A Holistic Approach to Model-Building in and Around Injectites: A Case-Study Offshore Norway*

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Search and Discovery Article #42193 (2018)**
Posted April 9, 2017

*Adapted from extended abstract based on oral presentation given at AAPG/SEG International Conference and Exhibition, London, England, October 15-18, 2017

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Abstract

The presence of injectites is a common and often time consuming area to be addressed during velocity model building. In addition to their impact on deeper structures and prospects, re-worked injectites are increasingly being considered for hydrocarbon potential themselves. In order to handle these challenges, we should consider ways of producing an accurate velocity model of these structures within a framework that is efficient and commercially time-viable. Here we present a holistic approach and case study to model-building in and around injectites that utilizes robust broadband data pre-processing, a semi-automated identification and modeling of injectite bodies and subsequent high-resolution tomographic updating. Our results show that this method enables us to produce a highly accurate and detailed model of a complex injectite field and subsequent improvement on the deeper image within the timeframe of a conventional model building iteration.

Introduction

The Northwest European continental margin provides many well documented examples and case-studies of the origin and, more recently, hydrocarbon potential of remobilized injectites in the Paleogene (e.g., Husse, 2016; Hurst, 2004). In velocity model building (VMB) large injectite areas or fairways present a common challenge, in terms of both their effect on the image of deeper structures and as an imaging target for prospectivity themselves. In particular, the variety of sizes, number, and complex geometry of individual injectites pose the greatest challenge, with manual interpretation often un-viable in the scope of a commercial imaging exercise.

In this case study we present a workflow to constrain a complex velocity model of large reworked Paleogene sand injectite areas offshore Norway. Our approach uses a robust, deghosted pre-processing workflow, semi-automated identification and insertion of injectites, and finally a high-resolution tomographic update. All of these steps formed critical elements of a multi-faceted approach to detailed model building in and around injectites within the timeframe of a conventional VMB iteration.

Data Pre-Conditioning and Deghosting

The input seismic data consisted of three surveys of varying vintage and source and receiver tow depths amounting to a total input area of 1400 sq. km. Given that the injectite bodies display anomalous amplitude behavior, a Hilbert transform instantaneous amplitude extraction method was employed to highlight the location of the injectite geobodies. To optimize the performance of both the Hilbert transform based insertion of the injectite bodies and subsequent high resolution tomographic update, pre-processing focused on three key areas including:

1. Deghosting to remove the variable ghost notches for each survey respectively,
2. Survey matching to address variables associated with the acquisition setup of multiple input surveys,
3. Demultiple to remove multiple energy (the water-bottom first bounce sits over the injectite field).

A variable operator implementation of our proprietary deghosting technique was used for all three surveys (Zhou et al., 2012; O'Driscoll et al., 2013). Deghosting successfully suppressed side lobe energy on the pre-SDM stack image ensuring optimal performance of the Hilbert transform extraction to isolate the extent of the injectites. In addition to this, the deghosting had the benefit of extending the bandwidth and by removing the notches and associated phase effects of the ghost we correctly pre-condition the data for subsequent matching (Payne et al., 2016). Matching for all three surveys was performed following deghosting and used 4D co-location binning to optimize the result and ensure only traces with similar ray paths were considered. Following matching, the amplitude, phase and timing allowed for a consistent application of the injectite amplitude extraction and tomography across the three surveys. Finally, demultiple consisted of a 3D SRME and a wave-equation water-layer demultiple (Short Period Multiple Attenuation – SPMA) subtracted from the data simultaneously using multi-model adaptive subtraction. Following this a 2D SRME and Hi-Res Radon were applied to target residual multiple energy suitably conditioning the survey for VMB.

Starting Model

This workflow was part a five iteration tomographic model building update using Kirchhoff and beam TTI pre-SDM (e.g., Jones, 2010). The insertion of the injectites and high-resolution tomographic injectite update took place following the third iteration to ensure an appropriate well-tied, background velocity and anisotropy model was in place at the target level for the injectite update (Balder-Shetland: Figure 1a).

Insertion of Injectites

The extent, number and complexity of injectites in cases such as this usually preclude manual interpretation within the timeframe of a commercial imaging project. In order to handle the inclusion of injectites into the model a semi-automated approach is used. To map the extents of the injectites a Hilbert transform was first used to extract the instantaneous amplitude from the data on the basis that the injectites are high amplitude relative to background. Following this muting was applied above Balder +100 m and below Shetland, careful smoothing and clipping of the instantaneous amplitude field was used to achieve the injectite model (Figure 1c).

While deghosting and subsequent removal of ghost energy better represents the fine detail of events, the Hilbert transform, an amplitude based method, will not conform exactly to the top (-ve trough = increase in acoustic impedance) and base (+ve peak = decrease in acoustic impedance) of the injectite and instead produces a mask that is slightly larger than the true geological thickness. To compensate for this, and following scanning and validation, a fill velocity for the injectites of background interval velocity plus 5% was used as a starting point to help steer the hi-resolution tomographic update. Figure 1 shows the insertion of the injectites into the model.

