A NEW INSIGHT OF POSSIBLE CORRELATION BETWEEN THE LÜTZOW-HOLM BAY GRANULITES (EAST ANTARCTICA) AND THE SRI LANKAN GRANULITES

Y. OGIO¹, Y. HIROI¹, K. B. N. PRAME² and Y. MOOTOYOSHI³

¹Department of Earth Sciences, Faculty of Science, Chiba University, Yayoicho, Inage-ku, Chiba 263, Japan
²Geological Survey Department, Sri Jinaratana Road, 48, Colombo 2, Sri Lanka
³National Institute of Polar Research, 1-9-10, Kaga, Itabashi-ku, Tokyo 173, Japan

Abstract: Detailed petrological study was made on Sri Lankan pelitic granulites to reveal their metamorphic evolution which would be helpful in understanding the geological evolution of East Antarctica mostly covered by thick continental ice. The central-western part of southern Sri Lanka is divided into three areas, A-C, based on the lithological and petrographical characteristics as well as the distinctively different neodymium model ages. Rocks in areas A and B characteristically carry relict minerals and mineral assemblages such as kyanite + quartz, kyanite ± hercynite ± sapphire, corundum ± kyanite and stauroliite as inclusions within garnet. These relics were formed at a prograde metamorphic stage, suggesting a clockwise P-T-t path of the rocks. On the other hand, rocks in areas B and C commonly contain cordierite which was produced at the expense of pre-existing garnet at the peak to later stages. In area A the sillimanite + garnet + quartz sub-assemblage is widespread, and rare cordierite is highly magnesian. These facts suggest that rocks in area A began to cool at high pressures while those in areas B and C experienced nearly isothermal decompression due to slow exhumation and recovery of geotherm. Retrograde andalusite occurs throughout the areas. These petrological data, together with the existing petrological data on the Lützow-Holm Bay granulites and the recent geochronological data on both Sri Lanka and the region around Lützow-Holm Bay, strongly suggest that the Highland/Southwestern Complex in Sri Lanka and the Lützow-Holm Complex in East Antarctica were once contiguous and formed in the same Late Proterozoic to Early Paleozoic orogenic belt in Gondwanaland. The data may also give a clue to the relationships between the Lützow-Holm Complex and neighboring the Rayner and Yamato-Belgica Complexes.

Key words: granulite, prograde metamorphism, retrograde metamorphism, exhumation rate, Gondwana

Introduction

In reconstructions of Gondwanaland, Sri Lanka is usually located next to East Antarctica. The study of Sri Lanka, therefore, would provide valuable information about the geological evolution of East Antarctica where the thick ice cover prevents extensive geological investigations.

The purpose of this paper is two-fold. First, to report briefly the occurrence of relict minerals such as kyanite and staurolite in a part of the Sri Lankan sillimanite-rich pelitic granulites (the Highland/Southwestern Complex; hereafter referred to as the HSWC) to unravel their prograde metamorphic history and possible geological correlation with the Lützow-Holm Bay granulites in East Antarctica. The pelitic granulites from around Lützow-Holm Bay (the Lützow-Holm Complex) characteristically contain similar relict minerals as inclusions in garnet and plagioclase, suggesting a clockwise P-T-t path during prograde metamorphism (Hiroi et al., 1983a, b, 1991; Motoyoshi et al., 1985, 1989). In addition, although there are problems concerning the sporadically reported ages of c. 1000 Ma (Kröner et al., 1987; Fanning et al., 1991), it has recently been revealed that, in both Sri Lanka and the region around Lützow-Holm Bay, main high-grade regional metamorphism took place 500–600 m.y. ago (Baur et al., 1991; Hözl et al., 1991; Kröner et al., 1991; Fanning et al., 1991; Shiraishi et al., 1992). Second, to present new information about the peak to later metamorphic histories of Sri Lankan granulites belonging to both the HSWC and the Wanni Complex (WC), which may provide a new insight into the tectonic evolution of that portion of East Antarctica.

