Staurolite Petroprovince in the East China Sea

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Staurolite Petroprovince in the East China Sea

Hakuyu OKADA, Yuko HAMADA*, Mizue MORIOKA, Shichiro HAMADA and Takashi SAKAI**

Abstract

Heavy mineral composition of the bottom sediments of the northeastern part of the East China Sea has been analyzed. The result shows that some diagnostic mineral suites can be used for establishing three petroprovinces: Goto, Tsushima Strait, and Cheju. The Cheju Petroprovince is the northernmost part of the newly proposed Staurolite Petroprovince on a large scale, which characterizes the main shelf region of the East China Sea. The Goto Petroprovince is represented by a mineral suite of clinopyroxene and hypersthene, that characterizes the coastal seas of the Goto Islands and mainland Kyushu. The Tsushima Strait Petroprovince is composed mainly of green and brown hornblende and clinopyroxene, which prevail in the area of the Tsushima Strait. The Cheju Petroprovince is characterized by a suite of staurolite, well-rounded zircon, rutile, tourmaline, and garnet, which are widely scattered in the shelf region south of latitude 33°.

Staurolite as an index mineral of high-grade metamorphic rocks is also found in many Neogene sediments in northwestern Kyushu, Okinawa, Miyako Island, Yaeyama Island, and North Taiwan. These occurrences of staurolite suggest the establishment of the Neogene Staurolite Petroprovince, on which the Present Staurolite Petroprovince overprints.

Such an occurrence of staurolite seems to be important for reconstructing tectonics and paleogeography of the East China Sea area.

1. Introduction

Submarine sediments on the extensive shelf area of the East China Sea have been of interest to many geologists and geophysicists, resulting in detailed studies on sediments of the East China Sea (EMERY *et al.*, 1969; WAGEMAN *et al.*, 1970; OHSHIMA, K. *et al.*, 1982; QIN *et al.*, 1987; CLARK and LI, 1991; JIN, 1992; KATSURA, 1992).

We have studied the heavy mineral composition of sediments collected mainly from the northeastern part of the East China Sea (Fig. 1), where no sedimentological study has been carried out so far. The result of the study shows an interesting fact that a diagnostic heavy mineral species such as staurolite characterizes a particular region, which is important for constructing the paleogeography and geohistory of the

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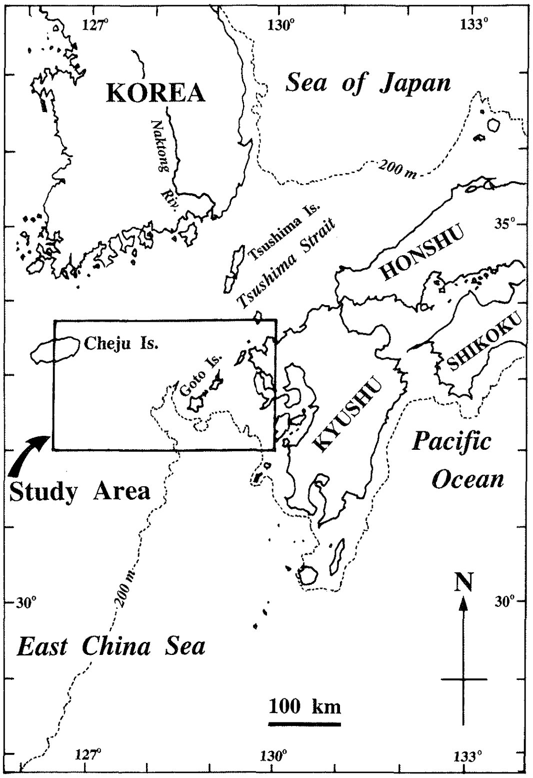

Fig. 1. Index map showing the location of the study area.

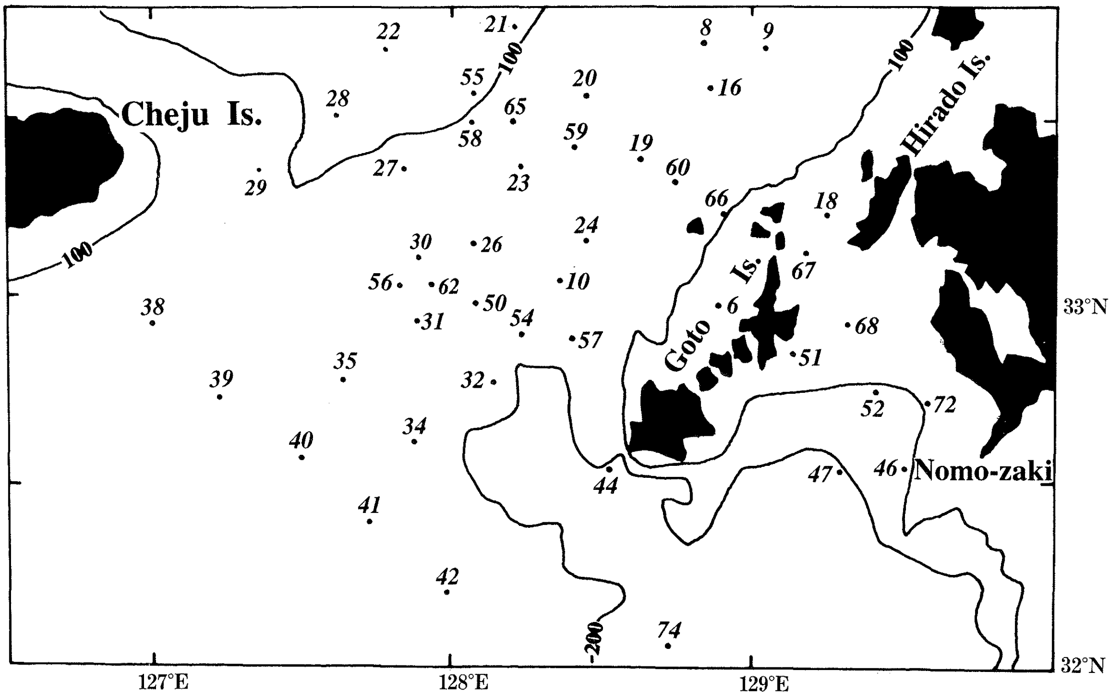

Fig. 2. Locations of the samples used for this study. Contours in meters.

