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Attenuation effects on the seismic response of a bottom-simulating reflector

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A B S T R A C T

Bottom simulation reflectors (BSR) are seismic events generally corresponding to a partially saturated layer with gas separating hydrate-bearing sediments from brine-saturated sediments. Seismic attenuation and velocity dispersion affects the waveform of the BSR event. In this work, we consider a 1D methodology to study the effects of seismic *Q*, velocity dispersion, layer thickness and properties and characteristics of the overburden on the reflection coefficients and waveform of such event. We describe the media by using a rock-physics model based on poroelasticity, calculate the reflection coefficient of the BSR layer of varying thickness and compute the waveforms with a full-wave pseudospectral method. The proposed rock-physics/modeling methodology is fast in terms of computer requirements and can be used to quantify the seismic properties and compute waveforms useful for seismic interpretation and inversion of quantities such as porosity, hydrate content, gas saturation, clay content and thickness of the BSR layer. We show that in many cases the interpretation can be counterintuitive and a proper rock-physics methodology is essential to reach valid conclusions about the influence of the different parameters on the wave properties.

1. Introduction

Gas hydrates may represent an important source of fuel energy (e.g., Makogon, 2010). The most common detection and quantification technique is seismic surveying. Bottom simulating reflectors on seismic profiles are interpreted to represent the seismic signature of the base of gas hydrate formations overlying a layer partially saturated with free gas. It is observed that the seismic response of the BSR is characterised by low frequencies, called the "low frequency shadow" by Taylor et al. (2000) (see also Geletti and Busetti, 2011). The shift to low frequencies is interpreted as attenuation due to partial saturation with free gas (e.g., Vanneste et al., 2001). However, some caution is required since the presence of low frequencies may be due to other causes, such as NMO stretching, which is important at far offset traces (Dunkin and Levin, 1973). This effect will be investigated in a future work. Here, we focus on intrinsic attenuation by using a 1D model, keeping the description of the physics, while providing a fast and efficient tool for seismic interpretation. Scattering attenuation is not taken into account, since it is important at high (sonic-log) frequencies.

Recently, Dewangan et al. (2014) analysed the effect of gas hydrate and free gas on seismic attenuation. The zones of gas hydrate, identified by the increase in seismic velocity, show high quality factors (*Q*), a result that agrees with the rock-physics models proposed by Carcione and Tinivella (2000), Gei and Carcione (2003), Carcione and Gei (2004) and Carcione et al. (2005a), and with the experimental results in Rossi et al. (2007). On the other hand, they show that the presence of free gas within the gas hydrate stability zone increases seismic attenuation.

In this work, we study the normal-incidence reflection coefficient of a layer as a function of the layer thickness and quality factor and perform numerical simulation of transient wavefields to obtain the seismic events. The modeling is based on a spectrum of relaxation mechanisms and the differential equations are solved in the space-time domain by using a direct method based on the Fourier

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pseudospectral method (e.g., Carcione, 2015). The media are described by a poroelastic model based on a generalisation of Gassmann equation. In particular, the upper medium containing gas hydrates is a sediment whose skeleton has three phases, namely, quartz, clay and gas hydrate, forming three frames. The model describes also the BSR layer partially saturated with gas as a particular case. To quantify the seismic loss (Q), we use the mesoscopic White model (White, 1975; Carcione, 2015).

Several effects due to wave loss are investigated here. Attenuation in the BSR layer is very low, due to mesoscopic-loss effects because of the presence of gas (e.g., Carcione and Picotti, 2006) and this fact affects the reflection coefficient and the amplitude related to the BSR event. Moreover, the thickness of the BSR layer generates interference effects which also affect the reflection coefficient and the waveform. In order to analyze these phenomena, we compute 1D synthetic seismograms by varying the quality factor and thickness of the BSR layer. In addition, the intrinsic attenuation of the upper layers induces a shift of the spectrum centroid to low frequencies as the traveled distance increases.

Regarding temperature effects as the gas-hydrate stability zone, Gei and Carcione (2003) have compared two empirical equations to ODP data showing a very good agreement. The BSR is deeper for lower geothermal gradients, increasing depth and decreasing temperature of the seafloor. Moreover, temperature and pressure affect the acoustic properties of the fluids, mainly those of the free gas. The relevant equations can be found in Gei and Carcione (2003). In this work, we focus the research on the geometrical and intrinsic attenuation effects. For clarity in reading, we include a list of symbols in Appendix A.

