Calibration of Igneous Systems and Basin Prospectivity using 2D Seismic and Potential Field Interpretations*

Andrew Krassay[1], Karen Connors[1], Lynn Pryer[1], and Cedric Jorand[1]

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[1]FrOG Tech, Canberra, ACT, Australia (akrassay@frogtech.com.au)

Abstract

Exploration for unconventional and conventional hydrocarbons is experiencing a boom in older, onshore basins where seismic data is commonly sparse. In Australia, large onshore Proterozoic to Mesozoic basins host multiple working petroleum systems, potentially huge volumes of gas and oil, and have been affected by many igneous events. In onshore South America, the interior Paleozoic basins feature Triassic and younger igneous events that affected generation timing, reservoir quality, preservation potential and migration.

Regional 2D seismic is used to interpret the location, depth and thickness of igneous rocks that have intruded into source-reservoir systems. Seismic facies analysis is important for assessing lithofacies variations where interbedded volcanics are present. In the Jurassic-Cretaceous Otway Basin, seismic interpretation helps distinguish synrift flow-basalts from lacustrine shale source intervals.

In the greater McArthur Basin in northern Australia, dolerite sills have been intruded directly into the main marine source rock and above and beneath the main conventional reservoir. Similarly, in onshore South America (eg. Solimões, Amazonas basins) Mesozoic sills and dykes have been intruded directly into the Paleozoic petroleum systems elements and provide the critical moment for these systems.

Basalt flows and diabase sills are commonly able to be mapped on the seismic data but it is more difficult to interpret dykes on seismic data alone. Igneous units commonly exhibit high seismic reflection amplitudes compared to surrounding basin units.

Seismic interpretation of the character and type of the igneous units is important for identifying the likely location of igneous feeder systems and the possible extent of the igneous systems.

Combining seismic and potential field interpretations provides many benefits. Firstly, potential field data commonly cover a greater area than seismic grids and allow an interpretation to be expanded across an entire basin to rapidly assess prospectivity and volcanic risk. Secondly, high resolution magnetic and gravity data can help distinguish subtle igneous features such as dyke trends and igneous centres (igneous complexes, feeder systems) that may be obscured on seismic. Thirdly, the correlation of seismic and wells to potential field data is critical for mapping basement depth, and composition and interpreting deep-seated fault control on igneous bodies and the role of basement heat flow for basin modeling.

References Cited

Goldberg, A.S., 2010, Dyke swarms as indicators of major extensional events in the 1.9-1.2 Ga Columbia Supercontinent, *in* M. Santosh, (ed.), Supercontinents and crustal evolution: Journal of Geodynamics, v. 50/3-4, p. 176-190.

Silverman, M. and T. Ahlbrandt, 2011, Mesoproterozic Unconventional Plays in the Beetaloo Basin, Australia: The World's Oldest Petroleum Systems: AAPG Search and Discovery Article #10295, 41 p. Web accessed 20 November 2012. http://www.searchanddiscovery.com/documents/2011/10295silverman/ndx_silverman.pdf

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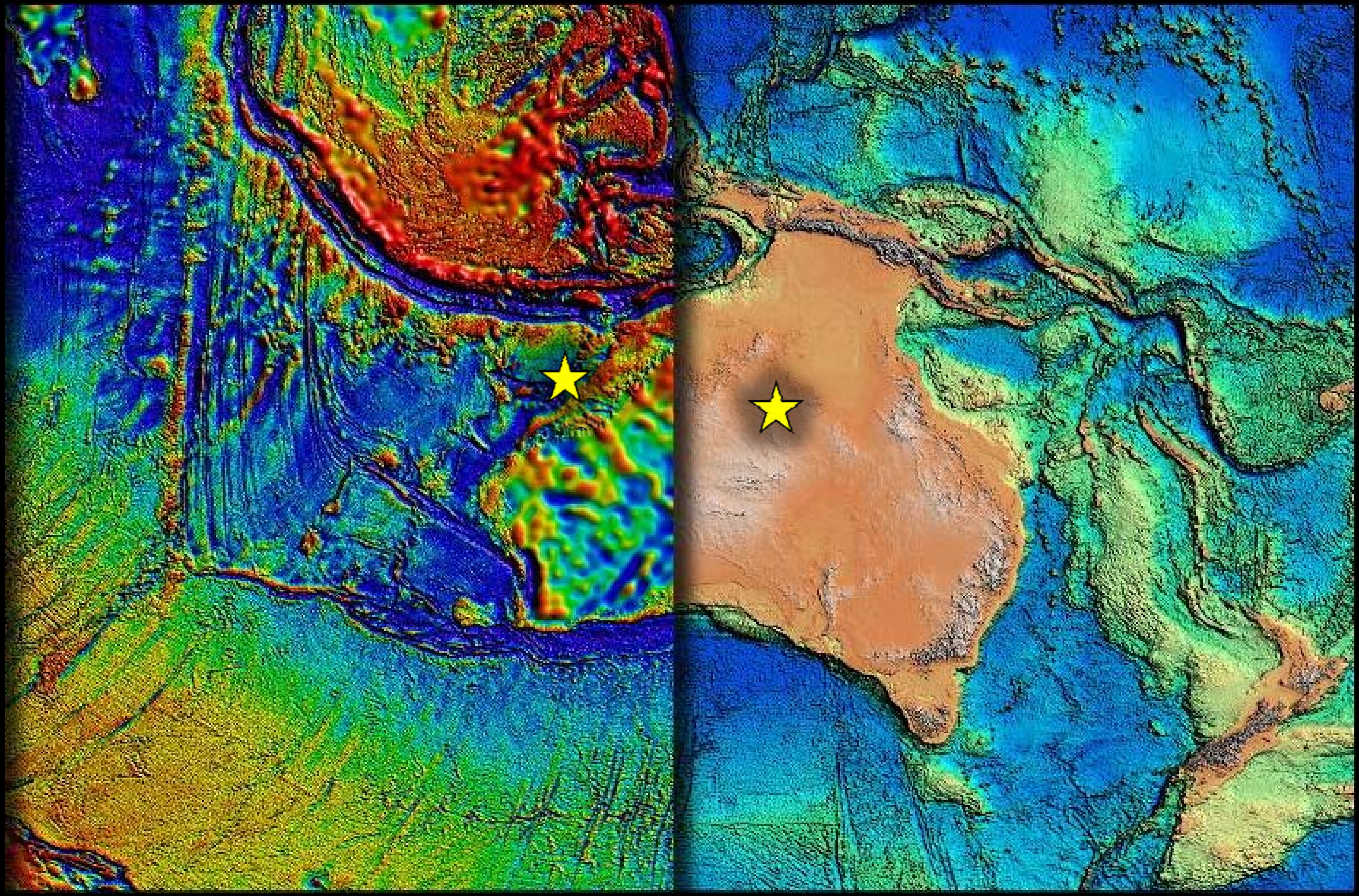
FrOG Tech Pty Ltd



Acknowledgements

Santos

MURPHY

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OSAKA GAS

Cooper Energy

BEACH ENERGY

Outline

- Northern Australian onshore Proterozoic unconventional petroleum system
- Northwest Shelf offshore Mesozoic conventional petroleum system
  - Stratigraphic Setting
  - Igneous rocks – seismic & well characters
  - Potential field interpretation
  - Potential field modelling & calibration
  - Igneous effects on prospectivity
- Conclusions

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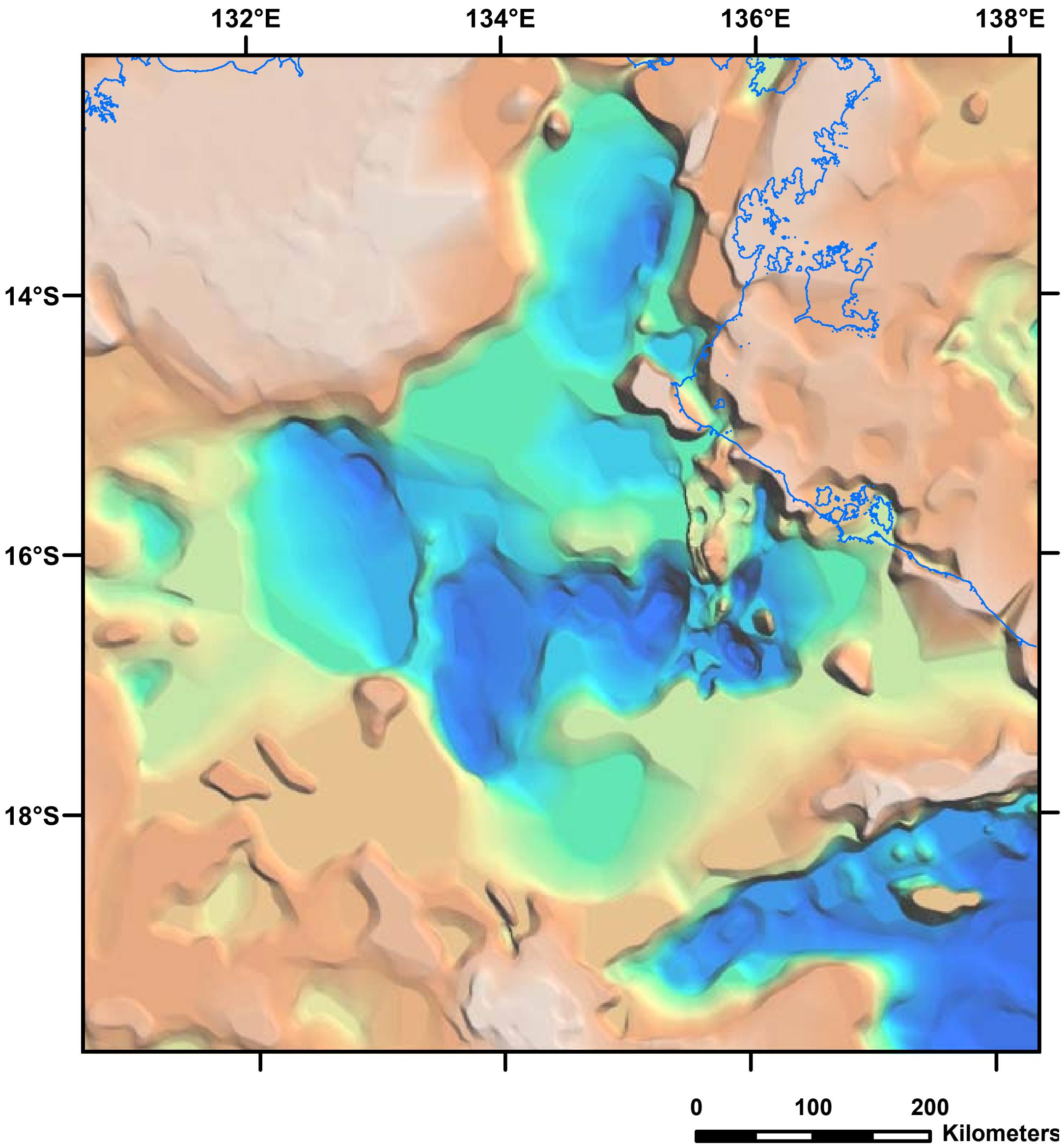
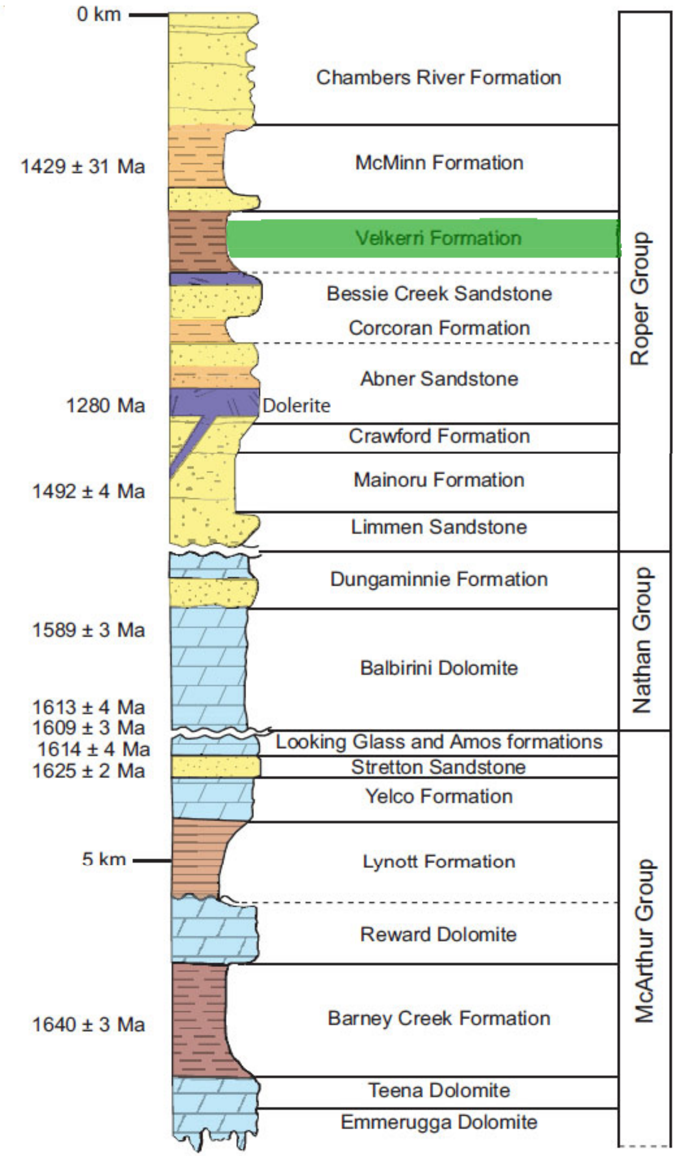
Presenter's Notes: First case study is an old, onshore Proterozoic basin where unconventionals (mostly shale gas) is the priority. This area is affected by two major thermal events with thick dolerite sills and dykes followed by flood basalt development. Second case is an offshore Mesozoic basin where conventional exploration is the priority. This area is heavily affected by Triassic-Jurassic and older intrusives and a wide range of Mesozoic extrusive and volcaniclastic igneous units. In both cases, the main seismic datasets are 2D and 3D is either unavailable or only covers small areas – The talk aims to show the importance and versatility of combining potential field geophysical analysis with traditional seismic- and well-based basin analysis

Greater McArthur Basin

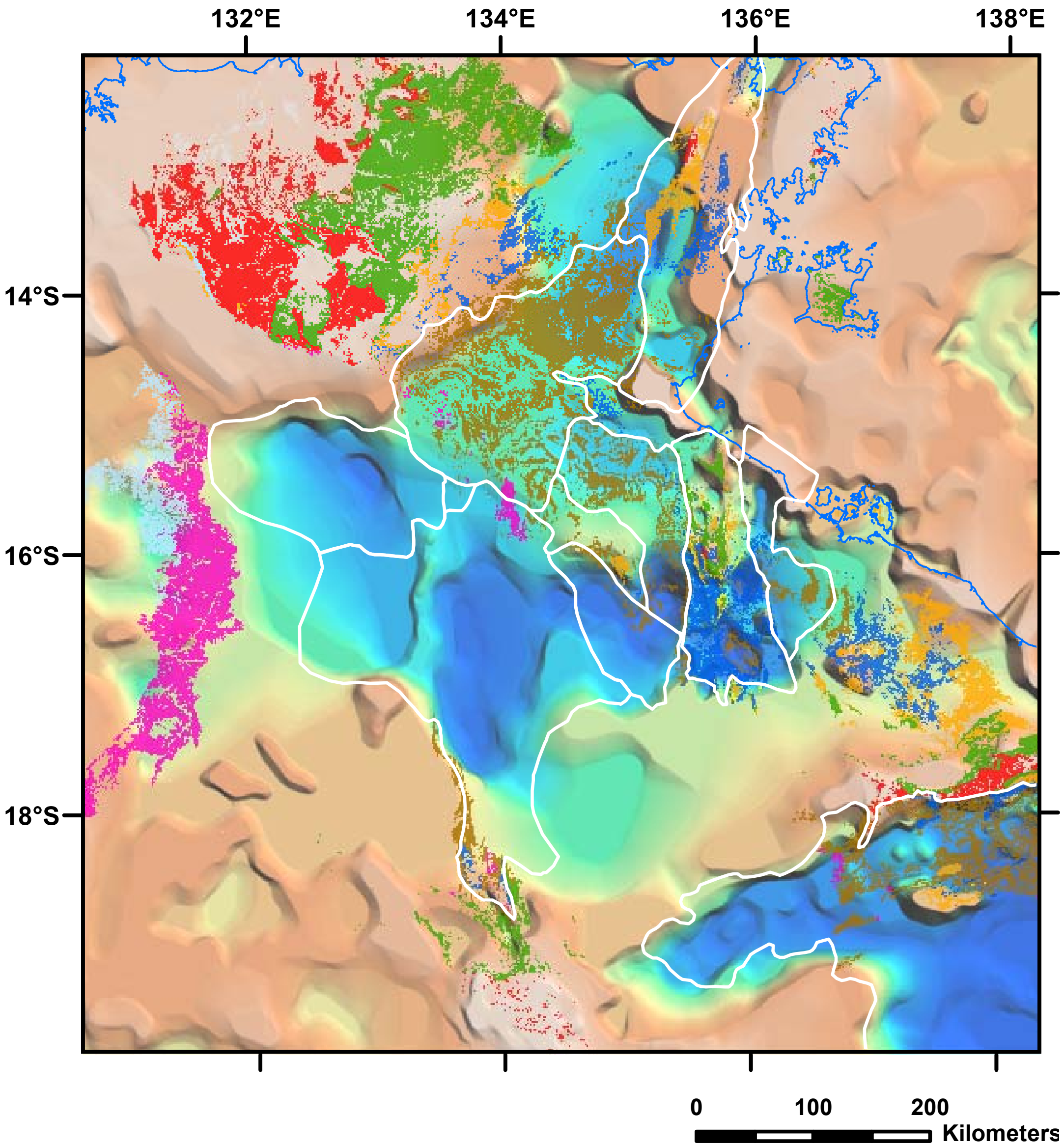


Stratigraphy



Silverman & Ahlbrandt (2011)

Greater McArthur Basin



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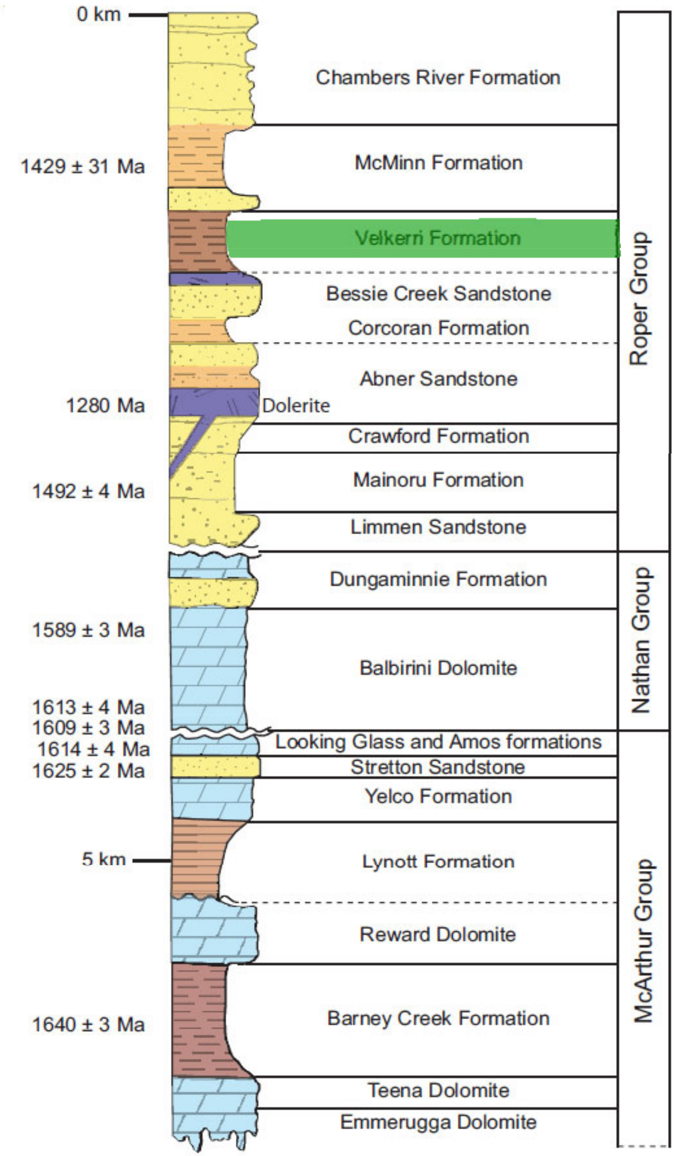
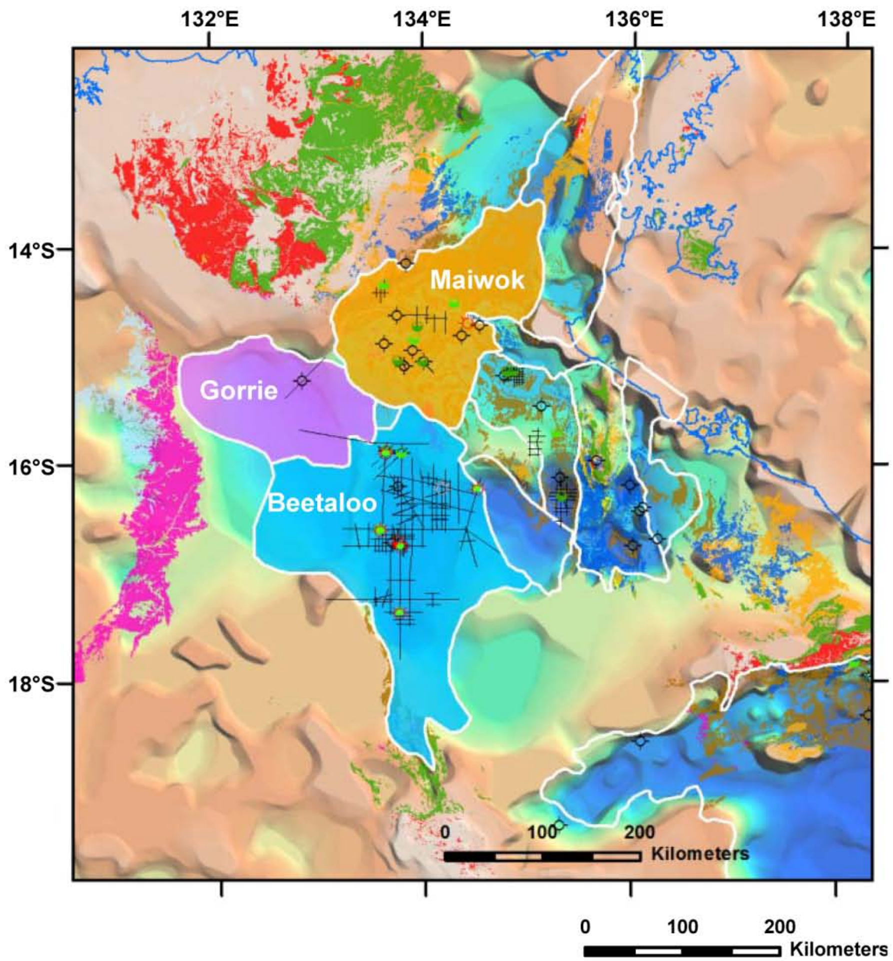


Silverman & Ahlbrandt (2011)

Greater McArthur Basin



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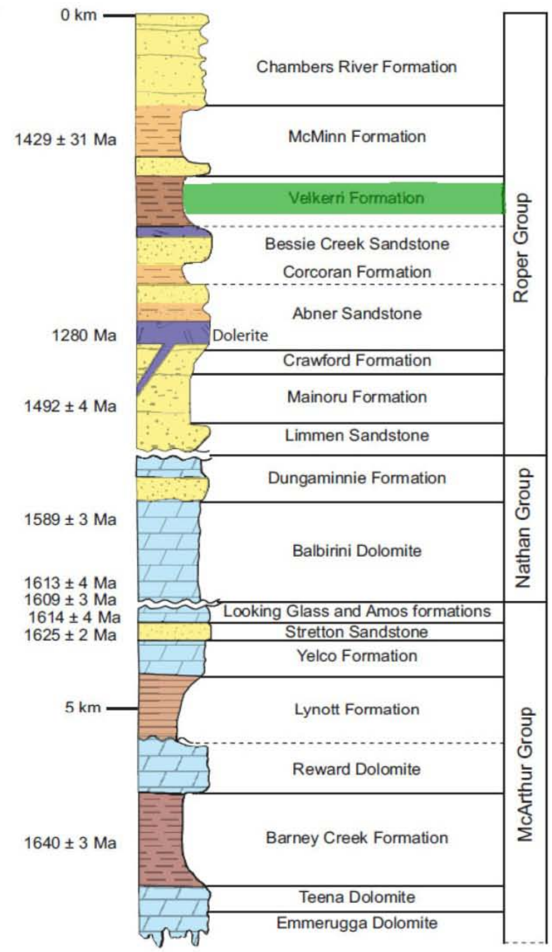
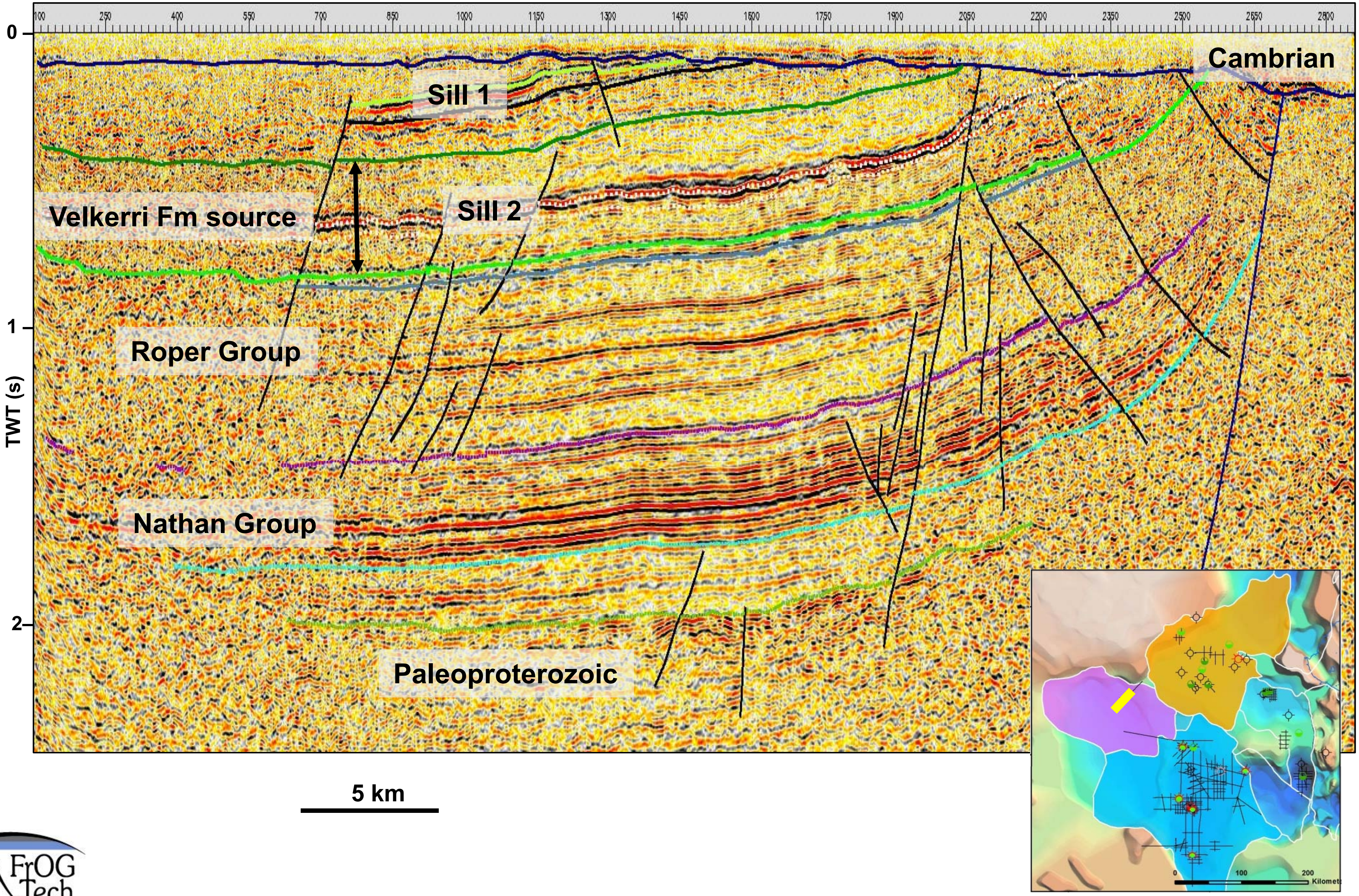
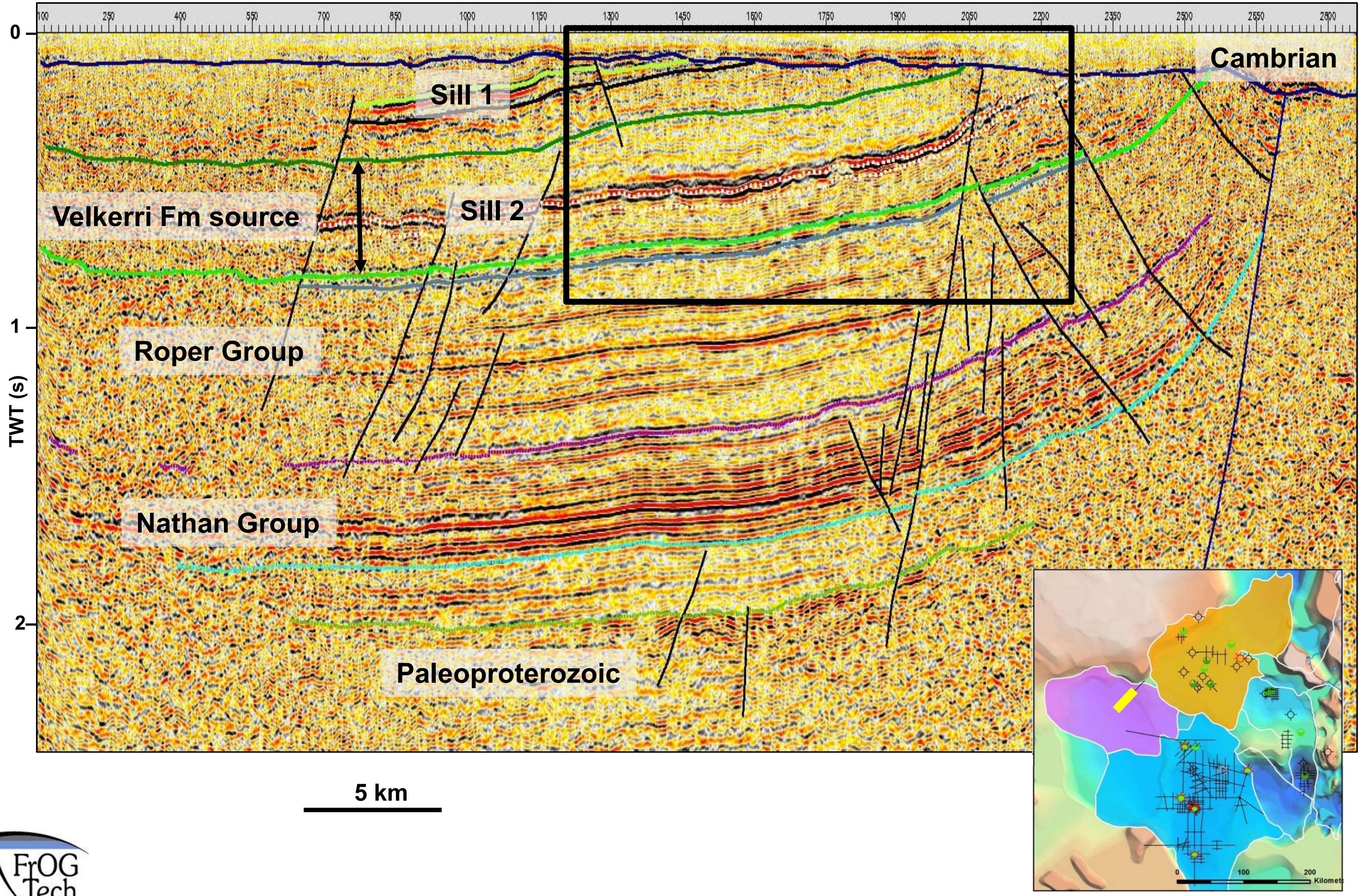


