Beyond Bright Amplitudes: Characterising Gas-Bearing Intervals with Viscoelastic Multi-Parameter Full Waveform Inversion

A Columbus Basin study combines FWI-derived elastic properties, attenuation, well data and structural imaging to characterise gas-bearing intervals.

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Characterising a gas-bearing interval requires more than simply recognising a bright seismic amplitude anomaly. Its elastic response, relationship to the wells and conformity within the surrounding structure all contribute to the interpretation. In the Columbus Basin, offshore Trinidad and Tobago, shallow gas, strong attenuation and complex faulting make that task particularly demanding. The results presented here use a multi-parameter form of FWI that extends the method into reservoir characterisation. Viscoelastic MP-FWI jointly inverts for P-velocity, P-impedance and Vp/Vs, with Q incorporated in the final joint update. P-velocity, P-impedance and Vp/Vs are interpreted alongside inverted reflectivity and well data (Figure 1). The combined elastic response, expressed through RGB blending and a new Blended Elastic ATtribute (BEAT), helped characterise known gas-bearing intervals and trace their 3D spatial distribution.

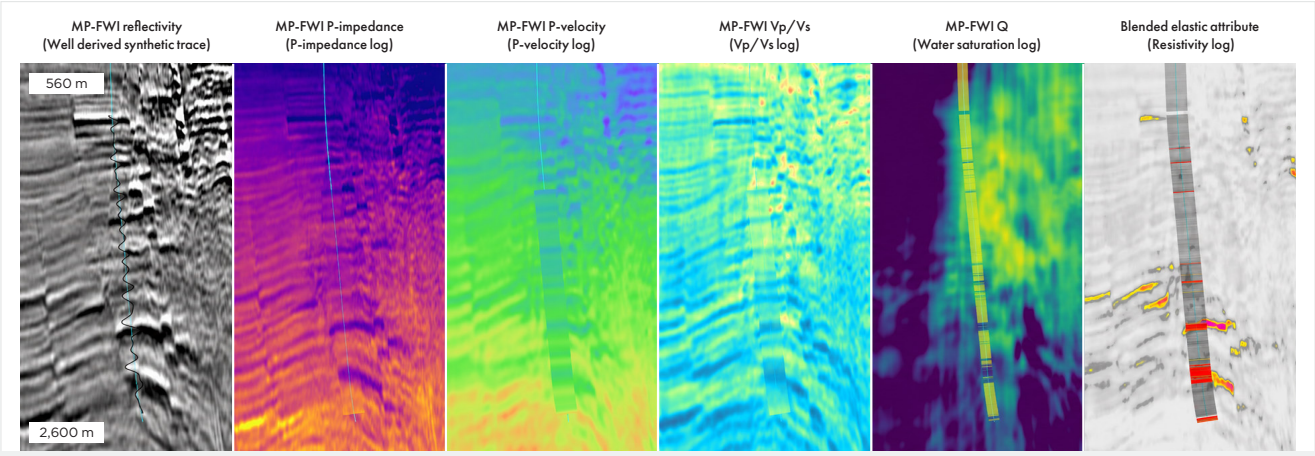


Figure 1. A common section through reflectivity, P-impedance, P-velocity, Vp/Vs, Q and the Blended Elastic ATtribute (BEAT), with synthetic or well-log overlays. The panels bring geological structure, elastic contrasts, attenuation and the combined response of the gas-bearing intervals into one view.

CHARACTERISING GAS IN A COMPLEX BASIN

The Columbus Basin combines thick Plio-Pleistocene sedimentation from the proto-Orinoco system with a complex structural history. Transpressional folds and faults intersect gravity-driven normal faults, creating a dense network of reservoir compartments. Interpreting a gas-bearing sand also requires the inverted elastic response to be geologically conformable with the surrounding stratigraphy and fault-block geometry before it is treated as a robust reservoir response. The seismic, wells and interpretation provide the basis for examining those relationships in an established field.

