Basin Structure Group

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Exploring structural uncertainty through seismic forward modelling.

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Concept

1. Introduction

Seismic reflection profiles provide invaluable information on the geometry and composition of the subsurface, however the complexity of their acquisition and processing often limits their imaging quality. This is particularly the case for areas of complex geological structure.

During interpretation, this leads to reliance on the application of deformation templates and validation through kinematic balancing methods. Both, provide non-unique solutions, frequently biased by the interpreters past experience.

Using group interpretation, facilitated by Agile Geoscience's Pick This application, we demonstrate an approach to compile a selection of interpretations, validated by kinematic modelling and subsequently seismically forward modelled for direct comparison to the original input data.

Such approaches are common in application to amplitude analysis, however tend to be avoided at larger scales due to the requirement for elastic properties. Applying broadly representative parameters we demonstrate valuable geometric information may be gained informing the interpreter of likely illumination patterns and potential resolution constraints.

This allows direct comparison of an interpretation in the form of a seismic profile to the original data, effectively allowing informed mapping of the imaging uncertainty within a section.

2. Background

Seismic imaging quality

Seismic imaging quality may be considered in terms of resolution and detectability. Resolution describes the ability to discriminate between two responses (Sheriff, 1977). Originally considered in terms of two equal impedance contrasts (Widess, 1973) and later as two responses with opposite polarity (Kallweit & Wood, 1982; Ricker, 1953).

Detectability describes the potential to identify responses within the background noise (Kallweit & Wood, 1982). In areas of deformation, this often limits imaging quality.

Resolution may be calculated with relative ease, however detectability requires modelling of acquisition design and wave interaction with the subsurface (Kallweit & Wood, 1982).

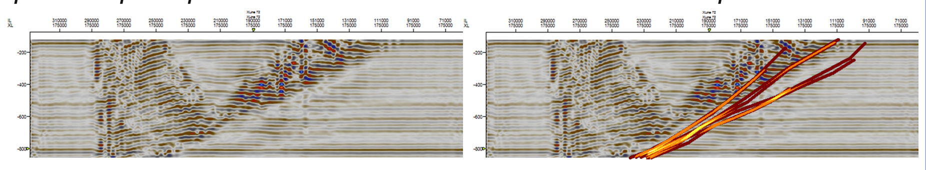
Risk, variability and uncertainty in seismic interpretation

Application of subsurface data invariably requires consideration of uncertainty. Uncertainties may be divided into those that represent natural variability within expected constraints (aleatory) and those due to incomplete knowledge (epistemic) (Bowden, 2004), also referred to as objective or subjective uncertainties, respectively (Bond 2015, Macrae et al. 2016).

Probabilistic modelling provides an accepted approach to estimate probability distributions of aleatory uncertainty, however addressing epistemic uncertainty is more contentious as it is often categorical and and dependent on other risks (Aven, 2010; Ferson & Ginzburg, 1996; Nilsen & Aven, 2003). In section 5, we apply industry standard methodologies using decision trees to catalogue individual risks and calculate the relative likelihood of scenarios (Peel & Brooks, 2016).

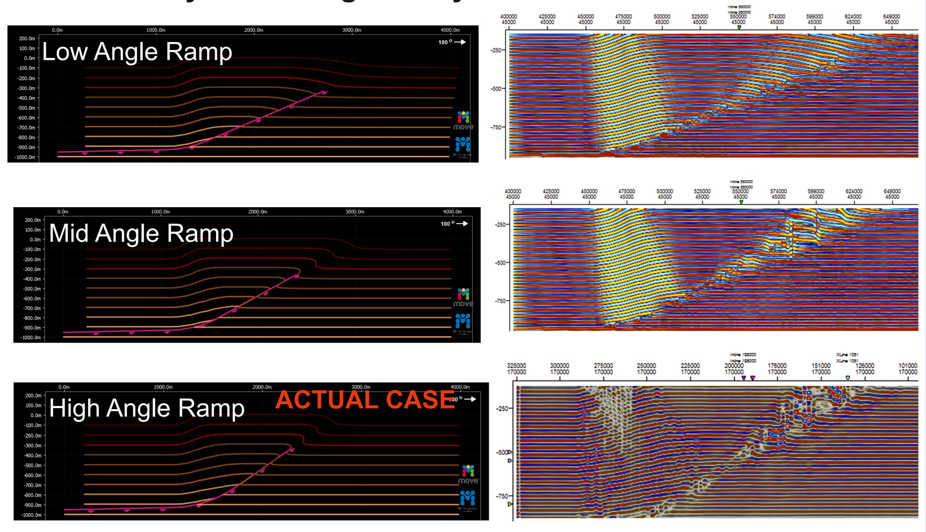
3. Multiple interpretations

Synthetic data provided to nine structural geologists, asked to:
"pick the principle fault structure from basement to fault tip."