Silverman & Ahlbrandt (2011)

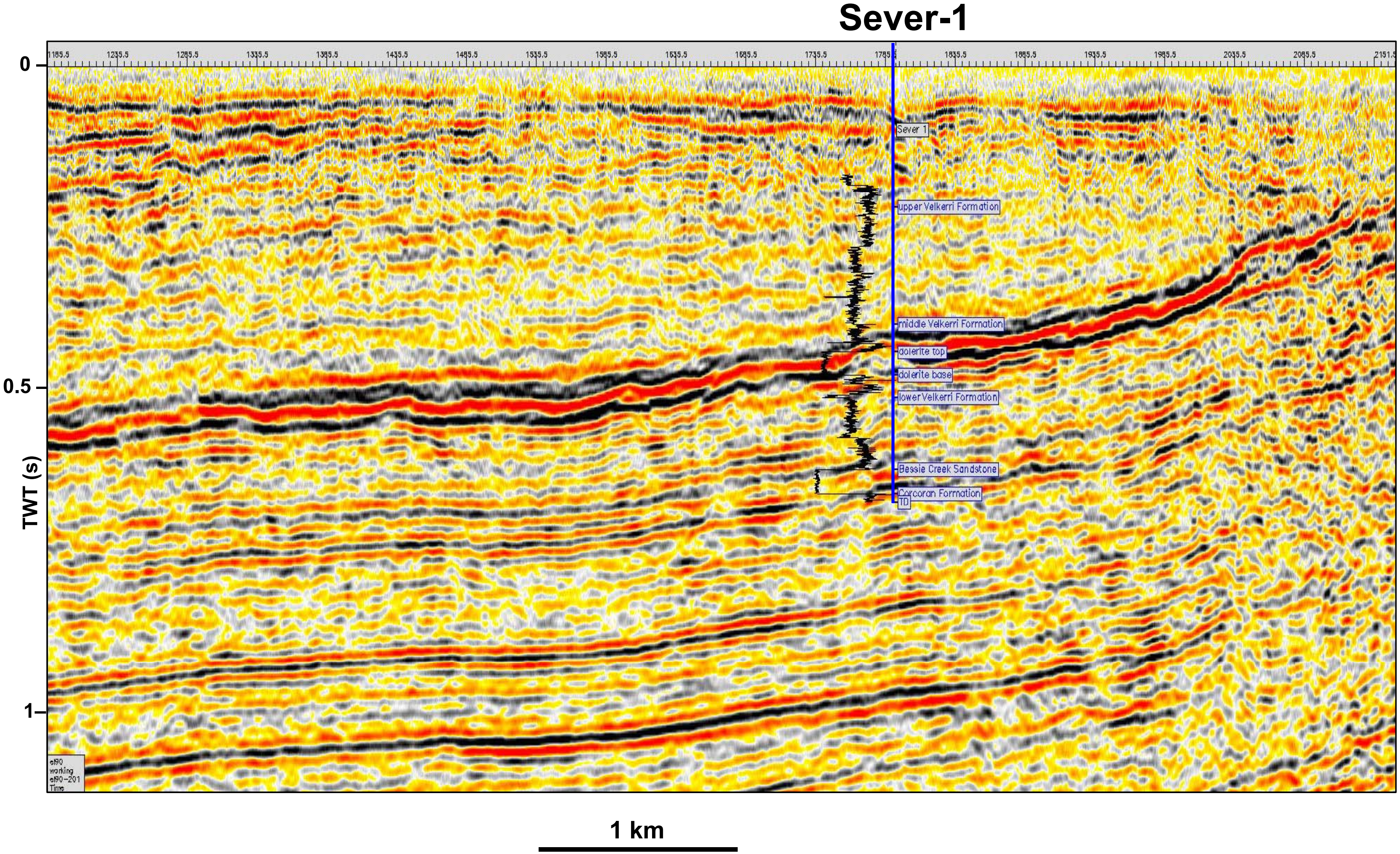
Regional Seismic Character



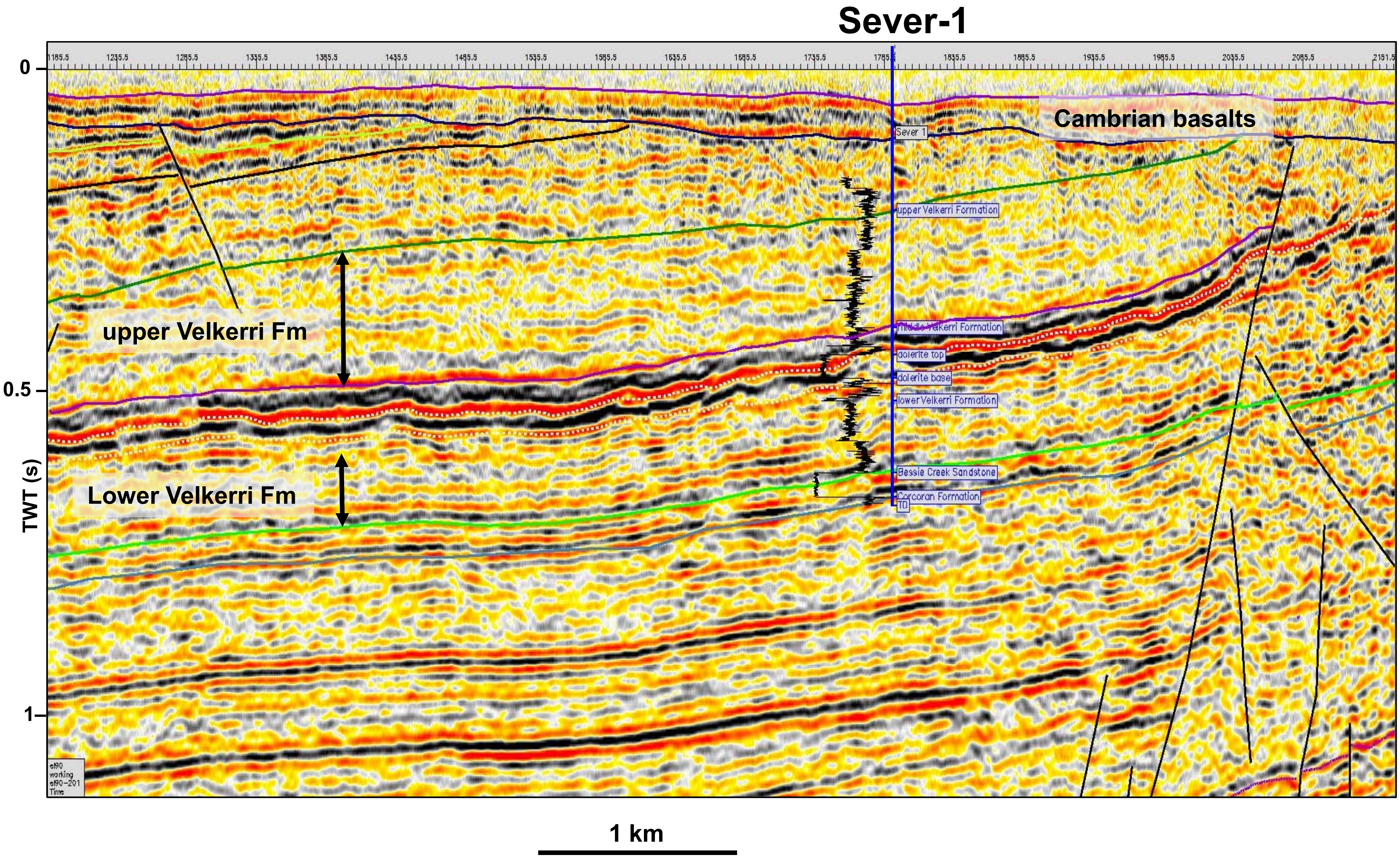
Regional Seismic Character



Seismic Anomalies



Seismic Anomalies



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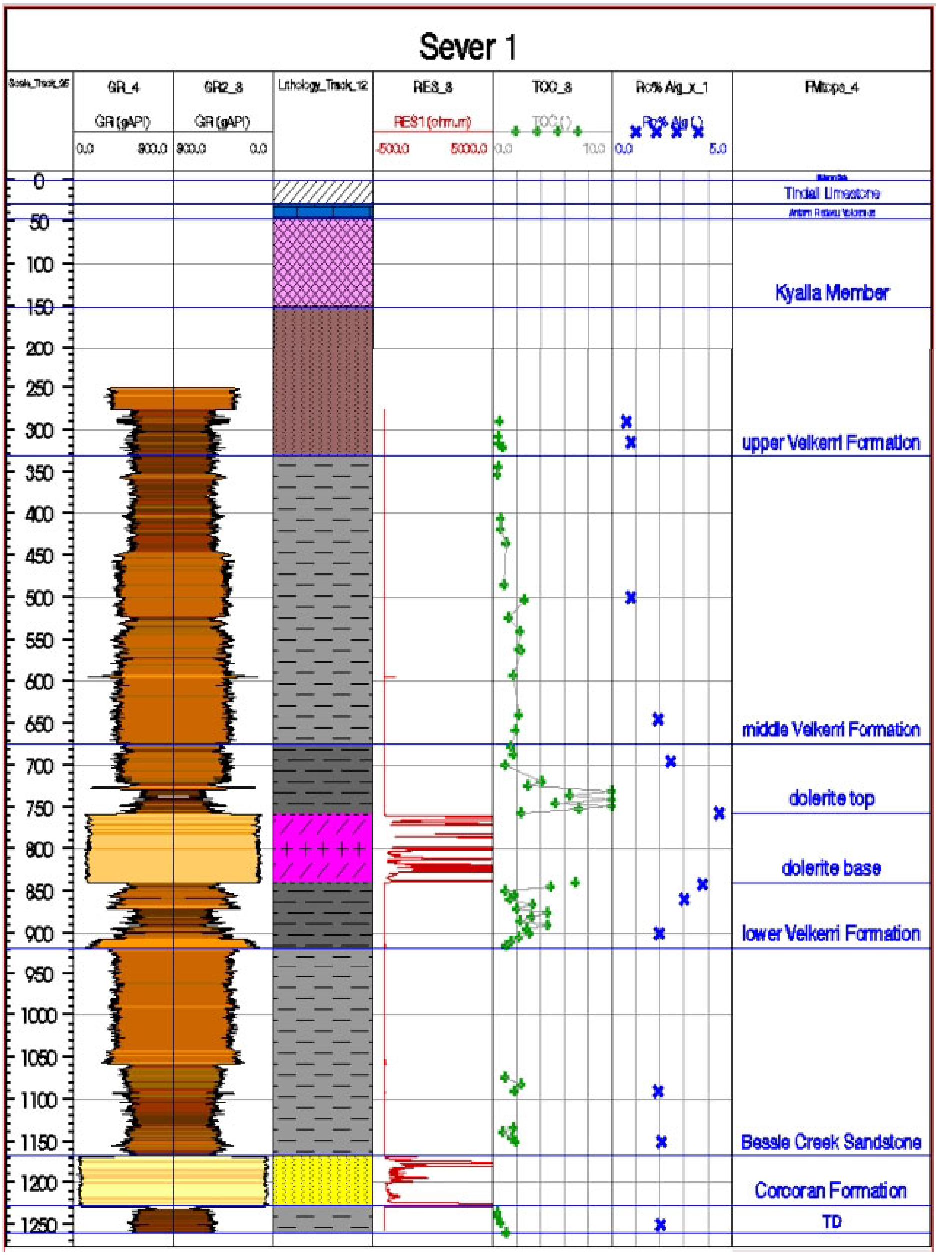
Igneous Well intersections



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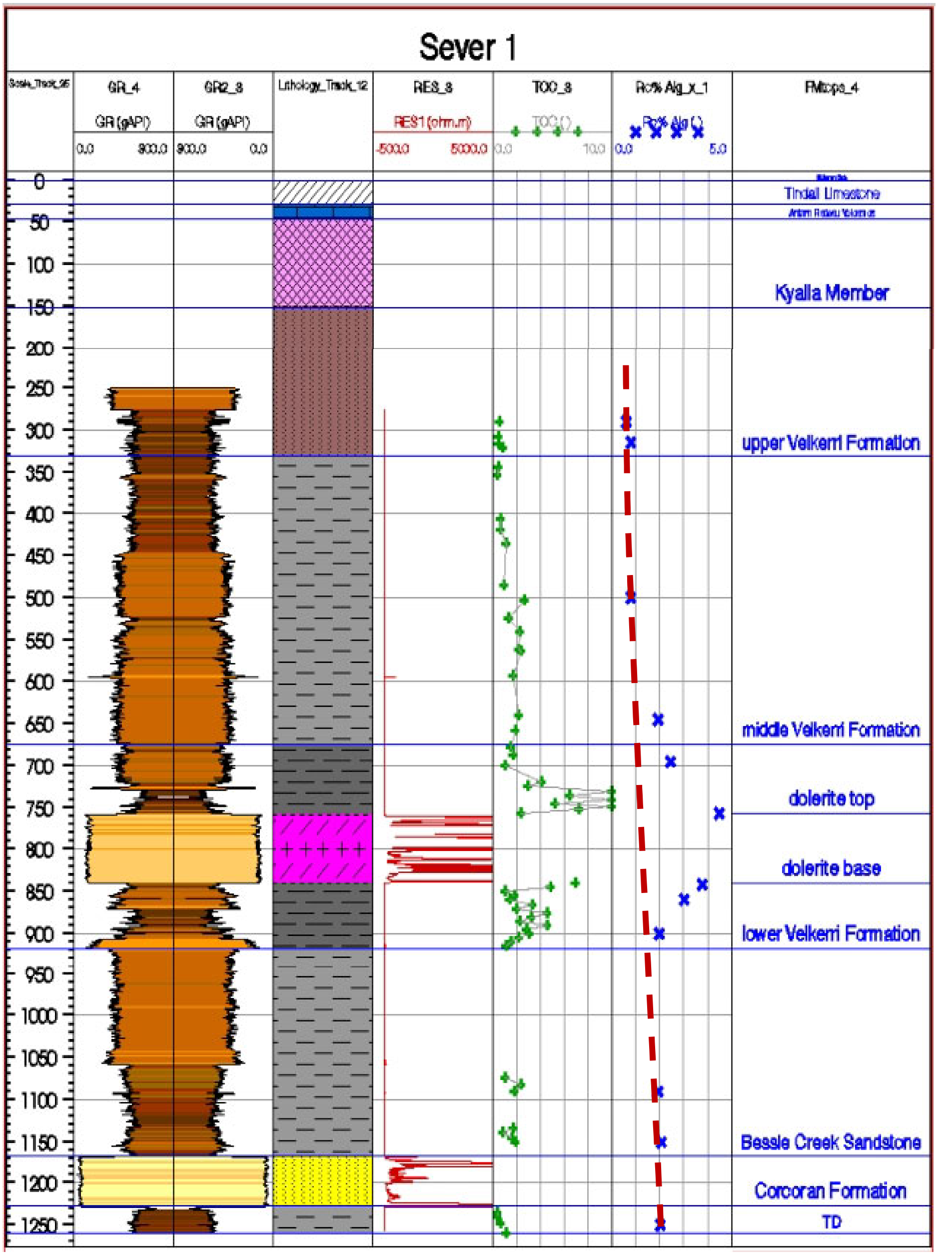

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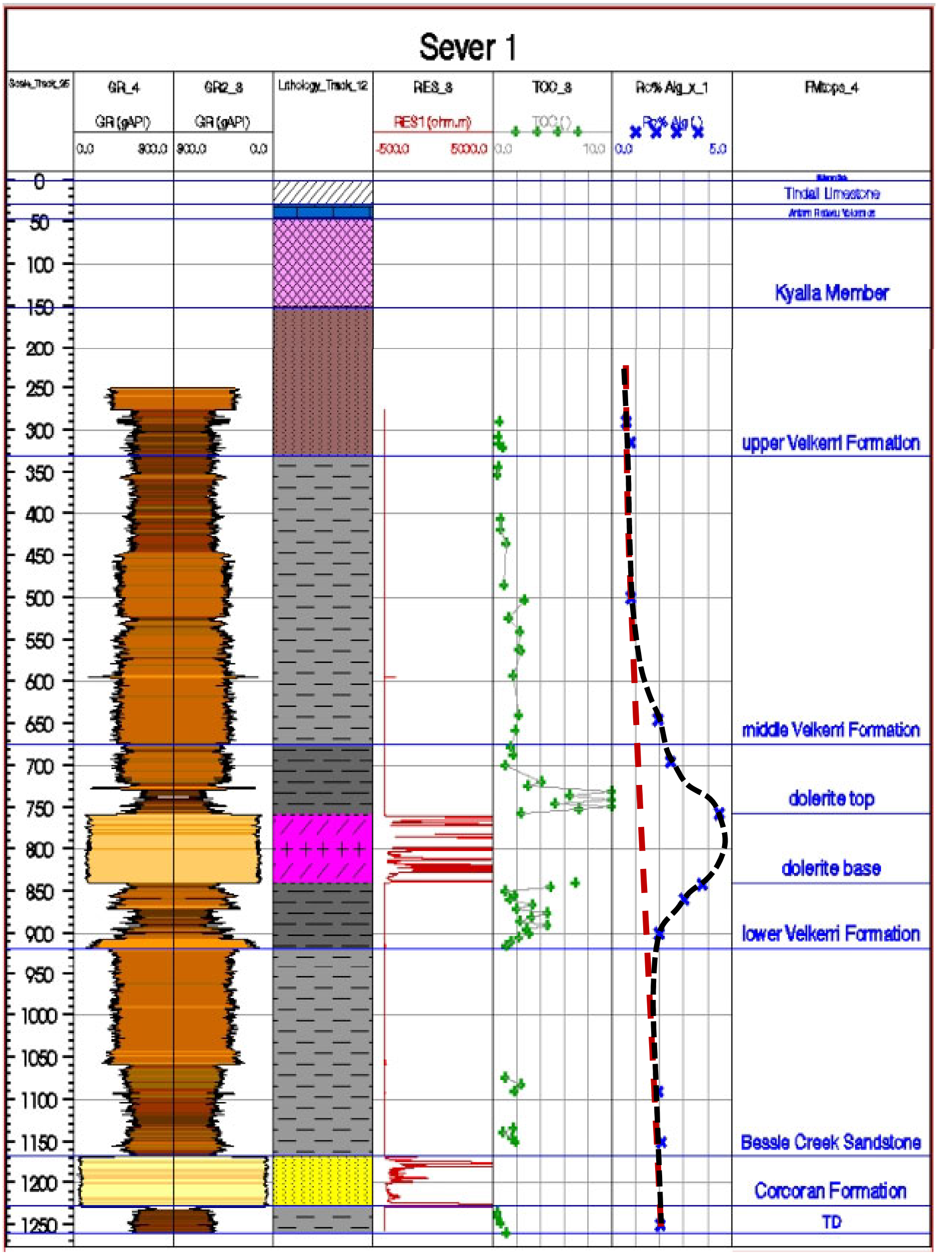
Igneous Well intersections



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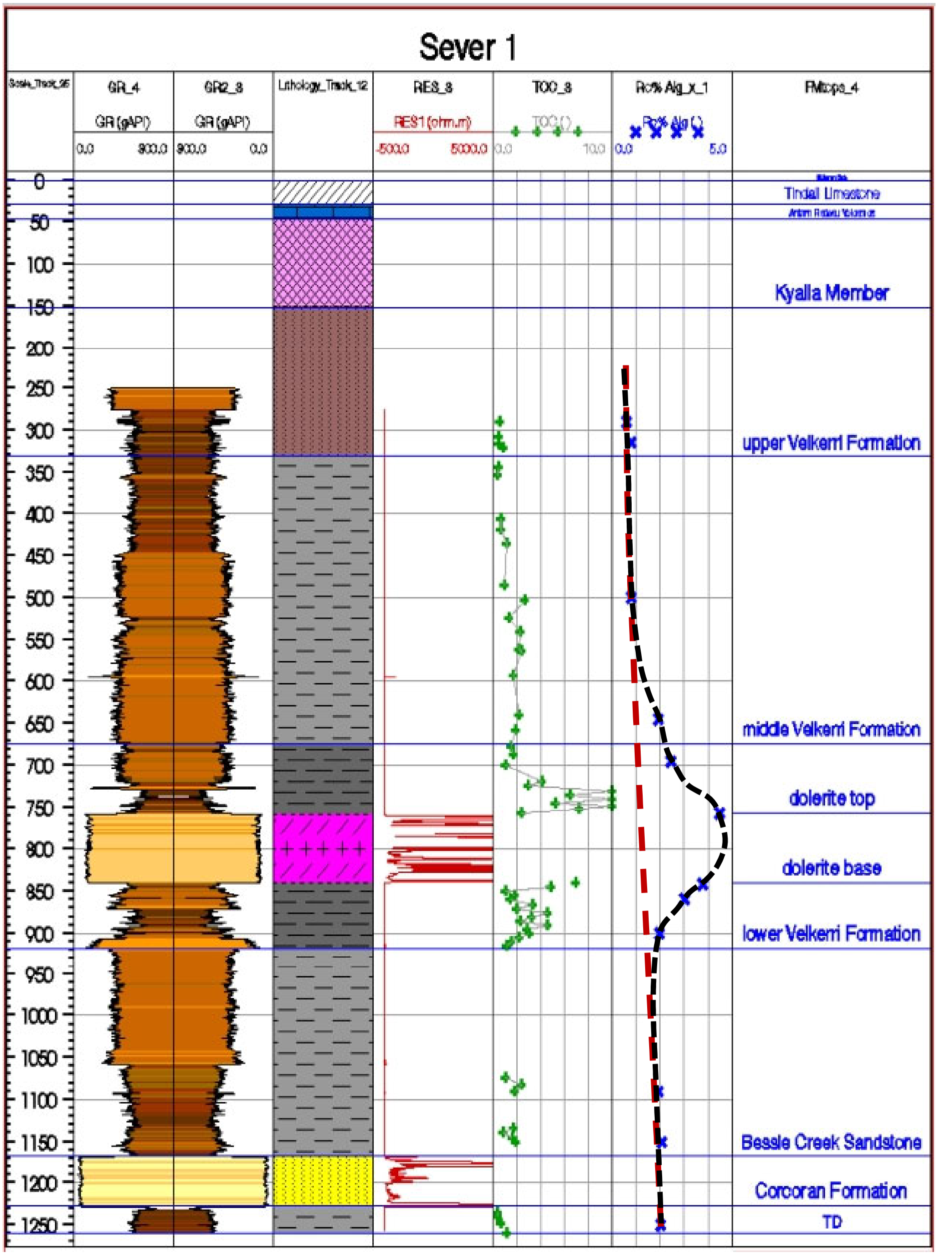

