Further Geological Problems concerning the Northwestern Philippine Sea

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Introduction

Geology of the Northwestern Philippine Sea was discussed and clarified during and after the time of GDP and DSDP (AOKI *et al.*, 1976; RM. GDP-21; KARIG, 1972; KLEIN and KOBAYASHI, 1980, 1981; KOBAYASHI, 1983; MIZUNO *et al.*, 1975; MIZUNO, OKUDA and TAMAKI, 1977; OKUDA *et al.*, 1976; SHIKI *et al.*, 1977; SHIKI *et al.*, 1979; SHIKI, 1979; UYEDA and BEN-AVRAHAM, 1972).

Results of studies of the constituent rocks of the ridges in the Northwestern Philippine Sea are summarized in the article by SHIKI and MIZUNO in this volume. It has been revealed that the crust of the ridges and basins in the Daito Ridge Group Region is the oldest in the Philippine Marginal Sea. However, many problems remain unsolved. In this article the writer wishes to discuss further the geotectonic history mainly of the northwestern part of the Philippine Sea, and to illustrate the need of further researches to elucidate the origin and tectonics of the ridges and basins in the region.

Fig. 1 shows the idealized geological profile of the Daito Ridge which has the most complicated structure of all the ridges in the region. The idealized profile of the Northern Kyushu-Palau Ridge is shown in Fig. 2. These profiles together with other compiled data offer useful information about the geotectonic history of these ridges and the whole northwestern Philippine Sea.

Meso-tectonics of the Daito Ridge Group

Ages of two ridges are yet unknown

The term "Mesotectonics" is applied to the Late Cretaceous and Paleogene tectonics of the Northern Philippine Sea, here.

As has been mentioned repeatedly, Late Cretaceous ages of the granite intrusion and the basaltic volcanism in the Amami Plateau are evident (MATSUDA *et al.*, 1975; MATSUDA, 1983; MATSUDA, this volume). The age of the granite of the Daito Ridge was correlated tentatively to that of the granite of the Amami Plateau (ISHIKAWA and AOKI, 1979; SHIKI, *et al.*, 1977). However, it must be noted that there exists no logical proof of the age correlation of the granite of the Daito Ridge to that of the Amami Plateau (SHIKI, 1979). The former is possibly younger than the latter when the K–Ar age of the thermal-metamorphosed basalt pebbles of a core form DSDP Site 445 (OZIMA *et al.*, 1980) is considered.

The age of the basalts of the Oki-Daito Ridge is unknown yet.Dredged samples from the ridge are too small for the measurement of the isotopic age. ISHIKAWA and AOKI (1979)

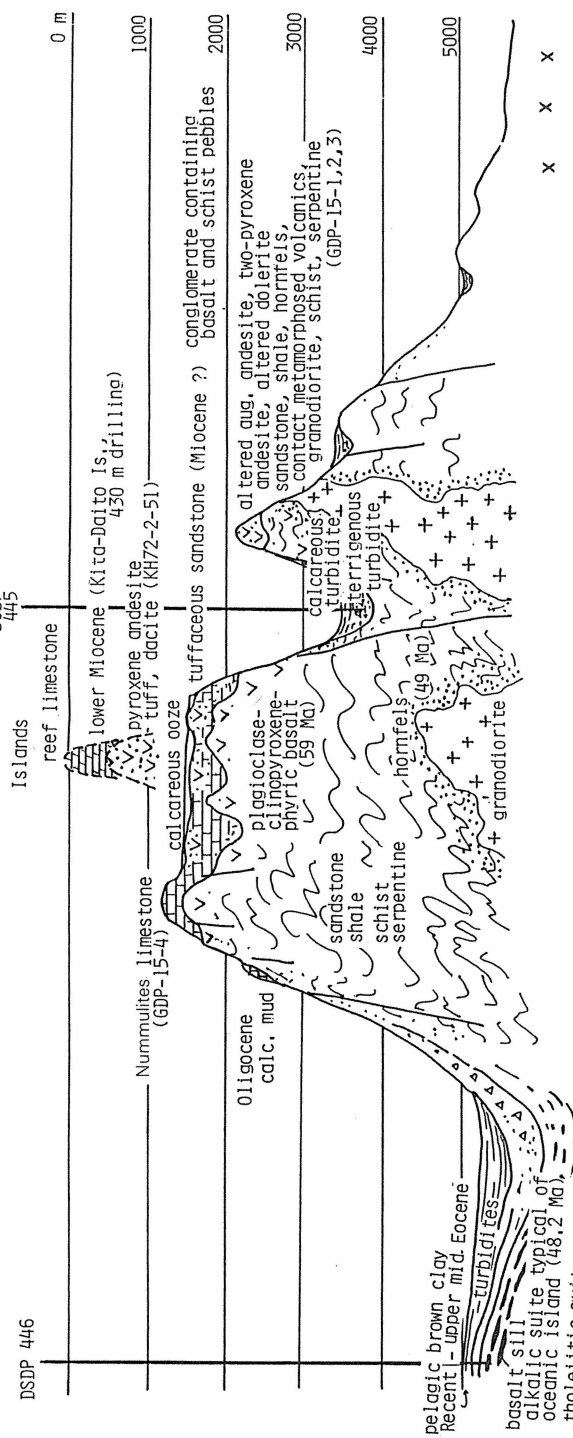

Fig. 1. Schematic profile showing geological information concerning geohistory of the Daito Ridge in the Daito Ridge Group Region, Northwest Philippine Sea.