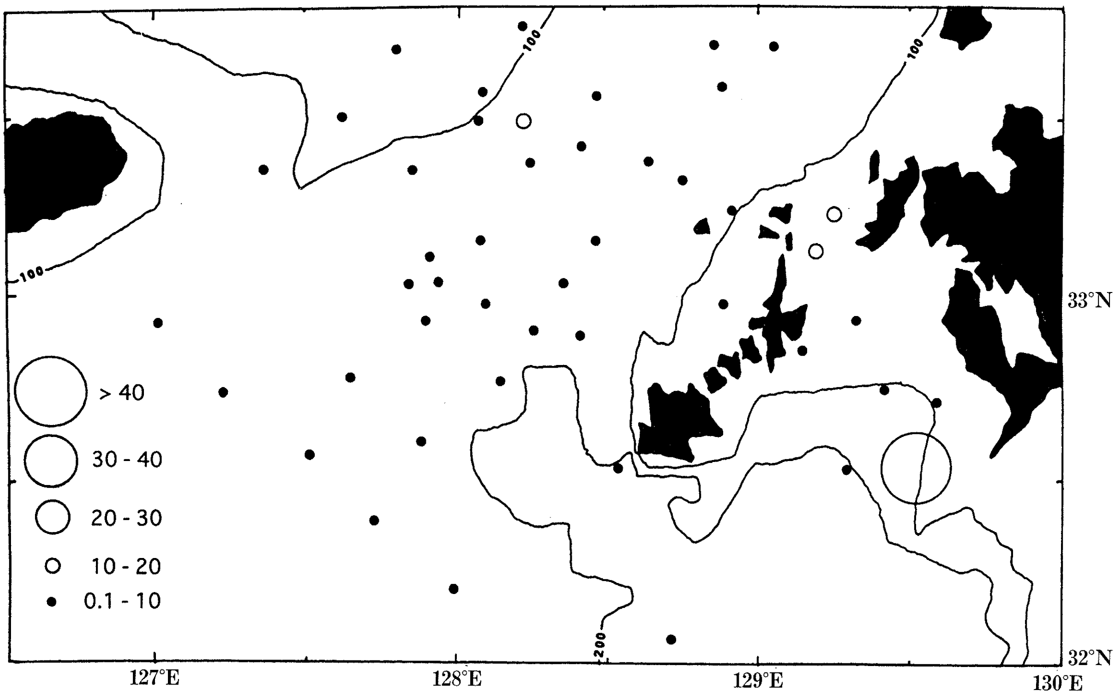

Fig. 3. Distribution of heavy mineral contents (in weight percentage).

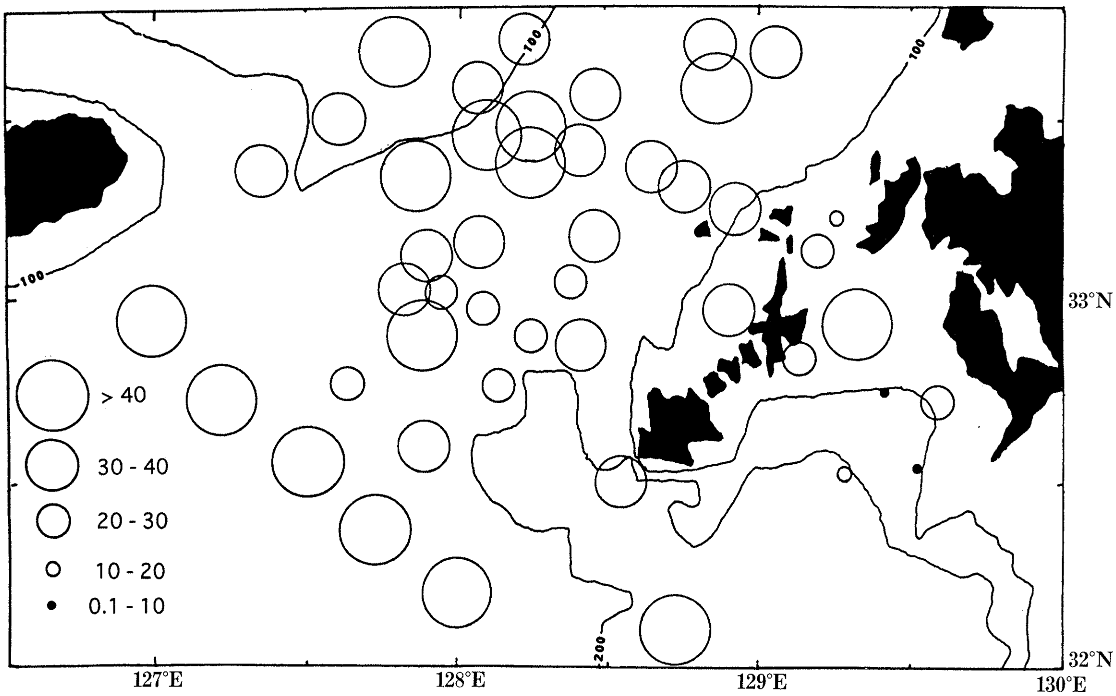

Fig. 4. Distribution of green hornblende.

East China Sea.

2. Methods

The 45 samples used for this study were collected with SK-type dredgers by one of us (Shichiro HAMADA) and his colleagues of the Saikai National Fisheries Research Institute, Fisheries Agency, Nagasaki, Japan (Fig. 2). A few samples were added from the Naktong River mouth in South Korea for comparison. The samples were first analysed for grain-size distribution, and then used for heavy mineral analysis.

The heavy mineral separation was achieved by using bromoform heavy liquid (s.g.= 2.85) for the fractions between 3 and 4 phi, because this size range shows the highest concentraion of heavy minerals according to our preliminary studies (YOKOTA *et al.*, 1990; OKADA *et al.*, 1996 a, b). The separation procedure and identification of minerals were made after OKADA (1960). The relative abundance of each mineral species was expressed in percentage of more than 200 grains. The roundness of individual heavy mineral grains was evaluated on the POWERS' (1953) roundness scale.

3. Result of heavy mineral analysis

(1) Heavy mineral composition

The identified species of transparent heavy minerals are, in order of abundance, common hornblende, clinopyroxene, hypersthene, olivine, zircon, garnet, rutile, epidote, tourmaline, staurolite and glaucophane.

Common hornblende is further subdivisible into green and brown varieties. Green hornblende is generally prismatic, showing pleochroism either from deep green to light green or from greenish brown to pale brown and extinction angles from 12°to 34°. Brown hornblende also consists of prismatic crystals pleochroic from pale brown to deep brown.

Zircon grains are commonly euhedral and rounded, and most of the latter are pink to purple in color. Garnet is largely colorless, but some grains show an orange tint.

Staurolite grains are prismatic to platy, displaying weak pleochroism from pale yellow to orange color. This mineral species occurs rarely but widely, showing a characteristic distribution as described below.

