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Application of Sediment Physical Properties to Paleoclimatic Interpretation: Preliminary Results in the Ulleung Basin, the East Sea

GIL YOUNG KIM, DAE CHOUL KIM, JOCK KEENE[1] AND JEONG CHANG KIM[2]
Department of Exploration Engineering, Pukyong National University, Pusan 608-737, Korea
[1]Division of Geology and Geophysics, School of Geosciences, University of Sydney, N.S.W. 2006, Australia
[2]Department of Shipboard Training, Pukyong National University, Pusan 608-737, Korea

Sediment physical properties (compressional wave velocity, grain density, dry bulk density, and wet bulk density) are correlated to the paleoenvironmental parameters (coarse fraction, oxygen isotope, and planktonic foraminifera fragmentation) to reveal the possible interrelationship in the latest Quaternary sediments of the Ulleung Basin, the East Sea of Korea. Laboratory determinations of physical properties and paleoenvironmental parameters have been conducted on four piston core sediments. There are slight differences in the physical properties between glacial and interglacial period sediment sections. This is due to the large fraction of coarse grains of volcanic and terrigenous sediments relative to carbonate sediments. However, dry bulk density as an indicator of carbonate abundance in pelagic environment shows higher values at the lower part of cores, reflecting deeper CCD in the glacial period. Changes in velocity also relatively parallel to those in sediment coarse fraction, number of planktonic foraminifera, and wet bulk density. Therefore, we suggest that high-resolution physical properties may be used as a valuable tool for paleoenvironmental interpretation in the Ulleung Basin.

INTRODUCTION

Detailed studies of physical properties of marine sediments have proved that temporal changes are partly determined by paleoceanographic changes including paleoclimate (Johnson *et al.*, 1977; Mayer, 1979; Embley and Johnson, 1980; Mienert, 1986; Mayer *et al.*, 1986). Environmental factors such as dissolution of biogenic sediments, dilution by non-biogenic materials, changes in biogenic productivity and current winnowing govern the depositional processes in the ocean basins (Mienert *et al.*, 1988). The depositional processes in turn control the grain size and the proportion of sediment components such as clay, quartz, biogenic carbonate and silica, and therefore the acoustic and physical properties of sediments. Acoustic and physical properties of marine sediments such as velocity, wet bulk density, porosity, and water content are closely related to sediment texture and composition (Hamilton, 1970). They mainly reflect changes in grain-size distribution and ratio of terrigenous to biogenic components (Mayer, 1991; Bassinot, 1993).

Attempts have been made to relate the properties to the paleoenvironmental and paleoclimatic changes (Mienert *et al.*, 1988; Weber *et al.*, 1997). Mayer (1979) reported that warm climate represents the times of enhanced carbonate dissolution and low bulk sediment densities while the opposites are true for cold climate in the equatorial Pacific. In contrast, Mienert *et al.* (1988) documented that carbonate is strongly dissolved in glacial periods in the western equatorial Atlantic sediment. These studies imply that the variation in pelagic carbonate content contains strong paleoceanographic signal (Mayer, 1979; Mayer *et al.*, 1986; Mienert *et al.*, 1988). Several studies (Morton, 1975; Berger and Mayer, 1978; Hamilton *et al.*, 1982; Briggs *et al.*, 1985) noted that temporal changes of carbonate content with depth may contribute partly to the vertical variations in velocity and related physical properties of sediments. The validity of this assumption, however, is questionable for the latest Quaternary hemipelagic sediment in the Ulleung Basin where carbonate content is significantly low (<10%; KORDI, 1997).

In this paper, we present preliminary results for the relationship between sediment physical properties and paleoceanographic changes in the Ulleung Basin. The main goal is to evaluate a potential for possible application of high resolution physical properties to paleoceanographic and stratigraphic studies in a hemipelagic basin.

