Vol. 86 No. 6 pp. 1426–1433 ACTA GEOLOGICA SINICA (English Edition) Dec. 2012

Radiolarians from the Pohang Basin, Southeast Korea and Paleoceanographic Implications

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Abstract: We identified a total of 101 species and two subspecies of radiolarians belonging to 56 genera from 95 samples collected from the Hagjeon and Duho Formations in the Pohang Basin of the southeastern Korean Peninsula. On the basis of the biostratigraphic range of *Cyrtocapsella cornuta* and *Theocorys redondoensis*, the depositional period of the upper Hagjeon and lowest Duho Formations was determined to be early to late Middle Miocene. The occurrence of deep-dwelling radiolarians indicates that the paleobathymetry seems to become gradually progressing toward an upper bathyal environment in the middle part of the Hagjeon Formation. However, we prefer to accept another interpretation for the occurrence of deep-sea indicators in the Hagjeon and the lowest part of the Duho Formations, and consider the presence of a region of upwelling cold water that might have simulated a deep-water environment in relatively shallow water. This interpretation is based on the present upwelling of a cold-water mass off the southeast coast of Korea, the occurrence of upwelling microfossils from the Pohang Basin, and the effect of the closing of the Korea Strait approximately 15 Ma. We also considered that the uppermost part of the studied section represents a shallow-water environment.

Key words: radiolarian, depositional environment, upwelling, Pohang Basin

1 Introduction

The north–south extending Pohang Basin is located east of the Yangsan Fault and west of the east coast of Korea. The Cenozoic sedimentary sequences of the Pohang Basin provide useful clues in understanding the tectonic history of southeastern Korea, and provide important information on the subsidence, depositional, paleoceanographic, and developmental history of the Ulleung Basin in the southern part of the East Sea (Sea of Japan). Paleoenvironmental studies of changes in the paleoclimate, paleobathymetry, and sedimentology of the Pohang Basin were conducted by Kim (1965), Yoon (1975), You et al. (1986), Lee (1986), Lee et al. (1991), Yi (1992), Jung (1993), Byun (1995), Hwang et al., (1995), Kim (1999), and Chung and Koh (2005). The environmental interpretations of the fossil groups vary somewhat in detail. One intriguing observation is the coexistence of deep-sea and shallow-water species in the same formation. It is therefore not surprising that the interpretation of the paleobathymetry and bottom conditions for the Pohang Basin has been contradictory.

Radiolarians are useful microfossils to reconstruct paleoceanographic conditions in low and high latitudes of the oceans. Because radiolarians live at all depth in the oceans and follow oceanic water masses, they are ideally suited for studied oceanic circulation, past and present (McMillen and Casey, 1978). Paleoenvironmental studies of radiolarian fossils are scarce in the Pohang Basin (Kim, 1965; Kim et al., 1982; Ling et al., 1988; Bak et al., 1996, 1997). Kim (1965) first reported radiolarians in the Pohang Basin. In his biostratigraphic and foraminiferal research, he divided the Yeonil Group into six formations, and at the same time, established three biozones: two using foraminiferans, and one using radiolarians. Ling et al. (1988) reported the occurrence of radiolarians from the lower part of the Hagjeon Formation. Bak et al. (1996, 1997) classified and described of the parts of the Hagjeon and Duho Formations based on the occurrence of radiolarians. The purpose of this paper was to reinterpret its controversial paleoenvironmental conditions based on radiolarian data.

