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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 planktons, whereas it became increase during the IIIb. High T_d values which indicate an influence of warm current are recorded both in diatom assemblage zone I and III, and low T_d 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 Peninsular 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

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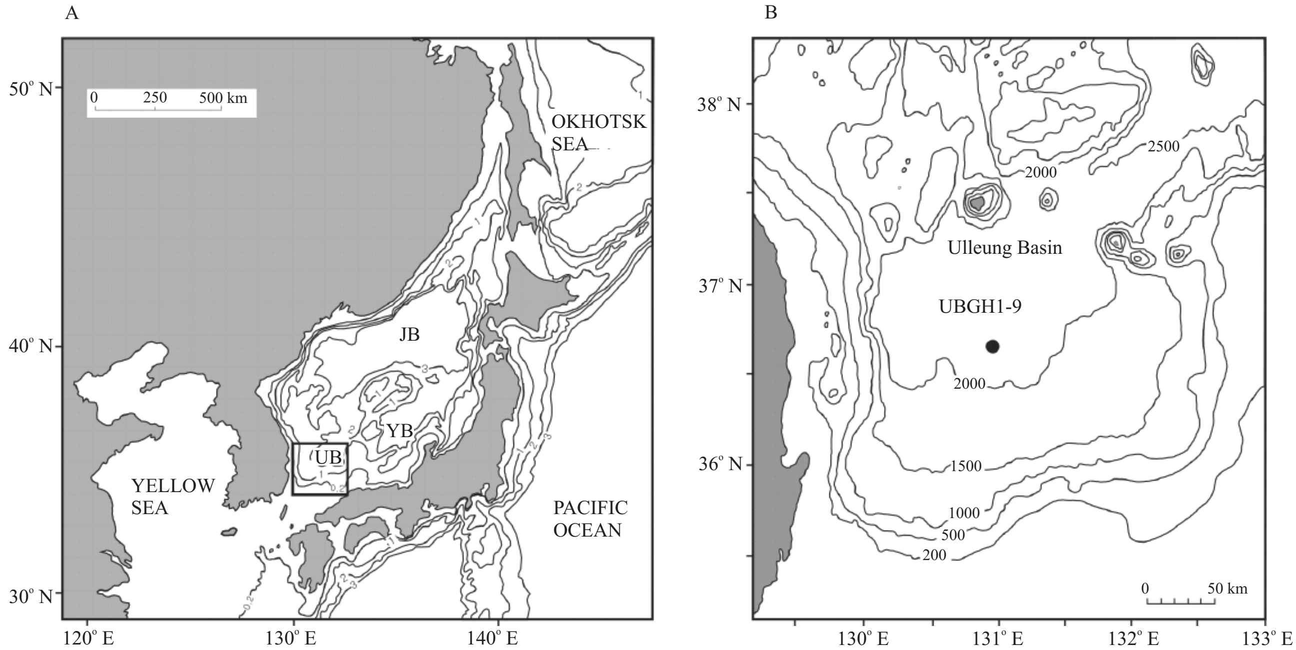

Fig. 1. A. Physiography of the Ulleung Basin; B. Core UBGH1-9 was collected from the plain at 2099 m water depth (modified from Oba et al., 1991).
JB – Japan Basin; UB – Ulleung Basin; YB – Yamato Basin.

Basin, using diatom assemblages.

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 1 (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% H_2O_2 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 × 10^7/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*, *Actinoptychus 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., *Campylodiscus 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 (*Rhaphoneis 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 *Rhaphoneis 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,*

