Geophysical Survey as a part of a Multi-tiered Investigation in Fault Characterization and Dam Seismic Hazard Assessment

a case study from South Australia

Authors:

Zivko Terzic – Technical Director - Geophysics
Oleg Ermakov – Senior Geophysicist

Introduction

The geological fault investigation was a crucial part of a comprehensive safety review and upgrade design of a dam in South Australia

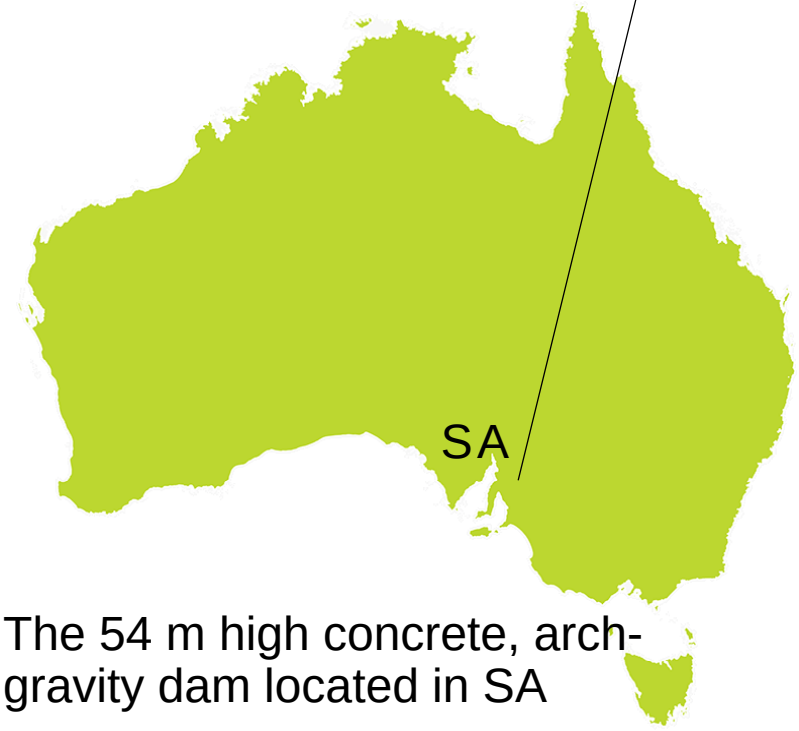
There is a major geological fault that was listed in Geoscience Australia Neotectonic Data Base. The feature runs in proximity to the dam with the following previously estimated parameters:

Length ~ 55 km

Dip direction – SE

Reverse Fault

Site location



The 54 m high concrete, arch-gravity dam located in SA

Dam is regularly reviewed against the up-to-date dam safety guidelines and standards

The goal of this investigation was to confirm and establish more accurate location and parameters of the fault within dam's area

Approach

The stages of a multidisciplinary approach for geological fault characterization used in this investigation

Desktop study including LIDAR data analysis and geomorphological mapping

✓ **Geophysical survey**

Geotechnical drilling

✓ **Paleo seismic trenching and mapping**

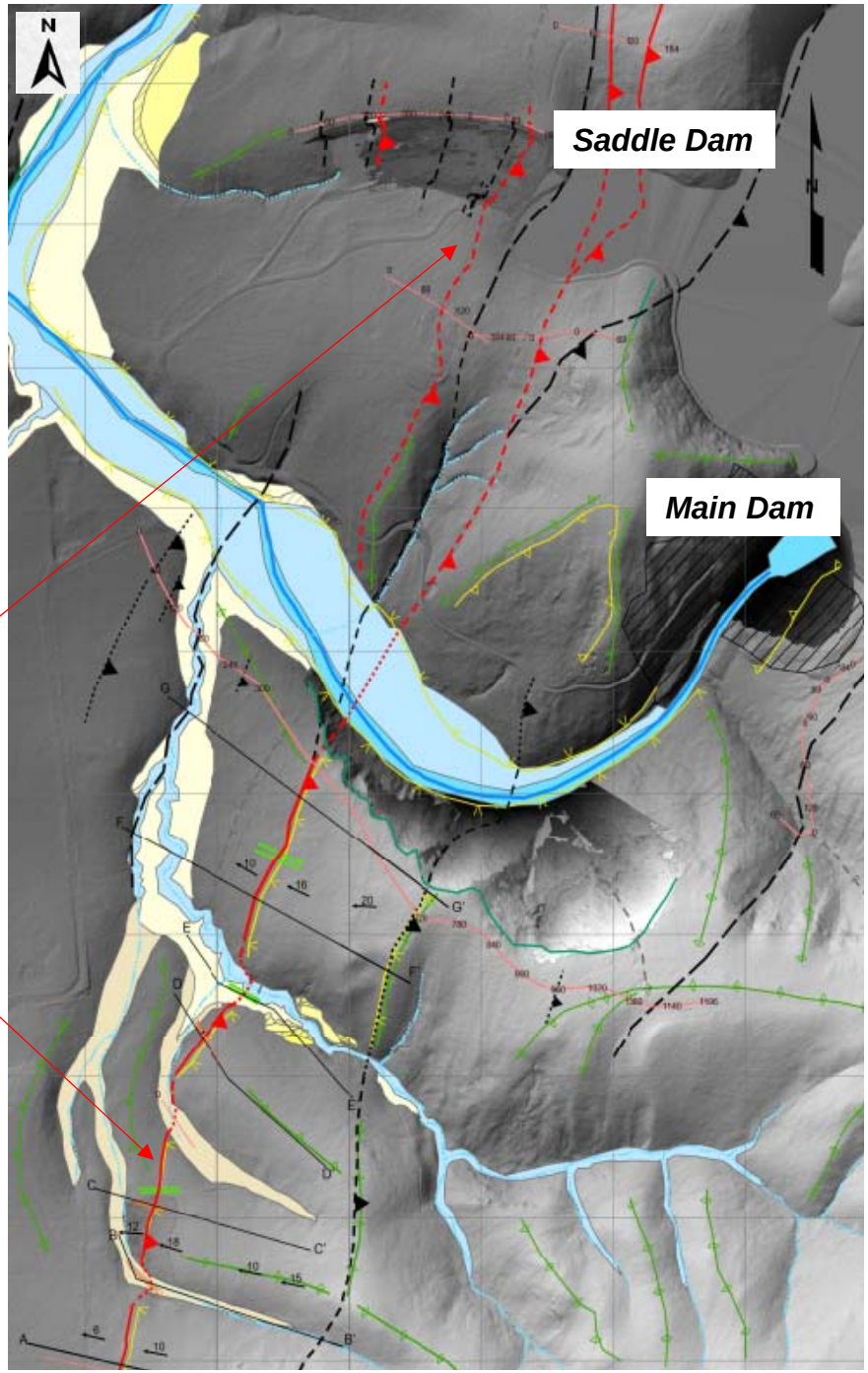
Optical dating of the excavated material

