The Influx of the Tsushima Current into the Central Ulleung Basin of East Sea (Sea of Japan), Korea

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Abstract: A total of 85 samples, collected from the UBGH1-9 core taken from the Ulleung Basin, East Sea, Korea, were analyzed using diatom assemblages. 111 diatom species belonging to 46 genera were identified, and three diatom assemblage zones were established on the basis of occurrence and distribution pattern of diatoms. Diatom assemblage zone I (134.10-174 m) is characterized by a relatively high abundance of marine species, while the increased number of the brackish species is recorded in diatom assemblage zone II (75-125 m). The assemblage zones IIIa became drastic drop of valve abundances and brackish plankton, whereas it became increase during the IIIb. High Tₘ values which indicate an influence of warm current are recorded both in diatom assemblage zone I and III, and low Tₘ values in diatom assemblage zone II. Analysis of diatom assemblages indicating that the depositional condition moved from oceanic to littoral-neritic environments and that paleotemperature underwent a shift from warm to cold condition at the middle interval, and from cold to warm condition in the upper interval of the UBGH1-9 core. This suggests that the lower (130-162 m) and upper intervals (0-20 m) of the UBGH1-9 core were deposited in the warm current condition (Tsushima Warm Current).

Key words: Ulleung Basin, East Sea, diatom, UBGH1-09, Tsushima warm current

1 Introduction

The East Sea is a semi-closed marginal basin connected with the Pacific Ocean and the Okhotsk Sea, and the Ulleung Basin is one of the smallest basins in the East Sea (Fig. 1). The circulation of surface water around the Ulleung Basin is predominated by the inflow of warm and high saline Tsushima Warm Current through the Korean Strait, and the inflow of cold North Korean Current from the north along the east coast of the Korean Peninsula. The Pacific deep water cannot flow into the East Sea because the sill in the East Sea is very shallow. Therefore, a special vertical circulation occurs within the East Sea, unlike the Okhotsk and Bering seas (Hidaka, 1966).

The sea water condition of the Ulleung Basin is also influenced by influx of a large amount of freshwater (e.g., the Nakdong River and the Seomjin River). The Ulleung Basin is known to have been formed by an extension of the continental crust (Yoon and Chough, 1995), and bounded by the steep continental slope of the eastern Korean Peninsula to the west (Bahk et al., 2001). Several researchers (e.g., Chough et al., 1985, 1997) documented a wide variety of mass-movement deposits in the Ulleung Basin such as slump deposits and fine-grained turbidites, which indicates frequent events of slope failures adding coarser sediments to the floor of the Ulleung Basin.

Recently, there has been a great increase of interest in understanding of paleoenvironmental conditions during the period of deposition of the Ulleung Basin using microfossils. Diatom is very sensitive to changes in salinity, nutrient availability, and water temperature, research on the assemblage of diatoms contained in the sediments is widely used for paleoenvironmental research such as temperature change and sea-level fluctuations (Kashima, 2003; Freund et al., 2004; Kato et al., 2004; Yabe et al., 2004; Ojala et al., 2005; Vos and Gerrets, 2005). However, most of the micropaleontological studies conducted in the East Sea were restricted to basins on the Japan side, Yamato Basin and Japan Basin (Tanimura, 1981; Burckle, 1992; Koizumi, 1992; Ling, 1992; Muza, 1992). Indeed, micropaleontological studies on the Ulleung Basin are very limited (Ryu et al., 2003, 2005).

In this paper, we reconstructed the paleoenvironments from the UBGH1-9 core drilled in the central Ulleung
Fig. 1. A. Physiography of the Ulleung Basin; B. Core UBGH1-9 was collected from the plain at 2099 m water depth (modified from Oba et al., 1991).

JB = Japan Basin; UB = Ulleung Basin; YB = Yamato Basin.

2 Materials and Methods

Core UBGH1-9 was collected by the Fugro Hydraulic Piston Corer (FHPC) of M/S Rem Etive during the Ulleung Basin Gas Hydrate Expedition I (UBGH1) in 2007. The deep-drilling site is typically located over the seismic blanking zone with pull-up structure of the basin plain from the Ulleung Basin at a 2099 m water depth (Fig. 1). The penetration depth of UBGH1-9 reaches about 175 meter below seafloor (mbsf), but recovery rate of sediments was relatively low. The sedimentary lithology of the UBGH1-9 core is composed mainly of nine sedimentary facies including bioturbated mud, crudely laminated mud, homogeneous mud, indistinctly layered sandy mud, disintegrated mud or sandy mud, deformed mud, laminated sandy mud, laminated muddy sand or sand, massive muddy sand or sand, and tephra facies (Bahk et al., 2011). Bahk et al. (2011) are divided into three facies associations (FA): FA I (0–98 mbsf) consisting mainly of alternating thin- to medium-bedded hemipelagic mud and turbidite sand or mud beds, FA II (98–126 mbsf) dominated by medium- to very thick-bedded turbidite sand or sandy debris flow beds, and FA III (126–178 mbsf) characterized by thick hemipelagic mud without intervening discrete turbidite sand layers.

