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Acoustic Properties of Gassy Sediments: Preliminary Result of Jinhae Bay, Korea

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Abstract

Compressional wave velocity and shear wave velocity were measured for gassy sediments collected from Jinhae Bay, Korea. To distinguish inhomogeneities of gassy sediments, Computed Tomography (CT) was carried out for gassy sediment using CT Scanner. The cored sediments are composed of homogeneous and soft mud (greater than 8ϕ in mean grain size) containing clay content more than 50%. In depth interval of gassy sediments, compressional wave velocity is significantly decreased from 1480 m/s to 1360 m/s, indicating that the gas greatly affects compressional wave velocity due to a gas and/or degassing cracks. Shear wave velocity shows a slight increasing pattern from ~55 m/s in the upper part of the core to ~58 m/s at 320 cm depth, and then decreases to ~54 m/s in the lower part of the core containing a small amount of gas. But shear wave velocity in the gassy sediments is slightly greater than that of non-gassy sediments in the upper part of the core. Thus, the Vp/Vs ratio is decreased (from 30 to 25) in gas charged zone. The Vp/Vs ratio is well correlated with shear wave velocity, but no correlation with compressional wave velocity. This suggests that low concentrations of gas have little affects on shear wave velocity. By CT images, the gas in the sediments is mostly concentrated around inner edge of core liner due to a long duration after sediment collection.

Keywords: *acoustic properties, gas bubble, CT scanner, gassy sediments, Jinhae Bay*

I. Introduction

Acoustic properties (compressional (Vp) and shear wave (Vs) velocity) for unconsolidated sediments have been widely reported in the literature. But the studies for gassy sediments are still rare. Generally, acoustic properties in sediments and rocks are important parameters in modeling the seafloor for underwater acoustics, marine geophysics, and ocean engineering [1]. In particular, the Vp/Vs ratio may be useful in indicating the presence of gas in sediments and rocks, due to a significant drop in the Vp/Vs ratio [2][3].

Gassy sediments are widely distributed at shallow depth into the sediments of various areas such as coast, bay, and shelf around world [4]. These places are characteristically covered with thick fine grained sediments (e.g., muddy sediments). The gas in the sediments generally exists as dissolved and/or gaseous state. If in the gaseous state, it is termed free gas and the sediment is referred to as gassy or bubbly [5]. Bubble populations within the sediments vary according to the size and distribution pattern of bubble [5]. Acoustic propagation in sediments is severely affected by the presence of free gas; bubbles act as giving rise to scattering and attenuation of acoustic energy [4].Thus the existence of free gas is significantly

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responsible for the blanking of the acoustic data obtained in both laboratory and in situ. In particular, compressional wave velocity of laboratory is very sensitive to a presence of gas even though very small concentration [6]. Free gas in the sediments also affects the sediment's engineering properties [7].

Degassing structure caused by escaping of gas and distribution of gas in the sediments are measured by soft X-radiograph and X-ray CT scanner, respectively. Especially, the CT scanner provides distribution pattern of gas bubbles as well as individual slices and 3D image of cored sediments [8].

The objectives of this study are to characterize compressional and shear wave velocity for gassy sediments obtained from the Jinhae Bay, Korea and to provide the preliminary results for the distribution pattern of gas in cored sediments.

II. Materials and Methods

One core sample containing gassy sediments was obtained from the center area of Jinhae Bay, Korea (Fig. 1). The core length is 4.7 m (Fig. 2).

Mean grain size of core sediment was analyzed by dry sieving for the sand-sized fraction and by a Sedigrph 5100 for the silt- and clay-sized fraction. The specimen's compressional wave velocity was measured with the pulse transmission technique [9]. The measurement system includes a pulse generator (Model: Tektronix TM 502A, PG 508/50 MHz), digital oscilloscope (Model: Tektronix TDS 3012), and a modified Hamilton Frame. The condition of the pulse generator was set as following: period= 0.2 ms (5 kHz), duration= 10 s, transition time= 50 s. A pair of piezoelectric transducers of 1 MHz was used for the driving signal.

