



Improving the prospectivity of sub-basalt geology with elastic FWI imaging

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Keywords

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Summary

In this paper we apply an acoustic and elastic FWI Imaging approach to the difficult problem of improving sub-basalt prospectivity. FWI Imaging is rapidly becoming a key deliverable in any imaging and velocity model building workflow. It can be seen as a non-linear least-squares migration with the images being generated almost as a by-product of the model building approach. It allows for greater understanding of complex geology where typical migration images may have limitations and as such, is an invaluable guide for any interpretation work.

Introduction

Thick, complex volcanics dominate the sub-surface of many areas, for instance the west coast offshore India and much of the Atlantic Margin region of the North Sea. These volcanic structures are comprised of thick lava deltas, landward flows, inner flows and sills, all with highly variable velocities which make definition of sub-basalt structures challenging. Some of the features in these regions (e.g. tilted fault block) in the sub-basalt image suggest the potential to be prospective, so imaging of these features is identified as one of the key challenges in the area. We have attempted to address the challenge of imaging through these volcanic sequences over the past few years with varying degrees of

success. Reverse Time Migration (RTM) surface offset gathers allowed us to pick out coherent moveout in the sub-basalt (Baldock, et al. 2019), which was largely hidden behind noise with conventional ray-based migration gathers. This allowed tomography to update the velocity model in the region and in turn improve migration imaging. There are limitations however inherent in any conventional narrow azimuth (NAZ) streamer acquisition for imaging through sequences such as this. Least Squares migration approaches such as LSRTM can help recover signal here, but to some extent rely on an accurate velocity model. The FWI workflow can be considered equivalent to an LSRTM workflow with the key difference that we're updating the velocity model rather than the migration image (Figure 1). If we are to take the directional derivative of a sufficiently detailed FWI velocity model (a so called FWI image), we can in fact replace the LSRTM workflow entirely. In this paper we explored the potential of technology like FWI to enhance the sub-basalt imaging.

Method and examples

We show results from a test area of approximately 150 km² from a NAZ streamer acquisition survey acquired in a basalt province during 2020. This survey was acquired with a dense penta-source configuration using 12 streamers with streamer spacing of 125m. Ten out of twelve streamers was 8km long, whereas 2

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streamers was used with 11km streamer length for additional diving wave coverage.

The starting model came from earlier processing of the full volume, which was focussed on more conventional prospects, so was not tailored for sub-basalt FWI Imaging. This model was built using an interleaved combination of reflection tomography and acoustic Dynamic Matching FWI (DMFWI) up to a frequency of 12 Hz. Dynamic Matching FWI (Mao, et al. 2020) is a robust multi-channel FWI algorithm which utilises a local correlation based objective function after dynamically matching the observed and synthetic shot datasets, in order to focus on the kinematic differences between the two. For this, both refraction and reflection events were utilised. Care was needed with the model build across the basalt, as leakage was observed which was thought to be evidence of an elastic effect from mode converted energy at the interface.

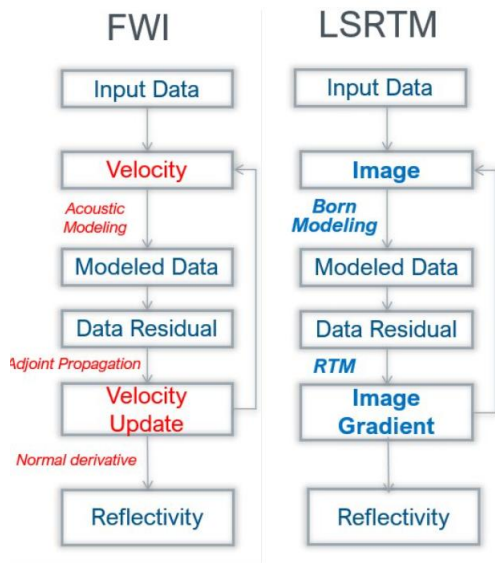


Figure 1: Comparison of FWI Imaging and LSRTM imaging workflows.

Although this provided a good model for correcting the kinematics with conventional depth migrations algorithms, the resolution of

subsequent FWI images was limited. Therefore, reflection FWI updates were carried out up to 30 Hz (over three iterations, each adding more detail to the velocity model and better focussing the resulting FWI Images. These FWI images were generated by calculating the directional derivative of the FWI velocity models. Figure 2 shows the image comparison between conventional imaging using Kirchhoff with FWI imaging, which clearly shows the improvement of imaging below the basalt layer.

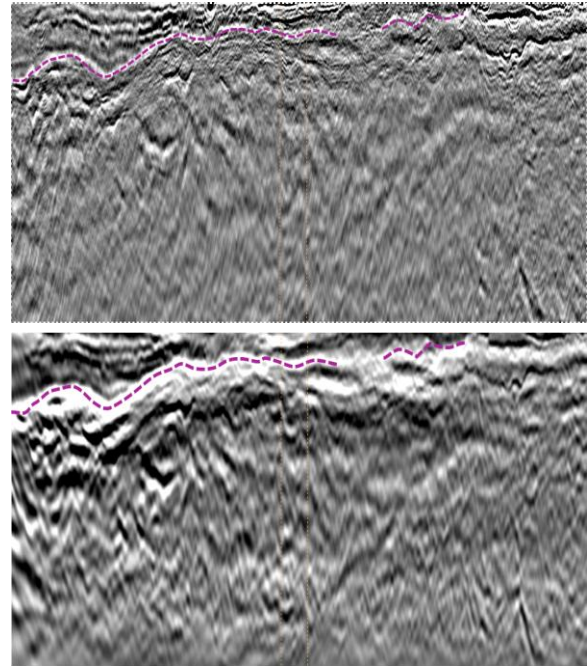


Figure 2: Comparison of conventional Kirchhoff PreSDM image (top) with the acoustic FWI image (below). The base basalt interpretation is shown with the dashed purple line

