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Interpretation of Physical Properties of Marine Sediments Using Multi-Sensor Core Logger (MSCL): Comparison with Discrete Samples

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Multi-Sensor Core Logger (MSCL) is a useful system for logging the physical properties (compressional wave velocity, wet bulk density, fractional porosity, magnetic susceptibility and/or natural gamma radiation) of marine sediments through scanning of whole cores in a nondestructive fashion. But MSCL has a number of problems that can lead to spurious results depending on the various factors such as core slumping, gas expansion, mechanical stretching, and the thickness variation of core liner and sediment. For the verification of MSCL data, compressional wave velocity, wet bulk density, and porosity were measured on discrete samples by Hamilton Frame and Gravimetric method, respectively. Acoustic impedance was also calculated. Physical property data (velocity, wet bulk density, and impedance) logged by MSCL were slightly larger than those of discrete sample, and porosity is reverse. Average difference between MSCL and discrete sample at both sites is relatively small such as 22–24 m/s in velocity, 0.02–0.08 g/cm^3 in wet bulk density, and 2.5–2.7% in porosity. The values also show systematic variation with sediment depth. A variety of factors are probably responsible for the differences including instrument error, various measurement method, sediment disturbance, and accuracy of calibration. Therefore, MSCL can be effectively used to collect physical property data with high resolution and quality, if the calibration is accurately completed.

Key words: Multi-Sensor Core Logger, Gravimetric Method, Physical Properties, Marine Sediments

INTRODUCTION

Physical properties of sediments, closely related to sediment composition, sedimentary formation, and environmental conditions of the deposits, can be measured rapidly and easily at high spatial resolution (core logging). They serve as good proxies for processes such as oceanographic and paleoclimatic changes, postdepositional processes (e.g., compaction and/or consolidation), and major lithological (sediment texture and mineral composition) changes (Blum, 1997). For this reason, physical properties have always been measured for all cores on board of each leg during Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) drilling. Especially ODP has general objectives for core-to-core and hole-to-hole correlation and for correlating core data to down-logging data. Recently, ODP have collected physical properties data scanning whole core sections from Multi-Sensor Track (MST) station. The MST system, fully automated, includes gamma-ray attenuation densiometry, compressional wave velocity, magnetic susceptibility, and natural gamma ray.

Nondestructive logging system of marine cores began in the early 1960s, measuring bulk density using gamma-ray attenuation (Evans, 1965; Preiss, 1968). After then, new systems have been continually developed (Boyce, 1973; Schultheiss and McPhail, 1989; Schultheiss and Weaver, 1992; Blum, 1997). Recently, Multi-Sensor Core Logger (MSCL) made by Geotek company in United Kingdom have been widely used.

MSCL is particularly useful for collecting acoustic impedance information in the upper 20 m sub-seafloor that corresponds approximately to the maximum depth of piston cores (Weaver and Schultheiss, 1990; Best and Gunn, 1999). The acoustic impedance information is needed for a range of applications such as sound propagation and reverberation modeling and seafloor characterization (Lambert, 1988; Lambert and Fiedler, 1991; Lambert *et al.*, 1993, 2002; Richardson *et al.*, 2002; Walter *et al.*, 1997, 1998, 2002).

Conventionally, density and porosity of sediments

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are determined most accurately through mass and volume determinations (gravimetric method) of discrete core specimens. Compressional wave velocity using Hamilton Frame can be measured in various directions of the specimens extracted from the core. But the gravimetric method is suspected to remove a substantial portion of the interlayer water from clays such as smectite in addition to interstitial water, which may result in porosity errors of up to 20% (Blum, 1997). In addition, this method is a time-consuming, expensive labor, and sediment destruction work and does not provide available data within a few centimeters (Weber *et al.*, 1997).

The purpose of this paper is to present and compare physical properties (density and porosity) measured by the gravimetric method and the MSCL belonging to Naval Research Laboratory (NRL). In addition, the compressional wave velocity data obtained by Hamilton Frame and MSCL is also included for comparison. We will then evaluate the potential of applying MSCL data to marine sediments.