Geological Outline of Sri Lanka

High-grade metamorphic rocks and associated plutonic rocks are widespread in Sri Lanka. On the basis of lithology, structure and age, they have traditionally been divided into three geological units; the Highland Series, the Southwestern Group and the Eastern and Western Vijayan Complexes (Cooray, 1978, 1984; Geological Survey Department of Sri Lanka, 1982) (Fig. 1). Both the Highland Series and the Southwestern Group consist mainly of granulite-facies metamorphic rocks and charnockitic rocks with subordinate meta-igneous rocks, whereas the E and W Vijayan Complexes are composed dominantly of migmatitic granitoids with minor amounts of amphibolite- to granulite-facies metamorphic rocks. The Highland Series differs lithologically from the Southwestern Group in that dolomitic marbles and associated quartzites and graphitic garnet-sillimanite gneisses (khondalites) are conspicuous constituents of the Highland Series. It is also distinctive that cordierite and wollastonite occur commonly in the Southwestern Group pelitic and calc-silicate rocks, respectively (Hapuarachchi, 1968). However, the boundary between these two geological units is gradational. The boundary between the Highland Series and the Western Vijayan Complex is also gra-
Fig. 1. Map of Sri Lanka, showing localities of pelitic granulites containing relict kyanite ± staurolite, boundaries between major geological units (their names are shown in parentheses) based on the Geological Map of Sri Lanka (Geological Survey Department of Sri Lanka, 1982) as well as those between newly proposed lithotectonic units (Kröner et al., 1991), and three areas, A-C, discussed the text. "Arenas" are after Vitanage (1972).
tional, whereas that between the Highland Series and the Eastern Vijayan Complex is rather definite, as represented by the thrust faults (see Fig. 1).

Recent extensive studies by the Japan-Sri Lanka Joint Geological Research (Hiroi and Motoyoshi, ed., 1990), the German-Sri Lankan Research Consortium (Kröner, ed., 1991), and others (e.g. Sandiford et al., 1988; Burton and O’Nions, 1990a, b) make it possible to revise the traditional geological division. Thus, based mainly on the neodymium model age mapping by Milisenda et al. (1988) and Liew et al. (1991), Kröner et al. (1991) proposed a new lithotectonic division of the Sri Lankan basement rocks; the HSWC, the WC on the NW and the Vijayan Complex (VC) on the SE (Fig. 1). The newly proposed WC includes not only the whole Western Vijayan Complex but also about halves of the Highland Series and the Southwestern Group of the traditional geological division. The newly defined VC and the traditional Eastern Vijayan Complex are essentially the same. Nd model ages of the HSWC are >2.2 Ga and older than those of the WC and the VC (1.0–2.2 Ga) (Milisenda et al., 1988; Liew et al., 1991). Although there are problems about the new lithotectonic division (e.g. Voll and Kleinschrodt, 1991), we will use both the divisions of the Sri Lankan basement rocks in this paper.

Petrography of Sri Lankan Pelitic Granulites

The central-western part of southern Sri Lanka is divided into three areas, A-C, based on the lithological and Nd model age distinctions mentioned above and the petrographical differences described below (Fig. 1). Typical mineral assemblages of the pelitic granulites in areas A-C are as follows. Minerals with asterisk are definitely secondary in origin.

Area A

1. Sillimanite + garnet + K-feldspar + quartz + ilmenite + graphite.
2. Sillimanite + garnet + biotite + plagioclase + K-feldspar + quartz + rutile + ilmenite ± graphite ± andalusite*.
4. Sillimanite + cordierite + biotite + plagioclase + K-

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**Fig. 2.** Photomicrographs of pelitic granulites from area A in Fig. 1. a: typical graphitic garnet-sillimanite gneiss (khondalite) (G89082204A), containing staurolite, corundum, kyanite + hercynite, and sillimanite + hercynite as inclusions in garnet (plane polarized light); b: typical hematite-bearing sillimanite-cordierite-biotite gneiss (H88112601) (plane polarized light); c: interlocking aluminous orthopyroxene and sillimanite in the matrix of a sapphirine-kyanite-bearing rock (H88112401A) (plane polarized light); d: garnet partially replaced by symplectic intergrowths of cordierite, orthopyroxene, magnetite ± quartz in H88112401A (plane polarized light). Mineral abbreviations: alm = almandine; and = andalusite; bt = biotite; crd = cordierite; crn = corundum; gar = garnet; grs = grossular; he = hercynite; hm = hematite; il = ilmenite; ky = kyanite; mt = magnetite; opx = orthopyroxene; pl = plagioclase; prp = pyrope; q = quartz; rt = rutile; sil = sillimanite; sp = spinel; sps = spessartine; st = staurolite.
feldspar + quartz + hematite± magnetite ± andalusite*.

