Seismic Expression and Petroleum System Implications of Igneous Intrusions in Sedimentary Basins: Examples from Offshore Australia*

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Abstract

The emplacement of shallow-level igneous intrusions in sedimentary basins may impact significantly on the development of petroleum systems. Understanding the geometry and evolution of sub-volcanic intrusive networks in volcanogenic basins is thus of interest to the petroleum industry. Whilst field-based studies permit a detailed investigation of magma properties and localised host rock relationships, outcrops are often too small to fully characterise the three-dimensional geometry and size of large igneous complexes. In contrast, seismic reflection data, although typically limited in terms of their vertical resolution, can provide spectacular images of the intrusive and extrusive components of igneous networks. In this study we use 2D and 3D seismic reflection and borehole data from the offshore Bight Basin (southern Australia) and Exmouth sub-basin (northwestern Australia), to illustrate the seismic expression and range of geometries associated with sill-dominated, intrusive igneous networks connected to submarine volcanoes and vents. Three main types of sill are documented: (i) tabular sills; (ii) saucer-shaped sills; and (iii) transgressive sills. Seismic data resolution restricts a detailed analysis of sill volume, but our analysis indicates that the sills are up to 150 m thick, 16 km wide and 208 km² in map-view area. In both basins, forced folds, which may represent hydrocarbon traps, are developed above a range of sills. In the Bight Basin, the fold amplitudes are consistently less than the thickness of the underlying intrusions. We interpret that this discrepancy reflects fluidisation and ductile flow of coal or carbonaceous claystones during sill emplacement at relatively shallow depths. From an applied perspective, the sill-dominated networks, although areally quite extensive, are not anticipated to impact the vertical migration of hydrocarbons, due to the presence of pervasive normal fault networks that may allow shallow level reservoirs to access deeply-buried source rocks. Although the sills may locally impact the reservoir quality of the host rock successions, forced folding, which is associated with sill emplacement in the shallow subsurface, can result in the formation of viable hydrocarbon traps.

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Data:

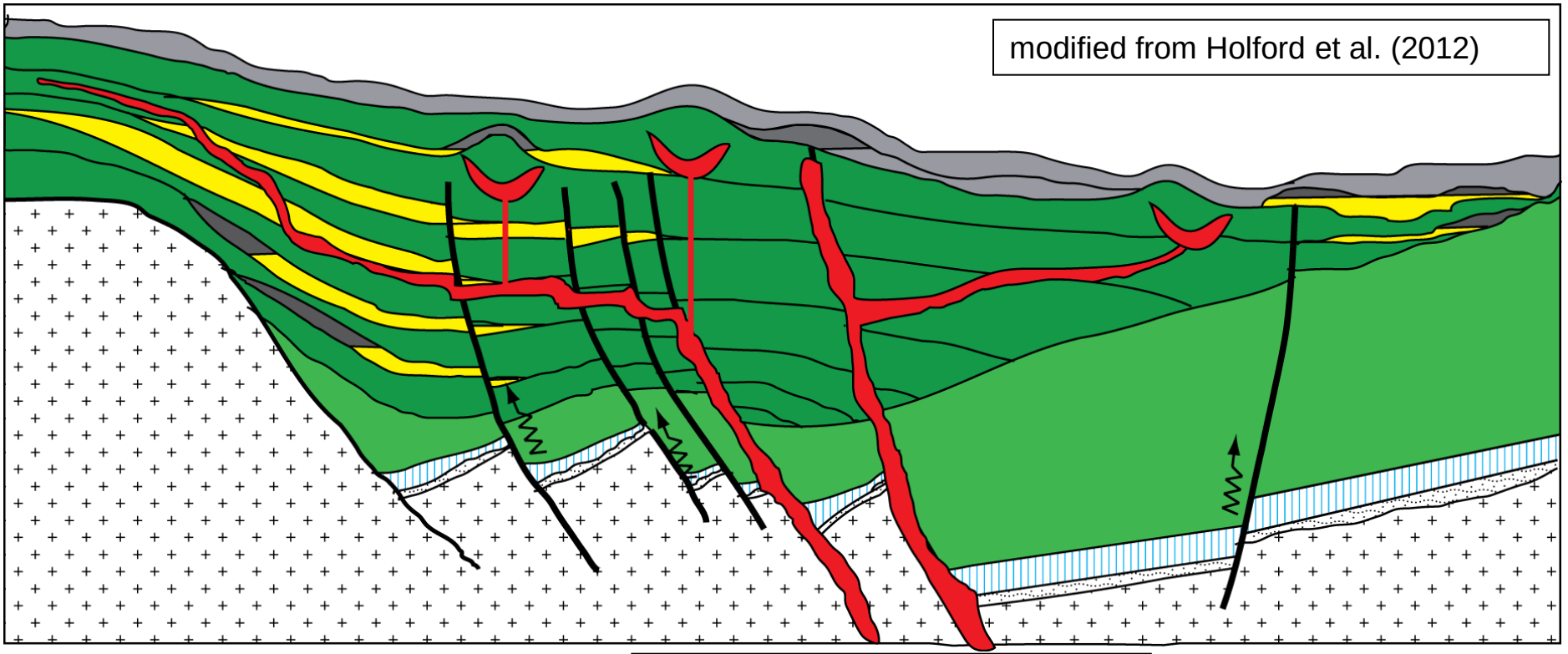
Australian Government
Geoscience Australia

Software:

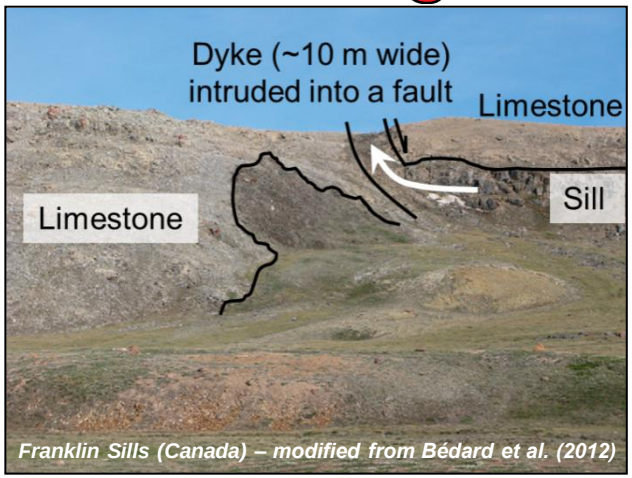
Schlumberger

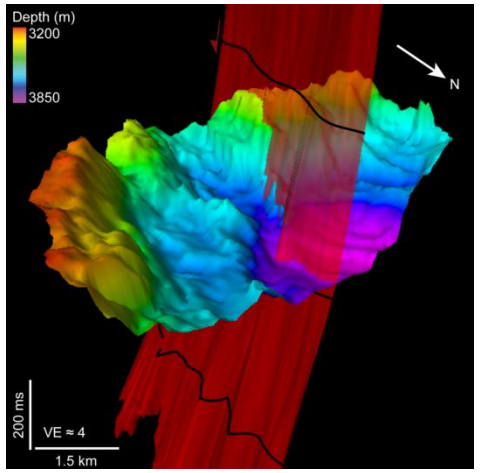
Rationale and talk outline

Imperial College London



- Petroleum system implications of igneous intrusions
  - Intrusion-related deformation and traps
  - Timing igneous activity in sedimentary basins
  - Reservoir quality
  - Source-rock maturation
- Seismic reflection data as an analytical tool





The Bight Basin, southern Australia

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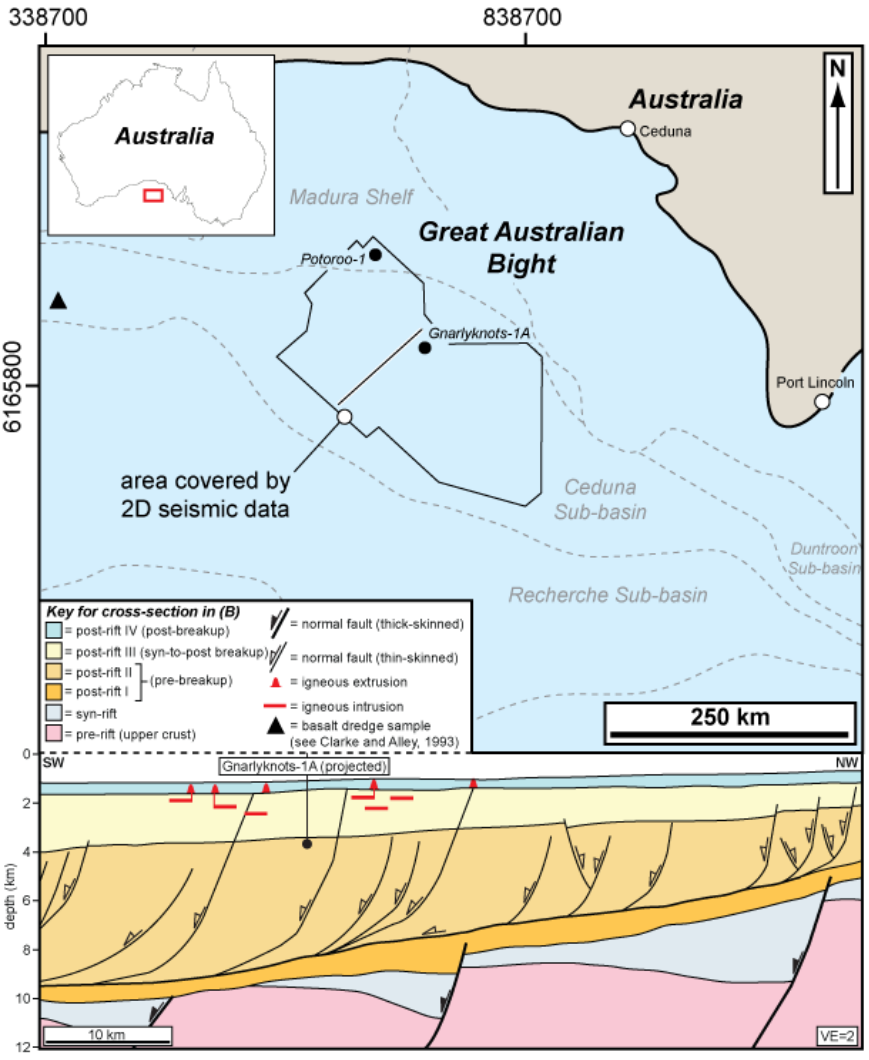

