Using Geological Expression Techniques to Reveal Complex Regional Structural Information without Conventional Interpretation*

Tom Wooltorton[1]

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[1]ffA, Houston, Texas (twooltorton@ffa-geosciences.com)

Abstract

The workflows applied in the interpretation of regional structure in post-stack 3-D seismic datasets are very much a legacy of techniques developed when 2-D seismic first arose to prominence decades ago as a regional mapping tool, and interpreters used pencil and paper to carry-out their analyses. Nowadays, despite the vast quantities of data contained in high-resolution 3-D surveys and the availability of high-end processing machines, the techniques most commonly applied have not advanced significantly.

Principally, structural interpretation of 3-D seismic is achieved through the manual picking of faults on inlines and crosslines, interpolating picks into surfaces, and then defining the geological context of the extracted results. Occasionally this will be aided by discontinuity-highlighting attributes or automated fault extraction techniques. It is then up to the geoscientist to determine whether the interpretation makes sense or what conclusions can be drawn. This can be inefficient for several reasons: firstly, manual interpretation is very time consuming; secondly, there is a high risk of subjectivity, particularly where the image is poor. Work may also be rushed or details insufficiently examined.

This article outlines the techniques applied and conclusions derived from fully-3-D analysis of a 3-D dataset, using Geological Expression techniques, in order to determine what results can be obtained without manual picking. The goal of Geological Expression is to define distinct geological elements within the seismic, using data-driven but interpreter-guided processes to carry-out analysis. The techniques include analysis of structural orientations within the data using volumetric dip and azimuth, extraction and analysis of different generations of faulting, and integration with knowledge of other exploration goals in the region.

After illuminating the data in terms of separate geological domains, with clearly identifiable structural regimes and bounding surfaces, the analysis highlighted results that can be confidently interpreted as fault extension and reactivation through a regional capping lithology, which represents a notable seal failure risk. The use of volumetric techniques provided a basis for quantitative analysis to validate the ongoing interpretation. It was also found that the time taken to complete the analysis was significantly shorter than conventional interpretation techniques for this data.

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Using Geological Expression Techniques to Reveal Complex Regional Structural Information Without Conventional Interpretation

Tom Wooltorton 5/21/13
AAPG ACE 2013 Pittsburgh, PA

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Structural Interpretation

3D Seismic structural interpretation workflows are a legacy of 2D interpretation styles

Manual interpretation is time-consuming, at risk of subjectivity, and an inefficient use of volumetric data

The aim of this study was to determine structural information contained in a 3D seismic dataset, without recourse to conventional manual interpretation

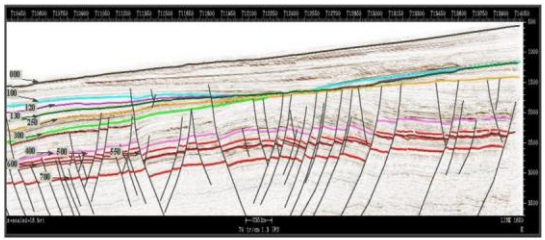

Image: Craig Dempsey/BHP Billiton, *WA-255-P HCA2000A 3D Seismic Survey Interpretation Report*, 19th Aug., 2002

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Presenter's notes: Principally, structural interpretation of 3D seismic is a legacy of the 2D origins of the medium and is achieved through the manual picking of faults on inlines and crosslines and then defining the geological context of the results. Occasionally this is aided by seismic attributes or automated techniques. This can be inefficient for several reasons:

- firstly, manual interpretation is very time-consuming.
- Secondly, there is a high risk of subjectivity, especially in poor quality or ambiguous data.
- Even the most meticulous interpreter can only process a portion of the total data by eye; so data usage is of low efficiency.

