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Geology and Geohistory of the Northwestern Philippine Sea, with Special Reference to the Results of the Recent Japanese Research Cruises

By

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Abstract

1) Collection of acidic intrusive rocks, schists and other basement rocks, and Eocene *Nummulites* is one of the most remarkable results of the recent research cruises in the Philippine Sea.
2) Pre-Cenozoic island arc activity, such as regional low pressure metamorphism, volcanism, and acidic intrusion occurred and formed non-oceanic crust of the Daito Ridge Group Region. These rocks suffered upheaval and subsequent erosion, and then overlain by the shallow sea sediments containing *Nummulites* and other foraminifers. Differential subsidence occurred in the Oligocene and/or the Miocene. After then, whole Daito Ridge Group Region sunk 1000–2000 m.

Activities of the Kyushu-Palau Ridge, such as volcanism, acidic intrusion, and upheaval occurred in the Eocene and the Oligocene. This ridge also sunk at least 600 m, since Late Miocene.

It may be assumed that the Kinan Seamount Chain has not appeared before the development of the Kyushu-Palau Ridge.
3) Based upon the results of the recent studies, maturity of the island arcs and ridges is suggested.

1. Introduction

Investigation of the geological development of West Pacific and the surroundings of the Asiatic Continent is indispensable for clarifying solid-earth dynamics. A study of the marginal seas around the Japanese Islands is therefore a matter of great importance.

Geological and geophysical investigation of the Philippine Sea had formerly lagged behind the studies of the Japan Sea and the other sea areas. However, steady and remarkable progress has been made on this field since the Geodynamics Project (GDP) started in 1972.

The special feature of the Philippine Sea is that it is bordered by the Izu-Bonin Trench and Mariana Trench in its eastern margin, and by the Ryukyu Trench and

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the Philippine Trench in its western margin. It is to be noted, moreover, that the Daito Ridge Group (the Amami Plateau, the Daito Ridge, and the Okidaito Ridge) is distributed in the northern margin of the western half of the sea, and that, according to the results of explosion seismological studies this ridge group has been found

