Journal of Asian Earth Sciences 89 (2014) 46–53

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Distributions and vertical variation patterns of sound speed of surface sediments in South China Sea

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ARTICLE INFO

Article history:
Received 25 December 2013
Received in revised form 24 March 2014
Accepted 31 March 2014
Available online 12 April 2014

Keywords:
Distributions of sound speed
Vertical variation patterns
Surface sediments
Physical properties

ABSTRACT

The distributions of sound speed show different characteristics in continental shelf, continental slope and Nansha Trough. The differences have closely related to the distributions of sediment physical properties in the southern South China Sea. According to the analysis of sound speeds and physical properties variation characteristics with buried depth, the vertical variations of sound speed are closely related to sediment texture, sedimentary environment, transport, erosion, compaction, consolidation, etc. The comparison results indicate 3 vertical variation patterns of sound speed: increasing model, invariant model and complicate variation model. The above 3 variation models represent the vertical distribution characteristics of sound speed in different depositional environments. Different variation patterns have different key factors which generally contain porosity or grain size. The calculated sound speeds with Buckingham's theory of compressional waves in fluid-like marine sediments follows the trend of measured speeds accurately.

1. Introduction

As the gas–liquid–solid three-phase medium, the seafloor surface sediments mainly consist of sand, silt, clay and pore-fluid. The sediments are unconsolidated, saturated material that consists of a more or less loose assemblage of mineral grains in contact, with seawater in the interstices. Sediment is postulated that the two-phase medium possesses no skeletal frame, implying that the elastic rigidity modulus of the material is zero (Buckingham, 1998). The common physical parameters of sediments include grain size, wet density, bulk modulus, porosity and water content (Hamilton, 1980; Stoll and Bautista, 1998). The semi-consolidation degree and seawater-contained pores determine the geo-acoustic properties. Some regression equations have been established between the compressional wave speed (hereafter called "sound speed") and physical parameters of the sediments in the continental terrace, abyssal plains and abyssal hills, respectively (Briggs et al., 1985; Briggs and Richardson, 1997; Richardson et al., 1997; Buckingham and Richardson, 2002; Fu et al., 2004; Robb et al., 2006; Lu et al., 2010; Liu et al., 2013). Theory of compressional waves in fluid-like marine sediments was developed, and is combined with a model of the physical properties to yield expressions relating the compressional wave speeds to the porosity, grain size and the density of the medium (Buckingham, 1997, 1998). Although these single parameter models can reflect the impact of a particular physical parameter on sound speed and the variation trends other parts of the world ocean (Orsi and Dunn, 1990), they cannot be used to explain the impact of complex depositional environment on sound speed.

According to the vertical variation of sound speed in different geomorphic units, Hamilton established the typical speed model for the shallow continental shelf and speed model for the abyssal hills and abyssal plain (Hamilton, 1985). Some researchers investigated the vertical variation of sound speed and physical properties by means of sampling and in situ measurements (Richardson and Briggs, 1996; Bowles, 1997; Best and Gunn, 1999; Brandes et al., 2001; Best et al., 2001; Gorgas et al., 2002, 2003; Lu et al., 2003; Kim and Kim, 2001; Kim et al., 2011). These studies are based on the assumption that sediments within the buried depth of several meters or dozens of meters in the shallow seas. Thereby, the specific research results cannot be applied in different study areas, and are less meaningful for the acoustic research of surface sediments in the complex depositional area.

In the southern South China Sea, the complex depositional environments, including continental shelf, continental slope and Nansha Trough, determine the relationship between physical properties and buried depth of sediments. Thereby, the variation

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http://dx.doi.org/10.1016/j.jseaes.2014.03.026
1367-9120/

of sound speed shows various features. Based on the measurements on 100-cm seafloor sediments, the variation of physical parameters and the distribution of sound speeds can be obtained. Vertical variation patterns of sound speed can be established for different sedimentary geomorphic units.

2. Study area and methods

2.1. Study area

The southern South China Sea and experimental stations were mapped in Fig. 1. The study area is located in the south of the central Spratly Islands (4°N–8°N and 110°E–116°E). The marine geological environment is the typical marine geological environment. The topography of this study area is complex with the gradually decreasing altitude from south to north and there are three main topographies: the continental shelf, the continental slope, and the trough. The continental shelf accounts for 17.2% of the area and is in the water depth of less than 150 m. The continental slope and trough accounts for 77.6% of the area and is in the water depth of 150–3800 m. The basin accounts for 5.2% of the area and is in the water depth of more than 3800 m.