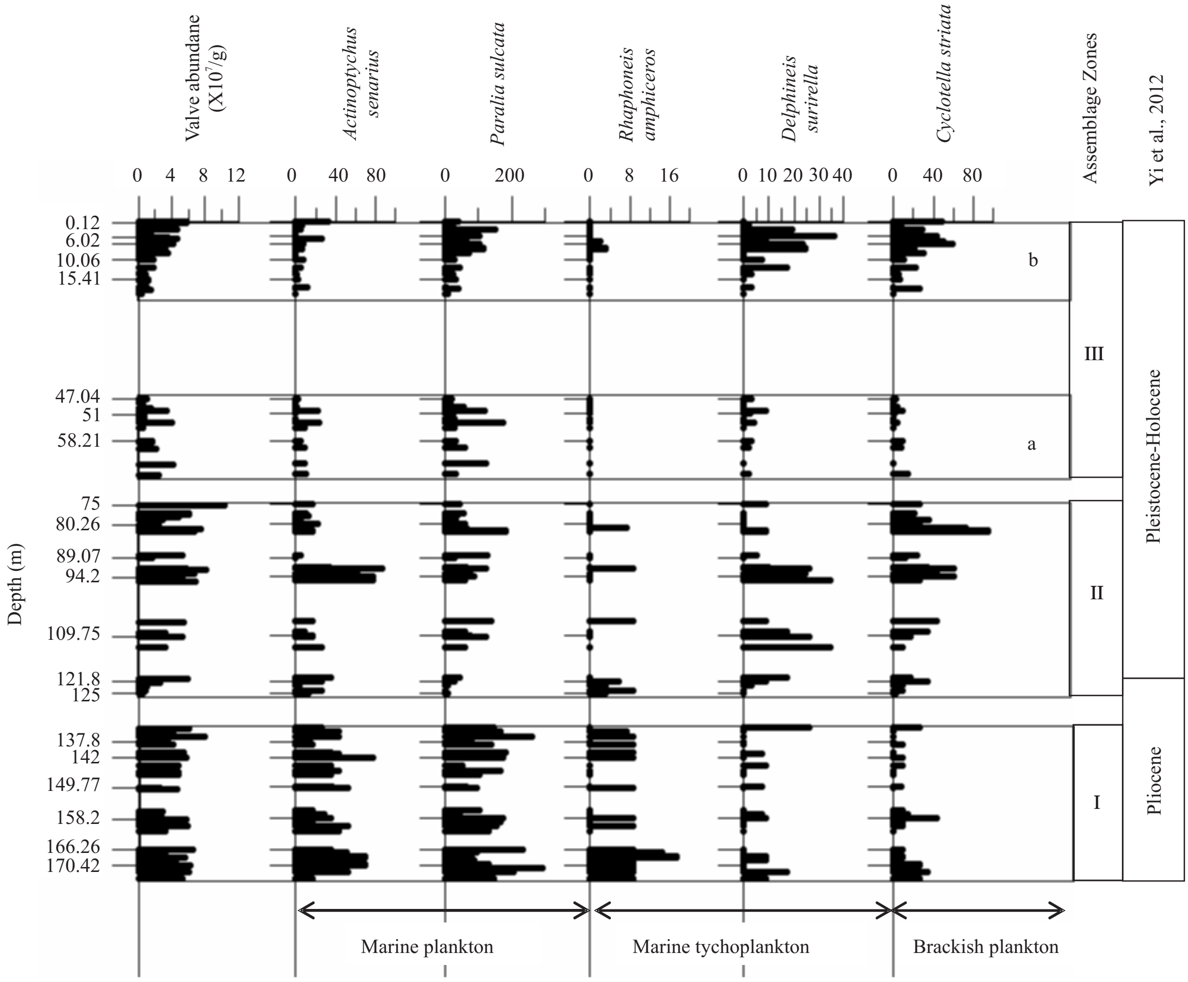

Fig. 2. Diatom assemblage zones and vertical variation of the diatom abundance (10^7 valves/g of dry sediment) and selected species (marine plankton, marine tychoplankton, brackish plankton) in UBGH1-09.

