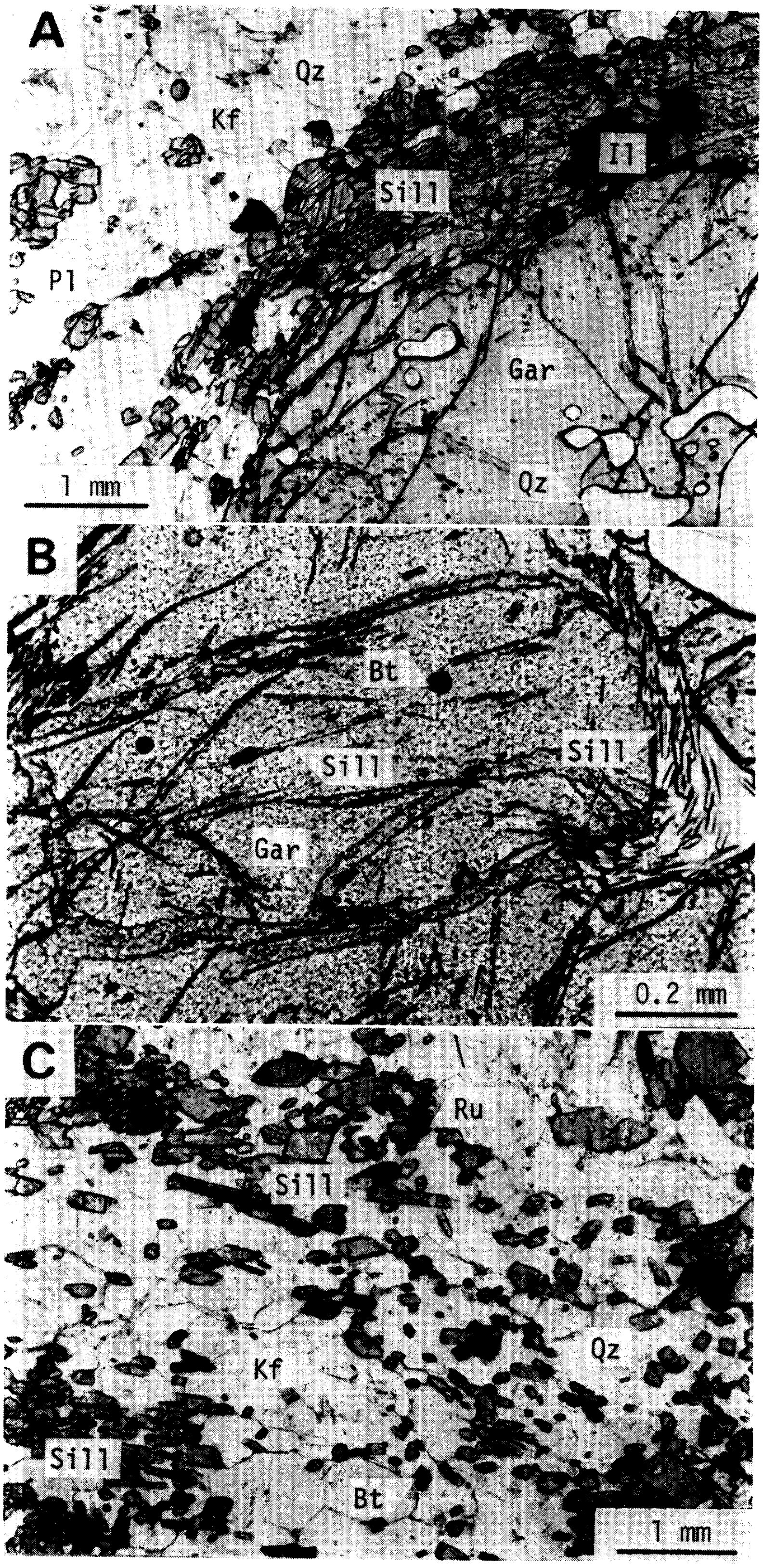


*Fig. 2A. Aggregate of idiomorphic sillimanite fringing garnet with quartz inclusions.*

*Fig. 2B. Needle-like sillimanite and tiny rounded biotite in garnet.*

*Fig. 2C. Idiomorphic sillimanite in the matrix. They coexist with K-feldspar, biotite, quartz and rutile.*