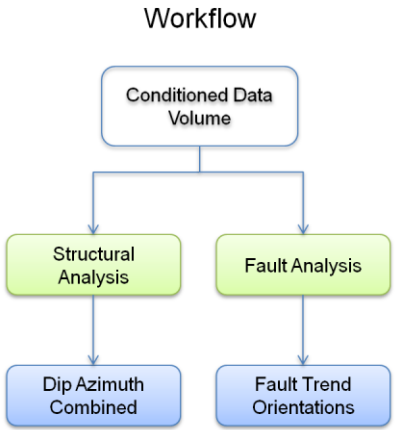
The aim of this study was to determine what results can be obtained without recourse to conventional manual techniques.

Theory

Geological Expression techniques convert geophysical data into geological information

Interpreter knowledge and geological experience combined with data-driven automation and accuracy

- Reduced time to generate geologically meaningful results
- More accessible information and reduced uncertainty
- Enhanced value of original seismic through maximum data usage



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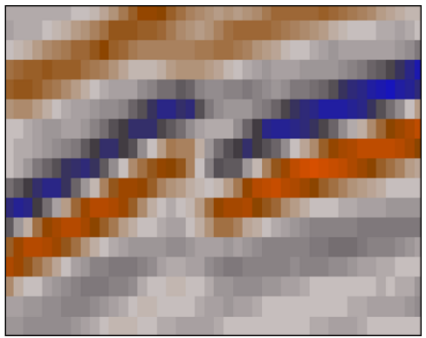
Presenter's notes: Using a Geological Expression workflow overcomes the limitations of the manual approach. This refers to a data-driven but interpreter-guided approach to understanding and defining the 3D morphology of the geological elements within the seismic data, striking a balance between the contextual knowledge, but subjectivity of manual interpretation, and the objectivity but speed and accuracy of an automated approach.

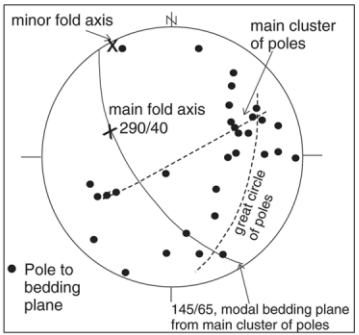
- Time to generate geological results is reduced.
- Transforming data into a specifically relevant medium reduces uncertainty by making information more accessible.
- Maximize value of original seismic by ensuring full data content is used.

For this analysis, a threefold workflow was applied.

- Noise cancellation to condition the data for analysis and improve the signal to noise ratio,
- Structural analysis to gain a rapid overview and understanding of the regional structure, and
- Fault analysis to describe the stress regimes in place and integrate the information gained with the local petroleum system.

Theory





Seismic data contains a vast number of individual data samples, each of which represents a potential measurement

These can be used to populate analyses, in a fashion analogous to classic structural interpretation methods

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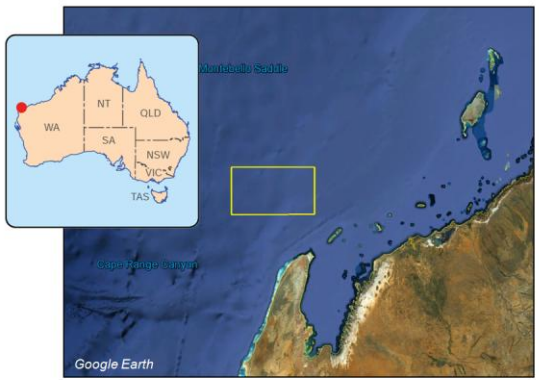
Presenter's notes: To add substance to this case study and diversify the techniques applied, interpretation was validated by using statistical analysis of structural information. Seismic data contains millions if not billions of individual samples, all potentially representing a measurement. Using exclusively volumetric computations builds-up a wealth of data for dissection.
This allows for a much more scientific approach analogous to field structural mapping, and has been used successfully for some time in seismic geomorphology.
To accurately control the analysis, applied processes were finely tuned through parameterization, imprinting the interpreter knowledge on the analysis, and discarding redundant information.