METHODS

Whole core data by Multi-Sensor Core Logger (MSCL)

MSCL is typical of the automated logging systems (non-destructive) in use at Naval Research Laboratory and designed to log whole cores. It presently comprises systems for measuring compressional wave velocity, bulk density, magnetic susceptibility, and core temperature. The MSCL uses a pair of 500 kHz piezoelectric ceramic transducer to measure compressional wave velocity. Wet bulk density is measured by gamma-ray attenuation, using a 137-Cs gamma source and scintillation counter. Further of procedure can be seen elsewhere (Schultheiss and McPhail, 1989; Weaver and Schultheiss, 1990; Blum, 1997; Weber *et al.*, 1997). Fractional porosity can be calculated directly from sediment density (mineral grain density and fluid density) under the assumption that the sediment is fully saturated. Magnetic susceptibility data is excluded here.

Two piston cores were collected in the western con-

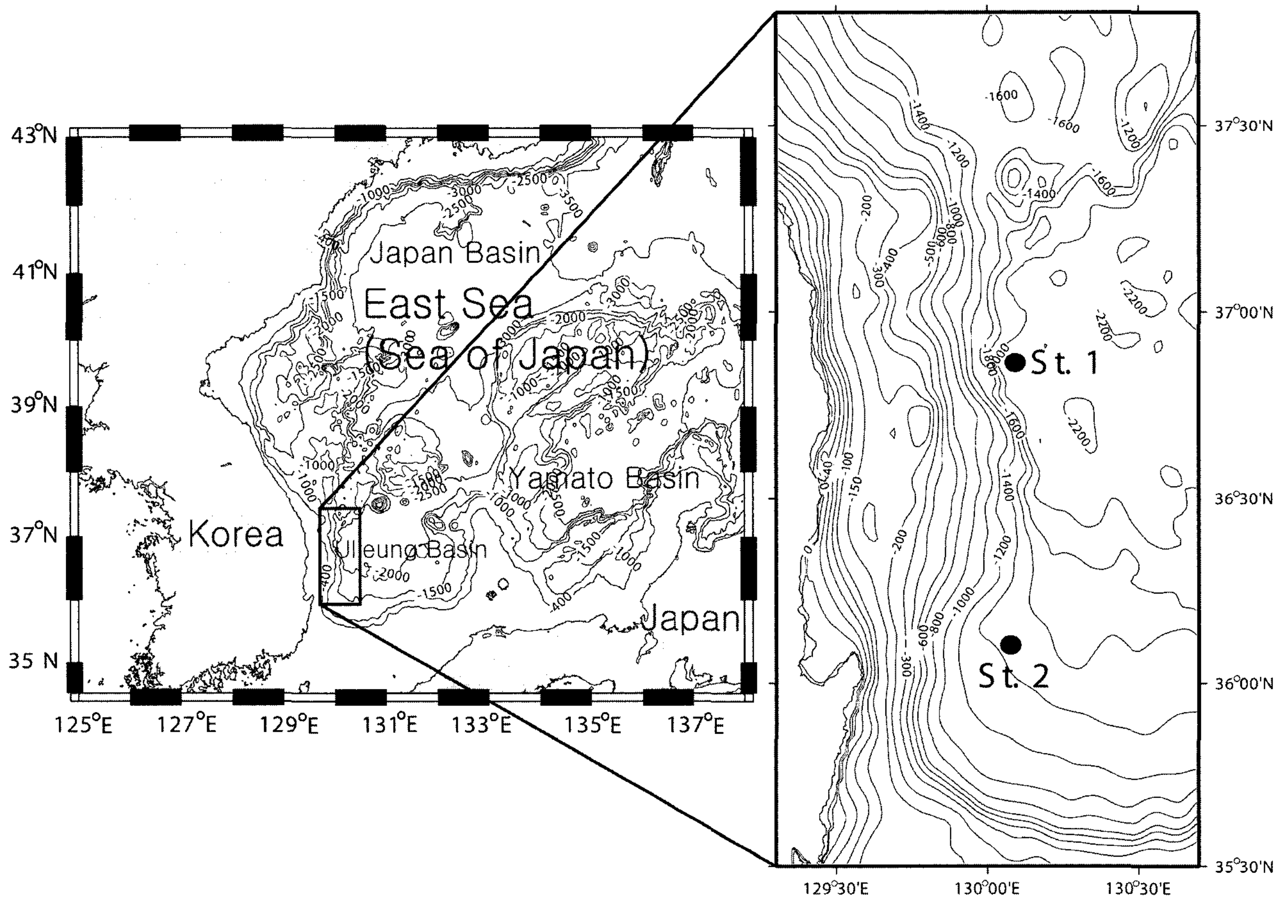

Fig. 1. Topographic features of the East Sea and location map of sampling sites in the western continental margin of the Ulleung Basin. Stations 1 (water depth, 2,205 m) and 2 (water depth, 1,481 m) are marked. Depth contours are in meters below sea level.

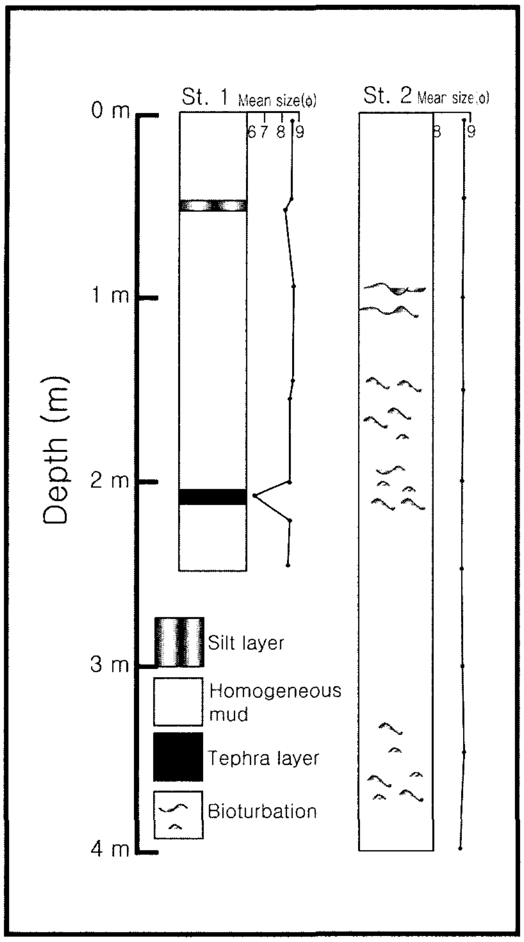

Fig. 2. Columnar sections of the cores at Stations 1 and 2. These cores consist of homogeneous mud with tephra layer (St. 1) and bioturbation (St. 2). Mean grain size is also displayed.

tinental margin of the Ulleung Basin, the East Sea (Fig. 1). The cores are mainly composed of homogeneous mud with tephra and silt layer (Station 1) and some bioturbation (Station 2) with the constant mean grain size throughout the cores (Fig. 2).

MSCL measurements to determine the physical properties of the core samples were made at constant intervals (1 cm) and periods (2 seconds), from the top to bottom of each section of the cores after the sediment cores were equilibrated to ambient laboratory room temperature (approximately 23°C). Derivative acoustic impedance and fractional porosity were additionally calculated for each sample interval. Fractional porosity values were reported relative to an average grain density value of 2.65 g/cm^3 and a pore water density of 1.026 g/cm^3. Compressional wave velocity values were converted to a standard condition of laboratory temperature of 23°C and 35‰ salinity.

Discrete samples data by Hamilton Frame and Gravimetric method

Compressional wave velocities were measured from the specimens at laboratory by the pulse transmission technique (Birch, 1960) using Hamilton Frame. The measurement system includes pulse generator (Model HP 8116A, 50 MHz), digital oscilloscope (Model HP 54520A, 500 MHz), and a Hamilton Frame modified. A pair of piezoelectric transducer of 1 MHz was used for driving signal. Distilled water was used as the acoustic coupling fluid.