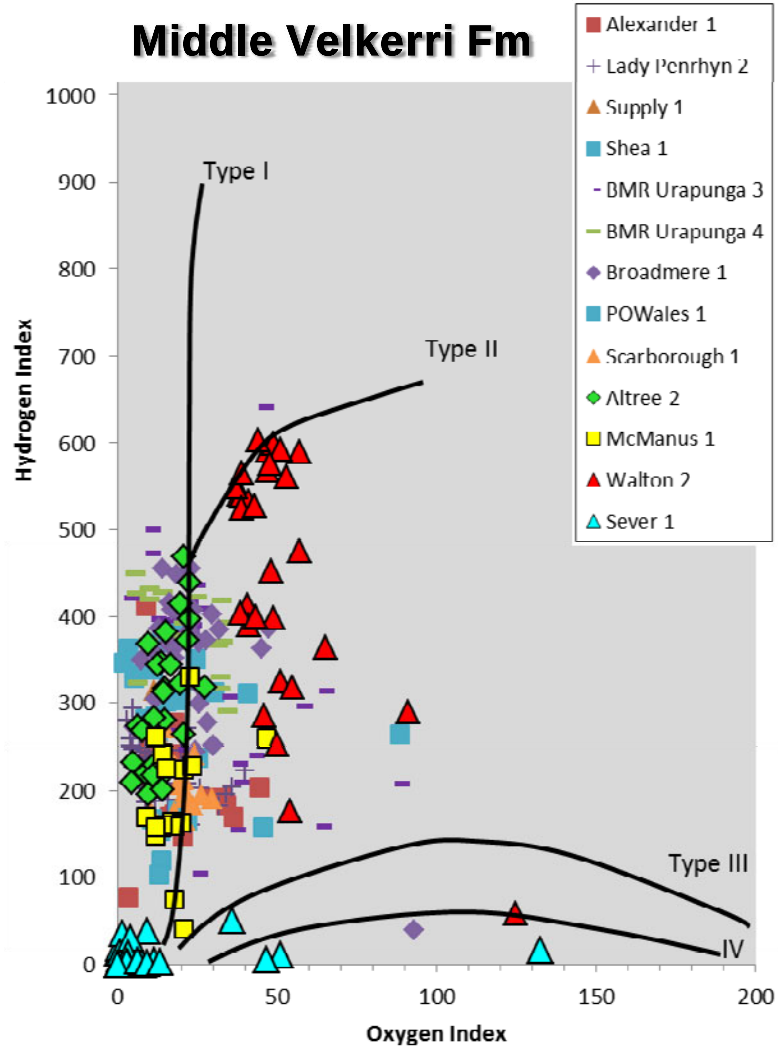

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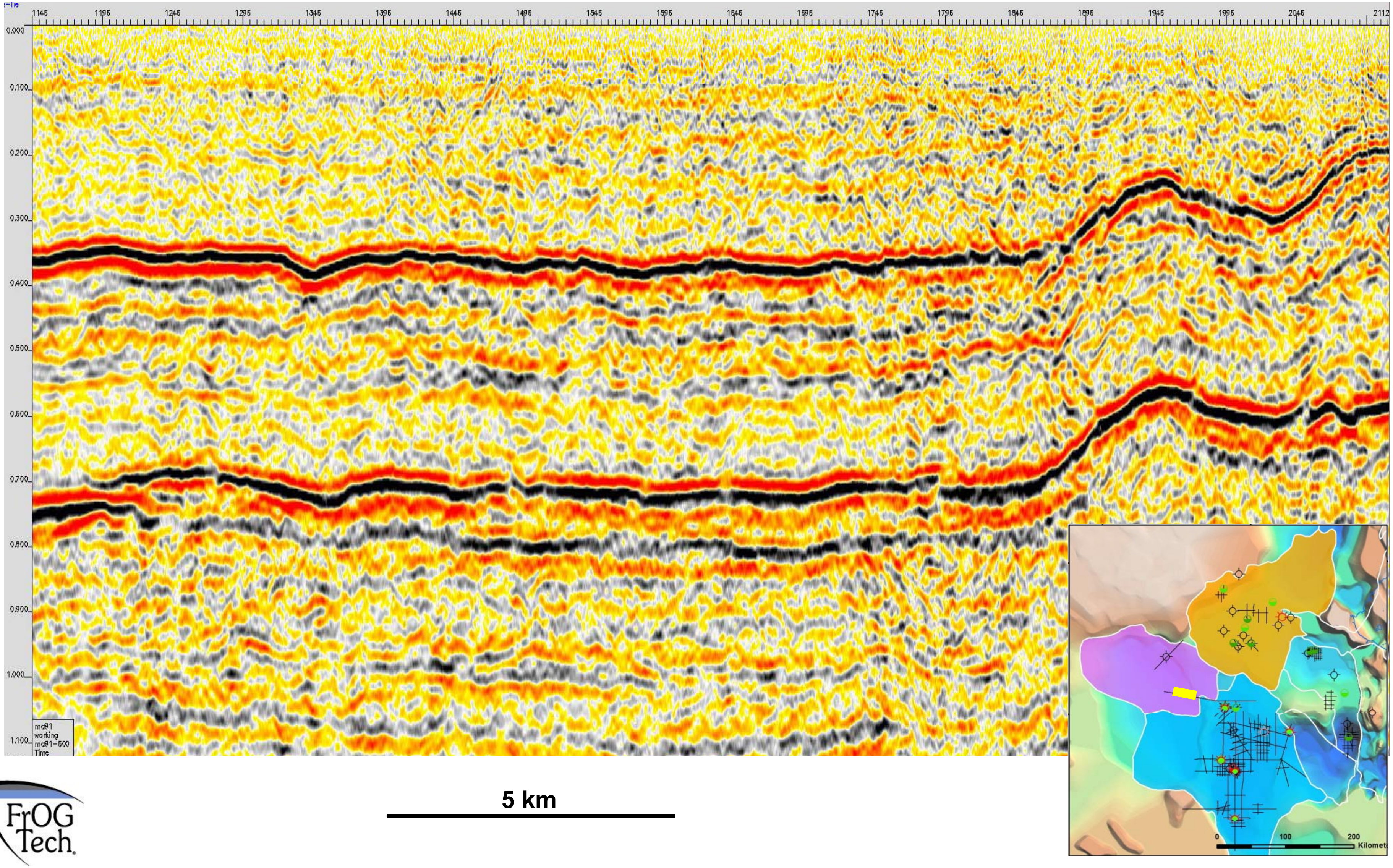
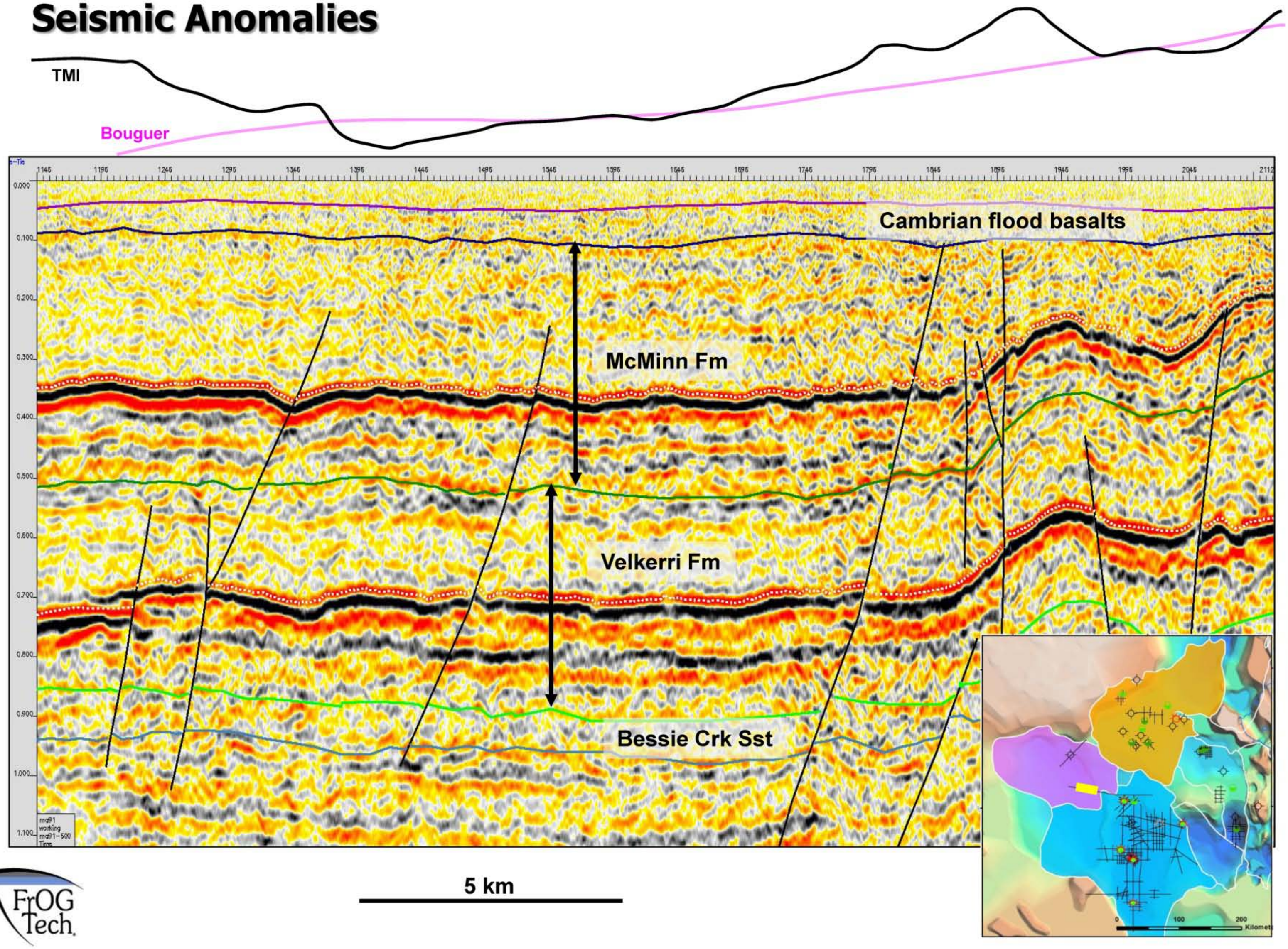
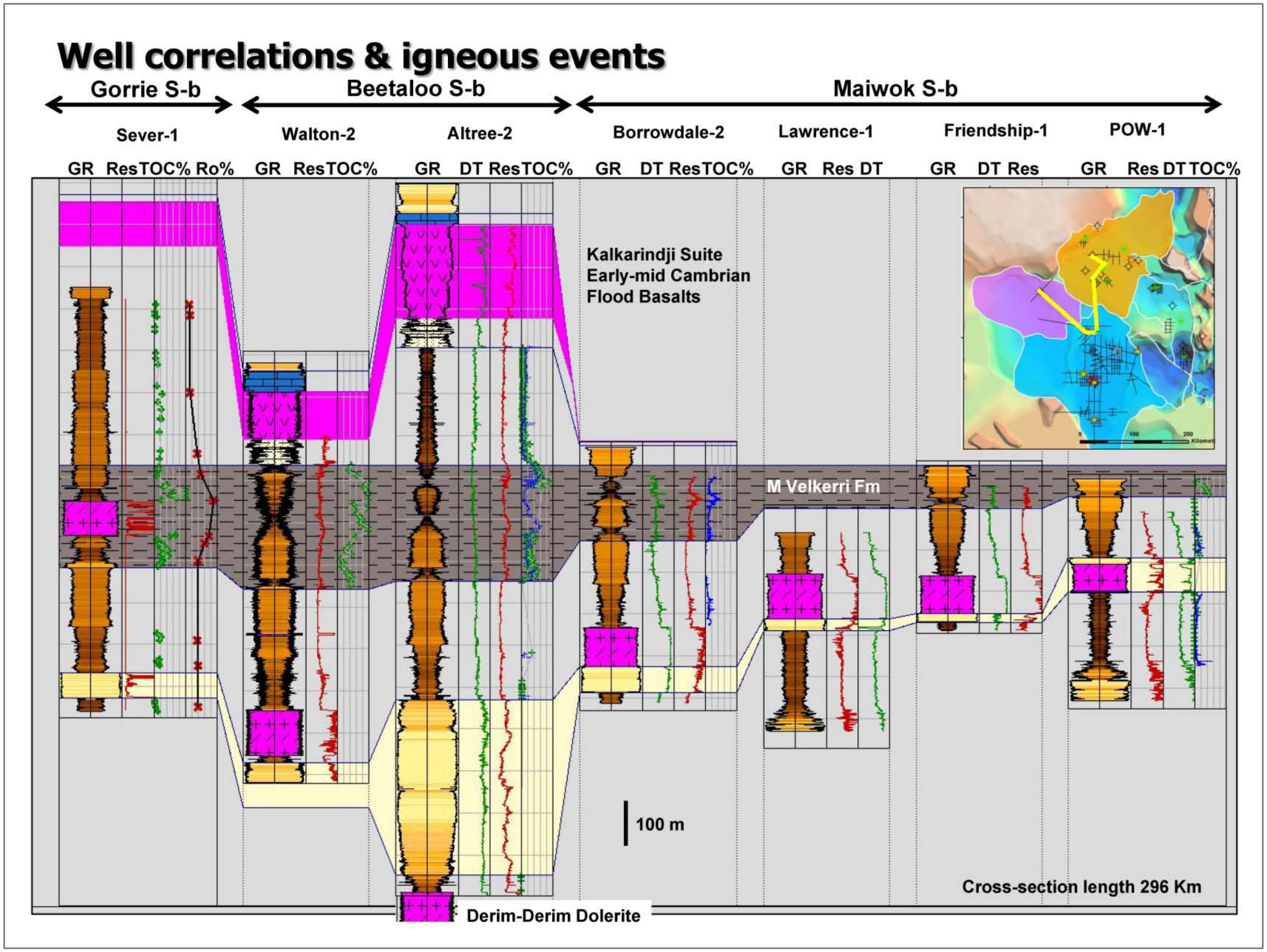


Seismic Anomalies



Presenter's Notes: Two major, distinct seismic anomalies. Seismic character = v high amplitude, generally flat, parallel continuous reflections. Note the mild post intrusion deformation. Also, note the absence of apparent feeders/dykes, forced folds, saucer shapes, and lack of transgression of the seismic events – they seem to be remarkably continuous and stratiform. It appears that the dolerites have preferentially intruded the finest-grained, uniform mudstones sequences – presumably, they are exploiting competency contrasts within the stratigraphic section.

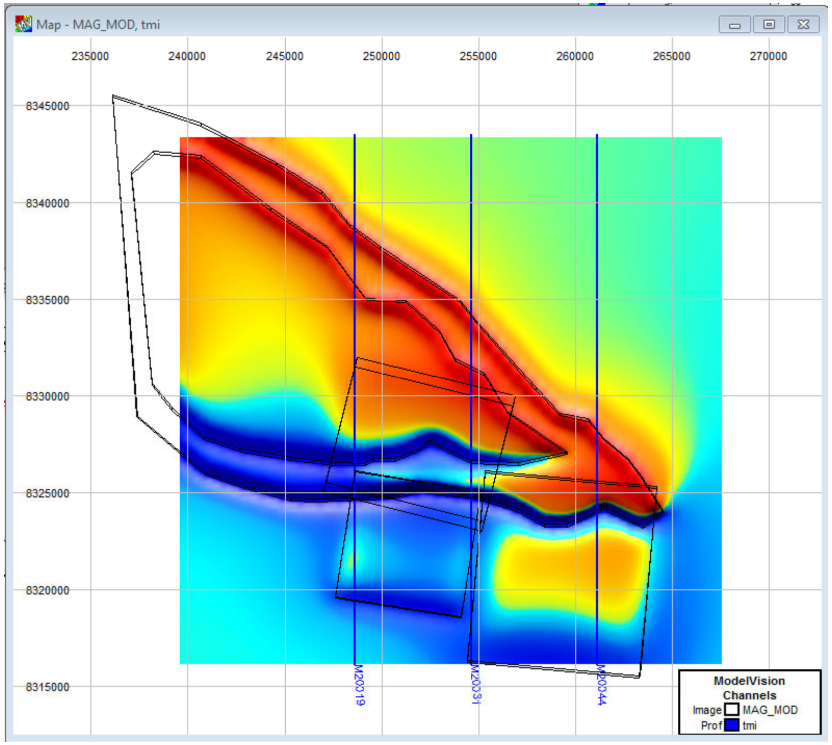


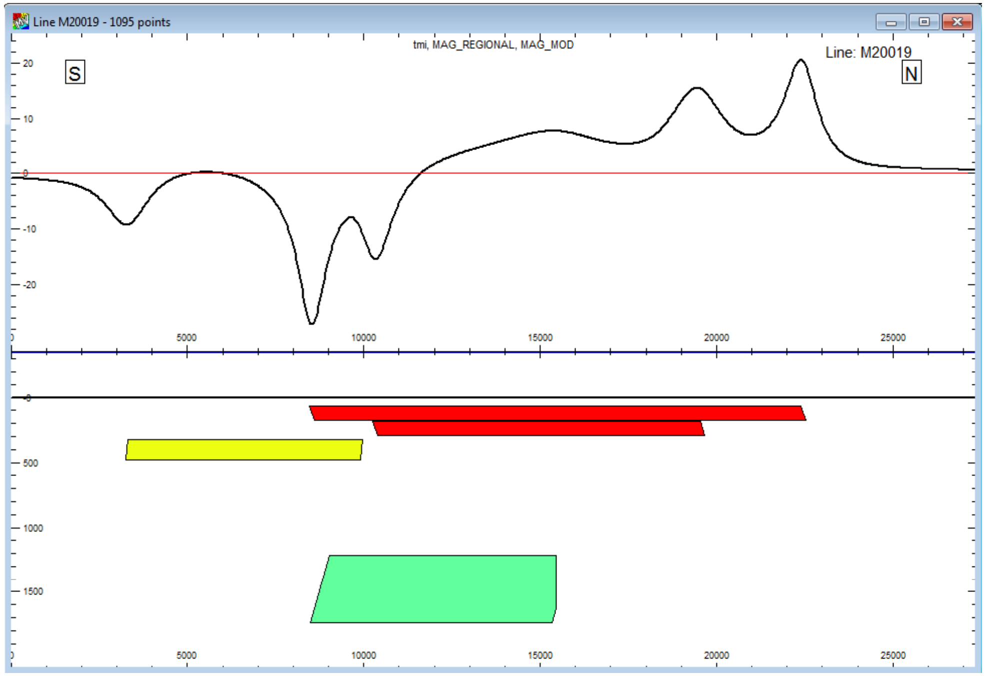
Presenter's Notes:

- Note that the Cambrian flood basalts form an overlying igneous blanket to much of the area but had little impact on petroleum systems.
- The older igneous intrusives however have had a significant effect on petroleum systems locally and the intrusives are widely distributed
- Note how the 1280 Ma dolerites have preferentially intruded 3 main stratigraphic intervals:
    - The Velkerri Formation (source quality risk)
    - The Bessie Creek Sandstone (reservoir quality risk)
    - The underlying Corcoran Formation (low risk as this is considered a non-source interval)

Magnetic Modelling – sills vs flood basalts

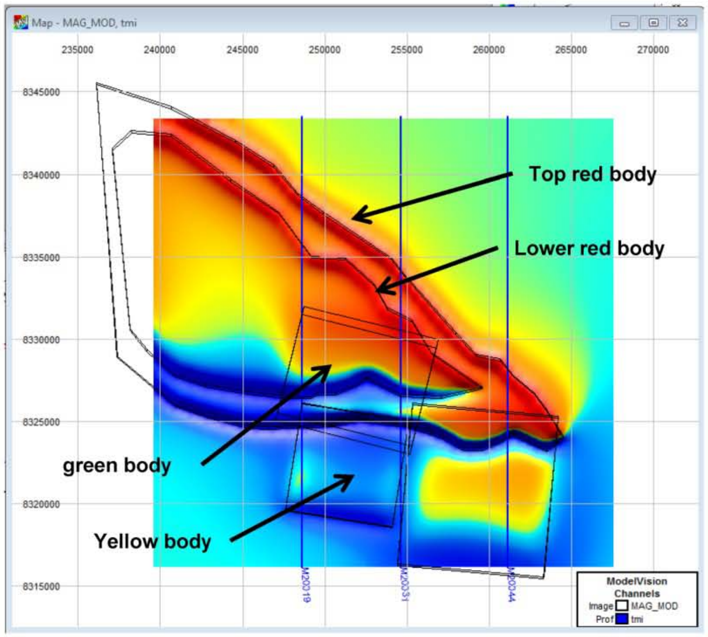
Theoretical Model

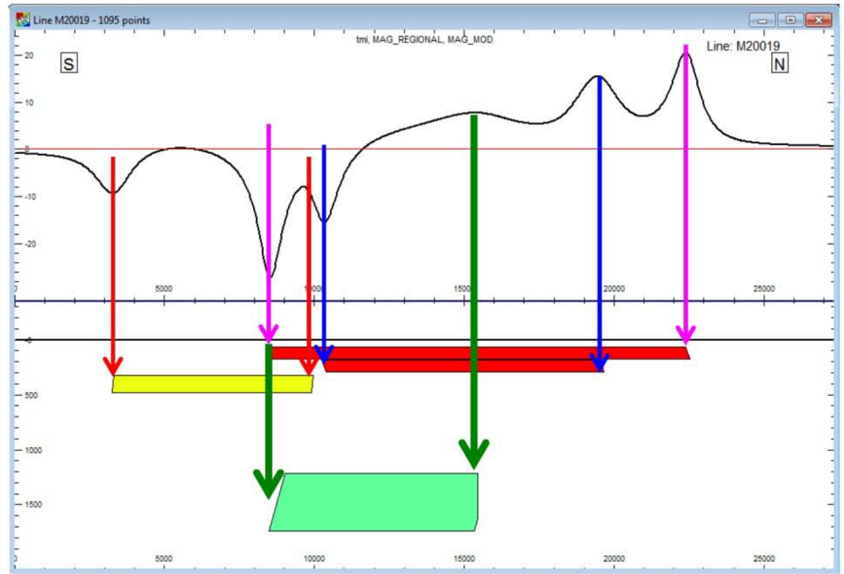




Magnetic Modelling – sills vs flood basalts

Theoretical Model





- **Flat sheet-like intrusions (sills) exhibit distinct magnetic signals at edges**
- **Marked by a dipole effect with a negative and positve mag anomaly**
- **Can be distinguished from shallower flood basalts and deeper intrusives**

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Presenter’s Notes:

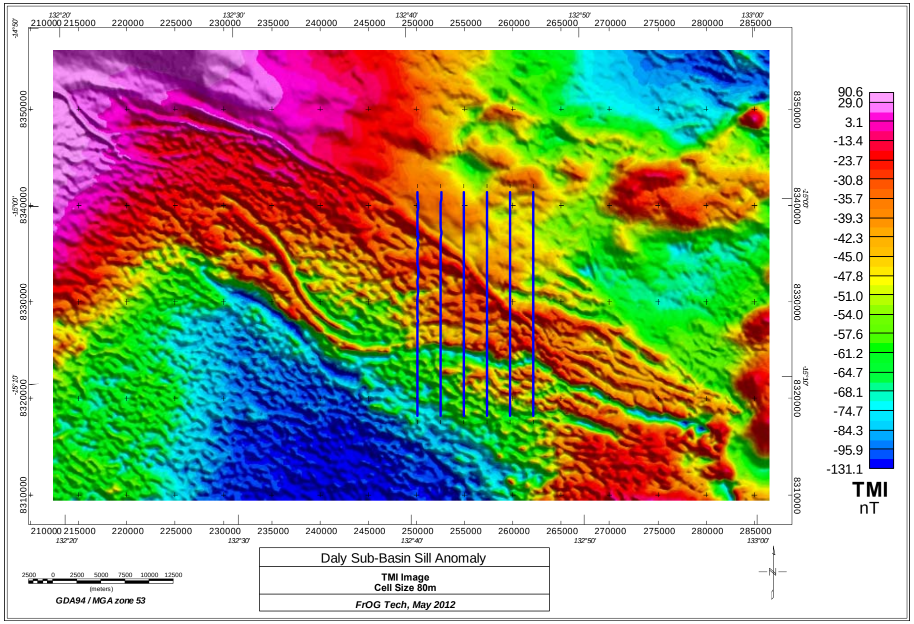
- The model profile (top right) shows the same positive and negative pair of anomalies associated with the flat “sill” body. The observed magnetic data is much noisier than the model data due to local variations in the Kalkarindji basalt. *Presenter’s Notes continued on next page*

- The shallow near surface bodies represent the Kalkarindji basalt disrupted by faults and/or erosion and the deeper larger bodies represent the Derim Derim sills. The depths to the top of the sills are approximate only. The depth can be varied along with the susceptibility of the bodies. The possible depth range can be tested with additional modelling.
- The theoretical model of the flat magnetic bodies (i.e. possible sills) highlights the pair of positive and negative anomalies that occur over the edges of the flat bodies. The edges of the bodies are the main features that are highlighted in the magnetic data. The colour of the model bodies (top right) indicate the relative susceptibility with red highest, yellow moderate and green lowest. The high susceptibility red bodies near surface create the dominant anomalies in the calculated magnetic response (lower left). The yellow body is less magnetic and slightly deeper and the resulting anomalies have lower amplitude and longer wavelength. Note that both of the high susceptibility red bodies show a strong anomaly along their edges, i.e. we still "see" evidence of the lower body.

Theoretical model used to better understand and interpret real data. Magnetic response generated from the theoretical model bodies. Note the positive anomaly on the northern edge and the negative anomaly along the southern edge of each sill body. The theoretical model was set up to mimic the main bodies in the Gorrie sub-basin.