(2) Distribution of heavy minerals

Heavy mineral contents in the examined samples are generally less than 10 % in weight, though some rarely exceeded 20 % (Fig. 3). Distributional trends of some representative minerals are descibed below:

a. Green hornblende: This mineral occurs widely over the whole area, although at a few localities between the Goto Islands and Nomo-zaki it is less than 10 % of the total amount (Fig. 4).

b. Brown hornblende: Brown hornblende is less abundant than the green variety, and it is found commonly in all the examined samples (Fig. 5). It tends to be more concentrated off the west coast of the Goto Islands.

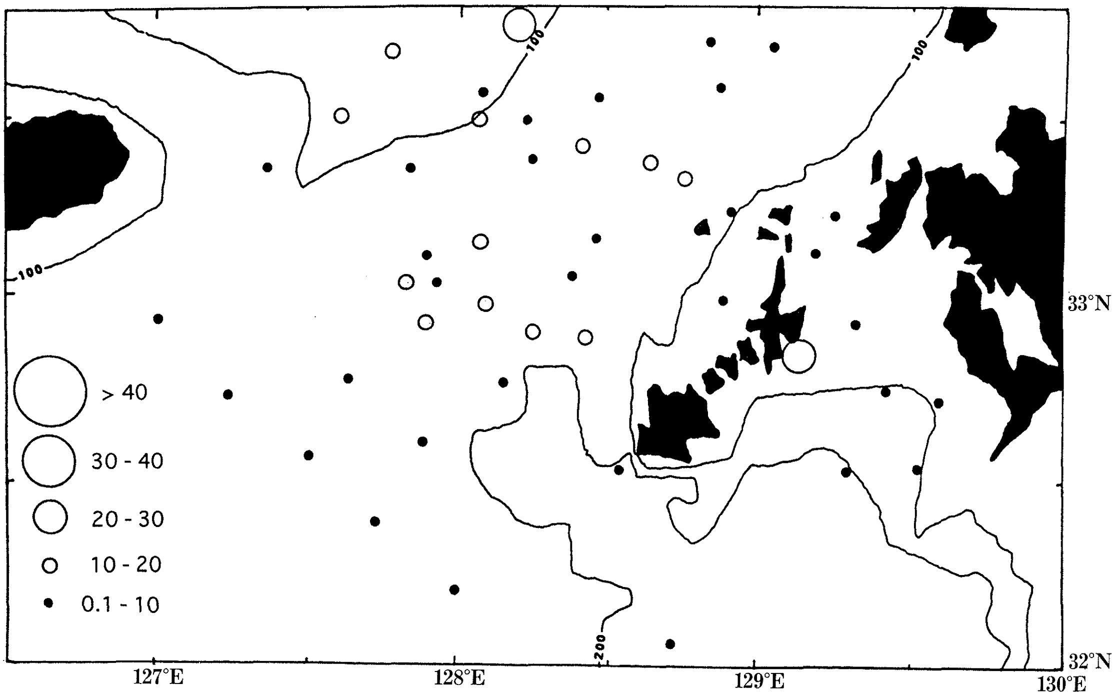

Fig. 5. Distribution of brown hornblende.

c. Clinopyroxene: Clinopyroxene occurs commonly in the whole area, but is more abundant off the west coast of the Goto Islands and between the Islands and Nomo-zaki (Fig. 6).

d. Hypersthene: Hypersthene occurs most abundantly between the Goto Islands and Nomo-zaki, and around the Goto Islands (Fig. 7).

e. Olivine: The occurrence of olivine is generally scarce, though it occurs in amount of 10 to 30 % at some sites (Fig. 8)

f. Garnet: This mineral tends to become richer off the west coast of the Goto Islands than in other areas (Fig. 9).

g. Zircon: The contents of zircon grains are not so high, but they are found constantly in the whole study area (Fig. 10). Rounded grains and purple-colored ones are also common in the area between the Cheju Island and the Goto Islands, showing more concentration in the southern part of this area (Figs. 11, 12). They are very few or almost nill around the mainland of Kyushu.

h. Staurolite: Staurolite is ubiquitous at many sites approximately south of latitude of 33°N (Fig. 13), though its contents are less than 1 percent.

(3) Distribution of rounded minerals

Many grains of heavy minerals from the shelf area are sub- to well-rounded(Fig. 14), according to the roundness scale of POWERS (1953).

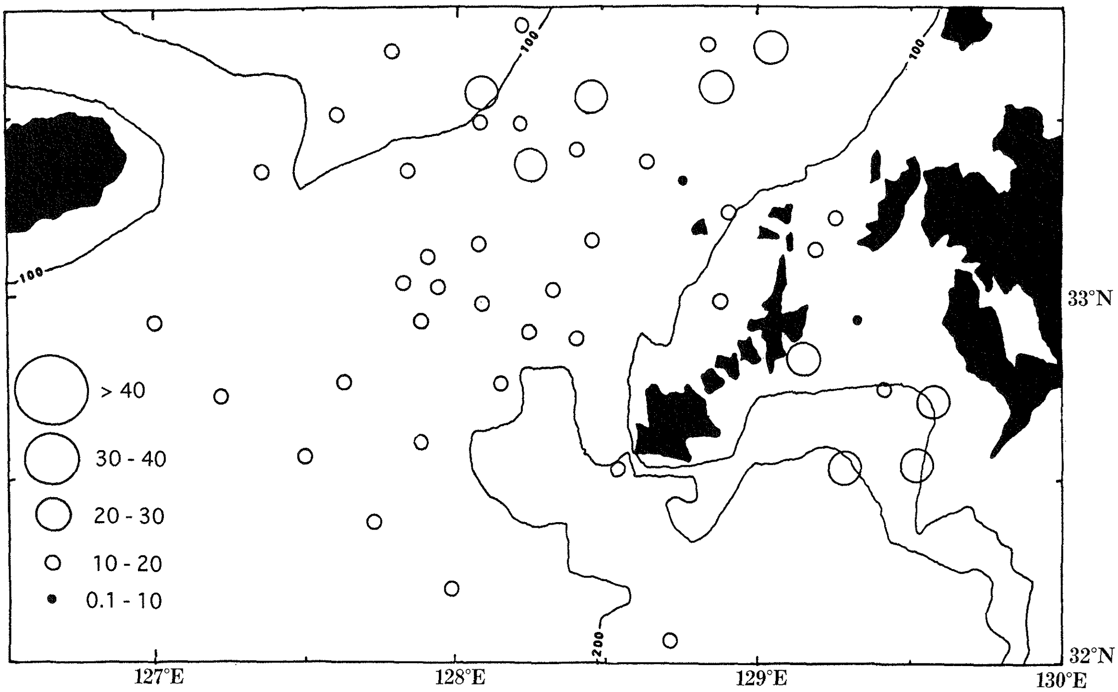

Fig. 6. Distribution of clinopyroxene.