Porosity and density by gravimetric method (Boyce, 1973) were determined from mass and volume of the same specimens. Sample weight was determined by using electronic balance. Sample volume was determined for both wet and dry samples by using an autopycnometer (Model Ultrapycnometer 1000). This system employs Archimedes principle of fluid displacement to determine the volume of solid objects. The helium gas was kept under pressure of 18 psi (1 psi = 0.07 kg/cm^2). The mass and volume of the evaporated pore-water salts were calculated for a standard seawater salinity (35‰) and seawater density (1.024 g/cm^3) at laboratory conditions.

RESULTS AND DISCUSSION

The velocity variations with sediment depth are more severe on discrete samples than MSCL data (Figs. 3a and 4a). Average differences between discrete sample and MSCL data sets at Stations 1 and 2 are 22 and 24 m/s, respectively (Table 1). Of various factors, temperature is considered to be a major one for the velocity variation. Weber *et al.* (1997) documented variations in compressional wave velocity on the order of 3 m/s/°C. The temperature on discrete sample was lower approximately 3°C than that of MSCL. Thus, the velocity value of discrete sample has to be added by approximately 9 m/s via arithmetical computation for correction to the same temperature condition as that of MSCL. The frequency of measurement system should be also considered as potential factor for the variation. In general, the compressional wave velocity logarithmically increases with increasing frequency within the limited frequency band (between approximately 10 kHz and 1 MHz) (Diallo *et al.*, 2003). Thus, the velocity of MSCL measured at the frequency of 500 kHz can be underestimated than that of discrete sample measured at the frequency of 1 MHz. Salinity of the interstitial fluid may also