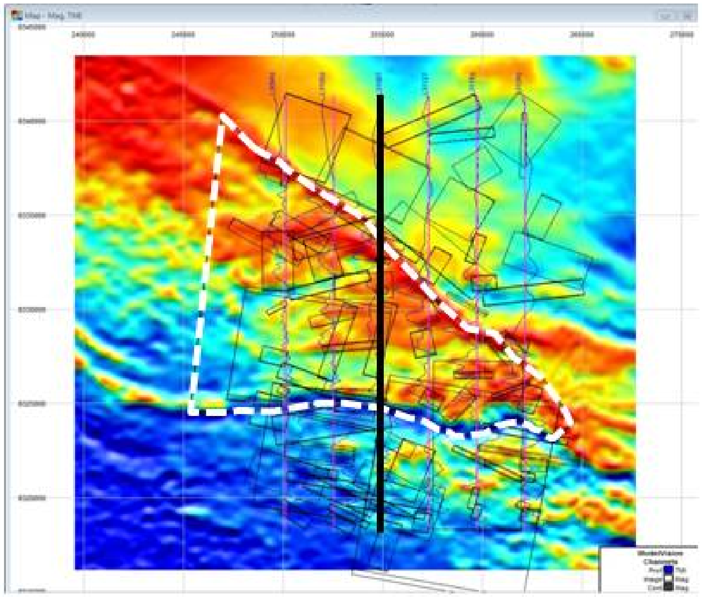
Magnetic Modelling – sills vs flood basalts

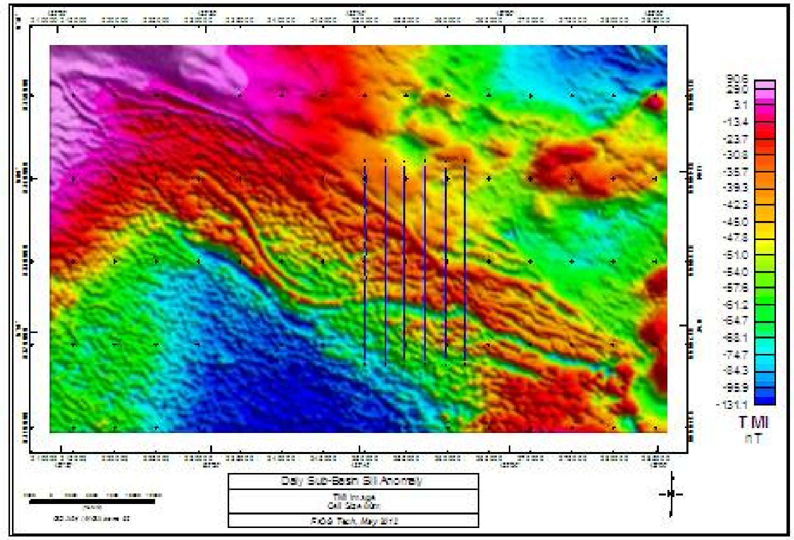
Real Data

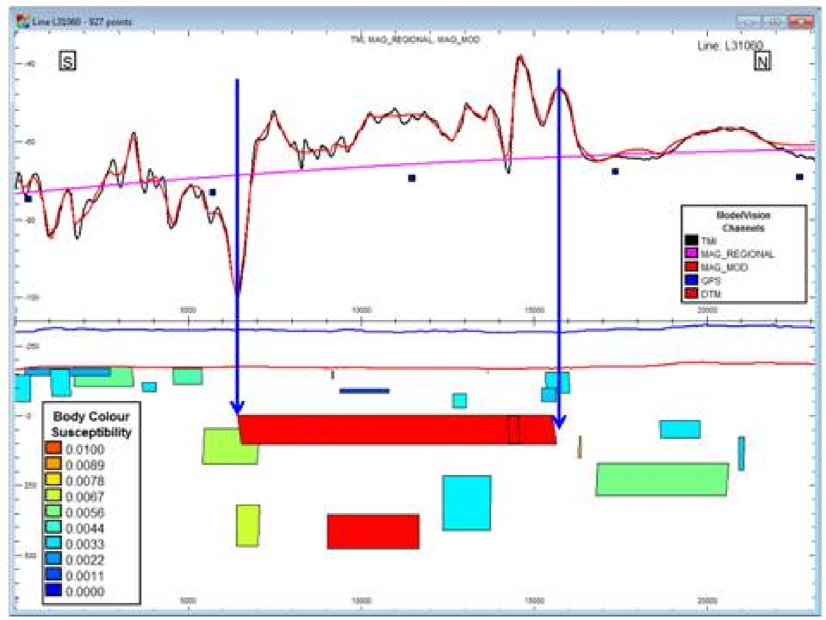


Magnetic Modelling – sills vs flood basalts

Real Data







- Edge of sills – marked by distinct anomaly pair
- Can be distinguished from shallower flood basalts

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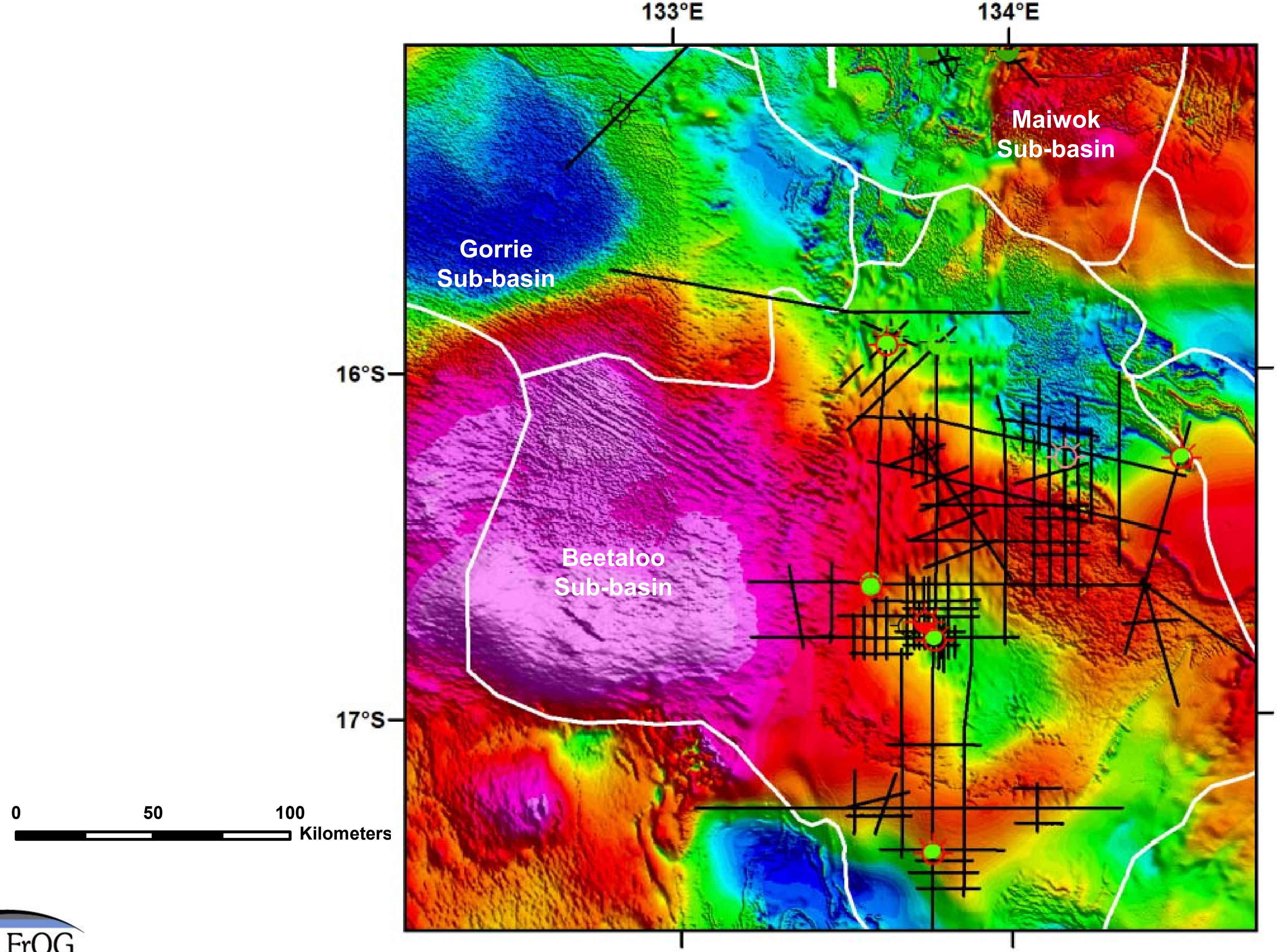
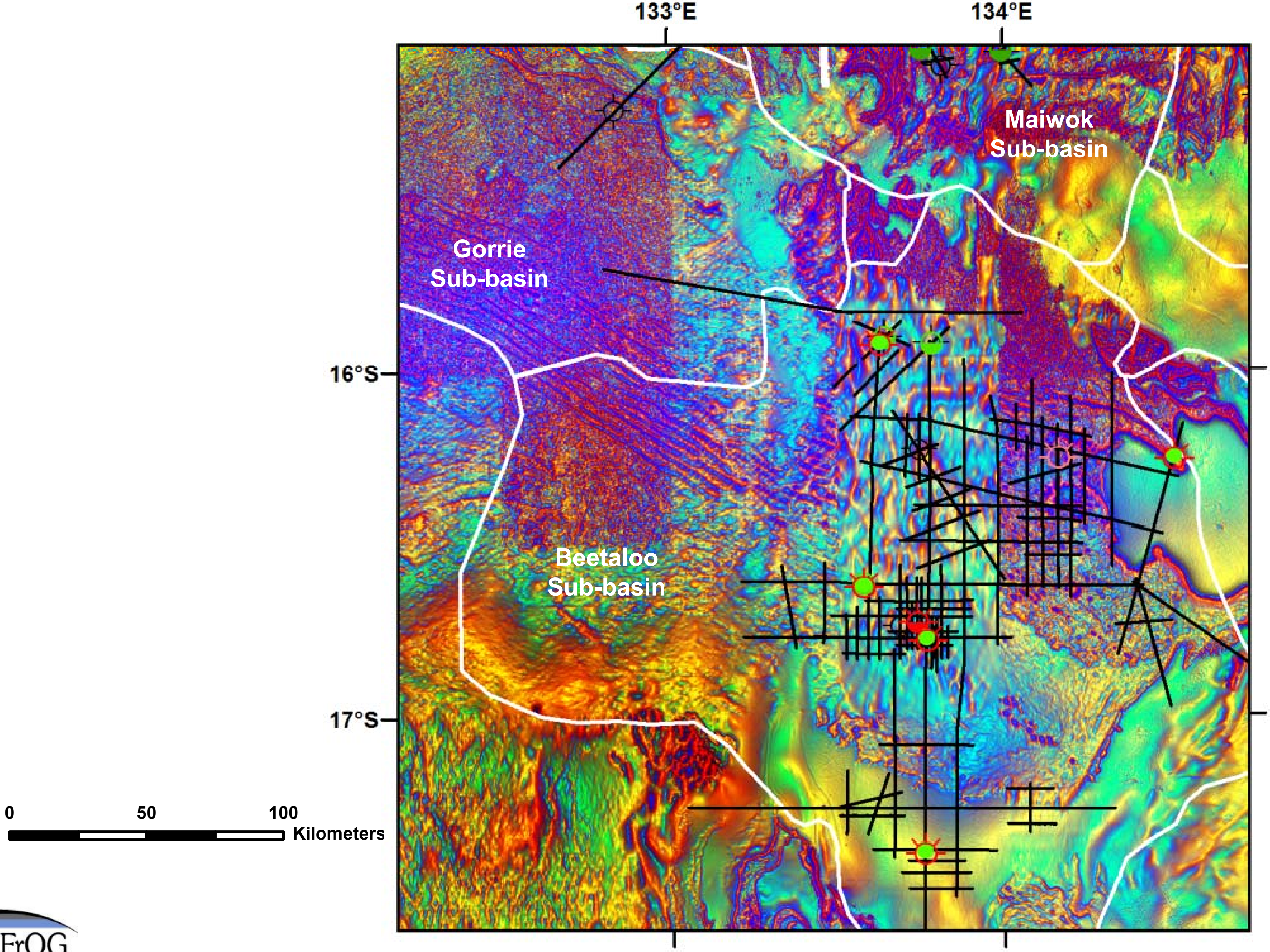
Presenter's Notes:

Left: Observed magnetic data in the Gorrie Sub-basin northwest of the Sever 1 well and seismic line. Note the positive anomaly on the northern edge and the negative anomaly along the southern edge of the irregularly shaped sill outlined in **yellow**.

Integrated igneous mapping & prospectivity

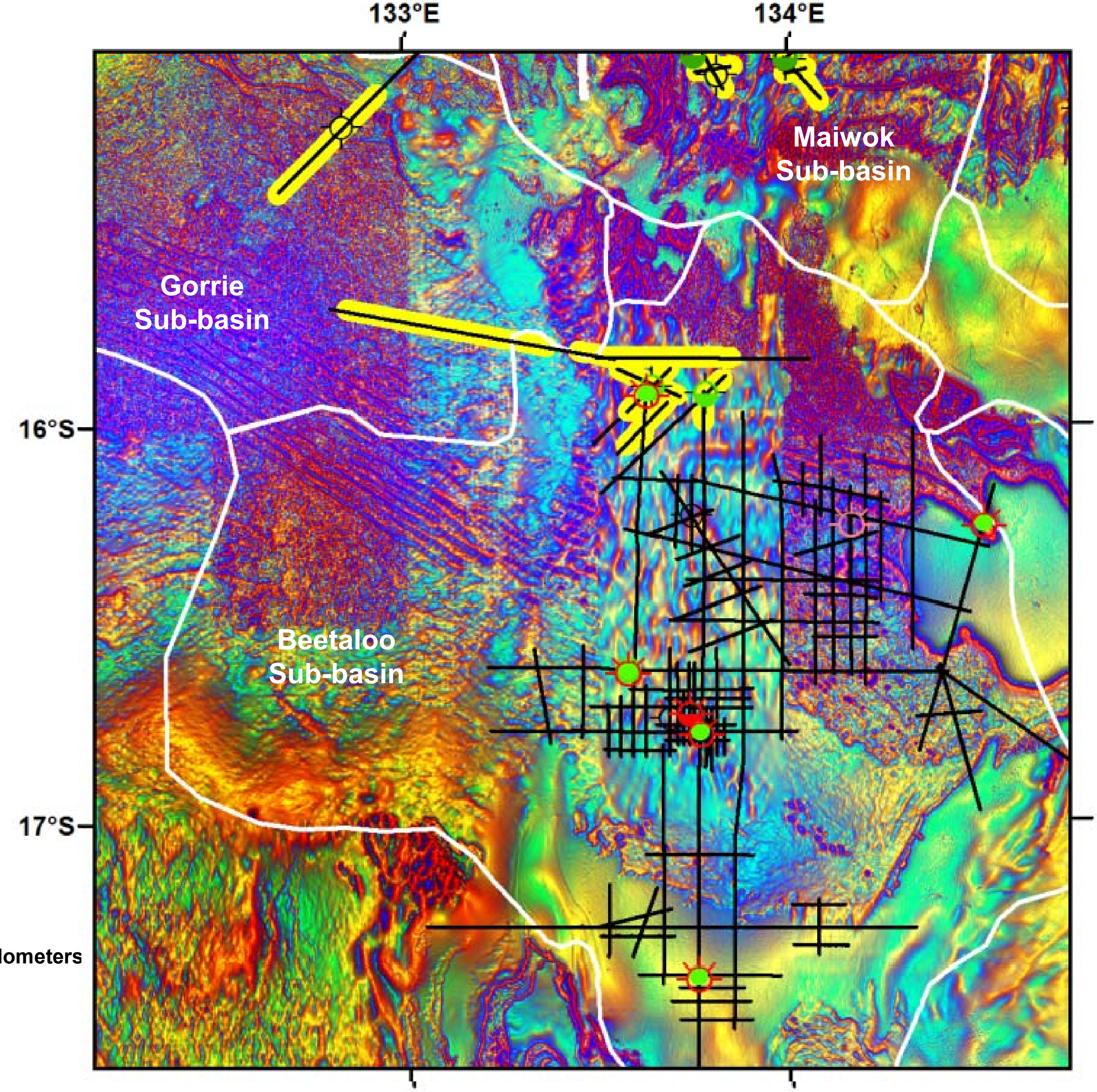


Integrated igneous mapping & prospectivity



Integrated igneous mapping & prospectivity

Intrusive mapped on seismic



0 50 100
Kilometers

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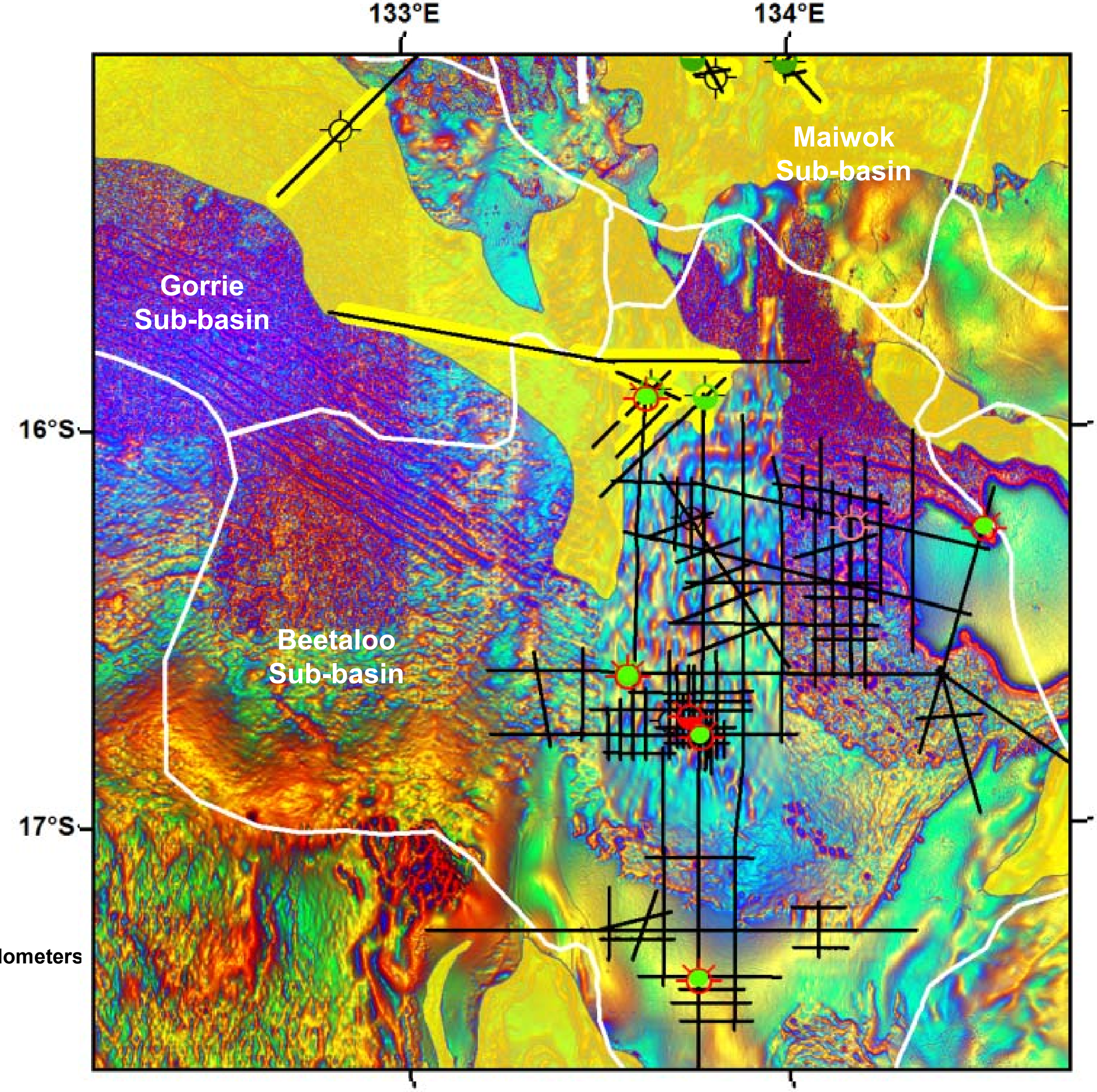
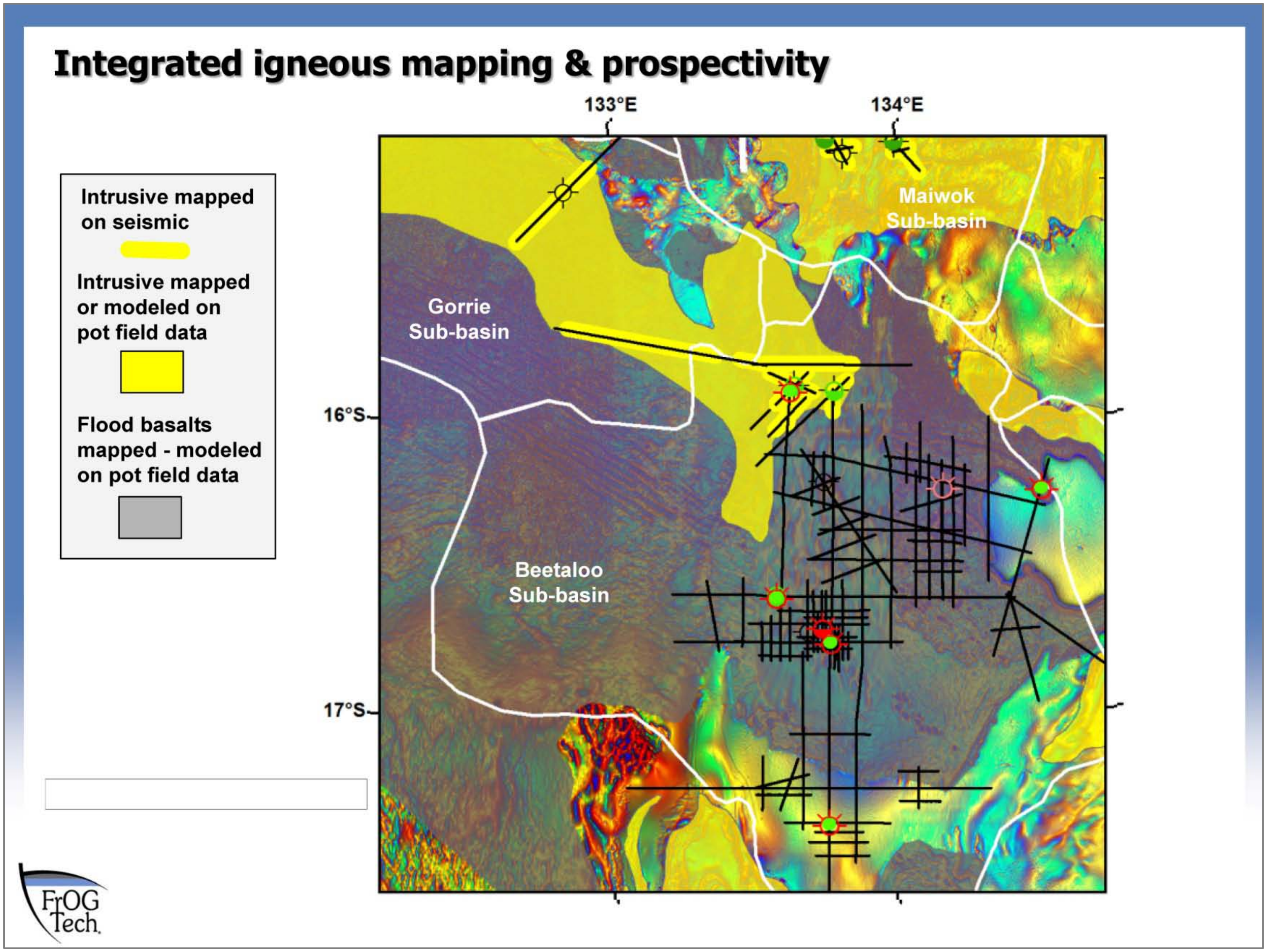
Integrated igneous mapping & prospectivity

Intrusive mapped on seismic

Intrusive mapped or modeled on pot field data



0 50 100 Kilometers



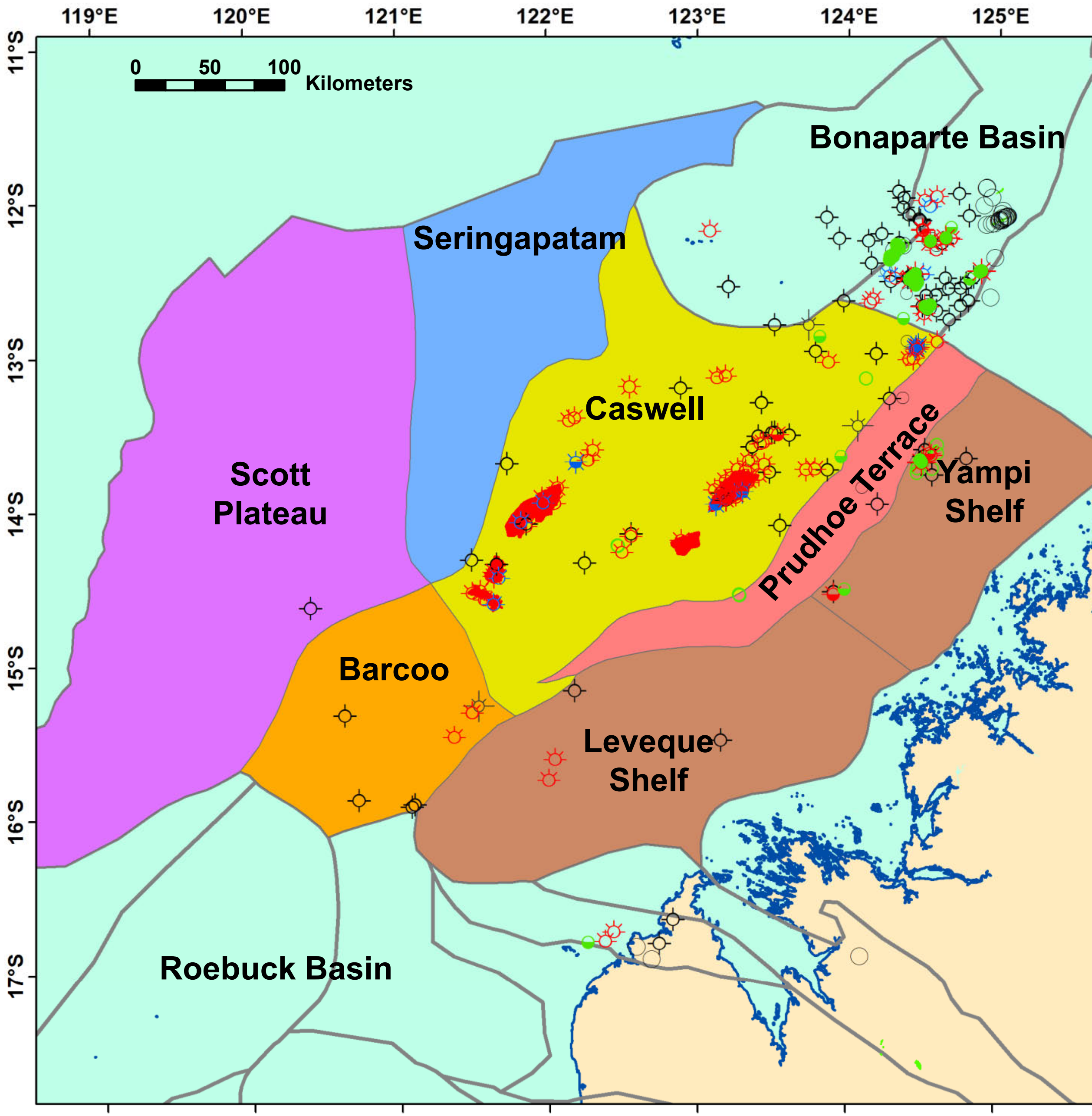
Presenter's Notes:

2nd image is an RTP_TernaryTiltMsAgc filter

Derim Derim Dolerite

- Sills up to 100m thick and dykes
- 1324 ± 4 Ma age from Kimberley region (J. Claoue-Long, written pers. comm., 2005 quoted by Goldberg, 2010)
- 1280 Ma age from this region

Browse Basin – Northwest Shelf



Wells

- Oil
- Oil & gas
- Gas & condensate
- Gas
- Gas, oil shows
- Oil Shows
- Oil & Gas Shows
- Gas & condensate shows
- Gas Shows
- Oil & Gas indication
- Dry hole
- Result unreported

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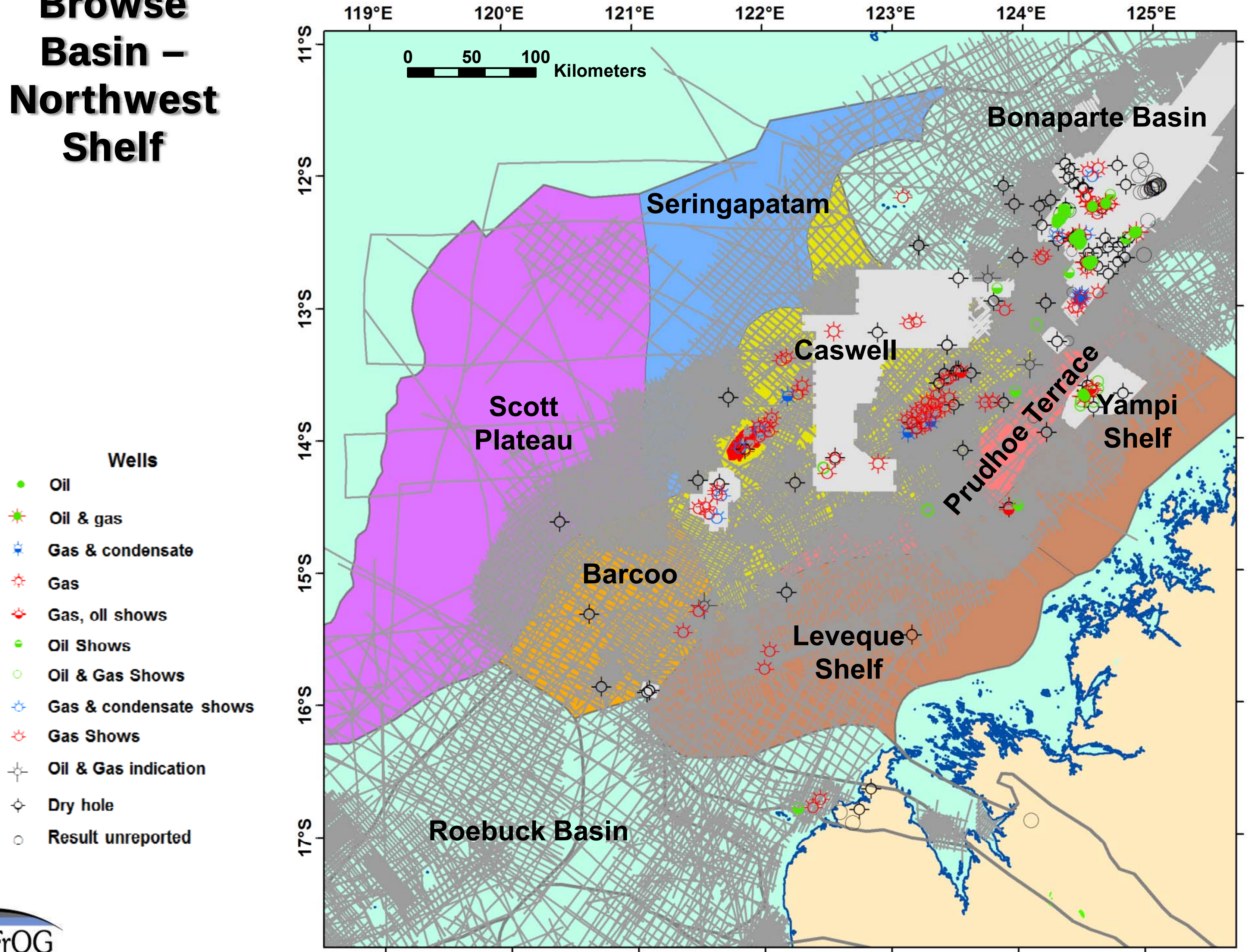
Browse Basin – Northwest Shelf