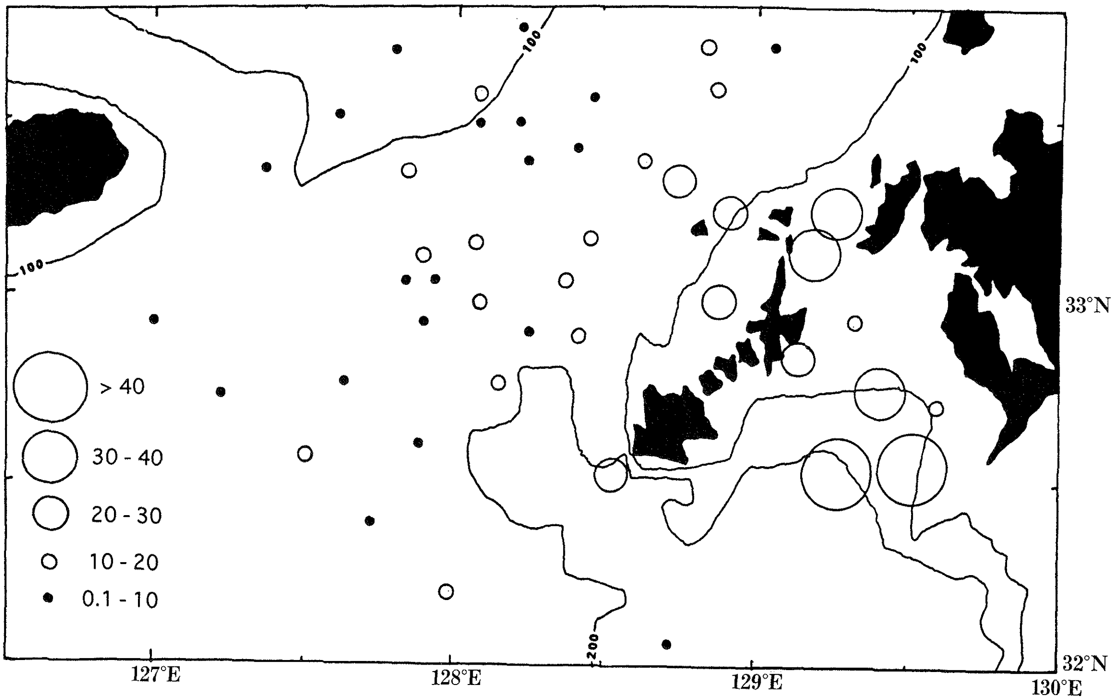

Fig. 7. Distribution of hypersthene.

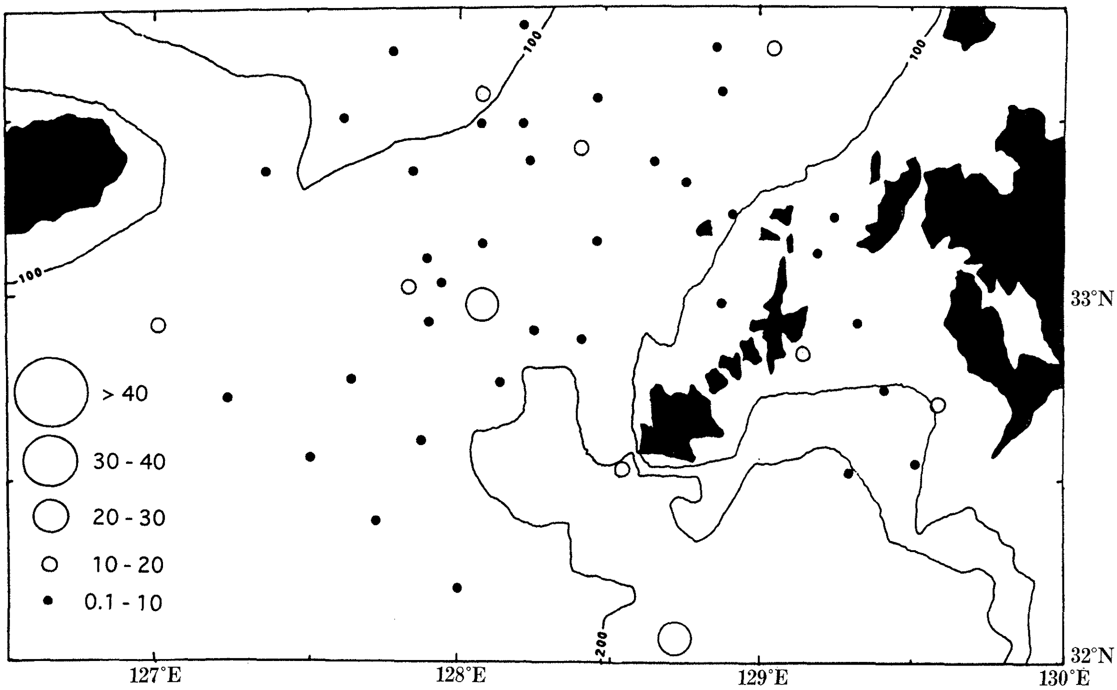

Fig. 8. Distribution of olivine.