*Fig. 2. Photomicrographs showing textures of garnet-sillimanite gneiss from Langhovde (sp. LH-126-06).*

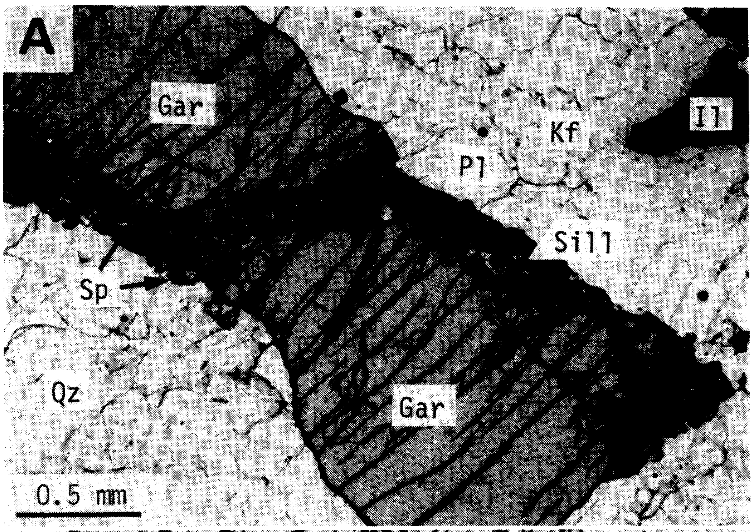


*Fig. 3A. Garnet + sillimanite + spinel association in the matrix of plagioclase, K-feldspar, quartz and ilmenite.*

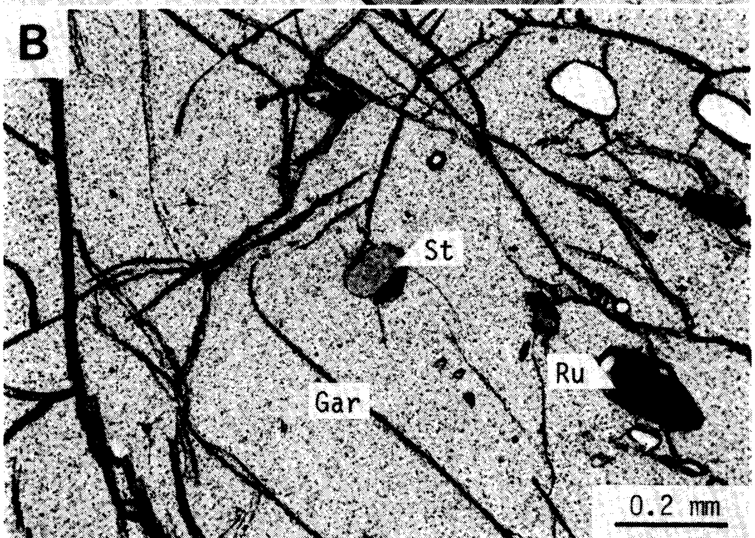


*Fig. 3B. Staurolite and rutile inclusions in garnet.*

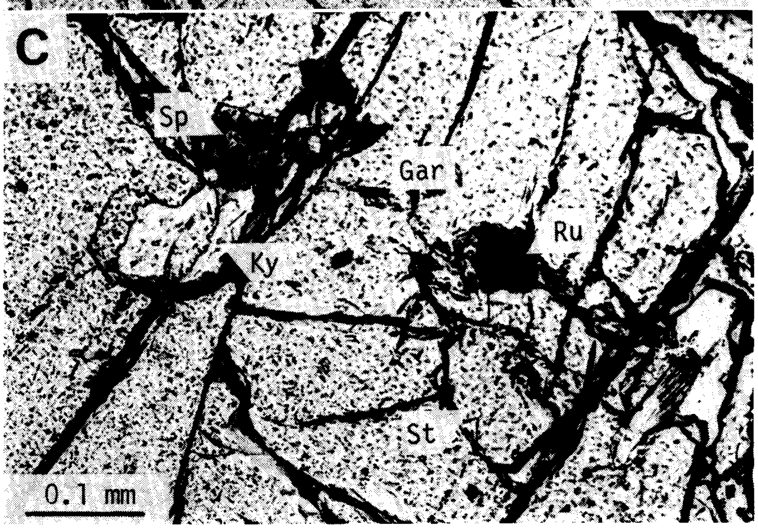


*Fig. 3C. Kyanite, staurolite and spinel inclusions in garnet. Kyanite is never present in the matrix.*