GEOLOGIC SETTING

The East Sea is a semi-isolated marginal basin with an average depth of 1350 m and a maximum depth of about 3700 m in the north (Fig. 1). The Ulleung Basin occupies the southwestern part of the East Sea and is bounded by the continental slope of the Korean Peninsula on the west and by the rugged Korea Plateau on the north side. In the east and southeast, the basin is bounded by a gentle slope extending from the northern Honshu. The basin floor is fairly smooth and dips gently northward from 2000 m water depth to more than 2500 m in the northeast where the basin joins the deeper Japan Basin through a 35 km wide constricting passage, the Ulleung Interplain Gap.

The continental slope along the western margin of the Ulleung Basin is steep with a gradient of about 6° and characterized by large-scale slump pits and scars; slump and debris flow deposits are common on the base-of-slope (Chough *et al.*, 1984). In the southern margin, slump and slides are ubiquitous. Here, mass-flow deposits are distributed in a contour-parallel fashion: slump and slide deposits occur mainly on the slope which are, in turn, replaced in the deeper area by debris-flow deposits and turbidites (Chough *et al.*, 1985, 1997)

MATERIALS AND METHODS

Physical properties and paleoenvironmental parameters for four piston cores (Kim, 1998) from the Ulleung Basin are used in order to evaluate climatic and stratigraphic relationships (Fig. 1). The cores are par-

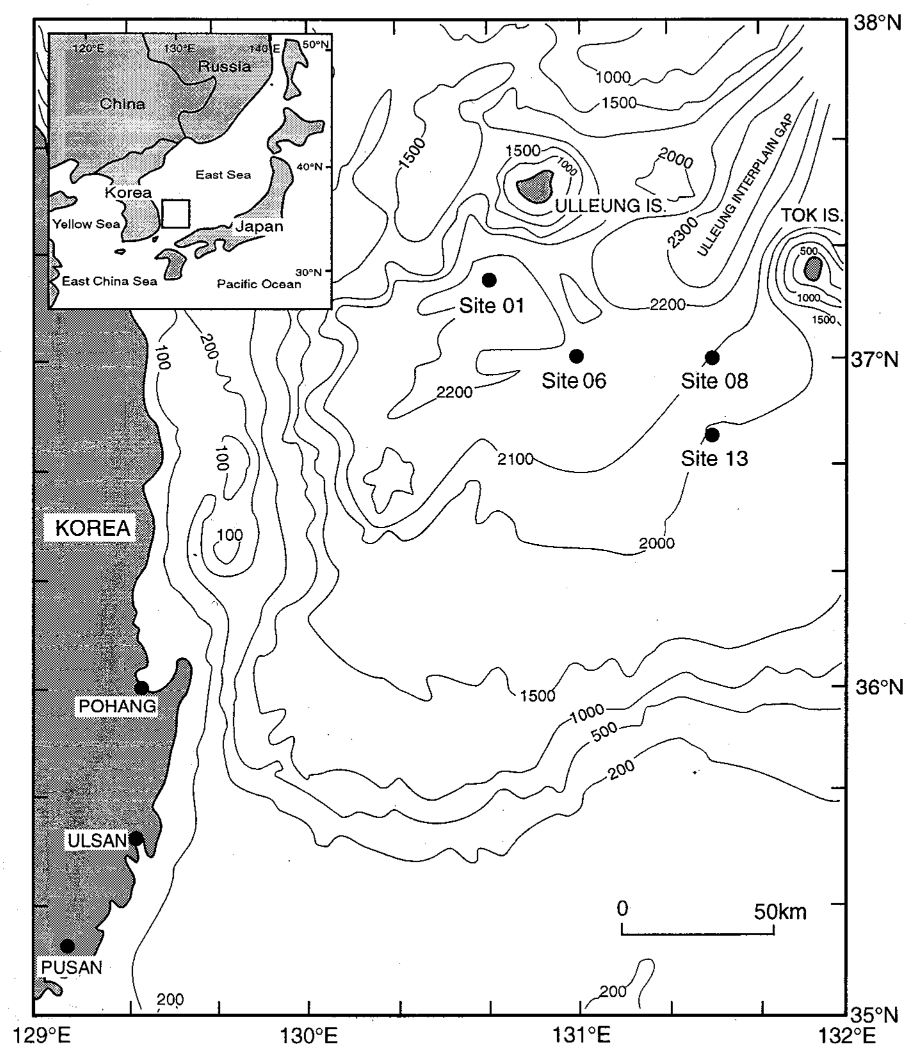

Fig. 1. Location and bathymetry of the study area. Solid circles mark the locations of four piston cores (Sites 01, 06, 08 and 13). Contours in meters.

