Elastic MP-FWI imaging: Changing geophysics

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Multi-parameter full waveform inversion is rapidly changing what's possible with seismic data, turning decades-old approaches on their head to deliver high-resolution rock properties from field data in ever-decreasing timeframes.

Conventional workflows contain many assumptions, approximations and simplifications. A significant amount of time and effort is required to condition the input data, resulting in the attenuation of a substantial amount of information through highly subjective workflows.

Multi-parameter full waveform inversion (MP-FWI) imaging offers a new approach. This novel application of FWI enables the simultaneous inversion of a range of parameters, including velocity, reflectivity, and rock properties. Since FWI can model the full wavefield, the inversion can use all the acquired information. The use of primary and multiple reflections enables the determination of high-resolution velocity and reflectivity in a least-squares manner, thereby bypassing the model-building and imaging workflows. Now, with visco-elastic MP-FWI imaging, it is possible to invert directly for elastic parameters without the need for AVA inversion. Entire workflows can now be bypassed using this novel, superior technology.

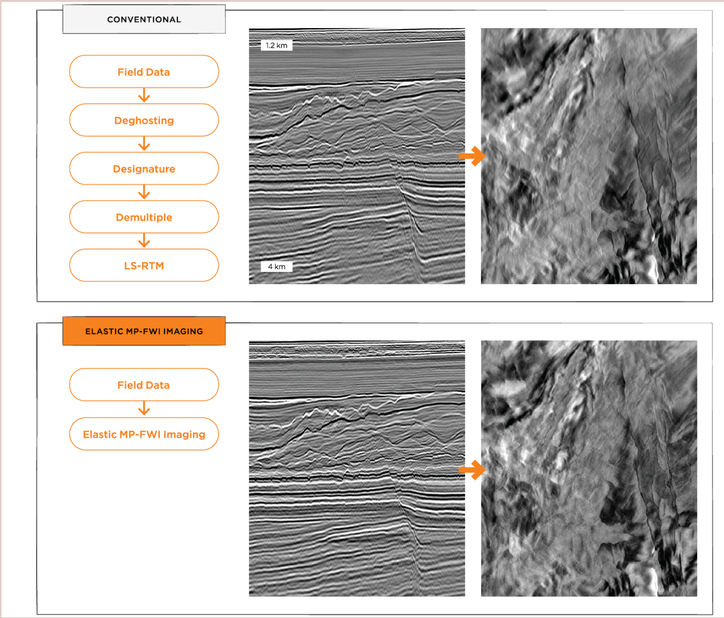


Figure 1: A section and depth slice comparison of conventional processing and imaging (top) and 60 Hz visco-elastic MP-FWI imaging reflectivity derived from raw field data (bottom). An increase in resolution is evident as well as improved structural consistency with depth.

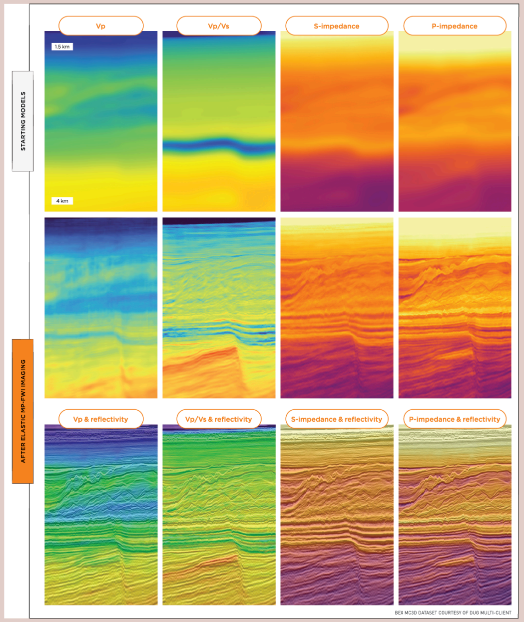
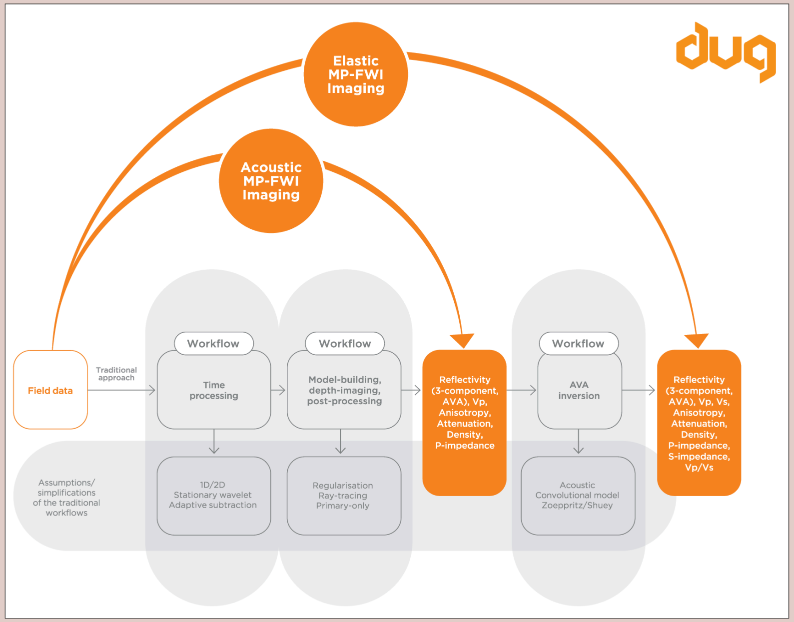