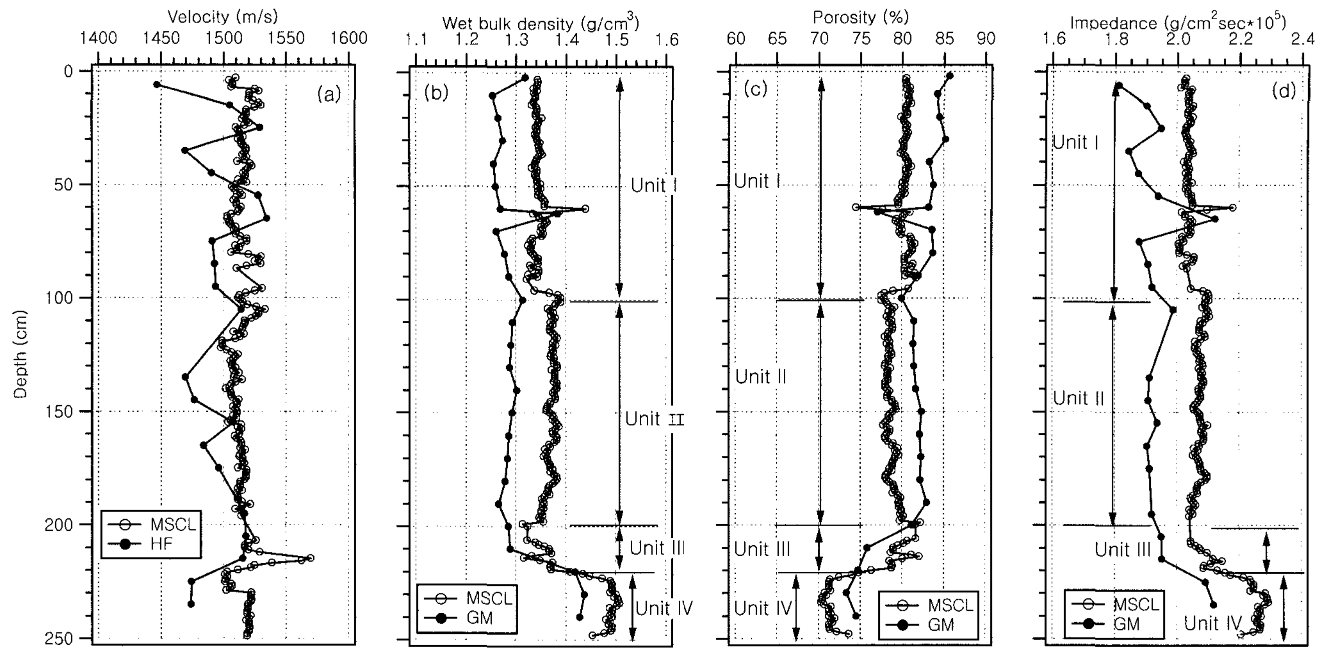

Fig. 3. Comparison of physical properties measured on both MSCL and discrete samples at Station 1. Four units are roughly identified based on the physical properties by MSCL. (HF: Hamilton Frame, GM: Gravimetric Method).

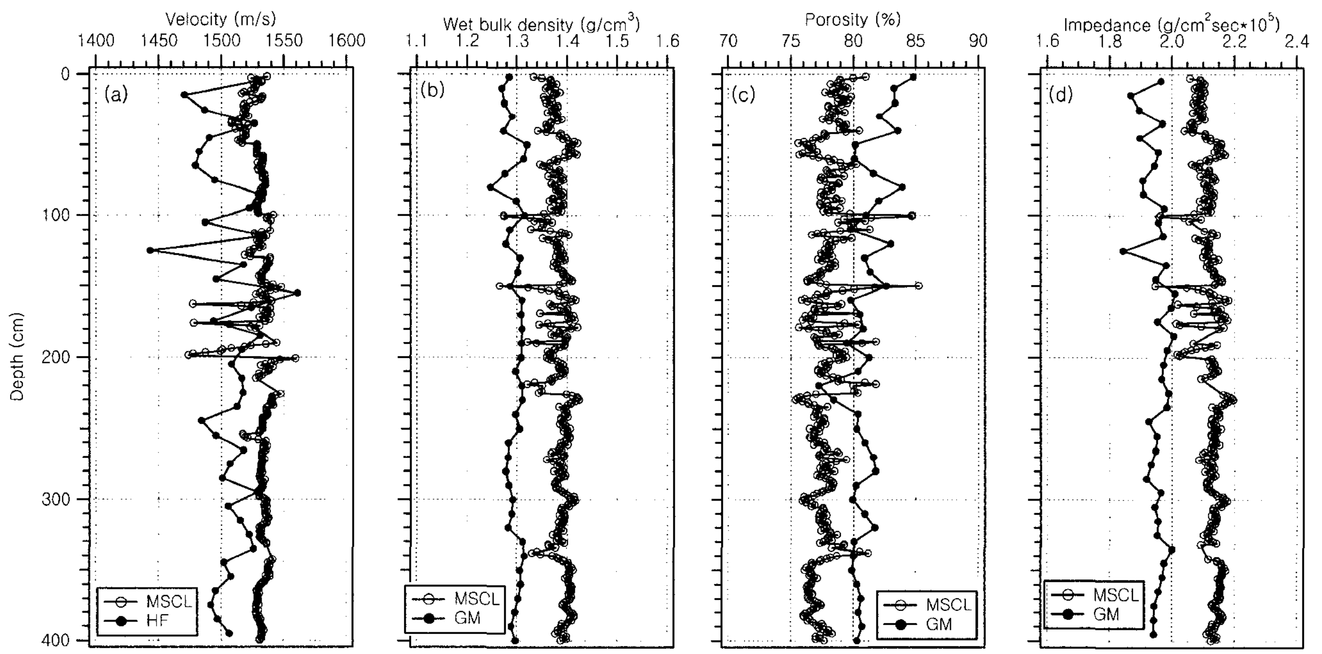

Fig. 4. Comparison of physical properties measured on both MSCL and discrete samples at Station 2. (HF: Hamilton Frame, GM: Gravimetric Method).