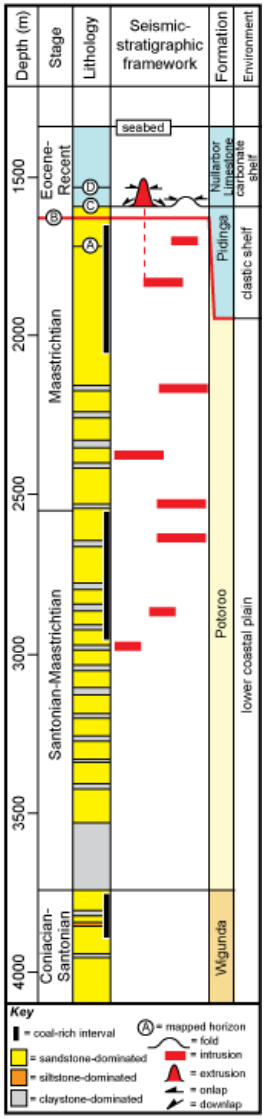

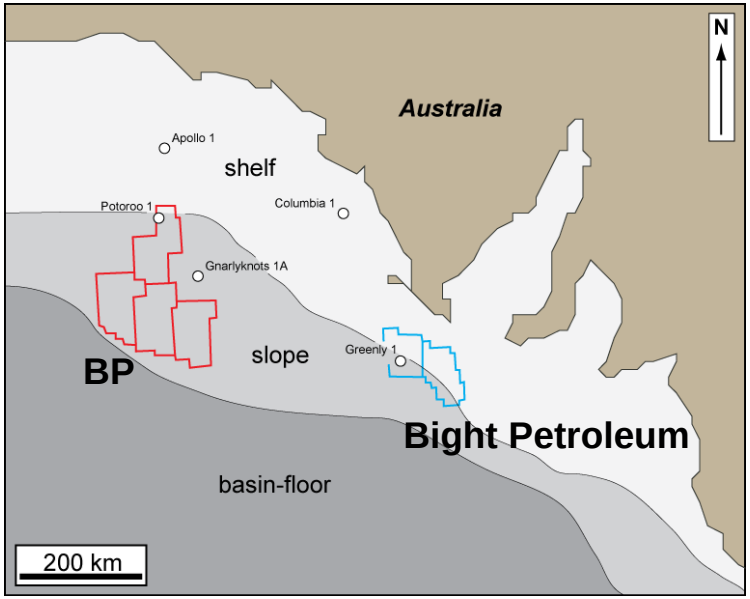

Modified from: http://bightpetroleum.com/bight-basin/overview (accessed 11th September 2012)

- Large frontier basin
- Nine exploration wells; no economic discoveries
- 2D seismic data; 3D seismic acquisition ongoing
- BP acreage awarded January 2011
- Bight Petroleum acreage awarded July 2011

Seismic expression of igneous features

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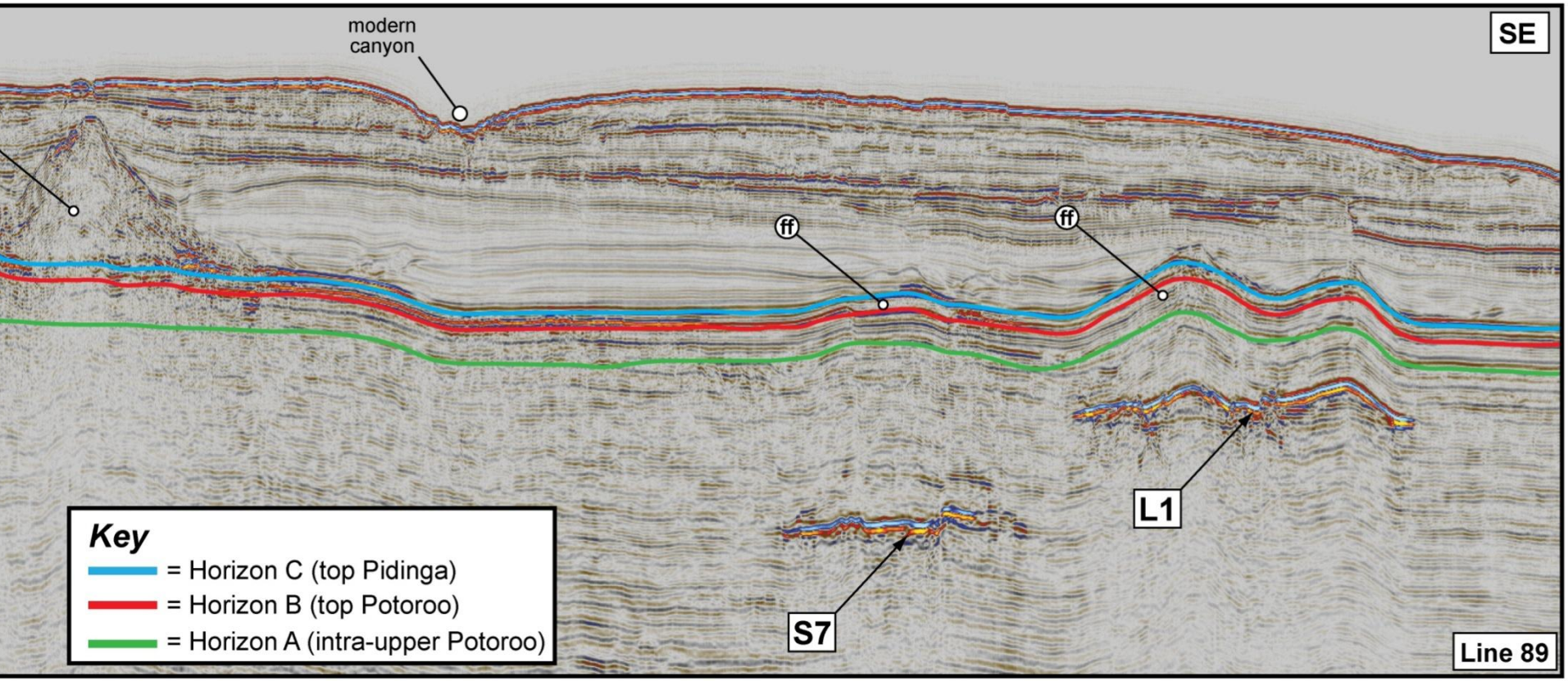

- Igneous intrusions acoustically hard and fast
- Intrusion either strata concordant (sills and laccoliths) or discordant (saucer-shaped sills)
- Intrusions overlain by extrusive igneous bodies
- Intrusions associated with folds

Seismic expression and structure of intrusions

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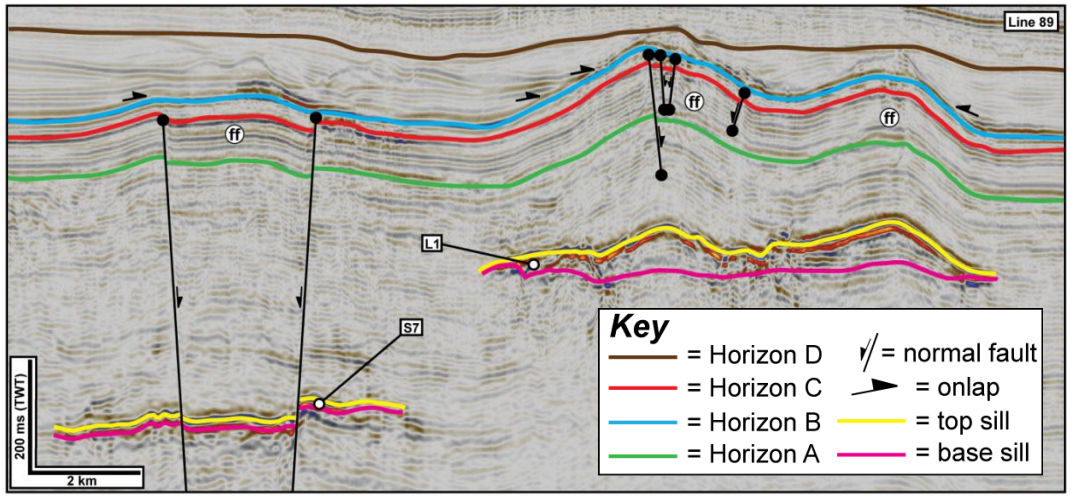