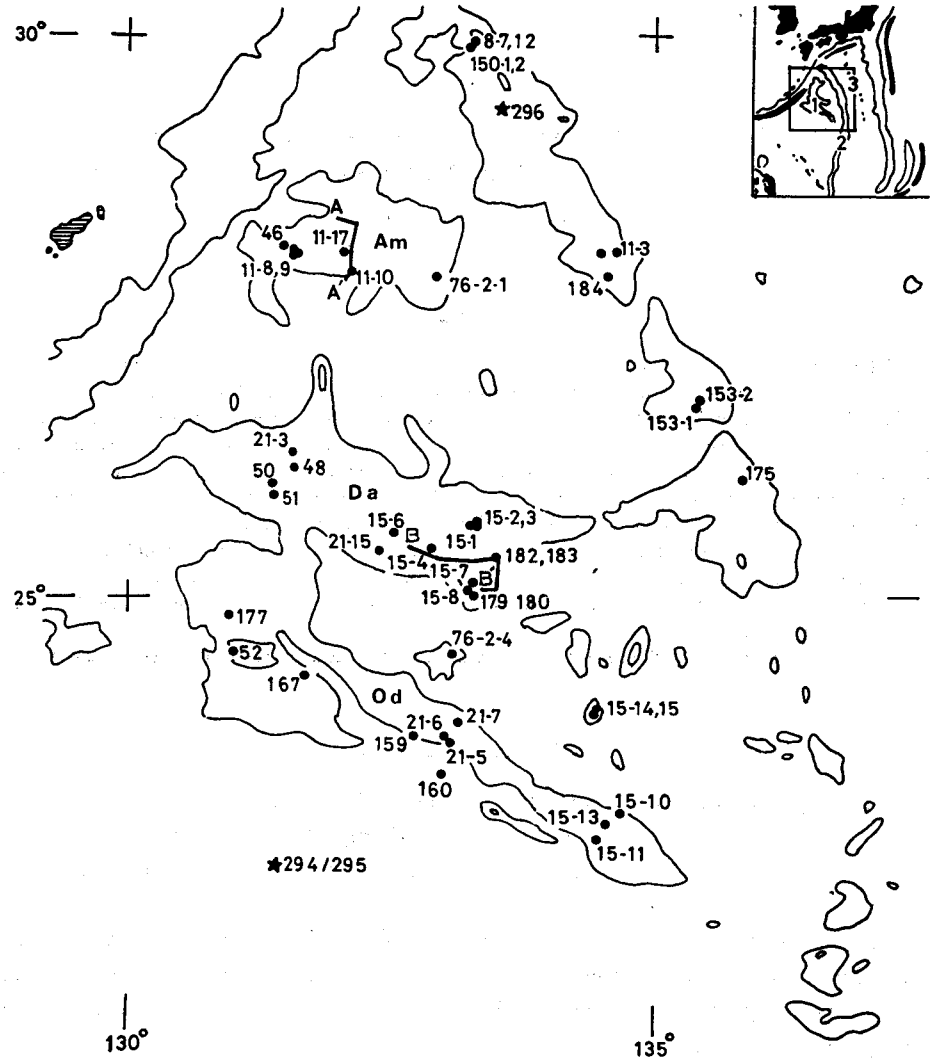

Fig. 1. Locations of rock sampling by Japanese research cruises in the Northwestern Philippine Sea. (GDP –8, –11,– 15, –21). (Star: DSDP sites). Contour: 2000 m, 4000 m. Am: Amami Plateau, Da: Daito Ridge, Od: Okidaito Ridge. A–A′, B–B′: Lines of reflection profiles of Fig. 2 and 3.

Index map 1: Daito Ridge Group, 2: Kyushu-Palau Ridge, 3: Kinan Sea-mount Chain.

to consist of non-oceanic crust (MURAUCHI *et al.*, 1968; Geol. Inst. and Inst. Ocean. USSR, 1970). These ridges are bordered by the Kyushu-Palau Ridge stretching from north to south in the sea, and does not extend eastward. In carrying out the Japanese Geodynamics Project, these characteristics of the Philippine Sea were noticed. Consequently, most of the geological research cruises have been concentrated on the Daito Ridge Group Region and the Kyushu-Palau Ridge Region.

2. Geological Results Obtained

One of the remarkable results of the recent geological research cruises of the Japanese Geodynamics Project and other cruises is that various volcanic rocks, acidic or basic intrusive rocks, black and green schists, clastic sedimentary rocks, and limestones were collected from those ridges in the northwestern part of the Philippine Sea. Another notable result was that Eocene *Nummulites* and the other larger foraminifers were also collected.

The localities of thses samples are shown in Figure 1. Most of the rock samples were obtained from the acoustic basement, and a few of the continuous seismic profile along sample localities are shown in Figure 2 and 3.

2.1 Daito Ridge Group

It is to be noted above all that crystalline schist was discovered from the Daito Ridge during the GH74–7 Cruise by R/V Hakurei-maru (MIZUNO and NOHARA *et al.*, 1975). It is inferred from this that at least a portion of the foundation of the ridge consists of a product of the regional metamorphism belonging to the epidote-amphibolite facies (MIZUNO and OKUDA *et al.* 1975; MIZUNO *et al.*, 1976). The formative period of this metamorphic rock is not obvious, but it seems to be older than *Nummulites*-bearing rock to be described later, and may be pre-Tertiary together with other hard clastic rocks obtained from the ridge.

It is also significant that several acidic and basic plutonic rock were collected from the Amami Plateau and the Daito Ridge (SHIKI, AOKI *et al.*, 1975; SHIKI, TOKUOKA *et al.*, 1975; SUWA and AOKI, 1975). Of these rocks, the K–Ar age of biotite hornblende tonalite is 75.1 ± 2.4 m.y. The ratio of $^{87}Sr/^{86}Sr$ of this tonalite, however, is very low; K is small in quantity and Rb is surprisingly small. The ratio of K/Rb, therefore, is abnormally high (MATSUDA *et al.*, 1975). That is, this tonalite has characteristics revealing that it was originated in the upper mantle.