Synthetic data | Synthetic data with interpreted picks

Kinematically balanced geometry | **Seismic forward model**

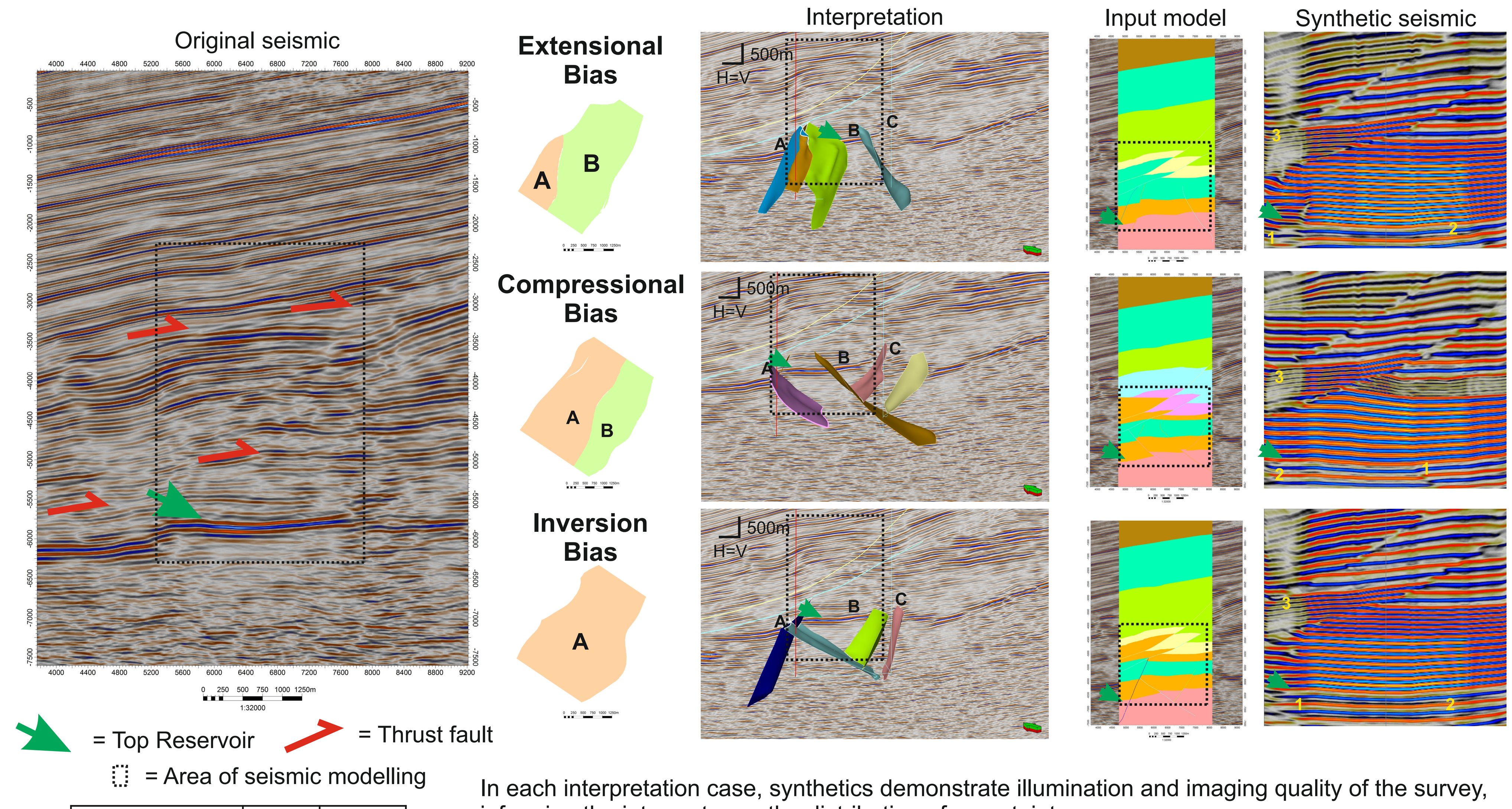


Extracting a range of potential geometries from multiple interpreters allowed identification of different interpretation scenarios, subsequently kinematically validated and seismic forward modelled.

The synthetic seismic sllows direct comparison between the original data and proposed interpretation. In this case the high angle ramp model matches the original input geometry.

Application

4. Forward modelling to support volumetric risking



Parameter		Sand	Shale
P-wave	Vp	3.2	2.4 km/s
S-wave	Vs	Vp/1.7	Vp/1.73
Bulk density	Rho	2.3	2.15

Table 1: Elastic properties used in seismic forward modelling. All layer thicknesses were constrained to 20m, alternating sand / shale.

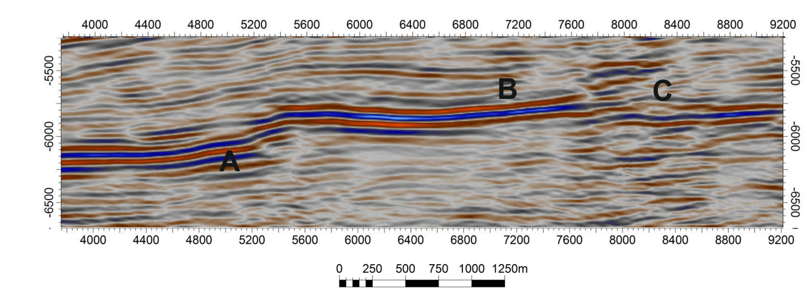
In each interpretation case, synthetics demonstrate illumination and imaging quality of the survey, informing the interpreter on the distribution of uncertainty.