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2 Materials and Methods

A thick Cenozoic sequence composed of Neogene marine sedimentary deposits is well developed in the Pohang Basin. Both the particle size and composition of the sediments were used by Yun (1986) to classify the Yeonil Group into three formations: the Chunbuk Conglomerate, Hagjeon, and Duho Formations, in ascending order. The present research deals with from the Hagjeon Fromation to the Duho Formation. The Hagjeon Formation, with a thickness of approximately 500 m, generally dips eastward 10–20° and strikes northwestward to northeastward. This formation, conformably overlying the Chunbuk Conglomerate, is composed of alternations of sandstone, mudstone, shale, and siltstone. The Duho Formation consisting of siltstone and mudstone, overlies the Hagjeon Formation conformably. The mudstone is dark gray on fresh surfaces, and yellowish gray on weathered surfaces. The thickness of the formation is approximately 300 m. In total, we collected 95 samples of radiolarians from 15 sections at four localities: Dongsan-ri sections (C1–C5), Songra-myeon sections (I1, I2, I5, I6), Ducksung-ri section (G5), and the Sodong-ri sections (H1, H3–H6) (Fig. 1). The samples were commonly taken every 30 cm, according to outcrop conditions, after completing columnar sections and measurements for each outcrop. Samples were compared to each other lithologically and sedimentologically on the columnar section for each formation, and were aligned stratigraphically from lower to upper (Fig. 2). The sample preparation procedure was based on those of Sanfilippo et al. (1985) and Boltovskoy et al. (1983).

3 Radiolarian Assemblages

We identified a total of 101 species and two subspecies of radiolarians belonging to 56 genera from 95 samples collected in this study. Generally, radiolarian diversity and abundance was relatively low. The most common species was *Lithomitra lineata*, which occurred in 65 of the 95 sampling intervals. Less common species included *Lithelius minor*, *Antarctissa robusta*, *Spongurus* sp. A, *Spongurus* sp. B, and *Spongodiscus maculatus*, which were found in 30–40 of the sampled intervals. Section H1 in Sodong-ri, which was stratigraphically equivalent to the lowest Duho Formation, revealed the most diverse and

