ARTICLE IN PRESS

Deep-Sea Research Part I xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Deep-Sea Research Part I

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

Deep-towed high resolution seismic imaging II: Determination of P-wave velocity distribution

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ARTICLE INFO

Keywords:
Deep-towed seismic
Seismic imaging
P-wave velocity distribution

ABSTRACT

The acquisition of high resolution seismic data in deep waters requires the development of deep towed seismic sources and receivers able to deal with the high hydrostatic pressure environment. The low frequency piezoelectric transducer of the SYSIF (SYstème Sismique Fond) deep towed seismic device comply with the former requirement taking advantage of the coupling of a mechanical resonance (Janus driver) and a fluid resonance (Helmholtz cavity) to produce a large frequency bandwidth acoustic signal (220–1050 Hz). The ability to perform deep towed multichannel seismic imaging with SYSIF was demonstrated in 2014, yet, the ability to determine P-wave velocity distribution wasn't achieved. P-wave velocity analysis relies on the ratio between the source-receiver offset range and the depth of the seismic reflectors, thus towing the seismic source and receivers closer to the sea bed will provide a better geometry for P-wave velocity determination. Yet, technical issues, related to the acoustic source directivity, arise for this approach in the particular framework of piezoelectric sources. A signal processing sequence is therefore added to the initial processing flow. Data acquisition took place during the GHASS (Gas Hydrates, fluid Activities and Sediment deformations in the western Black Sea) cruise in the Romanian waters of the Black Sea. The results of the imaging processing are presented for two seismic data sets acquired over gas hydrates and gas bearing sediments. The improvement in the final seismic resolution demonstrates the validity of the velocity model.

1. Introduction

High Resolution (220–1050 Hz) seismic acquisition performed in great water depth using deep-towed systems provides unrivalled lateral resolution when compared to conventional surface seismic methods (50–250 Hz, Chapman et al., 2002; Gettrust et al., 2004). This gain in lateral resolution is primarily related to the acquisition geometry as it decreases the width of the first Fresnel zone. The gain also depends on the processing sequence in which imaging algorithms (migration) improve the resolution down to the mean wavelength of the seismic signal. Yet this ideal resolution may only be obtained if the correct velocity model is used. This requires the determination of the fine scale P-wave velocity distribution.

In a general case, P-wave velocities in shallow marine sediments are not expected to display strong variations due to the relative homogeneity of the medium. However, in the presence of existing fluid systems including the existence of gas or/and gas hydrates, the P-wave velocity distribution can vary significantly both laterally and vertically, making quantifying the velocity distribution (e.g., Helgerud et al., 1999) a key factor in gas/gas hydrate saturation assessment (He et al., 2009).

A large number of methods are available to access to the seismic velocity distribution. These methods differ according to their initial hypothesis, from the simplest (flat horizontal reflectors, Pythagorean theorem) to the most complex (calculation of the Green functions in a complex medium), yet they all rest on the accuracy of the source-receiver positions which remains the key point of any seismic acquisition.

The US NRL (Naval Research Laboratory) DTAGS (Deep Towed Acoustics Geophysics System) has successfully determined P-wave velocity distribution and thus acoustically characterized the medium (Wood et al., 2003, 2008). Nevertheless, the DTAGS pre-stack processing approach rests on the use of "Super Gather", up to 300 m-large and therefore the resulting smearing of information limits the accuracy for the determination of fine-scale P-wave velocity models.

A digital deep-towed multichannel streamer (52 traces @ 2 m) has been developed and the feasibility of performing high-resolution (220–1050 Hz) multichannel seismic imaging in deep water has been demonstrated (Marsset et al., 2014). Yet, the seismic data acquired during early sea trials of this streamer did not allow to determine the P-wave velocity distribution as the altitude of the towed fish was kept

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https://doi.org/10.1016/j.dsr.2017.12.005
Received 29 September 2016; Received in revised form 22 December 2017; Accepted 24 December 2017

Please cite this article as: Marsset, B., Deep-Sea Research Part I (2017), https://doi.org/10.1016/j.dsr.2017.12.005

conservatively high at 150 m above the sea floor.

One of the objectives of the GHASS project aims at studying the dynamics of gas hydrates and free gas associated with geological and climate processes (Ker et al., 2015). The GHASS project rests on a multidisciplinary approach including the fields of geotechnics, sedimentology and geochemistry. Such precise, but local, measurements require in turn high resolution spatial information to correlate them. The deep towed seismic source SYSIF (Marsset et al., 2010), together with its digital multichannel streamer (Marsset et al., 2014), was therefore deployed to obtain high resolution seismic image as well as fine-scale P-wave velocity model.

The deep towed high resolution seismic source SYSIF (Marsset et al., 2010; Ker et al., 2010) and its digital multichannel streamer have already been described as well as the processing sequence of deep towed multichannel seismic data (Marsset et al., 2014). This contribution focuses on the determination of P-wave velocity distribution of gas and gas hydrates bearing sediments, highlighting the specific acquisition constraints and the dedicated processing sequence to get full benefit of pre-stack depth migration - velocity model building seismic imaging scheme.

2. Methodology

2.1. Acoustic source directivity

The ability to determine P-wave velocities from multichannel seismic data depends on the ratio between the source-receiver offset range and the depth of the seismic reflectors, i.e. a function of the incidence angle. In the framework of deep towed acquisition, this ratio can be easily expanded by lowering the system closer to the sea floor: the lower the altitude over the sea bottom, the larger the interval of incidence angles. For safety purposes considering the overall streamer length of 120 m, the minimum altitude with respect to the sea-bed is set to 50 m. Such a geometry allows to record incidence angles exceeding 45° for the upper sedimentary layers. Yet, one technical issue related to the acoustic source directivity arises for this approach in the particular framework of piezoelectric seismic sources.