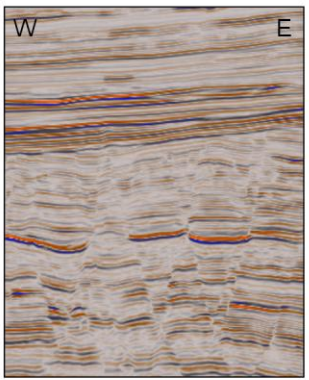
Data

HCA2000A 3D Seismic Survey

Courtesy of Geoscience Australia



Representative Section
Inline



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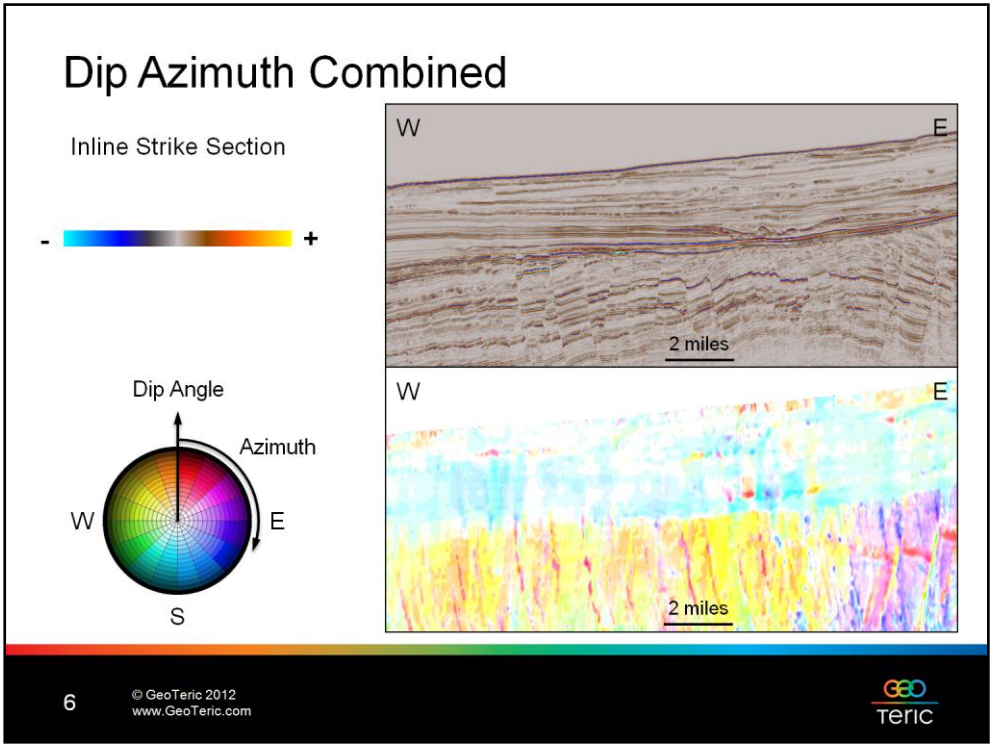
Presenter's notes: The data set in question is from the northwest shelf of Australia and comes courtesy of Geoscience Australia. Approximately 155mi2 of data was used for this study, from seabed down to almost 3 seconds.

We can see an indication of the structural style in this inline here, including faults and varying dip angles, but it is not until we utilize a fully 3D structural analysis that we will get a full picture of the structure.

Although there is a large body of information to validate the conclusions in this study, the data was treated as unfamiliar, and the approach is similarly discussed here.

