GISERA W19 – Narrabri fault connectivity study

Matthias Raiber, Jorge Martinez and Axel Suckow

Aims of the project

We have identified the role of faults as a knowledge gap during a previous GISERA project. The role of faults was also identified as a knowledge gap by the IESC (2017).

In this project, we aim to:

- Confirm current understanding of subsurface geometry (with a focus on presence of connectivity pathways);
- Determine if deep-seated faults are reactivated and extend to the shallow subsurface (upper 400 m), including into Surat Basin strata;
- If/where faults are present, determine if they are likely to form pathways for connectivity and fluid flow (water and gas)

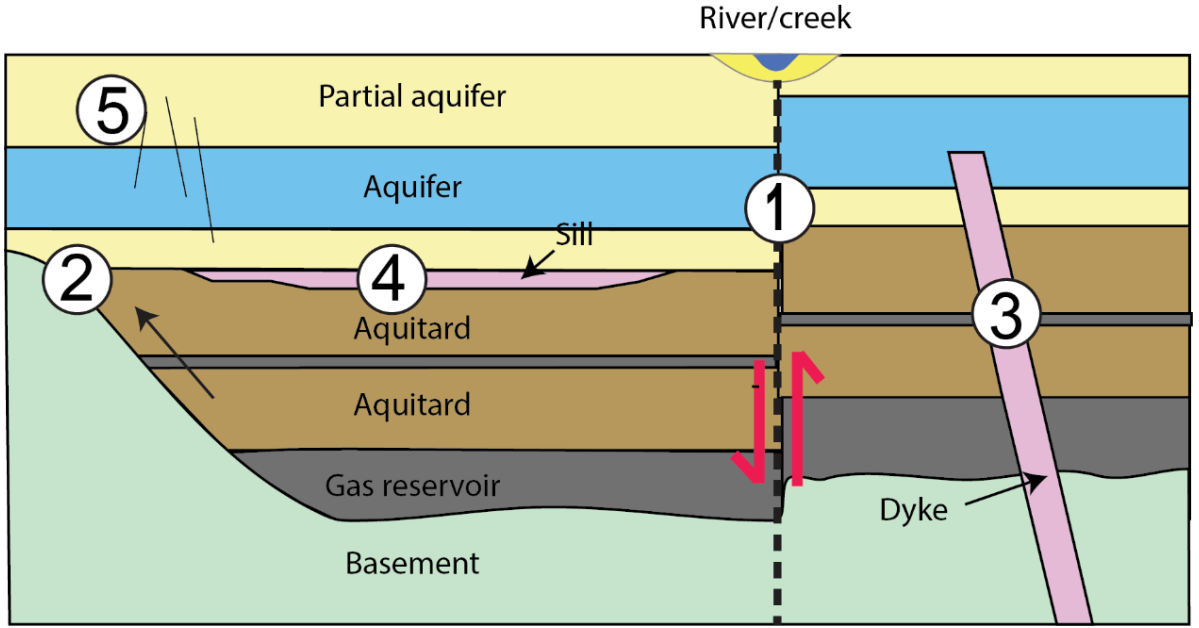
Integrated assessment using geophysical, hydrogeological and hydrochemistry/tracers

- Assessment of regional geological, hydrogeological and tectonic framework
- Assessed legacy seismic data and re-processed selected seismic lines (HiSeis)
- Ground-based transient electromagnetic (TEM) (Zonge Engineering)
- AgTEM (David Allen, Groundwater Imaging)
- Hydrochemistry and environmental tracers (compilation of existing data and new data collection (mostly Santos monitoring bores))

