Applied Ocean Research 39 (2012) 131–136

Contents lists available at SciVerse ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

Seabed sediment classification in the northern South China Sea using inversion method

Hong-bo Zheng[a,b,*], Pin Yan[a], Jing Chen[c], Yan-lin Wang[a]

[a] CAS Key Laboratory of Marginal Sea Geology, South China Sea Institute of Oceanology, Guangzhou, China
[b] State Key Laboratory of Acoustic, Chinese Academy of Sciences, Beijing, China
[c] South China Sea Marine Engineering Surveying Center, SOA, Guangzhou, China

ARTICLE INFO

Article history:
Received 8 March 2012
Received in revised form 5 November 2012
Accepted 5 November 2012

Keywords:
Continental slope of the northern South China Sea
Sub-bottom profile data
Seabed sediment
Sediment classification
Inversion method

ABSTRACT

Sub-bottom profile data can be used not only for the interpretation of the seabed strata structure and formation, but also for seabed sediments classification using inversion method. In the present paper, sub-bottom profile data from a survey line located on the continental slope of the northern South China Sea were processed. The data collected were used to calculate seabed reflection coefficient and attenuation rolloff, while sediment acoustic characteristics parameters, including porosity and permeability, were defined based on the Biot model that calculates wave propagation in sediment–fluid mixtures. Finally, the mean grain sizes and corresponding sediment classification were quantitatively estimated. By comparing the inversion result with sediment description of gravity piston cores which were acquired near the survey line, we found that the results from inversion method accord with the particle size analysis of sediment cores. However, the inversion method is only suitable for the soft seabed sediments such as mud or sand. The petrous sediment in the survey is classified by Gardner formula and we concluded the petrous seabed sediments are carbonate crusts which are generated from leaky gas hydrate.

1. Introduction

Seabed sediment classification method is an important research content in marine geology, marine military, marine fisheries, underwater communications and other research areas. At present seabed sediment classification methods include direct and indirect methods. Direct method contains in situ measurements and laboratory measurements [1,2]. Because of low efficiency and high cost, the direct method is not suitable for large-scale seabed sediment classification surveying. Indirect method is a remote acoustic measurement which is carried out by acoustic detection devices such as multi-beam system, side-scan and sub-bottom profile. The indirect method has always become the primary seabed sediment classification in actual marine surveying.

Three kinds of remote acoustic seabed sediment classification methods are currently applied [3]: (1) the characteristics of the echo signal statistical classification; (2) image texture classification; (3) submarine acoustic parameters inversion. The principle of the first two classification methods is similar. The charactertics parameters of benthic reflection signal are extracted from the acquired data based on statistics; sediment classification can be estimated using these statistical characteristic parameters and information from known sediments. There is much interrelated research about the two methods [47], and both are adopted by the most commercial software for seabed sediment classification, such as Norway Simrad's submarine sediment classification software Triton, Canada's Quester Tangent's seabed sediment classification software QTC VIEW, ASCS (Acoustic Seafloor Classification System) of the America NOARL company. The third method is based on reasonable seabed sediment model. The mean grain size of seabed sediment can be quantitatively computed using the method. Therefore, the inversion method is more direct and credible than other two methods. At present, the method has been regarded by a few researchers [8,9], but the related applications in China are rare.

High-resolution Chirp sonar data were acquired from the continental slope of the northern South China Sea (SCS) by the Guangzhou Center for Gas hydrate Research of Chinese Academy of Sciences in April 2008. Meanwhile, gravity piston sediment cores have been collected. Fig. 1 shows the location of sub-bottom profile survey lines and the sites of gravity cores. This study attempts to apply the inversion method for seabed sediment classification using Chirp sonar data, and compare the result with direct method.

* Corresponding author at: CAS Key Laboratory of Marginal Sea Geology, South China Sea Institute of Oceanology, Guangzhou, China. Tel.: +86 20 34066181.
E-mail address: hongbozheng@126.com (Hong-bo Zheng).