Denticulopsis dimorpha, D. hustedtii, D. lauta, D. praedimorpha, Nitzschia reinholdii and *Thalassiosira nidulus*), 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 *Fragilriopsis 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., *Actinoptychus 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 = $[X_w/(X_w+X_c)]$ ´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 curvatulus, Odontella aurita, Coscinodiscus marginatus, C. oculus-iridis, 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 seminae* (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; Kameo 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 taxa, while the diatom assemblage II (ca. >125 m) is marked by an increase of brackish planktonic diatom taxa and a

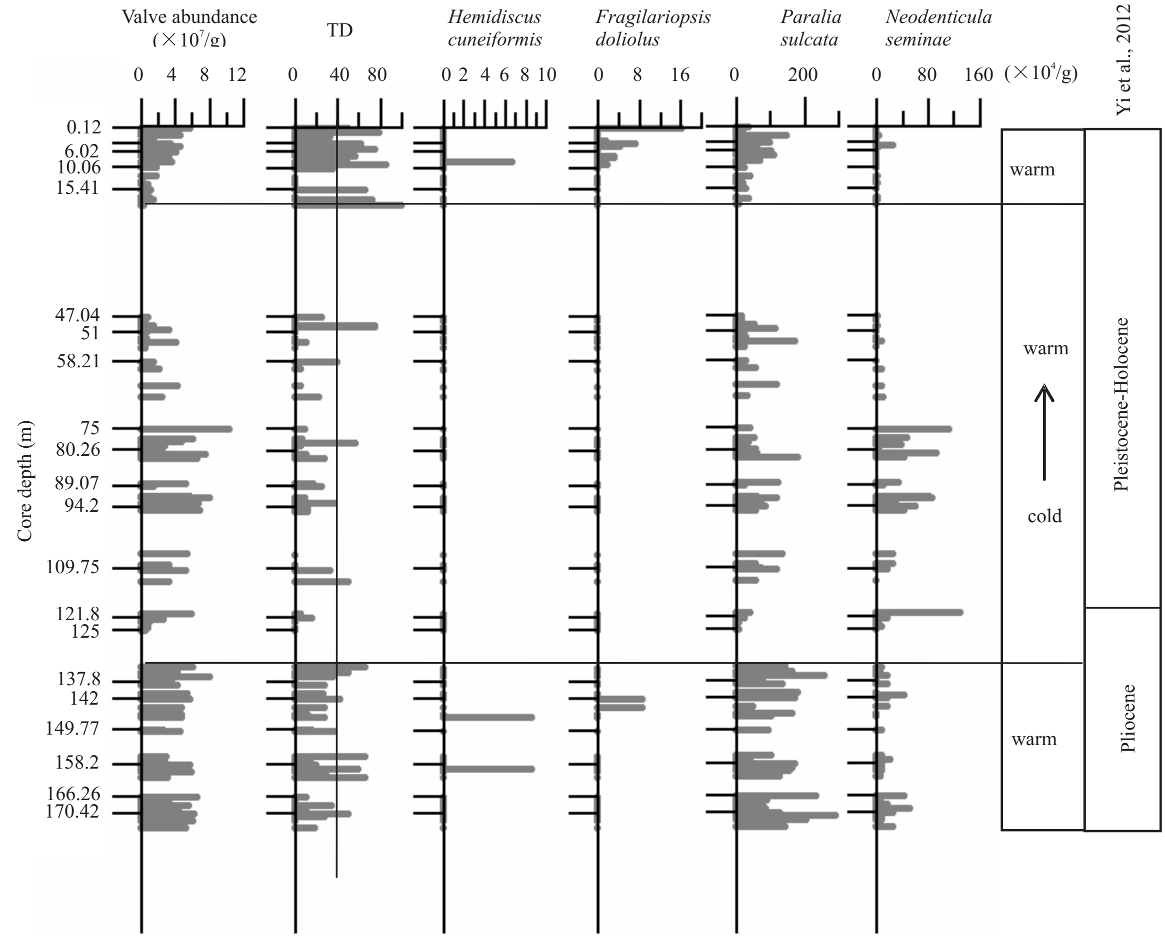

Fig. 3. Vertical variations of T_d values and warm current species (*Hemidiscus cuneiformis* and *Fragilariopsis doliolus*). The right box indicating paleocurrent changes.