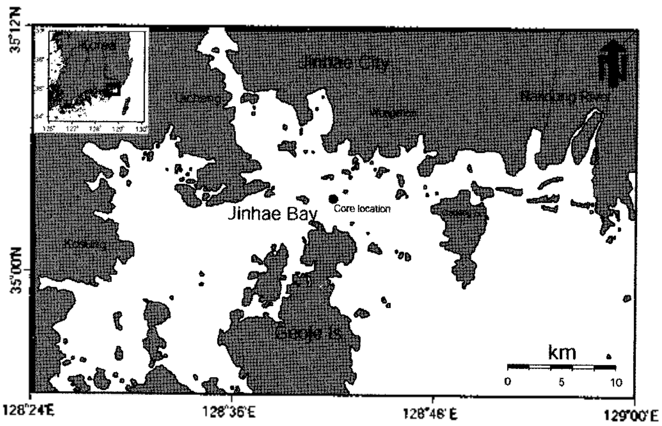

Fig. 1. Map showing physiography around Jinhae Bay, Korea. Solid circle is the location of core collected for this study. Water depth of core location is 17 m.

Shear wave velocity was also measured using a pulse transmission technique based on the Hamilton frame. A function generator (Model: Tektronix AFG 310) and oscilloscope (Model: Tektronix TDS 3012) were used to generate the transmitting pulse and receive the signals passed through sample. A duomorph ceramic bender transmitter and receiver, designed and constructed at the Naval Research Laboratory-Stennis Space Center [10, 11], was used to measure shear wave velocity. The transmitter was driven by a 10 V p-p pulsed sine wave. The driving frequency was set at 500 Hz.

Computed Tomography (CT) images of gassy core sediment were taken by high-resolution (to ~10 mm) HD-500 CT scanner at the Naval Research Laboratory, Stennis Space Center. The CT system is the most major equipment recently purchased at NRL. Subsample for CT scanning was prepared (Fig. 2). The dimension of the sample is approximately 15 cm in length and 8 cm in diameter, respectively. This work is preliminary study for investigation of the distribution pattern of gas in the

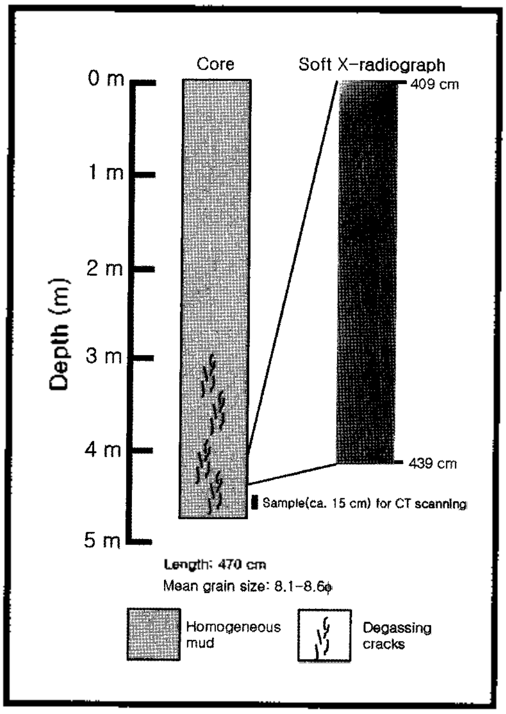

Fig. 2. Core lithology and soft X-radiograph of the core used for this study. Subsample for CT scanning is taken from the lower part of the core (Black column).

sediments. Thus, a detailed work for the distribution, shape, and size of gas bubbles will be proceeded in near future.

III. Results and Discussion

3.1. Sediment Characteristics

The sediments used for this study are composed of homogeneous (Fig. 2) and soft mud containing clay more than 50%. By soft X-radiograph, the sediments below 3 m depth are characterized by a lot of degassing cracks, caused by escape of gas after splitting of core (Fig. 2). The mean grain size is nearly constant with sediment depth (8.1-8.6ϕ) with some slight fluctuation (Fig. 3a), suggesting no significant change in the sedimentary processes and environments during deposition. This sediment pattern around the study area is well known from the previous reports [12][13][14]. According to these reports, the major source of sediment is probably the Nakdong River. The fine grained sediments discharged from the river are probably transported to the study area by the coastal and tidal currents [14].

