Compressional wave velocity measurements through sandy sediments containing methane hydrate

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ABSTRACT

An experimental apparatus was built to measure P-wave velocity \( (v_p) \) of sandy sediment during hydrate formation from brine and free methane gas. The influences of hydrate saturation, initial brine saturation, conversion ratio of water to hydrate, and grain size of sand upon \( v_p \) were investigated. The experimental results demonstrate that \( v_p \) strongly depends on both hydrate saturation and initial brine saturation, whereas the influence of the grain size of sand is unremarkable. During the formation of hydrate for different experimental runs at identical initial brine saturation, \( v_p \) increases with the increase of hydrate saturation; while it decreases dramatically with the increase of initial brine saturation for a given hydrate saturation. The correlation between \( v_p \) and conversion ratio of water into hydrate was studied, and it was found that the relation between \( v_p \) and the conversion ratio of water to hydrate is approximately the same for different experimental runs, regardless of how big the differences in initial saturation of brine and the size of sand grain are. \( v_p \) was calculated for four different hydrate distribution models. The results suggest that low conversion ratio of water to hydrate, hydrate mainly acts as a load component of a dry frame matrix, whereas at higher conversion ratio of water to hydrate it partly acts as a cement that coats grains at grain contacts, and thereby leads to a dramatic increase in \( v_p \). Compared with the hydrate saturation, the conversion ratio of water to hydrate has a large role in distributing hydrate in the pores of sediments.

Keywords: Methane hydrate, sediments, P-wave velocity, hydrate saturation

INTRODUCTION

Gas hydrate forms from gas and water with nonstoichiometric compositions under relatively low-temperature and high-pressure conditions (Sloan 2003). Many natural gas hydrate-bearing sediments were found in deep marine sediments and permafrost soils and could serve as a potential future global energy resource (Pearson et al. 1983). Natural gas hydrate is mainly identified through seismic prospecting methods (Lee et al. 1996). It is generally believed that naturally occurring hydrates act as part of the sediment framework rather than inter-granular cement (Winters et al. 2004). Its presence decreases the porosity of a sediment, and thereby changes the sediment’s geophysical characteristics such as electrical conductivity, density, elastic wave velocity, and the shear strength (Lee and Collett 2009; Vanneste et al. 2001; Waite et al. 2004; Winters et al. 2007). It is therefore important to establish the relationship between the geophysical characteristics and the properties of hydrate-bearing sediments, such as hydrate saturation, brine saturation, and grain size of sediments.

Acoustic P-wave velocities \( (v_p) \) are generally considered to be an effective way to detect hydrate-bearing sediments because of their penetration (Berge et al. 1999; Dvorkin and Prasad 1999; Carcione and Gei 2004; Waite et al. 2004; Winters et al. 2004). The acoustic wave velocity is an important geophysical property, which can give information about lithology, saturation, and in situ specific characteristic of sediments (Carcione and Gei 2004). Measurements of acoustic wave velocities in the laboratory can provide an important basis for the geological interpretation of seismic data (Zillmer 2006). In addition, P-wave velocities show large differences between cemented rocks and unconsolidated sands, with \( v_p \) of the latter being much smaller than for cemented rocks. Acoustic wave velocities are also affected by the cementation of sediment though the formation of hydrate within unconsolidated sand (Waite et al. 2004). The value of \( v_p \) can therefore be used to examine the spatial hydrate distribution for hydrate-bearing sediments.

To measure acoustic velocities of simulated natural gas hydrates, Pearson et al. (1986) formed hydrate-bearing sediments with a mixture of tetrahydrofuran and water within porous samples. As hydrate forms in the pores, the \( v_p \) of the sediment increases rapidly from 2500 to 4500 m/s and 1400 to 5000 m/s (with a measurement deviation of nearly 5%) for Berea sandstone and Austin chalk samples, respectively. But it soon approaches a limiting value, which was thought to be related to the porosity of the samples (Pearson et al. 1986). Acoustic laboratory measurements on CCl₄F hydrate-bearing sand were also