It is also interesting that some of the volcanic or pyroclastic rocks obtained from the Daito Ridge Group are very similar in appearance to the Neogene rocks distributed in the Green Tuff region of Japan, though this similarity does not signify that the former were produced in Neogene.

A few of the andesitic or basaltic rocks obtained from the Amami Plateau are

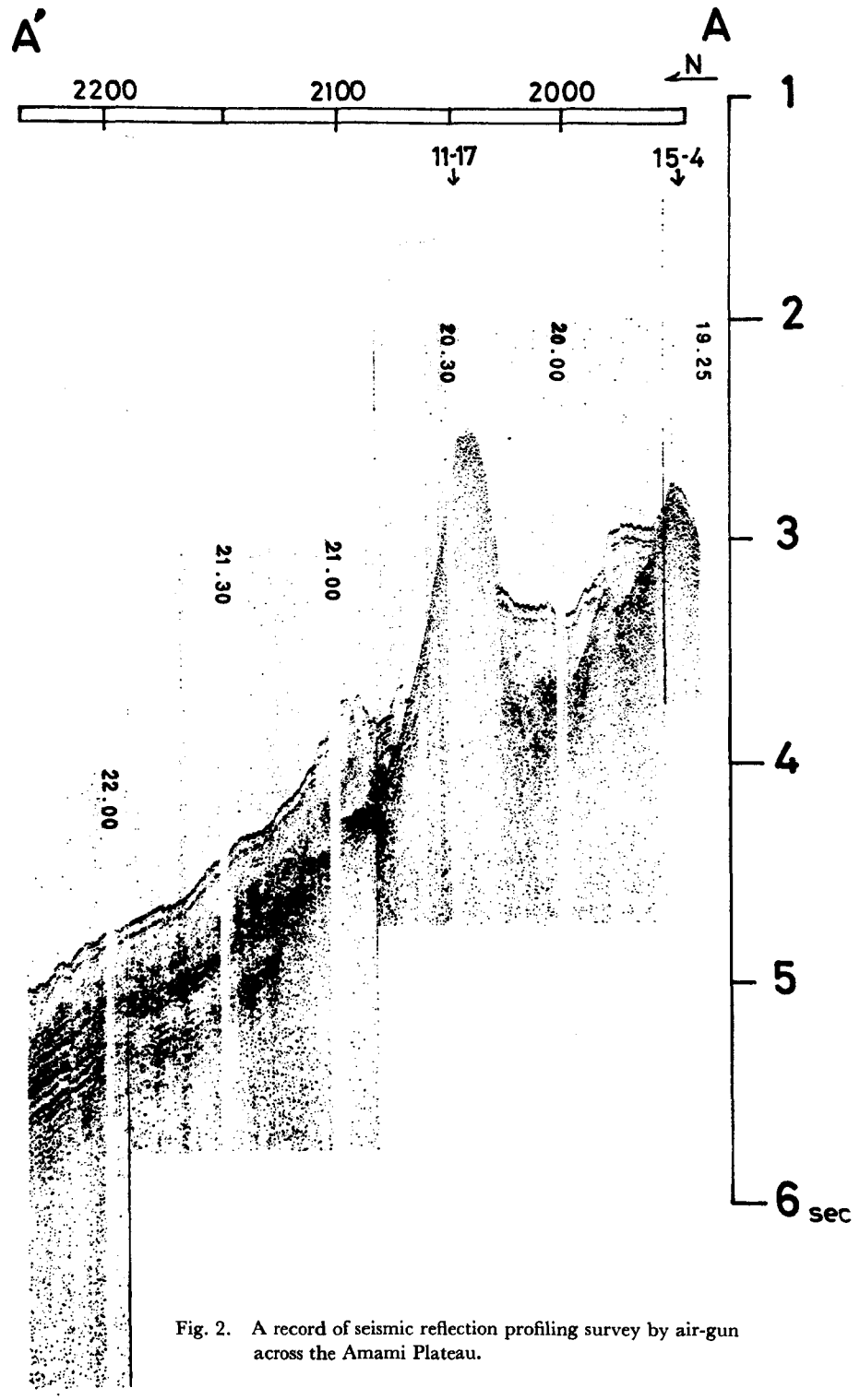

Fig. 2. A record of seismic reflection profiling survey by air-gun across the Amami Plateau.