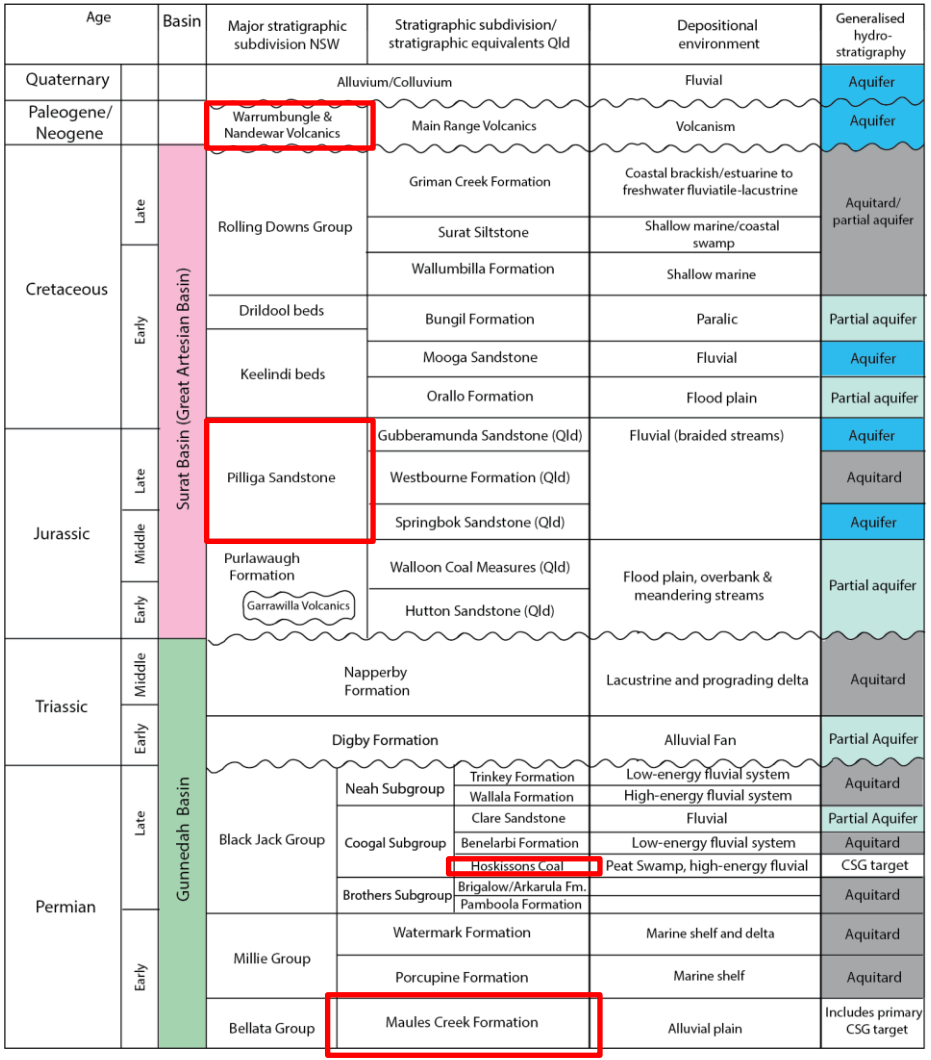
→ **Integration of multiple lines of evidence**

Potential connectivity pathways

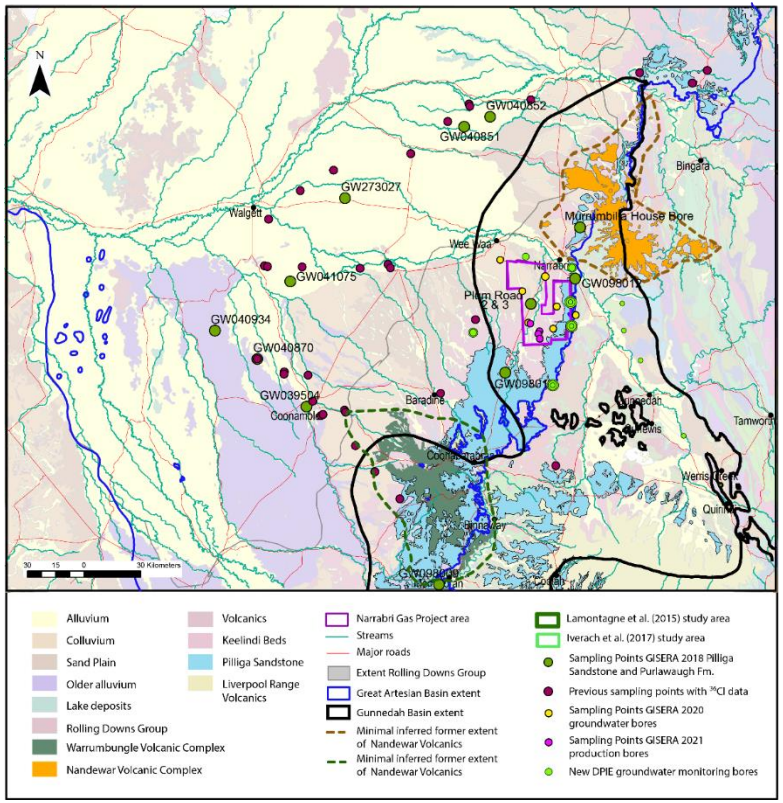
(1) Faults (with significant vertical displacements)
(2) Stratigraphic contacts
(3) Igneous intrusions (dykes)
(4) Igneous intrusions (sills)
(5) Fracture zones