be another variable (approximately 1 m/s/‰) in velocity measurements (Hamilton, 1971). This, however, is a minor impact and can be ignored for unconsolidated marine sediments. In addition, as other major causes for spurious reading of MSCL, there are sediment slumping in the core liner, disturbance of core for handling, and micro-cracks by free gas expulsion (Gunn and Best, 1998). Sediment slumping or sediment slurry is especially common in the upper parts (sediment/water interface) of the softest and most unconsolidated sediments. The sediment of Station 2 shows soupy texture partly disturbed when split, caused by free gas during coring. These factors and causes together are responsible for the velocity of

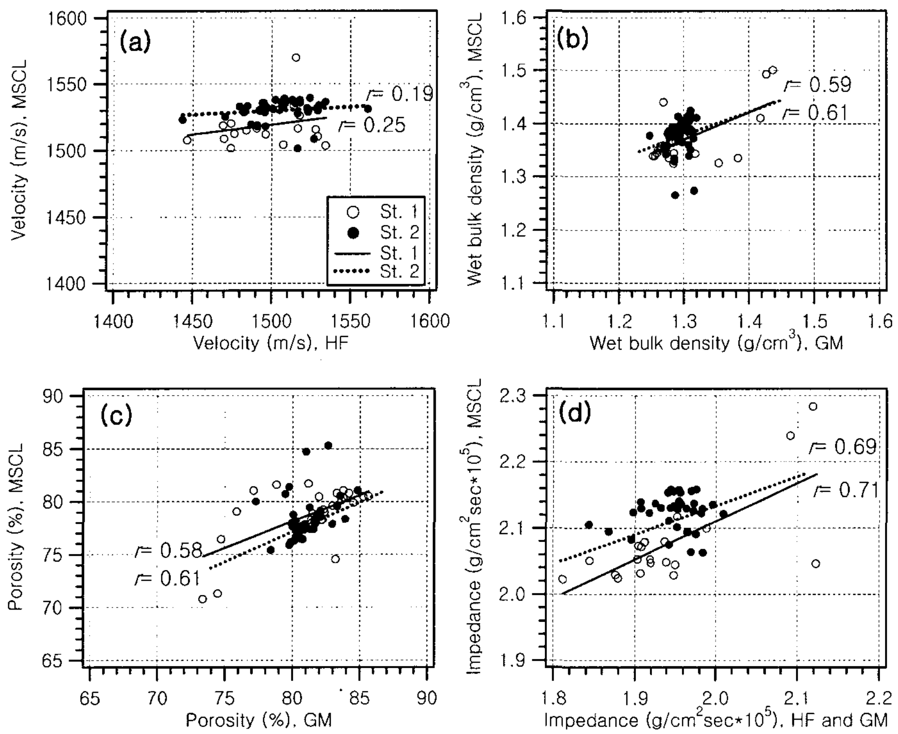

Fig. 5. Scatter diagrams of physical properties from MSCL versus discrete sample measurements. Note that wet bulk density and porosity shows well correlation between the two data sets. (HF: Hamilton Frame, GM: Gravimetric Method). Correlation coefficients (r value) for each regression line is also displayed.

discrete sample that is highly fluctuated with sediment depth (Fig. 4a). The velocity value of discrete sample at Station 1 is also more various than other physical properties (Fig. 3b, 3c, and 3d). This is most likely due to sediment disturbance during handling for measurement. The correlation between MSCL and discrete sample data is also poor at both stations (Fig. 5a). Thus, the sample for velocity measurement should be treated carefully.