(5) Sillimanite + cordierite + garnet + orthopyroxene + biotite + plagioclase + K-feldspar + quartz + hematite + magnetite.

In area A the sillimanite + garnet + quartz sub-assemblage is widespread (Figs. 2a and 4), and cordierite has been found to occur sporadically in rocks carrying hematite± magnetite (Figs. 2b, 2d and 4). In Sp. 88112401A with mineral assembly (5), orthopyroxene and sillimanite are interlocked in the matrix (Fig. 2c) and cordierite intergrown with magnetite± sillimanite ± orthopyroxene ± biotite ± plagioclase ± quartz replaces garnet partially from the rim and along cracks (Fig. 2d). Mineral assemblage (1) is peculiar to khondalites, which commonly contain small amounts of such local minerals and mineral assemblages as follows as inclusions in garnet; corundum, corundum + kyanite, corundum + sillimanite, kyanite + quartz, staurolite, kyanite + hercynite ± staurolite, sillimanite + hercynite ± staurolite, biotite and biotite + quartz (Fig. 2a) (Hiroi et al., 1987, 1988, 1990b, in press; Raase and Schenk, 1988; Schumacher et al., 1990; Schenk et al., 1991). Thus, in khondalites hydrous minerals occur only as inclusions within garnet, suggesting that dehydration reactions have completed in the matrix of this kind of rocks. Some other pelitic rocks with mineral assemblages (2), (3) and (5) also carry similar local minerals and mineral assemblages which are completely included in garnet (Hiroi et al., 1987, 1988, 1990b, in press; Raase and Schenk, 1988; Schumacher et al., 1990; Schenk et al., 1991). Moreover, garnet in Sp. 88112401A encloses the rare local mineral assemblage kyanite ± sapphire ± spinel ± biotite (see Hiroi et al., in press).

Area B

(6) Sillimanite + cordierite + garnet + biotite + plagioclase + K-feldspar + quartz + rutile + ilmenite ± hercynite ± andalusite* ± muscovite* ± siderite*.

In area B both the sillimanite + garnet + quartz sub-assemblage and cordierite are common and observed even within the same thin section. Cordierite with or without hercynite, plagioclase and K-feldspar replaces garnet, biotite and sillimanite partially (Figs. 3a and b). Garnet in rocks with mineral assemblage (6) sometimes contains inclusions of kyanite ± hercynite (Hiroi et al., 1987, 1988, 1990b, in press; Prame, 1991a).

Area C

(7) Sillimanite + cordierite + garnet + biotite + plagioclase + K-feldspar + quartz + hematite + magnetite ± hercynite ± ilmenite ± andalusite* ± muscovite* ± rutile* ± siderite*.

(8) Cordierite + plagioclase + K-feldspar + quartz + ilmenite + magnetite ± garnet ± biotite ± andalusite* ±

Fig. 3. Photomicrographs of pelitic granulites from areas B and C in Fig. 1. a: mineral texture suggestive of reaction (j) (H88120502 from area B) (plane polarized light), b: mineral texture indicative of reaction (k) (H88120206 from area C) (plane polarized light), c (plane polarized light) and d (crossed polars): mineral texture suggestive of reaction (m) (H88120103A from area C). See Fig. 2 caption for mineral abbreviations.
muscovite* ± rutile* ± siderite*.

(9) Cordierite + garnet + orthopyroxene + biotite + plagioclase + K-feldspar + magnetite ± hematite.

Mineral assemblage (8) is observed mainly in coarse-grained migmatitic rocks, and mineral assemblage (9) is seen in locally charnockitized rocks (see Hiroi et al., 1990b). Cordierite in area C is violet with the naked eye, and shows various textures (e.g. Hapuarachchi, 1968; Perera, 1984; Sandiford et al., 1988; Asami, 1990), most of which are similar to those observed in rocks from areas A and B. Cordierite in area C characteristically forms symplectic intergrowths with flaky biotite and quartz, replacing garnet partially or completely (Figs. 3c and d) (see also Asami, 1990).

