Project proposal

Low-frequency hydrocarbon indication in reflection seismic data (LowFreq)

University of Stavanger

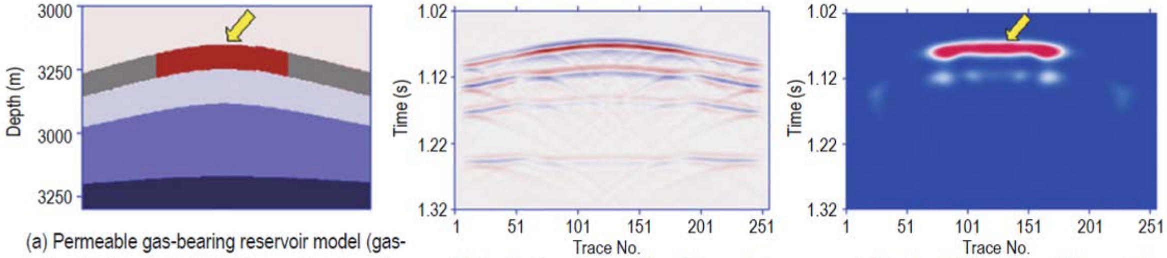
The overall goal of this project is to investigate how the low-frequency content on industry 3D seismic reflection data may be used as a hydrocarbon indicator for exploration and production (E&P) purposes. Previous and ongoing studies reveal a significant potential for research on this topic as well as for applications that could be of great importance to the oil industry.

The initial phase of the study aims to gather case studies from the literature and process a number of our own case examples from available 3D datasets to demonstrate the potential of this technique, to test and compare two or three of the current methods of spectral decomposition in use, and to investigate possible theoretical explanations of the effect in order to provide some enlightenment on the possible application of low-frequency analysis. For this purpose, we seek collaboration between industry and the University of Stavanger (UiS), in cooperation with Skagen44 AS. In addition, we expect to collaborate with researchers working on the topic at the University of Houston (UH) (eg. Prof. Gennady) with whom the UiS petroleum geoscience group has a collaborative agreement and ongoing cooperation.

Background and status of knowledge

Several synthetic (numerical modeling) studies, laboratory (physical modeling) studies, and field examples have been reported in the literature, in which the low-frequency components of reflected seismic waves are shown to be potentially useful as hydrocarbon indicators to image, delineate and monitor petroleum reservoirs. Numerical modeling (Fig. 1) has been done by e.g. Castagna et al. (2003), Quintal et al. (2007) and Chen et al. (2012), the last-named based on theory of Silin and Goloshubin (2010). Physical modeling studies are reported by e.g. Goloshubin et al. (2002), Korneev et al. (2004a) and Madonna et al. (2010). In reflection-seismic field data acquired for petroleum exploration and/or production, effects like these have been observed (Figs 2 and 3) by several authors, e.g, Goloshubin et al. (2002), Castagna et al. (2003), Korneev et al. (2004a, b), Goloshubin et al. (2006), Huang et al. (2006), Yu et al. (2011) and Chen et al. (2012).

In addition to reflection seismic data, several authors have claimed similar indication of hydrocarbons from passively acquired microseismic data (e.g. Dangel et al., 2003; Holzner et al., 2005; Lambert et al., 2009). However, much of this passive microseismic work is the subject of controversy (e.g. Green and Greenhalgh, 2010) and several negative studies have been reported (e.g. Ali et al., 2013). We therefore intend to focus on petroleum E&P reflection seismic data.



(a) Permeable gas-bearing reservoir model (gas-bearing layer is indicated by a yellow arrow)
(b) Synthetic seismic profile of the model
(c) Fluid mobility section of the model

Fig. 1. Fluid mobility analysis by Chen et al. (2012) of synthetic seismic data from a permeable gas-bearing reservoir model based on equations developed by Silin and Goloshubin (2010). The fluid mobility section in (c) has been determined at the peak frequency for reservoir fluid mobility, which in this particular model was 10 Hz.