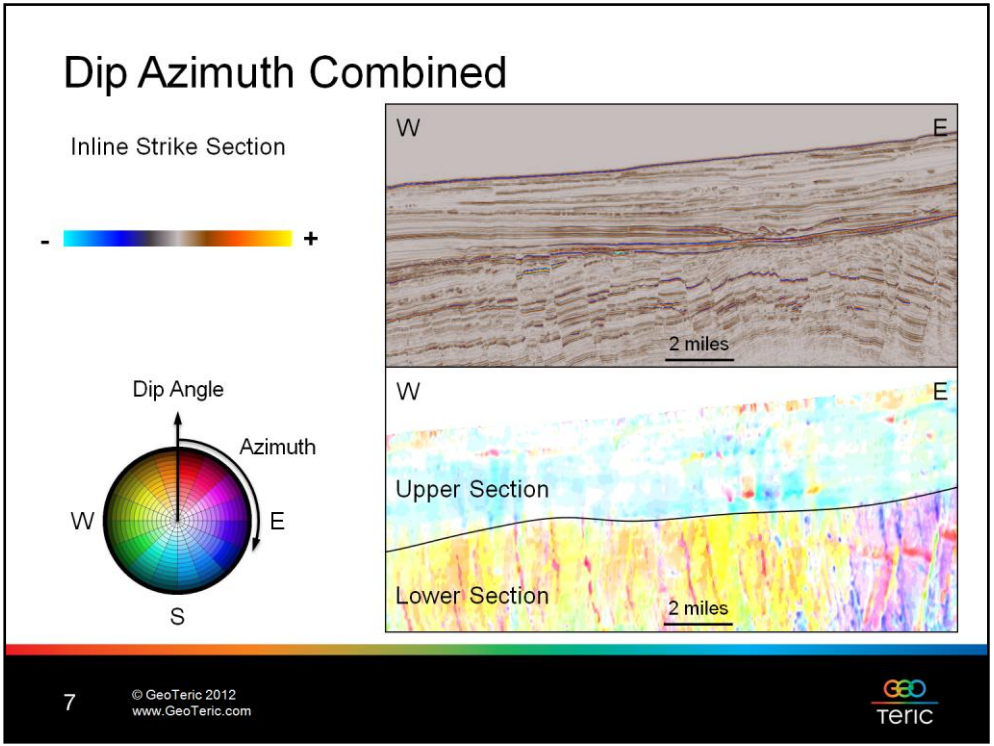


Presenter's notes: After noise cancellation, the first step was to understand the regional structure without having to manually pick and interpret an initial framework. Volumetric-dip and azimuth (dip direction) results are calculated in respective cubes; so each sample in the data has a local measurement for each.

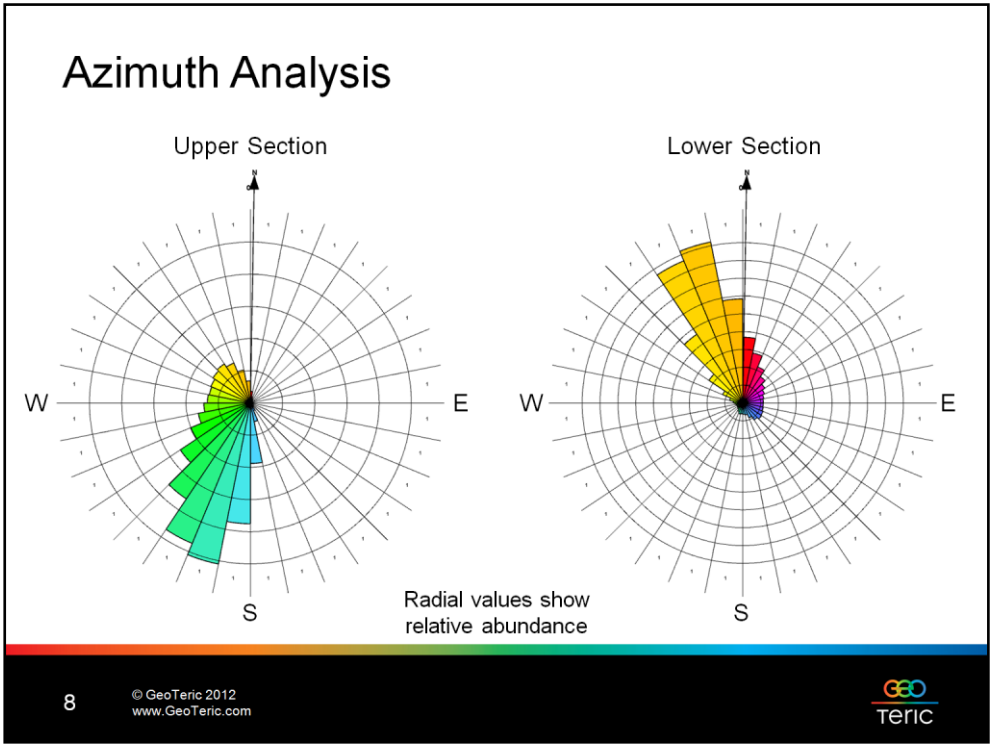
Calculation was parameterized to isolate local structure and discard stratigraphic edges, etc. In this way precise control over the processes was exerted.