Figure 2: Initial models (top), inverted 60 Hz visco-elastic MP-FWI imaging models (middle) and inverted models co-rendered with the derived reflectivity (bottom). A significant increase in resolution has been achieved using elastic MP-FWI imaging with a gas reservoir and flat spot readily observable.



Deriving rock properties from field data with elastic MP-FWI imaging

The seismic method has proven to be an invaluable tool to determine subsurface structures and properties since the first experiments in the 1920s.

The conventional processing, imaging, and inversion workflows for deriving reflectivity and elastic rock properties have evolved over the last century to use increasingly accurate physics, enabled by advancements in highperformance computing. However, this workflow still contains a wide range of assumptions, approximations, and simplifications, which are mainly due to the fact that legacy acoustic imaging algorithms are limited to using primary reflections. As a result, a significant amount of time and effort is required to remove parts of the recorded data that these algorithms are unable to handle, such as surface waves, converted waves, source and receiver ghosts, internal multiples and free-surface multiples. These workflows can be very lengthy and subjective to implement.

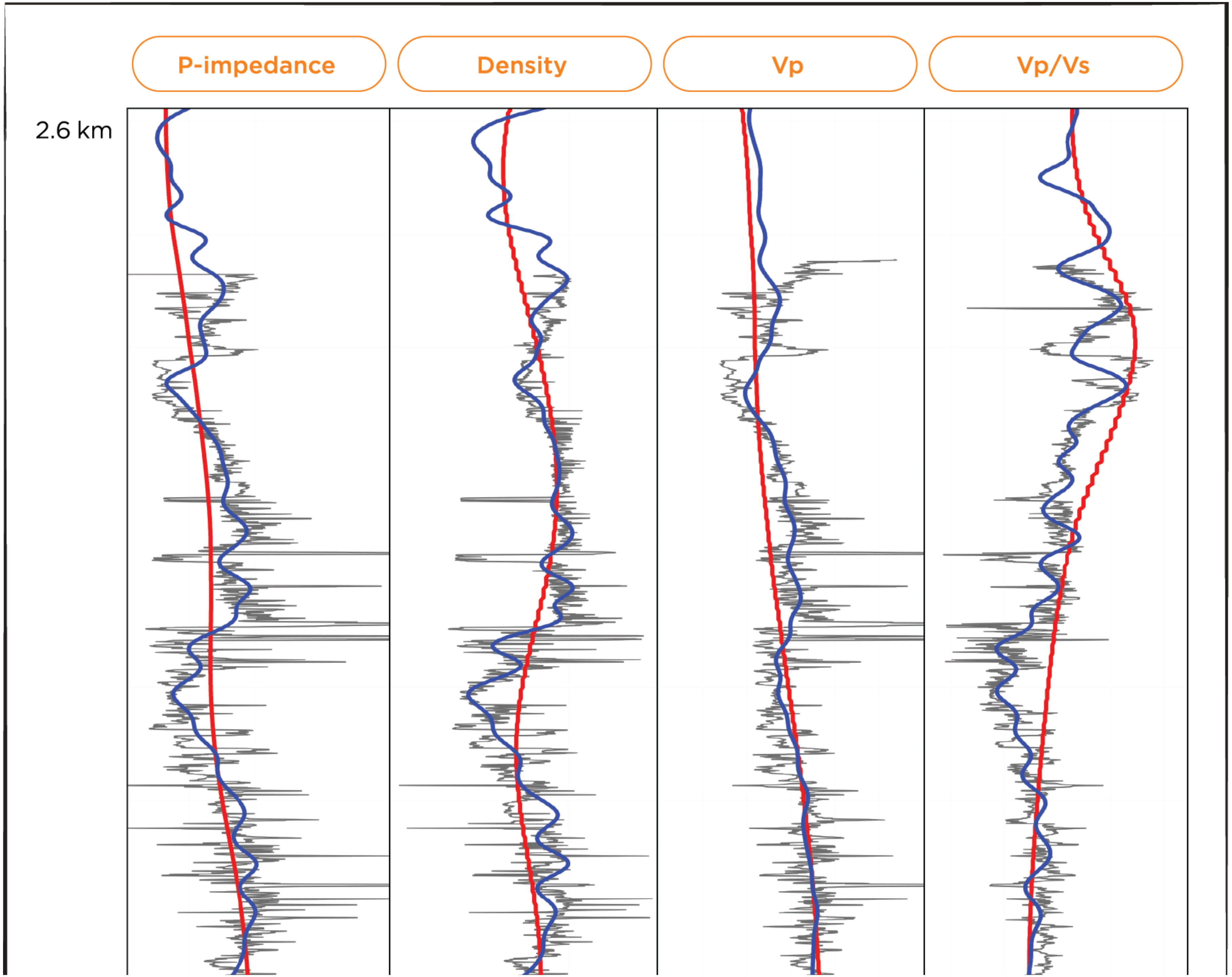
This processing and imaging approach yields pre-stack image gathers or angle stacks, which are used in a subsequent inversion step to determine elastic rock properties, such as P-impedance and Vp/Vs ratio. However, their assumptions still ultimately limit their resolution and amplitude fidelity in regions with high impedance contrasts or complex geology.

A new era of Elastic Least-Squares Imaging

Elastic multi-parameter full waveform inversion (MP-FWI) is a novel form of FWI that can bypass these legacy workflows. The algorithm realises Tarrantola's original vision for FWI, solving for elastic parameters and high-resolution reflectivity directly from raw field data. The full wavefield is modelled, and so the inversion can use all the acquired information. The use of primary and multiple reflections enables the determination of high-resolution Earth models in a least-squares manner. By employing complete and accurate physics and by solving the elastic wave equation, MP-FWI imaging is able to provide much-improved outputs compared to the conventional approach in a much-reduced timeframe.

Case study from Australia

Here, we present a case study that demonstrates the benefits of high-frequency visco-elastic MP-FWI-derived rock properties.



