

Age constraint on the obduction of ophiolitic rocks in the Yap Island, Philippine Sea, using nannofossils

Kantaro Fujioka*,
Hiromi Matsuoka**,
Gaku Kimura***,
Akira Takeuchi****,
Hiroaki Matsugi*****
and Hisatake Okada*****

Received August 12, 1997.

Accepted March 25, 1998.

* Japan Marine Science and Technology Center, Yokosuka 237-0061, Japan

** Department of Geology, Faculty of Science, Kochi University, Kochi 780-8520, Japan

*** Geological Institute, University of Tokyo, Tokyo 113-0030, Japan

**** Department of Earth Sciences, Toyama University, Toyama 930-0087, Japan

***** Fukkentyousasekai Inc., Hiroshima 732, Japan

***** Division of Earth and Planetary Sciences Graduate School of Science, Hokkaido University, Sapporo 060-0810, Japan

Key words: Yap Island, obduction, ophiolitic rocks, Miocene calcareous nannofossils, Map Formation (Yap Islands)

Introduction

The Yap Islands occupy southeastern margin of the Philippine Sea Plate where the Pacific and Caroline plates meet with along the Yap and Palau trenches. The Yap Islands consist mostly of metamorphosed basic and ultramafic rocks which are originally ophiolite (Hawkins and Batiza, 1977; Ogawa and Naka, 1984) and quite different from ordinary oceanic islands that are composed mostly of volcanic rocks with or without coral reefs (Tayama, 1935; Aoki et al., 1976). Hawkins and Batiza (1977) proposed that the unique geologic feature of the Yap Islands is due to obduction of oceanic crust caused by seamounts collision sometime in the Tertiary. Poor constraints on the timing of the collision is because of few data on age of rocks in the Yap Islands. Timing of collision is very significant to know the origin of the ophiolite. If the collision and resulted obduction of ophiolite took place before opening of the Parece Vela Basin (from 27 Ma to 17 Ma), the ophiolite is equivalent to the basement of the West Philippine Sea Basin. If the obduction occurred after 17 Ma, the ophiolite includes

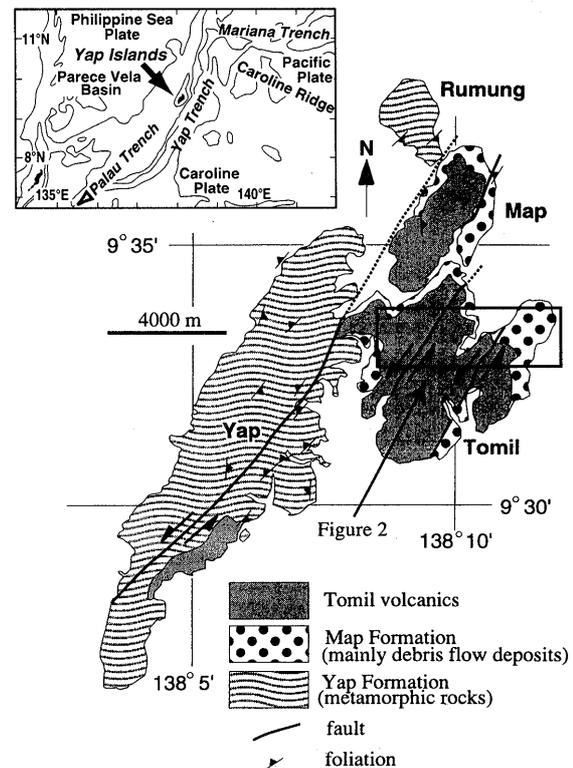


Fig. 1. Geologic map of the Yap Islands with index.

various origin; back-arc related, island arc related or older oceanic basement related before opening of the Parece Vela Basin. The key geologic units to clarify the timing are obduction related debris flow deposits (the Map Formation) and metamorphic rocks themselves.