ticularly well suited to monitor the paleoenvironmental history of the East Sea because they are located away from the areas of mass-flow deposits (Kim *et al.*, 1998). Physical properties are measured by weight-volume method (Kim, 1998). Paleoenvironmental parameters and sediment ages are used the data investigated by Kim *et al.* (1998, 1999).

The physical properties are compared to oxygen isotope stratigraphic records of the planktonic foraminifera, coarse fraction (>63 μm), planktonic foraminifera fragmentation, and number of planktonic foraminifera to understand down-core changes during glacial and interglacial periods. Sediment ages are estimated from the Ulleung-Oki tephra layer of which the age is well documented. Absolute ages determined by accelerator mass spectrometer (AMS) are also presented. The detailed core description and experimental technique are available in Kim's (1998) thesis.

RESULTS AND DISCUSSION

Vertical variations in physical properties and paleoenvironmental parameters for the cores are displayed in Fig. 2. We roughly divided glacial (20 cm depth below a tephra layer from core bottom) and interglacial (above the tephra layer) sediment sections based on the Ulleung-Oki eruption time (*ca.* 9.3 ka B.P.) (Kim *et al.*, 1998) and AMS age data.

Changes in physical properties are not correlated well to those in the glacial-interglacial sediment intervals (Fig. 2). The zones of highest coarse fraction, which occur around the tephra layers, corresponds to maximum values of wet bulk density and velocity for all four cores. Peaks in the coarse fraction at sites 01 and 06 are also found at intervals in which planktonic foraminifera are dominant. The highest $\delta^{18}O$ value in each core, suggesting an abrupt cooling event, occurs at depth below the peak of coarse fraction at 9.3 ka B.P. The low $\delta^{18}O$ value in the glacial period sediment section is probably due to less saline water, caused by freshwater input (Oba *et al.*, 1991) from the adjacent lands and/or increased precipitation over evaporation in the East Sea (Keigwin and Gorbarenko, 1992).

Mienert *et al.* (1988) reported that velocity (p-wave) can be correlated with interglacial maxima and glacial minima in the equatorial Atlantic sediments, emphasizing the potential of velocity records as a stratigraphic tool in deep-sea carbonates. The stratigraphic resolution and signal shape, however, can be changed drastically as a function of sediment accumulation rate (Mayer, 1980) and grain-size distribution (Mienert *et al.*, 1988). This, in turn, is responsible for variations in sediment physical properties that may limit the application of physical properties to paleoenvironmental interpretation. The sediment accumulation rates in the Ulleung Basin, estimated from the AMS data and the event of Ulleung-Oki tephra eruption range 12 to 24 cm/kyr (Kim *et al.*, 1999), with higher values in glacial period than interglacial period. This probably suggests increased supply of hemipelagic sediments as well as terrigenous materials during the former period due to activated ocean and atmospheric circulations.

Sediment grain density is slightly higher in the glacial sediment sections (Fig. 2), probably related to lowered CCD that increased carbonate accumulation (Oba *et al.*, 1991; Kim *et al.*, 1998). Significantly low grain density values are observed in the tephra layer. Dry bulk density is also strongly influenced by the carbonate content in sediment as revealed preiously (Luz and Shackleton, 1975; Lyle and Dymond, 1976; Murray, 1987; Farrell, 1991; Snoeckx and Rea, 1994). The higher dry bulk densities in the lower part than the upper part of cores (Fig. 2) are ascribed to increased carbonate production and accumulation. Levels of CCD in the East Sea remained deep during the glacial and shallow during the interglacial period (Oba *et al.*, 1991).