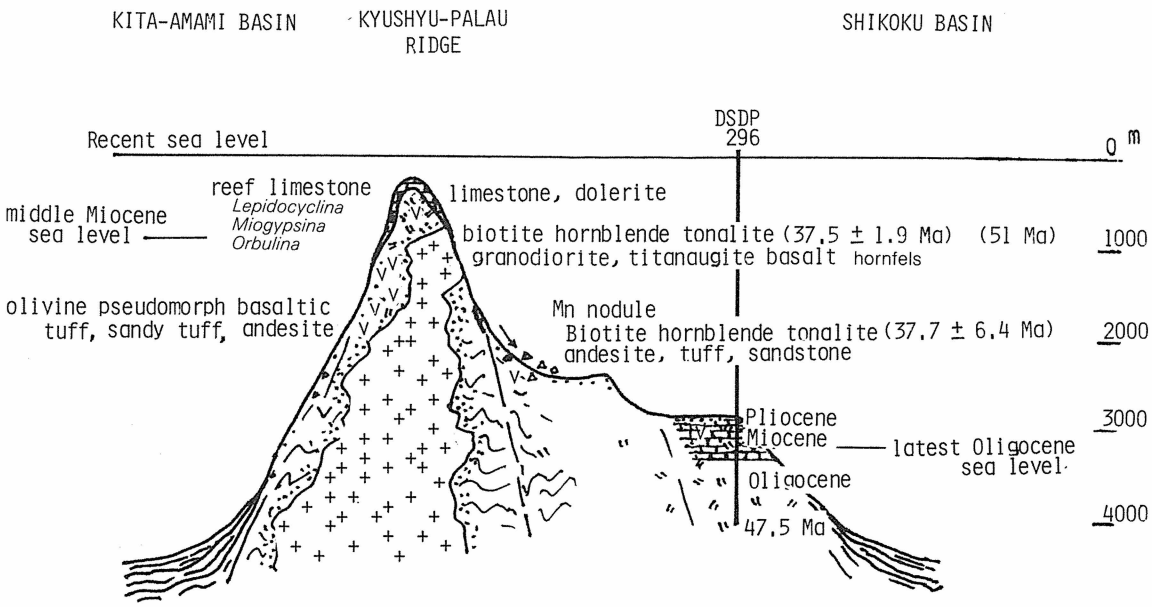

Fig. 2. Schematic profile showing geological information concerning geohistory of the Northern part of the Kyushu-Palau Ridge.

discussed the difference of the petrological character of the volcanic rocks between the Daito Ridge and the Oki-Daito Ridge. They assumed that the difference is related to the difference in ages of the treated samples, considering the stratigraphic relations of the rocks with the *Nummulites*-bearing limestones investigated by acoustic observations across the dredge sites of the samples. The need to obtain new sample materials, large enough for age determination, is obvious, in order to clarify the origin and the mesotectonic development of the Daito Ridge Group in more detail. However, a tentative discussion may not be meaningless in finding some working hypotheses for the future study of the Northern Philippine Sea.

Subduction from the north?

Tectonic setting responsible for the occurrence of the granitic rocks and schists is an interesting subject to be investigated.

As is well known, the arrangement of rocks revealing "paired metamorphism" is a characteristic feature of orogenic belts and island arcs such as the Japanese Islands. As for as the samples are concerned, the arrangement of the rocks in the Daito Ridge Group seems to indicate possible paired metamorphism in the Cretaceous age. That is to say, grainitic rocks exist in the northern ridge (Amami Plateau) and the middle ridge (Daito Ridge). On the contrary, schists are found only from the middle ridge. Thus, subduction of an oceanic plate from the south at that time was conceived by a few persons (personal communications), with reference to the polarity of the Jurrasic subduction tectonics which produced the paired metamorphic belt in the Japanese Islands.

A great difficulty exists, however, in applying the paired metamorphism model to the

development of the "Paleo-Daito Ridge Group Island Arc" ("Paleo-Daito Island Arc"). This is the petrological character of the granitic rocks of the Amami Plateau. The rocks are plagiogranite as stressed repeatedly ISHIZAKA and YANAGI, 1975; MATSUDA *et al.*, 1975; MATSUDA, 1983; MATSUDA, this volume; and associated with gabbroic rock. They have notable resemblance with the granitic rocks which occur in the "Shiono-Misaki-(tectonic)-zone at the Miocene fore-arc tectonic high studied by HISATOMI and MIYAKE (1981) and MIYAKE (1981). Granitic rocks of similar petro-chemical cahracter, poor in Potasium, low in initial $^{87}Sr/^{86}Sr$ ratio, and so on, occur in the Permo-Triassic tectonic belts in Japan (ISHIZAKA and YANAGI, 1975; MATSUDA *et al.*, 1975), associated with ophiolitic rocks such as basalt, gabbro, and amphibolite, etc.