Visual interpretation of dipazi combine allows rapid conclusions:

- See unconformity, different characters above and below, and faults.
- A structural history would be: deposition of one unit, tectonic uplift/tilting/erosion, then later resumption of deposition.

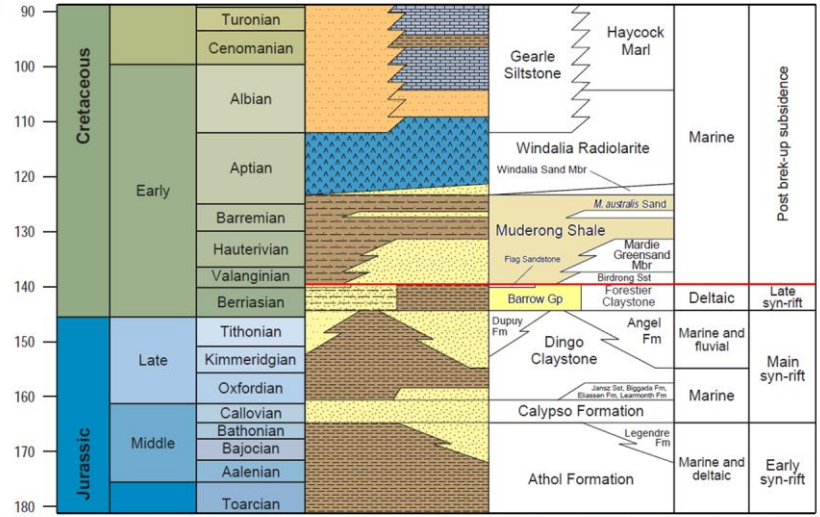


Presenter's notes: We can use the unconformity to divide data into different structural domains, for the sake of reference, we will call these the upper and lower sections.



Presenter's notes: There is a need to back-up interpretation with statistical evidence, achieved using rose plots.
This display shows relative abundance of dip directions; an alternative would be to generate stereonet-type plots.
One conclusion we can make already: due to consistency of orientations, it is extremely unlikely to locate potential dip closures for accumulations within each zone, or away from the unconformity.
So having established different structural trends are present, we need to know about stress regimes in each section by analyzing faults. Also, we need to know how faults will behave in different sections and what implications that will have for petroleum system, for migration, trapping, sealing. [Note: each measurement is averaged over approx. 400m.]

Stratigraphic Relationships



Adapted from: *Exmouth Sub Basin 2010 Offshore Petroleum Exploration Acreage Release*, Geoscience Australia