3.2. Compressional (Vp) and Shear (Vs) Wave Velocity

Compressional wave velocities are relatively constant from the top to 320 cm depth, and then significantly decrease with depth except for the depth interval of 420 cm (Fig. 3b). Generally, compressional wave velocity for unconsolidated and soft marine sediments mostly depends on sediment texture (e.g., mean grain size) [1][10][11]. Thus the compressional wave velocity profile above 320 cm depth (Fig. 3b) is correlated well with the variation of mean grain size. This pattern is typical of saturated marine sediments. But, the dramatic fall in the compressional wave velocity below 320 cm depth can be attributed to gas replacing some of the pore fluid or degassing cracks caused by escape of gas. Therefore, in the case of gassy sediments, the compressional wave velocity can indicate the presence of gas [4][5][6][15]. Especially, the compressional wave velocity is highly sensitive to small volume changes in gas concentration [6][15]. Figure 4 shows the variation of the compressional wave velocity with increasing gas content. The speed calculations of Figure 4 are based on the Anderson and Hampton model. As shown in the Figure 4, very small concentrations of gas reduce compressional wave speed substantially. In this study, the volume fraction of gas was quantitatively measured much less than 1% [12]. According to Anderson et al. [5], gas bubbles in the sediments can be separated into three types as illustrated in the Figure 5. These bubble populations directly affect to acoustic properties through absorption and scattering reducing acoustic energy. The effect of gas bubbles to acoustic properties depends on acoustic frequency [6].

Shear wave velocity shows the ranges from ~50 to ~58 m/s (Fig. 3c). The value would rather high in the lower part containing gas than in the upper part of the core. These values are similar to those (50-60 m/s) of Richardson et al. [16] reported for a similar sediment

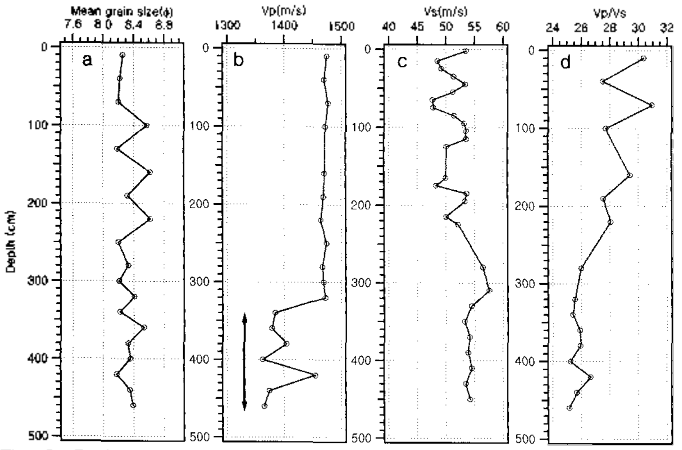

Fig. 3. Profiles of mean grain size and compressional and shear wave velocities. Arrow indicates gas charged zone. Note that compressional wave velocity (b) and Vp/Vs ratio (d) is significantly decreased below 310 cm depth.

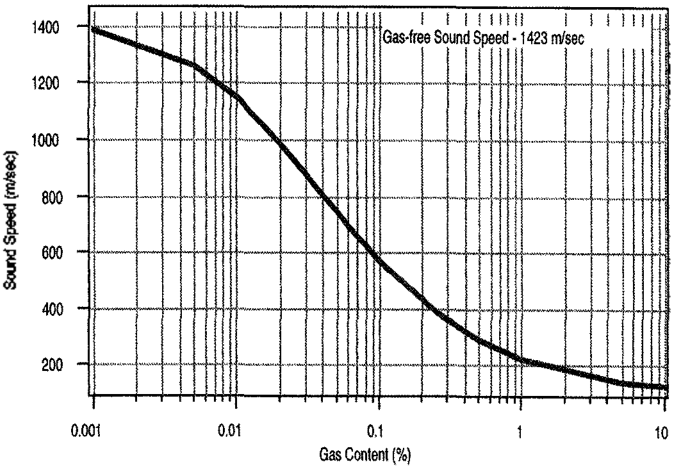

Fig. 4. Compressional wave speed as a function of free gas content (From Wilkens and Richardson, 1998).

type. Shear wave velocity is generally sensitive to the change of sediment frame by overburden pressure or compaction [15]. Thus, a detailed investigation for shear wave velocity variation in unconsolidated sediments can be used to examine the change of microstructure caused by diagenesis such as compaction and/or consolidation with burial depth. As a result, the sediments of the study area have been normally consolidated after deposition. In addition, our result suggests that shear wave velocity is much less sensitive to the presence of small amount of gas. This observation is good agreement with the previous reports [1][15].