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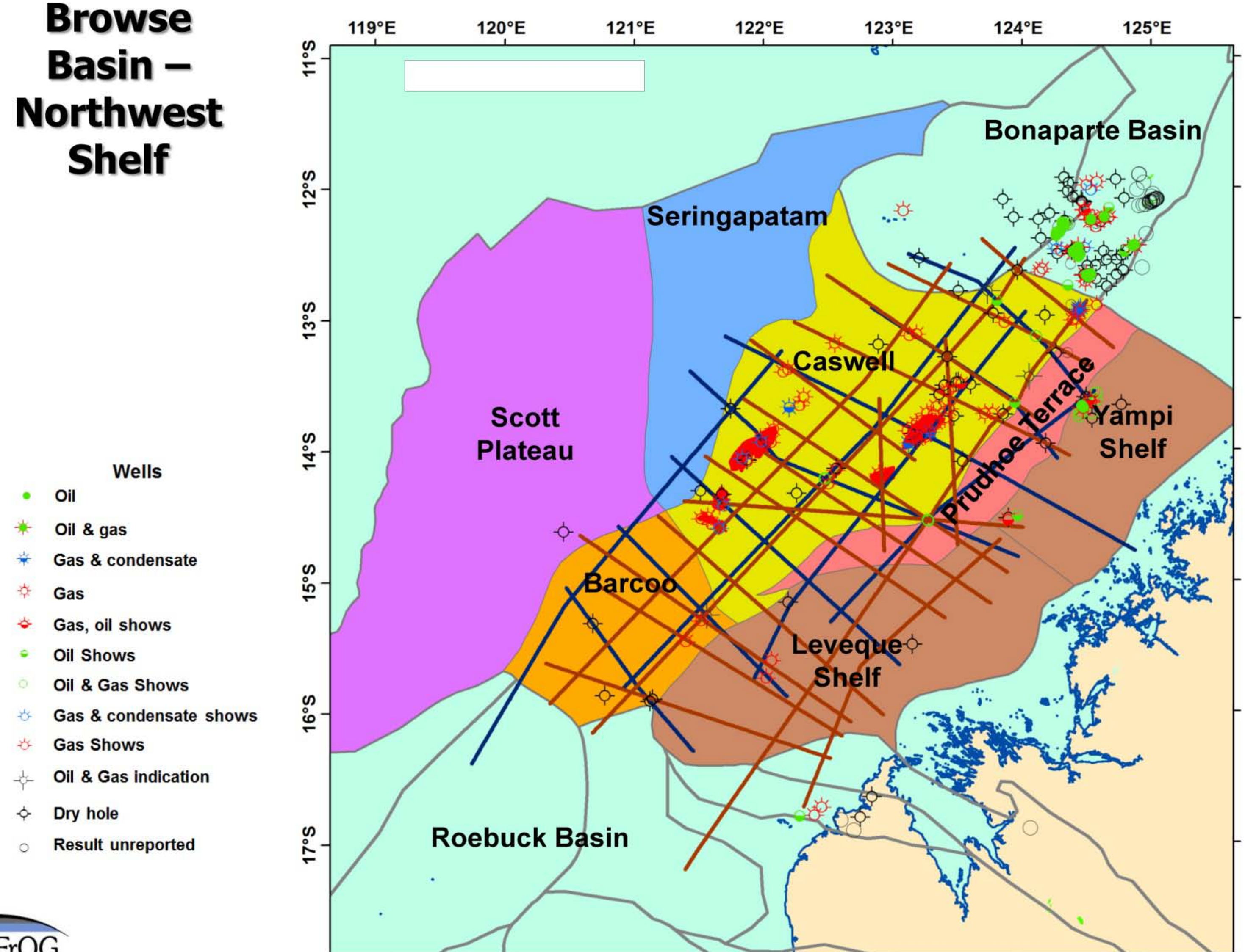
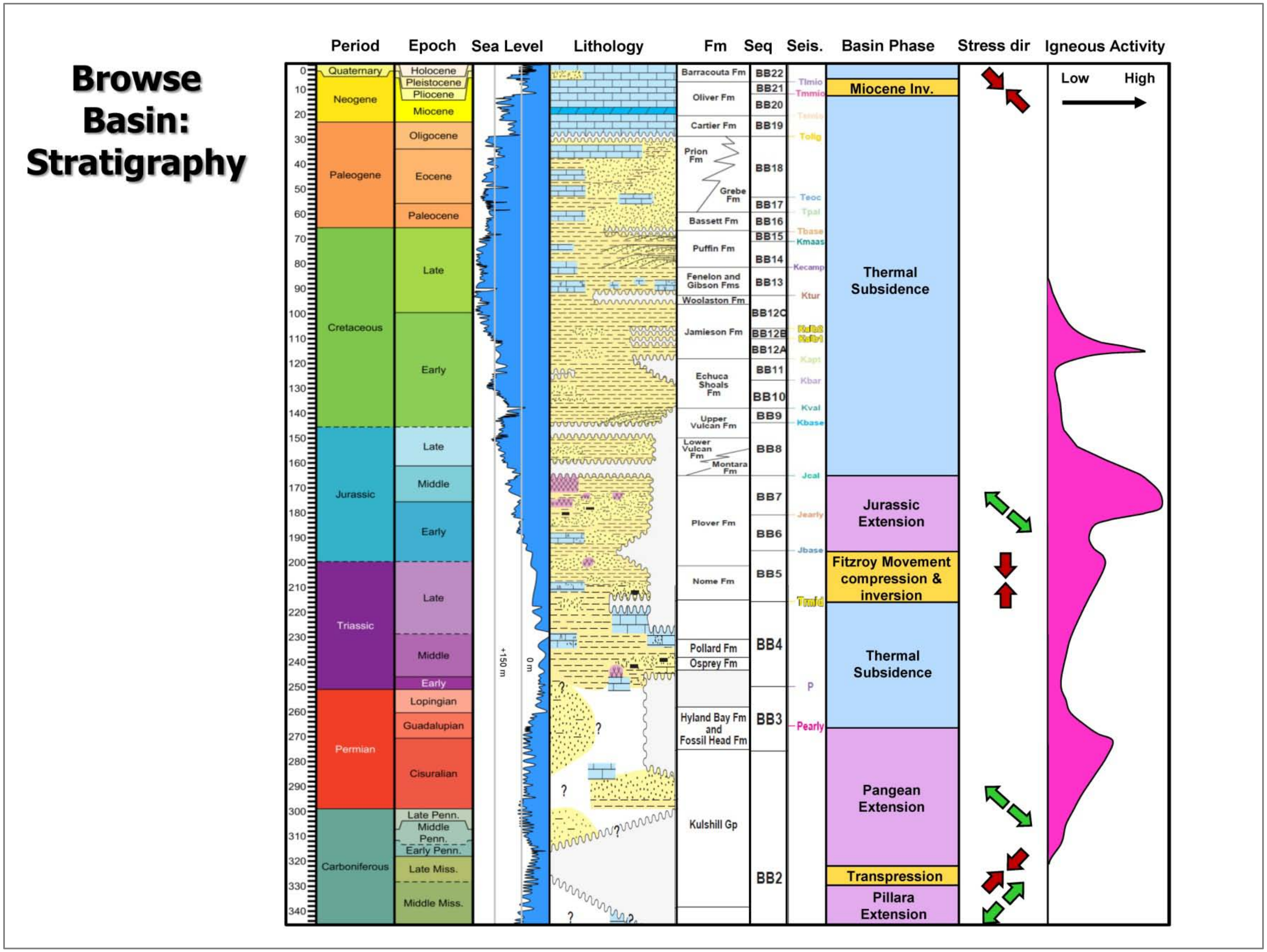
Browse Basin – Northwest Shelf





Presenter's Notes:

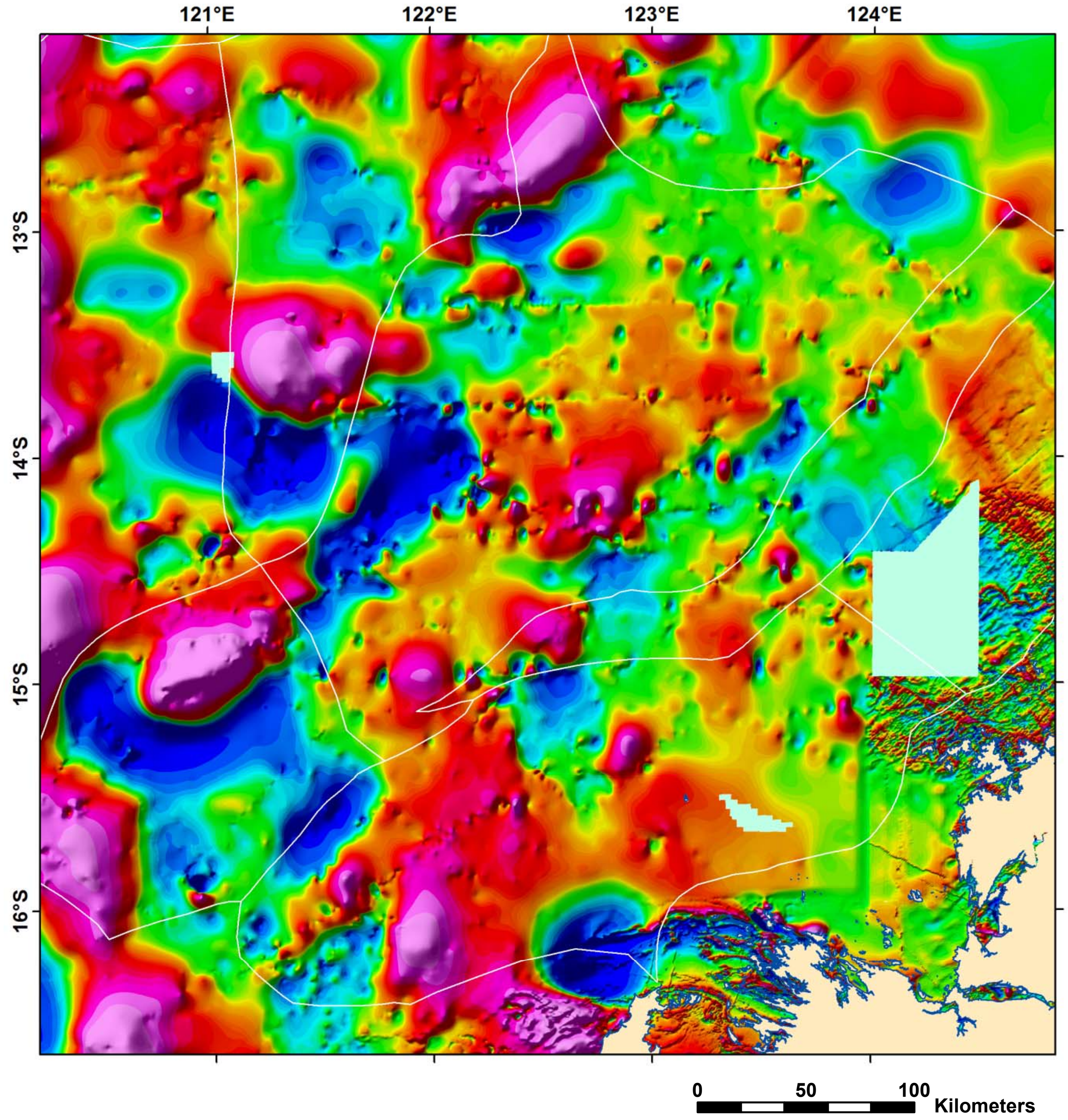
Main Igneous events are associated with:

1. Permo-Carboniferous extension
2. Early-mid Jurassic extension

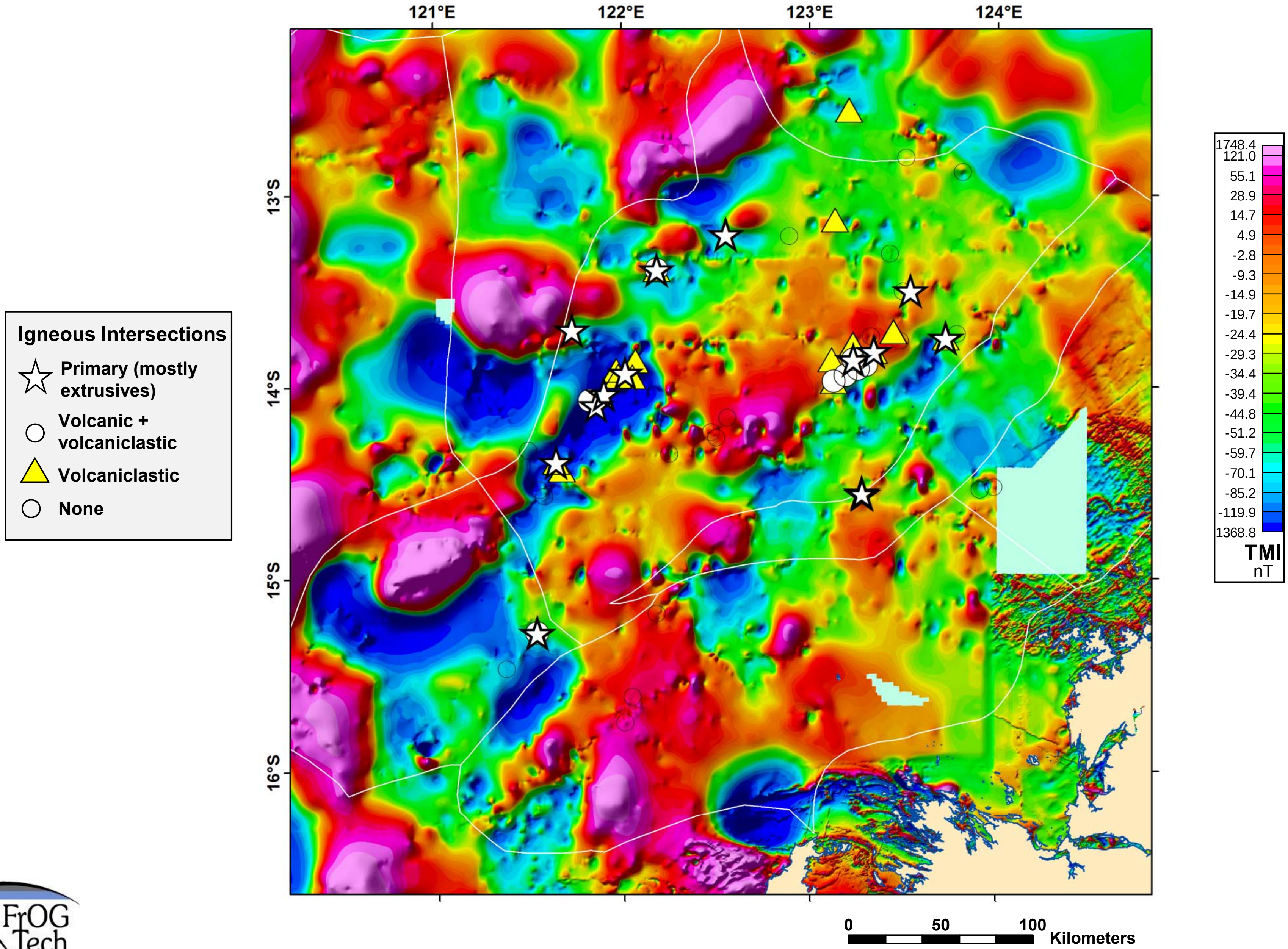
There are to less voluminous and extensive peaks in igneous activity during:

1. Triassic compression and partial basin inversion
2. Minor volcanism during the Aptian (far-field effects?)

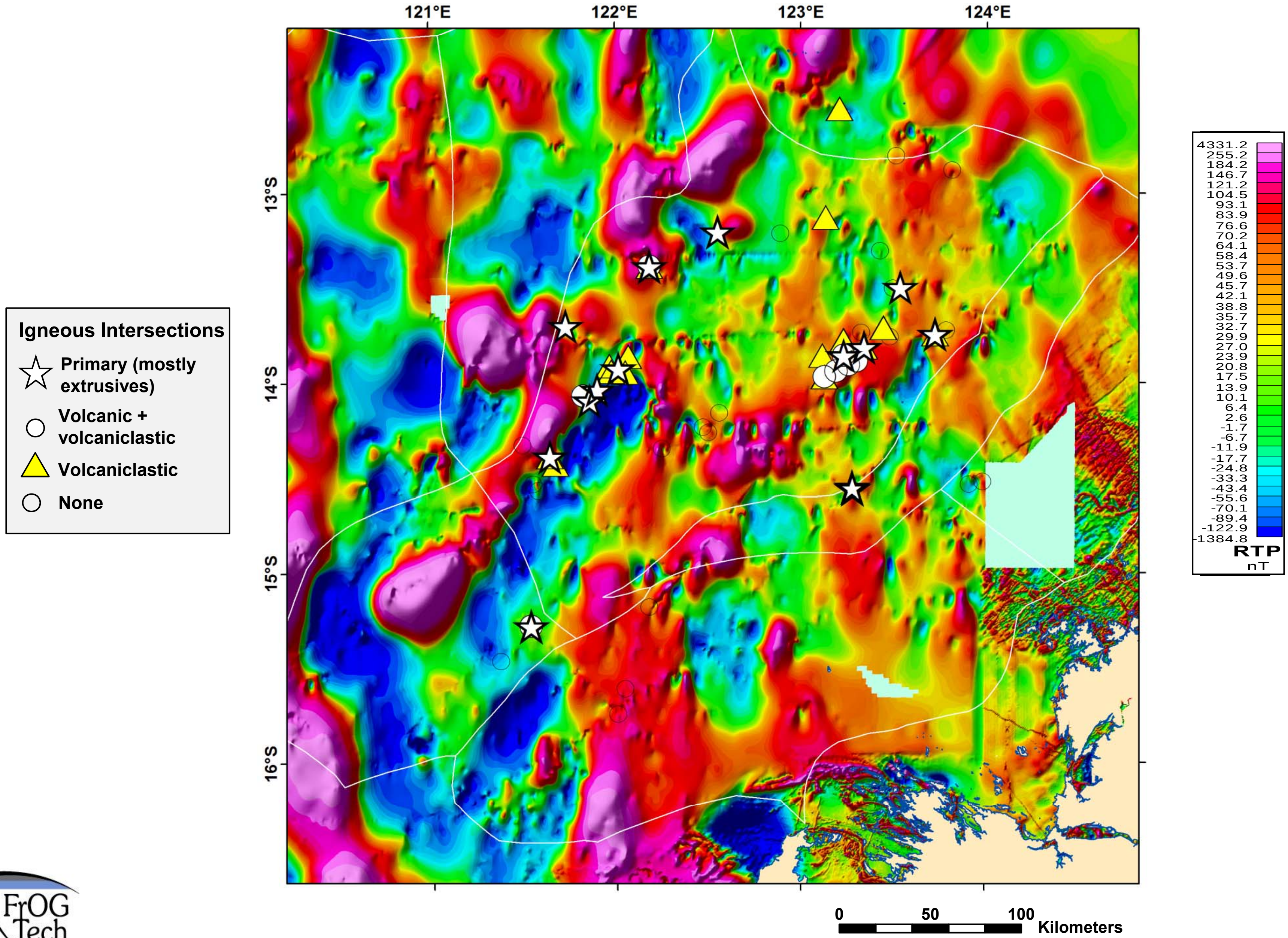
Igneous Character from Magnetics & Well Calibration



Igneous Character from Magnetics & Well Calibration



Igneous Character from Magnetics & Well Calibration



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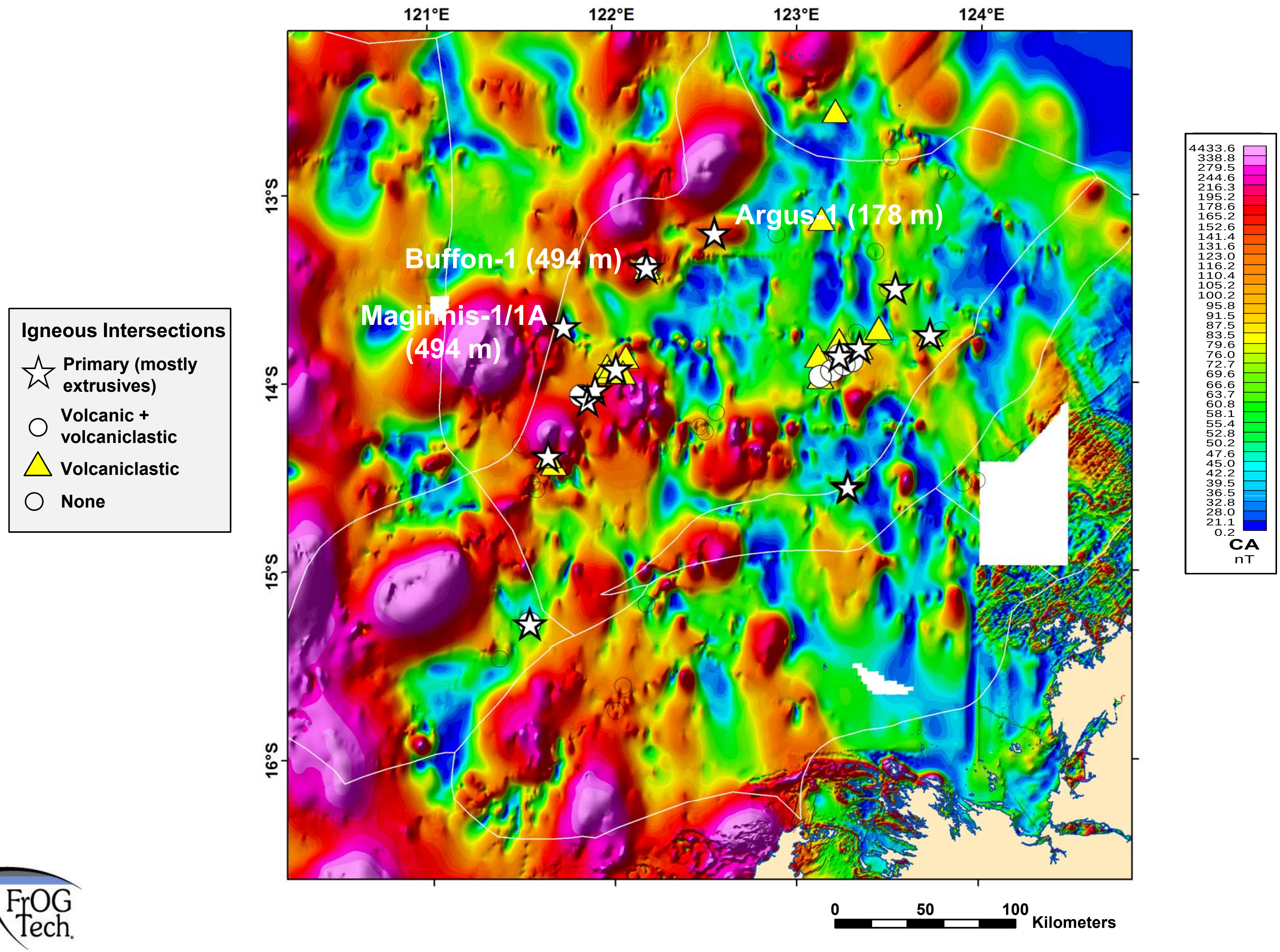
Igneous Character from Magnetics & Well Calibration



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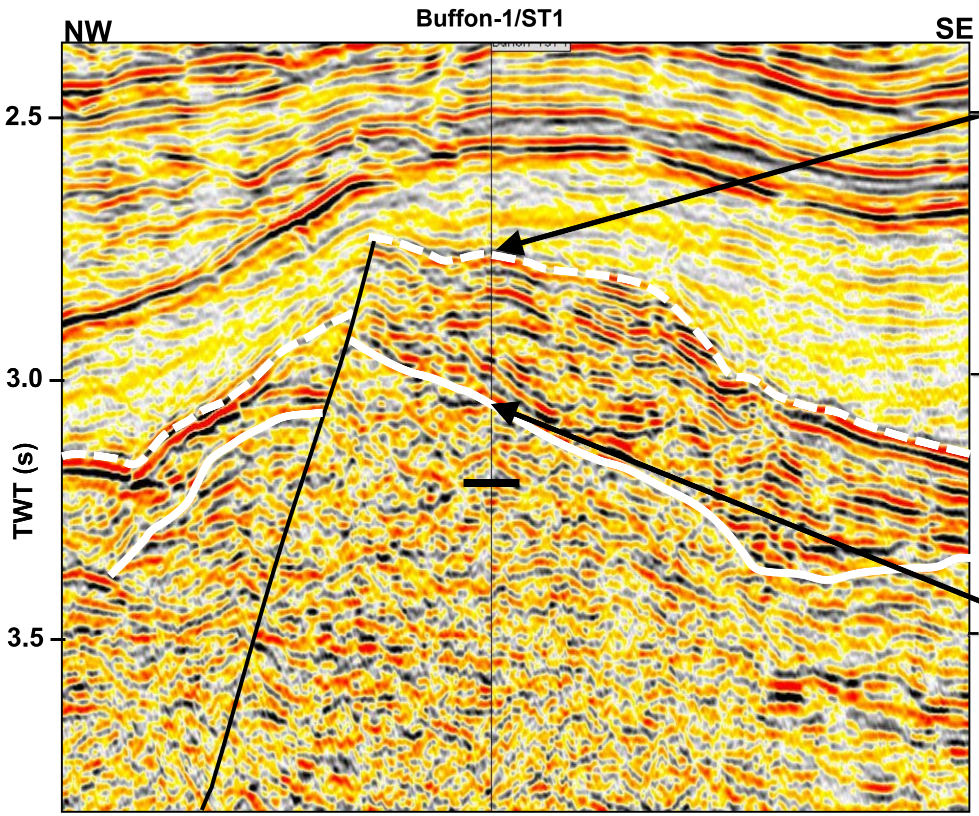
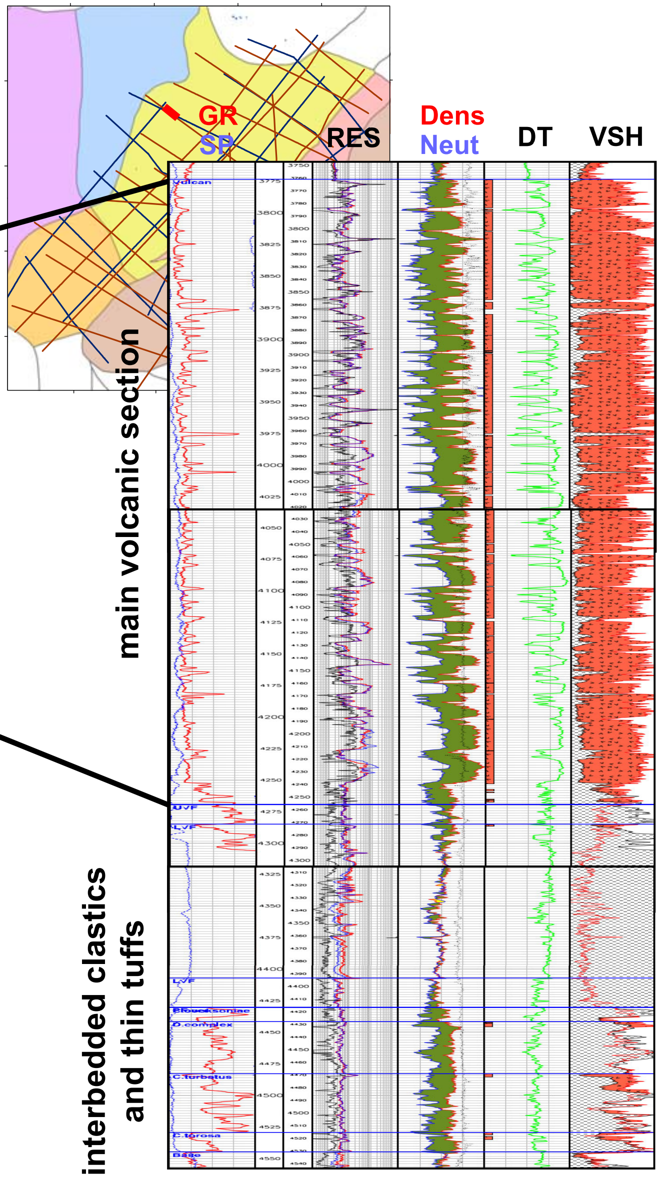
Igneous rocks at Buffon-1