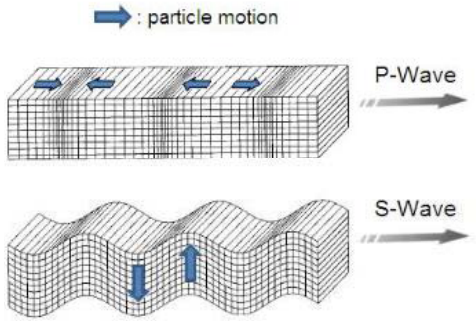
✓ **Seismic hazard analysis (PSHA and DSHA)**

Geomorphological mapping

Lidar data with the geomorphologic map was used to target location of seismic lines

Certain and inferred fault traces shown in red





Geophysical survey

The techniques used in the geophysical survey and their objectives

Seismic Refraction Tomography

Result is P-wave velocity model

- ✓ Highlight zones of anomalous velocities which may be related to geological structures (faults, dykes, etc.).

Seismic Reflection Survey

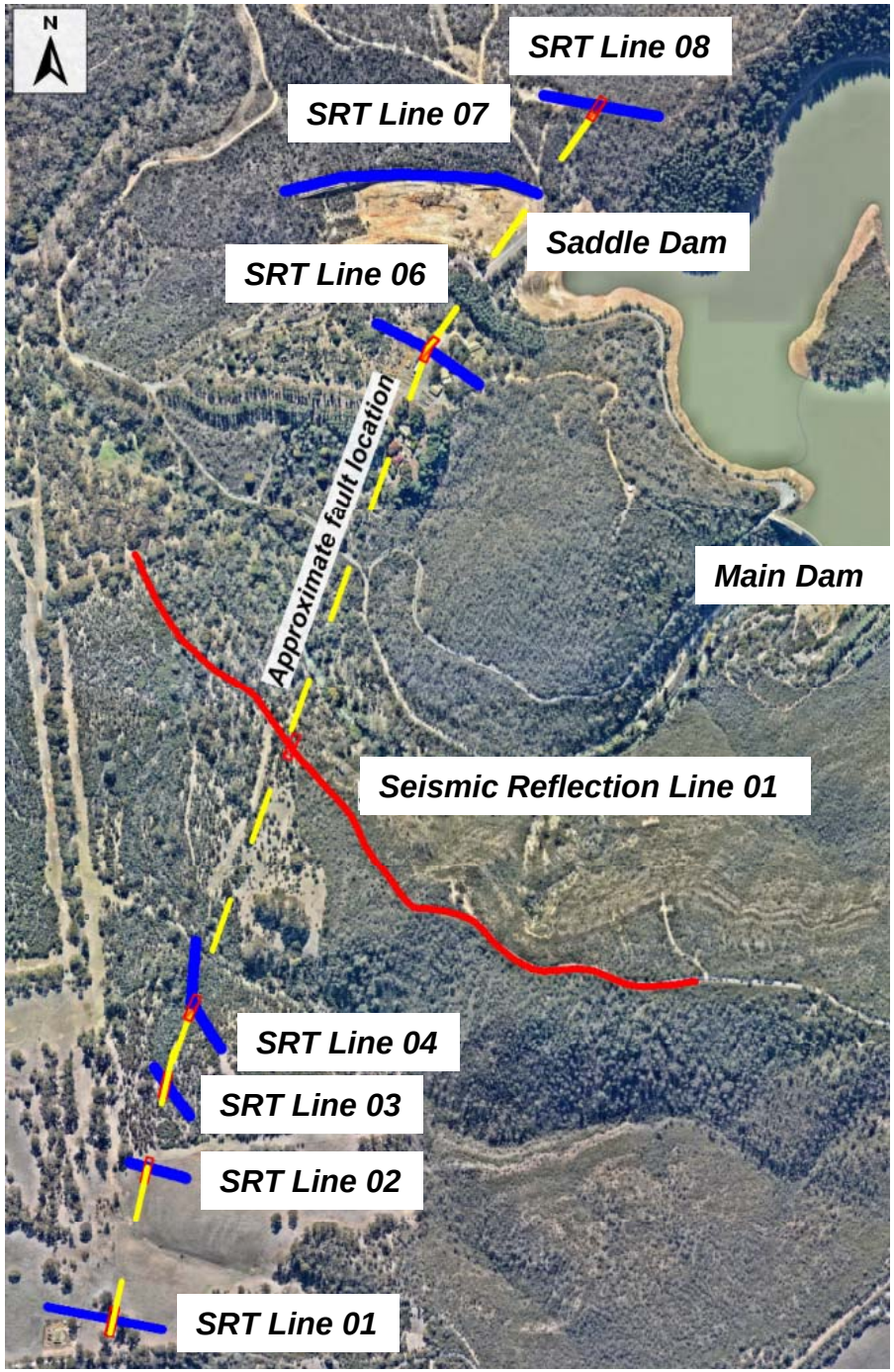
Result is Time domain

- ✓ Fault confirmation/detection; and
- ✓ Fault spatial definition

Geophysical survey coverage

Seismic Refraction Tomography
~2100 metres

Seismic Reflection
~1200 metres



Geophysical survey setup

Seismic Refraction Tomography