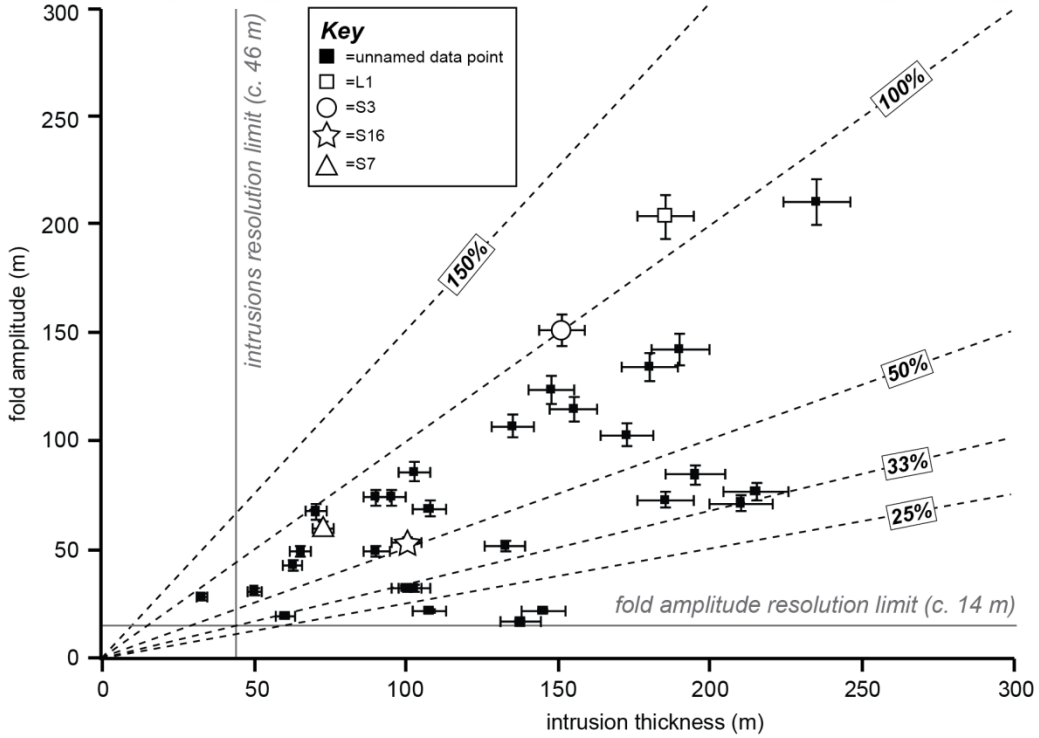

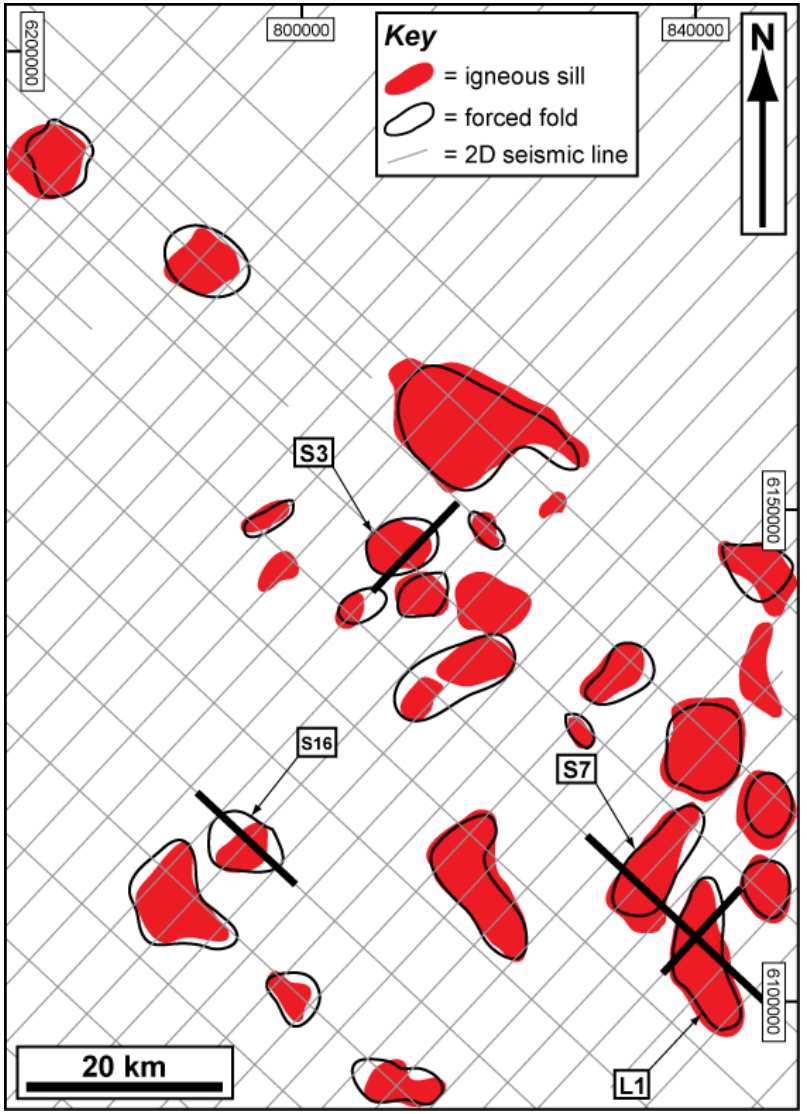

Structure of igneous intrusions

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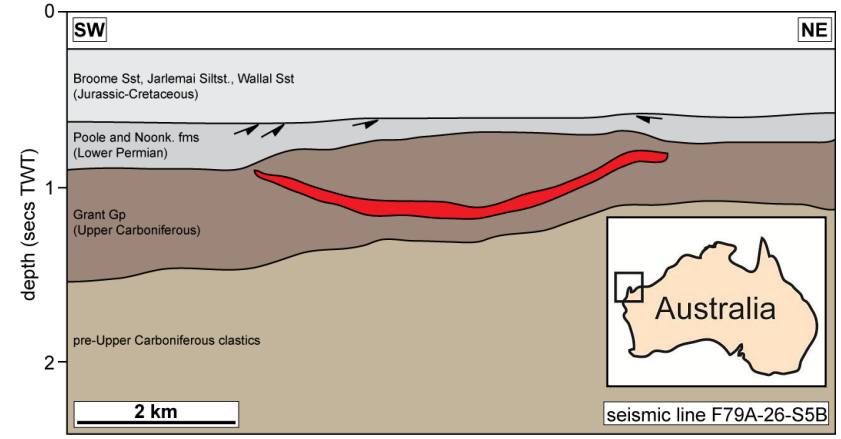
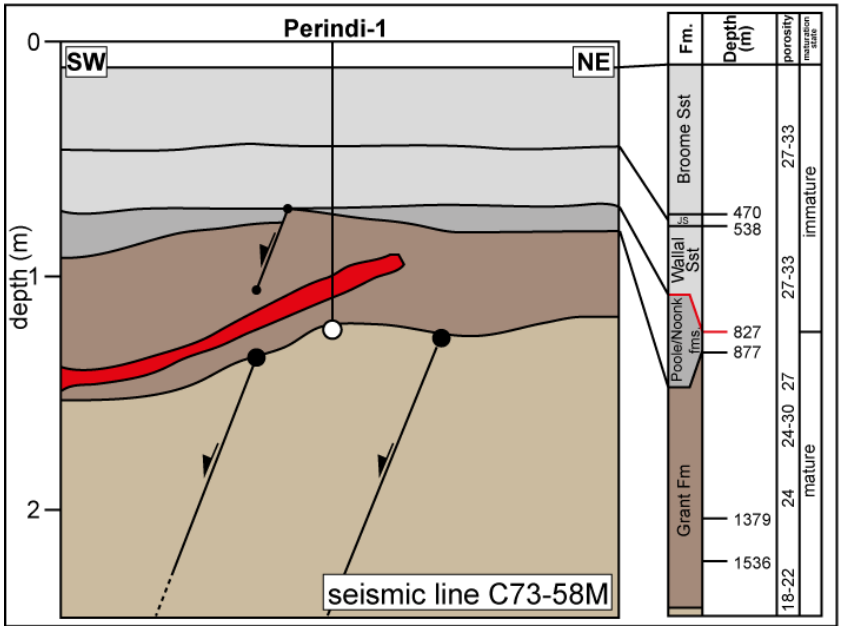
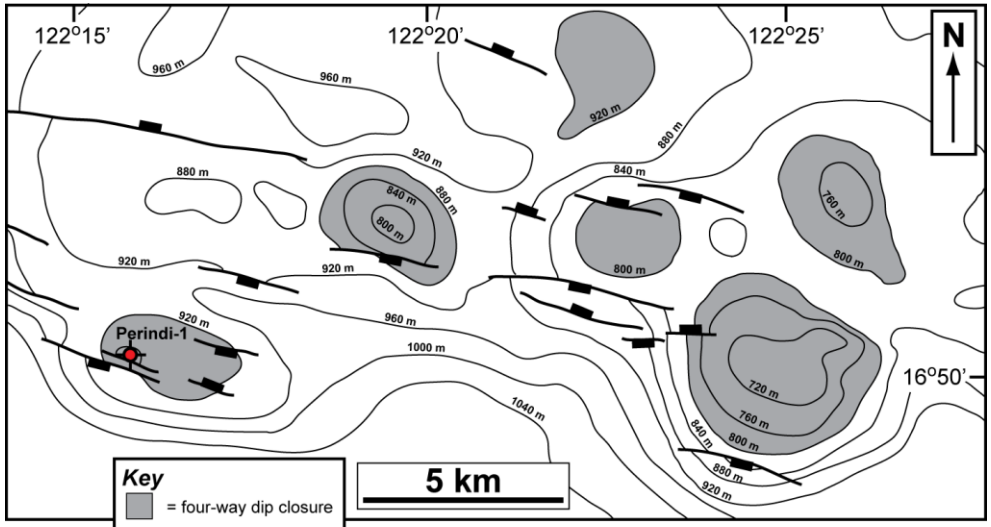
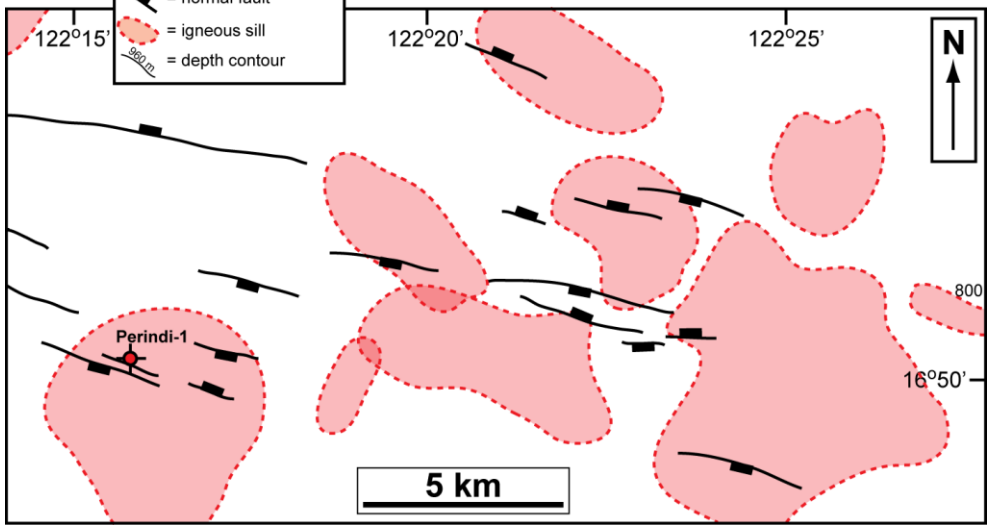
modified from: Reeckmann and Mebberson (1984)









Forced fold-related traps

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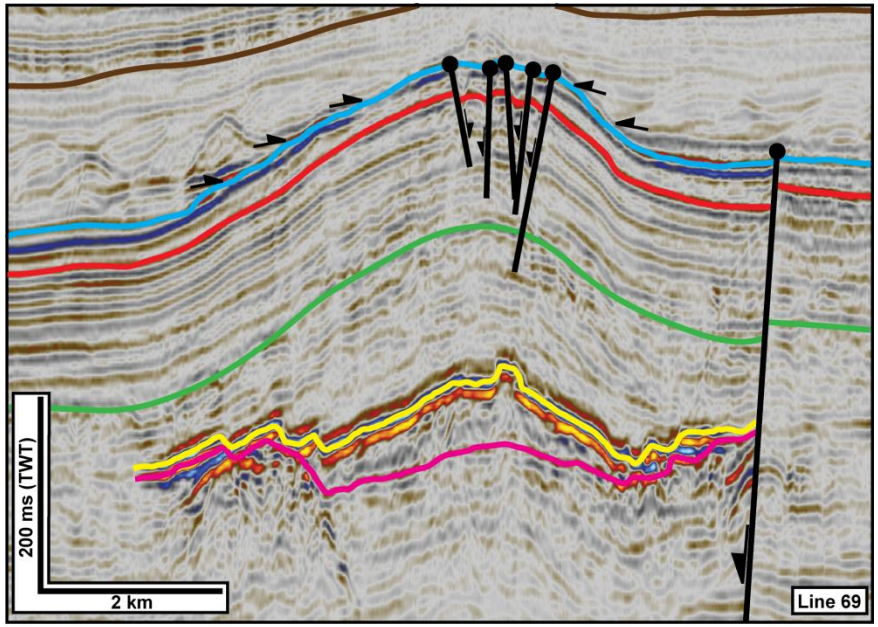

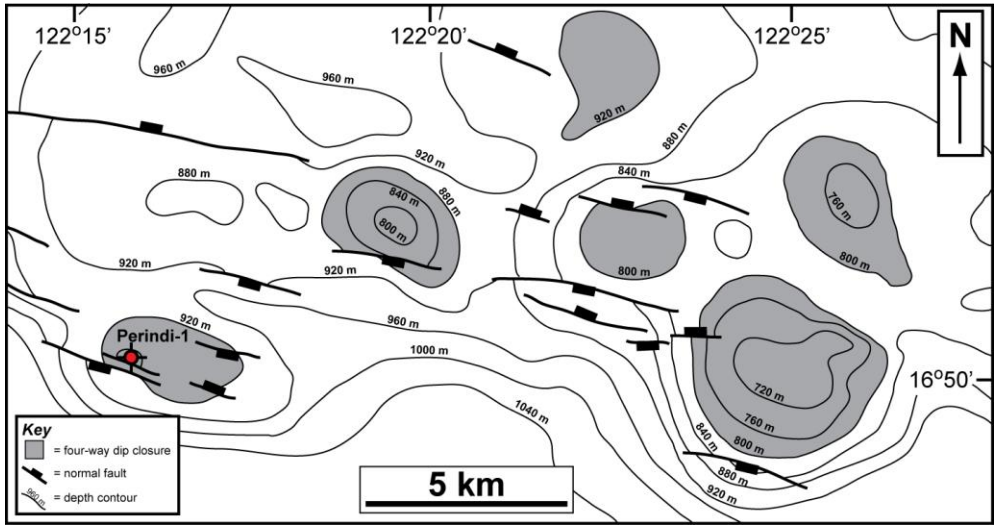

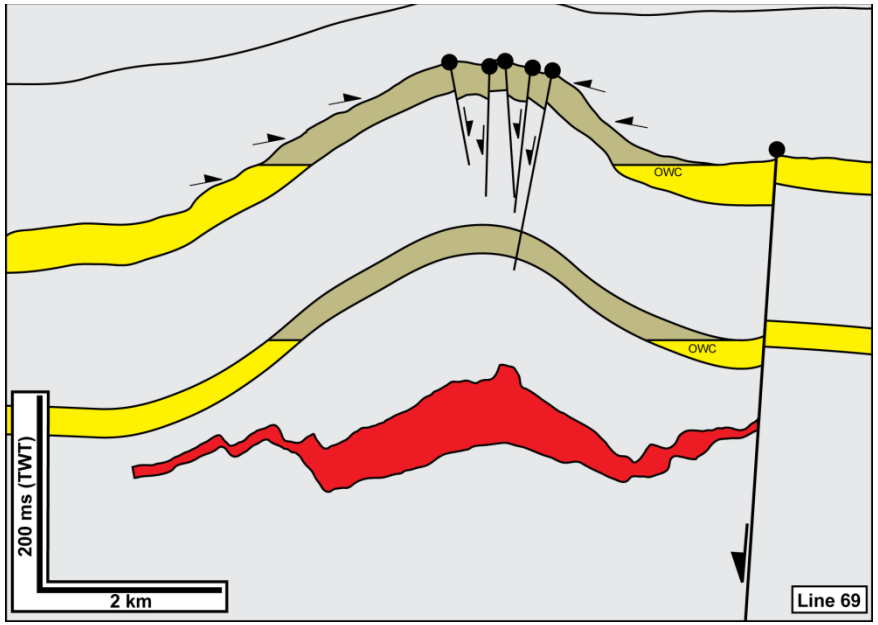

- Reservoir thickness=100 m
- N:G=0.4
- Porosity=25%
- Saturation=70%
- FVEF (Bo)=1.3
- STOIIP=**193,038,461** m^3
- Recovery factor=30%
- Recoverable oil=**364,263,576** Mbbls