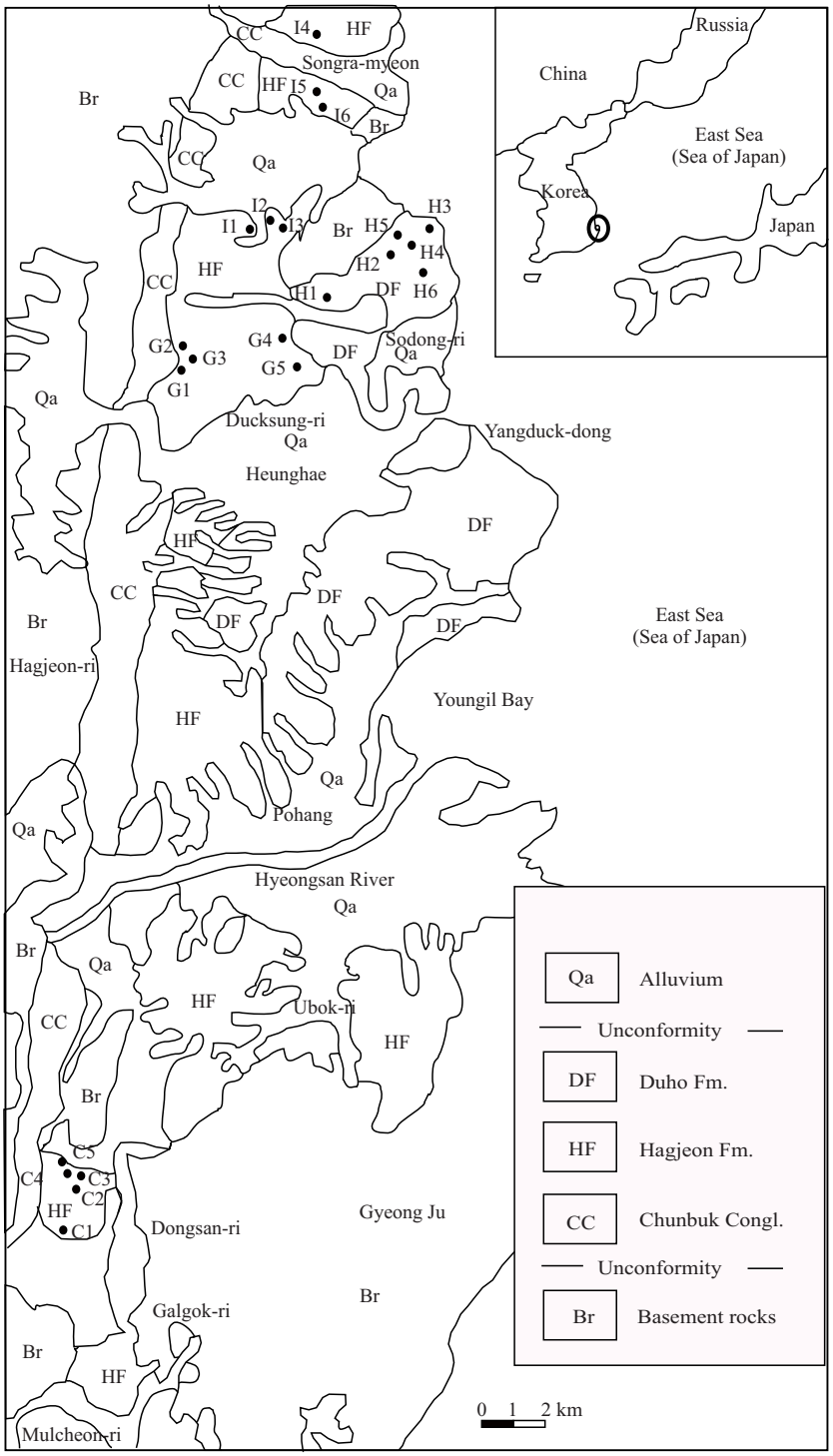

Fig. 1. Geologic map of the Pohang Basin (after Yi and Yun, 1995) and study area. Areas inside the ellipses indicate the sampling sites in which radiolarians were found.

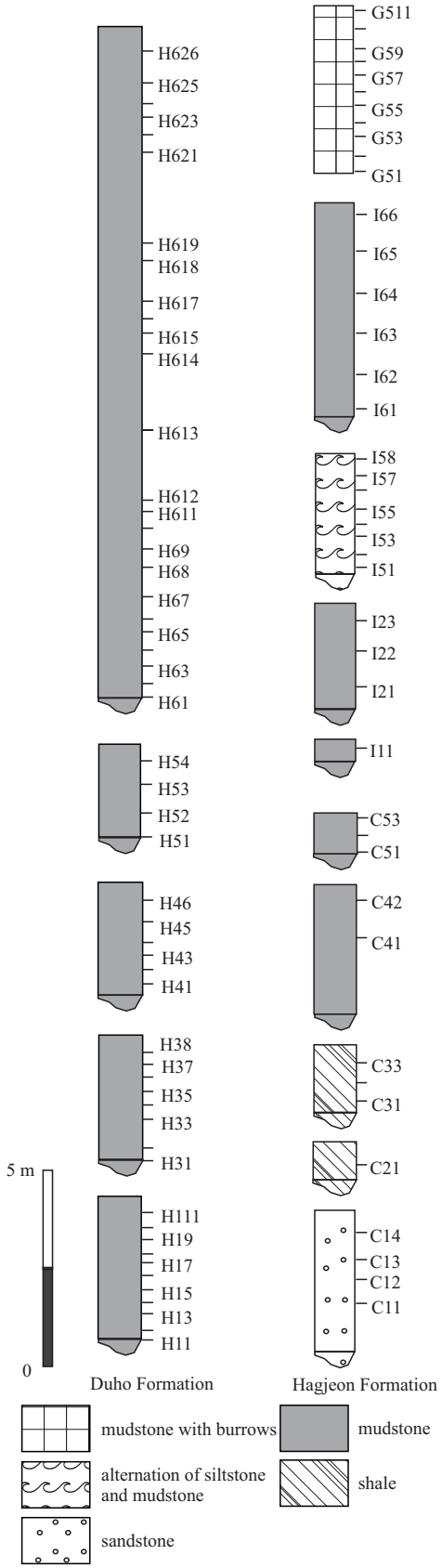

Fig. 2. Columnar section of the Hagjeon and Duho Formations. Stratigraphic position of each section is relatively positioned by the lithologic characteristics and detailed field surveys. C, Dongsan-ri section; G, Ducksung-ri section; H: Sodong-ri section; I, Songra-myeon section.

abundant radiolarian fauna among the Pohang radiolarian fauna. The unique faunal characteristics of section H1, such as species composition and relatively greater abundance and diversity, suggest a depositional environment or paleoceanographic condition of this area that differed from those of other sections and geologic times.

