Characterization of the seismic response of gas-hydrate bearing sediments

Juan E. Santos[a], Patricia M. Gauzellino[b], José M. Carcione[c], Jing Ba[d]

[a]*School of Earth Sciences and Engineering, Hohai University, Nanjing, 211100, China, Instituto del Gas y del Petróleo, Facultad de Ingeniería, Universidad de Buenos Aires, CONICET and Universidad de La Plata and Department of Mathematics, Purdue University, 150 N. University Street, West Lafayette, Indiana, 47907-2067, USA, santos@math.purdue.edu*

[b]*Departamento de Geofísica Aplicada, Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Paseo del Bosque s/n, La Plata, B1900FWA, Argentina pgauzellino@gmail.com*

[c]*Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), Borgo Grotta Gigante 42c, 34010 Sgonico, Trieste, Italy, jcarcione@inogs.it*

[d]*School of Earth Sciences and Engineering, Hohai University, Nanjing, 211100, China*

Abstract

Gas-hydrate bearing sediments are composite materials modeled as a porous rock frame and gas-hydrates, which consist of an ice-like lattice of water molecules with gas molecules, mostly methane, trapped inside. These type of sediments are highly heterogeneous at multiple mesoscopic scales, which induce attenuation and dispersion of traveling seismic waves due to mode conversions. This work presents a numerical upscaling procedure that allows to define a viscoelastic medium that in the average has the same behavior than the original heterogeneous sediment. The upscaling procedure consists of determining the complex moduli associated with the viscoelastic medium by solving numerically boundary value problems representing compressibility and shear experiments. The procedure is applied to composite media with regions of different ice content of fractal or periodic layered distribution. The examples demonstrate that variations in ice content induce strong attenuation and dispersion effects on seismic waves due to the WIFF mechanism.

*Corresponding author

Email address: `jingba@188.com` (Jing Ba)

Keywords: CO_2 Sequestration, Multiphase Flow

1. Introduction

Gas-hydrate bearing sediments are partially frozen porous rocks containing heterogeneities at multiple mesoscopic scales. These structures consist of a water phase and two non-welded solid phases, the porous skeleton and gas-hydrates, which are ice-like lattices of water molecules with gas molecules trapped inside (Ecker et al. (2000), Guerin and Goldberg (2005)). These formations, found in permafrost and continental margins, are considered as important future energy resources (Ecker et al. (2000)). Their elastic properties and seismic velocities were analyzed by Lee and Collet (2001), Lee (2002) and Carcione and Tinivella (2000).

A theory to describe the static and dynamic behavior of partially frozen porous media was presented by Leclaire et al (1994). The theory, valid for uniform porosity, predicts the existence of additional compressional and shear waves which were observed in laboratory experiments (Leclaire et al (1995)). Carcione and Seriani (1998) designed a generalization of this theory to evaluate gas-hydrate concentration. Carcione et al. (2003) and Santos et al. (2004) generalized the theory of Leclaire et al. (1994) to the variable porosity case. Numerical simulations of wave propagation in partially frozen porous media was presented by Carcione and Seriani (2001) and Carcione et al. (2003).

Seismic waves traveling through partially frozen porous media with regions of different ice content suffer mode conversions at interfaces between those regions, generating wave-induced fluid flow (WIFF) in what it is known as the mesoscopic loss mechanism. This mechanism was first analyzed by White et al. (1975) for the case of layered porous rocks with alternating gas and water saturation.

Eventhough the generalized theory of Leclaire could in principle be used to simulate wave propagation in highly heterogeneous gas-hydrate bearing sediments, large linear systems of equations need to be solved to properly represent the heterogeneities As an alternative, this work proposes the use of a numerical upscaling procedure allowing to obtain an *effective viscoelastic isotropic medium* (EVIM) that in the average behaves as a highly heterogeneous gas-hydrate bearing sediment.

The complex moduli that determine the EVIM are obtained as solutions of two boundary value problems (BVP's) for the quasistatic equations for composite materials derived by Santos et al. (2004). The BVP's impose boundary conditions associated with compressibility and shear experiments which approximate solution is obtained using a Finite Element (FE) procedure.

For a detailed description of using harmonic experiments combined with FE procedures to determine the seismic response of Biot-type media with different types of heterogeneities we refer to Santos and Gauzellino (2017).

2. The Elsevier article class

Installation. If the document class *elsarticle* is not available on your computer, you can download and install the system package *texlive-publishers* (Linux) or install the LaTeX package *elsarticle* using the package manager of your TeX installation, which is typically TeX Live or MikTeX.

Usage. Once the package is properly installed, you can use the document class *elsarticle* to create a manuscript. Please make sure that your manuscript follows the guidelines in the Guide for Authors of the relevant journal. It is not necessary to typeset your manuscript in exactly the same way as an article, unless you are submitting to a camera-ready copy (CRC) journal.

Functionality. The Elsevier article class is based on the standard article class and supports almost all of the functionality of that class. In addition, it features commands and options to format the

- document style
- baselineskip
- front matter

- keywords and MSC codes
- theorems, definitions and proofs
- lables of enumerations
- citation style and labeling.

3. Front matter

The author names and affiliations could be formatted in two ways:

(1) Group the authors per affiliation.

(2) Use footnotes to indicate the affiliations.

See the front matter of this document for examples. You are recommended to conform your choice to the journal you are submitting to.

4. Bibliography styles

There are various bibliography styles available. You can select the style of your choice in the preamble of this document. These styles are Elsevier styles based on standard styles like Harvard and Vancouver. Please use BibTEX to generate your bibliography and include DOIs whenever available.

Here are two sample references: [1, 2].

References

References

[1] R. Feynman, F. Vernon Jr., The theory of a general quantum system interacting with a linear dissipative system, Annals of Physics 24 (1963) 118–173. `doi:10.1016/0003-4916(63)90068-X`.

[2] P. Dirac, The lorentz transformation and absolute time, Physica 19 (1-12) (1953) 888–896. `doi:10.1016/S0031-8914(53)80099-6`.