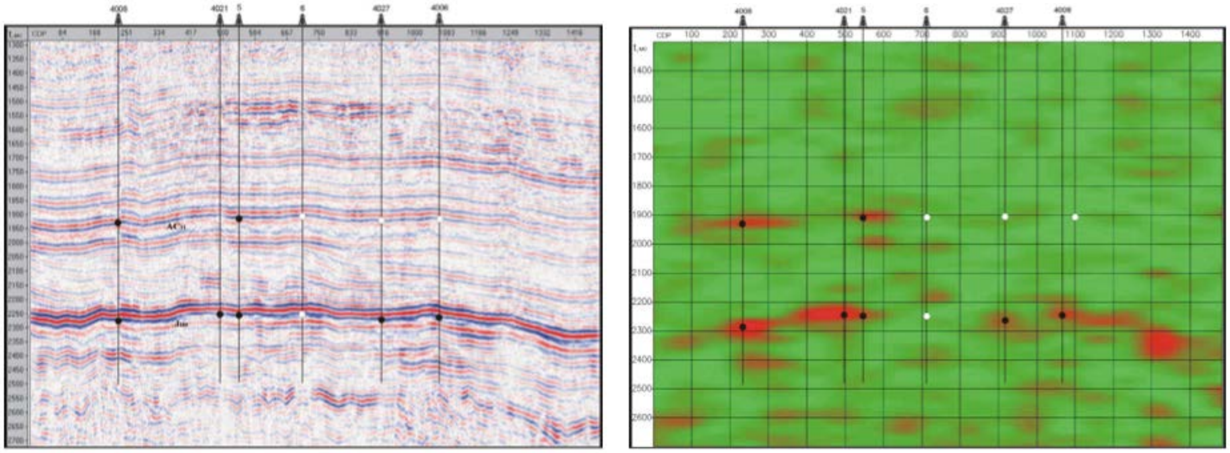


Fig. 2. Left: conventionally processed seismic data from a producing oilfield with an upper (sandstone) and lower (shale) reservoir. Right: low-frequency processed data. Wells: ● = oil, o = dry (from Goloshubin et al., 2002).

This effect is probably best observed in prestack common-offset gathers, considering that poststack data has usually been subjected to nonlinear processes, notably NMO analysis with its attendant NMO stretch, and others like migration. It would be advantageous if one could work with seismic data processed to final stack as there would then be far smaller volumes of data to analyze, with greater statistical significance due to the typically far greater signal-to-noise ratio in postack data. In fact, possibilities exist for processing data in a way that preserves frequency integrity using NMO-correction modules that avoid NMO stretch, such as that proposed by Hilterman and Van Schuyver (2003) and discussed further by Goloshubin et al. (2006).

The choice of spectral-decomposition method to be used in low-frequency analysis is evidently of some significance. Several methods have been proposed in the literature and some commercial seismic processing packages include algorithms based on one or another of these. For example, Castagna et al. (2003), present a method known as 'instantaneous spectral analysis' (ISA), and show a number of field examples applying it (e.g. Fig. 3).