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 paleoetemperature 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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References

Bahk, J.J., Um, I-K., and Holland, M., 2011. Core lithologies and their constraints on gas-hydrate occurrence in the East Sea, offshore Korea: Results from the site UBGH1-9. *Marine Petrol. Geol.*, doi:10.1016/j.marpetgeo.2010.12.003.

Bahk, J.J., Chough, S.K., Jeong, K.S., and Han, S.J., 2001. Sedimentary records of paleoenvironmental changes during the last deglaciation in the Ulleung Interplain Gap, East Sea. *Global Planet. Change*, 28: 241–2253.

Barron, J.A., 1992. Neogene diatom datum levels in the equatorial and North Pacific. In: Ishizaki, K., and Saito, T. (eds.), *The Centenary of Japanese Micropaleontology.* Tokyo: Tokyo Univ. Press, 413–425.

Burckle, L.H., 1992. Diatom biostratigraphy: Legs 128: Sea of Japan. *Proceedings of the Ocean Drilling Program, Scientific Results*, 127/128: 359–364.

Byun, H., and Yun, H., 1992. Miocene Dinoflagellate cysts from the central part of the Pohang Basin, Korea. *J. Paleontol. Soc. Korea*, 8: 164–235.

Byun, H., 1995. Cenozoic dinoflagellate cysts from the Pohang Basin and the southern margin of the Ulleung Basin, East Sea. Ph.D thesis, Chungnam National University, 1–283.

Chough, S.K., Jeong, K.S., and Honza, E., 1985. Zoned facies of mass-flow deposits in the Ulleung Basin, East Sea. *Marine Geol.*, 65: 113–125.

Chough, S.K., Lee, S.H., Kim, J.W., Park, S.C., Yoo, D.G., Han, H.S., Yoon, S.H., Oh, S.B., Kim, Y.B., and Back, G.G., 1997. Chrip (2–7 kHz) echo characters in the Ulleung Basin. *Geosci. J.*, 1: 143–153.

Cronin, T.M., 1991. Pliocene shallow water paleoceanography of the North Atlantic ocean based on marine ostracods. *Quaternary Sci. Rev.*, 10: 175–188.

Dowsett, H., Barron, J., and Poore, R., 1996. Middle Pliocene sea surface temperatures: a global reconstruction. *Marine Micropaleontol*, 27: 13–25.

Freund, H., Gerdes, G., Strief, H., Dellwig, O., and Watermann, F., 2004. The indicative meaning of diatoms, pollen and botanical macro fossils for the reconstruction of palaeoenvironments and sea-level fluctuations along the coast of Lower Saxony. *Germany. Quaternary Intl.*, 112: 71–87.

Hidaka, K., 1966. *Japan Sea: Encyclopedia of Oceanography*. New York: Reinhold Publisher, 417–424.

Kameo, K., Saito, K., Kotake, N., and Okada, M., 2003. Late Pliocenesea surface environments in the Pacific side of central Japan based on calcareous nannofossils from the lower part of the Chikura Group, southernmost part of the Boso Peninsula. *J. Geol. Soc. Japan*, 109: 478–488 (in Japanese with English abstract).

Kanaya, T., and Koizumi, I., 1966. Interpretation of Diatom Thanatocoenoses from the North Pacific Applied to a Study of Core V20-130. *The Science Reports of the Tohoku University*, Series 2: 89–130.

Kashima, K., 2003. The quantitative reconstruction of salinity changes using diatom assemblages in inland saline lakes in the central part of Turkey during the Late Quaternary. *Quaternary Intl.*, 105: 13–19.

Kato, M., Tanimura, Y., and Fukusawa, H., 2004. Survival strategy of diatom species living on now-depositing non-glacial varves. *Quaternary Intl.*, 123–125: 21–26.

Koizumi, I., 1989. Holocene pulses of diatom growths in the warm Tsushima current in the Japan Sea. *Diatom Res.* 4: 55–68.

Koizumi, I., 1992. Diatom biostratigraphy of the Japan Sea: Leg 127. *Proceedings of the Ocean Drilling Program, Scientific Results*, 127/128: 249–290.

