Marine and Petroleum Geology 52 (2014) 1–8

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Acoustic response of gas hydrate formation in sediments from South China Sea

Gaowei Hu [a,b,c], Yuguang Ye [b,c,*], Jian Zhang [b,c], Changling Liu [b,c], Qing Li [c]

[a] Key Laboratory of Marine Hydrocarbon Resources and Environmental Geology, Ministry of Land and Resources, Qingdao, Shandong 266071, China
[b] The Key Laboratory of Gas Hydrate, Ministry of Land and Resources, Qingdao, Shandong 266071, China
[c] Qingdao Institute of Marine Geology, Qingdao, Shandong 266071, China

ARTICLE INFO

Article history:
Received 28 February 2013
Received in revised form
19 December 2013
Accepted 13 January 2014
Available online 21 January 2014

Keywords:
Gas hydrate
South China Sea (SCS)
Acoustic response
Bender element
Time domain reflectometry (TDR)

ABSTRACT

Gas hydrate has been recognized as a potential energy resource in South China Sea (SCS). Understanding the acoustic response of gas hydrate formation in the SCS sediments is essential for regional gas hydrate investigation and quantification. The sediments were obtained from gravity core sampling at E 115°12.52363′ N 19°48.40299′. Gas hydrate was formed within a "gas + water-saturated SCS sediments" system. Combination of a new bender element technique and coated time domain reflectometry (TDR) was carried out to study the acoustic response of hydrate occurrence in SCS sediments. The results show the acoustic signal becomes weak when hydrate saturation (S_h) is lower than 14%. The acoustic velocities (Vp, Vs) of the sediments increase with S_h during hydrate formation, and Vs increases relatively faster when S_h is higher than 14%. These results indicate that tiny hydrate particles may firstly float in the pore fluid, which causes a significant acoustic attenuation, but has little influence on shear modulus. As time lapses and S_h approaches 14%, numerous particles coalesce together and contact with sediment particles. As a result, Vs has a sharp increase when hydrate saturation exceeds 14%. Several velocity models were validated with the experimental data, which suggests a combination of the BGTL (Biot–Gassmann Theory modified by Lee) model and the Weighted Equation is suitable to estimate S_h in SCS.

1. Introduction

Gas hydrates exhibit relatively high elastic velocities (both Vp and Vs) compared to either gas or water; thus the velocity of gas hydrate-bearing sediments (GHBS) is usually elevated (Holbrook et al., 1996; Waite et al., 2009; Pecher et al., 2010). Many velocity models have been constructed to reveal the potential relationship between elastic velocities and hydrate saturation (S_h) of GHBS (e.g., Helgerud et al., 1999; Lee et al., 1996; Lee, 2002; Lee and Waite, 2008; Sava and Hardage, 2009; Lee et al., 2012), which could provide better constrains on the estimation of gas hydrate resources from seismic data. Unfortunately, as there is rarely observed data on both S_h and acoustic properties of the hydrate-bearing sediments, it's difficult to validate these models, or to choose a suitable model and model parameters for S_h estimation. As a result, velocity models were rarely used as a tool to estimate the gas hydrate saturation on board during field explorations. For example, during China's first gas hydrate drilling expedition in South China Sea (SCS) (Zhang et al., 2007; Wu et al., 2007), S_h was estimated with electrical resistivity data and pore water data (J. A. Lu et al., 2008; Wu et al., 2011), velocity models were only discussed in post-expedition reports (Wang et al., 2011). More detailed research on acoustic response of gas hydrate formation in sediment from gas hydrate reservoir is needed.

Laboratory data relating S_h with acoustic velocities of marine GHBS are commonly focused on artificial materials (Priest et al., 2005; Ye et al., 2008; Hu et al., 2010a). Although there are also acoustic data measured on sediments recovered from gas hydrate reservoir, it rarely has measured S_h data (Winters et al., 2007), or tetrahydrofuran is substituted used for methane as the hydrate former (e.g. Lee et al., 2008). Consequently, the relations between gas hydrate saturation and acoustic properties of the recovered samples were rarely revealed, which is commonly attributed to the difficulties in real-time detecting of S_h during hydrate formation (Wright et al., 2002), and in measuring both Vp and Vs of the GHBS simultaneously in one system (especially when the system has a relatively high pressure). Also, it's hard to get a unique model in most gas hydrate reservoirs as hydrate may occur in various types such as in massive veins, massive nodules and in fractures. However, the distribution of gas hydrate in the Shenhu region, SCS, is

* Corresponding author. Qingdao Institute of Marine Geology, Qingdao, Shandong 266071, China. Tel.: +86 532 85755850; fax: +86 532 85771905.
E-mail addresses: hgw-623@163.com (G. Hu), yeyug@public.qd.sd.cn (Y. Ye).

0264-8172/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpetgeo.2014.01.007

interpreted to be as evenly disseminated pore-fill, which is well-suited to test the assumptions and predictions, at various scales, of some gas hydrate models (Schultheiss et al., 2009).

Our previous work (e.g., Hu et al., 2010a) was mainly focused on the acoustic responses of gas hydrate formation in artificial sediments, which could provide basic information, but as the consolidated sediment core is made of mullite with very high modulus, it's not fully representative of natural sediments and the results may not directly used in field gas hydrate exploration. In recent years, we developed techniques both on acoustic measurement (Hu et al., 2012a) and hydrate saturation measurement (i.e. coated time domain reflectometry, TDR (Hu et al., 2010b)), which enabled us to measure Vp, Vs and hydrate saturation during gas hydrate formation in samples recovered from SCS gas hydrate reservoirs. This work presents our latest laboratory research results regarding to the acoustic response of gas hydrate formation in sediments from SCS. The results reveal the acoustic responses (i.e. acoustic signal and velocities) of the SCS sediments during gas hydrate formation. Moreover, the obtained relationship between hydrate saturation and acoustic velocities provides an approach to validate previous velocity models, which could give suggestions on field gas hydrate exploration and quantification in SCS.