3.3. Vp/Vs Ratio

Vp/Vs ratio in this study is high value (25 to 30)(Fig. 3d), compared to those (less than 3) of consolidated sediments and rocks [17][18][19]. If relatively high pore pressure is present, sand grains tend to go into suspension, shear strength fails, Vs decreases, and Vp/Vs ratio increases much greater than 45 [20]. While, Vp/Vs ratio decreases rapidly as a function of depth unless the grains are supported by high pore pressure. A similar pattern was observed by our result (Fig. 3d). On the other hand, presence of gas will also decrease Vp but Vs will remain unaffected and Vp/Vs will decrease. As shown in the Fig. 3d, our result strongly supports this pattern. Thus Vp/Vs, which increases with overpressure (burial depth) and decreases with gas saturation, can help differentiate between the two cases. As a result, Vp/Vs ratio can be used to estimate the lithology and/or the presence of gas in sediments and rocks.

Vp/Vs ratio versus compressional wave velocity is not correlated (Fig. 6a), due to low compressional wave velocity caused by gassy sediments. But shear wave velocity is correlated well with Vp/Vs (Fig. 6b).

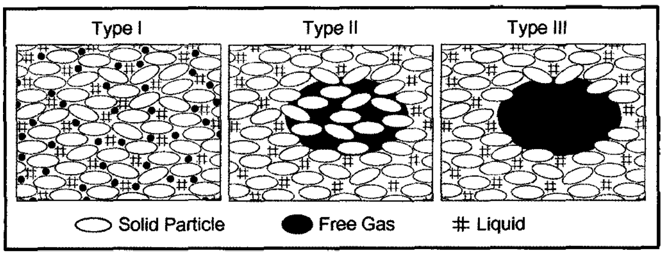

Fig. 5. Types of seafloor bubbles modified from Anderson et al., (1998). Type I, Interstitial bubbles. Type II, Reservoir bubbles. Type III, Sediment-displacing bubbles.

3.4. Investigation of Gas Bubbles

Computed Tomography (CT) was specifically designed for core imaging in the sediments. This system produces cross sectional CT images and digitized radiographs. In addition to density mapping, CT provides complete morphology of samples with highly accurate dimensioning capability. CT also provides superior detection capability of extremely small cracks, porosity and voids which are not visible with film radiography [21]. Thus in the case of gassy sediments, the dimension (e.g., size, scale, orientation, and volume) of gas bubbles can be identified through detailed investigation of cross section. Four images of Figure 7 are individual slices taken from whole core section of subsample (ca., 80 mm in diameter) using CT scanner at Naval Research Laboratory, Stennis Space Center, USA. The area of gas and/or empty space gradually increases from left to right. This suggests that