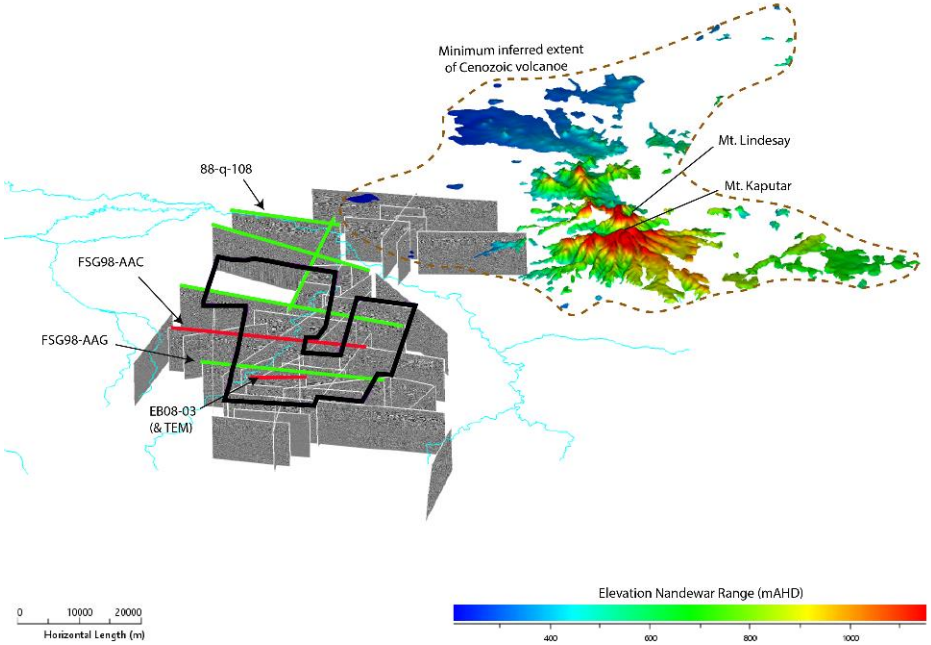


Geological framework

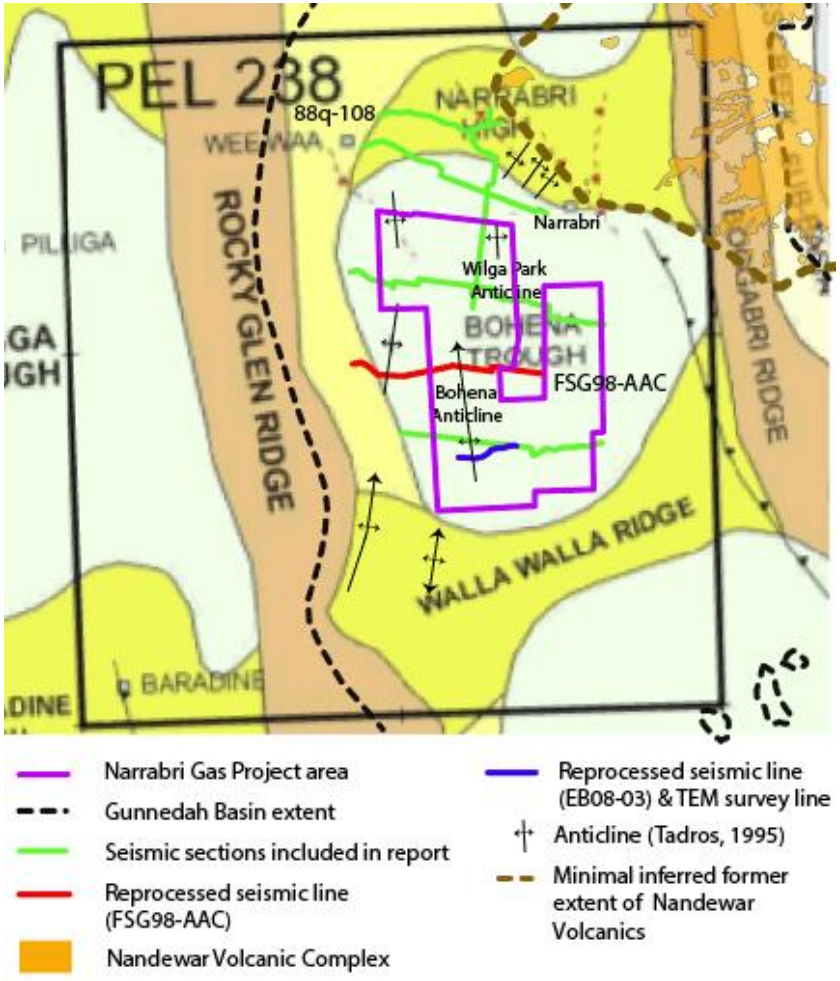


Spatial context