Wet bulk density of MSCL is calculated from the measurement of gamma-ray attenuation (Evan, 1965). While, wet bulk density of discrete sample is measured using autopycnometer. At Station 1, wet bulk density values are abruptly jumped at the depths of 60, 100, 200, and 220 cm (Fig. 3b, see the boundary of the units), even though the mean grain size is constant (Fig. 2). Wet bulk density around 210 cm depth is low with slight fluctuation, caused by tephra layer (Fig. 2). Based on these depths, the physical properties measured by MSCL are roughly divided into four units with sediment depth, but the data by gravimetric method do not show a clear boundary (Fig. 3b). This suggests MSCL data shows the change of physical properties in more details. This variation with depth may be related to a possible post depositional processes such as sediment compaction by overburden pressure and/ or redeposition after erosion, as would be expected in a normally consolidated sequence (Mosher *et al.*, 1994). This is clearly supported by gradual increase of shear strength (from 2 to 4 to 10 kPa) below this depth, although the data did not presented in this paper. The MSCL data of Station 2 shows a slight fluctuation above 220 cm depth (Fig. 4b). Wet bulk density of discrete sample relatively follows the pattern of MSCL (Fig. 4b). Both data sets are relatively coherent. Average differences between MSCL and discrete sample data at Stations 1 and 2 are 0.02 and 0.08 g/cm^3, respectively (Table 1). Considering a limit of error, the difference is not large. The good correlation of wet bulk densities shows that those can be precisely predicted from MSCL although the scattering exists (Fig. 5b). In the case of MSCL, grain density of 2.65 g/cm^3 is used for gamma-ray calculation. However, significant fluctuations in grain density, as would be expected in biogenic sediments (high opal and/or carbonate c ntents) are responsible for a greater difference between MSCL and discrete sample data. Thus, the geological knowledge about the sediment composition is very important. Pycnometer measurement on discrete samples also provides the most valuable information if grain density can be predicted well (Weber *et al.*, 1997).

The variations of porosity at both sites follow very well the pattern of wet bulk density, showing a mirror image (Figs. 3b, 3c, 4b, and 4c). These patterns can be expected from the calculation method using

Table 1. Average values and difference values of physical properties between MSCL and discrete samples.

	MSCL	Discrete sample	Difference value
Station 1			
Velocity (m/s)	1518	1496	22
Wet bulk density (g/cm^3)	1.37	1.35	0.02
Porosity (%)	78.7	81.2	2.5
Impedance (g/cm^{2}sec×10^5)	2.07	1.94	0.13
Station 2			
Velocity (m/s)	1530	1506	24
Wet bulk density (g/cm^3)	1.38	1.30	0.08
Porosity (%)	78.3	81.0	2.7
Impedance (g/cm^{2}sec×10^5)	2.12	1.95	0.17

weight and volume of sample. The porosity of Station 1 is also rapidly changed at the boundary of 100 cm sediment depth (Fig. 3c), suggesting more compacted sediments than the lower part of the core. Average differences between MSCL and discrete sample data at Stations 1 and 2 are 2.5 and 2.7%, respectively (Table 1). The correlation between MSCL and discrete sample data shows a good correlation (Fig. 5c). Thus, these data provide a distinct verification for an individual method.

Acoustic impedance (or impedance) is easily calculated from the product of wet bulk density and velocity. The variation of impedance reflects the mixture patterns of wet bulk density and velocity (Figs. 3d and 4d). The accurate calibration of MSCL is important for collection of density and velocity with high confidence. Several reporters (Gerland and Villinger; 1995; Weber *et al.*, 1997) presented that gamma-ray density measurements are particularly susceptible to large instrument errors (10% or higher) according to the accuracy of calibration. Thus, impedance data can be accurately calculated from the reliable density and velocity. The differences between MSCL and discrete sample data at Stations 1 and 2 are 0.13 and 0.17 g/cm^{2}sec x 10^5, respectively (Table 1). The correlation between MSCL and discrete sample is relatively good (Fig. 5d). Thus, MSCL can be effectively used to predict continuous impedance variation with sediment depth.

CONCLUSIONS

Velocity, wet bulk density and impedance measured and calculated by MSCL are slightly larger than those of discrete sample, while the porosity value is high at discrete sample. Average difference between MSCL and discrete sample is relatively small and shows systematic variation with sediment depth. The difference is probably responsible for instrument error, measurement method, sediment disturbance, and accuracy of calibration of system. The relationships between MSCL and discrete sample revealed a good correlation. This suggests both methods can be adopted for the measurement of physical properties with good confidence. Therefore, if the calibration of MSCL is accurately completed, physical properties data with high resolution and quality can rapidly be collected using MSCL.

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