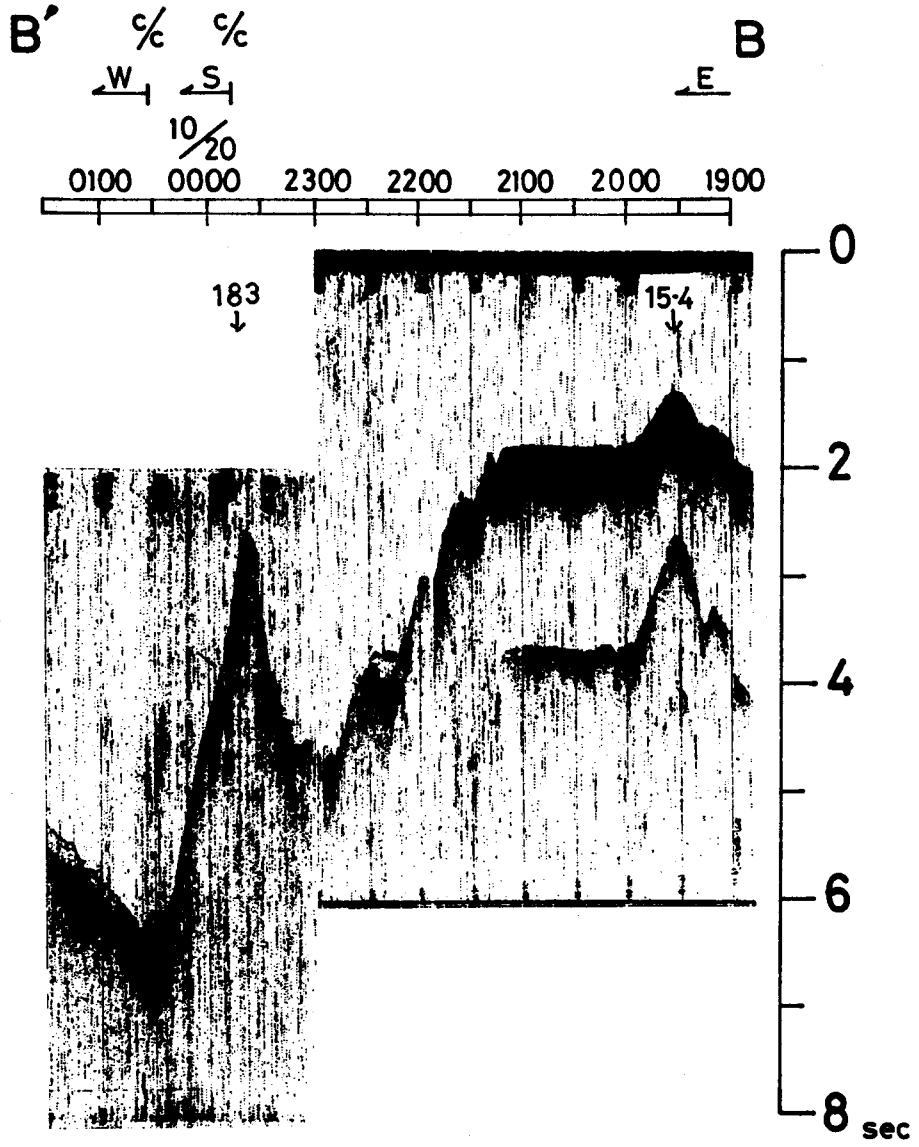

Fig. 3. A record of seismic reflection profiling survey by air-gun in the eastern part of the Daito Ridge.

not decomposed, and their K–Ar ages are ca. 82–85 m.y. (MATSUDA *et al.*, *op. cit.*).