Profiles of wet bulk density and velocity generally follow those of the coarse fraction (Fig. 2). Wave velocity is more or less variable with depth, ranging 1518 to 1553 m/s. Except around the tephra layer, the velocity is 1531 to 1538 m/s and 1532 to 1541 m/s in the interglacial and glacial sediment sections, respectively. It is well known that changes of the production and dissolution of planktonic foraminifera affect on the variation in velocity of pelagic sediment (Mienert *et al.*, 1988). These paleoenvironmental changes also cause the variation of physical properties. Similarly, wet bulk densities also show slight differences, 1.24 to 1.33 g/cm^3 and 1.29 to 1.42 g/cm^3 in the interglacial and glacial sediments, respectively. Physical properties are also controlled by concentration of sand-sized foraminifera than accumulation rate, particularly in areas of high terrigenous input (Morton, 1975). Thus the carbonate that is dominated by fine-grained terrigenous sediments in the Ulleung Basin may not play a major role in velocity change.

For calcareous sediment, changes in velocity are

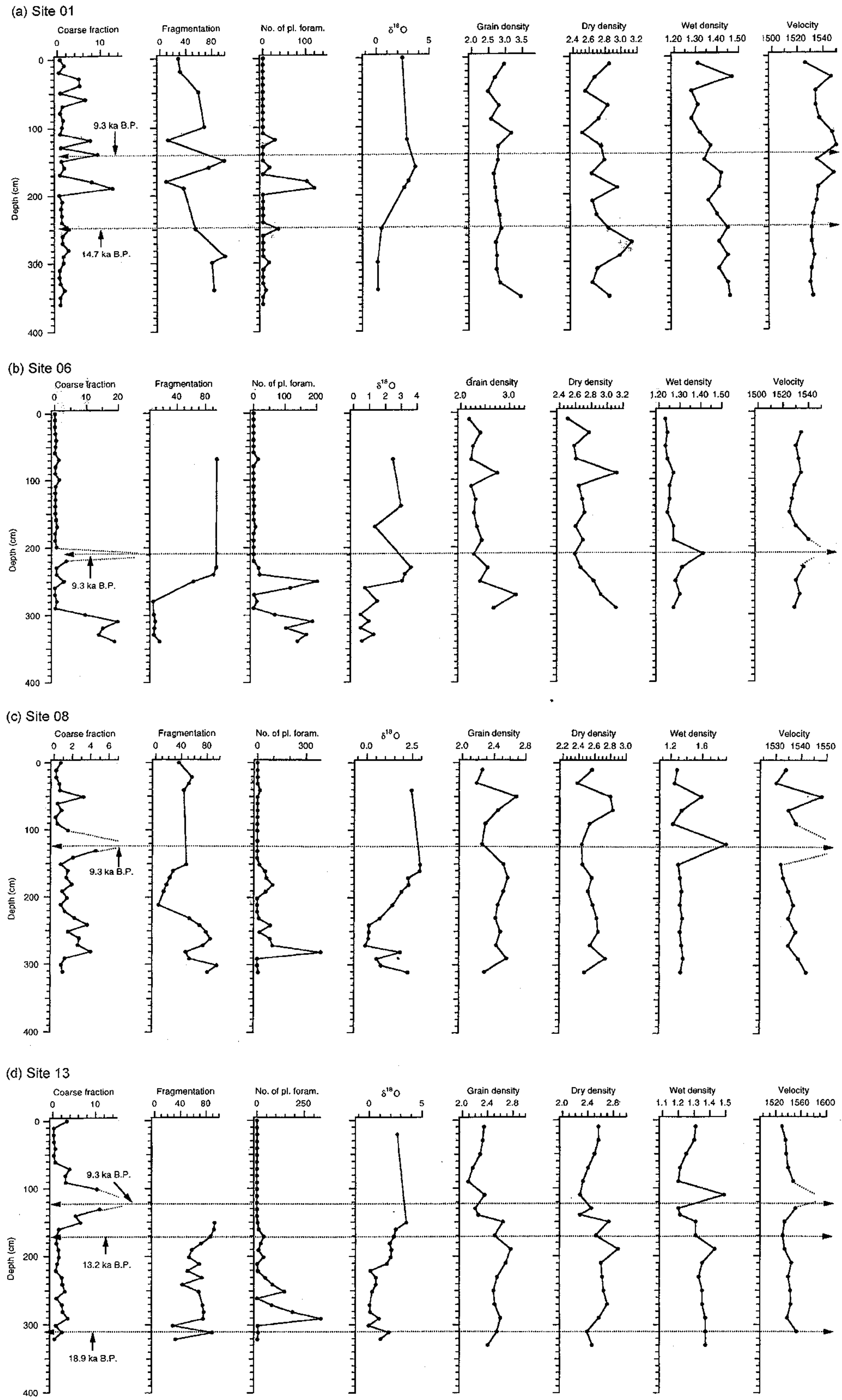

Fig. 2. Profiles showing coarse fraction content (%), planktonic foraminifera fragmentation (%), number of planktonic foraminifera, $\delta^{18}O$ values (‰), grain density (g/cm^3), dry bulk density (g/cm^3), wet bulk density (g/cm^3), and velocity (m/s) in the cores. Wet bulk density and velocity generally increase around the tephra layer, suggesting the physical properties are largely related to coarse fraction content. Age levels based on AMS and tephra layers are indicated.

largely determined by rigidity rather than bulk modulus and bulk density (Morton, 1975; Hamilton *et al.*, 1982; Mienert *et al.*, 1988). In turn, sediment rigidity is controlled by not only the percentage of sand-sized foraminifera (high rigidity in sand content more than approximately 40% and vice versa), but also packing, compaction, sorting, and shape of grain particles. Mienert *et al.