Tectonic settings of these granitic and other rocks of the tectonic belts were discussed by several persons. In particular, pictures by MARUYAMA (1978), and HADA and SUZUKI (1983a, b) are interesting showing the idea of occurrence along the suture zone between the island arc crust and the oceanic plate (Figs. 3 and 4). Similar idea was discussed by SHIKI (1978, 1982), SHIKI and MISAWA (1979, 1980, 1982) in connection with the composite basic problems concerning the subduction and accretion tectonics such as bottom structure of the accretion prism, effect or result of the activity of the Wadati-Benioff zone in the shallow places. MIYAKE (1981) gave a more petrological interpretation of the magma genesis and the course of uprising of the acidic and basic magmas along his "Shiono-Misaki zone".

That is to say, the notable resemblance of the petro-chemical character of the granitic rocks of the Amami Plateau and that of the Shiono-Misaki strongly suggests the possibility that the rocks belong to the fore-arc igneous rocks of the "Daito Ridge Group Island Arc". The Daito Metamorphics (MIZUNO, OKUDA *et al.*, 1975) are possibly high P and low T schists derived from the deeper parts of the accretionary prism in the ocean side of the zone of granite intrusion. However, the metamorphics can be older than the granitic rocks like in the case of the relation between the Carboniferous and Permian Sangun Metamorphic Rocks and the potassium poor granitic rocks in the Maizuru Tectonic Belt. In this case the metamorphics develop in the inner side of the tectonic belt. If there is a similarity in tectonic setting between the Daito Ridge group and the Maizuru Belt, the Cretaceous subduction must have occurred from the north and a ocean basin must have existed in the northern side of the ridge group.

At any rate, the lack of sufficient information is apparent again. More geological cruises to obtain many large dredge samples are required to investigate the geotectonic history of this interesting region in the Northern Philippine Sea.

Daito Paleoislands and Kuroshio Paleoisland

As has been mentioned repeatedly, the Daito Ridge Group was a group of islands and suffered erosion at the latest Cretaceous and the eariest Paleogene (SHIKI *et al.*, 1977). On the other hand, existence of the other islands of the Cretaceous and the Paleogene age has been assumed in the southern side of Southwest Japan from the south of the Honshu to the east of the Ryukyu islands (HARATA and TOKUOKA, 1974; HARATA *et al.*, 1979; SUZUKI and TATEISHI, 1975 etc.). Distinction of these two paleoislands has also been pointed out on the basis of the different character of the granites of the islands (SHIKI *et al.*, 1977). Namely, the granitic pebbles from the conglomerates of the present Japanese Islands and the Ryukyu Islands, which is assumed to have originated from the Kuroshio