2. Petro-elastical model

Fig. 1 shows the media (denoted by j = 1,2,3) and interfaces composing the system, where the BSR event is due to a composite reflection related to layer 2. The sediments above the BSR (medium 1) are saturated with brine containing clay and gas hydrate. This rock can be considered as a composite material with $n = 3$ frames, i.e., the rock (quartz) frame, the clay frame and that of the hydrate network. In the following $i = 1$, 2 and 3 indicate the properties of quartz, clay and gas hydrates, respectively. Carcione et al. (2005b) obtained the wet-rock (Gassmann) bulk modulus of a medium with n frames and one fluid. If ϕ_i is the fraction of the i-th solid and ϕ is the porosity, such that $\sum^n \phi_i + \phi = 1$, the Gassmann modulus is

$$K_G = \sum_{i=1}^{n} K_{mi} + \left(\sum_{i=1}^{n} \alpha_i\right)^2 M, \quad (1)$$

where

$$M = \left(\sum_{i=1}^{n} \frac{\phi_i'}{K_i} + \frac{\phi}{K_f}\right)^{-1}, \quad (2)$$

$$\phi_i' = \alpha_i - \beta_i \phi, \quad \alpha_i = \beta_i - \frac{K_{mi}}{K_i}, \quad \beta_i = \frac{\phi_i}{1-\phi}. \quad (3)$$

β_i is the fraction of solid i per unit volume of total solid. Here K_i, $i = 1,\ldots n$ and K_f are the solid and fluid bulk moduli, respectively, and K_{mi}, $i = 1,\ldots n$ are the frame moduli.

A generalization of Krief's model for a multi-mineral porous medium is used to obtain the frame moduli,

$$K_{mi} = (K_{HS}/v)\beta_i K_i (1-\phi)^{A/(1-\phi)}, \quad i = 1, \ldots, n, \quad (4)$$

where A is a dimensionless parameter, $v = \sum_{i=1}^{n} \beta_i K_i$ is the Voigt average, and $K_{HS} = (K_+ + K_-)/2$, where K_+ and K_- are the Hashin–Shtrikman (HS) upper and lower bounds (Mavko et al.,

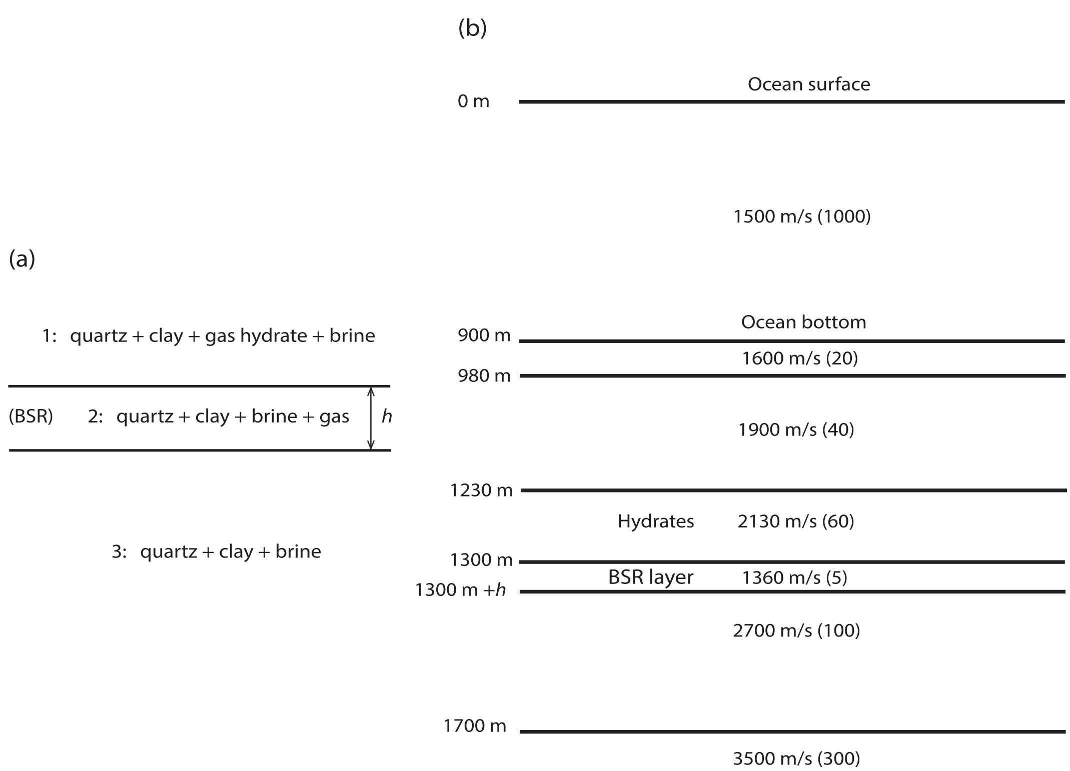

Fig. 1. Geological model. Composition of the BSR system (a) and general model (b). The velocities and quality factors are indicated.