However, all of the volcanic rocks gathered from the region around the Daito

Ridge Group (Daito Ridge Group Region) are not necessarily members of the Pre-Tertiary system. As a result of an investigation by air gun, some hard rocks which intrude into the *Nummulites*-bearing strata overlying the foundation rocks, were recognized (OKUDA *et al.*, 1976). The probable origin of the seamounts rising from the basins in this region is submarine volcanism in Tertiary Period.

There is no doubt that the layer of *Nummulites* rocks is widely distributed in this sea region. These *Nummulites* are identified with *Nummulites boninensis* HANZAWA yielded in the Eocene strata of Haha-jima (Hillsborough Island), Ogasawara (Bonin) Islands (KONDA, 1975; MIZUNO and KONDA, 1977). Most of the *Nummulites* rocks obtained are limestone, but some have changed into some kind of phosphate rocks.

Also, tuff and tuffaceous sandstone are distributed in the Daito Ridge Area (RESEARCH MEMBERS OF THE GDP–15 CRUISE, 1976). They are much softer than the above-mentioned igneous and clastic rocks. Their formative period is unknown, but it is likely that they are members of the Paleogene System and that their origin is related to the above-cited volcanic rocks intruding into the *Nummulites*-bearing strata.

Pliocene - early Pleistocene foraminifer- and nannoplankton-bearing sediments were collected from many localities in the flat top of each ridge (RESEARCH MEMBERS OF THE GDP–15 CRUISE, *op. cit.*). Most of them are sand or ooze, and others are semiconsolidated calcareous siltstone. The former contains Holocene foraminifers and nannoplankton also. On the other hand, the latter does not contain any Holocene fossils. This leads us to infer that Pliocene and lower Pleistocene sediments are distributed in a fairly wide area.

Another matter to be noted is that matrix-free *Nummulites*, and rocks containing *Nummulites* and other Eocene larger foraminifers were obtained frequently together with Pliocene microfossil-bearing sediments. On the other hand, late Oligocene and Miocene sediments determined from the fossil evidence have never been discovered from this region. Therefore, it appears that Oligocene and Miocene strata are not distributed in the ridge area of the region.

As to the basins of this region, we have to wait for the execution of the International Program of Ocean Drilling (IPOD) in order to obtain the foundation rocks. From the results of studies of gravity and magnetic anomalies, it is assumed that oceanic crust exists under the basin floor between the Amami Plateau and the Daito Ridge, and under a part of the basin near the Kyushu-Palau Ridge (MIZUNO, OKUDA *et al.*, *op. cit.*). In these areas the sediment layer is considered to be equivalent stratigraphically to the *Nummulites*-bearing strata of the plateau and the ridge part, and shows different acoustic reflection pattern from those of the other basin areas (OKUDA *et al.*, *op. cit.*). It seems to consist not of calcareous sediments but of clastic sediments wich include turbidite and had deposited on the relatively deep sea bottom.

2.2 Kyushu-Palau Ridge

It is only several years since ASTAPENKO and other members of Sakhalin Complex Scientific Research Institute collected the granitic rocks at the Komahashi Seamount II located near the north end of the Kyushu-Palau Ridge. It was the first collection of the basement rock from the northern part of the Philippine Sea, and gave strong encouragement to the subsequent geological exploration and investigation of the sea.

Acidic plutonic rocks were obtained, thereafter, from the same seamount during GDP–8 and GH74–7 Cruises and also from a seamount situated nearly 500 km south-east of the seamount during the latter cruise (SHIKI *et al.*, 1974; MIZUNO, OKUDA *et al.*, *op. cit.*). According to the results of analyses of two samples selected, they are both characterized by poor Potassium and Rubidium contents, especially of the latter, and by being rich in sodium content (ISHIZAKA, 1975). Consequently, these rocks may have the same orgin as the tonalite of the Amami Plateau. However, one of them is nearly 37.5 m.y. in K–Ar age (SHIBATA and OKUDA, 1975) and the other is nearly 51 m.y. in fission track age (NISHIMURA, 1975). Namely, the basement rocks of the Kyushu-Palau Ridge are younger than those of the Amami Plateau.

