Australian Government
Australian Renewable Energy Agency

ARENA

ARENA Structural Permeability Map Project

Project results and lessons learnt

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Table of Contents

Executive Summary

This ARENA Measure entitled The Australian Structural Permeability Map Project, set out to conduct a scientific research-driven analysis of methods for the subsurface detection of structural permeability, the characterisation of these structures, and analysis of their ability to act as conduits for subsurface fluid flow. Structural permeability, or secondary permeability, is defined as pathways for fluid flow through faults, fractures, and other tectonic features.

This project arose from a key finding of the now-complete ARENA Measure Reservoir Quality in Sedimentary Geothermal Resources led by South Australian Centre for Geothermal Energy Research (SACGER) was that deep sedimentary aquifers in Australia are unlikely to be viable geothermal reservoirs due to the effect that mineral formation accompanying sedimentary burial has on rock permeability. Consequently, it is likely that structural permeability from natural or induced fracture networks will provide the primary means for fluid flow in geothermal reservoirs.

The outcomes which the project set out to achieve in this ARENA Measure were:

a) To map fracture distributions, orientations and their connectivity in key onshore sedimentary basins using a range of geophysical techniques, well-bore image logs, drill core data and outcrop studies.
b) To take known fracture populations (see outcome 1) and identify those that are open or closed to fluid flow by investigating fracture histories for a subset of Australian sedimentary basins where key fracture attributes (orientation, aperture) are well understood.
c) To define a framework for prediction of permeability pathways within critical Australian basins that is based on our database of fracture character and fracture generation histories.
d) To improve our understanding of the relationship between fractures mapped in seismic data and borehole image logs, permeability measurements from both drill core and formation tests, and electrical resistivity including anisotropy.

Project Overview

Project summary

The project aimed to map fractures and faults in four key Australian Energy Basins: The Cooper Basin, Otway Basin, Perth Basin, and Bowen/Surat Basin. The project would use a variety of remote and direct detection techniques to identify these structures and compare their effectiveness and how well they identified features at a range of scales. From the smallest scale (outcrop measurements in the field) to the largest scales (3D seismic data and magnetotellurics) a key challenge was to compare and integrate data of different scales effectively.

Project scope

While much has previously been done to understand the pattern of crustal stresses (forces that control the formation and character of fractures) across Australia, little is known about the resultant fracture networks themselves that are the key to permeability. Therefore, the project consisted of collecting a database of fracture and fault orientations and characteristics, and providing the workflow for assessing structural permeability, in the four Australian Basins which were selected due to the high density of existing petroleum exploration data.

Understanding structural permeability and improving our ability to detect and predict it was seen as a key objective for future geothermal and unconventional hydrocarbon exploration. Both of these resource types often target deep reservoirs with very poor primary permeability. As such, being able to detect faults and fractures in these targets, and then predicting if they will help or hinder the flow of economic fluids is vital.

By investigating how existing petroleum data as well as field data could be integrated to detect structural permeability, this project aimed to further understand how faults and fractures interact at a variety of scales, and how some direct datasets might be used to ground-truth remote sensing data. From this we hoped to establish a method for appraising the structural permeability of a target area (regardless of its scale) and exploiting existing open-source data to cost-effectively predict the fluid flow properties of rocks at depth, before expensive drilling.

Outcomes

All data collection from image logs, 3D seismic analysis, and geophysical analysis was carried out in the four basin areas successfully within the allotted milestone periods. This involved collecting fracture and fault density and orientation data from 6 separate 3D seismic surveys, analysing 53 petroleum well image logs, and gather a new 3D magnetotelluric survey in the South Australian Cooper Basin. This data provided an opportunity to better constrain the relationship between faults and fractures detected in 3D seismic surveys and those from well data, and several improvements were made in data processing which reflect this.