During the cruise of R/V Hakuho-Marui, Ocean Research Institute, University of Tokyo (Fujioka et al., 1986), we visited the Yap Island and collected calcareous rocks from several localities in the Map Formation in which calcareous nannofossils were yielded. Careful examination of the biostratigraphic analysis was done for these calcareous rocks. As a result, late Early Miocene to early Middle Miocene age of the Map Formation has been precisely determined. It is very significant constraint on the timing of obduction of metamorphosed ophiolite because the Map Formation is debris flow deposits in association with the ophiolite obduction.

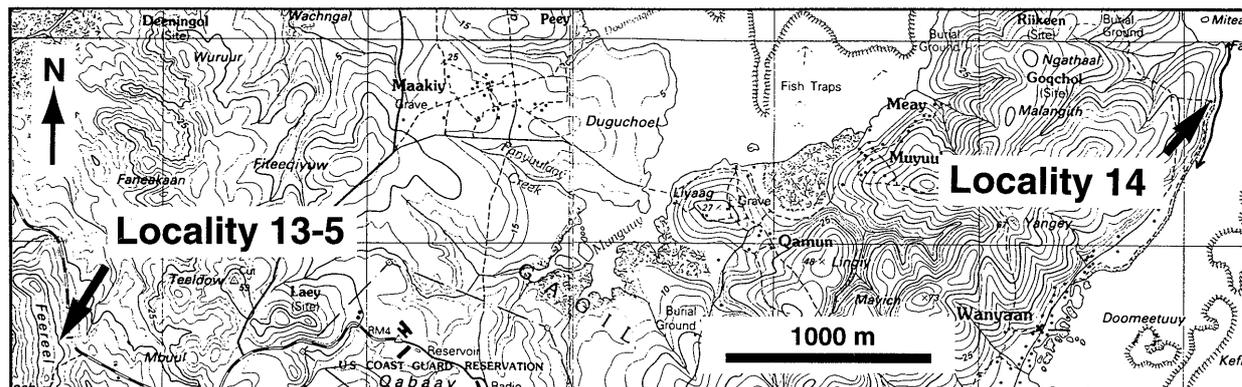


Fig. 2. Locality map of the sampling points of the nannofossil bearing mudstones of the Yap Formation (Locations were plotted on the Topographic map of the Yap Islands (WAQAB) Federated States of Micronesia, 1 : 25000, 1983).

Geologic outline of Yap Islands

The Yap Islands are composed of four major islands ; Yap, Gagil, Map and Lumung islands (Fig. 1). General trend of the islands is NNE to SSW, almost parallel to the direction of the Yap Trench. The islands constitute four principal geologic units (Tayama, 1935 ; Shiraki, 1971 ; Fujioka et al., 1986 ; Fujioka et al., 1989). They are the Yap and Map formations, Tomir volcanics, and Garim Limestone in ascending order.

The metamorphic rocks, the Yap Formation, crops out dominantly in the islands (Shiraki, 1971 ; Shiraki and Maruyama, 1978). The Yap Formation is composed dominantly of greenschists, amphibolites, metagabbros and others with minor deformed acidic to intermediate plutonic rocks. The formation is considered to be metamorphosed ophiolite and originally oceanic crust (Shiraki, 1971 ; Hawkins and Batiza, 1977). Some radiometric ages (7.6 and 10.9 Ma) have been obtained from the metamorphic rocks cropping

out not on land but under the sea surface in the forearc region (Bogdanov et al., 1977 ; Hamilton, 1979 ; Beccaluva et al., 1980 ; Tsunakawa, 1985). The metamorphic rocks are the same kinds as those on land but their ages are too young and not consistent with the age of the Map Formation covering the Yap metamorphic rocks as mentioned later.