Forced fold-related traps

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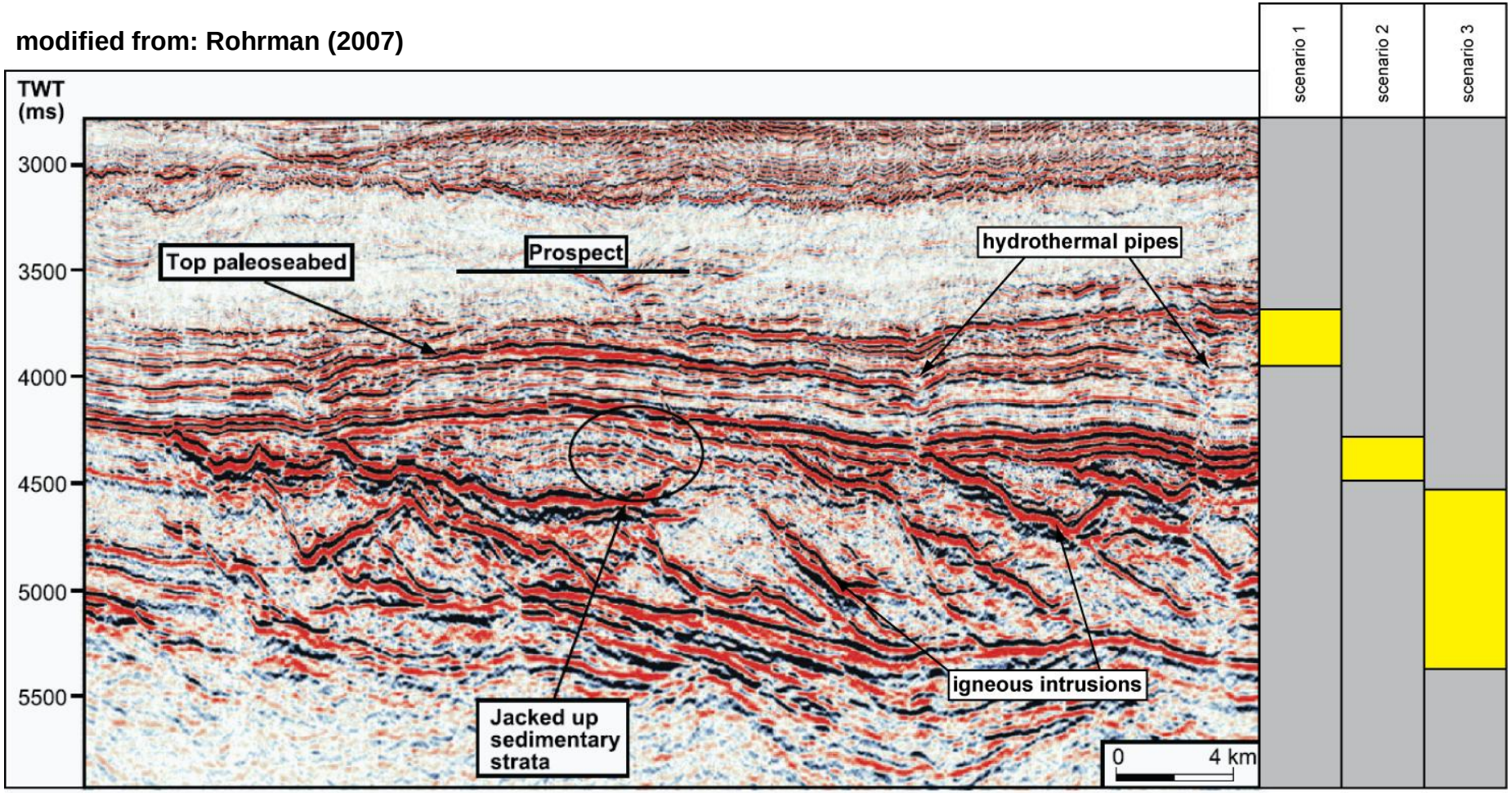
modified from: Rohrman (2007)



- **Scenario 1** – Reservoir interval several hundred metres above intrusion complex; minor influence of intrusions on reservoir compartmentalisation and quality
- **Scenario 2** – Reservoir interval in upper part of intrusion complex; moderate influence of intrusions on reservoir compartmentalisation and quality
- **Scenario 3** – Intruded reservoir interval; major influence of intrusions on reservoir compartmentalisation and quality

Forced fold-related traps

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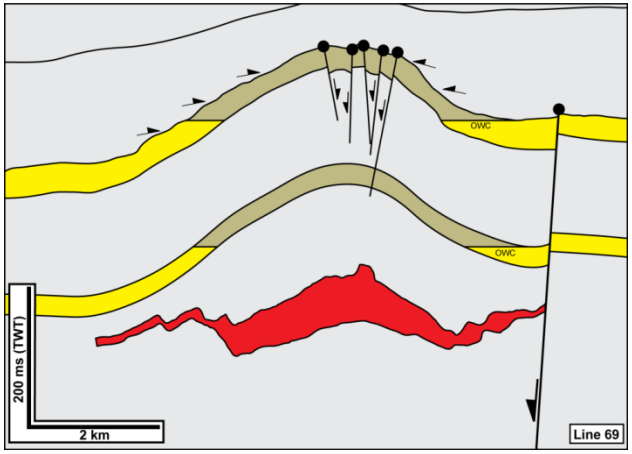
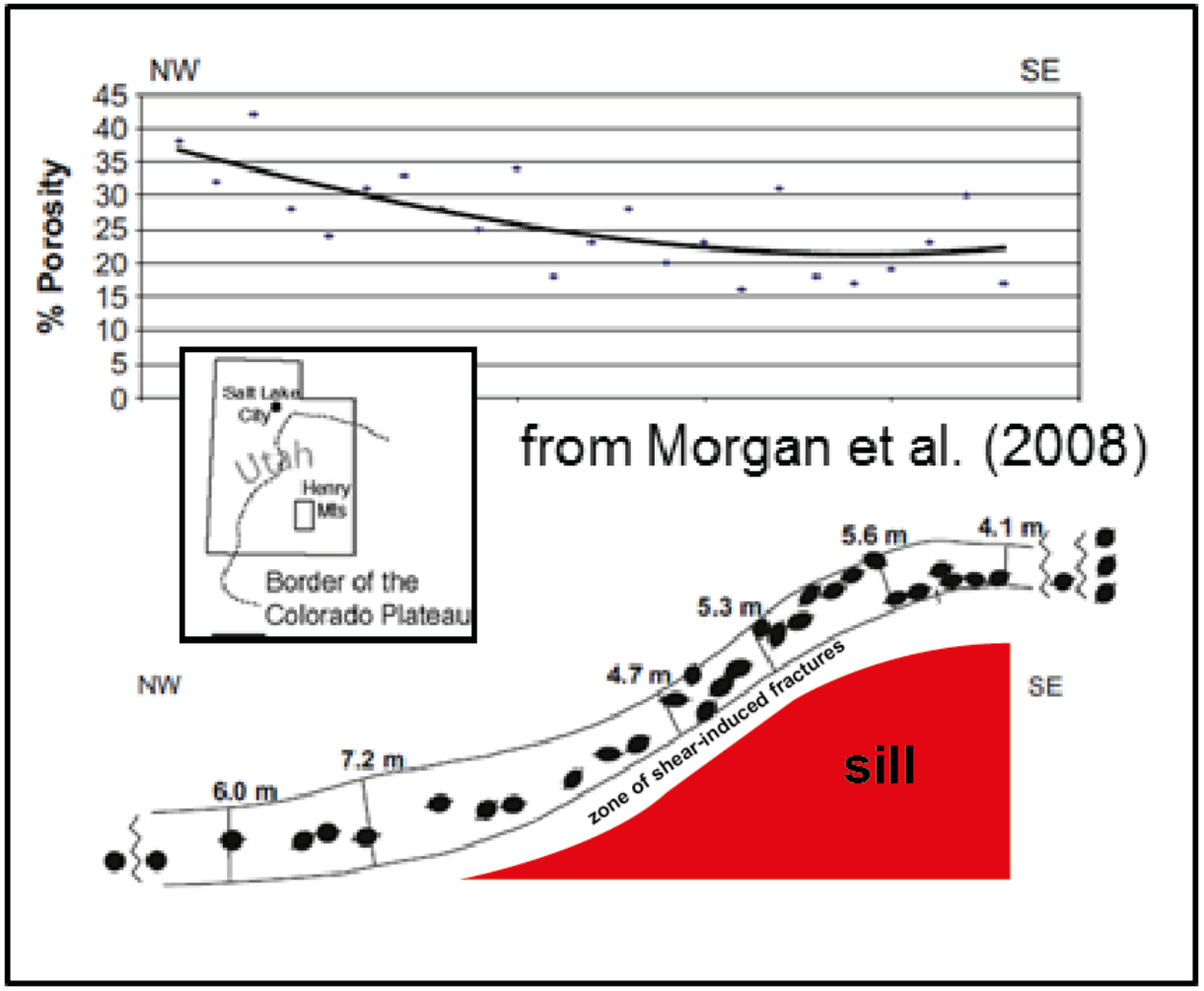


- Hydrothermal activity may result in pore-occluding cementation
- Intrusion-related stresses can directly strain host rock
- Grain comminution
- Fracturing
- Deformation bands
- Variable reservoir quality