While the Cooper Basin location provided a wealth of data on fractures and faults which appear conductive to fluids in the sub surface, surprisingly our new magnetotelluric survey did not reflect this as expected. Favourable fluid flow orientations should be reflected in electrical anisotropy in the survey. However, this was not observed and is potentially the result of a lack of interconnectivity between permeable structures, or low salinity of fluids in them.

All data types were integrated into building maps of structural permeability. To do this stress data was collected in out study areas from petroleum wells and added to that available through the World Stress Map. Fault, fracture, and stress data were combined into a geomechanical analysis called FAST, which uses the orientation of structures in relation to the stress directions and magnitudes to predict which structures will be open or closed to fluid flow. This was ground-truthed with well data and compiled into basin- and field-scale maps for each study area.

Data from the Bowen/Surat Basin was used to create a workflow example of using the data and maps generated by FAST analysis to identify areas or orientations of potential structural permeability. Findings indicate the integration and spatial correlation of geomechanical risking along with other "geothermal favourability proxies", such as density of fault terminations and intersections, can be applied at regional-scale to identify structural permeability anisotropy, based on existing open-file datasets.

Finally, the maps of structural permeability in each basin were built into the new open-file Structural Permeability Map Project website, hosted and maintained by the University of Adelaide www.aspmp.com.au.

Transferability

Our advancements in detection of faults and fractures through 3D seismic analysis are applicable to many basin studies and operations where accurate analysis of fault and fracture (or fracture proxy) orientations are necessary. The results from our 3D magnetotelluric study have given pause for thought on how electrical resistivity and structural permeability in the sub surface are related, and under what conditions. Discussion in forthcoming publications on this study are vital to further work in this field and technique. The www.aspmp.com.au also hosts a freely available workflow for investigation of structural permeability in sedimentary basins, based on the work completed in this project.

Publications

List any academic journal articles that have been published in relation to this project. Where possible, include a link to access the paper.

Intellectual Property: Patents / Licences

All data from this project is either contained in the Australian Structural Permeability Map Project website, available as open-file on request, and/or incorporated into forthcoming journal publications.

Conclusion and next steps

We believe a significant outcome of this measure has been to refine the process of detecting fracture and fault populations and properties in the sub-surface, and to pilot integrating these data with stress data and other “geothermal favourability proxies” to identify structural permeability anisotropy at a range of scales. Our recommendation would be for future study to focus on field-scale investigations of fluid-flow pathways by incorporating all geological data available into 3D structural models, and incorporating this with heat flow data, and mechanical stratigraphy to identify pathways for fluid flow in the subsurface.

Lessons Learnt

Lessons Learnt Report: 3D magnetotelluric data does not always reflect permeability

Project Name: *The Australian Structural Permeability Map Project*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Geothermal
State/Territory:	South Australia

Key learning

While it was expected the permeability anisotropy (directional permeability) would be reflected in directional resistivity of the magnetotelluric survey acquired as part of this project, results were inconclusive. Previous studies in the Otway Basin had shown promise for magnetotellurics as a cheap, non-invasive survey mechanism for identifying the same permeability anisotropy identified in well and/or seismic datasets. Whether this is a result of fractures lacking an interconnectivity at depth, non-saline fluid filling them, or the fractures showing as open to conductive fluids in image logs being a false positive.

Implications for future projects

Further study of magnetotellurics as a method for detecting permeability anisotropy are require, as this is still a nascent field. The obvious answer is to use this technique where fluid flow and permeability are better constrained or expected, the active geothermal fault system at Paralana, South Australia is an obvious candidate.

Knowledge gap

How magnetotelluric resistivity signals reflect structural permeability direction, and the conditions under which noise in the data is too loud to detect useful data.

Background

Objectives or project requirements

A report documenting the study testing the relationship between fractures imaged on existing 3D seismic reflection data to the MT data, and where possible permeability measure in boreholes.

Process undertaken

A new 3D Magnetotelluric dataset was acquired in the Cooper Basin, located over the Moomba/Big Lake 3D seismic cube for integration with other seismic and borehole data.