Extensional model
1) Visible drop in reservoir level to left
2) Sweeping rise to right
3) Weak response due to overlying convexity and poor angle for illumination

Compressional model
1) Offset clearly visible in synthetic
2) Aliasing to left obscures drop to left
3) Weak response due to overlying convexity and poor angle for illumination

Reactivated model
1) Reverse fault optimal orientation for illumination
2) Sweeping rise to right
3) Weak response due to overlying convexity and poor angle for illumination

(Numbering refers to synthetic seismic images above.)



	Extensional	Compressional	Reactivated
A	Footwall fault drag	Fault-fold	Fault-fold
B	Normal fault	Synthetic fault-fold	Antithetic fault-fold
C	Footwall deformation	Antithetic fault	Antithetic fault

Table 2: Illustration of alternate interpretation of three simple geometries, dependent on interpreted setting.

Aspects of the geometry can be interpreted differently, dependent on the overall setting assumed. In this sub-thrust setting with a break-down of seismic signal below, the range of acceptable solutions is broad and guided by the assumed tectonic setting. However in this area that assumption is interpreter dependent.

Synthetic data suggests a right-dipping fault in position C, should be visible, decreasing the likelihood of a compressional case.

Case	Chance	Justification
Extension	0.4	Known passive margin history, normal offset faults visible.
Compression	0.2	Synthetic suggest compressional features would be visible if present. Limited features identified with certainty.
Inversion	0.4	Known passive margin history, normal offset faults visible.

Table 3: Breakdown and justification of relative likelihood

Conclusions

5. Volume risking

	Extension		Compression		Inversion
Area	A	B	A	B	A
Recoverable HC	23.8	127.6	116.2	113.5	196.9
Prospect totals	151.4		229.7		196.9

Table 4: Recoverable hydrocarbon volumes (MMbbls). Assumes porosity 0.22, average water saturation 0.6, formation volume factor 1.2, recovery factor 0.6.

Interpretation case	COS	Fault seal	Total probability	Potential volume	Risked volume
0.4 Extensional	0.42 Success, p(B)	0.5 Fault open	0.084	151.4	12.7
		0.5 Fault closed	0.084	127.6	10.7
	0.58 Failure	- - - - - - - - - -	0.232	0	0
0.2 Compressional	0.42 Success, p(A)	0.5 Fault open	0.042	229.7	9.6
		0.5 Fault closed	0.042	116.2	4.9
	0.58 Failure	- - - - - - - - - -	0.116	0	0
0.4 Reactivated	0.42 Success, p(A)	- - - - - - - - - -	0.168	196.9	33.1
	0.58 Failure	- - - - - - - - - -	0.232	0	0

Table 5: Decision tree and table of risked volumes for segments (MMbbls). Risked for overall project risk, as detailed in section 4 and for fault seal risk.

Risk strategy	COS	Fault seal	Risked volume
Best guess (Reactivated case)	0.42	N/A	82.7
Multi-deterministic	0.42	0.5	71.0

Table 6: Mid-case risked recoverable volumes for each risk assessment strategy show a16% difference, likely significant enough to affect decision-making.

6. Conclusions

Using broadly representative elastic properties and kinematically validated geometries, we demonstrate that synthetic seismic volumes allow direct comparison of interpretation to acquired data. This considers seismic imaging quality and illumination in the likelihood of detection for interpreted features.

Modelling illustrates the presence of coherent noise in geologically reasonable geometries. While such deformation is expected, evidenced by many field analogues, this provides an additional caution to validate seismic observations wherever possible.

Application of an industry-standard risking approach demonstrates a 16% difference in expected volumes when applying a best-case versus multi-deterministic derived approach.

This significant difference in potential volumes could significantly affect decision-making processes. Seismic forward modelling facilitates broader consideration of geometric uncertainty and aids consideration of an appropriate risk assessment strategy.

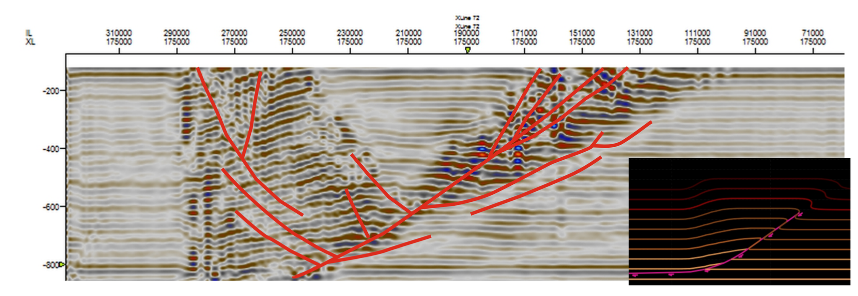


Figure: A complex fault interpretation made on the synthetic seismic data from section 3. Note the simplicity of the inset input geometry.

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