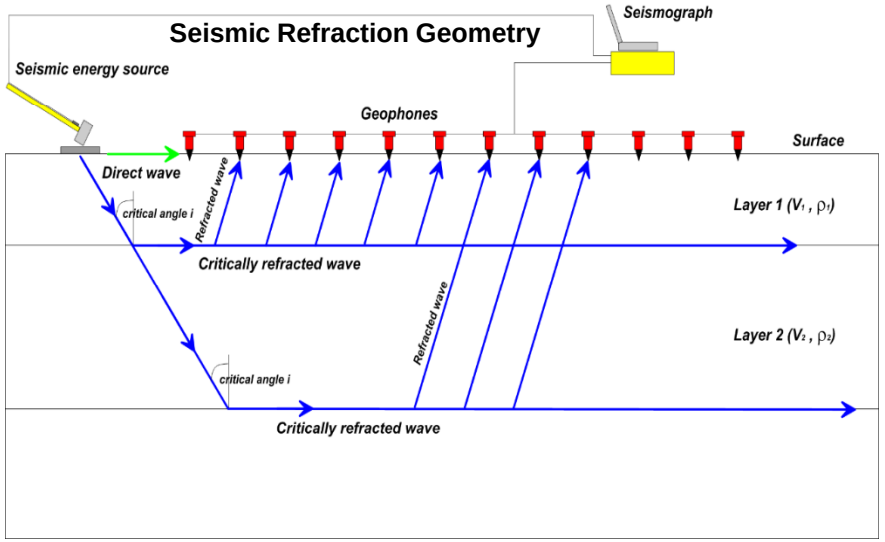
- 24-channel system
- 3 and 4 metres geophone spacing
- 8 metres shot interval
- Seismic source – sledge hammer
- Max depth of investigation ~ 30 – 40 metres

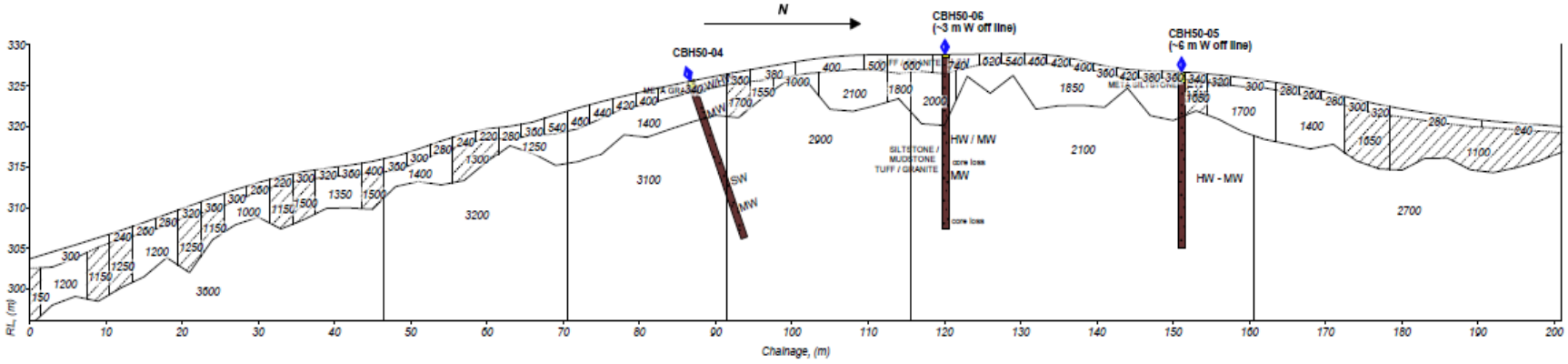
Seismic Reflection

- 300-channel system
- 4 metres geophone spacing
- 4 metres shot interval
- Seismic source – weight drop and explosives
- Max depth of investigation in excess of 1,000 metres

Classic Refraction Methodology

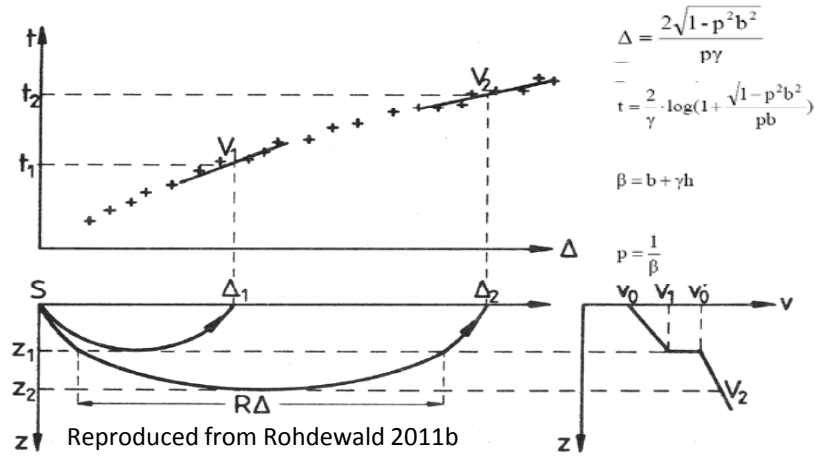
- Plus-Minus Method Hagedoorn 1959; Generalized Reciprocal Method (GRM) (Palmer –1980); Seismic Wavefront Method – (Jones and Jovanovich 1985);
- Shot Sorted Traveltimes
- Layered Earth Model (velocity trend changes only in horizontal direction)
- Constant layer - internal Seismic Velocity
- Assumption of velocity increasing with depth between layers