P-impedance
Density
Vp
Vp/Vs
2.6 km

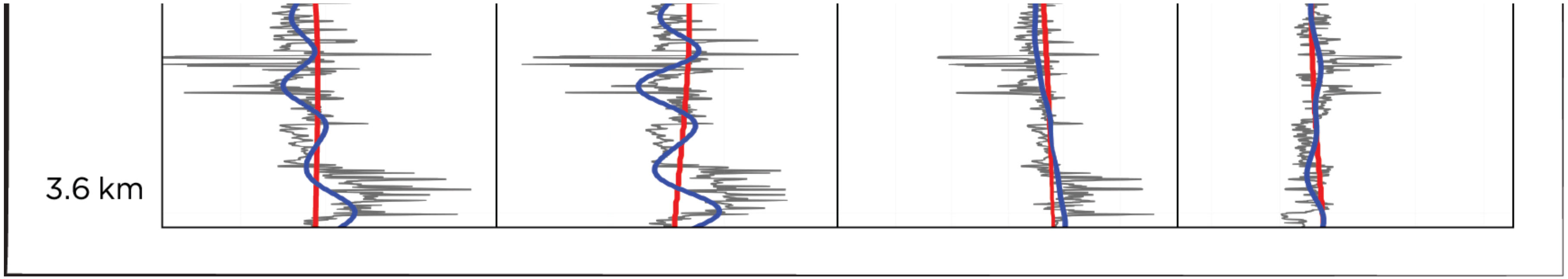


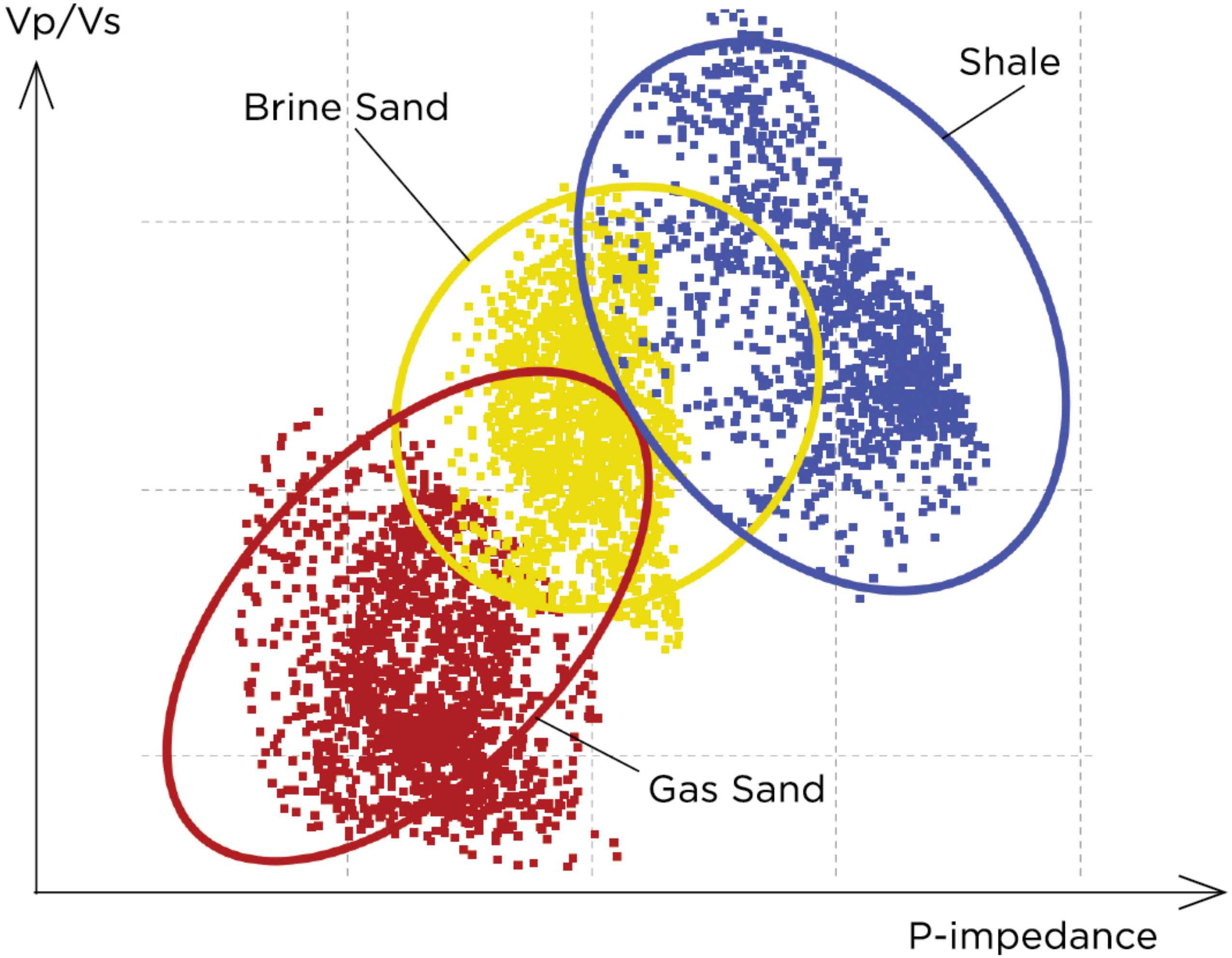
Figure 3: Well logs (grey) compared to initial elastic MP-FWI imaging models (red) and final 60 Hz elastic MP-FWI imaging models (blue). Elastic MP-FWI imaging has added significant resolution that accurately ties the wells.