Further work was done to check if elastic FWI technology can further improve the velocity model and hence the image, as elastic component may not be ignored considering large velocity contrast around volcanic bodies. Figure 3 shows the shot gather comparison of acoustic and elastic modelling. Image shows the recorded shot

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gathers interleaved with synthetic model shots using acoustic modelling engine (left image) in comparison to elastic modeling engine (right image). One can observe that once elastic components are considered during modelling, the modelled shot gather shows better match with recorded shot gather. As a result, elastic FWI produces accurate and more geologically consistent velocity updates in comparison to acoustic.

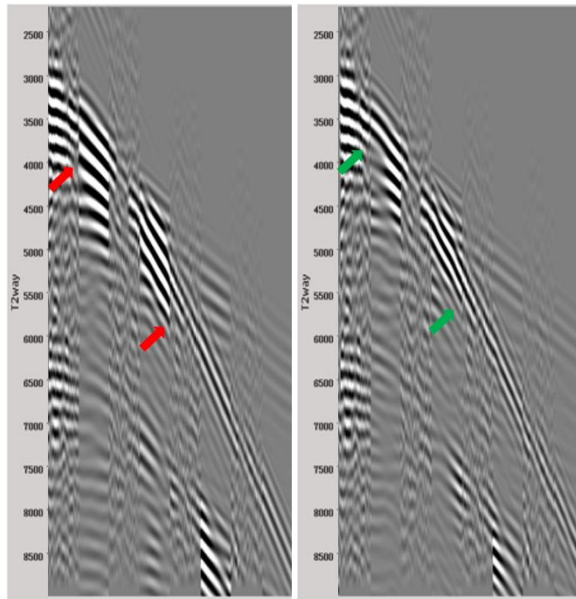


Figure 3: Interleaved observed and modelled synthetic data using acoustic forward modelling (left) and using elastic forward modelling (right). Arrows show the location where elastic modelling shows a better match with the observed data.

Figure 4 shows the comparison of 4Hz Acoustic (middle) and elastic (bottom) FWI velocity model overlay with corresponding image. Top image of Figure 3 shows the initial velocity model overlay with the corresponding image. It can be observed that due to acoustic assumption, the velocity update is leaked at top basalt interface in acoustic FWI update which has been improved using elastic FWI (purple arrow). As a result, deeper events get simplified producing more

geologically plausible image (light orange arrow).

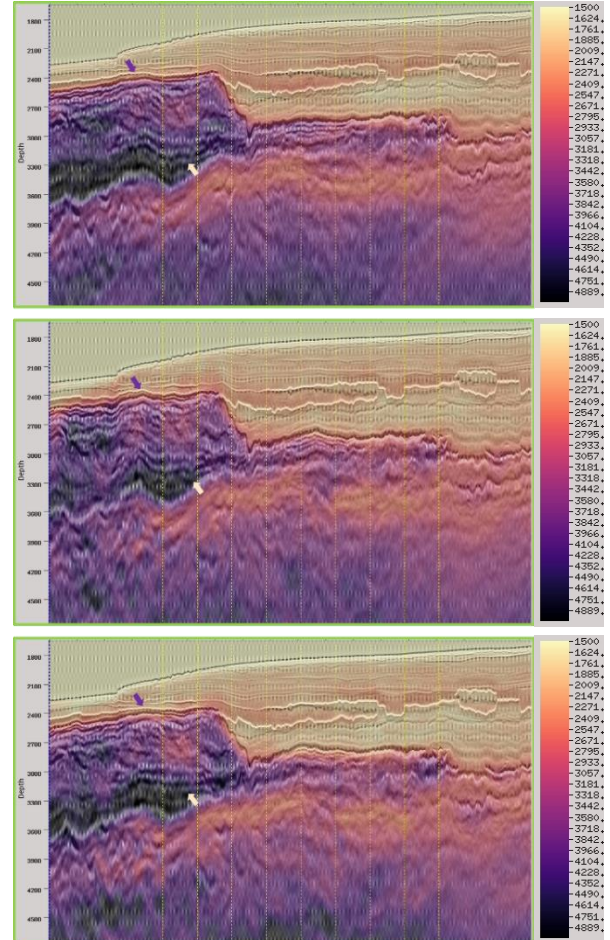


Figure 4: Comparison of Initial velocity (top), the acoustic FWI velocity (middle) and elastic FWI velocity (below). Each one is overlay with corresponding migrated image.

Conclusions

Significant uplift can be seen in the acoustic FWI images when compared to the earlier 12 Hz results, which is perhaps unsurprising (Figure 2). When compared to a conventional Kirchhoff migration image, we begin to see the structure of the sub-basalt geology in much clearer detail.

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Noise is significantly reduced, and event continuity becomes much clearer and easier to understand. Early testing with elastic FWI has shown promise (Figure 3) in resolving issues associated with acoustic modelling around volcanic bodies with large velocity contrasts. Model leakage around the top-basalt interface is significantly reduced by elastic modelling, which significantly simplifies the migration image and produces flatter gathers with no need for additional model constraints.

References

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