*Fig. 3. Photomicrographs showing textures of garnet-sillimanite gneiss from Skallen (sp. 80S14).*

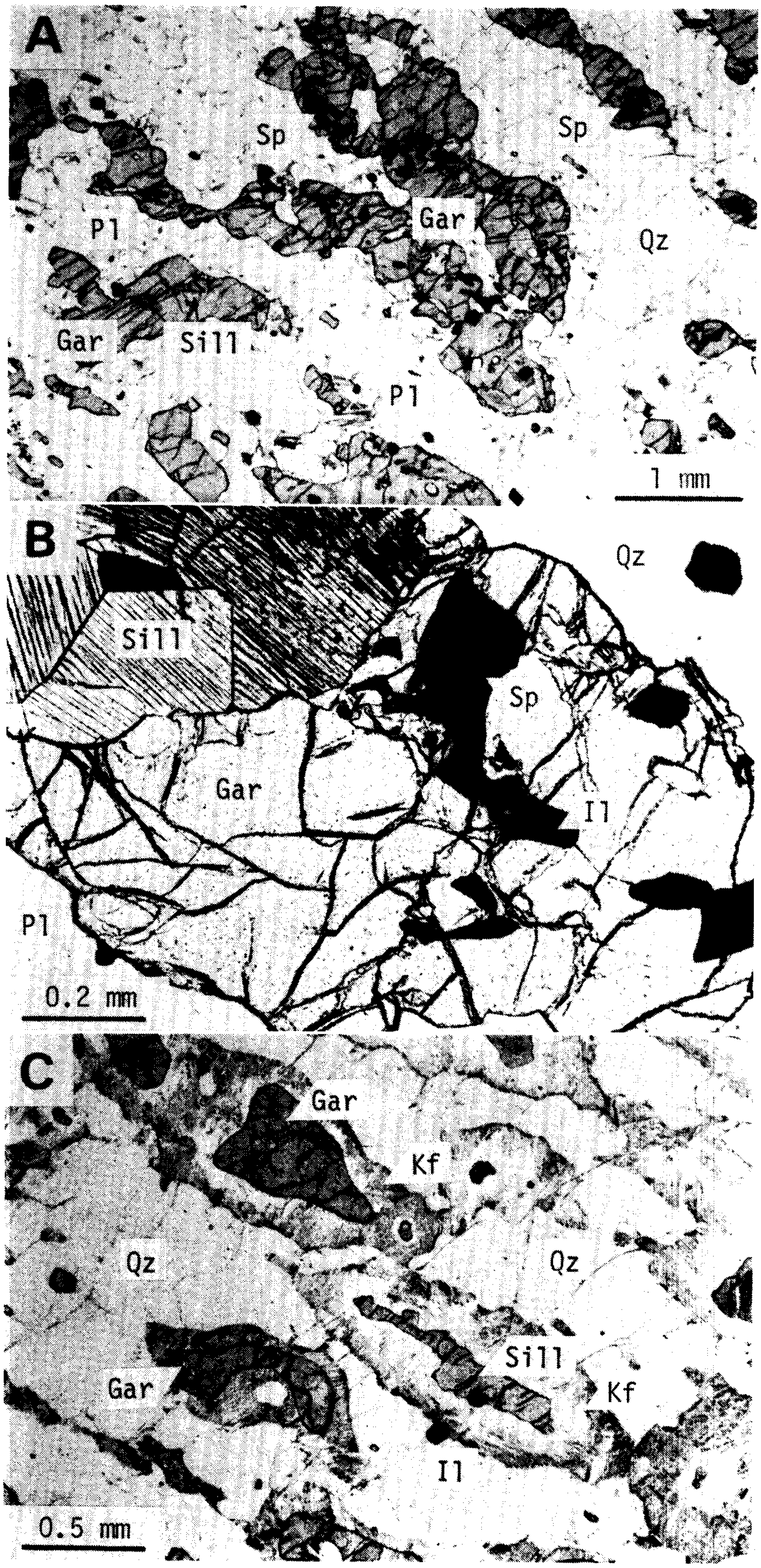


*Fig. 4A. Garnet + sillimanite + spinel association in the plagioclase + quartz matrix.*