This narrow azimuth towed streamer data was acquired in 2006 on the Australian North West Shelf, approximately 115 km northwest of Barrow Island. This region contains rapidly changing shallow velocity variations due to localised channel features and carbonates.

Well data located within the survey area and regional knowledge were used to build an initial low-frequency Vp/Vs, density, and anisotropy models, which, combined with a legacy Vp model, formed the input to elastic MP-FWI imaging. Through this approach, a simultaneous update of Vp, P-impedance and Vp/Vs was performed up to a maximum of 60 Hz using a frequency stepping scheme. From these output parameters, others were derived, including Vs, S-impedance, density and reflectivity.

Conventional Workflow

TIME PROCESSING, DEPTH IMAGING
AND AVA INVERSION



Elastic MP-FWI Imaging

USING FIELD-DATA INPUT

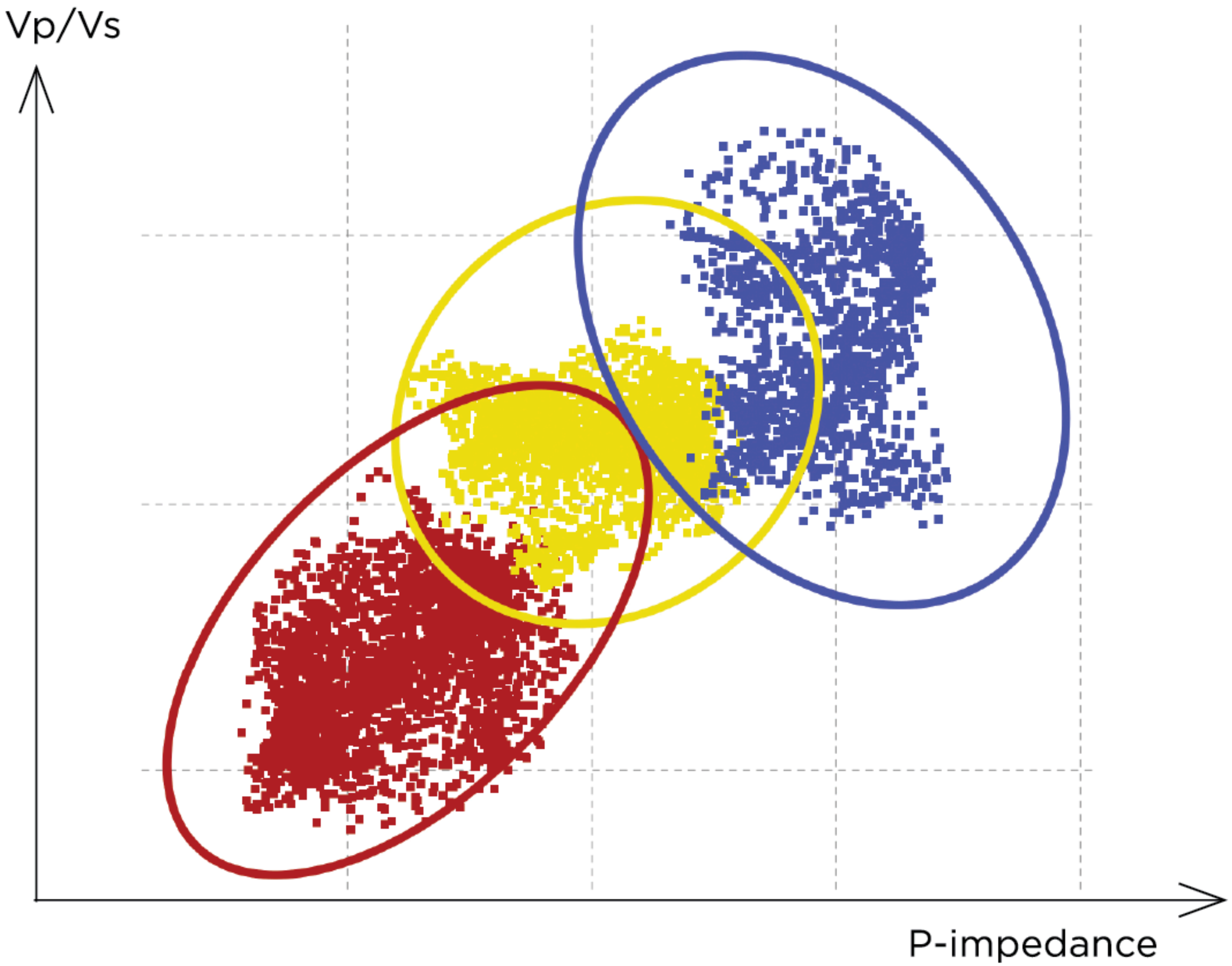
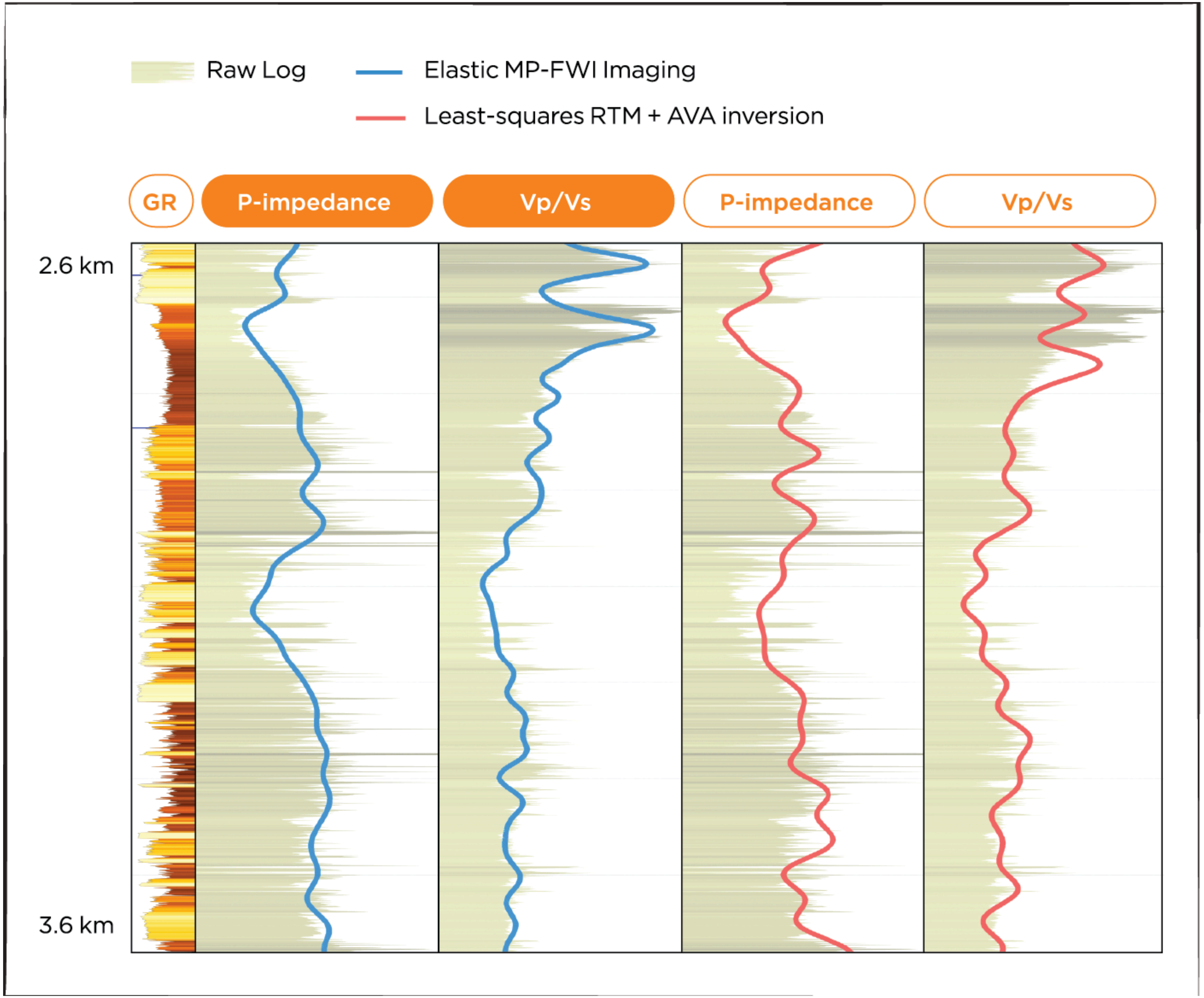


Figure 4: Crossplots of Vp/Vs and P-impedance for conventionally-derived parameters and elastic MP-FWI imaging-derived parameters.