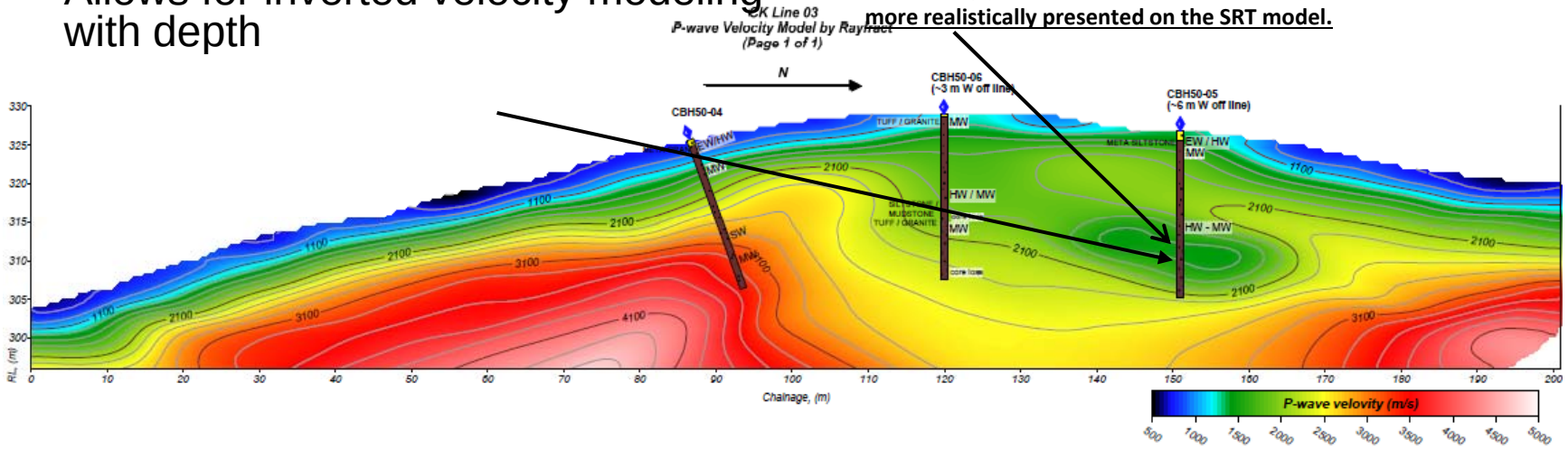
Seismic Refraction Tomography Method

- Delta-t-V initial model – Gebrande and Miller – 1985
- CMP sorted travel time based Method
- Less Prone to errors caused by idealized refractors assumption
- Allows for both lateral and vertical velocity changes
- Realistically predicts gradient increase of velocity with depth
- Allows for inverted velocity modeling with depth



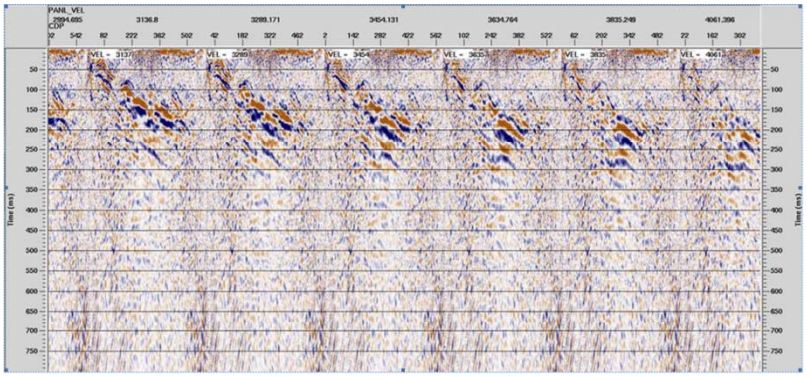
Reproduced from Rohdewald 2011b

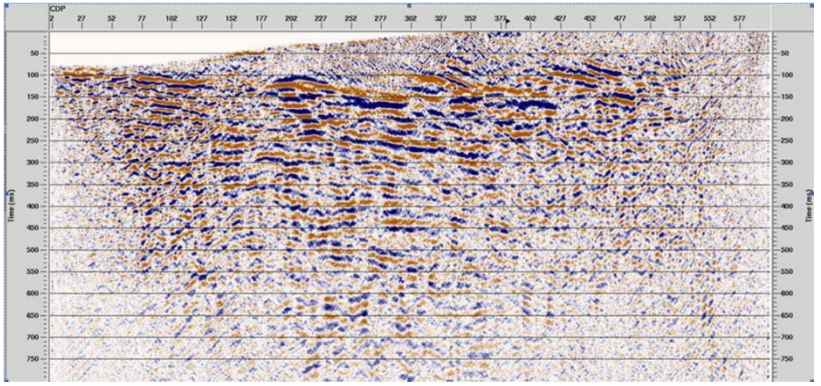
An example of the SRT model is presented below.
The same line with the model derived from the classic refraction approach is shown on the previous slide. Correlation with boreholes – weathering grades indicate possible velocity inversion which is much more realistically presented on the SRT model.



Seismic Reflection data Processing

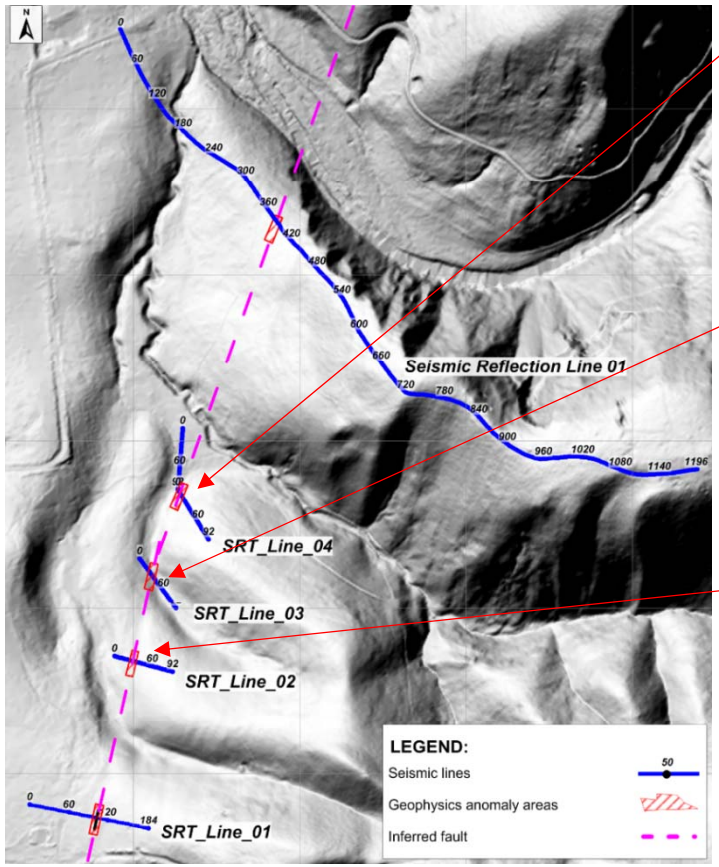
- Seismic Reflection processing eliminating background noise increasing SNR
- Adjusting for Refraction statics (minimising effects of regolith)
- The Brute stack
- Final product is the time migrated residual stack shows clear reflector discontinuities and amplitude ‘whitening’ as a result of faulting