High-Resolution Tomographic Update of Injectites

Following insertion of injectites, the volume was migrated in preparation for the high-resolution tomography. A non-parametric generalised move-out picker (GMO) is used to resolve fine velocity details required here, having been used with success on previous ION projects to target similar scale anomalies (Fruehn et al., 2014). The GMO picker tracks wavelets above a user-defined semblance value to feed into the tomographic update of velocity (tomographic updating of Epsilon was not used in this instance). Tomography with a cell size of 100 m x 100 m x 25 m to a maximum of 200 internal conjugate gradient iterations was used to capture the fine detail of the injectite features and surrounding material.

The results of the tomography can be seen in Figure 2. The yellow arrows show that tomography suitably inserts expected speed-up within and slow-down around the injectites. An assumed, approximately flat reflector beneath the injectites (dotted line) is significantly flatter following tomography (orange arrow). A slice of Balder + 400 m was produced through the injectite area at all stages (Figure 3). Figure 3a and 3b show the successful insertion and fine detail of the injectites achieved through the Hilbert instantaneous amplitude extraction, followed by tomography to refine the velocities further (Figure 3c). The slice of the tomography difference shows successful insertion of slowdowns and speedups across the volume carefully conforming to the boundaries of the injectites.

Conclusions

Improved data pre-conditioning, including a robust deghosting workflow, in conjunction with a two-step approach to VMB including instantaneous amplitude extraction to model these injectite bodies followed by a high resolution tomography has enabled a detailed, accurate and efficient approach to imaging the Paleogene on these surveys. The new control over the velocity of these injectites has not only enhanced the positioning of the injectites themselves (as potential targets) but also significantly improved the image and positioning of targets below. In addition to the high level of model detail achieved, this workflow was also incorporated effectively into the time constraints of a conventional model building timeframe.

Acknowledgements

We are grateful to Engie E&P Norge, Monarch Geophysical Services, PL786 partners and ION for project input and permission to publish these results.

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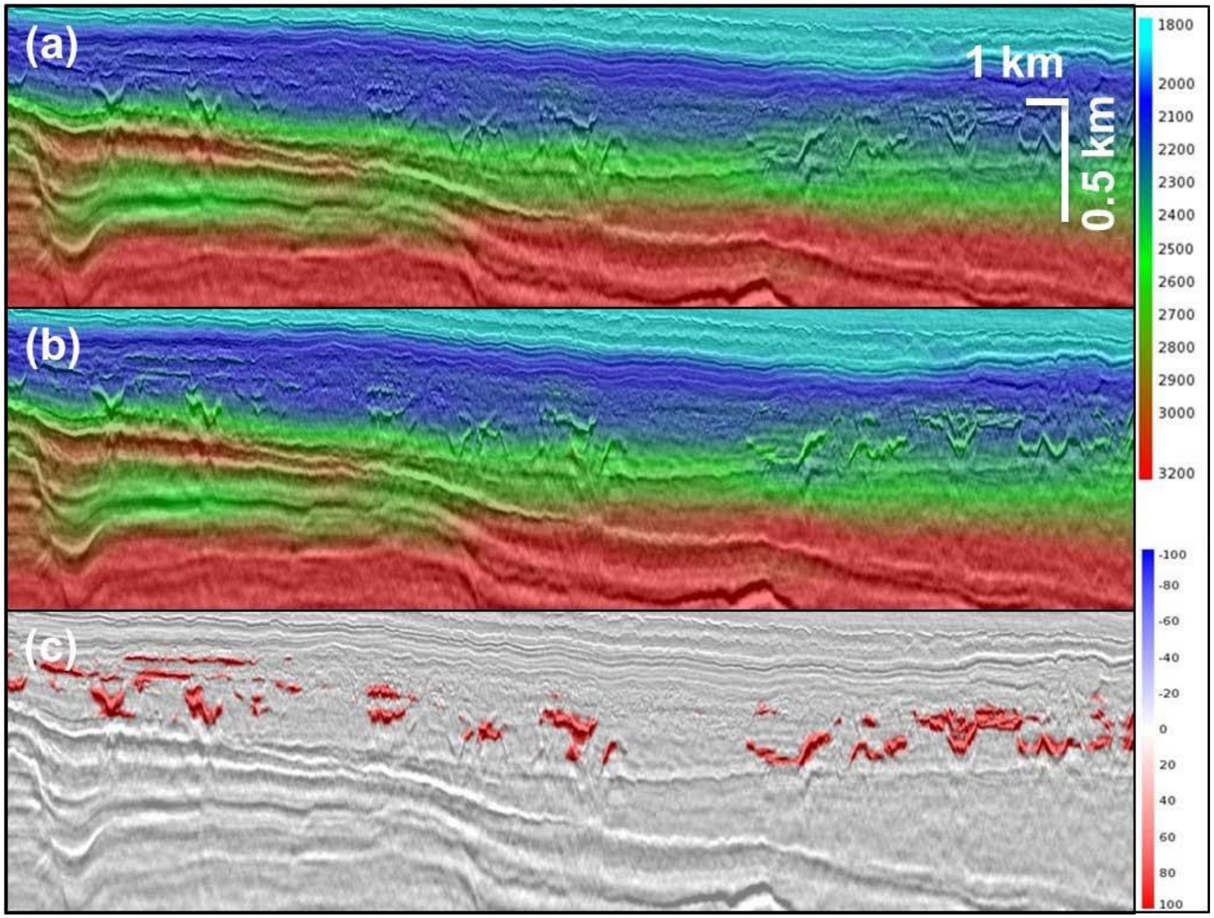