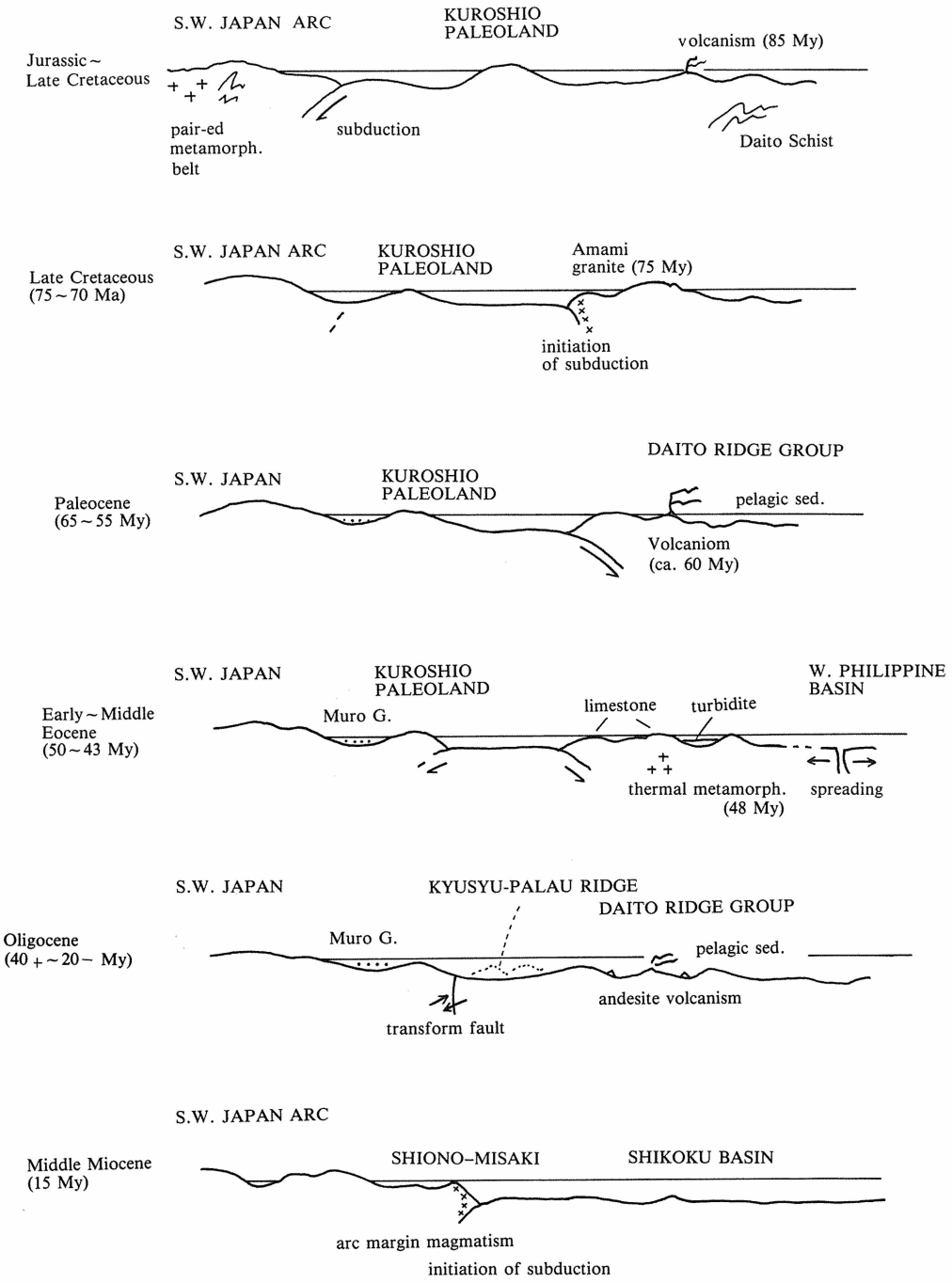

Fig. 3. Simplified two dimentional scenario for change of the "meso-tectonic" settings due to collision of the Kuroshio Paleoland.

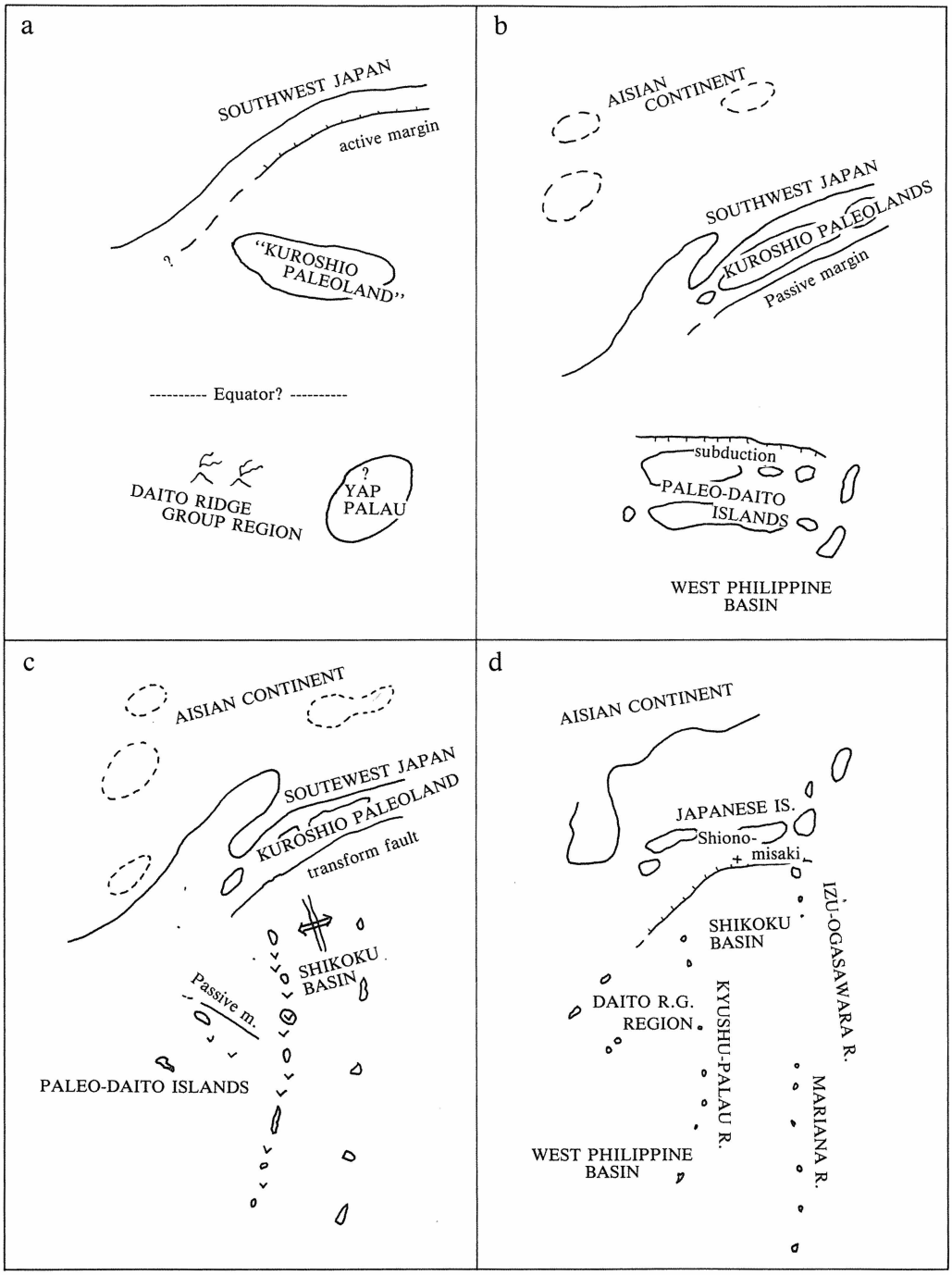

Fig. 4. Schematic scenario for change of the geotectonic settings of subduction. (Subduction of the Paciffic Plate from the east is not shown).
a: Late Cretaceous
b: Paleocene-Eocene
c: Oligocene
d: Middle Miocene