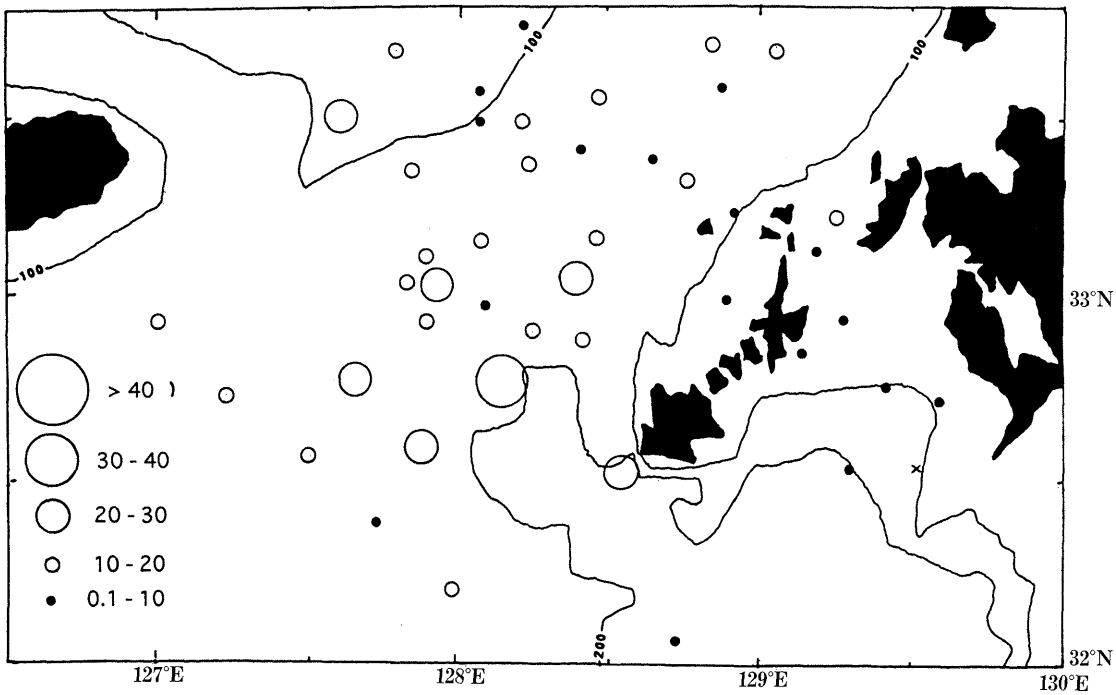

Fig. 9. Distribution of garnet.

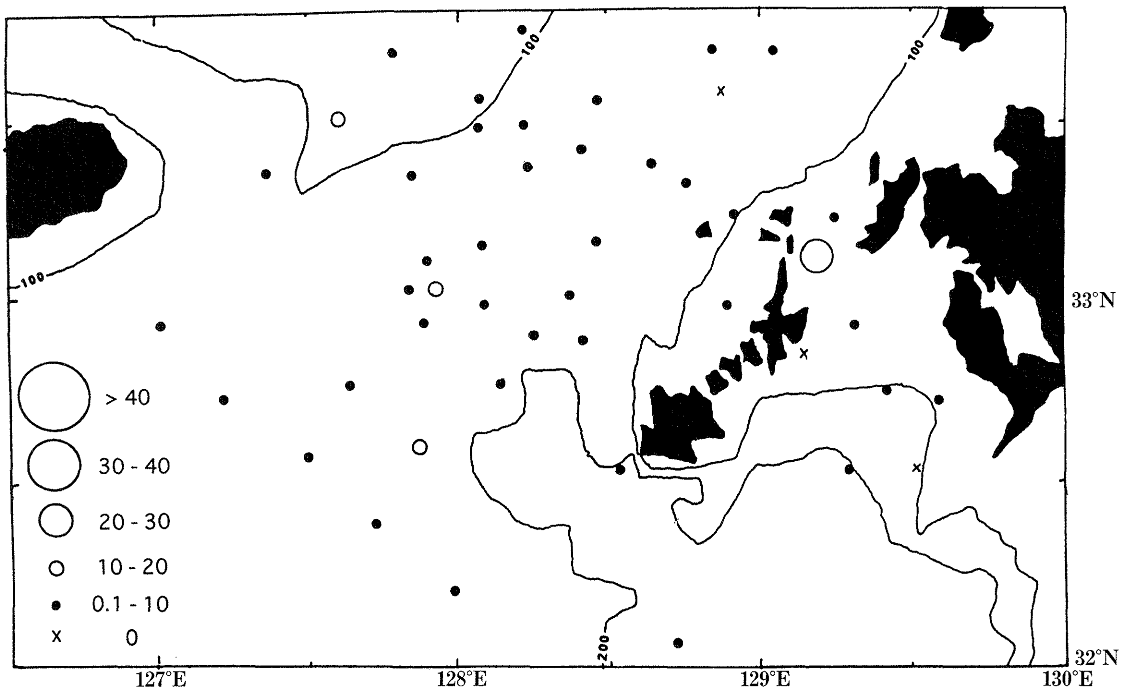

Fig. 10. Distribution of the whole zircon grains.

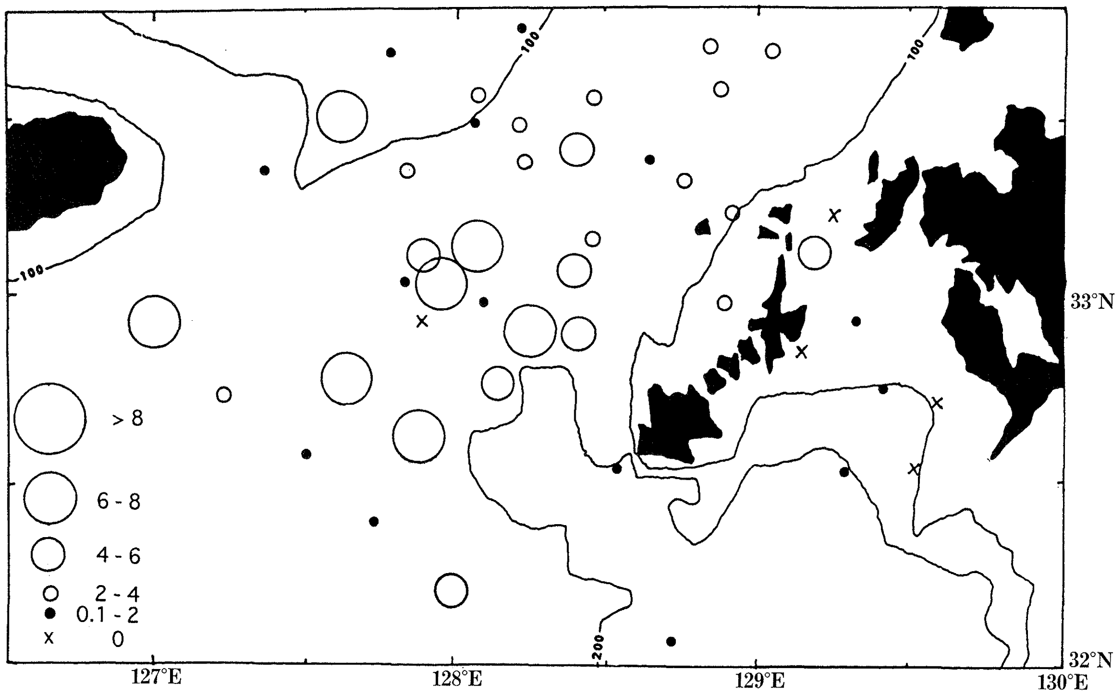

Fig. 11. Distribution of rounded zircon grains.