A total of 85 samples were collected from the UBGH1-9 core for diatom analysis. Core samples were collected with respect to lithology except for depths where no core sediments were recovered. To study diatom assemblages, the sediment subsamples were kept for 24 h in distilled water to which 10 ml of 30% H2O2 had been added. Two drops of 2N HCl were then added to remove carbonate, and the samples were allowed to stand for another 24 h. They were then centrifuged three times and washed in distilled water to remove chemical residue and salt crystals between centrifuging. Washed samples were prepared for quantitative diatom abundance analysis as conventional microscope slides, random settling method of Scherer (1994). All diatoms were counted up to a minimum of 200 specimens excluding resting spores of Chaetoceros spp. and identified under a Nikon E400 microscope at 400X and 1000X magnification.

3 Results

3.1 Diatom assemblages

The UBGH1-9 core yielded abundant and diverse diatom fossils but valve preservation was generally poor throughout the cores with many broken and dissolved frustules. The number of diatom valves per gram of dry sediment ranges from 0.3–10.4 × 10^2/g, and diatom valve concentration per gram dry sediment is calculated by quantitative diatom analysis of Scherer (1994). The highest abundance with moderate preservation was recorded in the core samples at lower (134.10–174 m) and middle (75–125 m) intervals, but less specimens were recovered from the
upper interval (0.12–64.24 m), showing a general tendency that the number of diatom valves recovered decreases toward the upper level (0.12–64.24 m) (Fig. 2). A total of 111 diatom species belonging to 46 genera were recognized, including the most dominant species Paraguay sulcata (22% of the total), Thalassionema nitzschioides, Actinocyclus senarius, and Cyclotella striata. The majority of diatoms are marine planktonic (ca. 16.6%), marine benthic and tychopelagic (ca. 20.3%) species. A few extinct (e.g., Actinocyclus ingens, Denticulopsis hustedtii, D. dimorpha) and freshwater (e.g., Campylococcus brightwelli, Eunotia praerupta, and Pinnularia sp.) species are also present in the core sediments which are believed to have been transported or reworked. The diatoms recovered are composed mainly of littoral to neritic taxa with a few oceanic species such as Neodenticula seminae. Three assemblage zones are established from the whole section of UBGH1-9, on the basis of diatom valve abundance and vertical distributions of major species. The frequency distributions of major species and valve abundance are plotted in Fig. 2.

Diatom assemblage zone I ranging from 134.10 to 174 m is characterized by high abundance of marine planktonic species (Actinoptychus senarius and Paralia sulcata) and marine tychoplanktonic species (Raphoneis amphiceros). Diatom assemblage zone II ranges from 75 to 125 m. This zone is characterized by less abundance of Actinoptychus senarius and Paralia sulcata than in diatom assemblage zone I and increase of brackish planktonic species Cyclotella striata. Diatom assemblage Zone IIIa is between 67 m and 47.04 m, characterized by sudden decrease of the number of diatom valves. The relative abundance of species such as Raphoneis amphiceros, Delphineis surirella (marine tychoplankton) and Cyclotella striata (brackish plankton) are remarkably lower than in zone II. Diatom assemblage zone IIIb ranges from 19.12 to 0.12 m. The relative abundance of littoral species such as Delphineis surirella and Cyclotella striata increased. But, the abundance of marine plankton (Actinoptychus senarius and Paralia sulcata) occurred continuously.

3.2 Reworked species

Reworked species of diatoms (e.g., Actinocyclus ingens,
Denticulopsis dimorpha, D. hustedtii, D. lauta, D. praedimorpha, Nitzschia reinholdii and Thalassiosira nidalis), and are present throughout the whole core, containing below 2% of the total diatoms. They are composed mainly of Miocene taxa and no levels concentrated with reworked fossils are observed. Their preservation state is generally poor with dissolved and broken specimens, most of which were generally found at the horizons composed of relatively coarser sediments. Such a phenomenon with poorly preserved Miocene taxa within the Quaternary sediments has been frequently reported from the several core sediments of the Ulleung Basin (Byun and Yun, 1992; Byun, 1995).

It seems that the reworked taxa may have been transported from the Miocene strata of adjacent continental shelf of the Ulleung Basin when considered the UBGH1-9 core site located very closely to the continental shelf. This interpretation may also be evidenced by a sedimentological study documenting that the Quaternary sediments of the Ulleung Basin were formed by mass flows such as slumping or sliding (Chough et al., 1997). The FO (first occurrence) of Fragilariopsis doliolus is observed in 144 m, and this datum is the upper Pliocene at 1.89–2.0 Ma (Barron, 1992). The age of Pollen and dinoflagellate cysts suggested that the Pliocene-Pleistocene boundary is at 120 m from UBGH1-9 (Yi et al., 2012).