Paleoislands, can not be regarded as plagiogranite by any means. Furthermore, many kinds of rocks which indicate the bigger arc or continental character of the source land such as welded tuff, gneiss, and ortho-quartzite are closely associated with the granites.

Southward positioning (and eastward to the Ryukyu Islands) of the paleo-islands was illustrated based on the measurements of the paleocurrent directions (HARATA, 1965). However, no evident remnant crust of the Kuroshio Paleoislands has been found in the Philippine Sea. Most probably, the remnants had collided and joined with the crust of the Honshu Arc and the Ryukyu Arc as suggested by NAKAZAWA and others (1983). Facies change of the sediments of the Shimanto Super Belt throughout the late Mesozoic to the Paleogene indicates such tectonic event. In short, probable trench sediments appear in formations older than Santonian, and the much coarser sediments including end-olisthostrom derived from the south reflect the upheaval of the provenance situated in the south.

Detailed discussion about the geohistory and collision tectonics of the Shimanto Belt is not the purpose of this article. However, it must be pointed that the time of the inferred collision of the Kuroshio Paleoland is very close to or correlative with that of the fore-arc intrusion at the northern margin of the Daito Paleo-Island Arc. In this connection, it must be remembered that fore-arc magmatism is a special event which can happen only at the initial stage of subduction of relatively warm oceanic plate (MIYAKE, 1981; JAKES and MIYAKE, 1984). It may suggest that the subduction of the unnamed Paleo-Philippine Sea Plate of the Mesozoic time (Kula plate ?) under the Paleo-Japan Island Arc ceased when the Kuroshio Paleo-Islands collided with the Japan Arc (Fig. 3b). Subduction to the south under the Paleo-Daito Arc occurred (Fig. 3c), but, did not continue long. However, the volcanic activities of the Paleocene and earliest Eocene age on and near the Daito Ridge confirmed by the DSDP Drilling (MCKEE and KLOCK, 1980; OZIMA *et al.*, 1980; TOKUYAMA *et al.*, 1980) may be related with the subduction tectonics from the north.

Geohistory of the post-Middle Eocene time has been clarified rather well. New subduction of the Philippine plate from the south to the north under the Kuroshio Paleo-Islands which had collided with the Paleo-Japanese Islands took place (Fig. 3d). That is, subduction zone jumped southward. Most probably, this new subduction was connected with the opening of the West Philippine Basin. As a result, the Daito Ridge Group drifted from the south to the north about 2000km since 42m.y.B.P. as clarified by drilling at the Site 445 (KINOSHITA, 1980).

Pre-mesotectonic history and maturity of Daito Ridge Arc

Geotectonic history of the Daito Ridge Group before the time of the subduction and granite intrusion discussed above is still very obscure. At any rate, presence of the schists and clastic rocks such as wacke and very hard shale reveals the old history of the Daito Ridge. That is, as mentioned above, the metamorphism itself may be older than granite intrusion in the ridge. And, the original rock of the schists must have existed before the metamorphism. Besides, the wacke and shale are hard enough to be regarded as Jurassic or older in age when compared with the sedimentary rocks of the Japanese Islands.

In this connection, the discussion about the maturity of the Daito Paleo-Island Arc must be corrected. That is, SHIKI and others (1976, 1977) thought that the Daito Ridge Group and the Kyushu-Palau Ridge are island arcs which died young. However, as in reser-

vation added by SHIKI and others (1979), the Daito Ridge Group may be said to have once been a fairly mature island arc. Presence of the schists and clastic rocks forces such correction. Besides, plagiogranite indicates intrusion of the mantle materials, and may suggest the appearance of deep fissure which allowed the intrusion at the time of initial stage of subduction as discussed above. However, such intrusion can occur in the older crust made by older cycle arc-activities.

As for the Kyushu-Palau Ridge, such correction is not required. The idea of the development and maturity of island arcs proposed by SHIKI and others (1976, 1977), MATSUDA and others (1977), OZIMA *et al.*, 1977 may be valied for the future comparative studies of the island arcs.

Miscellaneous problems to be studied

It may not be meaningless to mention on this opportunity some problems and questions concerning the geology and geohistory of the Northern Philippine Sea.

One of the reasons why the Daito Ridge Group was regarded as young when it died, was its size. The width of the ridge group is large enough for assuming high maturity. Its length seems, however to be, too small. Most probably, this problem will be solved by systematic efforts for searching the extension of the ridges of the group. A project for the comparative studies of the constituent rocks of the Daito Ridge Group, Philippine Islands, Yap Island, Palau Island, and so on must be carried out in future.