4 Biostratigraphy

Among the species recovered from the Hagjeon and Duho formations, four species (*Cyrtocapsella cornuta*, *Cyrtocapsella japonica*, *Cyrtocapsella tetrapera*, and *Theocorys redondoensis*) are biostratigraphically useful (Fig. 3). The last appearance of the datum of *Cyrtocapsella cornuta* was in the late Middle Miocene (late Serravallian; Sanfilippo et al., 1985; Morley and Nigrini, 1995), and the first appearance of the datum of *Theocorys redondoensis* was in the early Middle Miocene (early Langhian; Morley and Nigrini, 1995). *Cyrtocapsella cornuta* ranged up to the lowest Duho Formation, and the first appearance of *Theocorys redondoensis* was in the middle Hagjeon Formation. Thus, the age of the middle Hagjeon Formation through lower Duho Formation was between early Middle Miocene and late Middle Miocene. The distribution of species might be limited by either selective preservation or stratigraphic incompatibility. The radiolarian stratigraphy of the Pohang Basin is hard to tie directly to standard zonations from other parts of the Pacific, because Pacific indicator species do not occur or occur sporadically in the sediments.

This range can be correlated to that of the middle *Calocycletta costata* zone, from the *Eucyrtidium inflatum* zone established by Motoyama (1999) from Neogene strata in the North Pacific. The range is also equivalent to that of the middle *Calocycletta costata* and the lower *Diartus pettersoni* that were established by Sanfilippo and Nigrini (1998), and are globally recognized (Fig. 4). On the basis of radiolarian data, therefore, the age of the middle Hagjeon to lowest Duho Formations is within the middle Middle Miocene, which corresponds to the age obtained by nannofossils (Yi and Yun, 1995).

5 Paleoenvironment

The Pohang Basin assemblages have been included to surface water and deep-dwelling radiolarians. Investigation of all samples from the “C” to “H” sections shows that many samples yielding radiolarians contained surface water species (e.g. *Larcopyle butschlii, Spirocyrtis subscalaris*, *Ceratocyrtis histricos*, and *Spongotrochus glacialis*) and deep dwellers, such as *Cornutella profunda* (Equator >900 m to Arctic >200 m; Anderson, 1983) and *Perypyramis circumtexa* (latitude of 0–40° north, 200–700

Age	Middle Miocene														
Formations	Hagjeon Formation									Duho Formation					
Biozonation				*Theocorys redondoensis* - *Cyrtocapsella cornuta* zone											
Locations	C1	C2	C3	C4	C5	I1	I2	I5	I6	G5	H1	H3	H4	H5	H6
Cyrtocapsella cornuta										—					
C. japonica										—					
C. tetrapera	—	—	—	—	—	—	—	—	—	—					
Theocorys redondoensis				—	—	—	—	—	—	—	—	—	—	—	—

Fig. 3. Biostratigraphic range of radiolarian species from the Hagjeon and Duho Formations of the Yeonil Group.