Dating igneous activity

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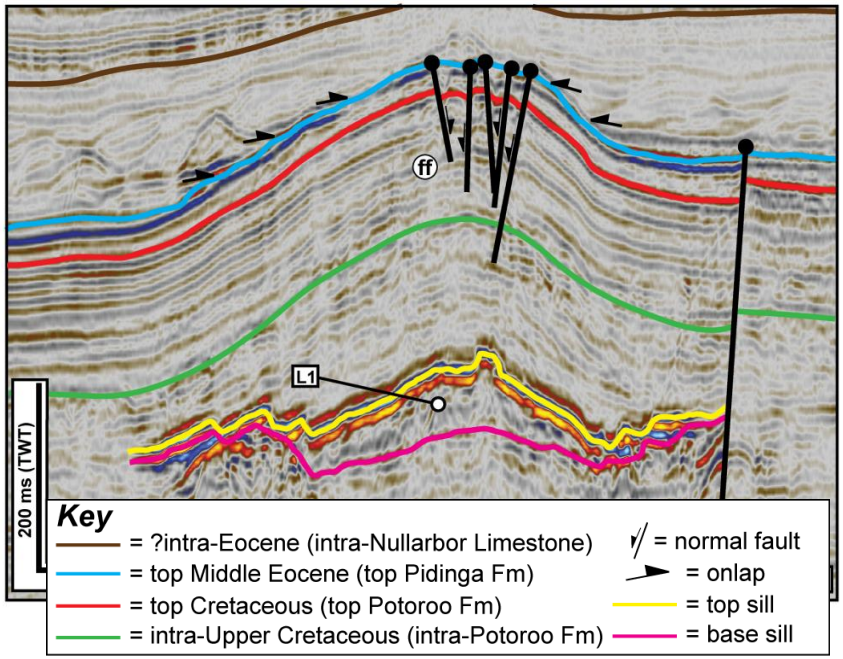
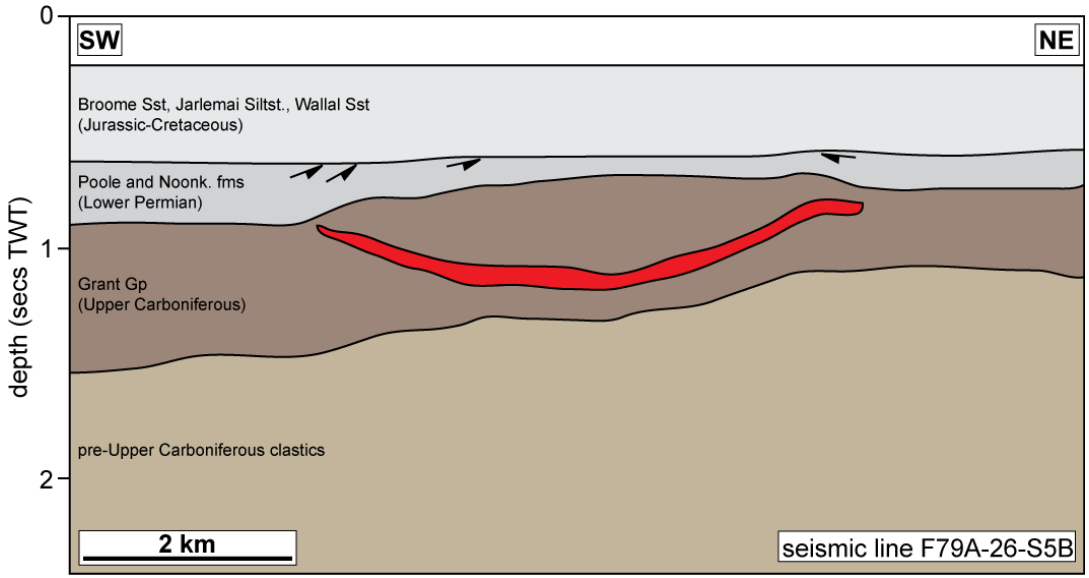
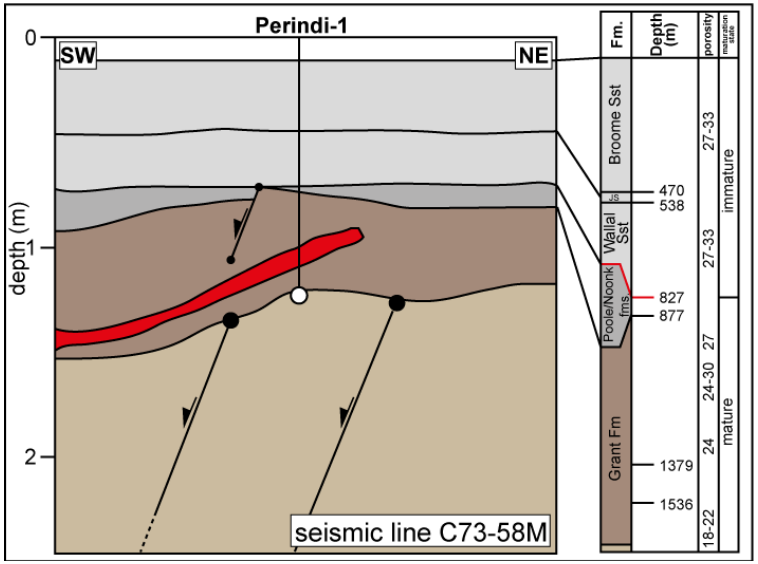
- **Importance**
  - Constraining periods of basin-scale heat flow – *basin modelling*
  - Constraining local heat flow and hydrothermal events – *reservoir-quality*
- **Methods**
  - Direct dating (e.g., K/Ar, Ar/Ar)
  - Indirect
    - seismic-stratigraphic analysis
    - AFTA and VR analysis







Dating igneous activity

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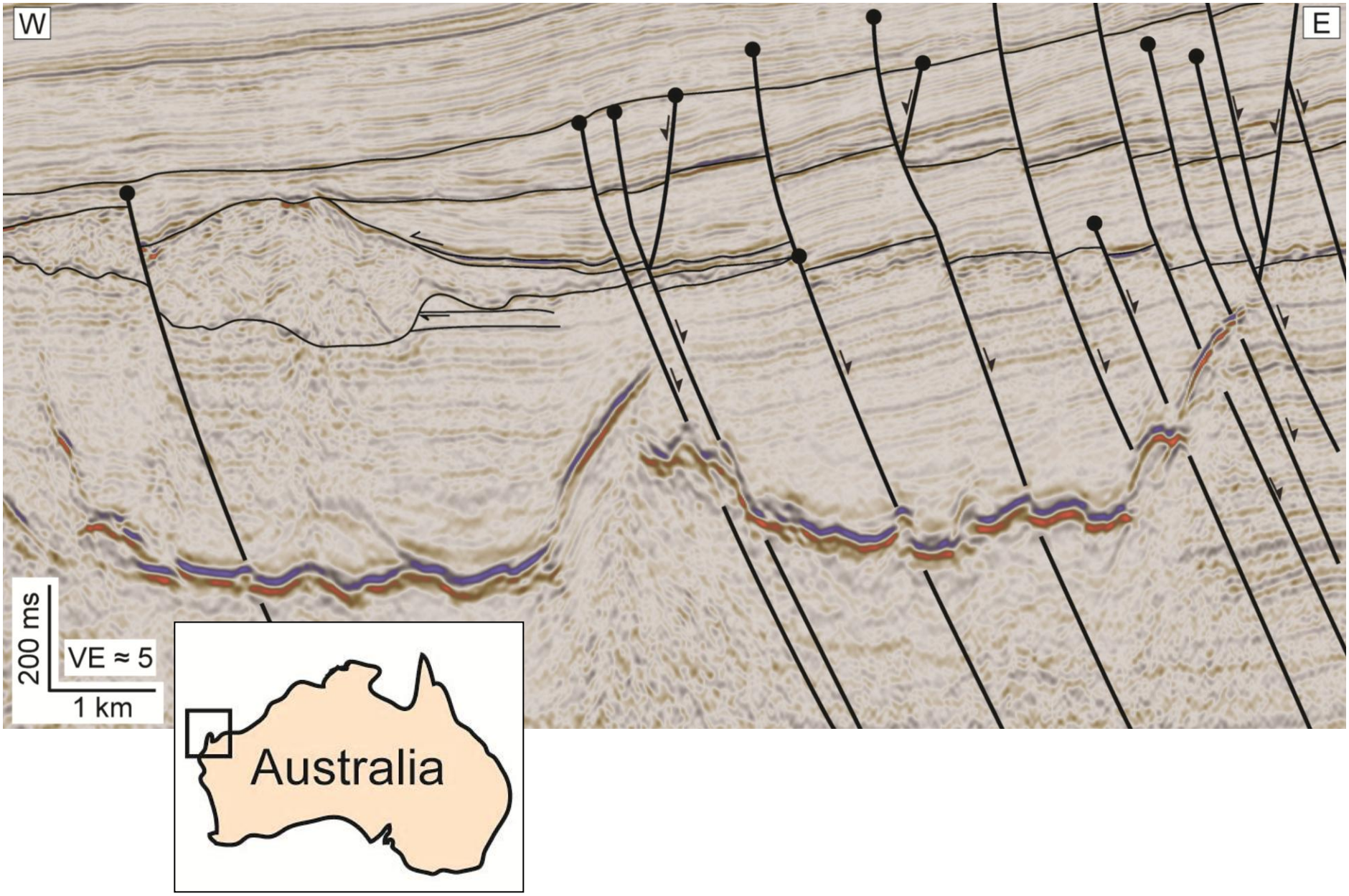

Dating igneous activity

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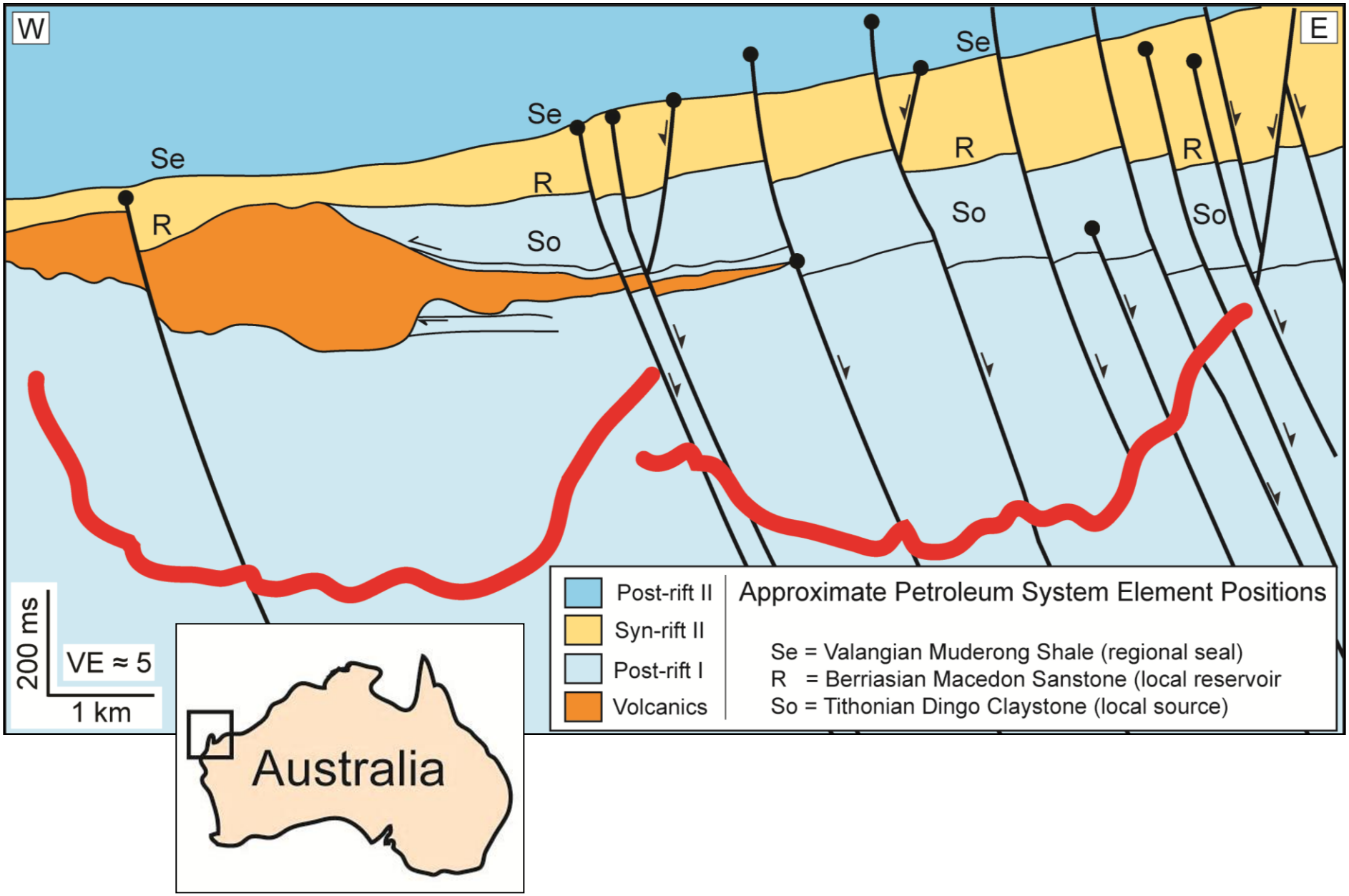