It can be considered that the genesis and activities of the Kyushu-Palau ridge and the Shikoku Basin must have had some influence on the geohistory of the Daito Ridge Group. Tuffaceous rocks obtained at topographic highs such as seamounts and ridges in the Daito Ridge Group Region may have sources in the Kyushu-Palau Ridge (RM. GDP-21; SHIKI, MIZUNO and KOBAYASHI, this volume). However, there are some highs of acoustic basement from which volcanic rocks were dredged (MISAWA *et al.*, 1976; MISAWA *et al.*, this volume). These volcanic rocks seems to be younger than *Nummulites* beds based on accoustic records and possibly show back-arc volcanism connected with the activities of the Kyushu-Palau arc.

Needless to say, this idea suggests subduction of Shikoku Basin Plate on the east side of the Kyushu-Palau Ridge in contrary to the current opinion. As is well known, the Palau Arc which is situated at the southern end of the Kyushu-Palau Ridge accompanies a trench at the eastern side. Because of the relative youngness of the Kyushu-Palau Remnant Arc, traces of trench may not be too dificult to find. A few fragmental information about the thick accumulation of sediments has been reported (KOBAYASHI, personal communication). Further detailed studies are required on the volcanic rocks in the Daito Ridge Group Region and also on sediment accumulation on the east side of the Kyushu-Palau Ridge.

Neotectonic history of the Northwest Philippine Sea is an interesting subject for further future study. General subsidence of the ridges in the region since the late Pliocene has been clarified (KONDA *et al.*, 1975; NISHIMURA *et al.*, 1977; SHIKI *et al.*, 1977; SHIKI, MISAWA and KONDA *et al.*, 1979; MIZUNO, OKUDA, NAGUMO *et al.*, 1979; INGLE *et al.*, 1975). However, block movement of the Daito Ridge Group assumed from the difference in depth of the topographic plane is not clarified (Rm. GDP-21, 1977; SHIKI, 1979). Probably, this movement is related with the tectonic of collision of the ridge with the Ryukyu Islands.

Effect of this collision on topographic change in the Islands was studied by KONISHI (personal communication). As for the effect on the topography of the Daito Ridge Group, however, very little is known except the tendency of shallower depth of flat plane on the ridges closer to the Ryukyu Trench. Further research is required in future.

Concluding remarks

There remain many problems and questions to be solved. For instance, the origin of the remarkable topography of the Oki-Daito Ridge having a central graben and the origin of the Kita-Daito Basin which have a basement of oceanic character seem interesting. However, as repeatedly stated, further detailed studies are needed to solve these many questions. At any rate, many of them may by related with the much wider background of the Philippine Sea and the entire transitional zone between the Asian Continent and the Pacific Ocean. In the present article, only the geological problems concerning the geohistory of the Northwestern Philippine Sea have been treated. More essential problems of the geotectonics of the Philippine Sea will be discussed in an another article in this volume.

References

AOKI, H., Y. KIM, Y. MISAWA, M. ISHIKAWA, and R. EGAWA, 1976: Some geological problems in the Shikoku-Philippine Basin. *Mem. Geol. Soc. Japan*, **13**, 395–398. (in Japanese with English abstract).

HADA, S. and T. SUZUKI, 1983a: Tectonic environments and crustal section of the outer zone of suthwest Japan. *In*: HASHIMOTO, H. and S. UYEDA (ed.), *Accretion Tectonics in the Circum-Pacific Regions*, Terra Sci. Publ. Co., Tokyo, 207–218.

HADA, S. and T. SUZUKI, 1983b: Accretionary melange of Cretaceous age in the Shimanto Belt in Japan. *In:* HASHIMOTO, H. and S. UYEDA (ed.), *Accretion tectonics in the Circum-Pacific Regions,* Terra Sci. Publ. Co., Tokyo, 219–230.

HARATA, T., 1965: Some directional structures in the Flysch-like beds of the Shimanto Terrain in the Kii Peninsula, Southwest Japan. *Mem. Coll. Sci., Univ. Kyoto, Ser.* B, 32 103–176.

HARATA, T., K. HISATOMI, F. KUMON, K. NAKAZAWA, M. TATEISHI, H. SUZUKI and T. TOKUOKA, 1979: Shimanto geosyncline and Kuroshio Paleoland. *In* UYEDA, S., R. W. MURPHY, and K. KOBAYASHI, Geodynamics of the Western Pacific, J. Phys. Earth, Supplement Issue, 357–366.

HARATA, T. and T. TOKUOKA, 1974: Kuroshio-paleoland. *Science*, Tokyo, **44**, (8), 495–502. (in Japanese).

INGLE, J. C. Jr., D. E. KARIG, *et al.*, 1975: *Initial Reports of the Deep Sea Drilling Project*, **31**, Washington (U. S. Govt. Printing Office), 837–855.

ISHIKAWA, M. and H. AOKI, 1978: On the volcanic rocks dredged in the Daito Ridge and Okidaito Ridge regions, northwestern Philippine Sea—with special reference to petrochemical characters on the GDP-15 and GDP-21 cruises—. *Earth Sci.* (*Chikyu Kagaku*), **32**, 244–253. (in Japanese with English abstract)

ISHIZAKA, K. and T. YANAGI, 1975: Occurrence of oceanic plagiogranites in the older tectonic zone, southwest Japan. *Earth Planet. Sci. Lett.*, **27**, 371–377.