The Map Formation covers the Yap Formation unconformably and composed of debris flow deposits and intercalates alternating beds of sandstone and mudstone. Many kinds of breccia are recognized within the debris flow deposits ; amphibolites, metagabbros, greenschists, and ultramafic rocks, which were derived from the Yap Formation, and gneissose granites, andesitic rocks and others, which are not observed as original outcrops in the islands. At several localities, cataclastic rocks of the Yap Formation showing breccia in matrix occurrence change gradually to the debris flow sediments of the Map Formation. In this case, sedimentary part of occurrence is discriminated only on the basis of existing of rounded exotic rocks in the breccia. This occurrence documents that the debris flow sediments of the Map Formation was formed in association with the exhumation of the Yap metamorphic rocks ; namely, obduction of the metamorphosed ophiolite. Hawkins and Batiza (1977) considered that the Map Formation is a tectonic melange related to overthrusting of the Yap Formation. However, no deformation of the matrix surrounding the many kinds of blocks and interbedding of sandstones and mudstones clearly document "sedimentary origin" of the Map Formation. Tayama (1935) found *Miogyopsina* in the Map Formation.

Tomir volcanics are distributed in the northeastern part of the islands and cover the Yap and Map formations. Although the volcanics are completely weathered into reddish soil, laterite, internal texture of the volcanic rocks and their original occurrence are remained. Hawkins and Batiza (1977) implicated that

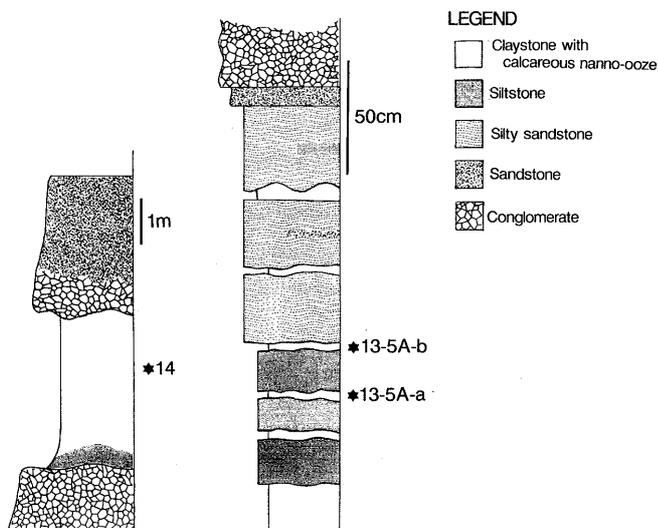


Fig. 3. Columnar section of the mudstones of the Yap Formation.

these volcanic rocks are almost the same age as weathered debris flow deposits of the Map Formation. The mode of occurrence and chemical composition, however, support that they are volcanics after the Map Formation and they have similar chemical affinity to calc-alkalic andesites (Tayama, 1935; Johnson et al., 1960). Garim Limestone, uplifted old coral reef, is located as small rocky island in the lagoon of coral reef.

Occurrence of calcareous nannofossil bearing limestone

We observed layers of calcareous nanno ooze in the Map Formation at two localities (Fig. 2). At the localities 13-5 and 14, the layers are interbedded within conglomerates, very coarse sandstones and siltstones. The layers are gently inclined. The conglomerates consist of ill sorted angular to subangular gravels. The gravels are composed mainly of amphibolites, gabbros, ultrabasic rocks, and granites which seem to be derived from the underlying Yap Formation. The sandstones and siltstones are alternating with calcareous nanno ooze at locality 13-5 (Fig. 3) and consisting of grains of amphibolites and others. The nanno ooze layers at locality 13-5 are rather thin and several centimeters thick, whereas the layer at locality 14 is very thick and about 2 m thick. We picked up two samples for the biostratigraphic age determination from two layers at locality 13-5 and five samples from one thick layer at locality 14 and photograph of the outcrop is shown in Fig 4.