Mineral Chemistry

Electron microprobe analysis of minerals was carried out with an energy-dispersive type instrument (Hitachi scanning electron microscope S-550 with Kevek 7000Q-75) at Chiba University. Data were processed by the method developed by Mori and Kanehira (1984). Supplementary analysis was performed on a wavelength-dispersive type JEOL JXA-733 at the National Institute of Polar Research, where data were processed by the Bence-Albee method. Generally several grains of each mineral at two or more spots per grain per section or specimen were analysed. Garnet porphyroblasts were analysed at many points in order to determine compositional zoning. Representative analyses of cordierite, garnet and other relevant minerals are given in Tables 1–3 (see also Fig. 4).

Cordierite

Cordierite grains are usually homogeneous, except for the outermost part in direct contact with garnet (e.g. Prame, 1991a). Cordierite in area A is highly magnesian ($X_{Mg} \geq 0.9$), whereas those in areas B and C are less magnesian ($0.6 < X_{Mg} < 0.9$).

Garnet

Garnet grains free of partial replacement by cordierite are usually homogeneous except for the outermost part, whose composition varies depending upon the minerals it is in direct contact with. However, larger grains (>1 cm in diameter) from area A sometimes shows core-to-rim compositional zoning, probably growth zoning modified slightly to extensively by volume diffusion (Hiroi et al., 1990a, in

![AFM diagrams showing mineral assemblages of pelitic granulites in areas A-C. Only a small number of specimens are shown for clarity. Arrows indicate the direction of compositional zoning of garnet toward replacing cordierite. See Fig. 2 caption for mineral abbreviations.](image-url)
press and unpublished data). This is in contrast with the fact that garnet porphyroblasts up to 4 cm in diameter in rocks from areas B and C do not preserve any growth zoning. When they are partially replaced by cordierite, garnets show a characteristic compositional zoning toward replacing cordierite. Mg/(Mg + Fe) ratio decreases markedly with little variation in Mn and Ca contents (Fig. 5) (see also Asami, 1990; Prame, 1991a).

Other minerals

Staurolite in rocks from area A is extremely rich in Al and Ti (Hiroi et al., in press). Sapphirine and orthopyroxene in

Table 1. Representative microprobe analyses of cordierite.

<table>
<thead>
<tr>
<th>Area</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sp. No.</td>
<td>H8811</td>
<td>H8811</td>
<td>Y8511</td>
</tr>
<tr>
<td>Min. Assem.</td>
<td>2601A</td>
<td>2401A</td>
<td>1509</td>
</tr>
<tr>
<td>SiO₂</td>
<td>49.91</td>
<td>49.11</td>
<td>48.39</td>
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<tr>
<td>Al₂O₃</td>
<td>32.85</td>
<td>33.51</td>
<td>33.31</td>
</tr>
<tr>
<td>FeO*</td>
<td>1.98</td>
<td>2.44</td>
<td>5.99</td>
</tr>
<tr>
<td>MnO</td>
<td>0.44</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>MgO</td>
<td>12.65</td>
<td>12.07</td>
<td>10.83</td>
</tr>
<tr>
<td>Total</td>
<td>97.83</td>
<td>97.13</td>
<td>98.51</td>
</tr>
</tbody>
</table>

O = 18

| Si | 5.020 | 4.980 | 4.926 | 4.907 | 4.915 | 4.897 |
| Fe* | 0.167 | 0.207 | 0.510 | 0.282 | 0.523 | 0.561 |
| Mn | 0.037 | — | — | 0.010 | — | 0.022 |
| Mg | 1.897 | 1.825 | 1.643 | 1.828 | 1.636 | 1.653 |
| Total | 11.015 | 11.017 | 11.076 | 11.069 | 11.086 | 11.080 |

Mg/Mg+Fe* | 0.919 | 0.898 | 0.763 | 0.866 | 0.758 | 0.782 |

* Total Fe as FeO.