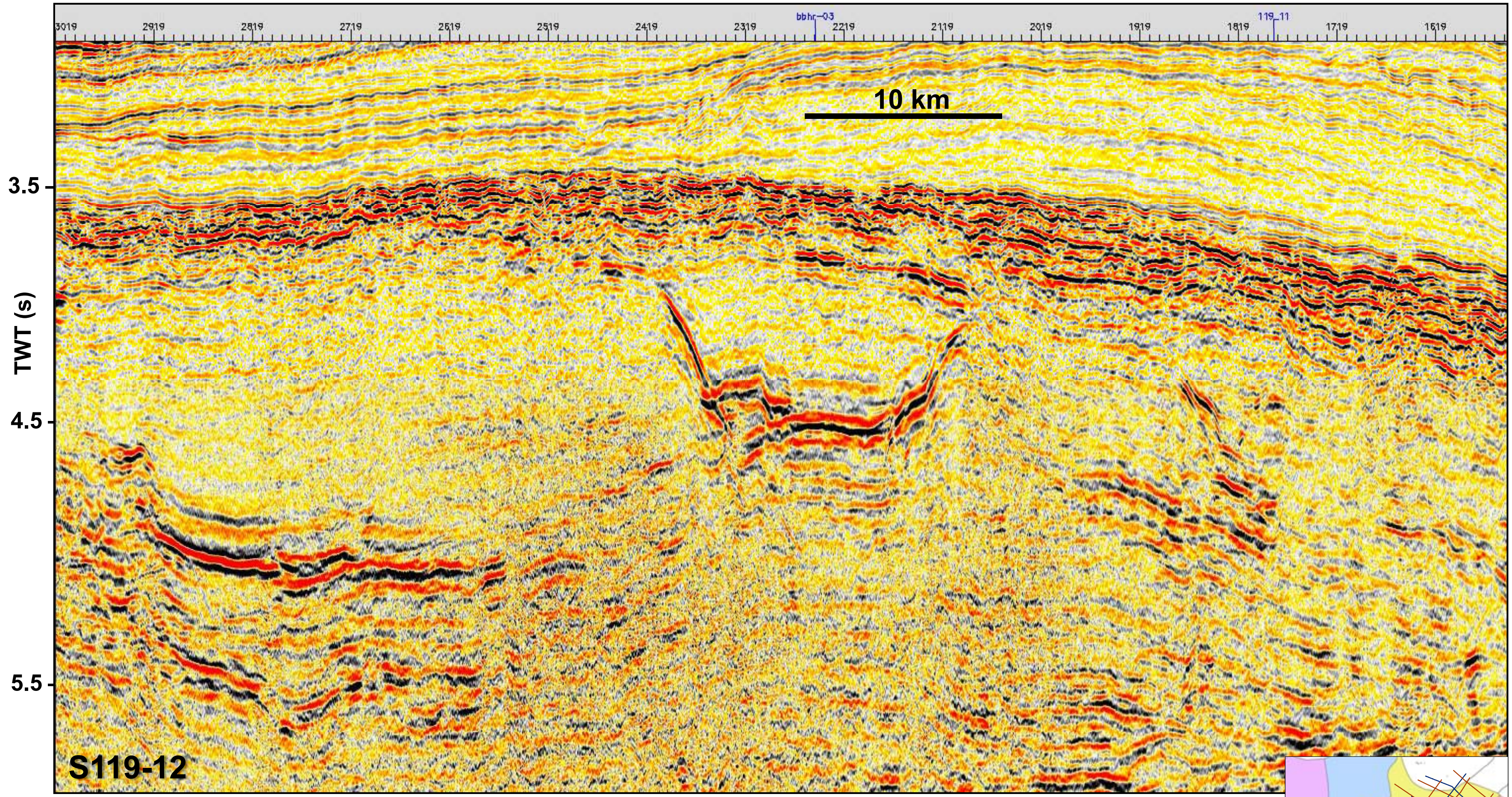


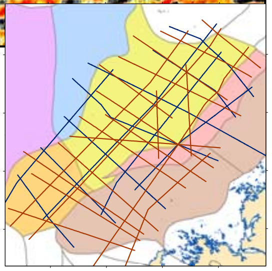


TD @ 4787mRT, ~ 3200 ms twt

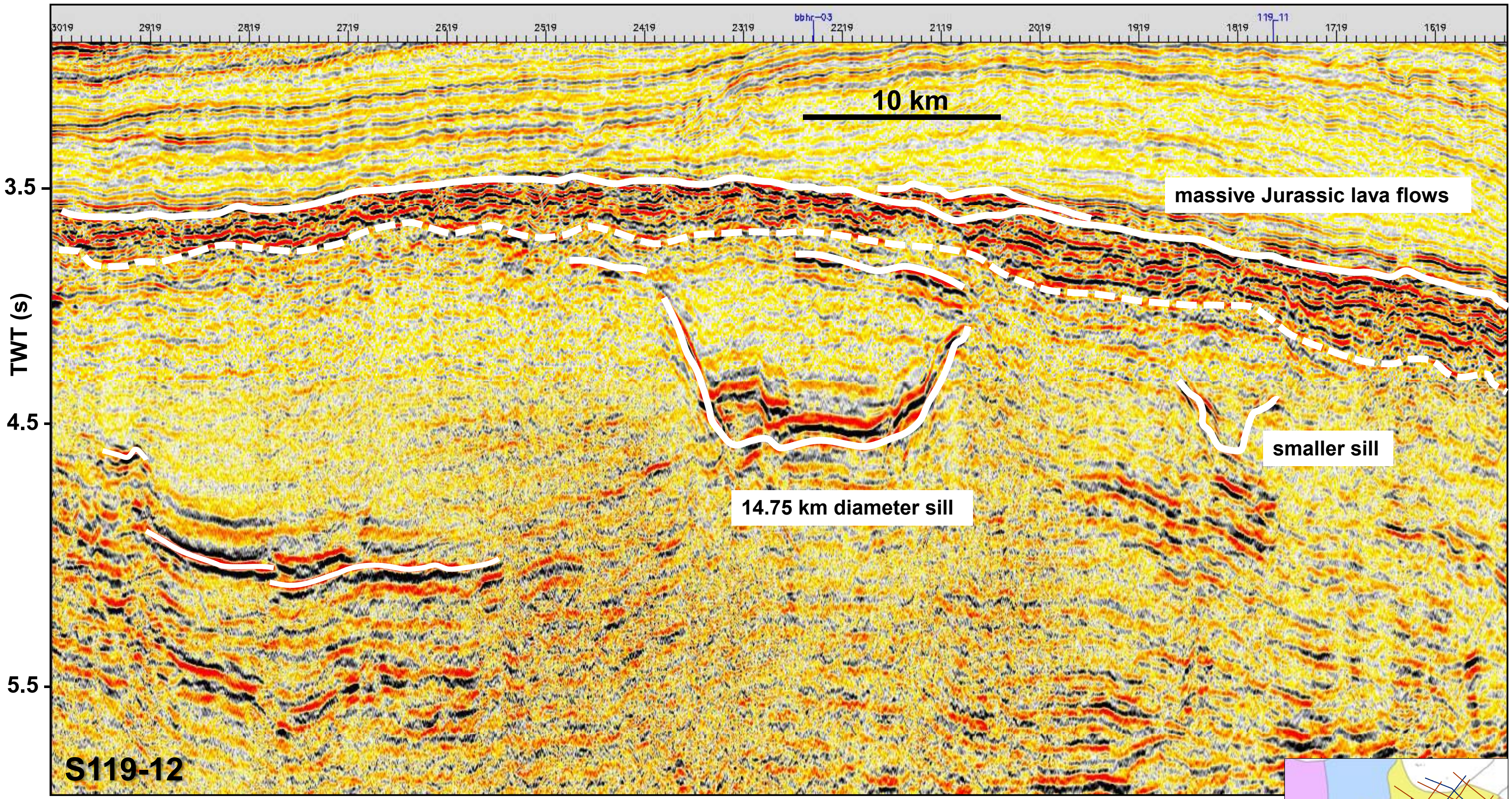
- Volcanic section 3760-4254 mRT (494 m thick)
- Clear seismic change top & base of volcanics
- 3 igneous facies: basalt flows (2-25 m thick), tuffs, coarse pyroclastics
- More lava interpreted off flanks

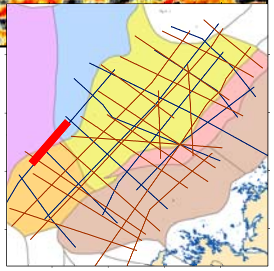
Seismic mapping & Calibration – outer Browse





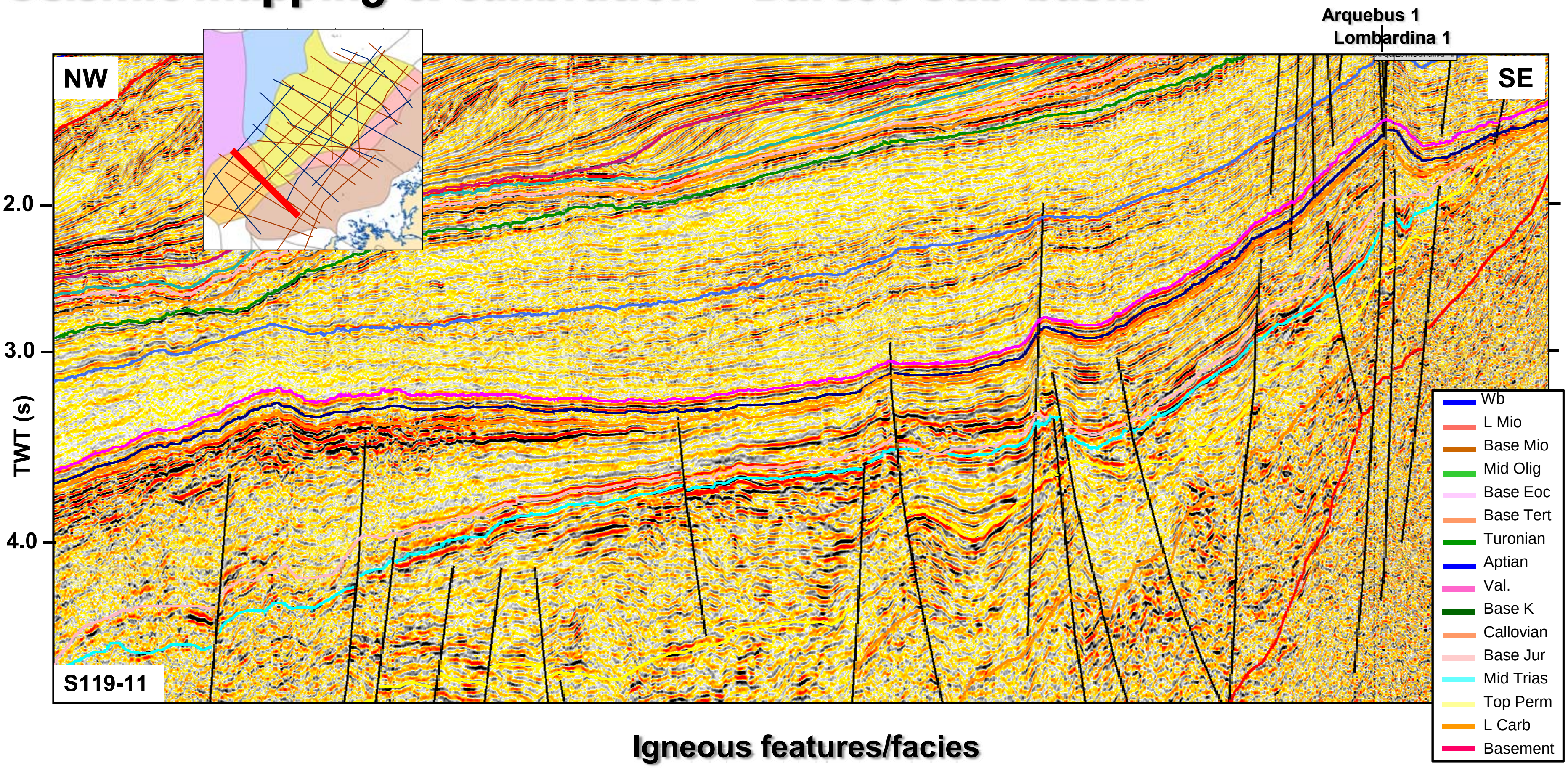
Seismic mapping & Calibration – outer Browse





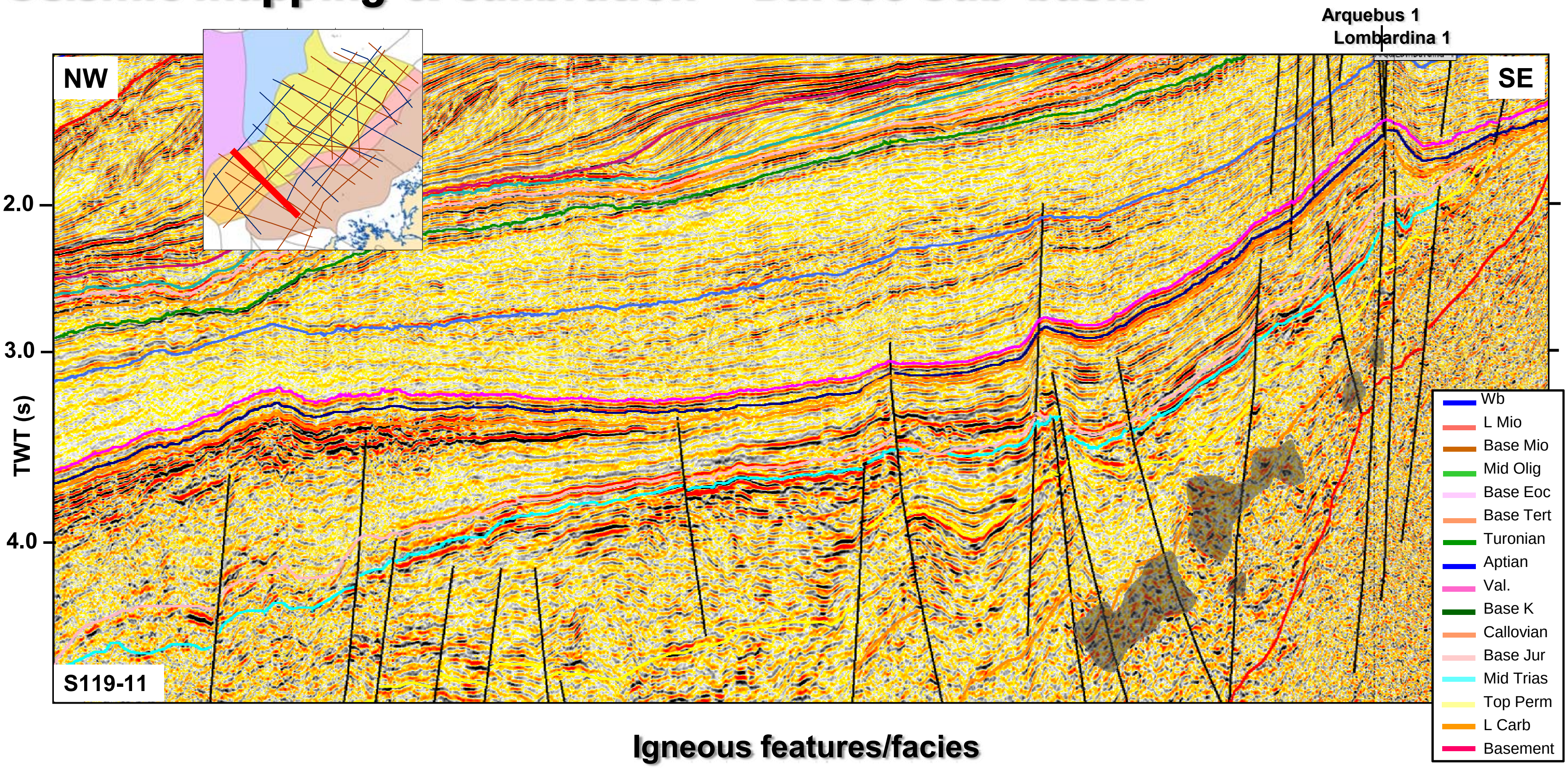
- Western Barcoo & Caswell S-b exhibit significant intra-basinal magmatism
- Massive sills and extensive Jurassic lavas. Multiple large magnetic anomalies
- Lavas reach thickness >300 ms twt (500 m+) = 483 m @ Maginnis 1/1A

Seismic mapping & Calibration – Barcoo Sub-basin



Igneous features/facies

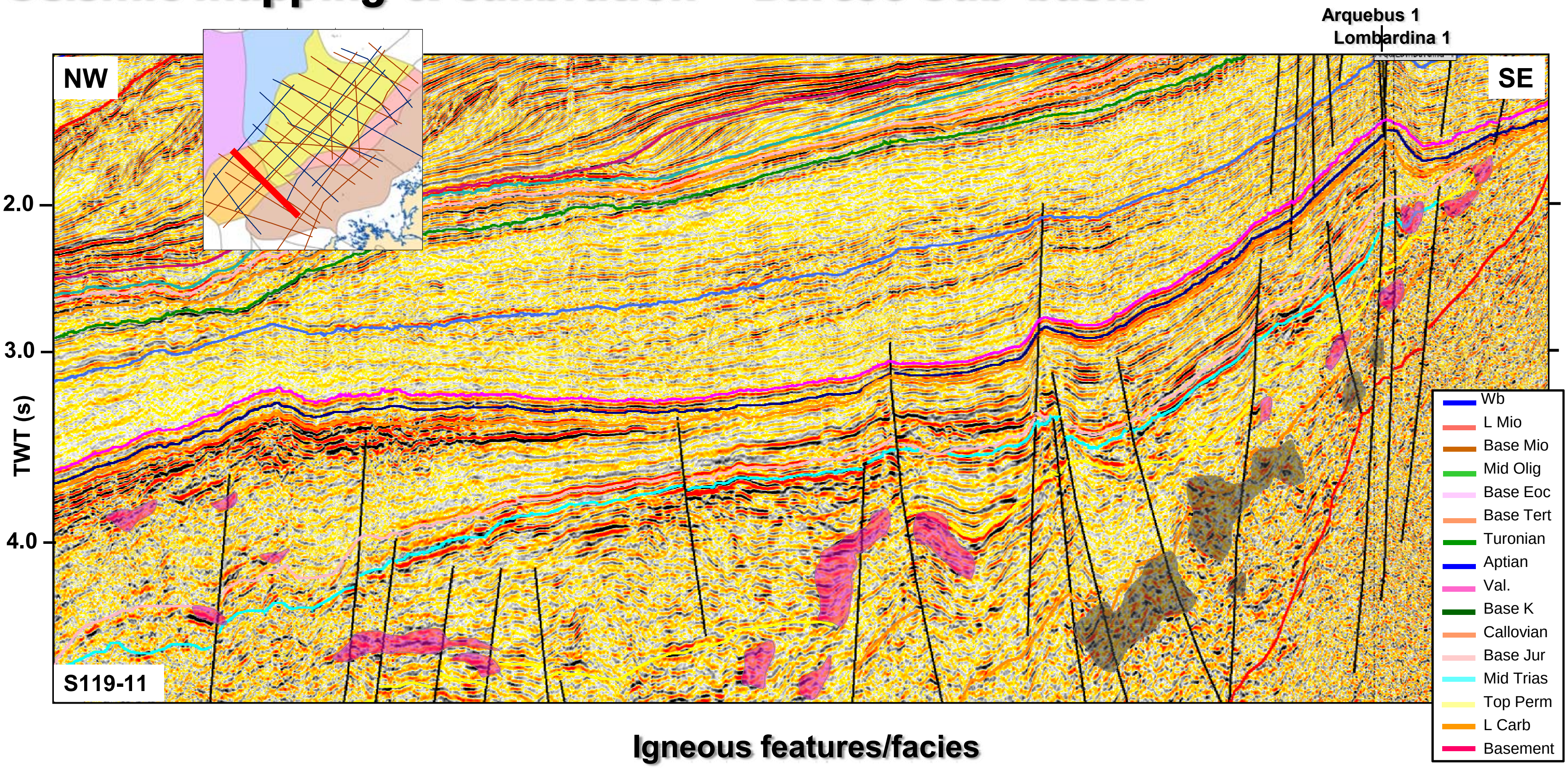
Seismic mapping & Calibration – Barcoo Sub-basin



Igneous features/facies

Chaotic, discontinuous, high amplitude, low frequency reflections at depth → early rift magmatism?

Seismic mapping & Calibration – Barcoo Sub-basin

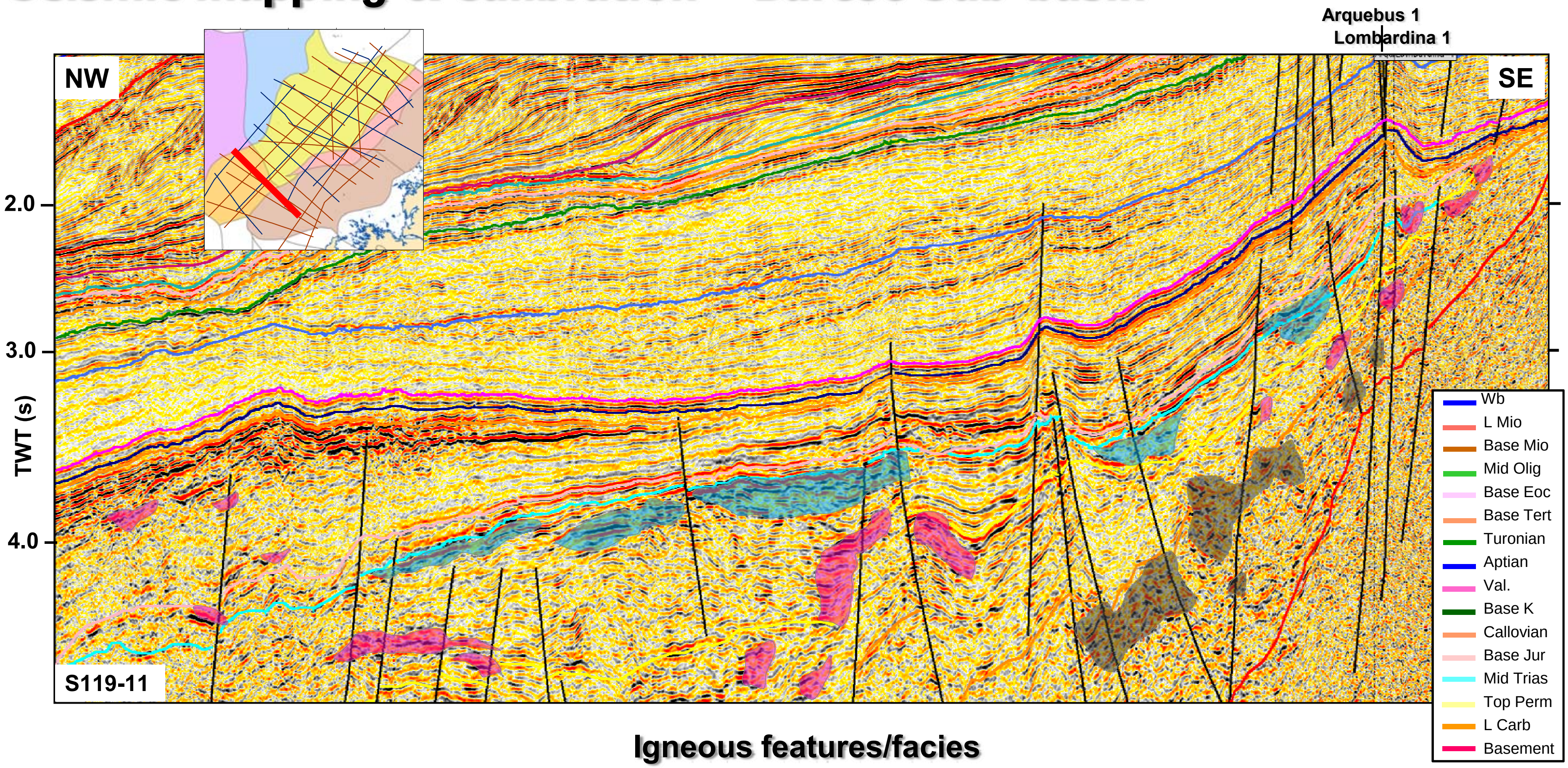


Igneous features/facies

Intra-Permo Carboniferous cross-cutting discontinuous & 'climbing' anomalies → Sills & dykes

Chaotic, discontinuous, high amplitude, low frequency reflections at depth → early rift magmatism?

Seismic mapping & Calibration – Barcoo Sub-basin



Igneous features/facies

- Intra-Triassic complex terminations and geometries → extrusive and very shallow intrusive features
- Intra-Permo Carboniferous cross-cutting discontinuous & 'climbing' anomalies → Sills & dykes
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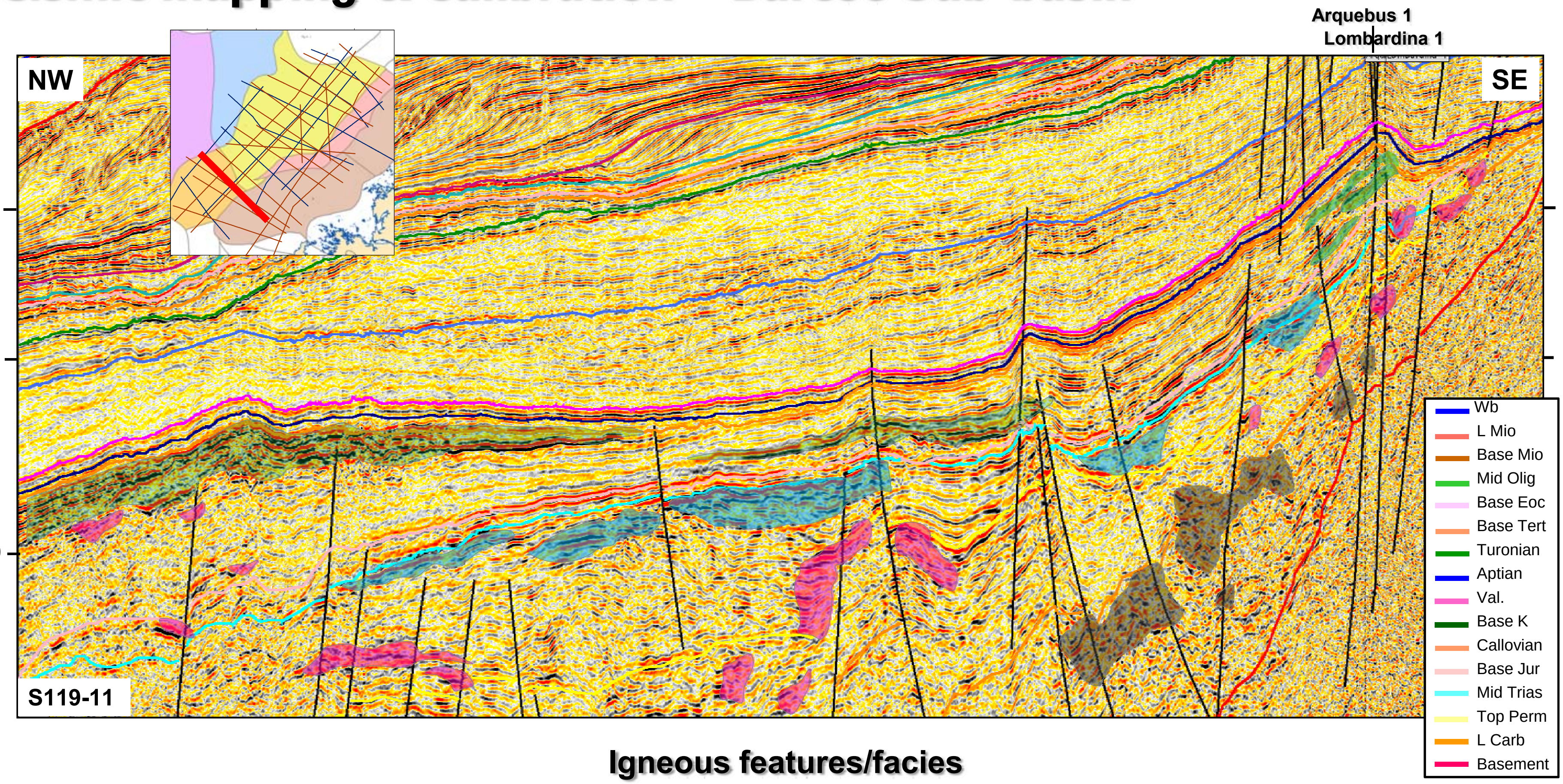

Igneous features/facies

- Laterally continuous, conformable, high amplitude reflections with clear coherent top, rubbly internal character and a diffuse base → massive, amalgamated basalts (lava flows)
- Intra-Triassic complex terminations and geometries → extrusive and very shallow intrusive features
- Intra-Permo Carboniferous cross-cutting discontinuous & 'climbing' anomalies → Sills & dykes
- Chaotic, discontinuous, high amplitude, low frequency reflections at depth → early rift magmatism?