Nannofossils and age of the Map Formation

Samples examined contain abundant calcareous

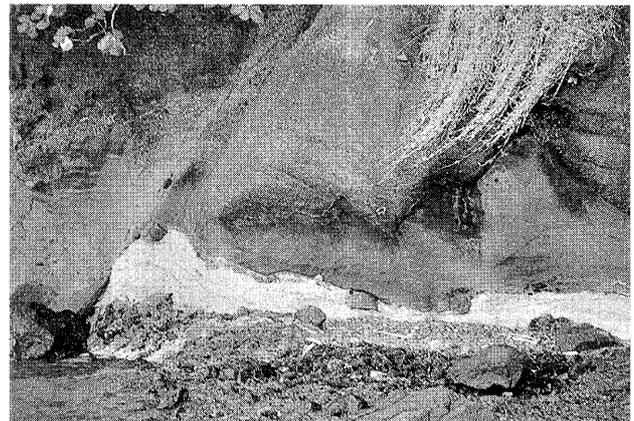


Fig. 4. Photograph of the outcrop of the sampling station 14.

nannofossils. Although nannofossils are heavily recrystallized, species identification is fairly easy for the key species of Early to Middle Miocene biostratigraphy. In addition to the abundant *Cyclicargolithus floridanus*, *Sphenolithus heteromorphus* is also abundant or common in these samples (Fig. 5 and Table 1). Because of the presence of the latter species, the nannoflora observed in these samples are identifiable to that of the late Early Miocene Zone CN 3 or early Middle Miocene Zone CN4 (Okada and Bukry, 1980). According to Berggren et al. (1995), these two zones range from 18.2 to 13.6 Ma in age. Short-rayed discoasters such as *Discoaster deflandrei* are more abundant than long-rayed discoasters such as *D. variabilis* in the CN3 flora. Nannoflora observed in samples 13-5A-a, 13-5A-b, 14-a and 14-b in which *D. deflandrei* far exceeds *D. variabilis* in relative

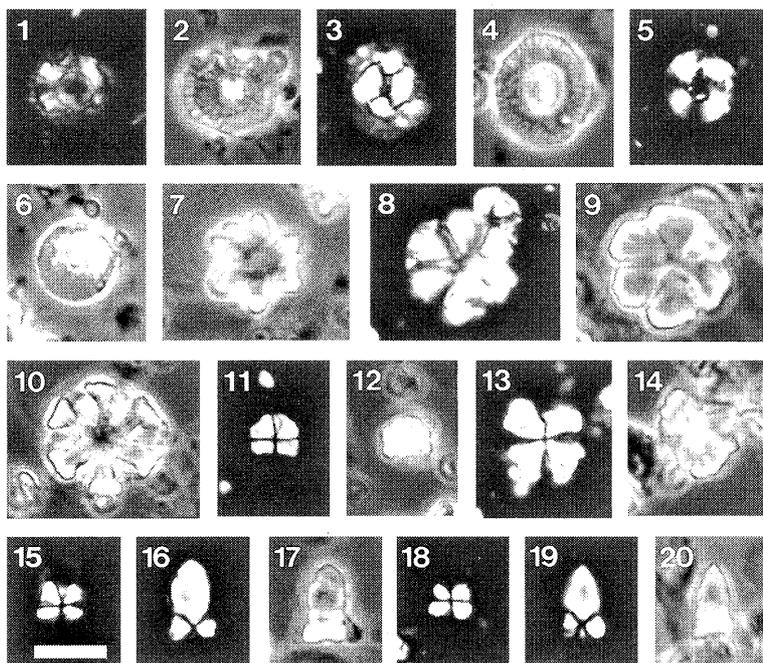


Fig. 5. Photomicrographs of the calcareous nannofossils of the Yap Formation. Photographs 2, 4, 6, 7, 9, 10, 12, 14, 17 and 20 are phase contrast micrographs, whereas all the others are micrographs of cross-polarized light images. Magnifications are all same, and the scale bar in photograph 15 represents 5µm.