Exmouth sub-basin, NW Shelf

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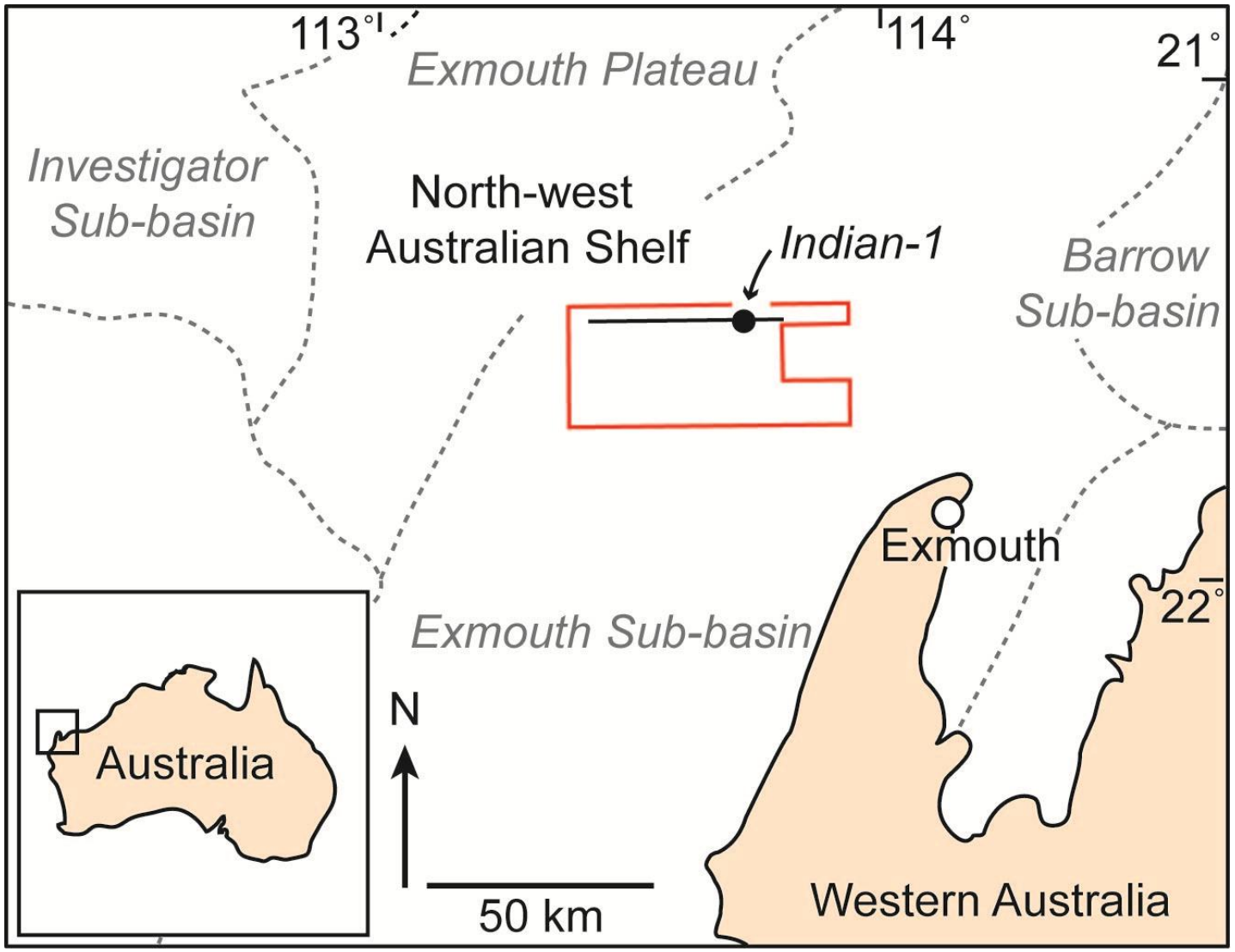

Exmouth sub-basin, NW Shelf

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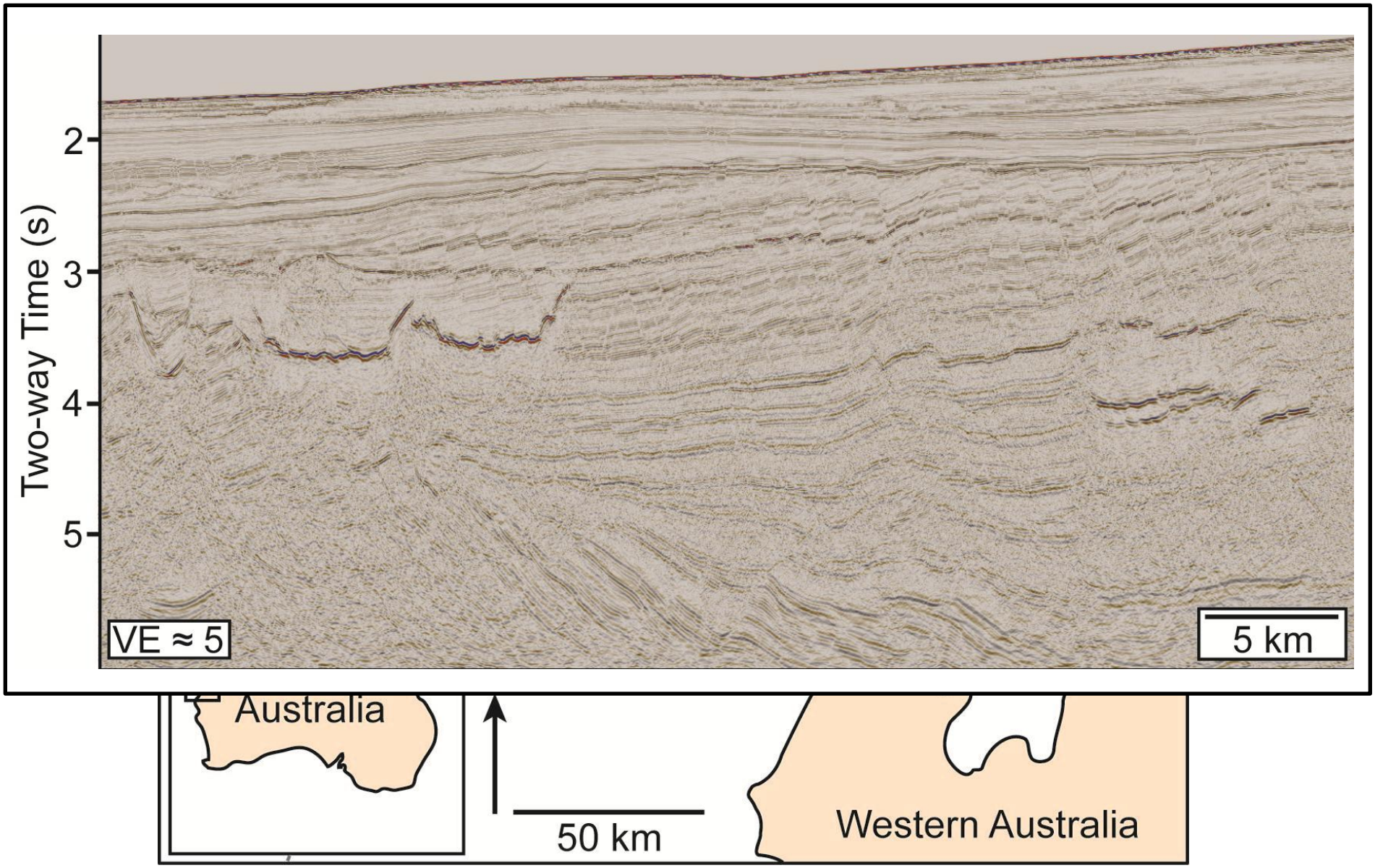

Exmouth sub-basin, NW Shelf

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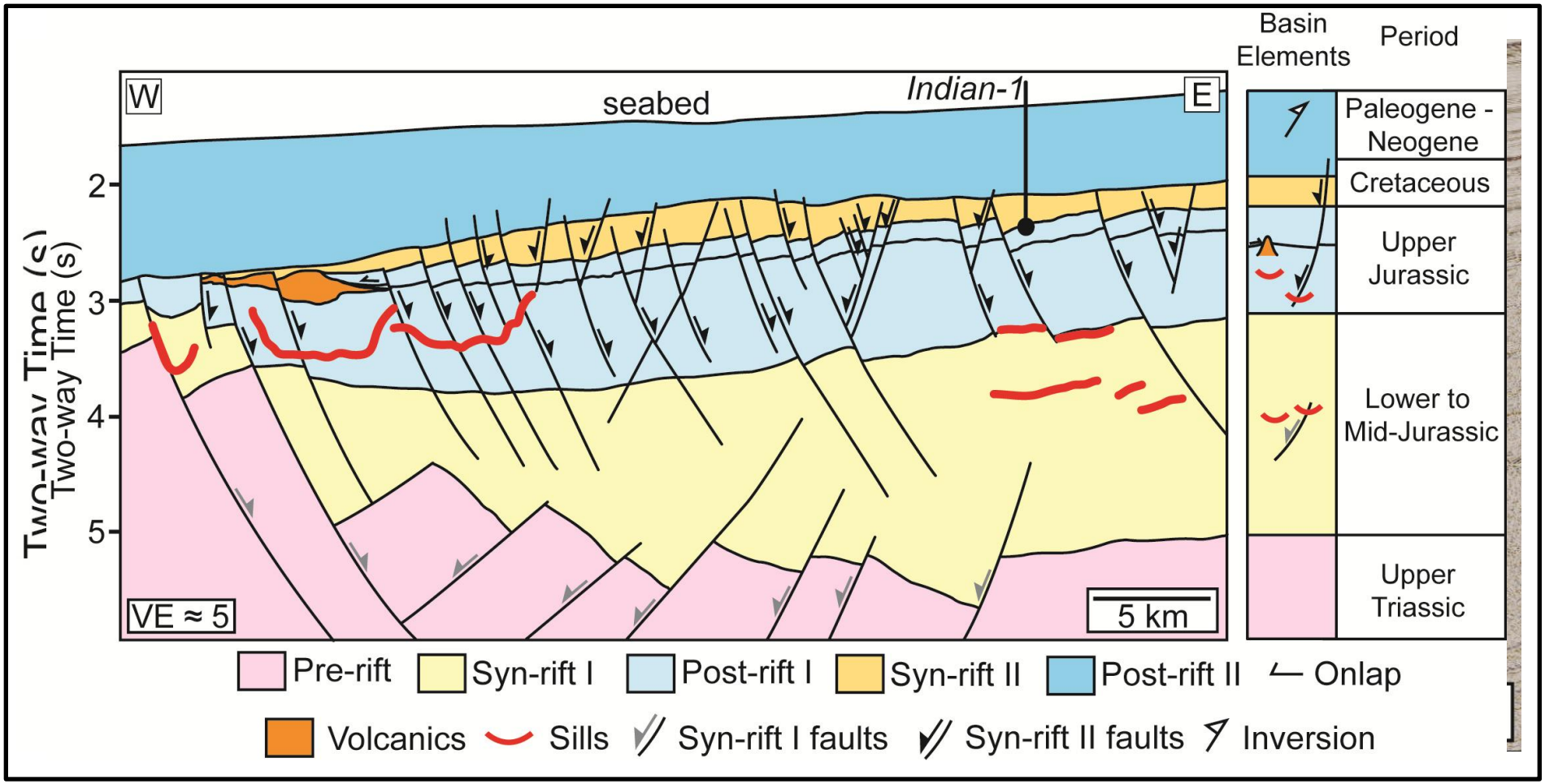