2.2. Data collection and methods

The 21 sediment gravity cores have been collected and each core is 100 cm long. Sound speed was measured with WSD-3 digital acoustic instrument. The measurement parameters include initial measurement length of 100 cm, measurement interval of 15 cm, measurement frequency of 100 kHz, single channel sampling length 1024 points and sampling interval 1 μs. The measurement method was called coaxial differential distance measurement method. After the whole 100 cm core was measured, 15 cm sample was cut from the top of the columnar sample. Then the rest 85 cm core was measured again. Repeat the above steps until the columnar sample was only 10 cm long. After each core was measured, 7 sound wave signals would be received and 6 sound speeds at different buried depth could be obtained. An example of 7 sound wave signals recorded from the different core lengths was presented in Fig. 2. From the record results and the normalization processing, the amplitude scales of wave signals were obtained. Thus, the amplitude scales in Fig. 2 are between 1 and −1. After small sample was taken at the bottom of different lengths cores, the wet weight of sediment sample was measured on the deck. The physical parameters of bottom samples would represent the entire 15 cm section. All the other sediments physical parameters are measured in the laboratory under the conditions of atmospheric pressure and 23 °C. Mean grain size was measured with the Cilas 940L granulometry in the Key Laboratory of Marine Geology and Environment, Institute of Oceanology Chinese Academy of Sciences (IOCAS).

3. Measurement results

3.1. Horizontal distribution of sound speed and physical parameters

Horizontal distribution of sound speed has been mapped in Fig. 3. The sound speed is the average value of every 1 m core. The continental shelf area in the southwest has larger sound speed than 1480 m/s. However, the continental slope and Nansha Trough are the low-speed zones: sound speed is below 1480 m/s and sound speed in most of the area is less than 1450 m/s. The sediments in slope and trough show lower speed value than that of the North Pacific sediments from Hamilton's geo-acoustic model (Hamilton, 1970).

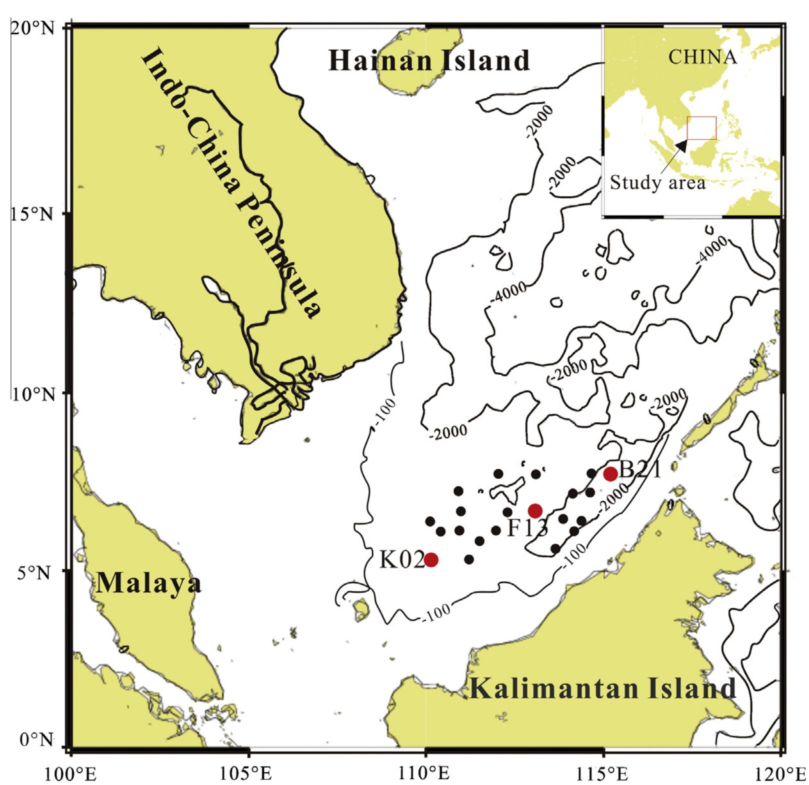

Fig. 1. 21 Experimental stations in the southern South China Sea (black and red dots). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)