It is well known that Oligocene basaltic tuff was obtained from the top of the Kyushu-Palau Ridge during the Leg 31 Cruise of DSDP (DSDP Scientific Staff, 1973). During the GDP and Hakurei-maru cruises, andesite, basalt, tuff, etc. have also been collected (SHIKI, TOKUOKA *et al.*, *op. cit*; AOKI *et al.*, 1975; MIZUNO and NOHARA *et al.*, *op. cit.*). These rocks are perhaps parts of the foundation rocks of the Kyushu-Palau Ridge.

In addition, limestones and phosphate rocks were obtained from the ridge at a depth of 1000 meters or so. These rocks overlie the foundation rocks. Some of the former are composed of organic sediments of reef origin, and their geological ages are early Miocene and middle Miocene judging from the fossils of foraminifers and others contained (KONDA *et al.*, 1975). Therefore, the rocks overlying the foundation rocks of the Kyushu-Palau Ridge are younger than those (*Nummulites* rocks) of the Daito Ridge Group. This fact, together with the difference of radiometric ages of the rocks obtained from the two ridges, may indicate that there are considerable differences in the age of ridge-forming movements and activities of two ridges. It is readily surmised that the Kyushu-Palau Ridge is younger than the Daito Ridge Group in age, because the former cuts across the latter. The results of the present studies support such an inference.

2.3 Kinan Seamount Chain

So far a few rock samples have been collected from the Kinan Seamount Chain. They are basaltic lava and tuff (TOKUYAMA and FUJIOKA, 1976). From the evidence

of these alone it cannot be said that all seamounts of this chain are composed of such rocks. However, considering the geophysical informations about the magnetic anomaly (KOBAYASHI, 1976), it is probable that these seamounts consist mainly of basaltic materials.

Furthermore, there are rather numerous seamounts rising from the foundation-like swell at the depth of 2500 meters or so in the Kyushu-Palau Ridge area (MISAWA, 1975). On the other hand, the seamounts of the Kinan Seamount Chain seem to be isolated from each other. This may also be related to the differences between the property of the seamounts of the Kyushu-Palau Ridge and that of the Kinan Seamount Chain—The seamounts of the latter are of volcanic origin.

Needless to say, the bottom of the Shikoku Basin is considered to be composed of oceanic crust, from various geophysical informations.

3. Geohistory of Ridges and Seamounts

Based upon the results of recent geological studies and other informations, a tentative interpretation of the tectonic history of the bottom of the northern Philippine Sea can be given.

The foundation rocks forming the non-oceanic crust of the Daito Ridge Group were basically formed by Pre-Cenozoic island arc activities, accompanied with regional metamorphism, volcanism, acidic intrusion, etc. These rocks suffered upheaval and subsequent erosion, and then were overlain by the shallow sea sediments yielding *Nummulites* and other foraminifers.

It seems that volcanic activities took place before and after the deposition of Eocene *Nummulites*-bearing sediments, and that the subsidence of the basin area had already occurred partially before the deposition of *Nummulites*-bearing sediments. Differential upheaval and subsidence were active especially in Oligocene and/or Miocene, and the present basins and ridges in the Daito Ridge Group Region were formed. At that time, the ridges of this Region might be the sites of erosion. After that the whole Daito Ridge Group Region subsided 1000–2000 meters especially since Pleistocene.

Activities of the Kyushu-Palau Ridge, such as volcanism, acidic intrusion, upheaval, etc., occurred in Eocene-Oligocene, that is, later than those of the Daito Ridge Group. On the seamounts formed by these activities, limestone of reef-origin developed in early Miocene and middle Miocene. The Kyushu-Palau Ridge has also sunk at least 600 meters (probably more than 2000 meters) since late Miocene.

As pointed out in the previous section, only a few data were obtained from the Kinan Seamount Chain, namely, basaltic rock samples and geophysical informations. However, it may be assumed that the seamounts consist mainly of basaltic materials

and that the chain had not appeared before the development of the Kyushu-Palau Ridge.