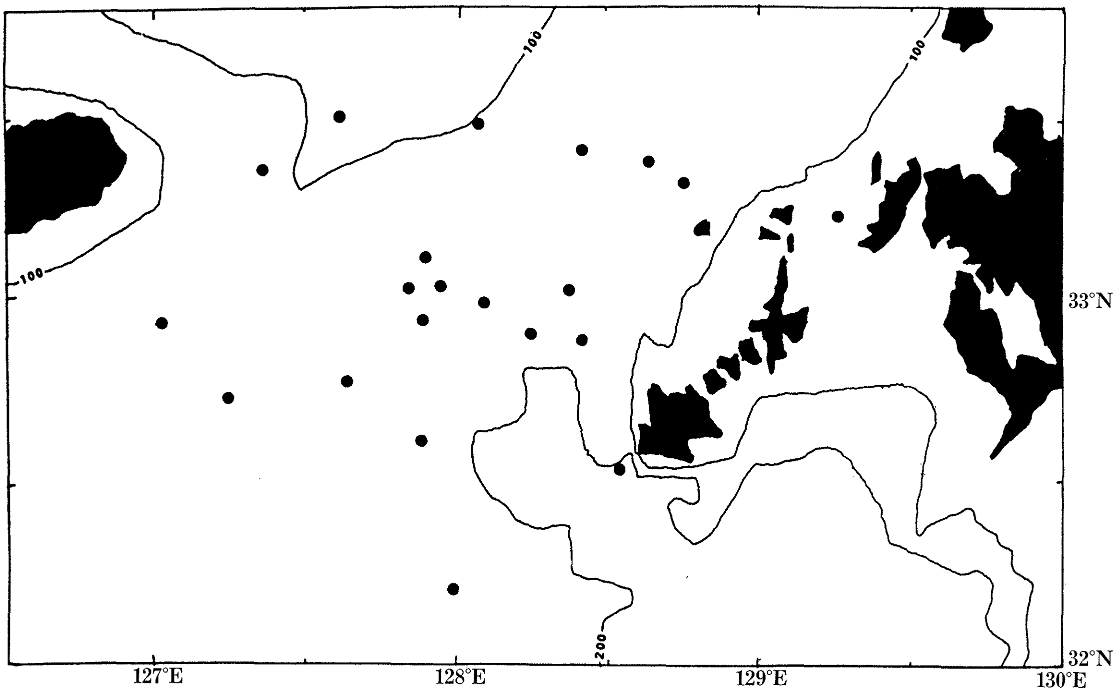

Fig. 12. Distribution of purple zircon (less than 2%).

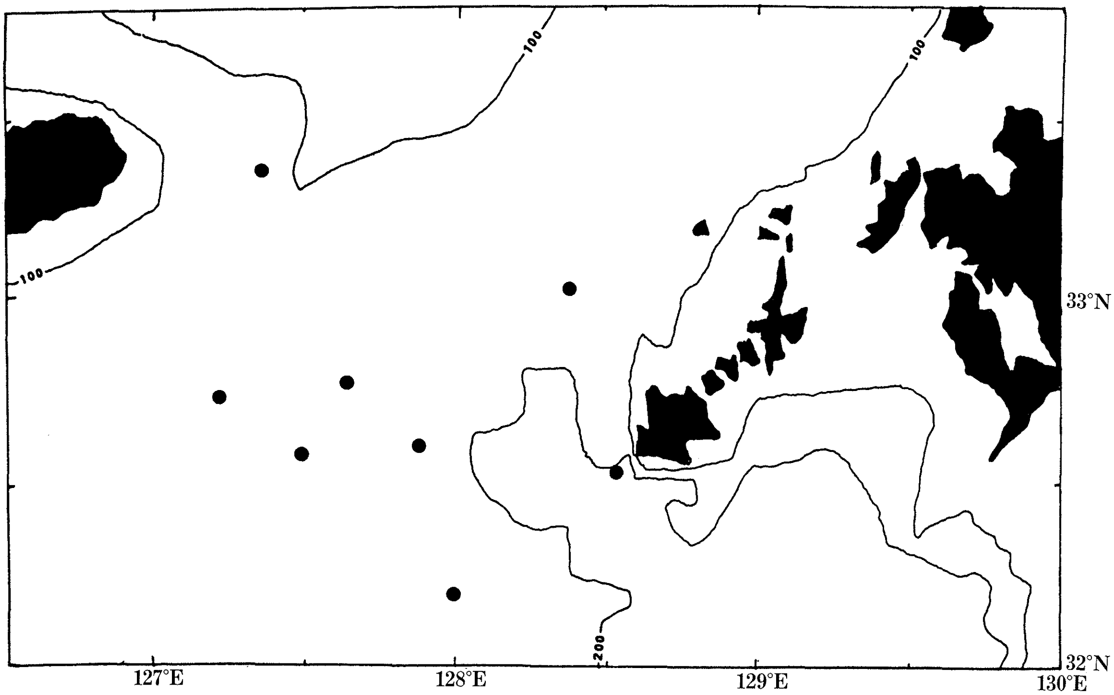

Fig. 13. Distribution of staurolite (less than 1%).

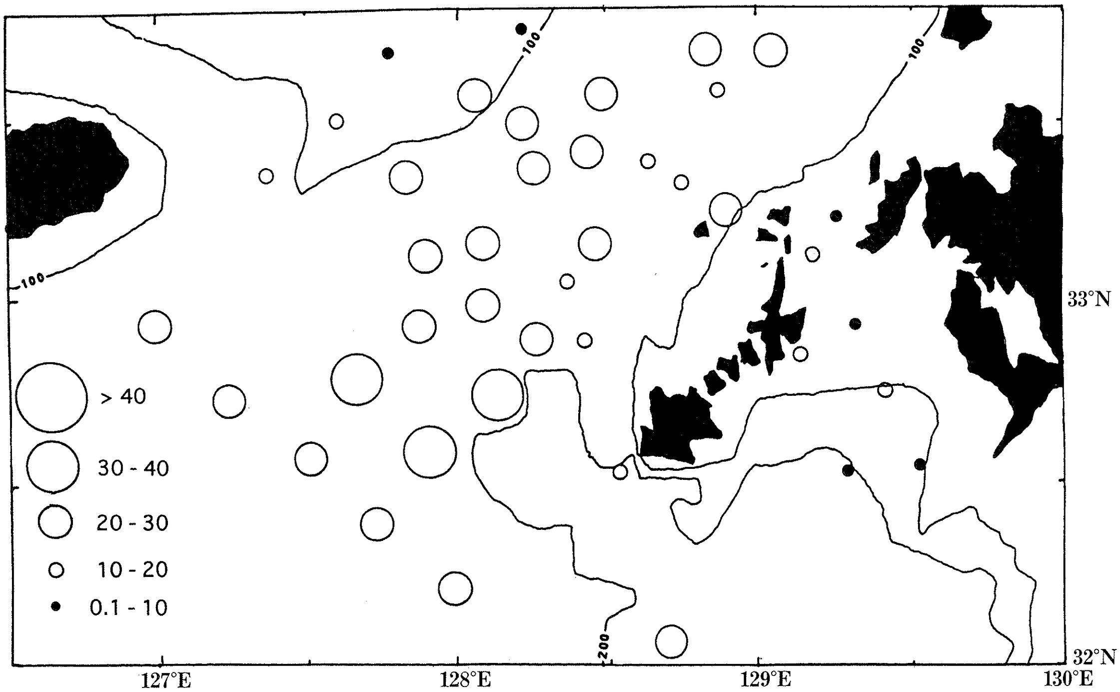

Fig. 14. Distribution of worn heavy minerals.