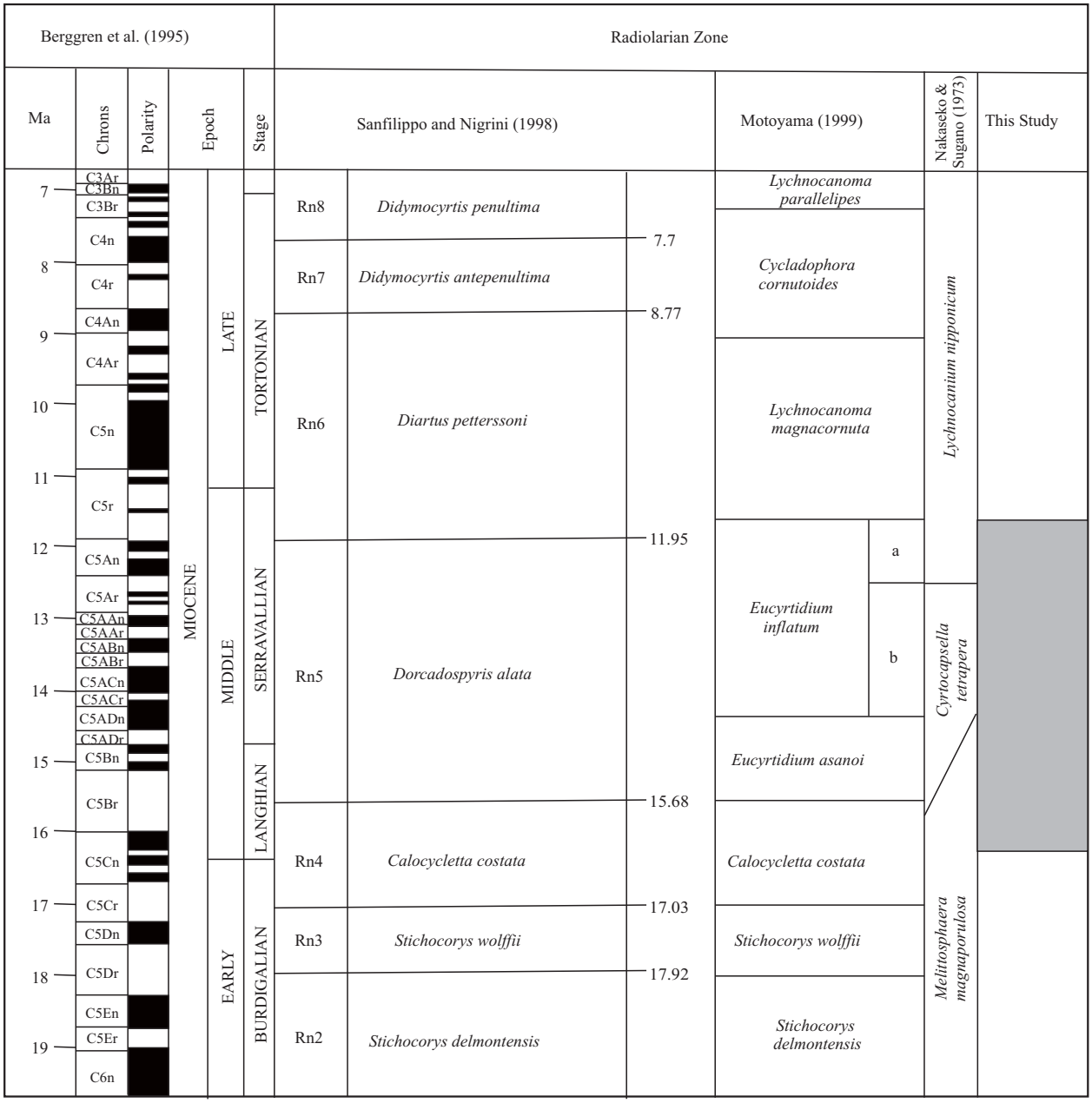

Fig. 4. Biocorrelation of the radiolarian assemblages from the Yeonil Group to previously established radiolarian zones. Maximum biostratigraphic range of the middle Hagjeon and lowest Duho Formations.

m; Casey, 1971) (Fig. 5). The living depth of radiolarians was based on plankton tows in the East Sea (Japan Sea); *Larcopyle butschlii* juvenile and *Spirocyrtis subscalaris* are abundant at a 40–120 m depth (upper subsurface-water species). *Larcopyle butschlii*, *Ceratocyrtis histricosa*, and *Spongotrochus glacialis* are abundant at a 40–300 m depth (lower subsurface-water species) (Itaki, 2003).