0141-1187/$ - see front matter
http://dx.doi.org/10.1016/j.apor.2012.11.002

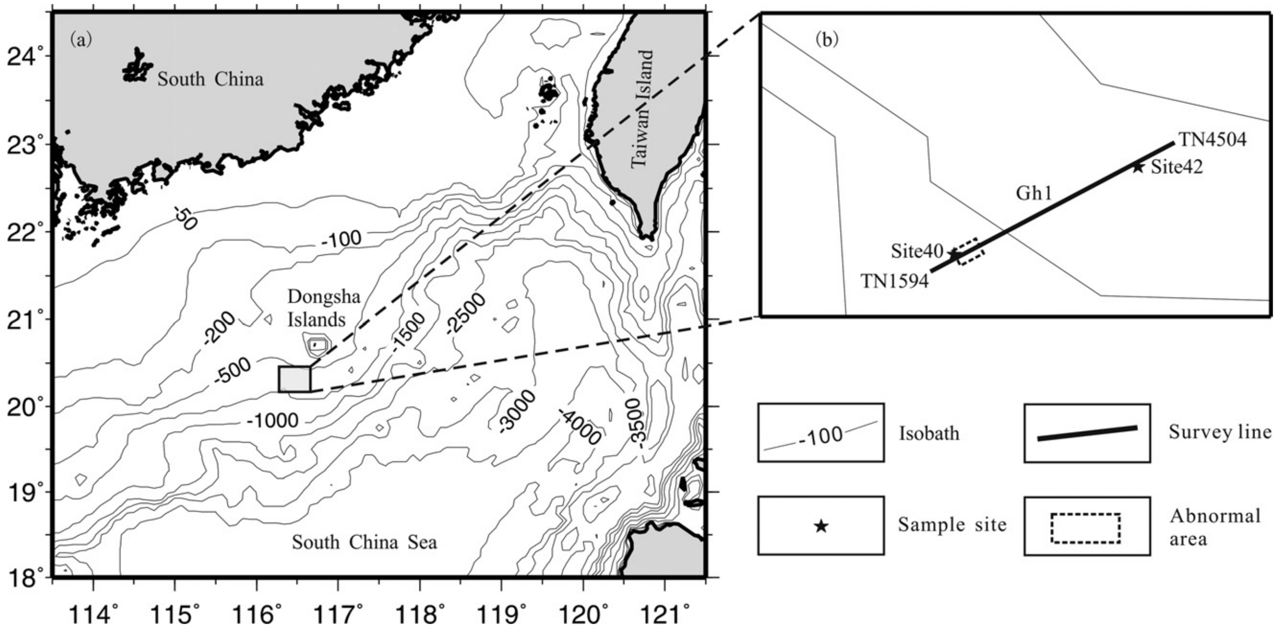

Fig. 1. (a) Map of SCS indicating the location of marine survey in 2008 with a black box and (b) expanded view of the box in (a) showing locations of sub-bottom profile survey line Gh1 and the sites of gravity cores 40 and 42. The dashed box shows the abnormal area.

2. Methods

Seabed sediment is typical fluid–solid two-phase medium which consists of porous solid frame generated by deposition of particle mineral and pore-water filled in the frame. Sound wave propagation theory can be used for the description of sound transmission in the two-phase mixture of the fully saturated sediment of the seabed. Acoustic impedance and acoustic attenuation coefficients are the most important acoustic parameters for sediments; other physical parameters are closely related to them. Biot assumed solid frame as an elastomeric substance and pore-water as a compressible fluid, considered the affection for elastic wave propagation characteristics of the relative movement between the fluid and solid, then confirmed the movement leading to elastic wave attenuation in the two-phase medium and corrected fluid viscosity factor to dynamic viscosity factor on high-frequency. Finally, Biot established the elastic wave equation of fluid–solid two-phase medium including the displacement of the fluid–solid medium [10,11].