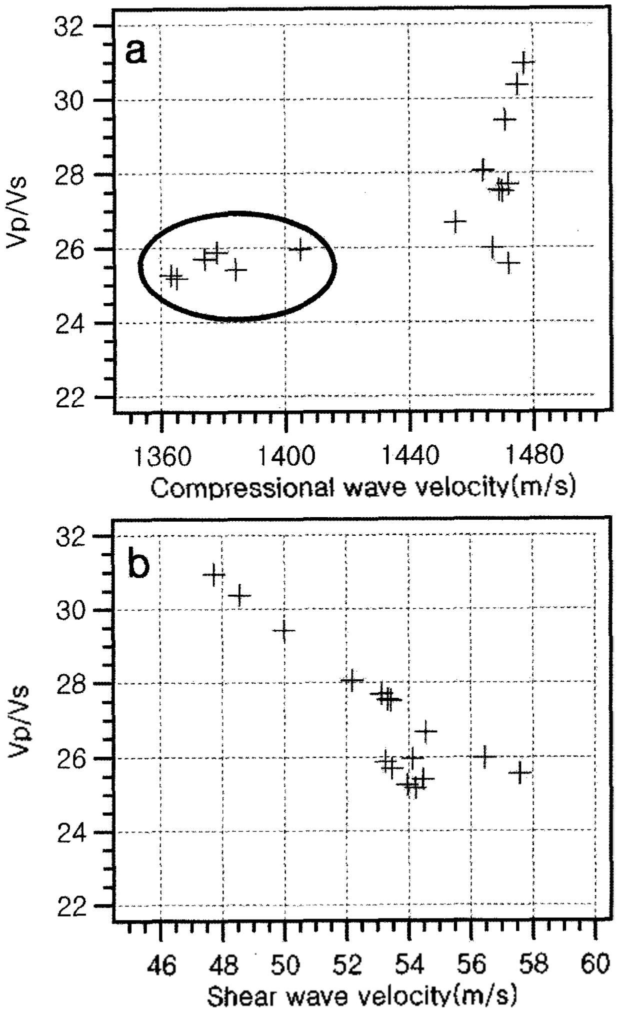

Fig. 6. Vp/Vs ratio versus compressional (a) and shear (b) wave velocities. Oval circle of Figure 6a indicates the data of gassy sediments. Note a good correlation of Figure 6b.

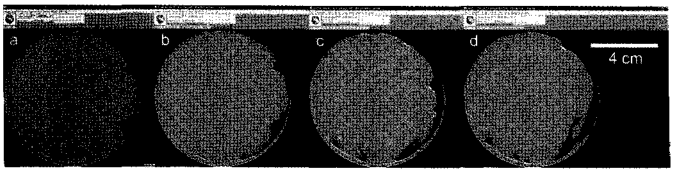

Fig. 7. Gas and/or empty space in cross section from gassy sediments collected from Jinhae Bay. Sample diameter is ~8 cm. Blue color means gas and/or empty space. The empty space including gas gradually increases from section a to section d. The gas was concentrated around inner edge of core liner.

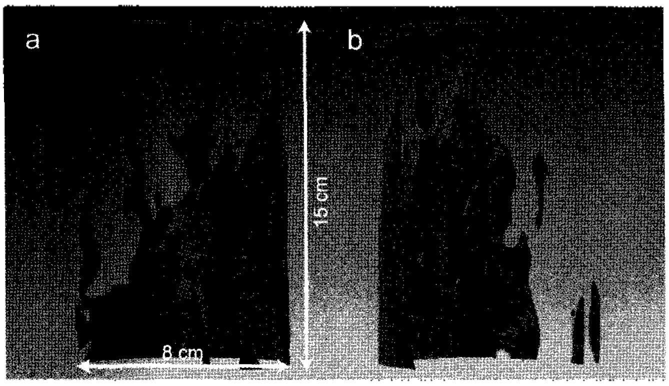

Fig. 8. 3D images of empty space including gas taken by HD-500 CT Scanner. Picture b was rotated by picture a. Vertical and horizontal lengths are approximately 15 and 8 cm, respectively.

the distribution pattern of gas is different from top to bottom of core sample. Figure 8 shows the images of whole core section (80 mm in diameter, 150 mm in length). The area colored by red color is the empty space not filled with sediments and/or filled with gas. Quantitative prediction of gas bubbles is not easy. First of all, gassy sediments should be collected under in situ condition (esp., in situ temperature and pressure). For this work, pressure core and sample tube should be needed to prevent escaping of gas within sediments when the gassy sediments are collected. Unfortunately, pressure core and sample tube was not used for this study. Thus, as shown in the Figures 7 and 8, most of the gas is likely to concentrate around inner edge of core liner. We carefully suggest that these CT images might be different from original pattern of gas bubble under in situ condition. These images are provided only as preliminary result for ongoing work. Further study is significantly needed.

IV. Conclusions

The cored sediments are composed of homogeneous and soft mud (mostly silt and clay) and uniform with depth. Compressional wave velocity of gassy sediments is significantly decreased from 1480 m/s to 1360 m/s, caused by a gas and/or degassing cracks. Shear wave velocity is not likely to relate the existence of gas in this study only. The Vp/Vs ratio is decreased in gas charged zone and is well correlated with shear wave velocity. This result suggests that low concentrations of gas are not affect to shear wave velocity. By CT images, most of the gas in the sediments is concentrated around inner edge of core liner. This result is not likely to provide the original pattern of gas bubbles. Thus, for the detailed characterization of gas bubbles within sediments, further study needs.

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