Koizumi, I., Shiga, k., Irino, T., and Ikehara, M., 2003. Diatom record of the late Holocene in the Okhotsk Sea. *Marine Micropaleontol*., 49: 139–156.

Kwon, T.H., Lee, K.R., Cho, G.-C., and Lee, J.Y., 2011. Geotechnical properties of deep oceanic sediments recovered from the hydrate occurrence regions in the Ulleung Basin, East Sea, offshore Korea. *Marine Petrol. Geol.* doi:10.1016/J.marpetgeo. 2011.02.003.

Ling, H.-Y., 1992. Radiolarians from the Sea of Japan: Leg 128. Proc. *Proceedings of the Ocean Drilling Program, Scientific Results*, 127/128: 225–236.

Muza, J.P., 1992. Calcareous nannofossil biostratigraphy from the Japan Sea, sites 798 and 799: evidence for an oscillating Pleistocene oceanographic frontal boundary. *Proceedings of the Ocean Drilling Program, Scientific Results*, 127/128: 155–170.

Oba, T., Kato, M., Kitazato, H., Koizumi, I., Omura, A., Sakai, T., and Takayama, T., 1991. Paleoenvironmental changes in the Japan Sea during the last 85,000 years. *Paleoceanography*, 6: 499–518.

Ojala, A.E.K., Heinsalu, A., Saarnisto, M., and Tiljander, M., 2005. Annually laminated sediments date the drainage of the Ancylus Lake and early Holocene shoreline displacement in central Finland. *Quaternary Intl.*, 130: 63–73.

Ryu, E., Yi, S., and Lee, S, 2005. Late Pleistocene-Holocene paleoenvironmental changes inferred from diatom record of the Ulleung Basin, East Sea. *Marine Micropaleontol*., 55: 157–182.

Ryu, E., Ryu, B.J., Yun, H., and Lee, S.-J., 2003. Late Quaternary paleoenvironmental implication of the Ulleung Basin, Korea, inferred from diatom floras. *J. Geol. Soc. Korea*, 39: 183–198 (in Korean with English abstract).

Sato, T., Yuguchi, S., Takayama, T., and Kameo, K., 2004. Drastic change in the geographical distribution of the cold-water nannofossil Coccolithus pelagicus (Wallich) Schiller at 2.74 Ma in the Late Pliocene, with special reference to glaciation in the Arctic Ocean. *Marine Micropaleontol*., 52: 181–193.

Scherer, R.P., 1994. A new method for the determination of absolute abundance of diatoms and other silt-sized sedimentary particles. *J. Paleolimnol.*, 12(2): 171–180.

Tada, R., Irino, T., and Koizumi, I., 1999. Land-ocean linkages over orbital and millennial timescales recorded in late Quaternary sediments of the Japan Sea. *Paleoceanography*, 14: 236–247.

Tanimura, Y., 1981. Late Quaternary diatoms and Paleoceanography of the Sea of Japan. *Quaternary Res*., 20: 231–242 (in Japanese with English abstract).

Vos, P.C., and Gerrets, D.A., 2005. Archaeology: a major tool in the reconstruction of the coastal evolution of Westergo (northern Netherlands). *Quaternary Intl*., 133–134: 61–75.

Yabe, H., Yasui, S., Urabe, A., and Takahama, N., 2004. Holocene paleoenvironmental changes inferred from the diatom records of the Echigo Plain, central Japan. *Quaternary Intl*., 115–116: 117–130.

Yi, S., Bahk, J-J Jia, H., and Yoo, D-G., 2012. Pliocene-Pleistocene boundary determination in hemipelagic sediment from the Ulleung Basin (East Sea, offshore Korea) inferred from terrigenous and marine palynofloras. *Rev. Palaeobotany Palynol.*, 181: 54–63.

Yoon, S.H., and Chough, S.K., 1995. Regional strike-slip in the eastern continental margin of Korea and its tectonic implications for the evolution of Ulleung Basin, East Sea. *Geol. Soc. America Bull*., 107: 83–97.

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