4. Discussion

(1) Establishment of petroprovinces

Areal distributions of heavy minerals constitute particular geographic provinces, for which OKADA (1989, 1996) proposed the term petroprovinces. The studied area is divisible into three petroprovinces: Goto Petroprovince, Tsushima Strait Petroprovince, and Cheju Petroprovince (Fig. 15).

The Goto Petroprovince is characterized by a suite of hypersthene and clinopyroxene restricted to the coastal seas of the Goto Islands and the Kyushu Island. These minerals may have been originated in Miocene to Quaternary intermediate to basic volcanic rocks in the Goto Islands and the northwestern part of the Kyushu mainland.

The Tsushima Strait Petroprovince, with a suite of green and brown varieties of hornblende and clinopyroxene, characterizes the Tsushima Strait area north of latitute 33°. These minerals may have been derived mostly from intermediate volcanics in northwest Kyushu. These minerals are also very common in the south Japan Sea off the north coast of West Honshu (YOKOTA *et al.*, 1990).

The Cheju Petroprovince has a suite of particularly diagnostic minerals such as staurolite, well-rounded zircon, rutile, tourmaline and garnet, and characterizes the northeastern part of the East China Sea south of latitude 33°. All the constituent minerals are subrounded to well-rounded and persistent. Among them, staurolite is regarded as an index mineral of high-grade metamorphic rocks, and purple-colored

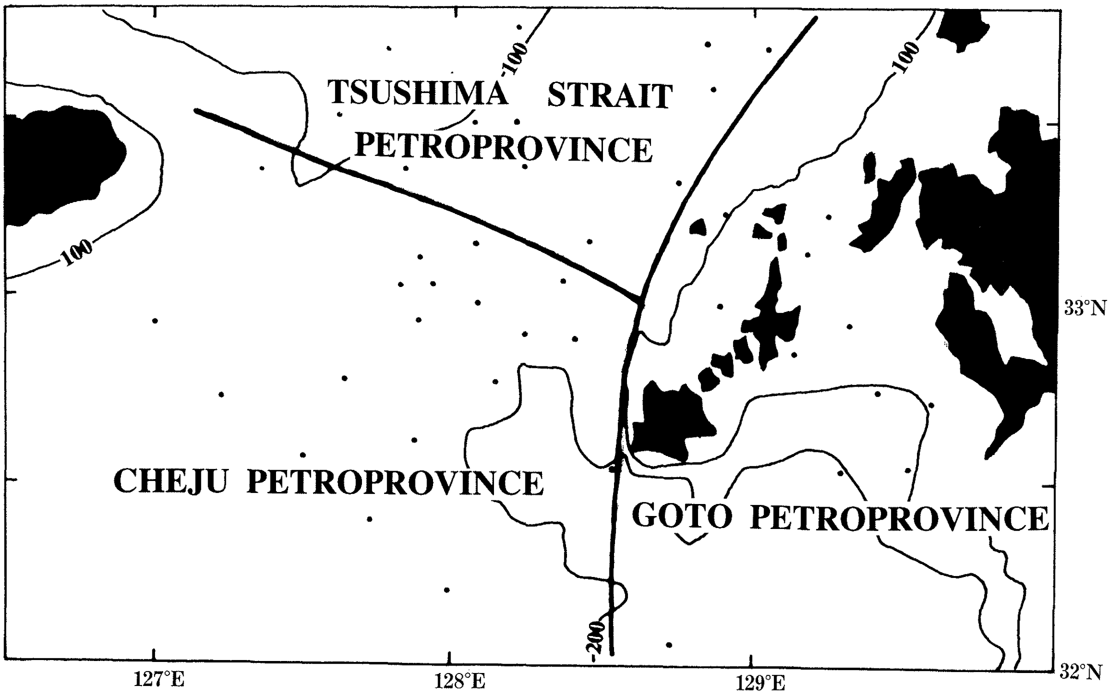

Fig. 15. Petroprovinces in the northwestern part of the East China Sea.

well-rounded zircon is highly probably originated in Precambrian rocks (TOMITA, 1954).

In this context, LEE *et al.* (1988) reported the occurrence of staurolite and sillimanite as high-grade metamorphic minerals in Holocene shelf sediments in the southeastern Yellow Sea, although they did not evaluate these metamorphic minerals.

(2) Staurolite Petroprovince on a large scale

QIN *et al.* (1987) reported that the sediments of the main shelf area of the East China Sea between latitudes 26°and 32°are characterized by the presence of metamorphic minerals such as staurolite, kyanite, cordierite and glaucophane, though their contents are, in general, less than 1 % . QIN *et al.* (1989) had not studied the mineral composition of sediments north of latitude 32°. The present study has revealed that the Cheju Petroprovince is a northward extension of the distributional area of the metamorphic mineral suite mentioned above. Therefore, it is proposed that the region characterized by the existence of staurolite be defined as the Staurolite Petroprovince on a large scale (Fig. 16).

It should be noted that the boundary between the Staurolite Petroprovince and the surrounding regions is quite sharp. No staurolite grains have been detected in the region to the north beyond latitude 33°. In order to trace the origin of staurolite, we have also examined sands from the mouth of the Naktong River, South Korea, but no high-grade metamorphic minerals have been detected. The paleo-river systems, which flowed between the Korean Peninsula and the Cheju Island (XIE *et al.*, 1995) seem to correspond to this sharp boundary. On the contrary, staurolite was disco-