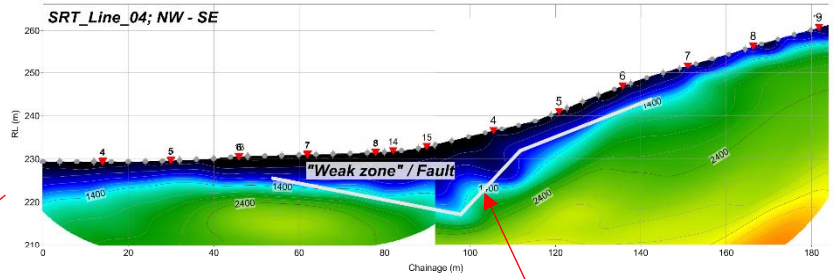


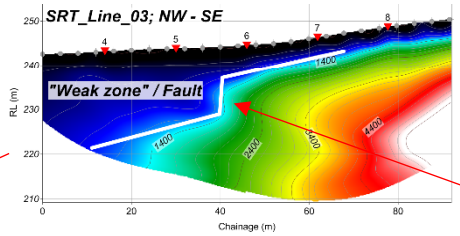


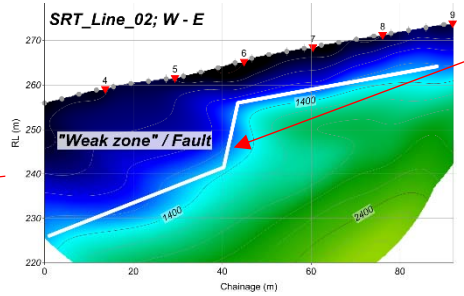
Seismic refraction tomography results

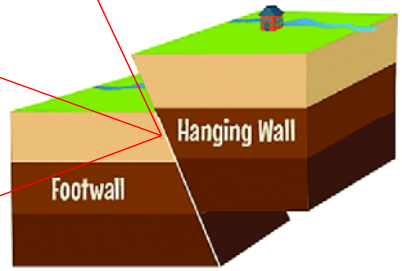
‘Step like’ velocity anomalies imaged on P-wave velocity models