- Multi-phase rift basin
- Two styles of faulting
- At least two phases of igneous activity

Sill-fault relationships

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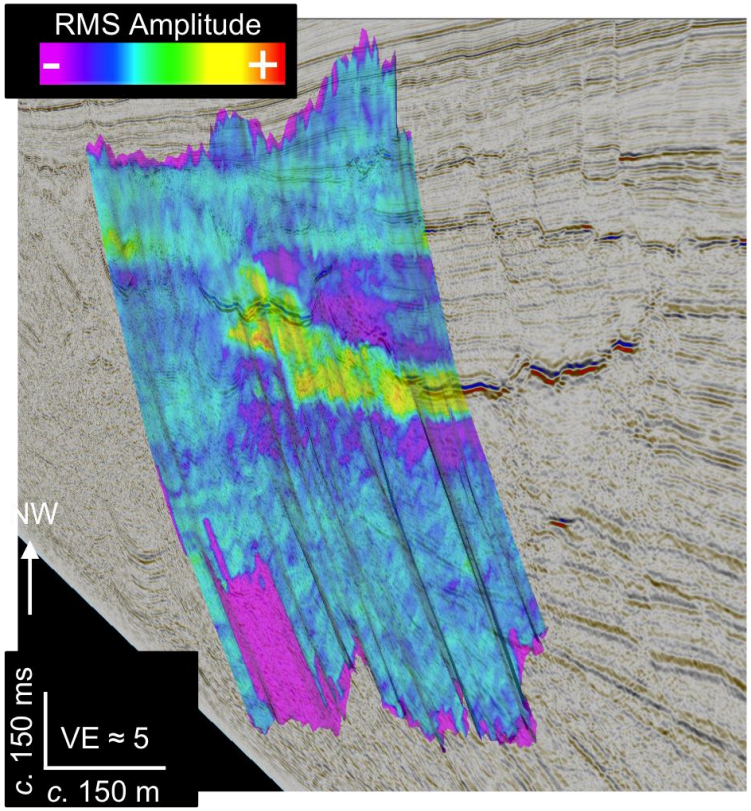

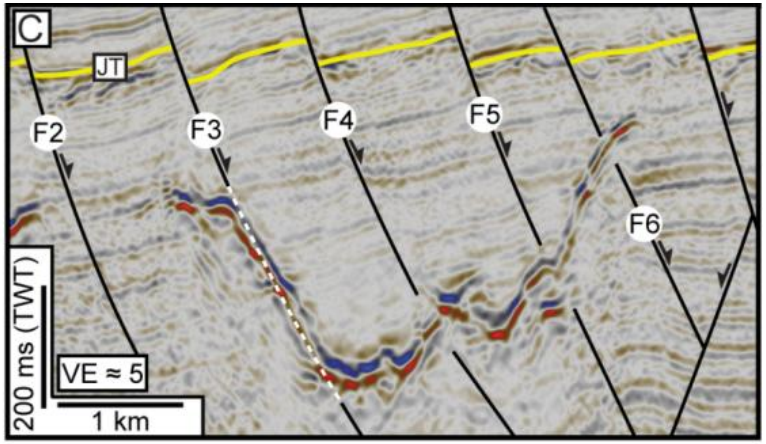

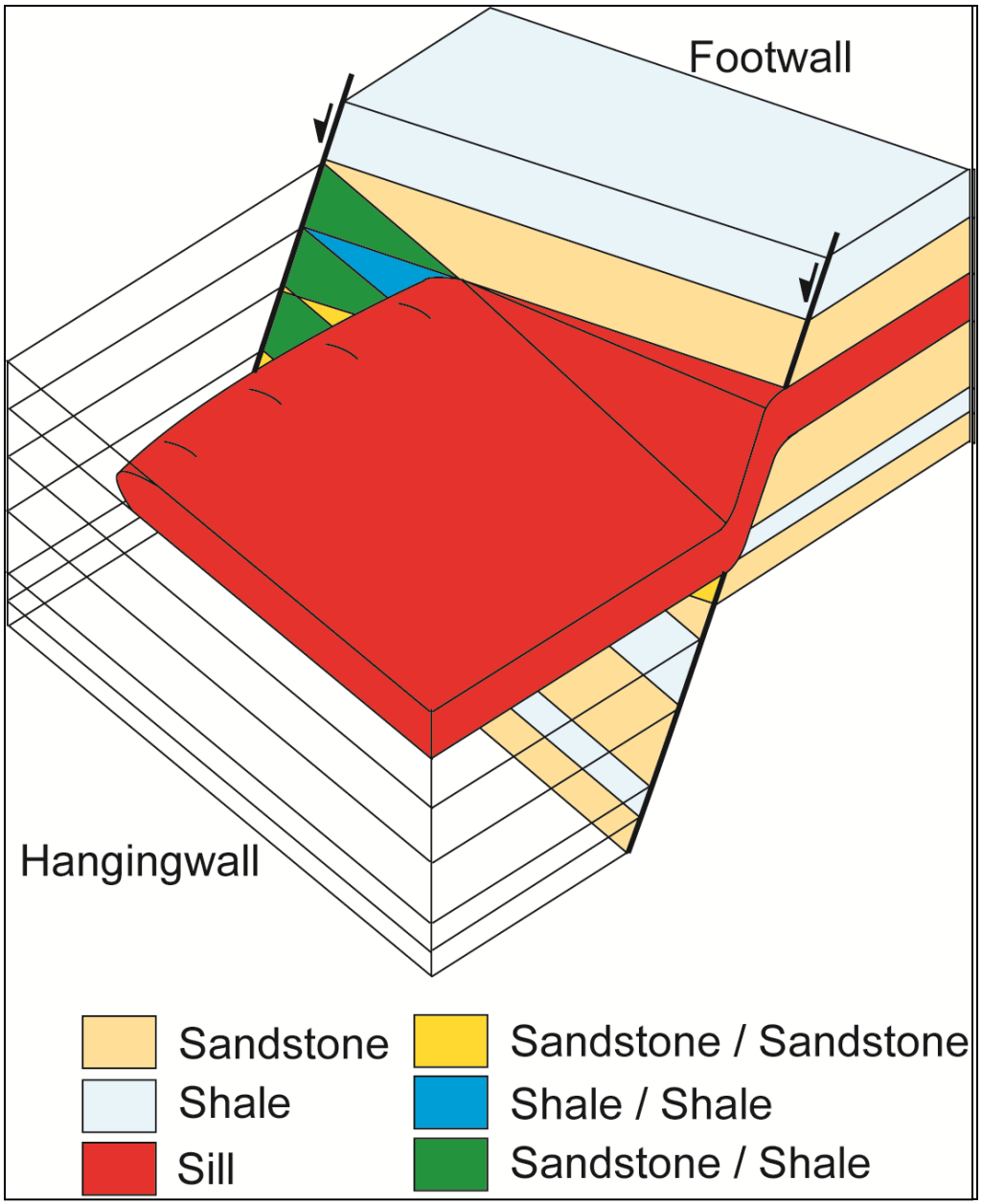

Sill-fault relationships

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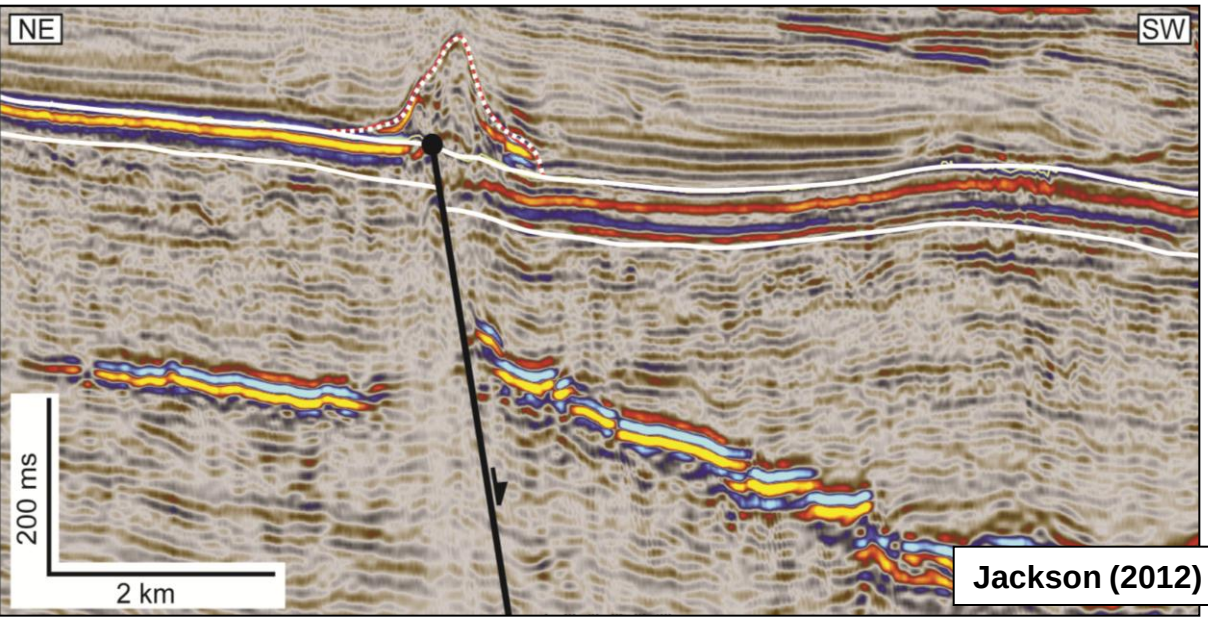
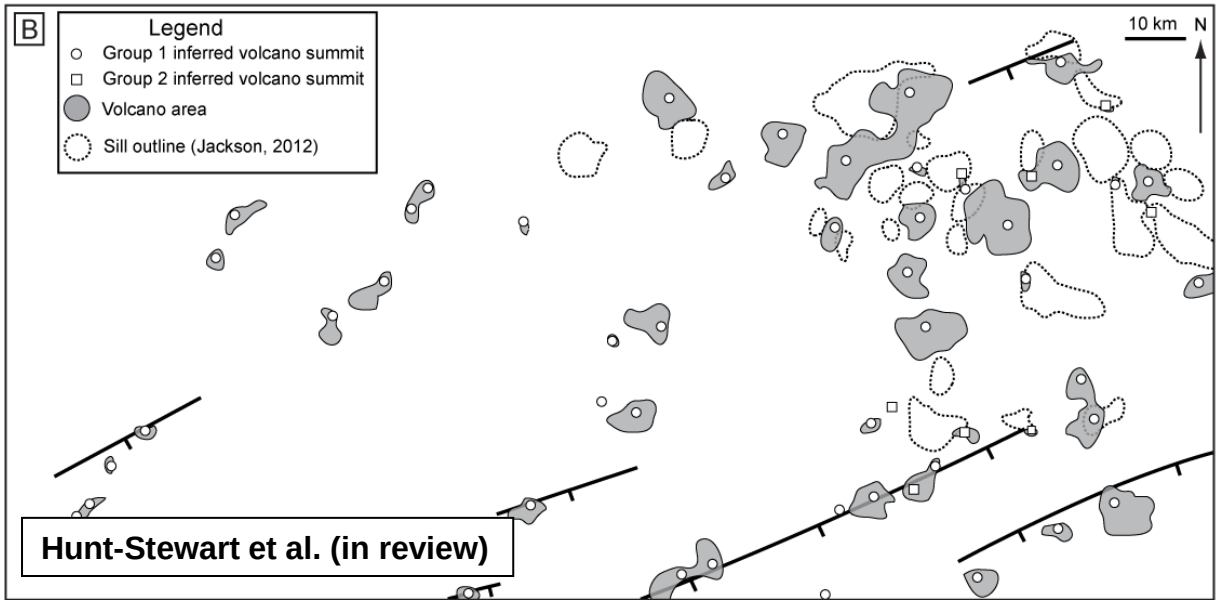