Table 2. Representative microprobe analyses of garnet.

<table>
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<td>2</td>
<td>6</td>
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<tr>
<td>Position</td>
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<td>rim</td>
<td>core</td>
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<td>SiO₂</td>
<td>39.78</td>
<td>38.93</td>
<td>38.30</td>
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<tr>
<td>Al₂O₃</td>
<td>22.64</td>
<td>22.35</td>
<td>22.14</td>
</tr>
<tr>
<td>FeO**</td>
<td>21.77</td>
<td>23.81</td>
<td>27.49</td>
</tr>
<tr>
<td>MnO</td>
<td>0.72</td>
<td>1.07</td>
<td>0.44</td>
</tr>
<tr>
<td>MgO</td>
<td>14.01</td>
<td>12.19</td>
<td>9.53</td>
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<tr>
<td>CaO</td>
<td>0.82</td>
<td>0.98</td>
<td>1.95</td>
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<tr>
<td>Total</td>
<td>99.74</td>
<td>99.53</td>
<td>99.84</td>
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O = 12

| Si | 2.981 | 2.961 | 2.958 | 2.959 | 2.960 | 2.975 | 2.976 | 2.975 | 2.985 | 2.988 |
| Al | 1.999 | 2.021 | 2.015 | 2.027 | 2.014 | 2.041 | 1.979 | 2.009 | 1.990 | 2.002 |
| Fe** | 1.364 | 1.514 | 1.775 | 1.814 | 1.891 | 2.228 | 1.721 | 1.810 | 1.907 | 2.074 |
| Mn | 0.046 | 0.069 | 0.029 | 0.029 | 0.028 | 0.043 | 0.107 | 0.139 | 0.079 | 0.111 |
| Mg | 1.565 | 1.382 | 1.098 | 1.127 | 1.061 | 0.644 | 1.169 | 0.991 | 0.962 | 0.736 |
| Ca | 0.066 | 0.080 | 0.161 | 0.073 | 0.079 | 0.074 | 0.082 | 0.096 | 0.097 | 0.100 |

| alm | 44.85 | 47.92 | 58.00 | 59.60 | 61.80 | 74.50 | 55.89 | 59.62 | 62.60 | 68.60 |
| prp | 51.46 | 45.39 | 35.80 | 37.00 | 34.70 | 21.50 | 37.97 | 32.64 | 31.60 | 24.40 |
| sps | 1.51 | 2.27 | 0.90 | 1.00 | 0.90 | 1.40 | 2.66 | 3.16 | 2.60 | 3.70 |
| grs | 2.17 | 2.63 | 5.30 | 2.40 | 2.60 | 2.50 | 3.48 | 4.58 | 3.20 | 3.30 |

Mg/Mg+Fe** | 0.534 | 0.477 | 0.382 | 0.397 | 0.359 | 0.224 | 0.405 | 0.354 | 0.335 | 0.262 |

* Next to cordierite.
** Total Fe as FeO.

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### Table 3. Representative microprobe analyses of kyanite, staurolite, sapphire, spinel, hercynite and orthopyroxene.

<table>
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<th>sp</th>
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<td>A</td>
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<td>B*</td>
<td>C**</td>
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<tr>
<td>Al₂O₃</td>
<td>62.47</td>
<td>58.54</td>
<td>60.01</td>
<td>63.71</td>
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<td>Cr₂O₃</td>
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<td>—</td>
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<td>Ca</td>
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<tr>
<td>Total</td>
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<td>Mg/Mg+Fe²⁺</td>
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<td>0.649</td>
<td>0.396</td>
<td>0.206</td>
<td>0.725</td>
</tr>
</tbody>
</table>

* Interlocked with kyanite in garnet.
** Inclusion in cordierite.
*** Total Fe as FeO.

Hematite-bearing Sp. H88112401A are rich in Fe³⁺, as suggested by stoichiometric calculations. Orthopyroxene coexisting with sillimanite in the rock is also rich in Al, containing up to 5% Al₂O₃. Hercynite interlocked with kyanite within garnet is usually rich in Zn, suggesting further evidence that it is a breakdown product of staurolite.