- 1, 2; *Calcidiscus macintyreii* (Bukry & Bramlette) Loeblich & Tappan. Sample 14-c.
- 3, 4; *Coccolithus pelagicus* (Wallich) Schiller. Sample 14-b.
- 5, 6; *Cyclicargolithus floridanus* (Roth & Hay) Bukry. Sample 14-d.
- 7; *Discoaster adamanteus* Bramlette & Wilcoxon. Sample 14-c.
- 8, 9; *Discoaster deflandrei* Bramlette & Riedel. Sample 14-d.
- 10; *Discoaster variabilis* Martini & Bramlette. Sample 14-b.
- 11, 12; *Sphenolithus compactus* Backman. Sample 14-e.
- 13, 14; *Sphenolithus moriformis* (Bronnimann & Stradner) Bramlette & Wilcoxon. Sample 14-c.
- 15, 16, 17; *Sphenolithus heteromorphus* Deflandre. Sample 14-d.
- 18, 19, 20; *Sphenolithus heteromorphus* Deflandre. Sample 14-d.

Table 1. Distribution of calcareous nannofossils of the Yap Islands.

Sample number	13-5A-a	13-5A-b	14-a	14-b	14-c	14-d	14-e
<i>Calcidiscus leptoporus</i>					R		
<i>Calcidiscus macintyreii</i>				R	R	R	R
<i>Coccolithus miopelagicus</i>			R	R	R	R	R
<i>Coccolithus pelagicus</i>	C	C	C	C	C	F	F
<i>Cyclicargolithus floridanus</i>	A	A	A	A	A	A	A
<i>Discoaster adamanteus</i>	F	F	F	F	F	C	C
<i>Discoaster deflandrei</i>	A	C	A	A	C	C	C
<i>Discoaster variabilis</i>	F	F	F	C	C	C	C
<i>Reticulofenestra pseudoumbilicus</i>						R	
<i>Sphenolithus compactus</i>	C	C	C	C	C	C	C
<i>Sphenolithus heteromorphus</i>	C	C	C	A	A	A	A
<i>Sphenolithus moriformis</i>	C	C	C	C	C	A	A

A = abundant ; C = common ; F = few ; R = rare.

abundance, therefore, seem to belong Zone CN 3. The first occurrence of *Reticulofenestra pseudoumbilicus* generally occurs within Zone CN 4. Sample 14-d in which rare specimens identifiable to this species occurred is possibly assignable to the lower Middle Miocene sediment.

As a conclusion of these discussion, nannoflora observed in these seven samples are identifiable to Zone CN 3–CN 4. Nannofossil biostratigraphic ages of the calcareous rocks overlying the Yap Formation is 18.2–13.6 Ma.

Geologic significance of the age constraint

Nannofossil bearing calcareous rocks belong to the Map Formation consisting mostly of debris flow deposits related to the rapid uplifting of the Yap metamorphic rocks as mentioned. This uplift and exhumation ; obduction of metamorphosed ophiolite appears to have caused by collision of the Caroline Ridge against the Philippine Sea Plate (Fujioka et al., 1989). Nannofossils data constrain that the collision started at about 18 and 14 Ma in place of "sometime in the Tertiary" by Hawkins and Batiza (1977). The timing is after the opening of the Parece Vela Basin (Kobayashi and Nakada, 1978 ; Seno and Maruyama, 1984).

Acknowledgments During our work, Drs. J. Ashi, S. Kuramoto, K. Koga, T. Seno, K. Kodama and M. Kinoshita were team member of the field trip of the Yap Islands. Drs. M. Okamura, K. Shiraki, M. Yuasa and T. Kanamatsu gave us invaluable suggestions on the geology and paleontology of the Yap Islands. Mrs. K. Kato and T. Sugawara gave us helpful support. Finally, we would like to say "Karrimagar" and "Ala Kafel" to all the native people of the Yap Island who were kind and helpful for us to investigate the geology of islands.

References

Because of the hardness to get the older references on the geology of the Yap Islands, papers older than 1934 were omitted here and if you want to read these papers, please consult Tayama (1935).