Jackson (2012)

- Faults may act as high-permeability conduits
- Seal and reservoir bypass of intrusion-related fluids
- Mapping of sill-fault-vent relationships is critical



Hunt-Stewart et al. (in review)

Intrusion impact on maturation

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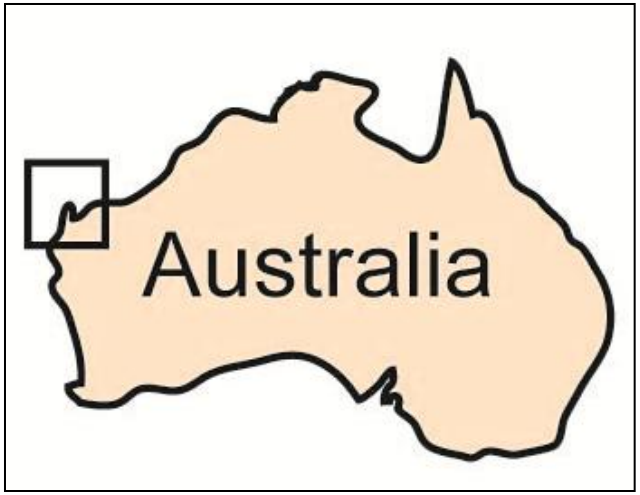
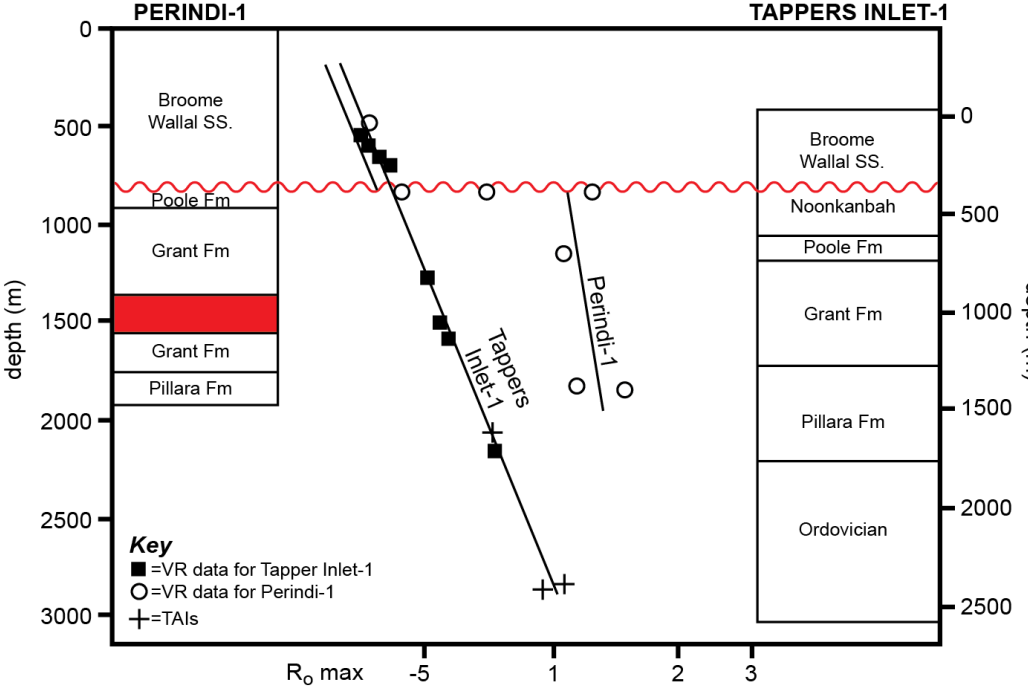
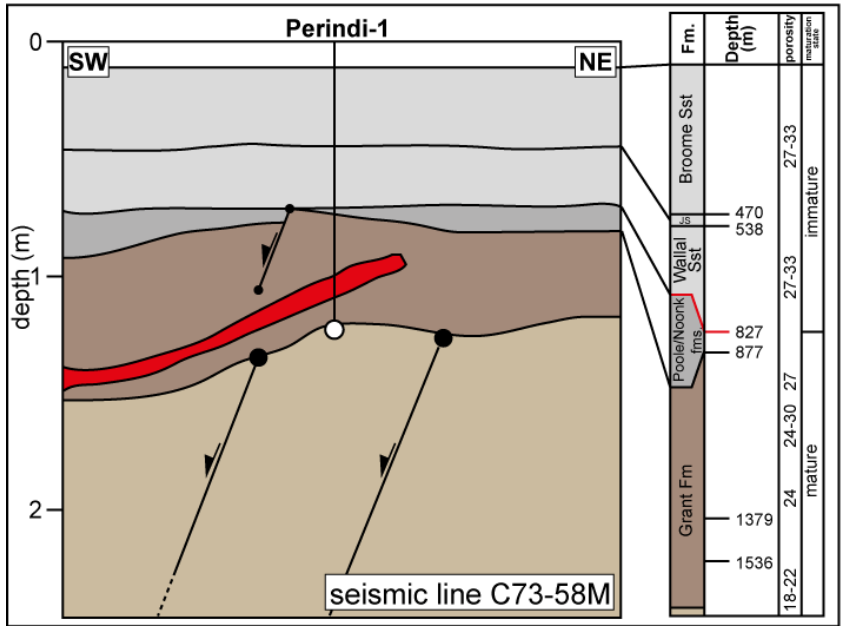
- Intrusions can cause heating by contact metamorphism and hydrothermal activity
- In Perindi-1 intrusions caused elevated VR values and source rocks were placed in oil window
- Tappers Inlet-1 VR values follow a background (burial) trend
- Can igneous intrusions result in source-rock maturation at anomalously shallow depths?







Implications and Conclusions

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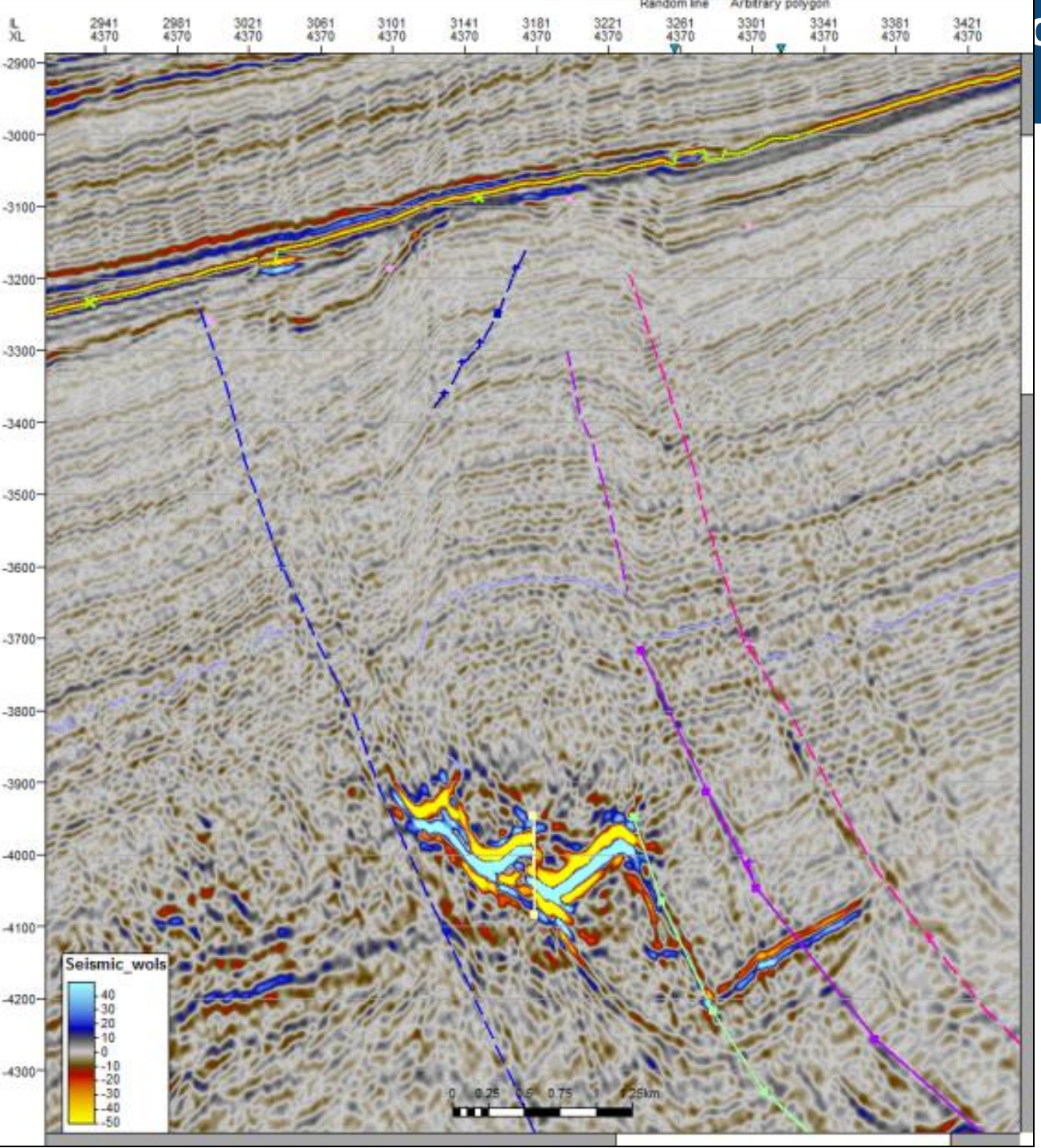
- Igneous intrusions can have a major impact on petroleum system development:
  - Positive: e.g., trap development, local heat source to aid maturation
  - Negative; e.g., reduction in reservoir quality, compartmentalisation of petroleum system elements

- Key areas for future research include:
  - Sill-fault relationships and influence on seal capacity
  - Impact of igneous emplacement on source-rock maturation
  - Reservoir quality variations as a result of igneous emplacement
  - Forced-fold trap mapping and volumetric calculations



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Structural framework

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