For comparison, a conventional processing and imaging workflow was also implemented, which included designature, deghosting and demultiple. 60 Hz acoustic LS-RTM full and partial angle stacks were generated using the output velocity models from the 60 Hz elastic MP-FWI imaging.

The reflectivity derived from elastic MP-FWI is shown in Figure 1, with a depth slice at 2,570 m, in comparison to the reflectivity generated by the full-angle LS-RTM. It is important to note that the elastic MP-FWI results used the raw, unprocessed shots as input, whereas the LS-RTM used highly processed input data.

The reflectivity generated by elastic MP-FWI demonstrates an increase in resolution compared to the acoustic LS-RTM, where subsurface channel features and complex faulting are sharper and more clearly delineated. A fault shadow is resolved by elastic MP-FWI imaging, and deeper events are more coherent compared to the conventional LS-RTM.



Raw Log
Elastic MP-FWI Imaging
Least-squares RTM + AVA inversion
GR
P-impedance
Vp/Vs
P-impedance
Vp/Vs
2.6 km
3.6 km

Figure 5: Well log comparisons of P-impedance and Vp/Vs derived through the conventional processing, imaging and AVA inversion workflows and elastic MP-FWI imaging.

The elastic MP-FWI imaging initial models, final 60 Hz models and those same models co-rendered with the derived reflectivity are shown in Figure 2. A dramatic increase in resolution has been achieved using MP-FWI imaging, with the presence of a gas body and associated flat spot readily identifiable in the Vp and P-impedance. As expected, this fluid effect is not observed on the inverted S-impedance.

In Figure 3, the well information is in grey, the initial models are in red, and the elastic MP-FWI imaging models are in blue. The elastic MP-FWI updated models correctly predict these properties as measured at the well location, demonstrating that the crosstalk between the various inverted parameters has been successfully resolved.

The conventionally processed LS-RTM angle stacks were used to obtain estimates of P-impedance and Vp/Vs ratio through a conventional AVA inversion. Crossplots of Vp/Vs and P-impedance are shown in Figure 4, and a comparison to a well is shown in Figure 5. The crossplots show a tighter distribution with elastic MP-FWI imaging compared to LS-RTM, indicating a reduction in noise and uncertainty. A significantly better match is observed between the elastic MP-FWI-derived models and the well information, demonstrating that the accurate physics and reduced subjectivity of the elastic MP-FWI approach have yielded superior results.

A TRANSFORMATIVE BREAKTHROUGH

Elastic MP-FWI imaging is a revolutionary technology for seismic data, which is delivering much improved results over decades-old conventional workflows. The use of the full wavefield and superior physics enables bypassing of processing, model-building, imaging, and AVA inversion workflows, allowing for the derivation of high-resolution

Earth models in significantly reduced timeframes. With these new developments, is it time to question whether the conventional workflow is now obsolete?

ACKNOWLEDGEMENTS

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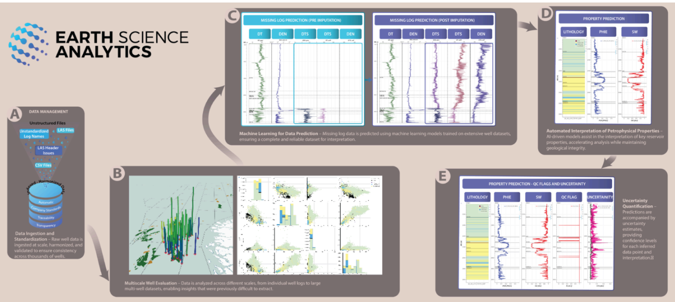

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