Interaction between Faults and Igneous Intrusions in Sedimentary Basins:
Insights from 3D Seismic Reflection Data*

Craig Magee¹, Christopher A. Jackson¹, and Nick Schofield²

Search and Discovery Article #41114 (2013)**
Posted February 28, 2013

*Adapted from oral presentation at AAPG International Conference and Exhibition, Singapore, 16-19 September, 2012. Please refer to companion article by the Basins Research Group, Imperial College, entitled “Seismic Expression and Petroleum System Implications of Igneous Intrusions in Sedimentary Basins: Examples from Offshore Australia,” Search and Discovery Article #10483 (2013).
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¹Department of Earth Sciences and Engineering, Imperial College London, London, United Kingdom (c.jackson@imperial.ac.uk; c.magee@imperial.ac.uk)
²School of Geography, Earth and Environmental Science, University of Birmingham, Birmingham, United Kingdom.

Abstract

Normal faults and igneous intrusion complexes can individually influence sedimentary basin evolution and petroleum system development through compartmentalisation, trap formation and the generation of hydrocarbon migration pathways. Whilst our understanding of fault and intrusive systems continues to improve separately, few studies have considered the interaction of the two and the potential impacts on petroleum system development. Here, we present 3D seismic reflection interpretations detailing the relationship between saucer-shaped sills and faults within the Exmouth sub-basin located offshore NW Australia. Transgressive sill segments are frequently observed to preferentially exploit specific pre-existing faults, potentially forming localised seals. Furthermore, mound-shaped structures, interpreted to represent hydrothermal vents, are often developed above the upper tips of the faults that are intruded by the sills. We consider how the fault-seal potential, which is related to fault throw and the physical properties of the faulted lithologies, controls the styles of both intrusive magmatic and extrusive hydrothermal products. This study demonstrates the complex interactions that may occur between normal fault arrays and igneous systems, and highlights how fluid migration pathways and hydrocarbon traps may be modified in petroliferous basins.

References Cited


Clarke, S.M., S.D. Burley, and G.D. Williams, 2005, Dynamic fault seal analysis and flow pathway modelling in three-dimensional basin


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Craig Magee\textsuperscript{1*}, Christopher Jackson\textsuperscript{1}, Nick Schofield\textsuperscript{2}

\textsuperscript{1}Department of Earth Science and Engineering, Imperial College, London, SW7 2BP, UK
\textsuperscript{2}School of Geography, Earth and Environmental Science, University of Birmingham, Birmingham, B15 2TT, UK

*e-mail: c.magee@imperial.ac.uk

Software:

Data:
Intrusion-Fault Relationships: Field

Franklin Sills (Canada) – modified from Bédard et al. (2012)

Paiute Ridge dykes (Nevada, USA) Valentine & Krogh (2006)
Intrusion-Fault Relationships: Seismic

Bright Basin (southern Australia) - Jackson (2012)
To test these hypotheses we need to understand what controls the location and mechanisms of intrusions along faults.

modified from Holford et al. (2012)
Exmouth Sub-basin (NW Australia)

- Multi-phase rift basin
- Two styles of faulting
- At least two phases of igneous activity
Exmouth Sub-basin (NW Australia)

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Exmouth Sub-basin (NW Australia)

- Multi-phase rift basin
- Two styles of faulting
- At least two phases of igneous activity
Onlap onto volcano and hydrothermal vent field

- ~N-S trending faults have large throws and extend into Lower Jurassic successions
- Denser network of NE-SW (some NW-SE) trending faults restricted to Upper Jurassic and Berriasian
Seismic Expression of Igneous Bodies

- Volcano truncates Kimmeridgian strata and onlapped by the Tithonian Dingo Claystone (source rock)
- Volcano displaced by Berriasian faults that controlled thickness of Macedon Sandstone (reservoir)
- Succession capped by the Muderong Shale (seal)
- Step in the intrusion does not fault displacement at shallower level; many sills not offset by faults
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Magma Flow Directions

Schofield et al. (2012)
Fault / Sill Interactions

Key to A, B and C

- Syn-rift II faults
- Sections of faults exploited by Sill A
Fault Influence on Sill Emplacement

RMS Amplitude

![Fault Influence on Sill Emplacement](image)

- VE ≈ 5
- Depth (m): 3200 to 3850
- Area of sill intrusion along fault
- Intrusive steps unrelated to faults

Vertical offset (m)
Distance along fault (km)

Vertical seismic resolution

up to 342 m height
Fault Influence on Sill Emplacement

- **T0** – pre-intrusion stratigraphy
- **T1** – sill intrusion and step development
- **T2** – juxtaposition of preferentially intruded horizons across pre-existing fault
- **T3** – step developed along fault
Fault Influence on Sill Emplacement

T0 – pre-intrusion stratigraphy
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Fault Influence on Sill Emplacement

JT hangingwall cut-off

JT footwall cut-off

Sill

Positive corrugation

F1  F2  F3  F4  F5  F6  F7

N 1 km

Average energy

c. 2.5 km

VE ≈ 4
Igneous Intrusion and Fault Seal Potential

Mechanisms of fault-seal generation:

1/ Bed juxtaposition

2/ Fault rock processes (e.g. Shale smear)

3/ Intrusion and crystallisation of magma

modified from Clarke et al. (2005)

after Færseth (2006)
Igneous Intrusion and Fault Seal Potential

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after Færseth (2006)
• Intrusions may affect vertical and lateral migration pathways

• Impact on lateral connectivity reduced because intrusion is likely to be focused at specific fault segments
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• Impact on lateral connectivity reduced because intrusion is likely to be focused at specific fault segments
Conclusions

• Faults can provide low-permeability magma conduits

• Intrusions exploit laterally restricted fault segments (e.g., convex-into-the-footwall corrugations)

• Magma emplacement and intrusion geometry controlled by stress-field variations and fault rock lithology

• Intrusion and fault interactions may affect:
  - Fault seal potential
  - Hydrocarbon migration
  - Hydrothermal systems
  - Location of volcanic vents