JAKES, P. and Y. MIYAKE, 1984: Magma in forearcs: implication for ophiolite generation. *Tectonophysics*, **106**, 349–358.

KONDA, I., 1975: Some paleontological results and problematic subjects on GDP Research Cruise. *Marine Sciences*/Monthly, **7**, 7, 465–470. (in Japanese with English abstract).

MARUYAMA, S., 1978: The dismembered ophiolite belt. *Earth Sci.* (*Chikyu Kagaku*), **32**, 317–320.

(in Japanese with English abstract).

MATSUDA, J., 1983: Absolute ages and isotope ratios of the rocks obtained in the Philippine Sea. *Marine Sciences*/Monthly, 473–477. (in Japanese).

MATSUDA, J., K. SAITO, and S. ZASHU, 1975: K-Ar age and Sr isotope of rocks of manganese nodule nuclei from Amami Plateau. West Philippine Sea. *In*: K., NAKAZAWA, *et al.* (eds.), *Geological Problems of the Philippine Sea*, 99–101. (in Japanese).

MATSUDA, J., S. ZASHU, and M. OZIMA, 1977: Sr isotopic studies of volcanic rocks from island arcs in the Western Pacific. *Tectonophysics*, 37, 141–151.

MCKEE, E. and P. R. KLOCK, 1980: K-Ar ages of basalt sills from deep sea drilling project sites 444, and 446, Shikoku Basin and Daito Basin, Philippine Sea. *Init. Repts, DSDP*, **58**, Waxhington (U. S. Govt. Printing Office), 921–922.

MILLS, W., 1980: Analysis of conglomerates and associated sedimentary rocks of the Daito Ridge, Deep Sea Drilling Project Site 445. *Init. Repts, DSDP*, **58**, Washington (U. S. Govt. Printing Office), 643–657.

MISAWA, Y., H. INOKUCHI, Y. OKUDA, K. TAMAKI, and T. SHIKI, 1976: Geophysical results of the GDP-15th Cruise in the Philippine Sea. *Marine Sciences*/Monthly, **8**, 10, 702–707. (in Japanese with English abstract).

MIYAKE, Y., 1981: Geology and Petrology of the Shionomisaki Igneous Complex, Wakayama Prefecture, Japan. *Jour. Geol. Soc. Japan*, **67**, 6, 383–483.

MIZUNO, A., 1975: New light on geologic problems relating to the Daito Ridges and the Palau-Kyushu Ridge in the western Pacific. *Proc. Twelfth Session, CCOP*, 1975, 178–184.

KARIG, D. E., 1972: Remnant ares. *Geol. Soc. Amer. Bull.* **83**, 1057–1068.

KINOSHITA, H., 1980: Paleomagnetism of sediment cores from Deep Sea Drilling Project Leg 58, Philippine Sea. *Init. Repts. DSDP*, 58, Washington (U. S. Govt. Printing Office), 756–768.

KLEIN, G. DeV. and K. KOBAYASHI, 1980: Geological summary of the North Philippine Sea, based on Deep Sea Drilling Project Leg 58 results. *Init. Repts. DSDP*, 58, Washington (U. S. Govt. Printing Office).

KLEIN, G. DeV. and K. KOBAYASHI, 1981: Geological summary of the Shikoku Basin and northwestern Philippine Sea, Leg 58, DSDP/IPOD drilling results. *Oceanologia Acta*, 1981, N SP, 181–192.

KOBAYASHI, K., 1983: Cycles of subduction and Cenozoic arc activity in the Western Pacific margin. *In*: HILDE, T. W. C. and S. UYEDA (ed.), *Geodynamics of the northwestern Pacific. AGU/GSA, Geodyn. ser.* 9, 287–372.

MIZUNO, A., M. NOHARA, Y. KINOSHITA, N. NAKAJIMA, Y. OKUDA, K. TAMAKI, and K. ISHIBASHI, 1975: Scientific data obtained by the Hakurei-Maru Cruise, with special reference to the results of bottom sampling and continuous seismic reflection profiling in the East of Okinawa. *In*: NAKAZAWA, K., *et al.* (eds.), *Geological Problems of the Philippine Sea*, 105–111. (in Japanese).

MIZUNO, A., Y. OKUDA, S. NAGUMO, H. KAGAMI, and N. NASU, 1979: Subsidence of the Daito Ridge and associated basins, North Philippine Sea. *Amer. Assoc. Petrol. Geol. Memoir*, **29**, 239–243.

MIZUNO, A., Y. OKUDA, and K. TAMAKI, 1976: Some problems on the geology of the Daito Ridges Region and its origin. *Geologial Studies of Ryukyu Islands*, **1**, 177–198. (in Japanese with English abstract).