Previous sedimentological data (Hwang et al., 1995) demonstrated that the Hagjeon Formation is mostly turbidites, and turbidite deposits are even intercalated with hemipelagic deposits in the Duho Formation, but the relative abundance of deep-dweller species are very low in Pohang Basin sediments. Thus, the deep water dwellers probably migrate into the Pohang Basin from other oceanic areas. Also, section H1 included the shallow warm-water species *Lamprocyclas maritalis* and very abundant *Carposphaera* spp., which generally occur at latitudes between 0° and 35°. Therefore, we propose the influence of upwelling water as the answer, and discuss the implications.

6 Discussion

The sequences of fossils in the Yeonil Group have been well documented, including foraminifera, mollusks, dinoflagellates, diatoms, and pollen (Kim, 1965; Yoon, 1975; Yun et al., 1989; Lee et al., 1991; Chung and Choi, 1993). Microfossil assemblages in the Yeonil Group indicate progressive deepening of the basin from shelf to lower bathal depths (Kim and Choi, 1977; Kano et al., 1991; Lee et al., 1991; Ingle, 1992; Jung, 1993, Akimoto et al., 1999).

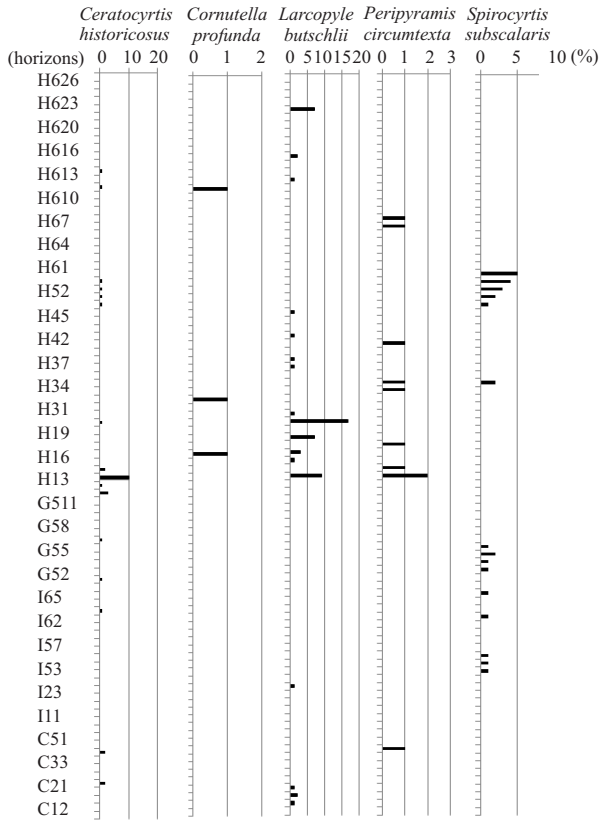

Fig. 5. Vertical distribution of surface water (*Ceratocyrtis histricosus*, *Larcopyle butschlii*, S*pirocyrtis subscalaris*) and deep-dwelling species (*Cornutella profunda*, *Peripyramis circumtexta*).

In this study, the main problem is the co-occurrence of deep- and shallow-water taxa of radiolarians. It is difficult to believe that they clearly indicate a deep-sea environment, since other geologic parameters conflict with such an interpretation. The micropaleontologic and oceanographic data of the Pohang Basin suggest that the deep-water species were associated with upwelling water, rather than with deep sea. (Alexandrovich, 1992).