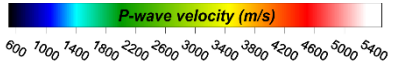






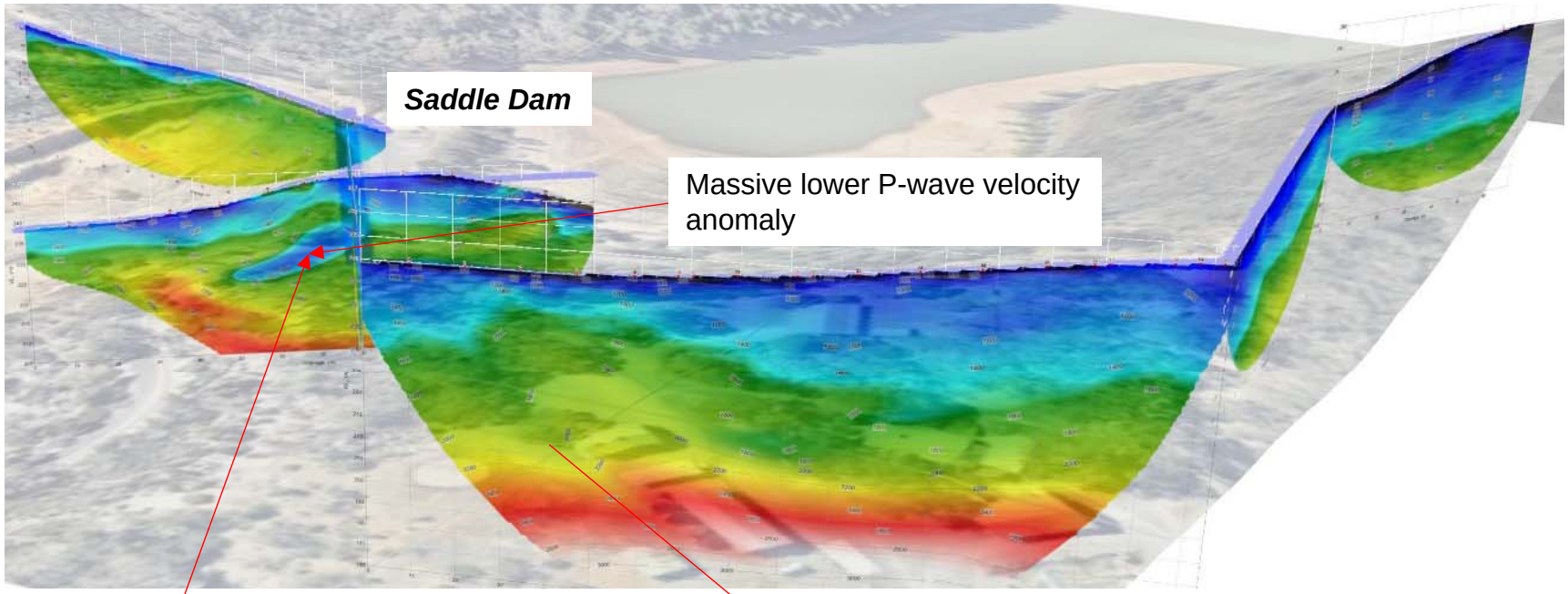


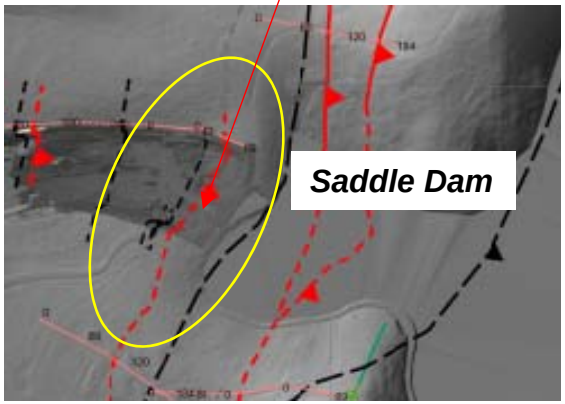
Reverse fault mechanism



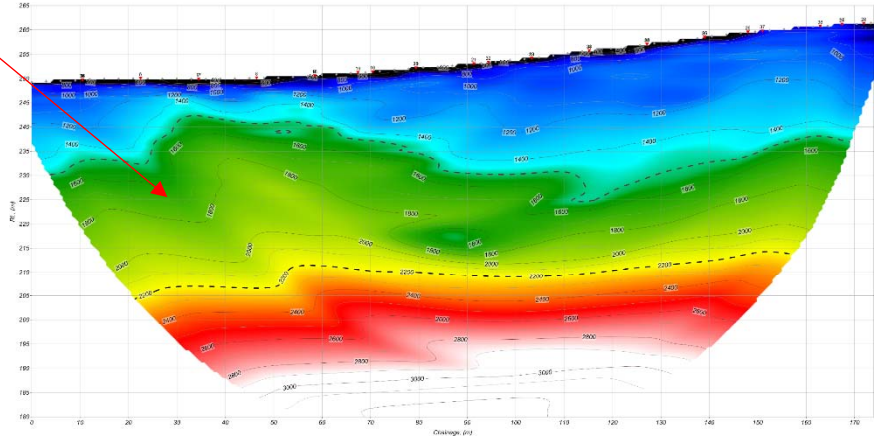
Seismic refraction tomography results cont.