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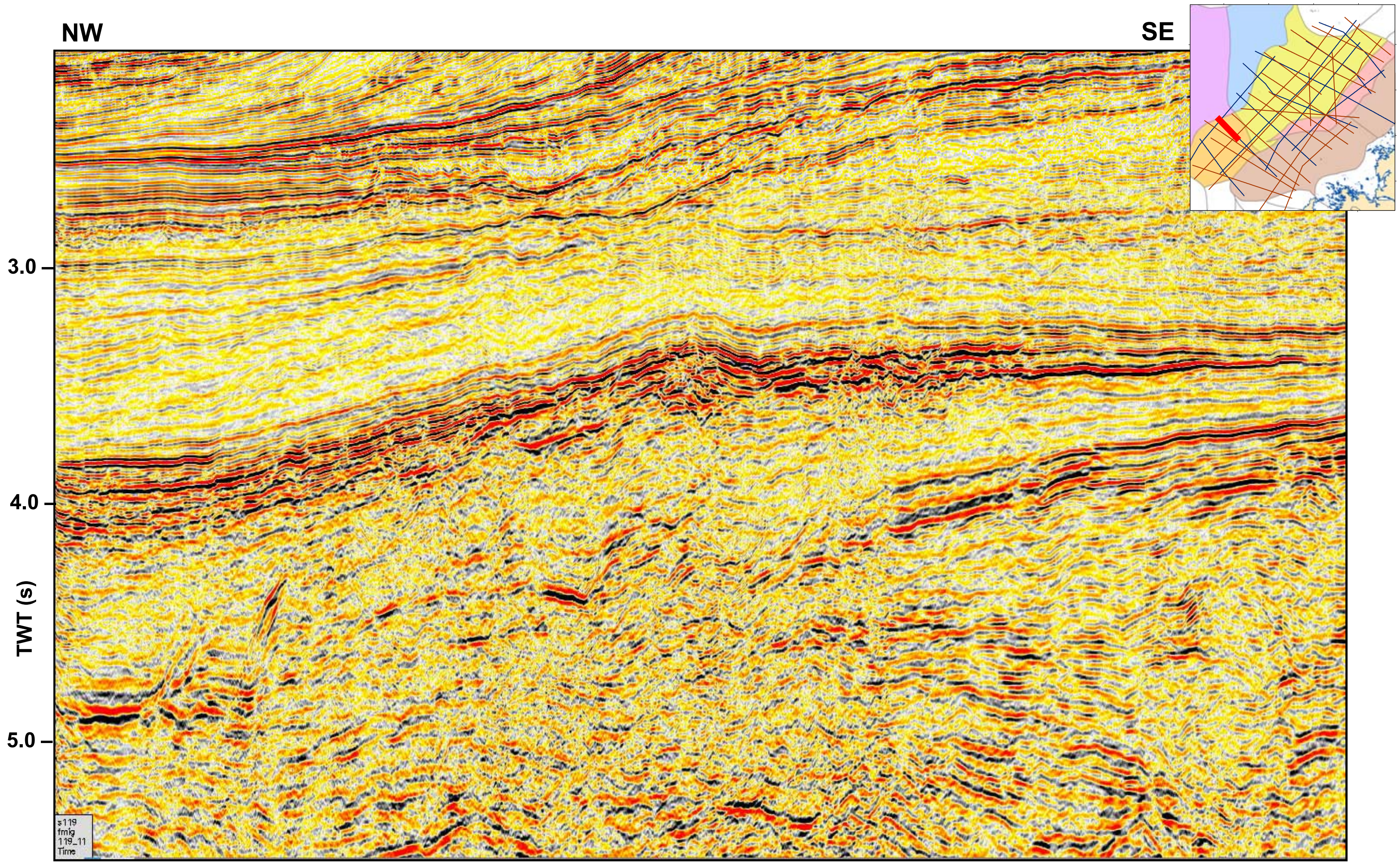

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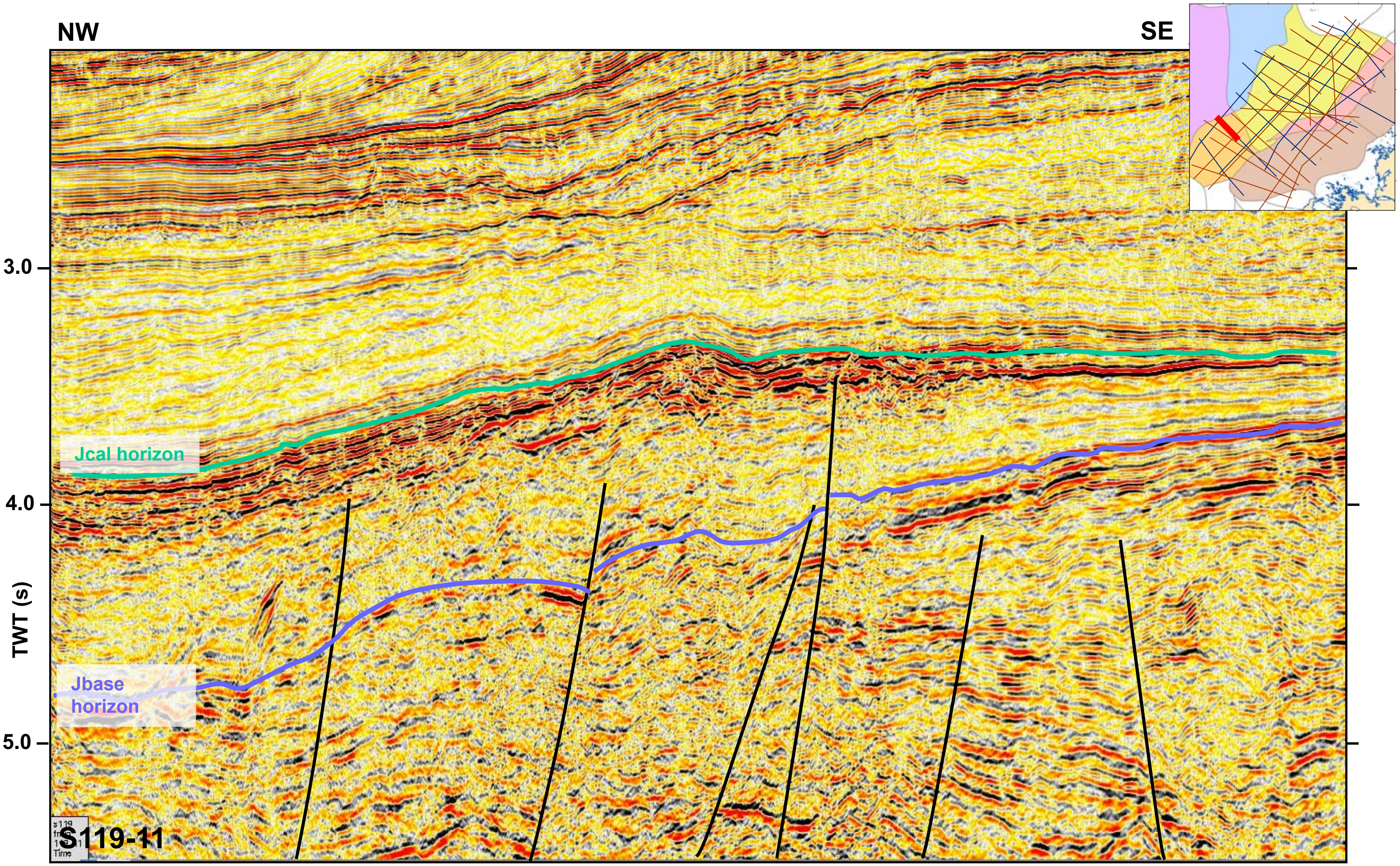

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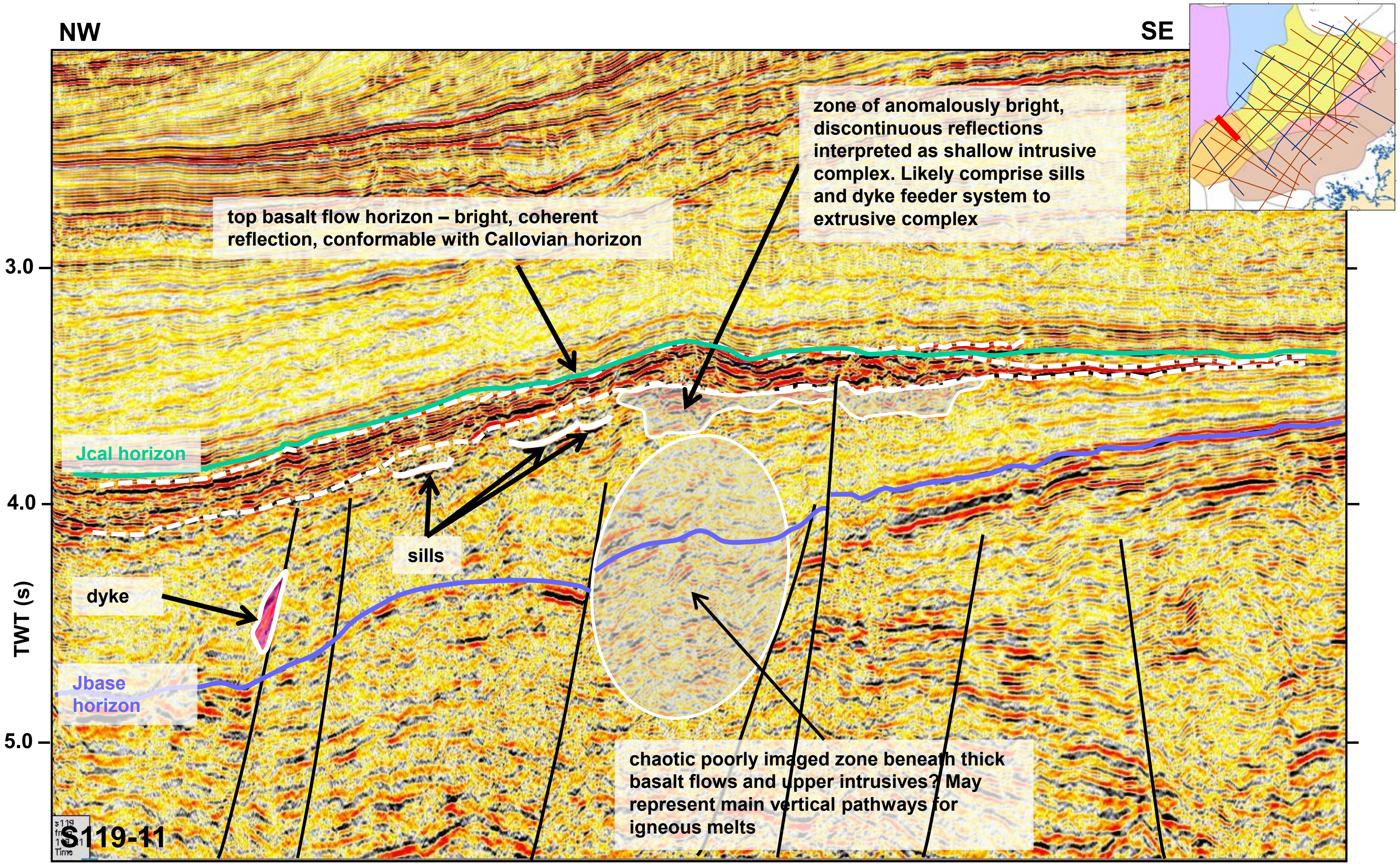
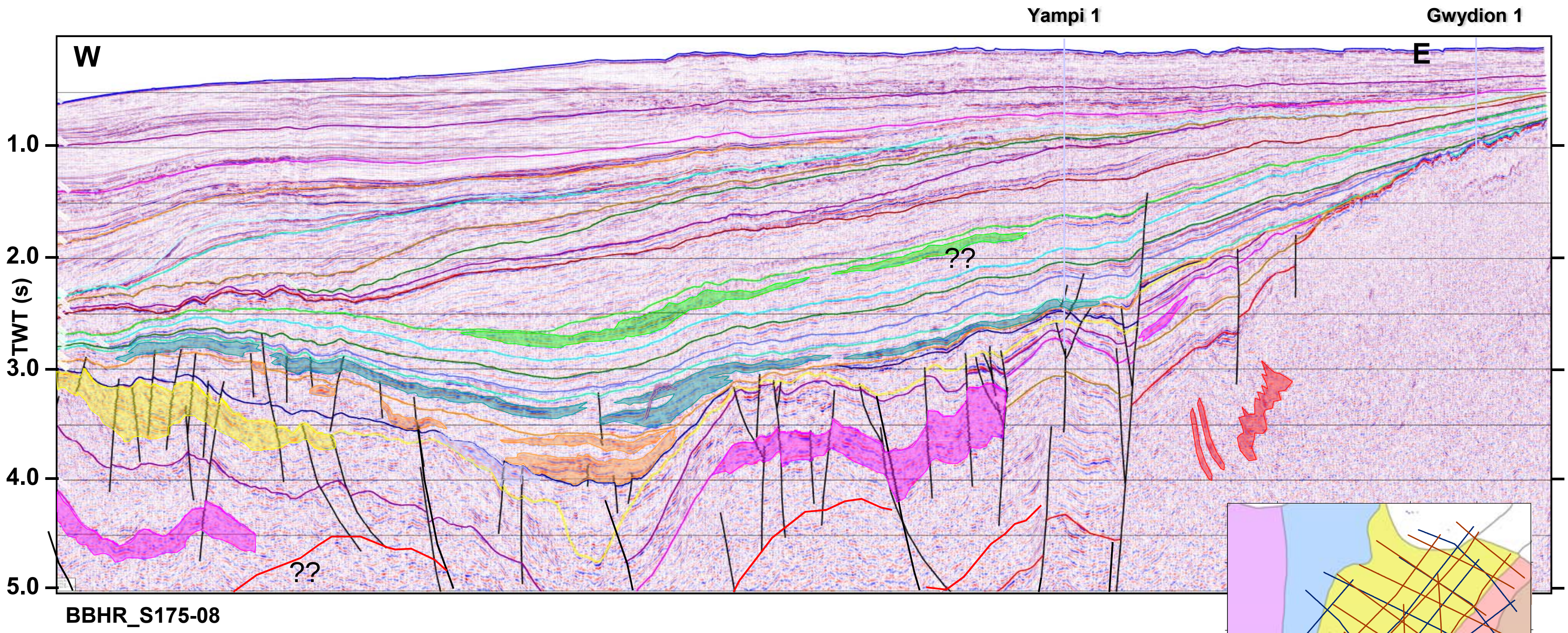
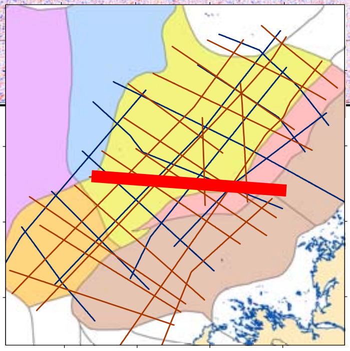


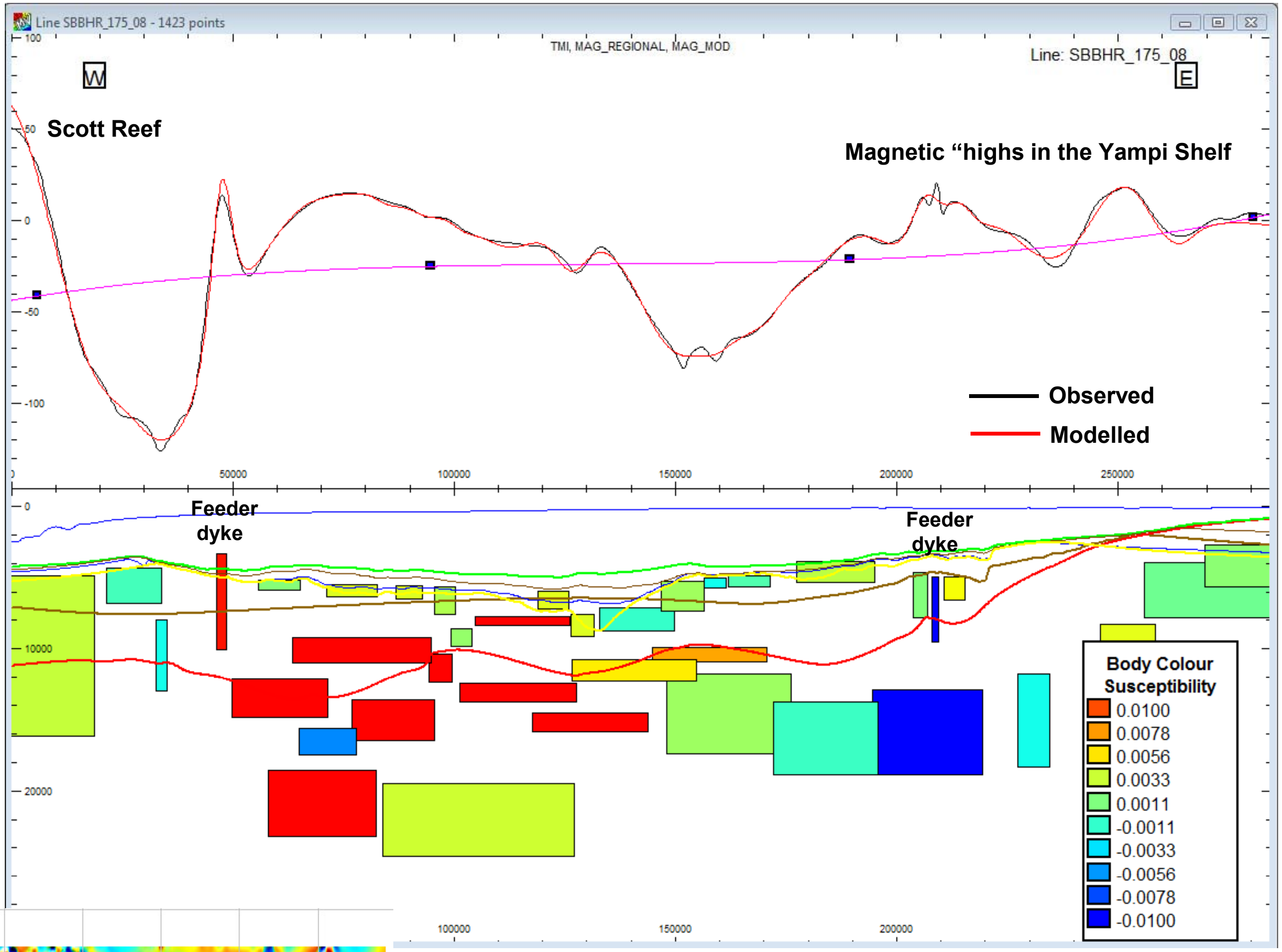
Geophysical Modelling: testing igneous seismic scenarios

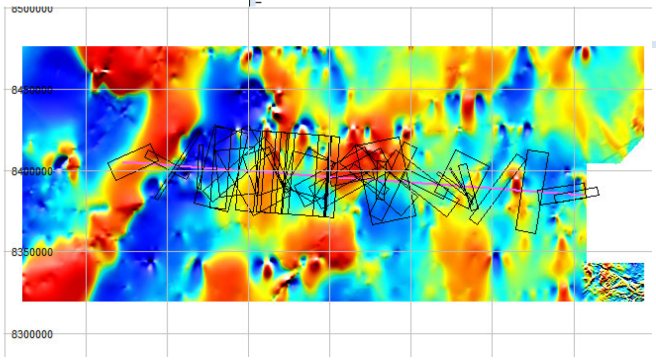




Geophysical Modelling: testing igneous seismic scenarios

Igneous Features





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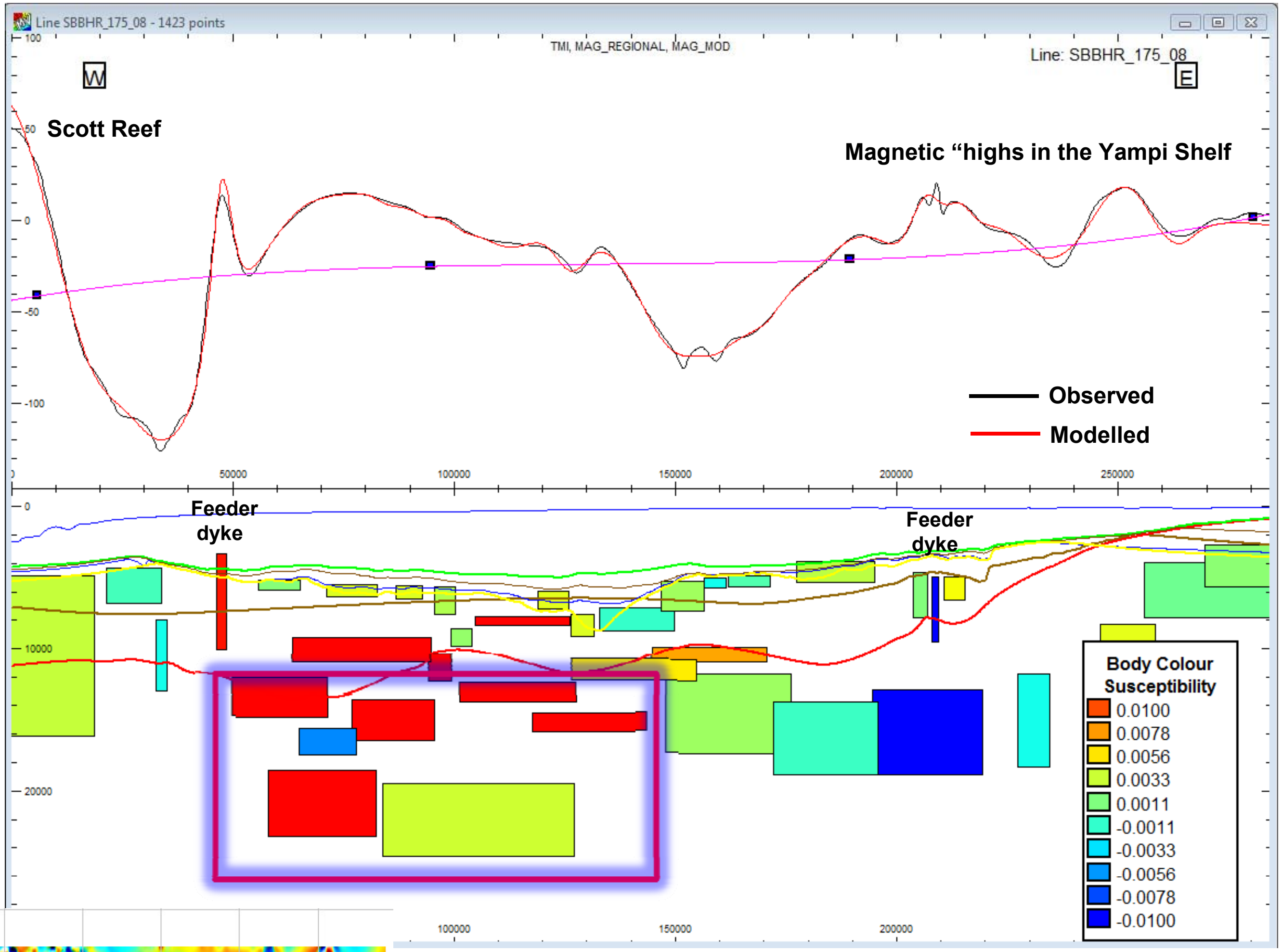
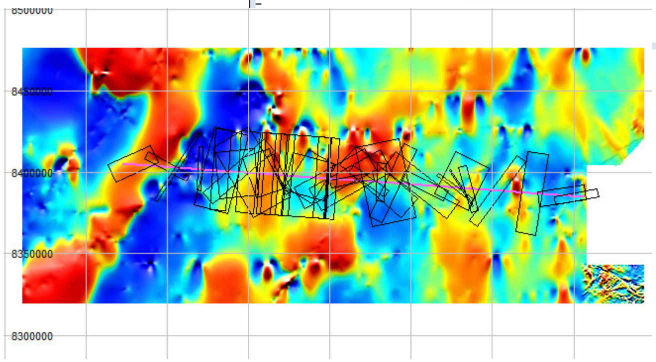
Geophysical Modelling: testing igneous seismic scenarios

Igneous Features

Strongly magnetised (mafic) intrusive complexes (Triassic?)