The large frequency bandwidth of the JH220-6000 Janus-Helmholtz acoustic source (220–1050 Hz) is obtained by coupling of a mechanical resonance (Janus driver) and a fluid resonance (Helmholtz cavity) (Le Gall, 1999). Each transmitter has its own directivity, and the coupling between the two resonances results in a specific directivity for the transducer. The directivity of the JH220-6000 has been modeled using the ATILA software (Fig. 1), a finite element software designed for the analysis of mechanical 2D/3D structures hosting piezoelectric materials (Hennion et al., 1990; Le Gall and Marsset, 2007). Based on acoustic

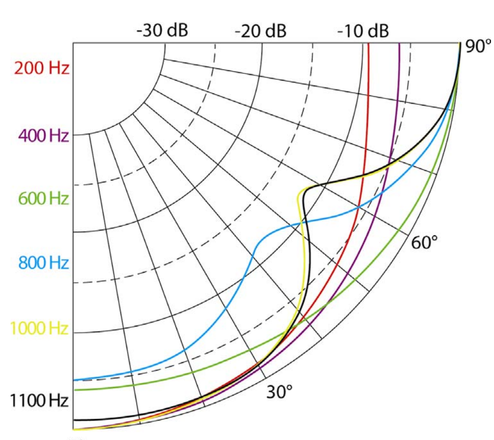

Fig. 1. Relative directivity of the JH220-6000 piezoelectric transducer performed using ATILA software. 0°/90° corresponds respectively to the vertical axis and to the horizontal axis of the transducer.

measurements acquired using OBH's (Ocean Bottom Hydrophone), Ker et al. (2010) evaluated the main lobe of reflectivity of the JH220-6000 to 40° (@ −3 dB), nevertheless the strong attenuation of the central frequencies (e.g. −8 dB @ 800 Hz @ 30°, Fig. 1) observed on the ATILA simulations suggests that the useful aperture is limited to 30°.

The electric pilot source signal is a 100 ms Linear FM (Linear Frequency Modulation) signal ranging from 220 to 1050 Hz. This initial signal is amplitude modulated taking into account the TVR (Transmit Voltage Response) of the transducer, in order to obtain an almost flat acoustic signal with a constant SL (Sound Level) of 196 dB ref 1 μPa @ 1 m over the entire frequency bandwidth in the nadir of the transducer. The "vertical" far field acoustic signature has been previously recorded (Ker et al., 2010). The "horizontal" far-field signature was recorded on the far hydrophone (in open water) during the GHASS cruise in order to assess the impact of the directivity of the transducer on the acoustic signal (Fig. 2, a-b). The classic processing sequence of linear FM signals involves performing either matching filter or deconvolution of the raw data with a known template in order to maximize the temporal resolution. The results of the deconvolution of the two signatures using the "vertical" signature as template clearly points out the incompatibility of this classic processing sequence for seismic data acquired with Janus-Helmholtz-like transducers as the source signature depends on the incidence angle (Fig. 2, c-d).

2.2. Acoustic interferences

The zero offset travel time corresponding to the source/sea-bottom/receiver ray is to be 66 ms for an altitude of 50 m (@ 1500 m/s) and therefore this ray will interfere with the direct arrival corresponding to the source/receiver ray. A processing step was therefore added, prior to source deconvolution, using STFT (short term Fourier transform) which allows to filter data in the Time-Frequency domain, a domain well adapted to Linear FM type signals (Allen, 1977).

The method was first applied on synthetic data (Fig. 3). The synthetic seismogram consists in the combination of a zero-delay "horizontal" signature with a 66 ms delayed / 20 dB attenuation "vertical" signature thus mimicking a reflection on the sea bed with a 0.1 reflection coefficient for a monostatic acquisition. The synthetic seismogram is then transformed, taking advantage of STFT algorithm, in the time-frequency domain where the two signatures appear as separated signals. The modulus of the STFT corresponding to the direct arrival, i.e. "horizontal" signature, is then zeroed and the inverse STFT is performed to compute the processed seismogram back into the time domain. After deconvolution, the gain in S/N (signal to noise ratio) is evaluated to 18 dB on synthetic data.

The former signal processing sequence was then applied on the SYSIF seismic data. Data are first deconvolved using the "horizontal" acoustic signature in order to precisely pick the direct arrivals (i.e. source-receiver ray) for each hydrophone. Raw traces are then time shifted to the direct arrival time of the first receiver so that filtering can use the same mask in the time-frequency domain for the entire data set. After filtering, data are shifted back to their original time and deconvolved with the proper template, i.e. "vertical" acoustic signature. The results are presented on Fig. 4 which illustrates the gain in S/N.

2.3. Positioning processing

Positioning is the key issue in seismic imaging processing where the calculation of travel times rests on the positions of the different source-receiver pairs. A relative error of one wavelength, i.e. ≈2 m for the mean wavelength of the JH220-6000 transducer, will prevent a proper focalization of the seismic events and therefore will lower the optimal resolution.

The streamer geometry is evaluated based on the hydrophones MEMS (Micro-Electro-Mechanical System) pitch and heading values. The geographic location of the source is ensured by an acoustic USBL