* (1988) ascribed small velocity variation and low velocity in glacial period sediments to low percentages of sand-sized foraminifera caused by higher carbonate dissolution and/or lower production. However, an interaction of bulk modulus, rigidity and bulk density compensate, resulting in only small variation in velocity (Morton, 1975; Hamilton *et al.*, 1982; Mienert *et al.*, 1988). However, the velocity of the Ulleung Basin sediments appears to be higher in glacial period different from the result in the equatorial Atlantic (Mienert *et al.*, 1988). The carbonate dissolution pattern, shown by fragmentation rate of foraminifera (Fig. 2) is similar to that in the equatorial Pacific sediment (Mayer, 1979), suggesting the oceanographic conditions of the East Sea coincide well those of the Pacific Ocean. Thus the velocity with core depth reflects this pattern. Briggs *et al.* (1985) and Schreiber (1968) also noted that the change of carbonate content by CCD may contribute to the variations in velocity and related physical properties of sediments.

We now present a more quantitative assessment of the interrelationships between coarse fraction content and planktonic foraminifera fragmentation and their significance in determining changes in physical properties. To examine the significance, linear regressions are presented for the variables obtained in entire depth of cores (Fig. 3). Amount of coarse fraction shows a slight positive correlation to both wet bulk density and velocity. There are no particular correlations between planktonic foraminifera fragmentations and physical properties, suggesting that terrigenous materials are the main constituent in the coarse fraction. Mienert *et al.* (1988) suggested that changes in physical properties were negligible in sediments containing less than 20% and 10% in $CaCO_3$ and sand content, respectively.

However, intercore correlations may still be possible if climate changes caused the paleoceanographic conditions resulting in intense cementation that is recorded as distinct increases in velocity amplitudes (Slowey and Neumann, 1984; Mienert *et al.*, 1988). These changes in physical properties can be linked to environmentally and climatically controlled changes in the concentration of sand-sized planktonic for-