P-velocity, P-impedance and Vp/Vs offer complementary views of the reservoir. P-velocity responds strongly to the compressibility associated with gas, while P-impedance includes the density contribution. Shaly brine sands in this area can also have low impedance, so an isolated anomaly is not a unique gas indicator. The focus here is on characterising gas intervals, examining how the inverted properties vary through them and following their combined response within the structural image.

DATA AND WORKFLOW

The dataset is a multicomponent ocean-bottom-cable

survey acquired in 2012 in water depths of 50–80 m. Minimal data preparation was performed on the field data, comprising geometry quality control and deblending. The initial models combined geological background trends and legacy tomographic velocity and anisotropy models.

The FWI workflow began with viscoelastic diving-wave FWI and progressed through viscoelastic MP-FWI bands with maximum frequencies of 8, 13, 17, 22 and 30 Hz. Updates to anisotropy and Q were interleaved with the elastic inversions. At the 30 Hz stage, a joint P-velocity, P-impedance and Vp/Vs inversion was followed by a joint four-parameter update that included Q.

FULL WAVEFIELD IMAGING: ESTABLISHING THE STRUCTURAL FRAMEWORK

The first step was to derive the structural image within which the gas-bearing intervals are interpreted. A key advantage of MP-FWI is that, within a single inversion framework, it simultaneously produces a high-resolution seismic image through the recovered reflectivity and derives elastic parameter volumes directly from the data. This provides a consistent, fully data-driven link between structural imaging and reservoir-property characterisation, rather than treating imaging and elastic inversion as separate processing steps.

MP-FWI also uses the full recorded wavefield, including multiples of all orders. Multiples play a major role in shallow imaging because their additional propagation paths provide illumination beyond that available from primary reflections alone, helping extend the image beyond the receiver carpet and remove the acquisition footprint associated with the sparse OBC geometry.

Figure 2 illustrates the improvement in the shallow image; the 250 m depth slice highlights the benefit of the full-wavefield approach. The legacy RTM retains a pronounced acquisition footprint, whereas the MP-FWI reflectivity reveals a much more continuous and detailed fault pattern. At target level, the detailed MP-FWI-derived velocity and Q models further improve the seismic image, providing clearer reflector continuity and sharper delineation of individual fault blocks.

Together, these imaging improvements provided the structural framework for the reservoir-property interpretation that followed.

FROM THE STRUCTURAL IMAGE TO THE RESERVOIR PROPERTIES

With that framework established, the next step was to examine the inverted properties against the wells (Figure 3). Gamma ray and resistivity locate the reservoir intervals; P-velocity, P-impedance and Vp/Vs describe their elastic response; and Q adds attenuation information.

In the examples, low P-velocity, P-impedance, and Vp/Vs values coincide with several known gas sands. Reading these properties alongside gamma ray and resistivity connects the inverted anomalies to the reservoir intervals at the wells and provides a basis for following their response into the surrounding volume.

COMPARING ELASTIC PARAMETERS AGAINST THE WELLS

An important step is to quality-control the inverted elastic parameters against the available well logs. The well logs are not used as direct constraints in the inversion; they are used only to help construct the smooth background starting models for density and Vs. The inverted results can therefore be compared independently with the measured logs. Overall, the agreement is very good. In the section views, the inverted response follows the well-log trends so closely that a box is used to highlight the position of the overlaid log, which would otherwise be difficult to distinguish from the surrounding inversion result.