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Lessons Learnt Report: Website development

Project Name: *The Australian Structural Permeability Map Project*

Knowledge Category:	Technical
Knowledge Type:	Outputs
Technology Type:	Geothermal
State/Territory:	South Australia

Key learning

A key road block to achieving all outcomes of the project was that we found the initial budgeted cost and time input insufficient for the development of an interactive GIS website to host the structural permeability map content. While the project had intended to keep website development in-house for ease of data management, we had to outsource this to a specialist who could provide a simplified version of our original template, as well as building a template and quote for a fully interactive GIS hosting platform in the future.

Implications for future projects

Future projects in this space will be able to use the outline time, cost, and technical requirements to build GIS hosting websites.

Background

Objectives or project requirements

All maps, data, and other outputs to be made freely available on a special purpose-built website hosted by the University of Adelaide.

Process undertaken

The website development was not within the universities in-house development team's capabilities in terms of integration into the university domain name platform, and time input. The development of the website was therefore outsourced to a provider who were able to produce a satisfactory product within time and budget.

Supporting information

The finished site can be found at www.aspmp.com.au

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Lessons Learnt Report: Successful use of geothermal favourability proxies

Project Name: *The Australian Structural Permeability Map*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Geothermal
State/Territory:	<insert state/territory>

Key learning

Recent studies in active geothermal areas have identified a variety of "geothermal favourability proxies" for identifying zones and/or pathways where permeability, heat, and fluids overlap. Focussing on the permeability, and permeability pathway proxies, this project demonstrated how regional-scale map data could also be interrogated in this was to provide more a broader, regional exploration tool to identify areas for more detailed investigation.

Implications for future projects

These findings are in the "Workflow for geothermal exploration in Australian energy basins" document found at the Australian Structural Permeability Map website and will feature in forthcoming journal publications. The methods herein will provide a guide for integrating open-file data from petroleum and minerals exploration, to a toolkit for identifying structural permeability.

Knowledge gap

The use of the geomechanical risking tool FAST was a key part of these findings. However, while stress orientation, and fracture data is now increasing, databases of stress magnitudes, and more detailed maps of structural geometries (faults/folds/fractures) in the subsurface are required for more comprehensive mapping of the permeability in Australian Basins.

Background

Objectives or project requirements

Creation of a new workflow to accurately predict the propensity of natural fractures to provide conduits or barriers for subsurface fluid flow, to be made freely available on a special purpose-built website hosted by the University of Adelaide.

Process undertaken

*Data from the Bowen/Surat Basin was used to create a workflow example of using the data **available** to identify areas or orientations of potential structural permeability.*

Appendix

Keywords

Geothermal, geology, structural permeability, faults, exploration, fluid flow, tectonics, sedimentary basins.

Glossary of terms and acronyms

3D Seismic data:	Geophysical method which uses reflected seismic waves to measure properties of the Earth's subsurface, measured from the surface along lines. 3D seismic involve tightly space seismic lines to create a 3D cube of data.
Anisotropy:	The quality of having different values or properties when measure along different axes or directions.
Fault:	discrete planar rock fracture, which shows evidence of a displacement.
Fracture:	Any crack or planar discontinuity in a rock which lacks evidence of displacement. Also know as a joint.
Geothermal reservoir:	A body of rock with the characteristics to act as a container for hot fluids as an exploitable resource.
Image log:	A pseudo-image of the inside of a well borehole created using the electrical resistivity of the boreholes surface.
Magnetotellurics:	A passive geophysical method which uses natural time variations of the Earth's magnetic and electric fields to measure the electrical resistivity of the sub-surface.
Sedimentary Basin:	Areas where long-term subsidence or rifting of the Earth's crust creates accommodation space for infilling by sediments.
Structural permeability:	The ability of faults and fractures to transmit fluid through rock underground.