*Fig. 4B. Spinel and ilmenite inclusions in garnet associated with sillimanite.*

*Fig. 4C. Garnet + K-feldspar and sillimanite + K-feldspar associations. This specimen lacks biotite.*

*Fig. 4. Photomicrographs showing textures of garnet-sillimanite gneiss from Einstödingen (sp. E-117-20).*

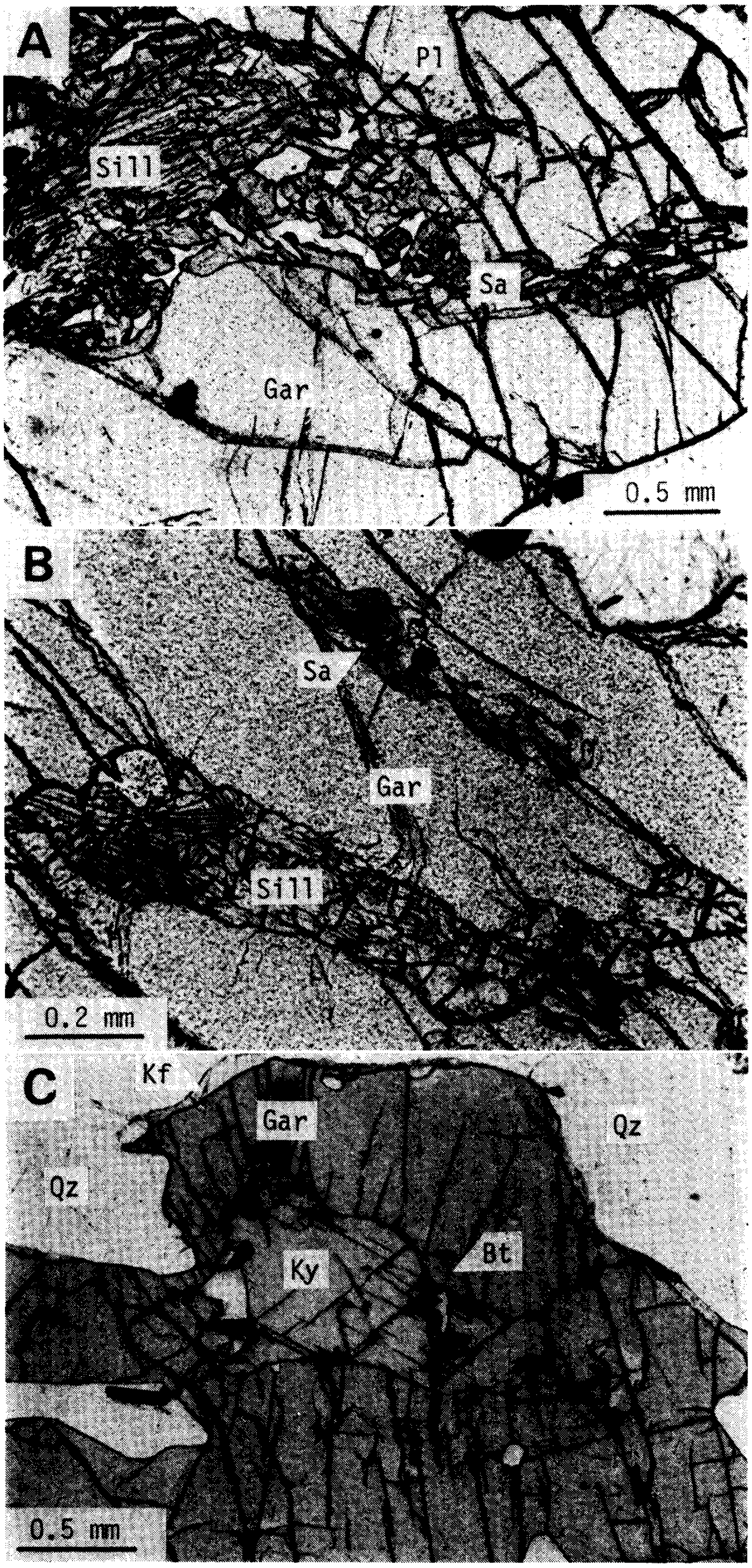


*Fig. 5A. Sapphirine + sillimanite + plagioclase association included in garnet.*