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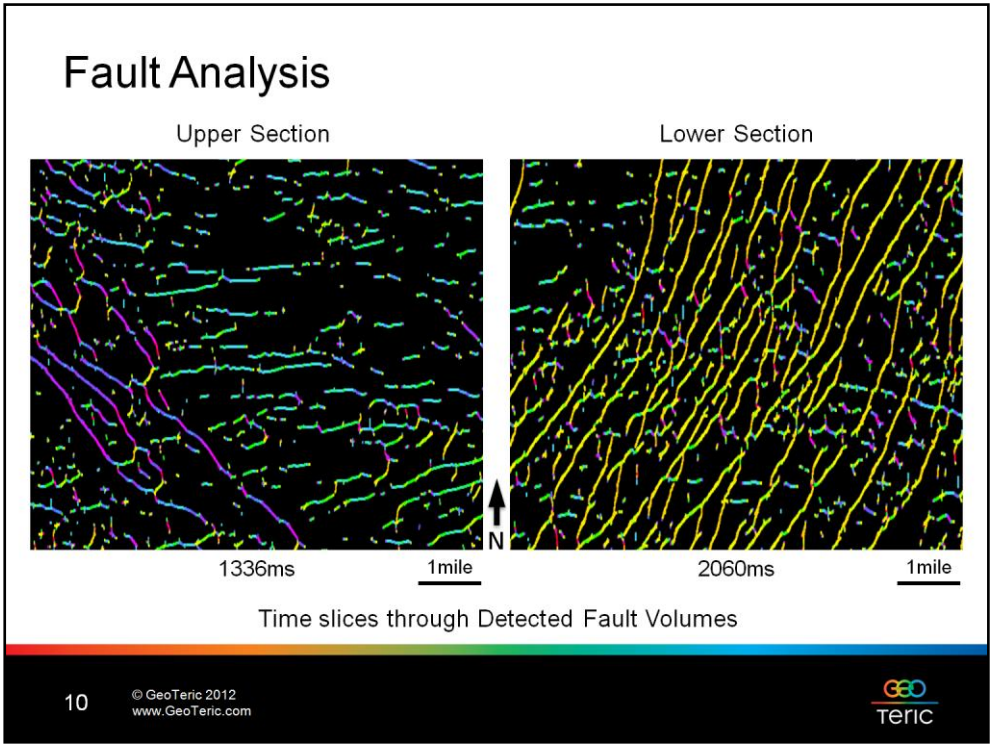
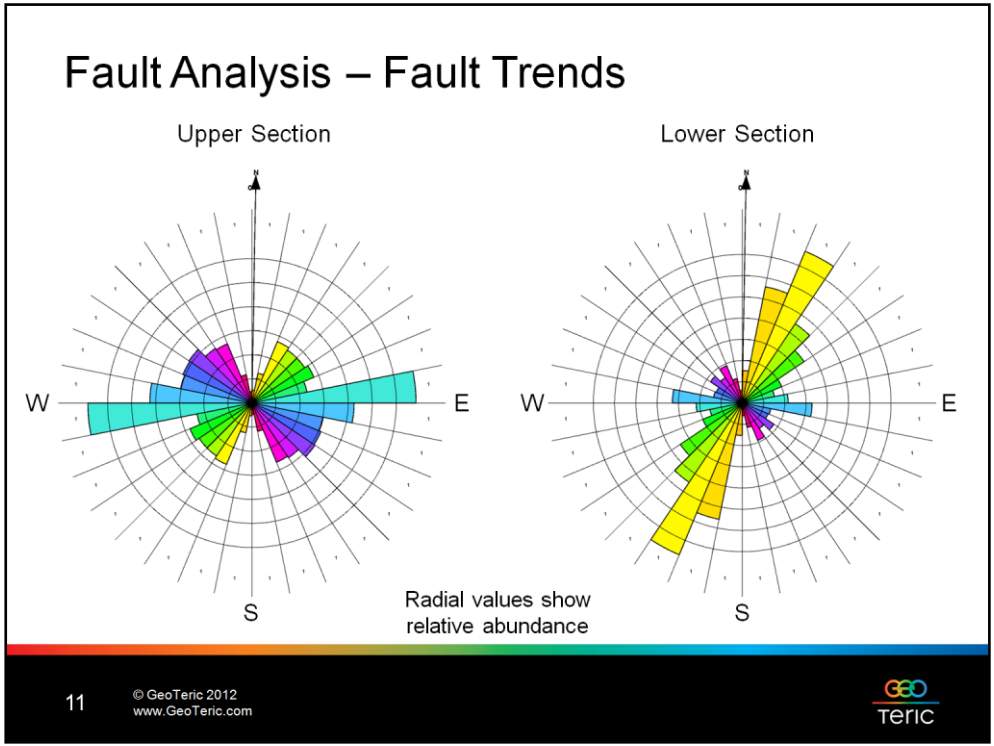
Presenter's notes: This unconformity represents a combination of Valanginian and Hauterivian chronostratigraphic gaps, and the separation of the producing Barrow Group sandstones and the regional seal of the Muderong Shale.
Note the syn-rift/post-rift positions of each, respectively.
We know that the stress regimes changed between each time period; we need to see how this is manifested in the faulting styles.