P-wave velocity models in 3D view



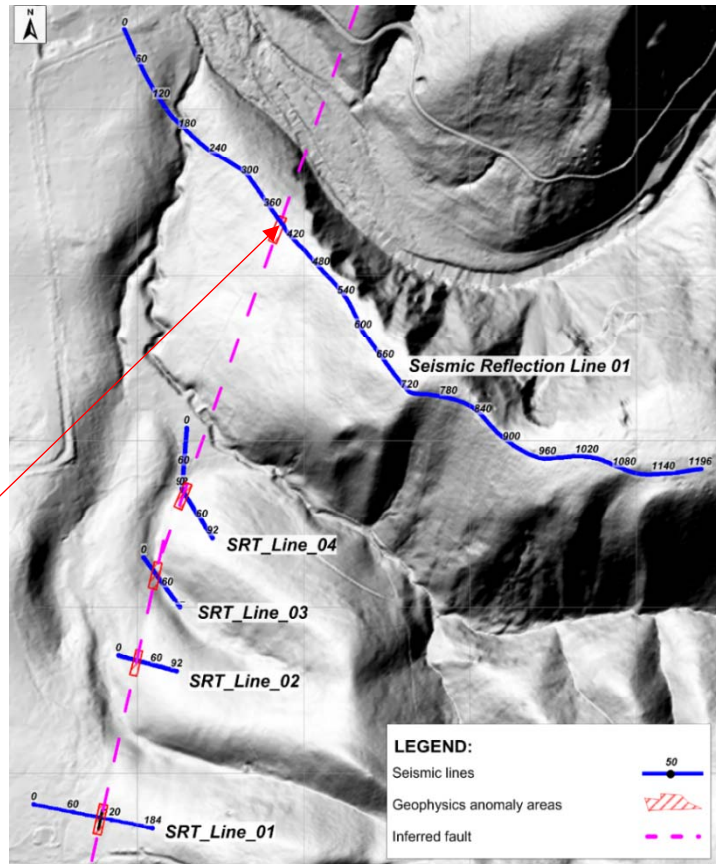


Step-like linear feature is indicative of a fault

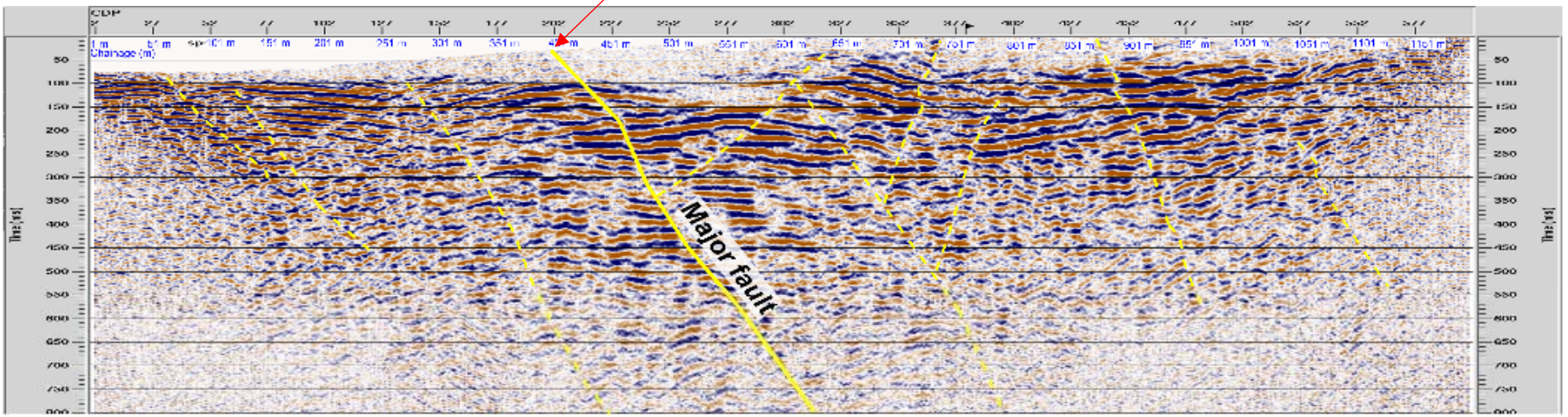


Seismic reflection results

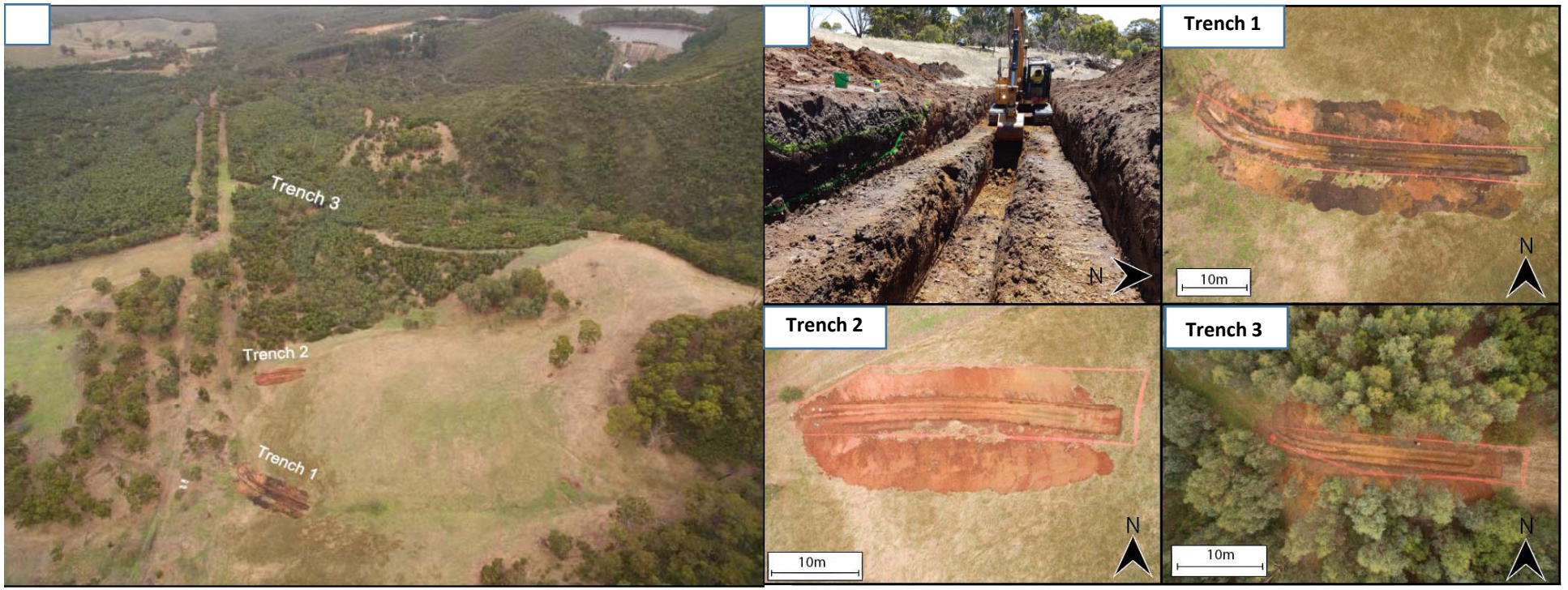
Major discontinuity observed on time section helped to confirm fault location orientation and mechanism