MIAUNO, A., Y. OKUDA, K. TAMAKI, Y. KINOSHITA, M. NOYARA, M. YUASA, N NAKAJIMA, F. MURAKAMI, S. TERASHIMA, and K. ISHIBASHI, 1975: Marine geology and geologic history of the Daito Ridges area, northwestern Philippine Sea. *Marine Sciences*/Monthly, **7**, 7, 484–491; **7**, 8, 543–548. (in Japanese with English abstract).

MIZUNO, A., K. SHIBATA, S. UCHIUMI, M. YUASA, Y. OKUDA, M. NOHARA, and Y. KINOSHITA, 1977:

Granodiorite from the Minami-koho Seamount on the Kyushu-Palau Ridge, and its K-Ar age. *Bull. Geol. Surv. Japan*, **28**, 8, 507–511. (in Japanese with English abstract).

NAKAZAWA, K., H. MATSUYAMA, and F. KUMON, 1983: Olistostrome stratigraphy in the Shimanto Belt and its formation mechanism. *Marine Sciences/*Monthly, **15**, 448–452. (in Japanese).

NISHIMURA, A., I. KONDA, K. MATSUOKA, S. NISHIDA, and T. OHNO, 1977: Microfossils of the core sample GDP-11-15 from the Amami Plateau, the northern margin of the Philippine Sea. *Mem. Fac. Sci, Kyoto Univ., Ser. Geol. Mineral.*, **43**, 111–130.

OKUDA, Y., A. MIZUNO, K. TAMAKI, and K. NAGAYAMA, 1976: Tectonic development of the Daito Ridges. *Marine Sciences/*Monthly, **8**, 6, 414–422. (in Japanese with English abstract)

OZIMA, M., I. KANEOKA, and H. UJIIE, 1977: $^{40}Ar/^{39}Ar$ age of rocks, and the development mode of the Philippine Sea. *Nature*, **267**, 816–818.

OZIMA, M., T. TAKIGAMI, and I. KANEOKA, 1980: $^{40}Ar/^{39}Ar$ geochronological studies on rocks of Deep Sea Drilling Project Sites 443, 445, and 446. *Init. Repts, DSDP*, **58**, Washington (U. S. Govt. Printing Office), 917–920.

SHIKI, T., 1978: Structure and tectonics under the continental slopes of the Honshu Arc. *Tectonopysics EOS, Trans. Am. Geophys. Union*, **59**, 1183.

SHIKI, T., 1979: Present knowledges of geohistory of the Northwestern Philippine Sea. *Marine Sciences/*Monthly, **1**, 1, 206–211. (in Japanese).

SHIKI, T., H. AOKI, and Y. MISAWA, 1975: Geological results of the recent studies of the Philippine Sea—with special reference to GDP-8, 11 cruises— *Marine Sciences/*Monthly, **7**, 7, 454-460. (in Japanese with English abstract).

SHIKI, T., H. AOKI, and Y. MISAWA, 1976: Island arc-like character and stages of developments of the Kyushu-Palau Ridge and the Daito Ridge Groups. *Marine Sciences/*Monthly, **8**, 3, 163–167. (in Japanese with English abstract).

SHIKI, T. and Y. MISAWA, 1979: A few problems concerning the structure under the continental slope and its origin. *Earth Sci. (Chikyu Kagaku).* **33**, 208–240. (in Japanese with English abstract).

SHIKI, T. and Y. MISAWA, 1980: Geologic structure and tectonics under the inner slopes of the Nankai Trough and the Japan Trench. *Geotectonics*, **6**, 98–109. (in Russian).

SHIKI, T. and Y. MISAWA, 1982: Forearc geologic structure of the Japanese Islands. *In*: LEGGETT K. (ed): Trench-Fore-arc Geology: *Sedimentation and Tectonics on Modern and Ancient Active Plate Margins*, Geol. Soc. Special Publ. 10, London, Black-well Sci. Publ., 63–73.

SHIKI, T., Y. MISAWA, and I. KONDA, 1979: The Daito Ridge Group and the Kyushu-Palau Ridge—with special reference to the tectonics of the Philippine Sea—. *J. Phys. Earth*, **27**, Suppl., S113–S124.

SHIKI, T., Y. MISAWA, I. KONDA, and A. NISHIMURA, 1977: Geology and Geohistory of the Northwestern Philippine Sea, with special reference to the results of the recent Japanese research cruises. *Mem. Faculty Sci., Kyoto Univ., Ser. Geol. Mineral.*, **44**, 67–78.

SUZUKI, K. and M. TATEISHI, 1975: The development of the Shimanto geosyncline and the Kuroshio Paleoland. *Marine Sciences/*Monthly, **7**, 685–691. (in Japanese with English abstract).

TOKUYAMA, M. and K. FUJIOKA, 1976: The petrological study on basalt from Kinan Seamount and DSDP Site 54, *Marine Sciences/*Monthly, **8**, 184–191. (in Japanese with English abstract).

TOKUYAMA, H., M. YUASA, and A. MIZUNO, 1980: Conglomerate and sandstone petrography, Deep Sea Drilling Project site 445, Philippine Sea. *Init. Repts. DSDP*, **58**, Washington. (U. S. Govt. Printing Office), 629–641.

UYEDA, S., and Z. Ben-AVRAHAM, 1980: Origin and development of the Philippine Sea. *Nature*, **240**, 176–178.