Figure 1. Inline stack section in depth with interval velocity overlay (a) before, and (b) after insertion in injectites. (c) Velocity difference following insertion of 5% speedup relative to background velocity. Note Hilbert transform successfully and accurately isolates the top and base of the injectite bodies enabling suitable insertion of speedup in preparation for following GMO picking and high-resolution tomography.

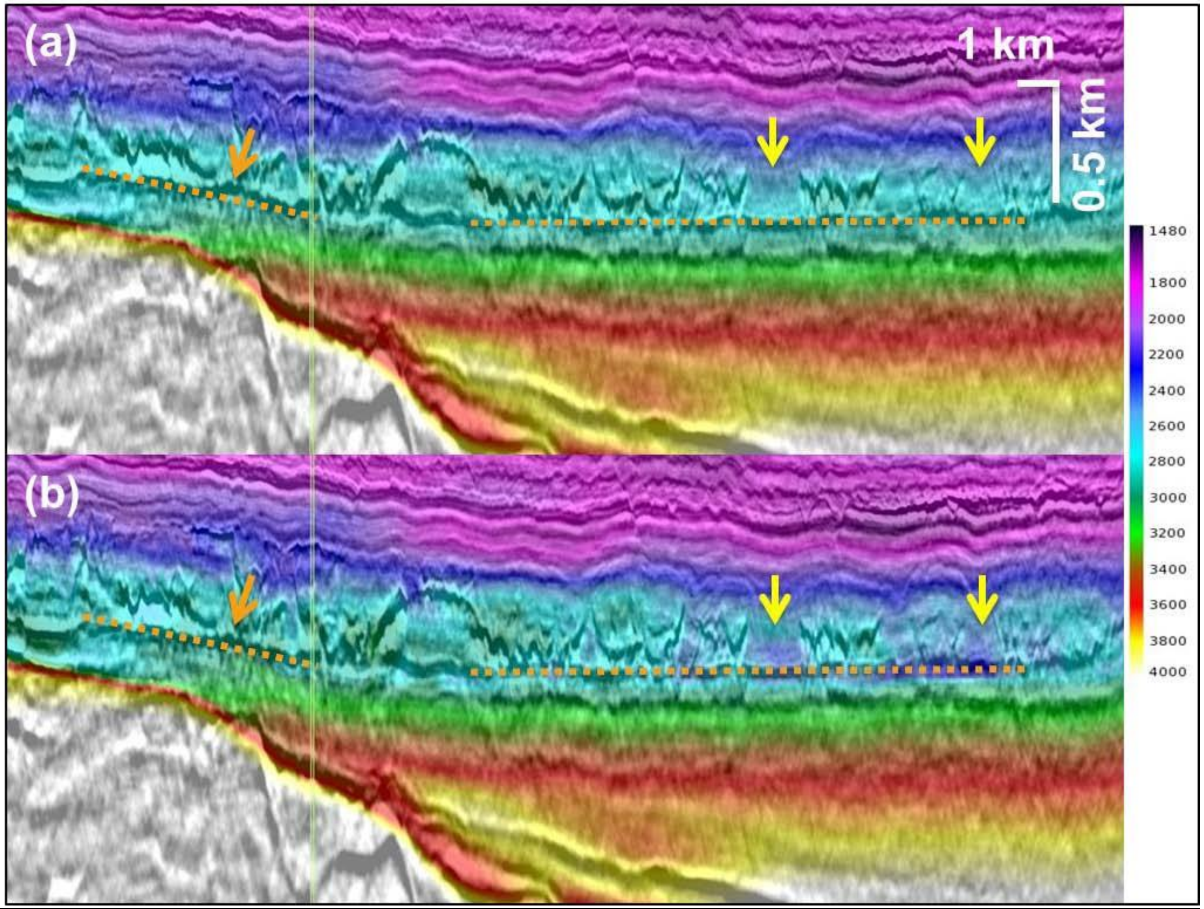

Figure 2. Inline stack section in depth with interval velocity overlay (a) before, and (b) after high-resolution tomographic update. Starting model (a) includes injectites (with 5% speedup velocity) inserted via Hilbert transform method to help steer the tomography. Note reflector immediately beneath injectites (assumed to be approximately flat) is flatter following tomography (orange arrow). Tomography is parameterized (100 m x100 m x 20 m IL/XL/Z cell size) to insert fine detail resulting in expected speedup within and slowdown outside of injectite bodies (yellow arrows).