6.1 Present upwelling of the Pohang Basin

The study area represents the southwestern margin of the Paleo-East Sea (Sea of Japan) during sediment deposition, and presently neighbors the East Sea (Fig. 6). Therefore, the recent hydrographical condition of the East Sea provides a good reference for the interpretation of the paleoenvironment and paleobathymetry of this region. The near-coastal marine realm along the southeastern coast of Korea is presently characterized by upwelling of a cold-water mass that is induced by the baroclinic tilting of isotherms related to the warm Kuroshio Current, eastward

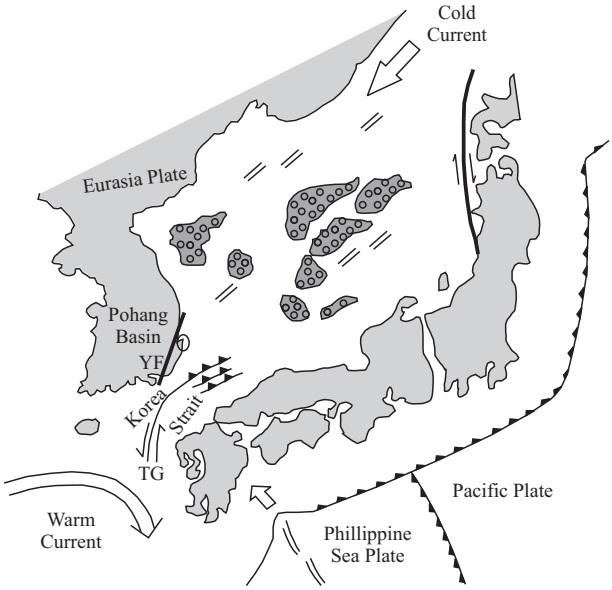

Fig. 6. Reconstruction of the East Sea (Sea of Japan) approximately 15 Ma, showing the closure of the Korea Strait by the northward tectonic movement of the Philippine Sea Plate, and subsequently, the clockwise rotation of southwestern Japan (modified from Lee et al., 1999).
Dotted areas represent extended continental crust. TG, Tsushima-Goto Line; YF: Yangsan Fault.

wind stress, and submarine topography (Lee and Na, 1985). At present, upwelling phenomena are particularly prominent off the Pohang Basin, as a result of the shoaling of cold water and the westward trapping of the coldest bottom water over the shallower shelf, which influences the plankton distribution and other environmental factors (Lee, 1985). Because other paleoecological factors of the Pohang Basin, such as water temperature, currents, and wind systems, have proved to be similar to recent ones, the upwelling water could also have developed in Miocene times (Yi and Yun, 1995; Tada, 1994).

In this case, the bottom environment of the Pohang Basin was dominated by upwelling cold water that might have simulated a deep-water environment. Upwelling would also have enabled deep-water radiolarians to live near the sea floor in a shallow shelf area. After death, the deep-water radiolarians would have been deposited and mixed with shallow-water taxa in the same area. Consequently, the coexistence of deep- and shallow-water taxa, along with frequent faunal changes in the vertical section, is observed in the Pohang sediments. We believe that the deep-water species might not necessarily have been transported from the deep sea by upwelling water, but might have inhabited a quasi-deep-water environment caused by upwelling water. An upwelling area off the Pohang Basin shows an oceanographic condition similar to that of the deep sea, in terms of lower water temperature, high nutrition (nitrate and phosphate) and chlorophyll contents, and higher organic matter found in bottom sediments (Korea Ocean Research and Development Institute, 1993; Park et al., 1999). These conditions seem to have simulated a deep-sea environment, despite the shallow water depth that enabled deep-sea species to inhabit the area.

6.2 Upwelling microfossils from the Pohang Basin

Deep-water taxa in a shallow-water environment and abundance fluctuation are considered to indicate the presence of an upwelling water mass, rather than paleobathymetric fluctuation within short time intervals. This is also evidenced by the abundance of diatoms in the Pohang Basin, such as *Thalassionema nitzchioides* and *Thalassionema hirosakiensis* (Lee et al., 1991) that reflect the recurrence of an intense upwelling condition (Blasco et al., 1981; Schuette and Schrader, 1981; Pokras and Molfino, 1986; Pokras, 1987; Abrantes, 1988, 1990). Also, *Actinomma* spp. are endemic indicator species for upwelling water. These species are reported to be upwelling radiolarians from the northwestern Arabian Sea. In the Pohang Basin, *Actinomma* spp. occurred in both the Hagjeon and Duho Formations, and were especially abundant in sections G5 and H1.