Presenter's notes: Fault extraction workflow was applied to highlight specifically the principal regional faults, again tailoring analysis to isolate large-scale faulting and exclude irrelevant data.

On interpretation, one can see a couple of families of faulting in each section. Identified major faults in lower section are recorded as principal mechanism for displacement.

Lower section experienced much more tectonic activity (syn-rift deposition, inversion, then peneplanation), hence the very strongly defined fault network.

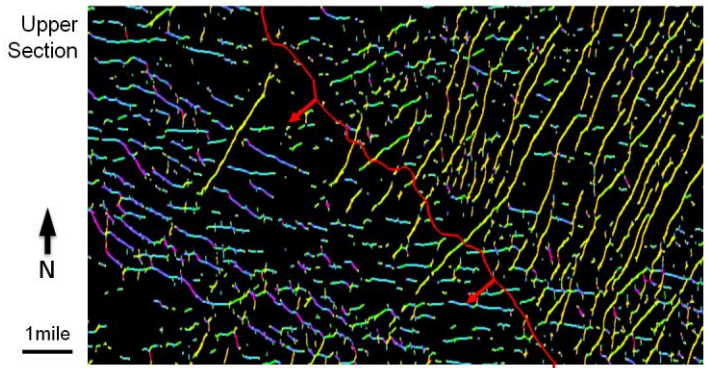


Presenter's notes: Because we know the older units in the lower section were subjected to structural processes prior to uplift and erosion and the eventual deposition of the upper section, we expected to see different faulting styles in each section due to varying stress regimes over time. However, the indications of similarity in the rose plots raise the question of whether the unconformity represents a total structural discontinuity or whether there is linkage between the structural frameworks.

Seal Failure Risk

Multiple faults can be seen transgressing the unconformity from the lower to upper sections

This represents a potential seal failure risk in the Muderong Shale



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Presenter's notes: Going back to a visual interpretation, faults from lower section transgress unconformity or reappear above unconformity, showing plane propagation.

This may be due to reactivation, continued movement along planes of weakness, etc. In any event, fault system, which provides bounding structure for local reservoirs, passes from reservoir strata through the regional sealing lithology, representing a significant seal failure risk.

This analysis has provided a product which not only informs us of this risk but also provides a means of addressing that risk by facilitating more accurate and confident interpretation of any prospect-specific fault or seal-damage risks.

Conclusions and Future Work

Geological Expression techniques were applied in order to obtain structural information from a 3D seismic dataset

- Structural analysis revealed Hauterivian-Valanginian age unconformities, which separate the producible Barrow Gp sandstones from the regional Muderong Shale seal, and described their structural trends
- Fault analysis allowed interpretation of the structural history and revealed a major fault family transgressing the unconformities, potentially jeopardizing seal integrity and increasing petroleum exploration risk
- The total workflow time for this analysis was on the order of days to a week and manual interpretation was not required
- Similar analyses could be developed for multi-scale structural analysis

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Presenter's notes : In terms of future work, the main advantages lie in developing workflows that can be applied to all new datasets, taking substantial amounts of time and subjectivity out of the initial structural interpretation workflow. By perhaps automatically classifying these volumes in geological or structural 'domains', interpreters can bring their knowledge to bear much faster, assigning their petroleum system knowledge to the problem and getting to these exploration risk conclusions that much faster and with reduced uncertainty.
The scalability of the techniques and level of interpreter control mean similar workflows could also be developed for other objectives, from fracture and reservoir scale to regional.