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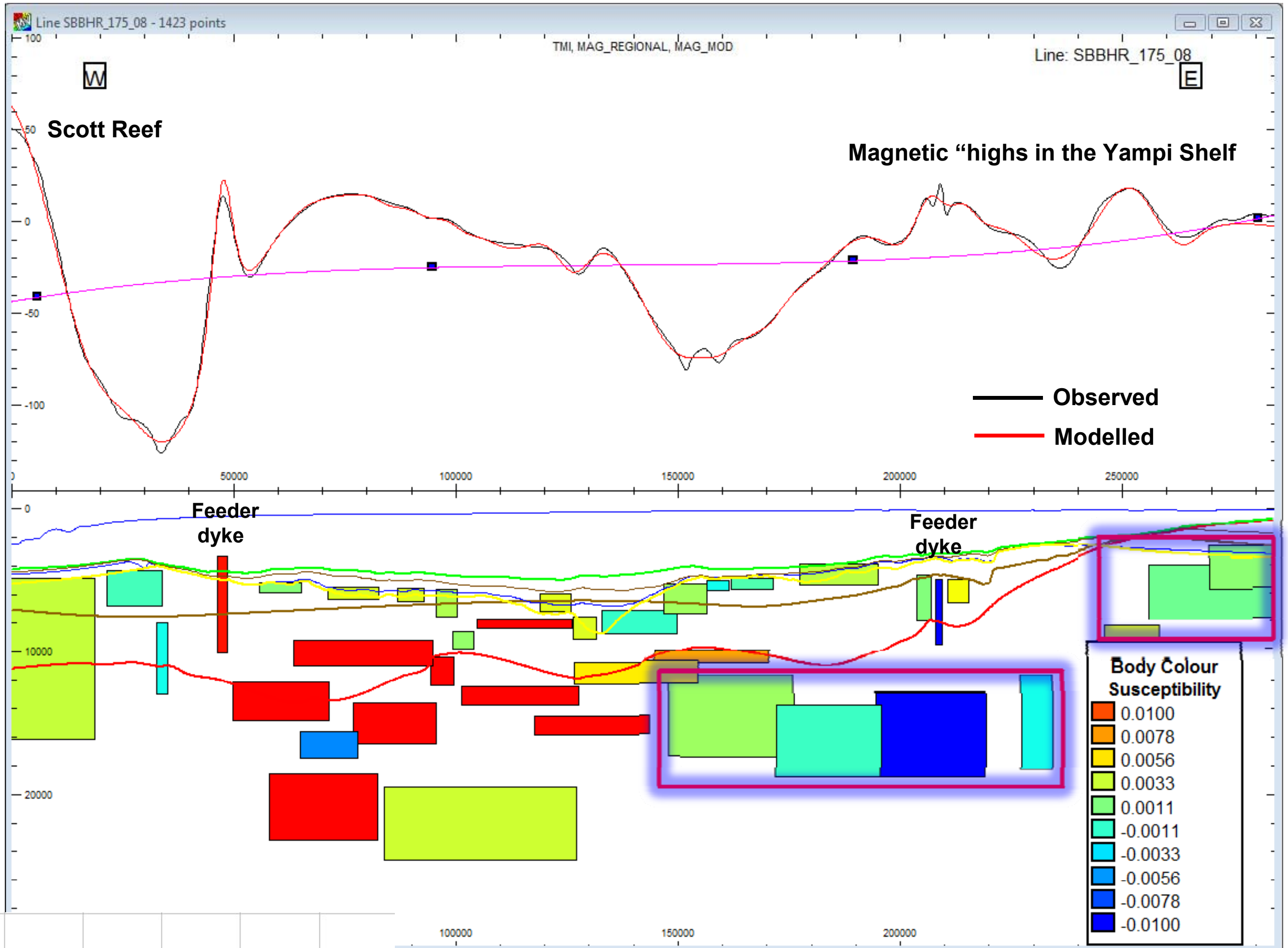
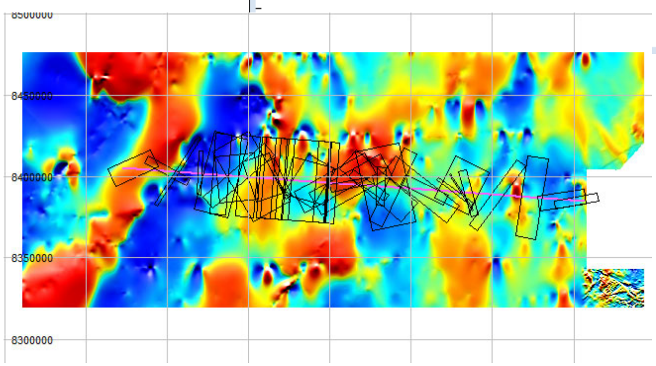
Strongly magnetised (mafic) intrusive complexes (Triassic?)

Mod-strongly negative magnetised (mafic-felsic) intrusions

Mod magnetised ?Prz basement intrusions





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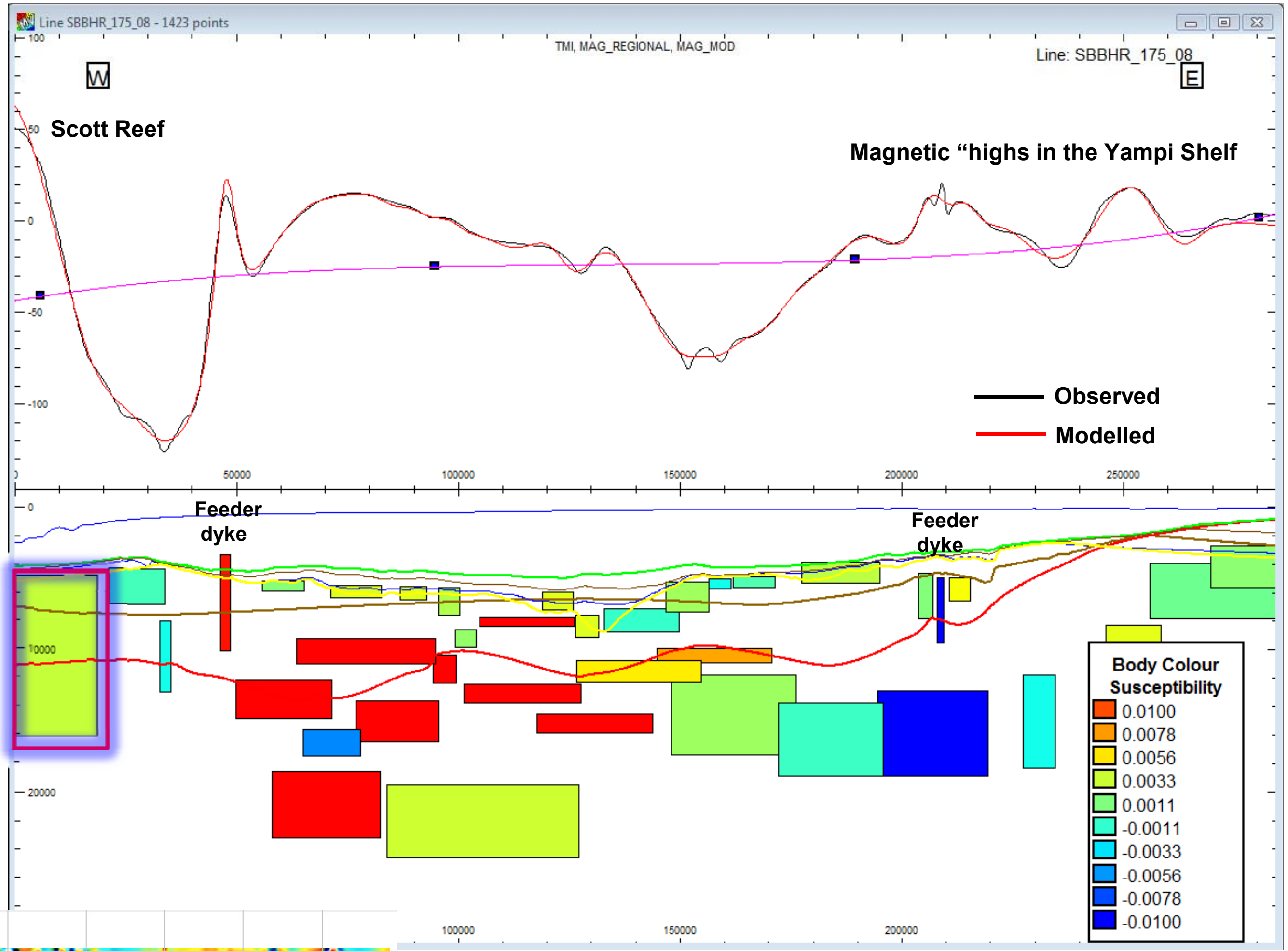

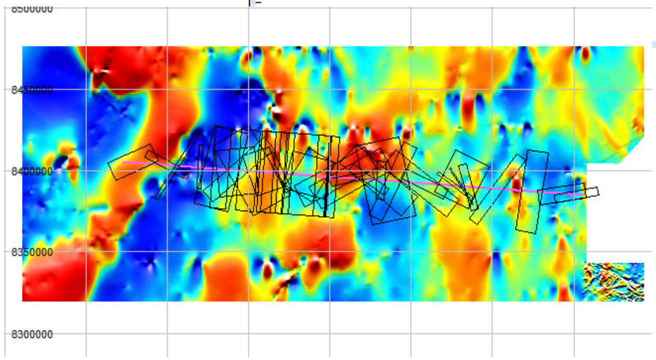

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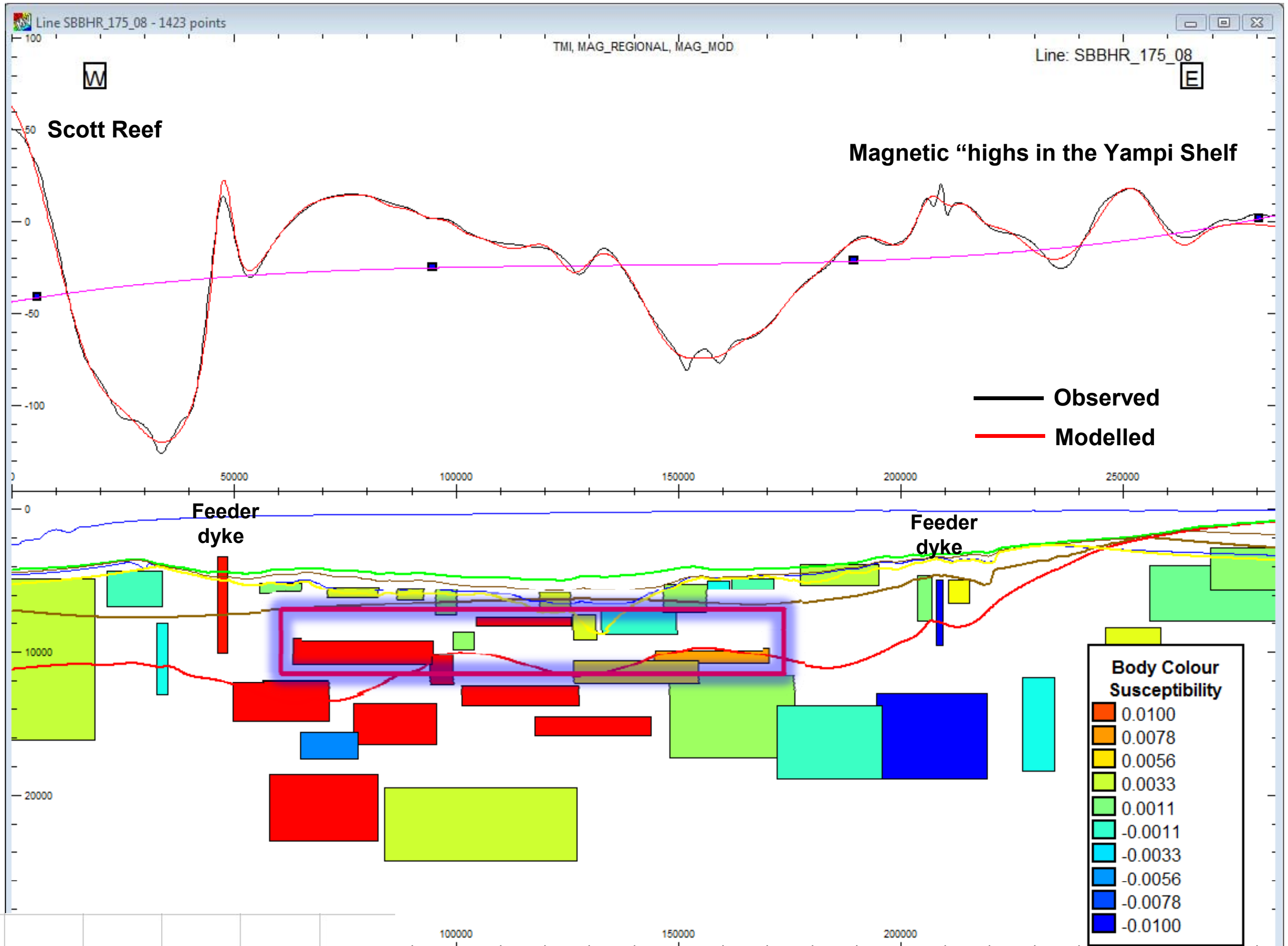

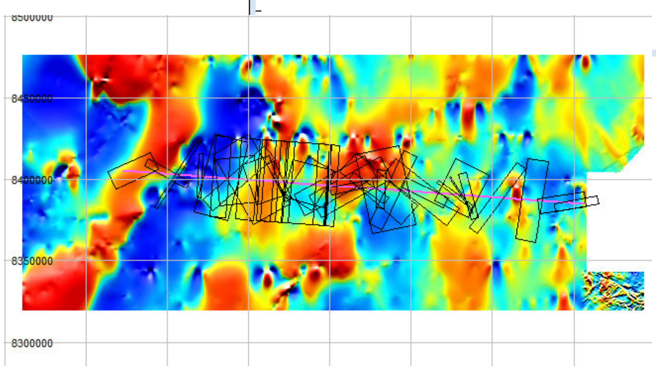

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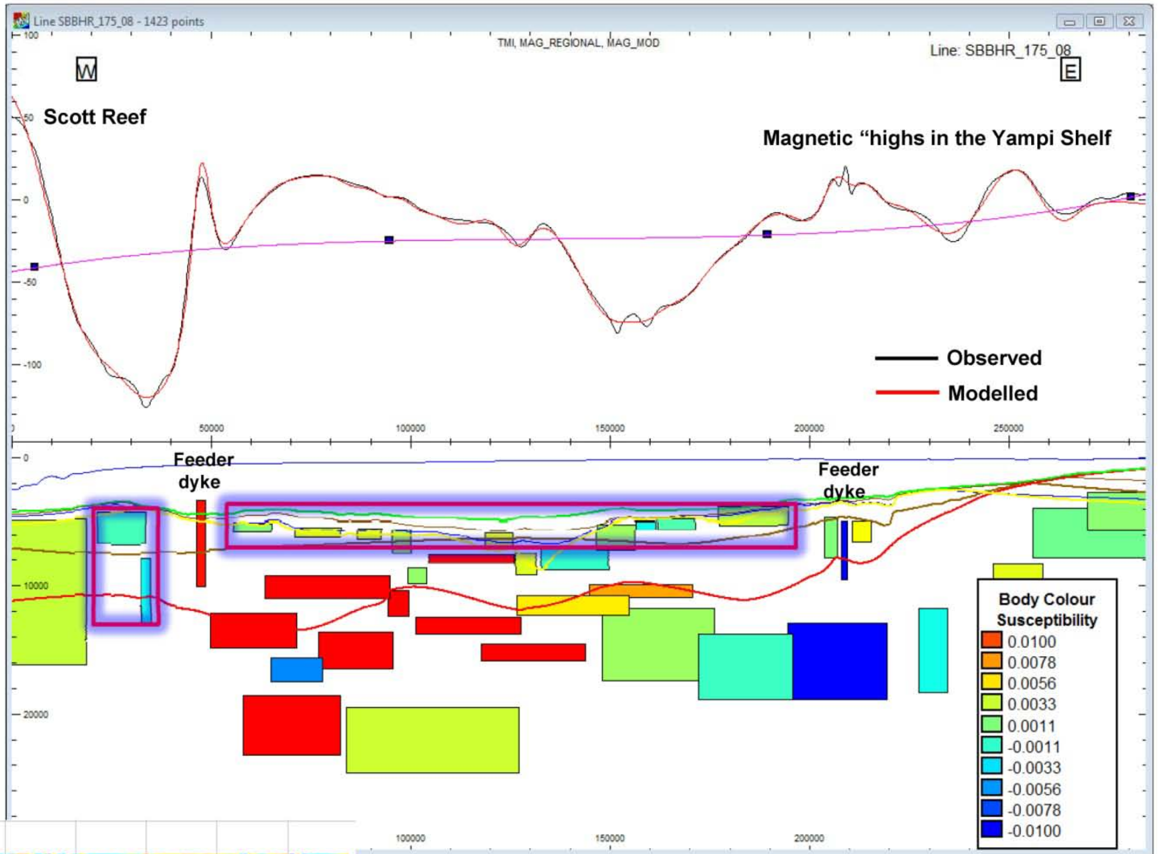

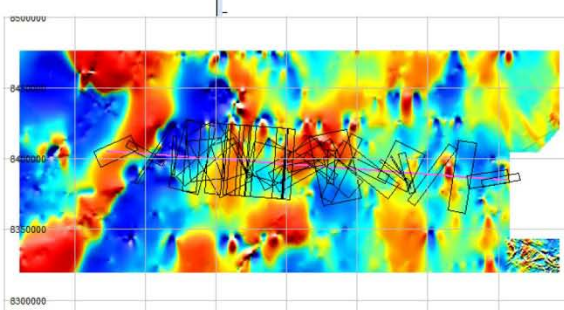

Negatively remanently magnetised Jurassic mafic plug/dyke

Moderately magnetised Jurassic mafic lava flows

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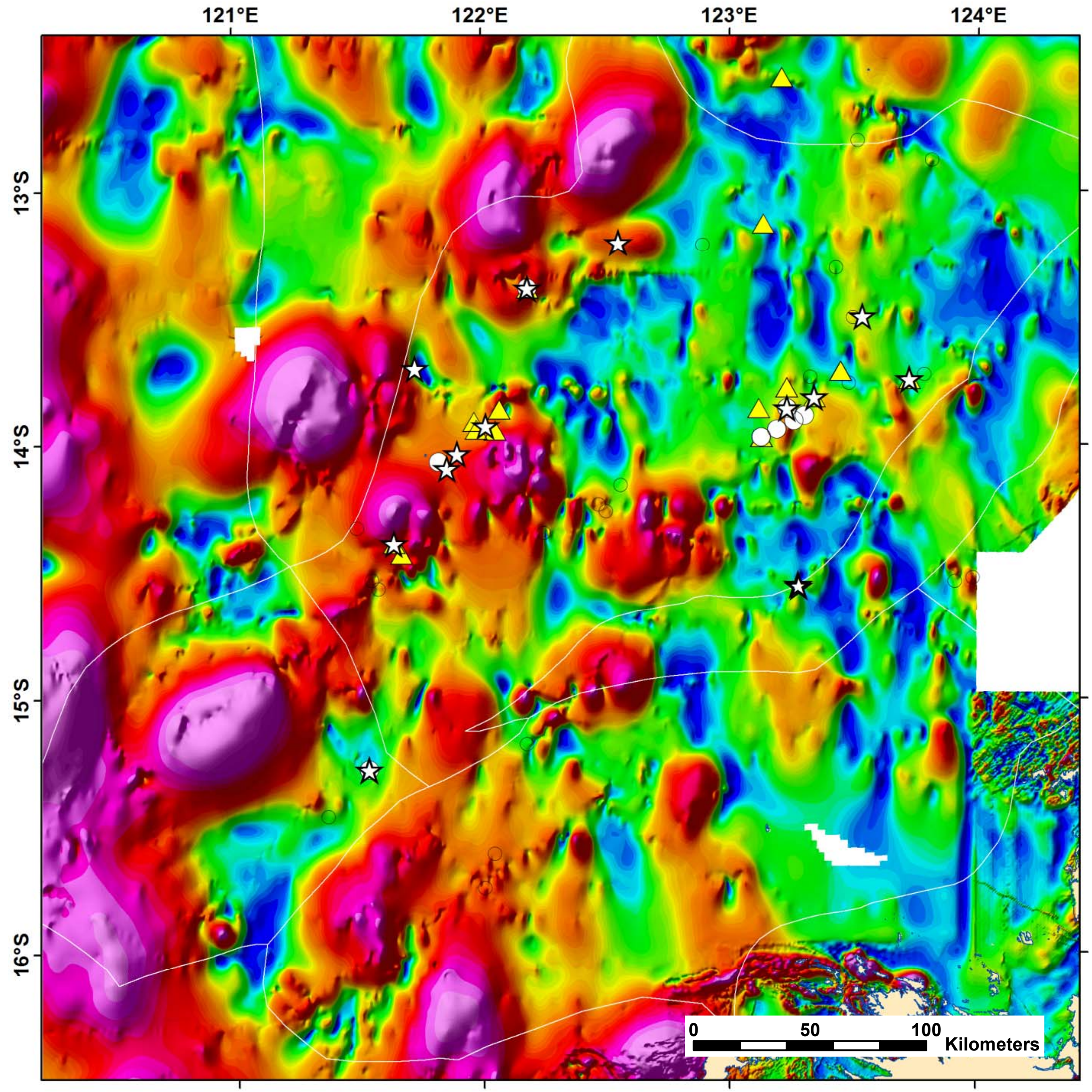
Integrated igneous mapping & prospectivity

Igneous Intersections

- ☆ Primary (mostly extrusives)
- ○ Volcanic + volcaniclastic
- △ Volcaniclastic
- ○ None



Integrated igneous mapping & prospectivity

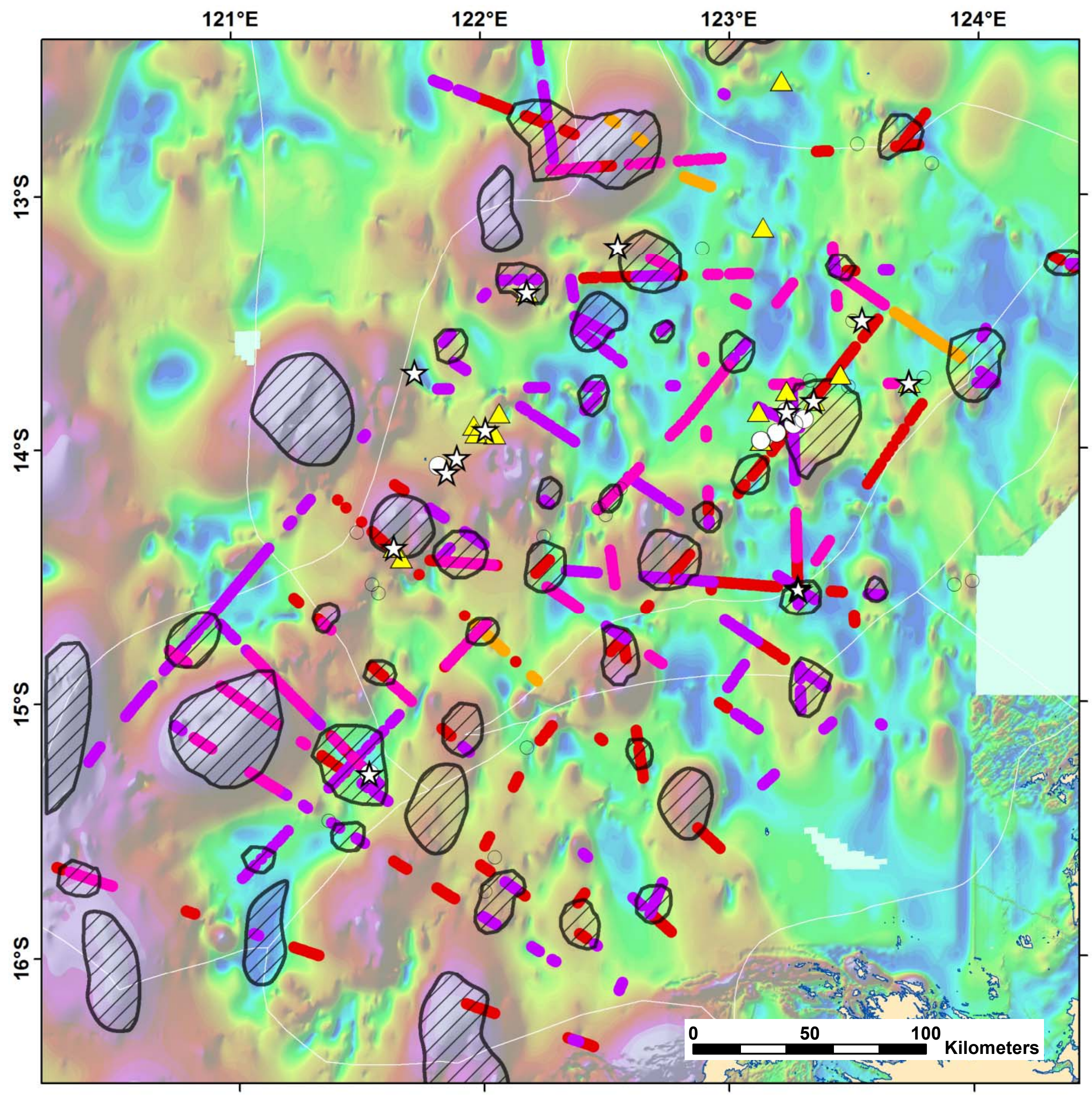
Igneous Intersections

- ☆ Primary (mostly extrusives)
- ○ Volcanic + volcaniclastic
- △ Volcaniclastic
- ○ None

Deep Intrusives

Seismic calibration mapping

- deep intrusive
- igneous complex
- sill/dyke
- Triassic intrusive



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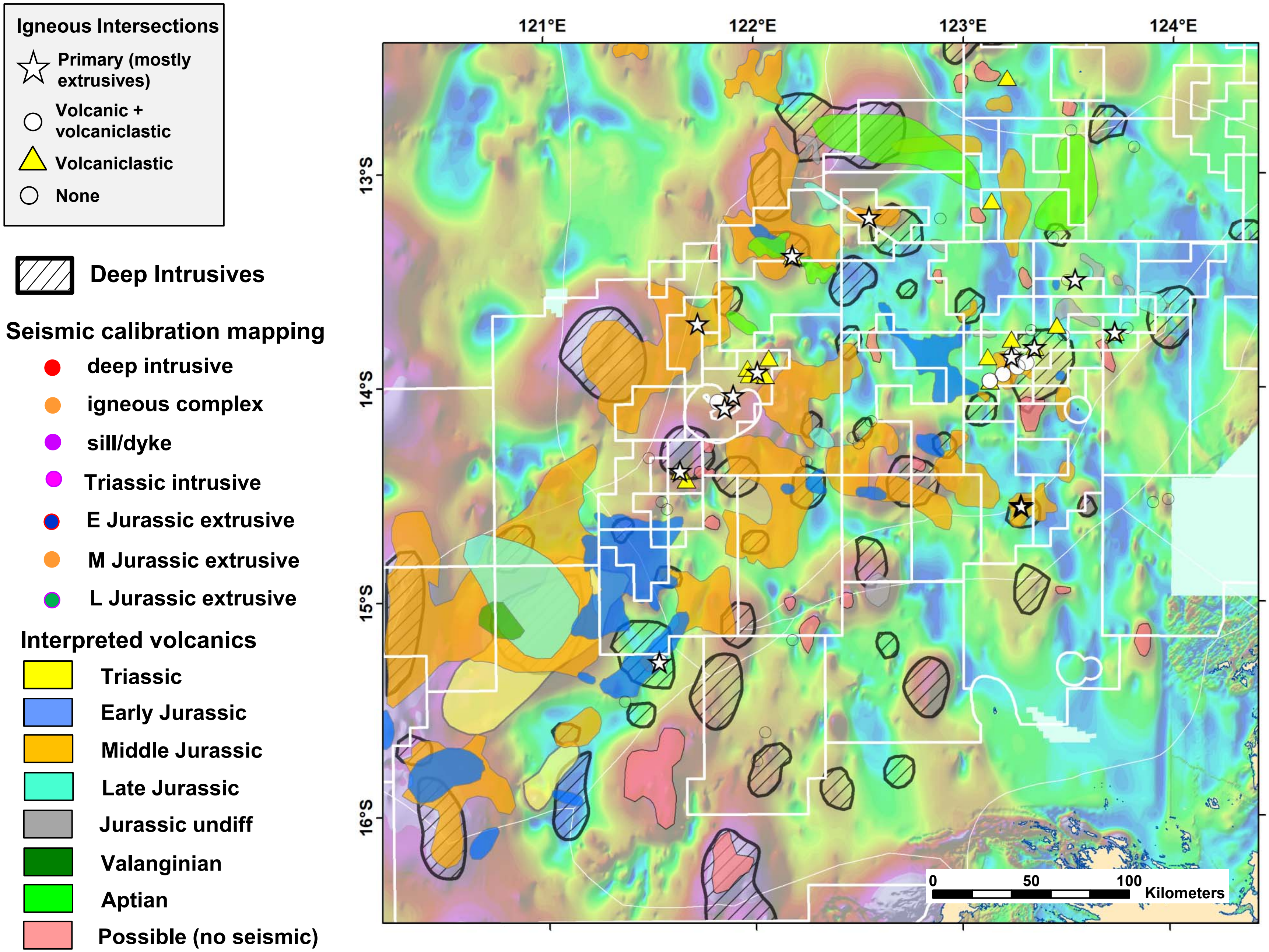

Conclusions

- Potential field data & interpretation are critical for sparse data regions and allow rapid assessment
- Even in mature basins with good seismic coverage magnetics & gravity data are useful:
  - Depth, extent, thickness of igneous bodies
  - Intrusives vs extrusives
  - Testing seismic facies models
- Potential field analysis can help avoid exploration pitfalls:
  - 400 m of basalt and no reservoir !
  - Map and predict areas of igneous risk to pet. sys.
- Seismic, well AND potential field interpretation are complementary and best used in an integrated approach

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