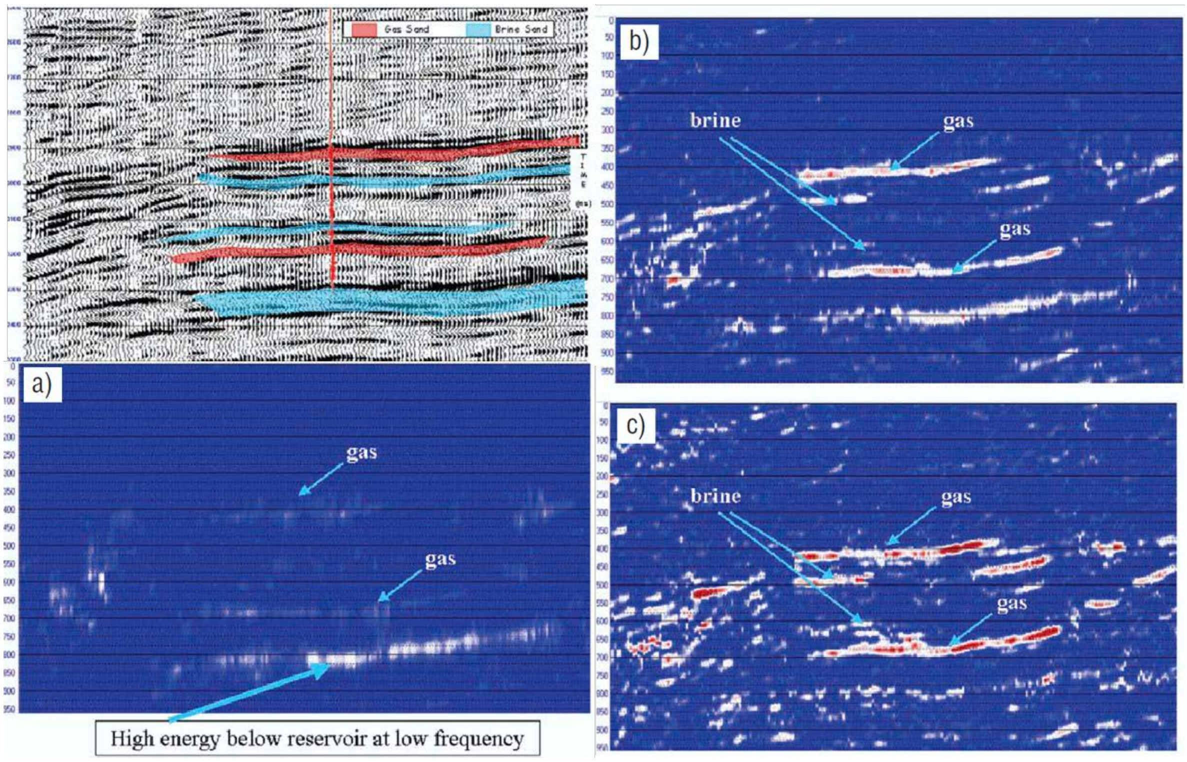


Fig. 3. Example of low-frequency analysis in a seismic line, showing gas-filled sandstone reservoirs (red) vs water-filled sandstone reservoirs (light blue). a) 10-Hz common-frequency section: the low-frequency shadow beneath the lower gas sand is the strongest event. b) 20-Hz common-frequency section: the low-frequency shadow beneath the lower gas sand persists but is weaker than the overlying gas sands. c) 30-Hz common-frequency section: the low-frequency shadow beneath the lower gas sand has disappeared (modified from Castagna et al., 2003).

The IHS Kingdom software incorporates a couple of spectral-decomposition attribute modules from Rock Solid Images (RSI) Inc. These are based on the so-called Gabor-Morlet spectral-decomposition method (Morlet, 1982). We have performed initial tests on vintage 3D data trying both the Gabor-Morley and the ISA methods. To date, preliminary results have been exciting and encouraging, and call for a much broader study. An example is shown in Fig. 4.

There are several other methods in the literature, such as the 'matching-pursuit decomposition' (MPD) algorithm (Mallat and Zhang, 1993; Huang et al., 2006) and various versions of the 'short-time Fourier transform' (STFT) method (Huang et al., 2006) including the 'short-time fractional Fourier transform' (STFRFT; Zhang et al., 2012) and the 'deconvolutive short-time Fourier transform' (DSTFT; Lu and Li, 2013).

Approaches to the project

The analysis of low-frequency data for fluid identification has shown a large spectrum of possibilities for better understanding of seismic signal and its importance for hydrocarbon E&P.

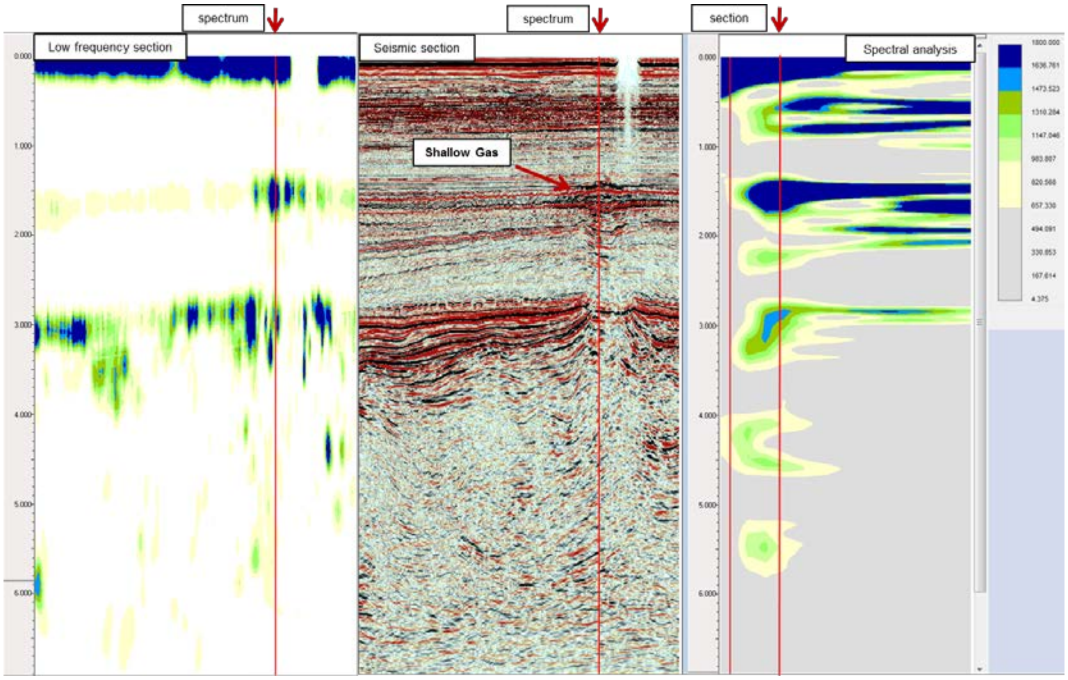


Fig. 4. Example of low-frequency analysis in the North Sea. Left: a low-frequency section with the same spatial coverage as the conventional section (middle). Right: spectral analysis of the trace indicated (red arrow in middle and left), frequency increasing to the right with red lines at 2 Hz and ~5 Hz (red arrow), identifying the shallow gas anomaly and other interesting anomalies in the area possibly associated with hydrocarbons.