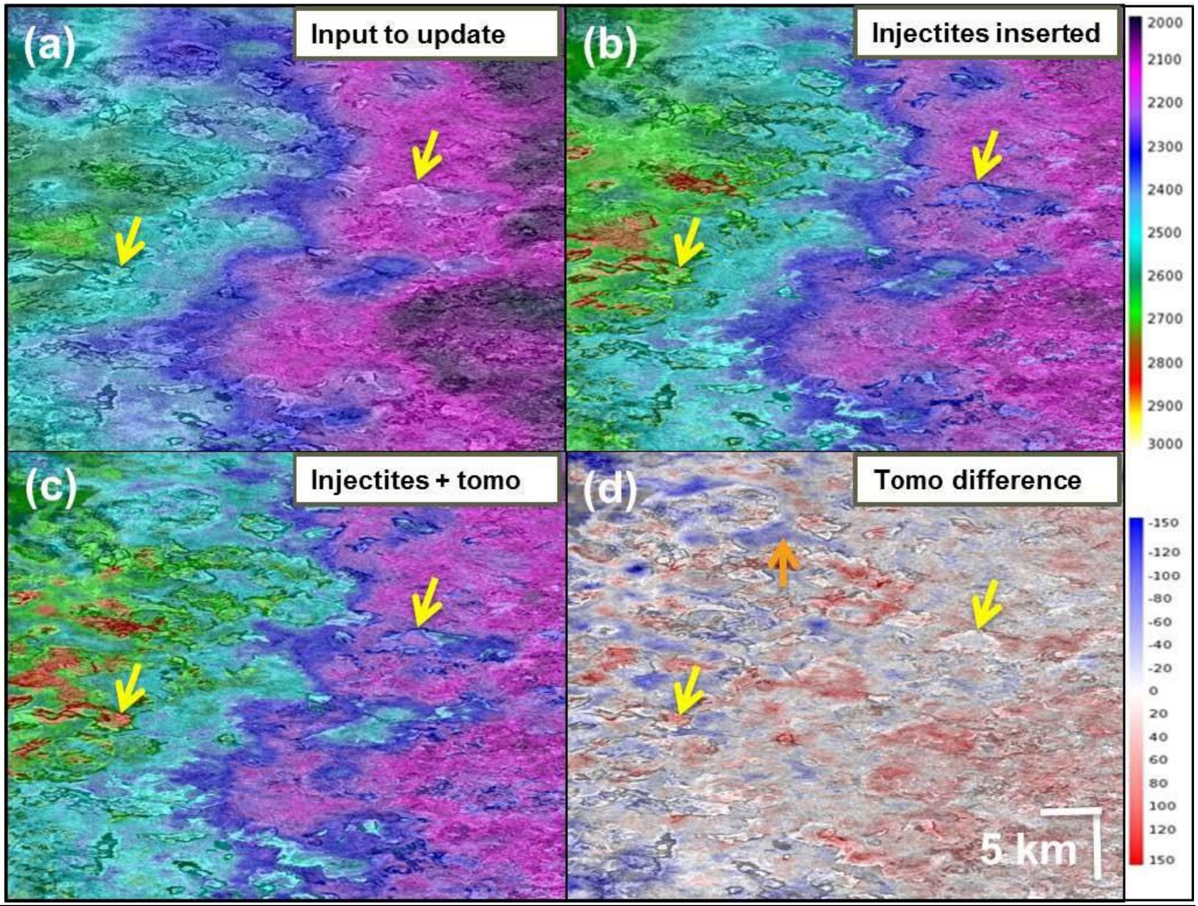

Figure 3. Balder plus 400 m depth slice (within injectite field) with interval velocity overlay (a) before, and (b) after Hilbert transform insertion of injectites, and (c) following high-resolution tomography. (d) Velocity difference following high-resolution tomography. Hilbert based insertion of injectites (b) provides detailed, highly accurate definition of the extent and distribution of the injectite features (yellow arrows) in preparation for injectite tomographic update (c). High resolution tomography successfully captures fine detail with the velocity difference showing appropriate speed ups and slowdowns in and around injectites respectively (d). Note tomographic slow-down suitably captures fine detail between neighboring injectites (orange arrow).