**P-T Conditions of Metamorphism**

Namba (1989) estimated peak metamorphic conditions to be 750–900°C and 7.5–10 kbar for rocks in area A and 650–850°C and 5–7 kbar for those in areas B and C, using several kinds of thermometers and barometers such as garnet-clinopyroxene (Ellis and Green, 1979) and garnet-orthopyroxene-plagioclase-quartz (Perkins and Chipera, 1985) for metabasites, and garnet-plagioclase-sillimanite-quartz (Newton and Haselton, 1981) for metamafites. These are in good agreement with the results of much more extensive studies by Schumacher et al. (1990), Fiorentini et al. (1990), Faulhaber and Raith (1991), Raith et al. (1991), Schenk et al. (1991), Frame (1991a, b) (Fig. 6). Thus, there is an apparent eastward increase in P-T values, and it has been speculated that the combined HSVC-WC domain represents a tilted crustal section (e.g. Hofmann, 1991).

The assemblage and compositions of minerals in Sp. 88112401A from area A suggest P-T conditions more than 8 kbar and 850°C (Hensen and Harley, 1990). In addition, garnet in Sp. 88112401A contains the rare local assemblage kyanite + sapphire ± spinel ± biotite, which may be the dehydration product of magnesian staurolite in the absence of quartz, as will be discussed later. Moreover, Osanai et al. (personal communication, 1989) found the extremely high-temperature (? >950°C) mineral assemblage sapphire + quartz + Al-rich orthopyroxene in a rock from area A. These indicate a range of peak metamorphic conditions even within area A.

**P-T Paths Followed by Sri Lankan Granulites**

On the basis of petrography given above, we will first mention prograde P-T-t paths followed by the HSVC pelitic granulites briefly, because Hiroi et al. (in press) argued them in some detail. Then, we will discuss the peak to later metamorphic histories of the Sri Lankan granulites more fully.

**Prograde P-T-t path**

The widespread occurrence of sillimanite in pelitic granulites, regardless of the geotectonic divisions, indicates that the peak metamorphic conditions were in the sillimanite stability field throughout Sri Lanka. The occurrence of kyanite only as inclusions in garnet indicates that it is a relict
formed during prograde metamorphism. Therefore, the following reaction is inferred at a prograde metamorphic stage:

Kyanite = sillimanite ........................................... (a)

More importantly, the local minerals and mineral assemblages within garnet in the HSWC rocks (those from areas A and B) suggest the following reactions:

Staurolite + quartz = kyanite + garnet + H₂O ............... (b)
Staurolite = corundum + kyanite + garnet + H₂O .......... (c)
Staurolite = kyanite + hercynite + garnet + H₂O .......... (d)
Mg-rich staurolite
= kyanite + sapphire + garnet + spinel + H₂O .......... (e)
Staurolite
= corundum + sillimanite + garnet + H₂O ............. (f)
Staurolite
= sillimanite + hercynite + garnet + H₂O ............. (g)

These are dehydration reactions and generally progress as temperature increases, i.e. at a prograde stage. Based on Schreinemakers' analysis of univariant reactions (a), (b), (c), (d), (f), (g) and corundum + garnet = aluminium silicate + hercynite in the system FeO-Al₂O₃-SiO₂-H₂O and its modifications by additional components such as MgO and ZnO, Hiroi et al. (in press) concluded that the HSWC pelitic rocks followed a clockwise P-T-t path during prograde metamorphism (Fig. 6). Reaction (e) is inferred for the rare local assemblage observed in Sp. 88112401A, and suggests a range of P-T-t paths (see Fig. 6). Hiroi et al. (in press) also inferred that the HSWC and the WC were juxtaposed during the very last part of prograde metamorphism of the HSWC rocks, because the prograde metamorphic evidence has been obtained only from the “higher-grade” HSWC rocks and none has been found in the “lower-grade” WC rocks in spite of extensive petrographical studies (e.g. Hiroi et al., 1990b; this work).

Peak to retrograde P-T-t path

The widespread occurrence of secondary andalusite, particularly in areas B and C, indicates that the Sri Lankan granulites were uplifted to shallower crustal levels by the time when they experienced the peculiar "local charnockitization and related metamorphism by CO₂ flushing" (Hiroi et al., 1990b; Hiroi and Ellis, 1991). The textural and compositional features of minerals, especially those of cordierite and garnet, suggest following reactions at the peak to later metamorphic stages.