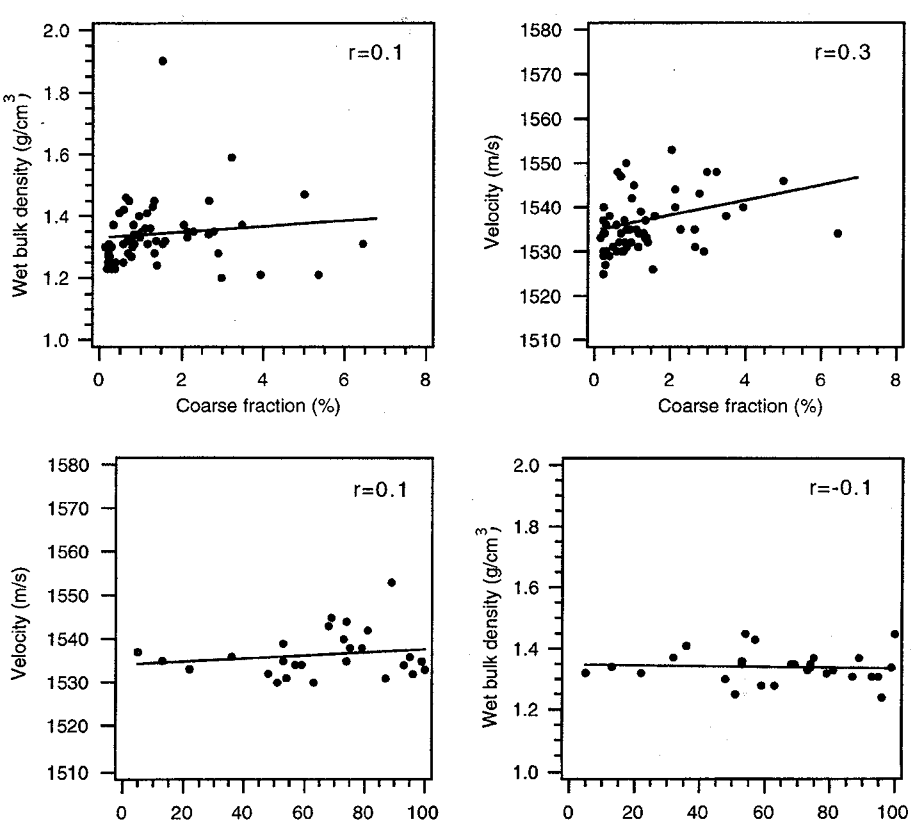

Fig. 3. Linear regressions between paleoenvironmental parameters and physical properties. Coarse fractions (>63 μm) have better correlation to physical properties than planktonic foraminifera fragmentation.

aminifera, converting a rapid and easily measured physical properties into a sensitive paleoceanographic and stratigraphic tool. Our result shows that a decrease in carbonate dissolution with depth causes a slight increase in sand grain size (except the tephra layer) and thus a increase in velocity and density with depth (Fig. 2). Physical properties in the Ulleung Basin sediments are dominantly controlled by the percentages of the sand-sized grains. Therefore, high resolution study of physical properties of latest Quaternary sediments in the Ulleung Basin is probably guaranteed to establish relationships between physical properties and paleoceanographic conditions.

SUMMARY

Paleoceanoghraphic interpretation, based on high-resolution physical property data as well as paleoenvironmental parameters, has been applied to the studies of latest Quaternary Ulleung Basin sediments. In this study, we report preliminary results for application of sediment physical properties to paleoclimatic interpretation. The values of sediment velocity and density in the Ulleung Basin during the interglacial (1531 to 1538 m/s) and glacial period sediments (1532 to 1541 m/s) show slight differences. Wet bulk densities are also slight differences ranging from 1.24 to 1.33 g/cm^3 and from 1.29 to 1.42 g/cm^3 in the interglacial and glacial periods, respectively. The results are probably responsible for the variation of carbonate content and sand-sized materials. Thus, low carbonate dissolution by deeper CCD of the East Sea during the glacial period results in high velocity and density at the lower part of cores. However, there are still considerable problems for accurate paleoclimatic interpretation using sediment physical properties in the Ulleung Basin, characterized by low carbonate content, low coarse fraction, high terrigenous materials, and intervened tephra layers. Accordingly for a better interpretation is needed a further detailed study.

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