We believe that by building applied research in this area, focusing on case studies from the Norwegian continental shelf, we can contribute to the enhancement of exploration techniques that can lead to new discoveries and increased reserves. In addition, the technique could be used to monitor the fluid development during production of a particular field as an alternative technique to 4D seismic. We propose the following activities within an initial frame of 4 years:

- Continue a literature search to gather as many of the relevant works in this area as possible, of which we already have about 50. Parallel with this, we plan to begin compiling a set of examples at well locations in available 3D seismic data volumes in order to establish how prevalent this effect is and for what types of geological settings. Since we have already had success using two or three accessible analysis methods (Fig. 4) we would continue, at least initially, with these. The objective would be to compile a catalogue of cases including description of the results, comparison with known lithology and saturants, and some formalization of interpretational characteristics – maybe even some prediction of prospects.

- Experiment with different methods of analysis to try to optimize the application. This will not focus only on different methods of spectral decomposition but also upon various methods for preparing seismic data for such spectral analysis. This would include experimenting with different gathers (starting with common-offset) and possible methods of eliminating NMO stretch prior to spectral decomposition of stacked traces.

- Investigate to what extent classical elastic/poroelastic wave-propagation formulations can account for the observed low-frequency responses or how they may be reformulated to incorporate such effects. We will consider all the theoretical formulations that turn up in our literature search and try to eliminate the least likely – or cull out the most reasonable – by testing them against observations, as well as through investigating their soundness on purely theoretical grounds. A number of papers have already been published proposing theoretical explanations for this effect, most of them elaborating on the theoretical work of Biot (1956) on wave propagation in fluid-saturated rocks (poroelastic media) and/or later developments thereof, and involving frequency dependence of *Q* (seismic quality factor).

  A paper by Silin and Goloshubin (2010) appears to constitute a major contribution to the explanation of this effect. Their theory shows, among other things, that the "permeability-based" P-wave reflectivity from a fluid-saturated reservoir layer is frequency-dependent, and for their representative examples had a maximum value around 8 Hz. Goloshubin and Chabyshova (2012) give a more descriptive and practical discussion of these results, wherein they state that they expect such effects to be strongest for highly interbedded permeable reservoirs and weakest for thick homogeneous reservoirs.

- Investigate how the methodology can be incorporated into conventional seismic interpretation methods, by applying it to various case studies

Organization, personnel and budget

The project will be managed by the University of Stavanger and the group will be led initially by Prof. Alejandro Escalona. The project is planned for an initial phase of four years and includes the initial personnel:

University of Stavanger:

- Prof. Alejandro Escalona: Expertise on basin- to reservoir-scale problems using subsurface data interpretation,
- Prof. Robert James Brown: Expertise in seismic processing, multicomponent seismic and seismic anisotropy,
- Assoc. Prof. Hosein Hashemi: Expertise in petroleum geophysics,
- 1 PhD student (4 years),
- 2-3 MSc students.

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- Børge Rosland: Expertise in signal analysis, seismic processing and interpretation.
- Karl Audun Lehne: Expertise in petrophysics.

We have approach Dr. Gennady Goloshubin at the University of Houston who has expertise in the topic and is interested in contributing to the project. We aim to have research visitors from

UH (among others) for varying periods at UiS and also to assign MSc and PhD students varying research periods at UH.

The project will require that sponsors provide 3D seismic datasets for the case studies and, primarily, pre-stack data will be required.

Deliverables

- A yearly meeting presenting the main results of the work carried out during the past year. A summary report will be provided.
- Copies of presentations and scientific publications at the time of submission to peer-reviewed journals.

Estimated preliminary costs (in millions of NOK):

ITEM:	2014	2015	2016	2017	TOTAL per item:
PhD	1,00	1,00	1,10	1,10	4,20
Professors costs (2@10%)	0,35	0,35	0,35	0,35	1,40
Travel and conferences	0,25	0,25	0,25	0,25	1,00
Exchanges/visitors	0,25	0,25	0,25	0,25	1,00
University of Houston	0,25	0,25	0,25	0,25	1,00
Equipment	0,10	0,10	0,10	0,10	0,40
TOTAL per year:	2,20	2,20	2,30	2,30	9,00

UiS will provide the support of a PhD for 3 years equivalent to . . . 3,0 MNOK

Industry funding: 1,5 MNOK a year for 4 years . . . . 6,0 MNOK;

The cost for each participating company is proposed as 500 000 NOK per year. However the commitment to participate in the project will be for one year at a time, and priority on the budget will be given to the PhD salary (in total, 1 MNOK in order to start the 4-year project). The level of activity and personnel will depend on the number of companies participating and supporting the project each year. Because sponsorship is on a year basis, access to the project deliverables will be given only to those companies supporting that particular year. We expect a minimum of two companies to start the project.

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