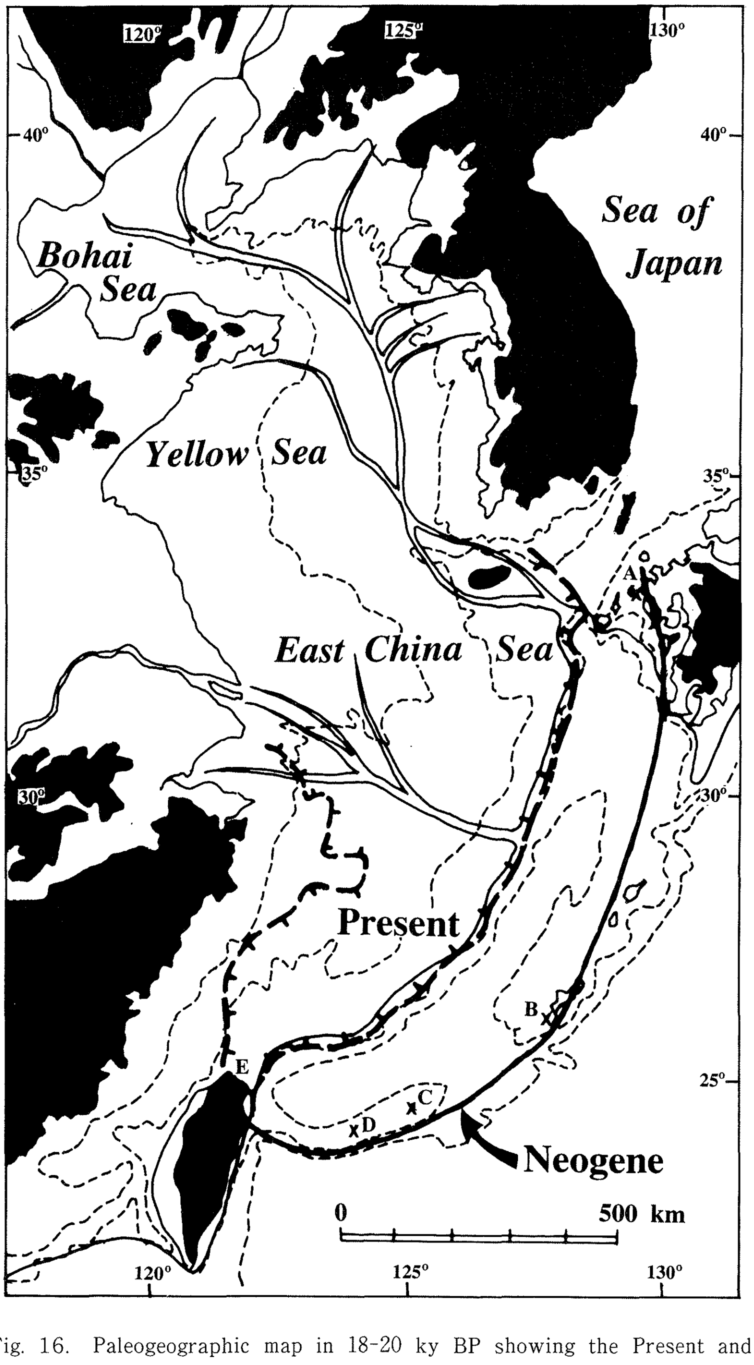

Fig. 16. Paleogeographic map in 18-20 ky BP showing the Present and Neogene Staurolite Petroprovinces (based on XIE *et al.*, 1995). Shaded parts are mountain areas higher than 300m. A: Miocene Hirado and Minamitabira Formations in the Sasebo Coal-field, B: Miocene Shimajiri Group, Okinawa, C: Miocene Shimajiri Group, Miyako Islands, D: Miocene Yaeyama Group, Iriomote Island, E: Miocene Shihti and Taliao Formations, North Taiwan.

vered in the Yellow Sea off the Korean Peninsula (LEE *et al.*, 1988).

Elsewhere, such a sharp delimitation of the Staurolite Petroprovince was also reported in the off-shore portion of the northern Gulf of Mexico, where the Eastern Gulf Province is characterized by staurolite and other metamorphic mineral assemblage derived from the Appalachian Mountains (GOLDSTEIN, 1942).

As far as the data in this study are concerned, heavy minerals distibuted on the shelf area are generally rounded to a considerable degree. This means that most of these worn grains must have been reworked from older shelf sediments and have been redistributed widely. Such erosive processes took place during the sea-level low stands in the last Glacial Period. In fact, we have collected well-preserved oyster shells (*Crassostrea ariakensis*) at the outer edge as deep as 100 m on the central shelf (latitude 29°09′30″; longitude 126°22′00″) and dated as $15,590 \pm 280$y. by ^{14}C method. Oyster shells were associated with coquina limestones, which contain molluscan fauna of littoral to shallow-sea elements. Therefore, it is reasonable to infer that during the late Würm Glacial Period the East China Sea shelf was largely under subaerial to very shallow-sea conditions. This fact is in accordance with previous studies of sea-level change during the Quaternary (*e.g.*, YANAGIDA and KAIZUKA, 1982; ODA, 1988). In addition, orthoquartzite pebbles were also discovered at latitude 37°11′ and longitude 123°11′, which suggest a continental origin.

Taking all these facts into account, staurolite and its accompanied minerals such as rounded zircon, rutile, tourmaline and garnet must have been derived from relict sediments on the shelf. Originally their provenance may have been Precambrian continental rocks in the mainland China and Korean Peninsula or Precambrian basements of the inner shelf region (ZHOU *et al.*, 1989) through river systems developed on the shelf during the sea-level low stand.

The Neogene Staurolite Petroprovince is recognized wider than the modern Staurolite Petroprovince (Fig. 16). Staurolite was detected in the Miocene Hirado and Minamitabira Formations in Northwest Kyushu (OHARA, 1961), Miocene Shimajiri Group on the Okinawa Main Island (SATO and SUZUKI, 1977) and on the Miyako Islands, Ryukyu (SUZUKI and SATO, 1977), and the Miocene Shihti and Taliao Formations in northernmost Taiwan (LU, 1966). Staurolite is, in many cases, accompanied by glaucophane and kyanite (for example, in the Okinawa, Miyako and Taiwan Miocene).

Thus, the modern Staurolite Petroprovince overprints approximately on the Neogene one. This means that there is a possibility that some staurolite and other associated minerals were derived from Neogene shelf sediments, which covered the continental shelf extended at least to the eastern margin of the present Ryukyu Arc (Fig. 16). It was the time just before the rifting of the Okinawa Trough.

(3) Tectonic and paleogeographic significance

It is interesting to note that the Miocene Staurolite Petroprovince seems to delineate the shelf region at that time. It was almost the time of starting of the rifting of the Okinawa Trough (KIMURA, 1985; LETOUZEY and KIMURA, 1986). According to ZHOU *et al.* (1989), since the Oligocene, two significant unconformities were developed on the shelf area of the East China Sea; one was below the middle Miocene and the other was below the Pliocene, which was more regional in extent. In addition, ZHOU *et al.*(1989) showed that the bedrock distribution between latitudes 28° and 32° and behind the Diaoyudao Uplift was generally composed of Proterozoic metamorphic basement.

Thus, staurolite and its associated minerals play an important role in reconstructing the tectonic and geographic situations in the East China Sea during the Neogene.

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