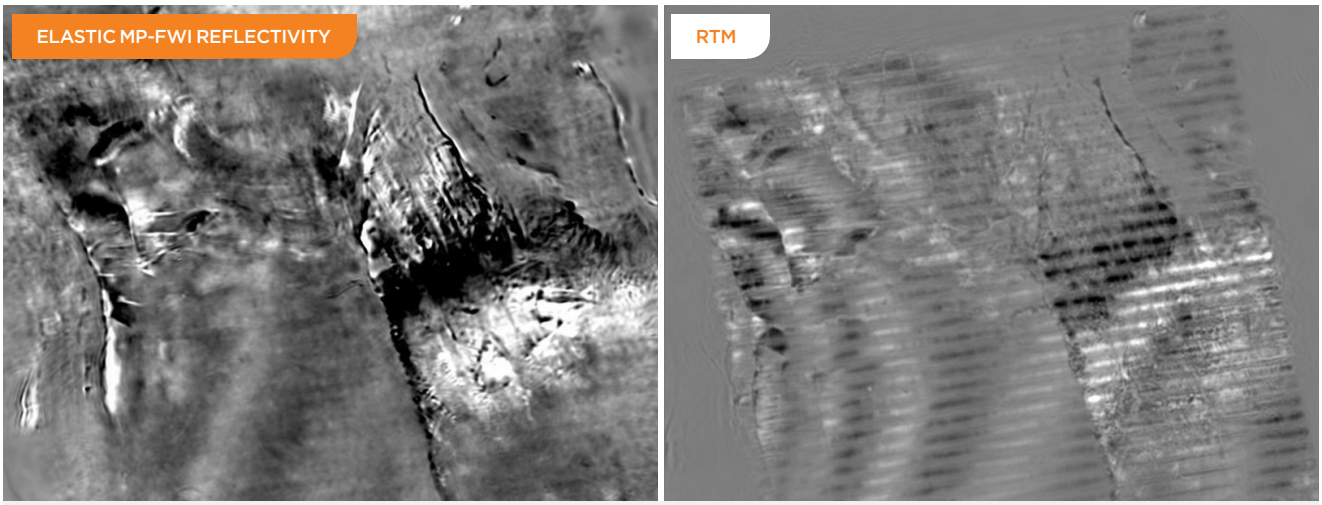


Figure 2. Shallow depth slices at 250 m: MP-FWI reflectivity (top) and legacy reverse-time migration (RTM; bottom). The full-wavefield MP-FWI result uses the illumination contributed by multiples and shows finer structural detail, less acquisition footprint and broader image coverage.