*Fig. 5B. Sapphirine and sillimanite inclusions in garnet.*

*Fig 5C. Kyanite with distinct cleavage and rounded biotite inclusions in garnet. K-feldspar fringes garnet.*

*Fig. 5. Photomicrographs showing textures of garnet-sillimanite gneiss from Rundvågshetta (sp. RH-111-09).*

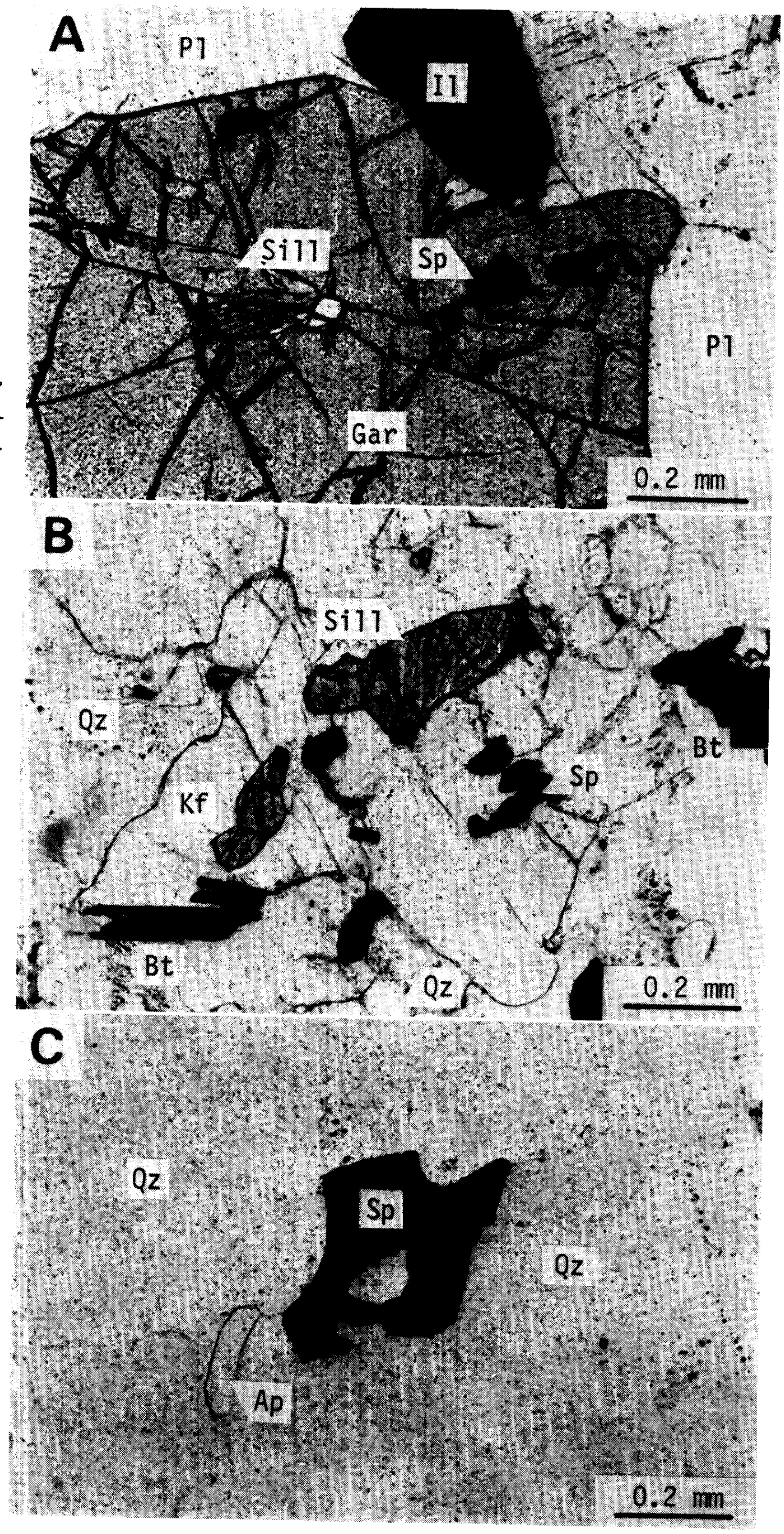


*Fig. 6A. Garnet + sillimanite + spinel association coexisting with ilmenite and plagioclase (sp. RH-112-20B).*

