# ADVANCES IN SURFACE SEISMIC TECHNOLOGY FOR RESERVOIR CHARACTERIZATION AND DRILLING HAZARD IDENTIFICATION

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## Introduction

Seismic data has a key role to play in exploration and field development, enabling reservoir delineation and characterization as well as reducing drilling risks. In this paper, we discuss recent seismic technology developments and show how they have provide new insights into subsurface geology, reservoir properties and drilling hazards.

The advent of broadband seismic in recent years has been driven by a combination of new acquisition techniques, such as the introduction of multimeasurement streamers, and sophisticated data processing workflows, which can significantly extend bandwidth at both the low and high frequency end of both newly acquired 'broadband' data and heritage conventional data.

One of the key benefits of broadband seismic is in the recovery of reliable low frequency information. This information is critical for the success of seismic amplitude inversions, allowing us to minimize the frequency 'gap' between low frequency velocity information and seismic reflectivity information, and rely less on well data to guide the inversion. When coupled with the latest high resolution velocity estimation techniques such as full waveform inversion, this gap is further reduced, resulting in more reliable inversion information. This effect of 'reducing the gap' is illustrated in figure 1.

## Broadband data processing

The objective of broadband data processing can be considered as optimizing the signal-to-noise ratio of the seismic data over as large a frequency range as possible. All steps in the seismic workflow need to be considered with this objective in mind, but the key enabler is 'deghosting' technology which reduces the interference effect of downgoing energy reflected from the sea surface – a significant limitation of conventional seismic. Deghosting is typically carried out early in the data processing workflow and in recent years algorithms have moved from deterministic techniques to data adaptive techniques and from 2D to 3D implementations which enable robust deghosting in complex geological environments or wide-azimuth acquisition geometries. 'Adaptive Deghosting' (Rickett et al 2014) is one such data adaptive deghosting algorithm which inverts for both the upgoing wavefield and the ghost delay time. This allows 3D deghosting in both 'single cable' and 'multi-cable' modes. The algorithm includes a sparsity constraint which acts to stabilize the deghosting process, enabling improved noise handling and increasing phase stability across frequencies, especially in the ghost notches. Figure 2 illustrates the benefits of the broadband reprocessing of conventional single component, shallow flat towed surface seismic data. Improvements in stratigraphic and structural information can clearly be seen.

**Full Waveform Inversion (FWI)**

Depth imaging has become the standard in complex geological environments like the Caspian Sea, where a complex overburden including shallow gas, mud volcanoes, gas hydrate accumulations and buried channels can disrupt the imaging of deeper reservoirs. Full waveform inversion (FWI) is a data driven model building technology which overcomes the limitations of typical reflection tomography approaches to provide accurate high-resolution velocity models which allow improved subsurface imaging and can also provide insights into drilling hazards such as shallow gas accumulations (illustrated in figure 3). Until recently, there were two key limitations associated with FWI. Firstly, the velocity update computed by FWI is based on the difference between forward modelled and the recorded seismic: for conventional FWI to be effective, these datasets were required to be within half a wavelength of each other to avoid ‘cycle skipping’. This meant that either very low frequency data or a well-developed initial model were required. Secondly, conventional FWI is based on early arrivals (refracted and diving waves). In deep water especially, and with limited source to receiver offsets, this meant that the depth of reliable updates which could be achieved from FWI could be limited. The introduction of new FWI technologies, including Adjustive FWI (Jiao et al 2015) and Reflection FWI (Vigh et al 2016) overcome these challenges to allow accurate updates to be produced from heritage data with limited low frequency content, in areas where only simple initial models exist and below the depth of penetration of diving waves.

**Summary**

While the latest broadband acquisition techniques provide the ‘ideal’ field data, significant developments in data processing and imaging technology mean that step-change improvements can be made to heritage conventional datasets, bringing improvements in both reservoir and overburden interpretation and characterization.