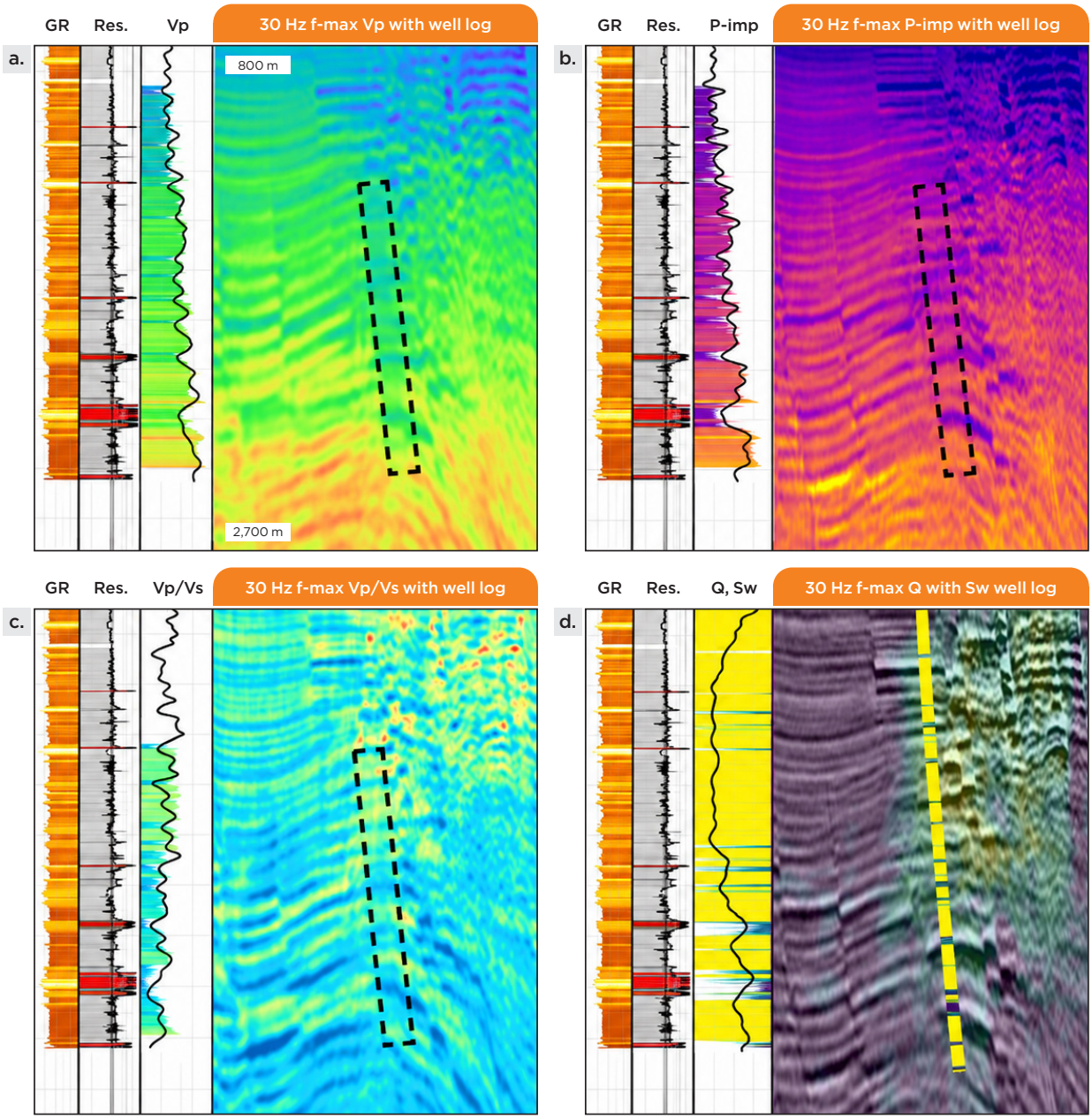


Figure 3. Well and section comparisons: (a) P-velocity; (b) P-impedance; (c) Vp/Vs; and (d) Q with the water-saturation log. Gamma ray and resistivity provide reservoir context, and well logs are overlaid on the sections. Panel (d) compares Q with water saturation.

ATTENUATION

Q is important for correctly modelling propagation-related amplitude loss as seismic waves travel through complex, strongly attenuating geology. This is particularly relevant where the overburden contains shallow gas and strong lateral changes in attenuation.

In this case, Q also shows an interesting relationship with saturation. Figure 3d compares the inverted Q response with the water-saturation log, with lower Q observed in the shallower, more water-saturated gas-bearing intervals and higher Q in the deeper gas sand. This suggests that Q may provide useful additional information on saturation when interpreted alongside the elastic properties and well data.

FROM RGB BLENDING TO THE BLENDED ELASTIC ATTRIBUTE (BEAT)

The next step was to identify where the characteristic gas responses occur together. Initially we created an RGB display, with P-velocity assigned to blue, P-impedance to red and Vp/Vs to green. Where P-velocity, P-impedance and Vp/Vs are all low, the three colour components combine to produce white, making the coincidence of the three low elastic responses immediately visible.

The RGB result inspired the creation of a new attribute, which we named the Blended Elastic ATtribute (BEAT), to leaverage the combination of all the elastic attributes. BEAT combines normalised, detrended components of P-velocity, P-impedance, Vp/Vs and Q. Here, detrending removes the background depth trend so that the blend emphasises local elastic variations. Figure 4 shows how larger BEAT values follow several known gas-bearing intervals when compared with the resistivity log.