4 Discussions

Diatom assemblage zone I (134.10–74 m) is dominated by marine plankton species (e.g., Actinopytthus senarius and Paralia sulcata), while the number of such species drops sharply at the level of diatom assemblage zone II (75–125 m) and III a-b (0.12–67 m). On the other hand, a marine plankton species Paralia sulcata decreases remarkably from the beginning of diatom assemblage zone II, and a brackish plankton Cyclotella striata increase at the level of diatom assemblage zone II (Fig. 2). It could thus be concluded that a depositional condition of the UBGH1-9 core moved from oceanic to littoral-neritic environments in diatom assemblage zone II (Fig. 2). The assemblage zones IIIa became drastic drop of valve abundances and brackish planktons, whereas it became increase during the IIIb. It suggested that the changes in the sea-level the periods of input of warm water species.

Changes of temperature during the period of the UBGH1-9 core deposition are estimated using the $T_d$ (diatom temperature) value. The $T_d$ values are calculated as follows: $T_d = \frac{X_w}{(X_w+X_c)} \times 100$, where $X_w$ is the frequency of warm-water species and $X_c$ is that of cold-water species (Kanaya and Koizumi, 1966). The warm water group ($X_w$) recovered from the UBGH1-9 core consists of Azpeitia nodulifera, Hemidiscus cuneiformis, Lithodesmium undulatum, Nitzschia marina, Fragilariopsis doliolus, Rhizosolenia bergonii, Roperia tessellata, Thalassiosira leptopus and T. oestrupii, while a cold water group ($X_c$) includes Actinocyclus curvatus, Odontella aurita, Coccosioides marginatus, C. oculisiridis, Neodenticula seminae, Porosira gracialis, Rhizosolenia hebetata f. hiemalis, Thalassiosira gravida and T. trifulta.

The general trend of $T_d$ values appears to be high at both the lower (130–162 m) and upper (0–20 m) intervals, and to be low at the middle interval (75–125 m) (Fig. 3). Two intervals showing high $T_d$ values (>40) are correlated with the increase in paleotemperature, while the middle interval with low $T_d$ values indicates a decrease in paleotemperature (Kanaya and Koizumi, 1966; Ryu et al., 2005). The two intervals with high $T_d$ values are also characterized by occurrence of Tsushima Warm Current (TWC) indicator species (Koizumi, 1989; Koizumi et al., 2003), Fragilariopsis doliolus and Hemidiscus cuneiformis. On the contrary, the middle interval with low $T_d$ values is characterized by very rare occurrence of warm water species (Fragilariopsis doliolus and Hemidiscus cuneiformis) and a remarkable increase of an oceanic cold water species Neodenticula seminæ (Tanimura, 1981). The warm climate in most of the northern hemisphere was dominant during the Pliocene (4–2.7 Ma) (Cronin, 1991; Dowsett et al., 1996; Kamco et al., 2003; Sato et al., 2004; Kitamura and Kimoto, 2006). Koizumi (1992) reported that the Hemidiscus cuneiformis emerged at 3.5 Ma in ODP site 794 sediments.

In the UBGH1-9 core, high resistivity anomalies ranged from 70 to 150 m. Cold IR anomalies, visual observation of hydrates and soupy layers, and pore water freshening were observed throughout this high resistivity interval (Kwon et al., 2011). Such a correspondence between $T_d$ values and occurrence of warm water or cold water species, high resistivity anomalies probably indicates synchronous events in the East Sea related to the strong inflow of the TWC during the accumulation of the UBGH1-9 core sediments.

5 Conclusions

Three diatom assemblage zones (I, II and III) were established from the UBGH1-9 core taken from the Ulleung Basin, East Sea, Korea. A lower interval (ca. 128–174 m) equivalent to diatom assemblage zone I is characterized by great abundance of marine plankton tax, while the diatom assemblage II (ca. >125 m) is marked by an increase of brackish planktonic diatom taxa and a
sudden decrease of marine species at cold periods. It is thus concluded that the depositional environments moved from oceanic to littoral-neritic conditions, which is probably related with a drop of sea level.

Analysis of $T_d$ values also documents a similar pattern of paleotemperature during the deposition of core UBGH1-09. The lower (130–162 m) and upper (0–20 m) levels show high $T_d$ values, but the $T_d$ values are lowered at the middle interval (75–125 m). This suggests that the lower and upper intervals of the UBGH1-9 core were deposited in a warm current condition (Tsushima Warm Current), and the period of the middle interval received an influx of cold water.

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