Garnet + O₂
= cordierite + orthopyroxene + magnetite ................... (h)

Garnet + O₂
= cordierite + quartz + magnetite .......................... (i)

Garnet + sillimanite + quartz = cordierite ................. (j)

Garnet + sillimanite + cordierite = hercynite ............... (k)

Biotite + sillimanite + quartz
= cordierite + K-feldspar + H₂O ............................... (l)

Garnet + K-feldspar + H₂O
= cordierite + biotite + quartz ............................... (m)

Oxidation reactions (h) and (i) are inferred for some rocks, particularly in area A, and will be discussed elsewhere in some detail. Reactions (j) and (k) are sensitive to a change in pressure (see Fig. 6) and, therefore, useful in unraveling the different peak to retrograde P-T-t paths of rocks in areas A-C. Cordierite produced by reactions (j) and (k) is widespread in areas B and C. Cordierite is highly magnesian in area A, whereas it is less magnesian in areas B and C. Likewise, garnet in some cordierite-free rocks from area A is more magnesian than those from areas B and C, even the compositions of the cores unaffected by the later modification being compared. These facts suggest that rocks in area A began to cool at high pressures while rocks in areas B and C experienced prolonged nearly isothermal decompression at high-temperatures (Fig. 6). The high-temperature unloading of rocks in areas B and C is also evidenced by the following facts: (1) garnet porphyroblasts (1–2 cm in diameter) in “higher-temperature” area A sometimes preserve growth zoning but those (1–4 cm in diameter) in “lower-temperature” areas B and C do not, as mentioned above, and (2) garnet porphyroblasts partially replaced by cordierite show the peculiar chemical zoning; Mg/(Mg + Fe) ratio decreases markedly toward replacing cordierite with almost no variation in spessartine and grossular contents (Fig. 5).
When garnet is replaced by biotite or cordierite during retrograde metamorphism, Mn usually increases approaching the replacing minerals (e.g. Tracy, 1982), but when it occurs at high temperatures, volume diffusion would effectively homogenize garnet. The conspicuous decrease in Mg/(Mg + Fe) ratio toward cordierite may have resulted from a Mg-Fe exchange reaction upon cooling. The inferred difference in $P$-$T$-$t$ path between area A and areas B and C may reflect different cooling and exhumation rates; the rocks in area A uplifted quickly which resulted in both

Fig. 6. $P$-$T$ diagram showing pressure-temperature-time paths followed by Sri Lankan granulites. Clockwise prograde $P$-$T$-$t$ paths of rocks in areas A and B are based on the local minerals and mineral assemblages enclosed within garnet in them. See Hiroi et al. (in press) for more detailed argument about them. The different peak to later $P$-$T$-$t$ paths of rocks in area A and those in areas B and C are inferred on the basis of compositional and textural features of minerals, especially cordierite and garnet. See text for detailed discussions. The isobaric cooling path of metagranulate rocks proposed by Schumacher et al. (1990), Schenk et al. (1991) and Prame (1991b) is also shown. 1 = estimated peak $P$-$T$ conditions for rocks in area A (data sources are Namba, 1989; Schumacher et al., 1990; Fiorentini et al., 1990; Faulhaber and Raith, 1991; Raith et al., 1991; Schenk et al., 1991; Prame, 1991a, b; Hiroi et al., in press, and this work). 2 = estimated peak $P$-$T$ conditions for rocks in areas B and C (data sources are the same as for 1). 3 = retrograde metamorphic conditions for rocks carrying the secondary andalusite + siderite assemblage (Hiroi and Ellis, 1991; Ellis and Hiroi, unpublished data). The univariant reactions in the FeO-Al$_2$O$_3$-SiO$_2$ and MgO-Al$_2$O$_3$-SiO$_2$ systems shown by thin lines are calculated, using the approach of Powell and Holland (1988) with expanded data set of Holland and Powell (1990). Metamorphic ages are after Burton and O’Nions (1990a, b), Baur et al. (1991), Hölz et al. (1991), Kröner et al. (1991) and Liew et al. (1991). Mineral abbreviations are in Fig. 2 caption.
pressure and temperature decreased rapidly, whereas those in areas B and C uplifted slowly which resulted in nearly isothermal decompression due to the recovery of geotherm. Hydration reaction (m) is inferred mainly for the rocks in area C. The origin of H₂O is not necessarily known, but there is a possibility that H₂O released by dehydration reactions in the HSWC rocks infiltrated into the overlying WC rocks after their juxtaposition.