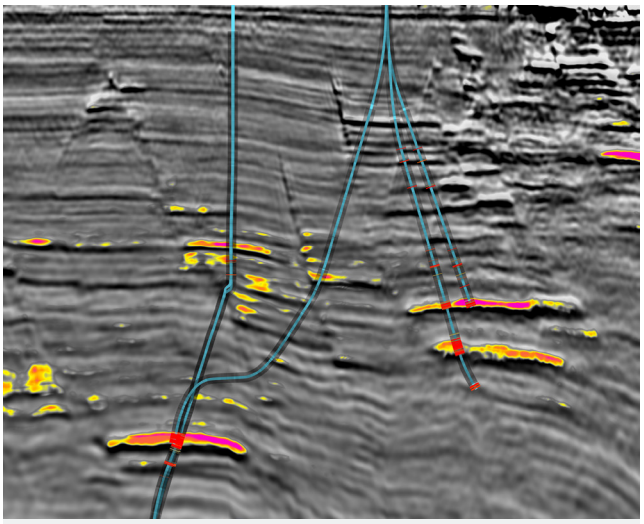


Figure 4. BEAT overlaid on reflectivity, with well trajectories and resistivity logs. Larger attribute values highlight several gas-bearing intervals producing a good match with the resistivity log.

BEAT AND REFLECTIVITY: COMPLEMENTARY VIEWS OF THE SAME HORIZON

Figure 5 compares one BEAT horizon extraction with the corresponding inverted reflectivity magnitude map. The paired white arrows identify two areas where their responses differ. At the central arrow, BEAT is high while reflectivity magnitude is relatively low. At the lower-right arrow, reflectivity magnitude is higher while BEAT is weaker. These contrasts show that BEAT and inverted reflectivity exhibit different spatial responses.

This difference is interesting: if BEAT simply mirrored the inverted reflectivity magnitude, it would add little to the interpretation. The inverted reflectivity is an interface property: within the bandwidth supported by the data and inversion, it represents the magnitude of the elastic contrast across an interface. BEAT, by contrast, combines inverted P-velocity, P-impedance, Vp/Vs and Q, therefore describing the combined elastic character of the interval rather than only the contrast at its boundary.

A strong interface contrast can produce high reflectivity magnitude without a strong BEAT response, while an interval with a pronounced combined elastic-property anomaly can show high BEAT where reflectivity magnitude is more modest. The arrowed differences are therefore useful places to examine the component volumes.

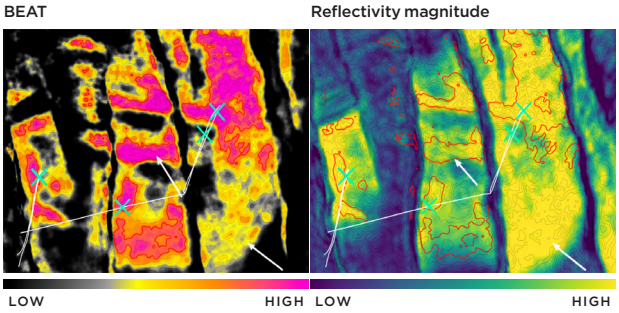


Figure 5. One horizon shown as BEAT (left) and inverted reflectivity magnitude (right). Paired white arrows mark high BEAT with relatively low reflectivity magnitude in the central area, and higher reflectivity magnitude with weaker BEAT in the lower-right area. Well trajectories are shown in white.

CONCLUSIONS

Viscoelastic MP-FWI has the great advantage of combining full-wavefield imaging with accurate elastic parameter inversions. In this project the inverted P-velocity and Q models enhanced the seismic image at target level, providing clearer reflector continuity and sharper fault block definition. The well comparisons showed an excellent match across all inverted parameters, providing confidence in the reliability of the results. We introduced the new BEAT parameter, which combines the elastic response into a single attribute volume that can be readily investigated. Its local differences from reflectivity magnitude provided a complementary view for characterising gas-bearing intervals and tracing their spatial distribution.

Further work will focus on increasing resolution. Higher-frequency inversion would allow investigation of finer-scale variations in thin intervals. A dedicated statistical rock-physics analysis would then be a natural next step to quantify the relationships between the inverted elastic parameters, lithology and fluid content.

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