Seismic reflection time section; NW - SE



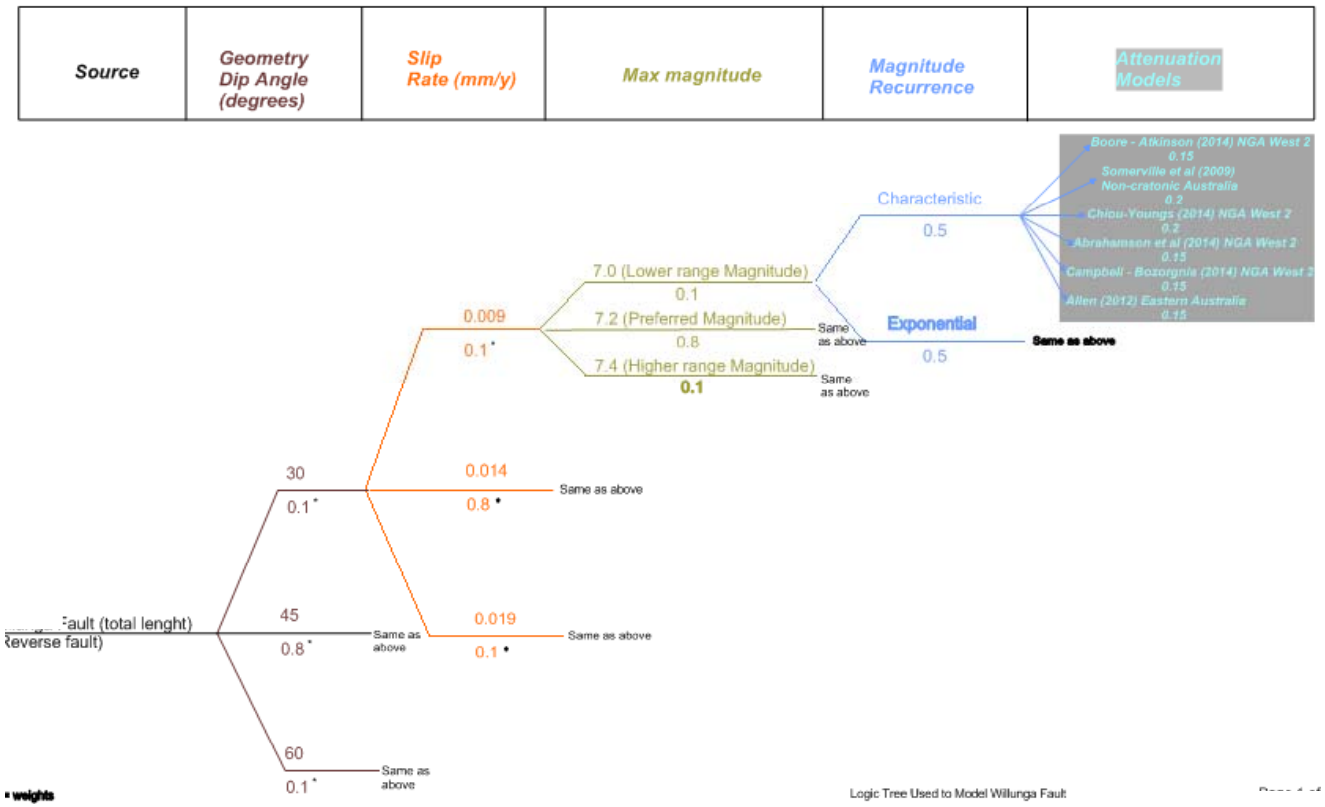
Paleo Seismic Trenching



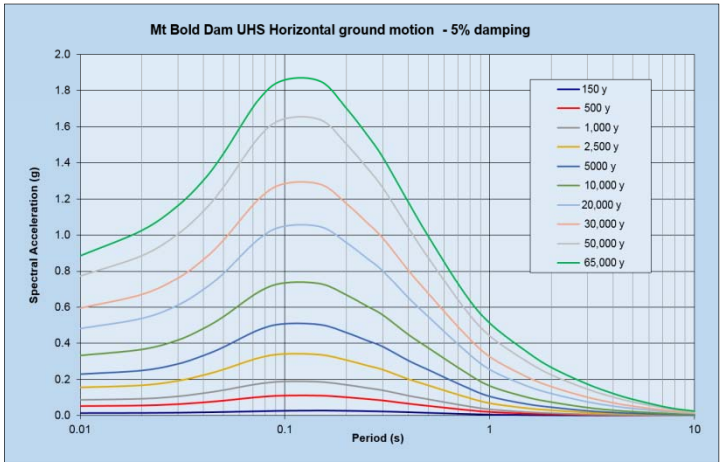
Paleoseismic interpretations from trench mapping and dating

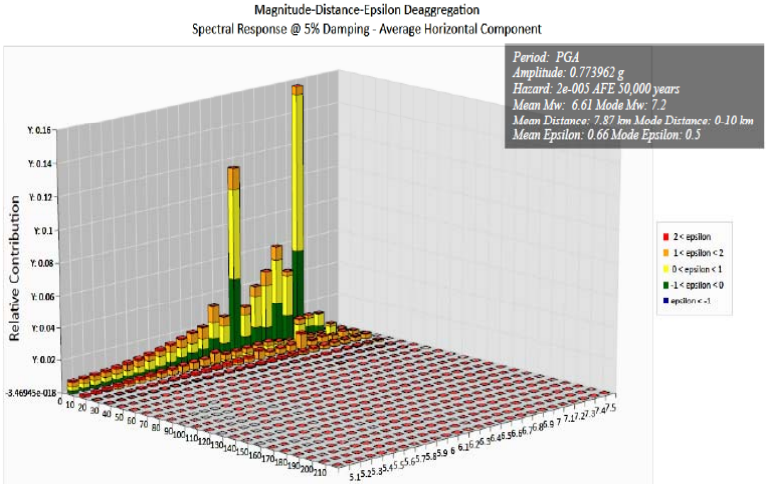
- The Fault classified as a 40 to 50 degree east-dipping reverse thrust fault;
- Optically stimulated luminescence dated the most recent earthquake to 60,000 to 80,000 years.
- A total estimated displacement of 120 cm was derived from the analysis.
- Cumulative vertical displacement of 135 m was estimated.
- A slip rate of 16 to 42 m per Million years was estimated in the dam's area.
- A preferred recurrence interval for the Fault is proposed at 37,700 (plus 39,300 yr minus 18,000 yr).
- A preferred total rupture Mw of 7.1 to 7.2 (plus minus 0.2) was estimated for the entire Fault.
- Deterministic magnitude of Mw 7.35 (plus minus 0.2) was estimated.

Seismic Hazard Assessment Results



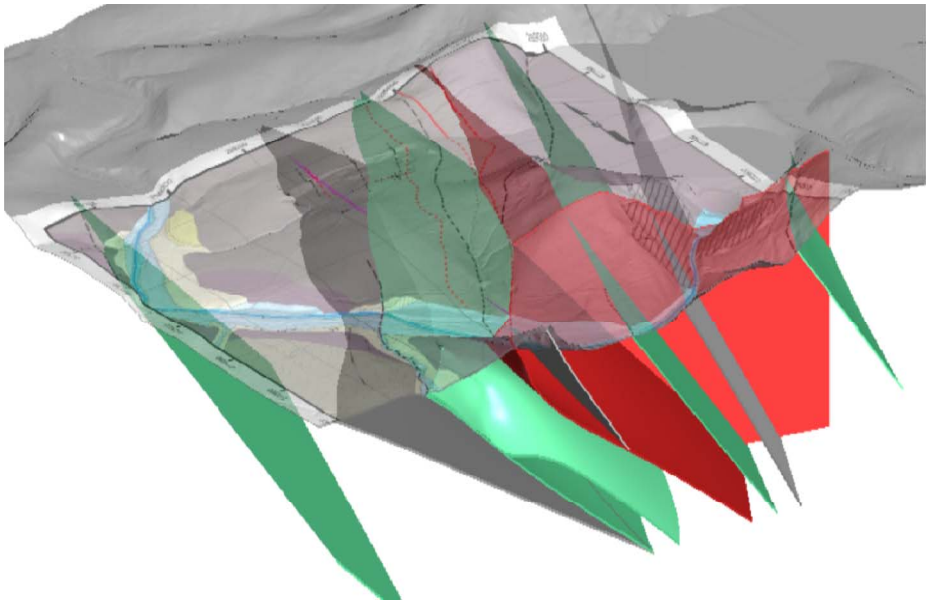
Logic Tree Used to Model Willunga Fault





Conclusions

- Geophysical investigation results indicated sharp change of velocity modelled on Seismic Refraction Lines
- The geophysics results confirmed the fault is a 40 – 60 degrees SE dipping reverse thrust fault.
- The paleo seismic results indicate the fault might currently be in a quiescent period.
- The mean MCE generated by the Fault produce mean PGA of 0.78g.
- Borehole drilled at saddle dam indicated relatively wide sheared zone at the location inferred from the investigation results.
- The geophysics results were incorporated into a 3D geological model of the dam site (Macklin et al 2019).



Thank you !