*Fig. 6B. Sillimanite and spinel in the matrix. They coexist with K-feldspar, quartz and biotite (sp. RH-113-26). Garnet is not present in this specimen.*

*Fig. 6C. Spinel in direct contact with quartz. Apatite is additionally present (sp. RH-113-26).*

*Fig. 6. Photomicrographs showing textures of garnet-sillimanite gneiss from Rundvågshetta.*

Sillimanite shows two modes of occurrence under the microscope; one is as idiomorphic stout prisms in the matrix out of garnet, and the other is as inclusions in garnet. The latter is mostly xenomorphic and is occasionally associated with spinel, sapphirine and plagioclase (Figs. 5A and 5B). The matrix sillimanite coexists stably with K-feldspar, plagioclase and quartz (Figs. 2A, 2C, 3A, 4B, 4C and 6B).

Kyanite is rare, and has been found from Langhovde (HIROI *et al.*, 1983a), Skallen (Fig. 3C) and Rundvågshetta (Fig. 5C). It always occurs as inclusion in garnet and is reasonably interpreted to be a relic.

Staurolite is extremely rare in the region and has been found from Skallen (Figs. 3B and 3C). It is a tiny grain included in garnet. It occurs together with kyanite and is also considered to be a relict mineral of prograde staurolite-consuming reactions which will be discussed later.

Sapphirine in a pelitic rock is firstly described in this paper. The locality is at Rundvågshetta (Fig. 1). As is shown in Figs. 5A and 5B, sapphirine shows a complicated form, being interlocked with sillimanite and plagioclase. They are totally included in garnet.

Spinel usually occurs as inclusions in garnet (Figs. 4B and 6A), but also occurs in the matrix closely associated with sillimanite (Figs. 3A and 6B). The stable association of spinel+quartz is found in sp. RH-113-26 (Fig. 6C), in which garnet is not present.

Biotite is a minor phase in these rocks. It is generally deep reddish brown and occurs as small grains included in garnet and as a matrix mineral with K-feldspar and quartz. Some of them are Ti-rich with up to 8 wt% $TiO_2$. However, in two specimens from Rundvågshetta (sp. RH-112-20B and RH-113-26), biotite is not rare and occurs as flakes with light brown color in the matrix (Fig. 6B). They might be retrograde products.

Rutile and ilmenite are present commonly and they are generally associated with garnet and sillimanite as well (Figs. 2A, 2C, 3B, 4B and 6A).

## 4. Interpretation of the Textures

### *4.1. The prograde metamorphism*

Kyanite and staurolite always occur as inclusions in garnet, and are reasonably interpreted to be relict minerals formed at early stages of the metamorphic recrystallization. Textural evidence suggests that sillimanite was the stable aluminum silicate at the peak of regional metamorphism while kyanite was a metastable one. Similarly, staurolite* was an isolated relic of staurolite-consuming reactions at that time. On the other hand, the common occurrence of its breakdown product, garnet+sillimanite +spinel assemblage, suggests that most staurolites were already hydrated. Thus, the following reactions are inferred to have taken place during prograde metamorphism of the gneisses,

kyanite = sillimanite,

* The staurolite in sp. 80S14 is characterized by high Ti and Al contents (HIROI *et al.*, in preparation), which may be noticeable features of the mineral from granulite-facies terrains over the world.

staurolite + quartz = garnet + sillimanite + $H_2O$,
staurolite = garnet + sillimanite + spinel + $H_2O$.

*4.2. The peak conditions of regional metamorphism*

In order to estimate the peak metamorphic conditions, the following petrographical evidence is important.