In carrying out geological studies of the seamounts and the ridges situated in the northern Philippine Sea, it is to be considered that the lowering of the sea level in the middle Miocene and its rapid rising during a certain period from the latest Pliocene to the Pleistocene in the Honshu and Ryukyu Arcs have already been discussed (HOSHINO, 1975; IKEBE, 1975), because these sea level changes must have affected the features of the Philippine Sea.

4. Some Problems related to the Tectonic History of the Philippine Sea

4.1 Kuroshio Paleoland

Judging from the direction of the paleocurrent and the distribution of orthoquartzite gravels observed in the Shimanto Belt in southwest Japan, the members of the Shimanto Research Group proposed that a piece of land had extended from the south of the Honshu Arc to the east of the Ryukyu Arc during the period from late Mesozic to Paleogene, and named the land Kuroshio Paleoland (HARATA and TOKUOKA, 1974; SUZUKI and TATEISHI 1975; etc.).

It is as yet uncertain whether or not this land is identical with the islands* of the Daito Ridge Group Region which were suffering erosion in the period from Oligocene to Miocene. If, they are regarded to be identical with each other, the question as to the reason why no continental crust is recognized in the Shikoku Basin should be answered. Oceanization, upheaval and erosion, or westward drift due to the spreading of the Shikoku Basin, etc. may be cited. As the reasons for the extinction of the continental crust, all of them are, however, hypothetical at present.

On the other hand, judging from the above-mentioned petrological characteristics of the acidic plutonic rocks obtained from the Daito Ridge Group, the Daito paleoislands may be different from the Kuroshio Paleoland. In this case, the former islands ought to be situated more to the south; otherwise it would overlap with the Kuroshio Paleoland. It is because the size of the paleoland is considered to have been almost equal to that of the Japanese Islands. Also, the spreading of the southern Philippine Sea may be considered with reference to the Central Basin Fault.

4.2 Island arc-like characters and stages of tectonic development

It may safely be said that the Daito Ridge Group was a sort of island arc or orogenic belt in the period before the end of Mesozoic. In the Kyushu-Palau Ridge,

* We call this islands the Daito Paleoisland Group.

no crystalline schists are found, but acidic plutonic rocks are certainly large in quantity as one of the ridge-forming rocks. Therefore, the Kyushu-Palau Ridge cannot possibly be equivalent to the ordinary ridge and seamount of the ocean.

On the other hand, as mentioned above, the plutonic rocks of both the Daito Ridge Group and the Kyushu-Palau Ridge are different in isotope ratios and other petrological characters from those of the ordinary island arcs and the continents. Furthermore, these ridges are not active now, and not accompanied by trenches or earthquake zones. In comparison with the island arcs bordering on the proper Pacific Ocean, they have, not first-class, but second-class structure.

In this regard, SHIKI, AOKI and MISAWA (1976) proposed that Daito Ridge Group and Kyushu-Palau Ridge are island arcs which died young. The former may have once been a fairly mature island arc. However, the latter may have stopped its activity in a very immature stage, which may have to do with its second-class structure due to its occurrence in the marginal sea.

It seems that some chemical characters of igneous rock, such as ratios of K/Na, K/Rb, and $^{87}Sr/^{86}Sr$ are related not only with the tectonic situation of the petrogenesis but also with the maturity of the arc and the orogenic belt.

Some granites of mature arcs such as the Honshu Arc have fairly continental character, though they are far different from the typical granite of the shield. The occurrence of the oceanic type rocks in such an old arc is due solely to the rejuvenation and the appearance of deep fissure penetrating to the upper mantle.

It may be interesting to investigate the characters and stages of development of the island arcs, seamounts, and ridges in the West Pacific from the above-mentioned point of view.

For instance, what is the Emperor Seamount Group? This should be investigated in more detail. By a glance at the submarine topographic map of the West Pacific, many marine geologists are already aware that the situation of the Emperor Seamount Group in the West Pacific has a little resemblance to that of the Izu-Bonin and Mariana Arcs that border the Philippine Sea.

Is it too speculative to consider that the Emperor Seamount Group may be the embryo of an island arc, and may develop into a first-class island arc in future?

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