Biot model is an idealized model mainly based on a set of assumptions: (1) the wavelength is much larger than the size of model elements (solid particles, porosity); (2) the particle movement of the solids and fluid is small; (3) fluid is continuous and the pores are interconnected, non-communicating pores are part of the solid; (4) solid frame is considered as uniform and isotropic; (5) fluid flow in the pores is of the Poiseuille flow, relative movement exists between the pore-water and solid frame and the fluid flow by Darcy's law; (6) the thermal effects caused by energy dissipation can be neglected when the elastic waves propagate and there is no chemical reaction between the pore fluid and the solid frame; (7) the scattering and gravity effect will be negligible. Therefore, the wave equation of model is given by

$$\nabla^2(He - C\zeta) = \frac{\partial^2}{\partial t^2}(\rho e - \rho_f \zeta) \tag{1}$$

$$\nabla^2(Ce - M\zeta) = \frac{\partial^2}{\partial t^2}(\rho_f e - m\zeta) - \frac{F\eta}{k}\frac{\partial \zeta}{\partial t} \tag{2}$$

where ρ_f is the fluid density; η is the fluid viscosity; k is the frame dynamic permeability; ρ_r is the grain density of sediment; e is the volumetric strain of frame; ζ is the incremental volume of fluid that enters or leaves the frame; ρ is the bulk density of sediment; $m = \rho_f/\varphi$ account for the phase of fluid flow with respect to the macroscopic pressure gradient; t is the time of sound wave propagation in the medium; F is a complex correction factor of fluid viscosity. D, M, H and C are the elastic parameters. $D = K_r(1 + (K_r/K_f)\ \varphi)$, $H = (K_r - K_b)^2/(D - K_b) + K_b + (4/3)\mu$, $C = K_r(K_r - K_b)/(D - K_b)$, $M = K_r^2/(D - K_b)$; K_r is the grain bulk modulus; K_f is the modulus of the pore fluid; φ is the porosity; K_b is the frame bulk modulus; μ is the frame shear modulus. Stoll develops the following expression for a harmonic plane wave traveling through a porous medium based on Biot theory [12]:

$$\begin{vmatrix} Hk^2 - \rho\omega^2 & \rho_f\omega^2 - Ck^2 \\ Ck^2 - \rho_f\omega^2 & m\omega^2 - Mk^2 - j\dfrac{\omega F\eta}{\kappa} \end{vmatrix} = 0 \tag{3}$$

The expression for wavenumbers of fast and slow wave can be deduced from Eq. (3). As $k = k_r - j\alpha$, imaginary component of k is attenuation, real component is $k_r = \omega\ /\ v$, where v is the phase velocity of the traveling wave and ω is the angle velocity. The phase velocity for fast wave can be calculated by the fast wavenumbers.

When vertically incident sound waves propagate through sediment–water interface, the following boundary conditions will be applied: (1) continuity of fluid displaced in and out of the skeletal frame in a direction normal to the interface; (2) equilibrium of total stress across the interface; (3) equilibrium of fluid pressure across the interface. The following equations can be deduced by the boundary conditions:

$$\frac{D_r}{D_i} + (G_1 - 1)\frac{A_1}{D_i} + (G_2 - 1)\frac{A_2}{D_i} = -1$$

$$\rho_\omega c_\omega \omega\frac{D_r}{D_i} + (Hk_1 - Ck_1G_1)\frac{A_1}{D_i} + (Hk_2 - Ck_2G_2)\frac{A_2}{D_i} = \rho_\omega c_\omega \omega$$

$$-\rho_\omega c_\omega \omega\frac{D_r}{D_i} + (Mk_1G_1 - Ck_1)\frac{A_1}{D_i} + (Mk_2G_2 - Ck_2)\frac{A_2}{D_i} = \rho_\omega c_\omega \omega$$

In these expressions, D_i and D_r are the displacement amplitudes of the incident and reflected waves, respectively; A_1 and A_2 are the displacement amplitudes of the sediment frame fast and slow wave