The sillimanite + K-feldspar association is commonly observed throughout the region without primary nor secondary muscovite. This means that the muscovite was no more stable in the presence of quartz by the following reaction,

muscovite + quartz = sillimanite + K-feldspar + $H_2O$.

Cordierite has not been reported in rocks from the Lützow-Holm Bay region, while it is occasionally found in rocks from the Prince Olav Coast (HIROI *et al.*, 1983a; SUZUKI, 1984). In particular, SUZUKI (1984) reported an extremely magnesian cordierite ($X_{Mg}=0.95$) from Cape Omega. Although it is questionable whether such Mg-rich cordierite is still stable in rocks from the Lützow-Holm Bay region, the common occurrence of garnet + sillimanite + quartz assemblage would be responsible for the disappearance of less magnesian cordierite in the region as follows,

cordierite = garnet + sillimanite + quartz,

which proceeds to the right-hand side as the pressure increases (*e.g.*, HENSEN, 1977; HENSEN and GREEN, 1971; HOLDAWAY and LEE, 1977; THOMPSON, 1976).

The spinel + quartz association (Fig. 6C) is also important indicating a high temperature condition of metamorphism. As MIYASHIRO (1965) and HENSEN and GREEN (1971) predicted theoretically and/or experimentally, that spinel can coexist with quartz stably at high temperatures possibly due to the next reactions,

garnet + sillimanite = spinel + quartz,
cordierite = spinel + quartz.

Recent reports of the natural coexistence of spinel + quartz in high-grade rocks (HARIS, 1981; KARS *et al.*, 1980; LEYRELOUP *et al.*, 1982; VIELZEUF, 1983) agree with the predictions.

Another important mineral assemblage is garnet + rutile + ilmenite + sillimanite + quartz which is univariant in the system $Al_2O_3$-$TiO_2$-FeO with excess $SiO_2$ as quartz as follows,

ilmenite + sillimanite + quartz = almandine in garnet + rutile.

The equilibrium relation is used as a potential geobarometer which has recently become available by BOHLEN *et al.* (1983).

## 5. Discussions

Petrographical evidence given in this paper suggests that granulite-facies rocks in the Lützow-Holm Bay region have undergone the prograde metamorphism of kyanite-sillimanite type. This conclusion is in good agreement with that of HIROI *et al.* (1983a) obtained from the Prince Olav Coast.

Further, HIROI *et al.* (1983b) and SHIRAISHI *et al.* (1984) revealed that the metamorphic grade increased progressively westwards from the amphibolite- to lower granulite-facies along the Coast. Since the studies by BANNO *et al.* (1964) and SUWA (1968), it has been generally accepted that the Lützow-Holm Bay region is the granulite-facies terrain. The quantitative estimation of the metamorphic conditions have been attempted using some geothermometers and geobarometers (*e.g.*, SUZUKI, 1983; YOSHIDA, 1979b; YOSHIDA and AIKAWA, 1983). Recently, MOTOYOSHI (1985) has revealed the existence of thermal gradient in the region based on the systematic investigation of the Fe-Mg partitioning between ortho- and clinopyroxene in pyroxene gneisses (charnockitic rocks). In this connection, MATSUBARA and MOTOYOSHI (1985) reported a potassium pargasite with $K_2O$ up to 3.19 wt% and a pyrope-rich garnet ($Pyr_{55.3}Alm_{38.3}Grs_{6.4}$) from Einstödingen, a small islet in Lützow-Holm Bay (Fig. 1). The high grade mineral assemblages described in this paper are consistent with the mineralogical data mentioned above. Taking these data into consideration, the highest grade rocks possibly occur at the southern part of the Lützow-Holm Bay region. The maximum *P-T* conditions would be up to 850°C at 10 kbars (MOTOYOSHI *et al.*, 1984), under which sapphirine would have existed stably in an appropriate bulk composition. Recent reports on natural garnet+sapphirine association (GREW, 1982, 1983; ARIMA, 1984) also yielded the high *P-T* conditions.

Conclusively, it is highly probable that rocks in both the Prince Olav Coast and the Lützow-Holm Bay region have the same metamorphic history. The grade of metamorphism increases progressively towards the southern part of Lützow-Holm Bay.

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