- Aoki, H., Ishikawa, M., Misawa, Y. and Egawa, R., 1976, The conglomerates of the plutonic and metamorphic rocks of the Yap Islands western Pacific. *Mar. Sci.*, **8**, 179–183.*
- Beccaluva, L., Macciotta, G., Savelli, C., Serri, G. and Zeda, O., 1980, Geochemistry and K/Ar ages of volcanics dredged in the Philippine sea (Mariana, Yap and Palau Trenches and Parace Vela Basin). In Hayes, D.E., ed., *The tectonic and geologic evolution of southeast asian seas and Islands*, *American Geophys. Union., Monograph*, **23**, 247–268.
- Berggren, W. A., Kent, D. V., Swisher, C. C., III and Aubry, M.-P., 1995, A revised Cenozoic geochronology and chronostratigraphy. In Berggren, W. A., Kent, D. V. and Hardenbol, J., eds., *Geochronology, time scales and global stratigraphic correlation : a unified temporal framework for an historical geology*, *Spec. Publ. Soc. Econ. Paleontol. Mineral.*, **54**, 129–212.
- Bogdanov, N. and Scientific Party, 1977, Initial reports of the geological study of oceanic crust of the Philippine sea floor. *Ofoliti*, **2**, 137–168.
- Fujioka, K., Furuta, T., Kimura, G., Kodama, K., Koga, K., Kuramoto, S., Matsugi, H., Seno, T., Takeuchi, A., Watanabe, M. and Yamamoto, S., 1986, Sediments and rocks in and around the Palau and Yap Trenches. In Tomoda, Y., ed., *Geological and geophysical investigation of Mariana, Palau and Yap Arc-Trench Systems. Prel. Rept. Hakuho Maru Cruise KH 86-1*, 38–148.
- Fujioka, K., Kimura, G. and Takeuchi, A., 1989, Development of Yap Islands and tectonics of the Philippine Sea Plate at its southern tip. *Jour. Geogr.*, **98**, 252–260.**
- Hamilton, W., 1979, Tectonics of the Indonesian region. *Geol. Surv. Prof. Pap.*, **1078**, 270–288.
- Hawkins, J. and Batiza, R., 1977, Metamorphic rocks of the Yap arc-trench system. *Earth Planet. Sci. Lett.*, **37**, 216–229.
- Johnson, C.G., Alvis, A.J. and Hetzler, R.L., 1960, *Military geology of Yap Islands, Caroline Islands*. U.S. Army, chief Engineer, Intelligence Div., Headquarters, U.S. Army Forces Far East (Tokyo), 163 p.
- Kobayashi, K. and Nakada, M., 1978, Magnetic anomalies and tectonic evolution of the Shikoku intra-arc basin. *Jour. Phys. Earth*, **26**, Suppl., S391–S402.
- Ogawa, Y. and Naka, J., 1984, Emplacement of ophiolitic rocks in forearc areas ; Examples from central Japan and Izu-Mariana-Yap island arc system. In Gass, J.G. ed., *Ophiolites and oceanic lithosphere*, *Geol. Soc. Spec. Pub.*, **13**, 291–301.
- Okada, H. and Bukry, D., 1980, Supplementary modification and introduction of code numbers to the low-latitude Coccolith Biostratigraphic Zonation (Bukry, 1973 ; 1975). *Mar. Micropaleont.*, **5**, 321–325.
- Seno, T. and Maruyama, S., 1984, Paleogeographic reconstruction and origin of the Philippine sea. *Tectonophys.*, **102**, 53–84.
- Shiraki, K., 1971, Metamorphic basement rocks of Yap Islands, western Pacific : possible oceanic crust beneath an island arc. *Earth Planet. Sci. Lett.*, **13**, 167–174.
- Shiraki, K. and Maruyama, S., 1978, Low pressure regional metamorphism in Yap Islands, western Pacific. *Abs. Intern. Geodynamic Conf.*, Tokyo, 152–153.
- Tayama, R., 1935, Morphology, geology and coral reef of the Yap Islands. *Tohoku Univ., Sci. Rep., 2nd.(Geol.)*, **57**, 105–137.
- Tsunakawa, H., 1985, Radiometric ages of the igneous activities in the Philippine Sea area. *Chikyū*, **7**, 694–700.*

* : in Japanese

** : in Japanese with English abstract