**Geological Correlation between East Antarctica and Sri Lanka**

Gondwana reconstructions have located Sri Lanka next to East Antarctica. The exact location of Sri Lanka is, however, different from literature to literature. The reconstructions of Barron et al. (1978) and Lawver and Scotese (1987) among others located Sri Lanka next to Lützow-Holm Bay based on the visual fit of the 2000 m bathymetric contours and paleomagnetic data, respectively.

The Highland Series of the traditional geological division is characterized by the widespread occurrence of dolomite marbles and associated quartzites and graphitic Al-Fe-rich rocks (khondalites) in addition to charnockitic rocks. Such a lithological assemblage is peculiar to the area around Lützow-Holm Bay (the Lützow-Holm Complex), East Antarctica. Matsumoto (1982), Matsuzea et al. (1983) and Hiroi and Kojima (1988) reported that dolomite marbles there occasionally contain corundum and spinel crystals of gneiss, which are the famous products of Sri Lanka. In addition, it has recently been revealed that, in both Sri Lanka and the region around Lützow-Holm Bay, high-grade regional metamorphism took place 500–600 m.y. ago (Baur et al., 1991; Hötzl et al., 1991; Kröner et al., 1991; Fanning et al., 1991; Shiraiishi et al., 1992). The prograde metamorphic histories of the HSWC granulites and the Lützow-Holm Bay granulites are essentially the same. Hiroi et al. (1983a, b, 1991) and Motoyoshi et al. (1985, 1989) reported similar relic kyanite and staurolite within garnet and plagioclase in the Lützow-Holm Bay pelitic granulites. In addition, Motoyoshi et al. (1989) found the rare local mineral assemblage sapphire + kyanite + spinel + biotite within garnet in the Lützow-Holm Bay granulites. Thus, it is highly probable that the HSWC rocks and the Lützow-Holm Bay granulites were once contiguous and formed in the same Late Proterozoic to Early Paleozoic orogenic belt, probably a continent-continent collision zone, as speculated by Shiraiishi et al. (1987) and Hiroi et al. (1991).

The Lützow-Holm Complex is neighbored by the Rayner Complex on the east and by the Yamato-Belgica Complex on the west. The boundaries between these complexes are not observed because of the thick continental ice cover, and therefore original relationships between these complexes are not known, although Shiraiishi et al. (1987) and Hiroi et al. (1991) speculated that the original rocks of the Lützow-Holm Complex were formed on the basement of the Rayner Complex. The lithological and petrographical features of the Rayner Complex are similar to those of the WC. Pelitic granulites of the Rayner Complex commonly contain cordierite (Grew, 1981; Ellis, 1983), and their metamorphic conditions were estimated to be 700 ± 30°C and 5.5 ± 1 kbar at Molodezhnaya Station (Grew, 1981). Except for the rare occurrence of kyanite in the area far east from Molodezhnaya Station (Ellis, 1983), no evidence for prograde metamorphism of the Rayner Complex rocks has been obtained. Moreover, the relatively slow exhumation inferred for rocks from areas B and C in Sri Lanka is in good agreement with the occurrence of cordierite replacing garnet in some relic kyanite-bearing pelitic rocks from the easternmost part of the Lützow-Holm Complex (Hiroi et al., 1983a, b; Grew et al., 1990). Thus, the Rayner Complex may have been once contiguous to the WC. The inferred timing of juxtaposition of the HSWC and the WC in Sri Lanka may be a clue to the relationship between the Lützow-Holm Complex and the Rayner Complex. Likewise, the lithological similarity between the Yamato-Belgica Complex and the WC suggests that they are correlative with each other.

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