According to Tada (1994), the surface water of the East Sea was strongly influenced by the southward migration of the subpolar front during this period, which caused a transition from warm- to cold-water conditions. He further posited that, in general, cold-water prevalence in the upwelling current helped to maintain siliceous productivity in the surface water by supplying required nutrients. This confirms the presence of an upwelling current in the East Sea, and subsequently, the enrichment in siliceous microfossils, although it does not directly explain the scattered distribution of deep-water forms in the shallow paleoenvironment of the Pohang Basin.

6.3 Effect of the closing of the Korea Strait

The Korea Strait closed due to local tectonic movement 15 Ma, and consequently, the Kuroshio Current could not flow into the East Sea (Yi and Yun, 1995; Kim, 1999) (Fig. 6). In fact, deep-water radiolarians were rarely encountered in the upper sediments of the Duho Formation, younger than 15 Ma, confirming the tectonic movement, as well as the presence of upwelling water in the southern part of the East Sea area. The upwelling phenomenon in the shallow shelf area becomes more active as a result of the inflow of the Kuroshio Current into the East Sea. When the Kuroshio Current was blocked due to the closing of its pathway, that is, the Korea Strait in the East Sea (Fig. 6), the upwelling current diminished and the abundance of its associated organisms decreased. Deep-sea taxa were abundant in the lower to middle parts of the Pohang sediments. Consequently, the occurrence of deep-water taxa is indirectly related to the closing and opening of the Korea Strait. In fact, deep-water species had disappeared when the upwelling diminished, during the depositional period of the upper part of the Duho Formation, due to the blocking of the Kuroshio Current. The limited distribution of siliceous microfossils, such as radiolarians and diatoms, also supports the presence of upwelling water.

6.4 Effect of differential preservation

Differential preservation has obvious implications for paleoecological interpretations. In the case of radiolarians, the more delicate shells are usually found in species living in shallower, warmer water. Therefore, when they are selectively dissolved from an assemblage, the remaining taxa with heavier shells give the impression of water conditions colder than might have actually existed. Also, interpretations based on the absence of fossils should be made with caution. Thus, because of the absence of warm-water species and the presence of only cold-water species, it might not be correct to assume that some of the sections were influenced by a cold climate. Because radiolarians are generally better preserved in much deeper environments than those of the Miocene Pohang Basin, additional studies

of co-occurring microfossils, such as diatoms and foraminiferans, are needed to develop a more complete biostratigraphy and a more refined paleoenvironmental interpretation of the Yeonil Group in this study area.

7 Conclusions

The biostratigraphic age of the radiolarians studied is within the middle Middle Miocene (from the middle of the Hagjeon Formation to lowest part of the Duho Formation). This range is similar to the range determined by nannofossils (Yi and Yun, 1995).

The presence of deep-water species is interpreted as the result of an upwelling water mass, rather than that of a deep-water environment. From the base of the Hagjeon Formation, the marine depositional environment becomes relatively deeper under the influence of upwelling cold water that is especially pronounced in the middle part of the unit. The upwelling water environment seems to be maintained into the lowest part of the Duho Formation, with some fluctuations in water depth. The depositional environment of the Duho Formation at Sodong-ri appears to have been repeatedly influenced by cold upwelling water and shallow warm water. The uppermost part of this section indicates only shallow-water environments. This suggests that the upwelling phenomenon became weak, because the warm Kuroshio Current that provided an important factor for upwelling could not flow into the East Sea (Sea of Japan). This hydrographic history is consistent with results obtained by other methods.

Acknowledgements

We are thankful to Orvil Roger Anderson of the Biological Oceanography, Lamont-Doherty Earth Observatory of Columbia University, and Annika Sanfilippo, Scripps Institution of Oceanography of University of California, San Diego for critical comments, improving our paper scientifically and linguistically. This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education, Science and Technology (2011-0002705).

Manuscript received Jul. 18, 2011
accepted Mar. 25, 2012
edited by Liu Lian

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