2. Experimental

2.1. Experimental setup

The apparatus consists of five functioning units (Fig. 1): (1) A high-pressure vessel with a plastic inner barrel for simulating in situ pressure and temperature, in which there are two platinum (Pt100) resistance thermometers with precision of ±0.1 °C used for measuring the temperature of inner of the sample and surface of the sample. (2) a vessel containing a magnetic stirrer used for making gas-saturated water, (3) a gas compressor and a pressure transducer (precision, ±0.1 MPa) responsible for gas pressure control, (4) a cooling system for temperature control, and (5) a computer system for measuring and logging data. For detailed information of the apparatus see the paper (Hu et al., 2010a).

2.2. Origin and properties of host sediment

Sediments were recovered via gravity core sampling by Guangzhou Marine Geology Survey (GMGS) from Shenhu area, SCS (Fig. 2). The detailed geological background of the gas hydrate system in this area has been described by (Wang et al., 2011). The location of the core in this study is E 115°12.52363′ N 19°48.40299′, the water depth is 1554 m and the sampling depth is 4.14–5.14 mbsf. Although no hydrate is found in the sediments, from Figure 2 we can see that the sampling position is close to the sites where hydrates have been obtained. The mineralogy of the sediments from Gas-hydrate Drilling Sites has been reported by Lu et al. (2009) and Wang et al. (2011), which show the sediments are consist of detrital minerals, clay and biocarbonate. Detrital minerals mainly include quartz, mica plagioclase and orthoclase, while clay minerals comprise illite, smectite, chlorite and kaolinite. The XRD analysis shows the samples in this study are consist of illite 17.3%, chlorite 2.6%, kaolinite 1.0%, quartz 23.6%, orthoclase 4.2%, plagioclase feldspar 6.5%, calcite 43.7% and dolomite 1.1%. A comparison of sediment constituents of sediments in this study and that from SCS Drilling Site SH2 are given in Figure 3a. The results show that the lithology of the samples used in this study has a similar nature to those in SH2. Porosity estimates derived from recovered cores is 40.24%, and the particle sizes of the sediments are distributed as: 0.02 μm–3.91 μm (9.24%), 3.91 μm–62.50 μm (48.70%), 62.50 μm–2000.00 μm (42.06%), which is similar to particle size of SH2 samples (by Liu et al. 2012), whose samples were gas-hydrate bearing sediments recovered from SH2 (Fig. 3b). According to the above evidences, the sediment used in this study can be treated as a representative sample of SCS gas hydrate reservoir.

Because fine-grained sediments may restrain hydrate formation (Wang et al., 2007), the sample was first frozen and then melting under high pressure methane gas to enhance the gas hydrate formation rate (Priest et al., 2005; Winters et al., 2007; Hu, 2010) in the first run of hydrate formation (we don't use data of this run as the process can't be a representative hydrate formation process in nature). In the next 13 runs of experiments, hydrate formed under ~7.5 MPa and ~2 °C to simulate the hydrate formation process in nature and we use data obtained in these runs to construct a relation between S_h and Vp, Vs. In the experiment, pure methane

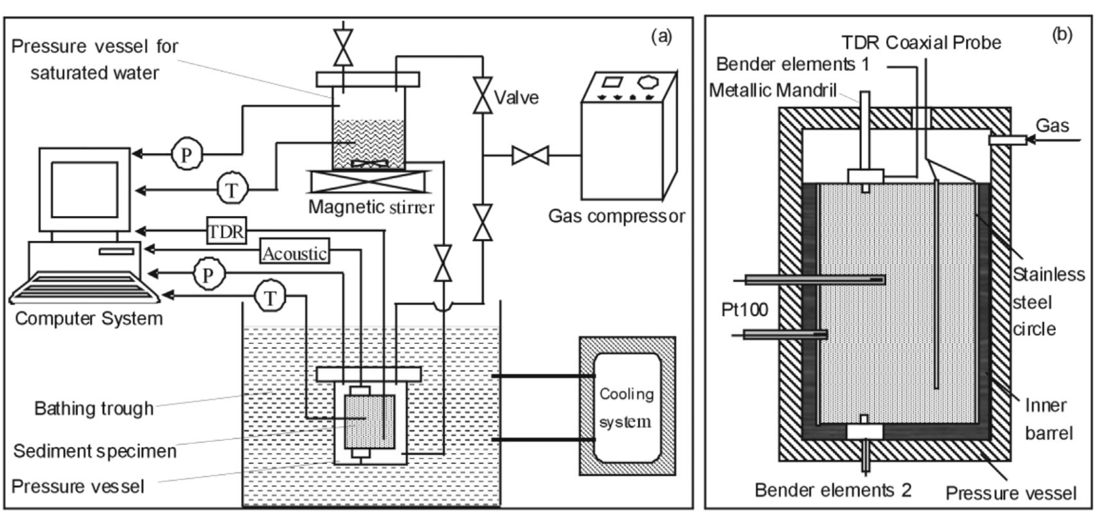

Figure 1. a) Experimental apparatus for research acoustic properties of hydrate bearing sediments. b) Cross section through the high pressure vessel. The metallic mandril is used to press the bender element transducers, so that they can cling to each end of the cylindrical unconsolidated sediments. A single coated probe and a stainless steel circle around the cylindrical core are two poles of the TDR coaxial probe. Two Pt100 resistance thermometers measure the surface and inner of the sample, respectively. Gas is introduced directly into the vessel and measured by a pressure transducer out of the vessel. Revised from Hu et al. (2010a).