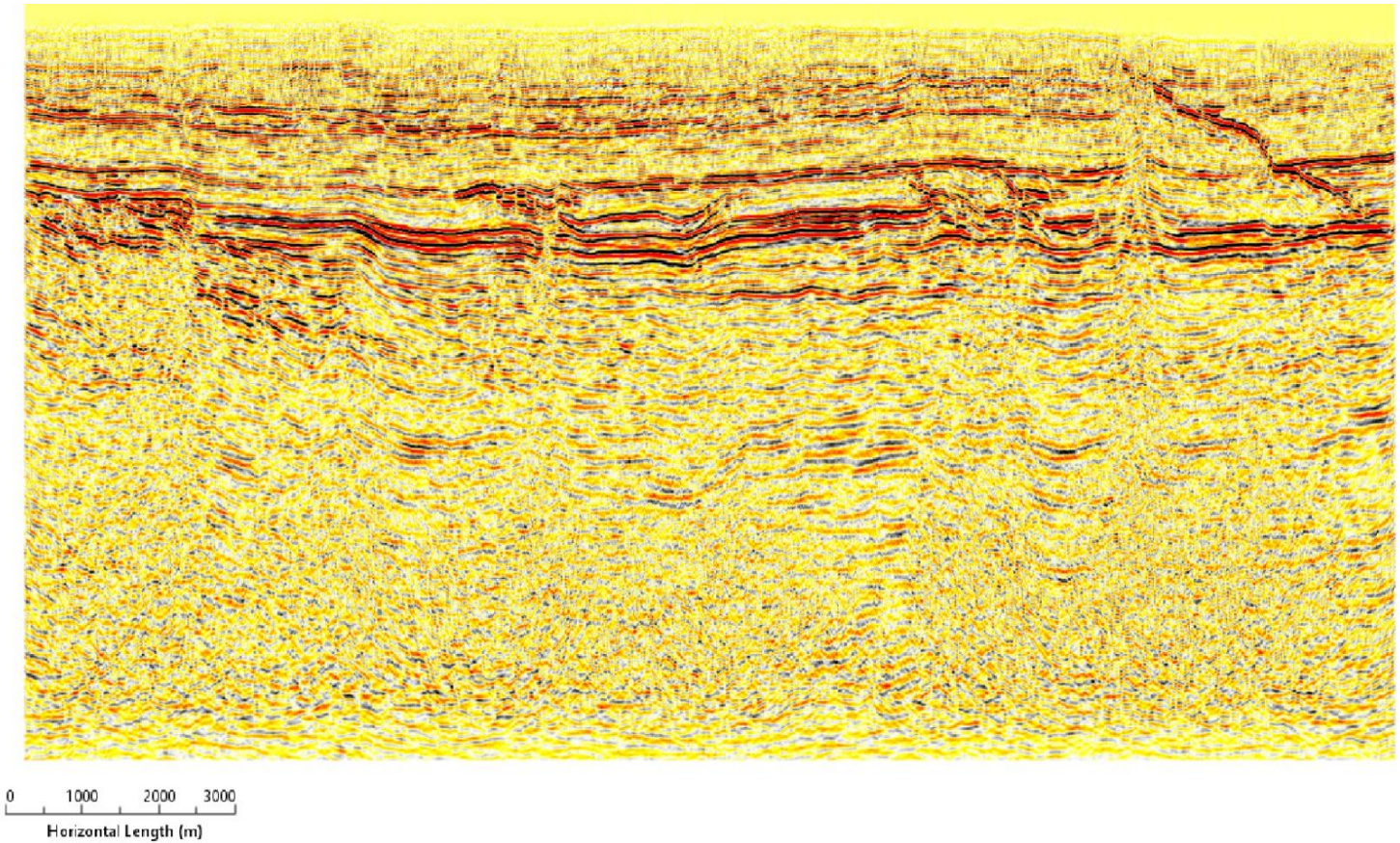


Geophysical assessment to identify potential connectivity pathways (subsurface architecture)

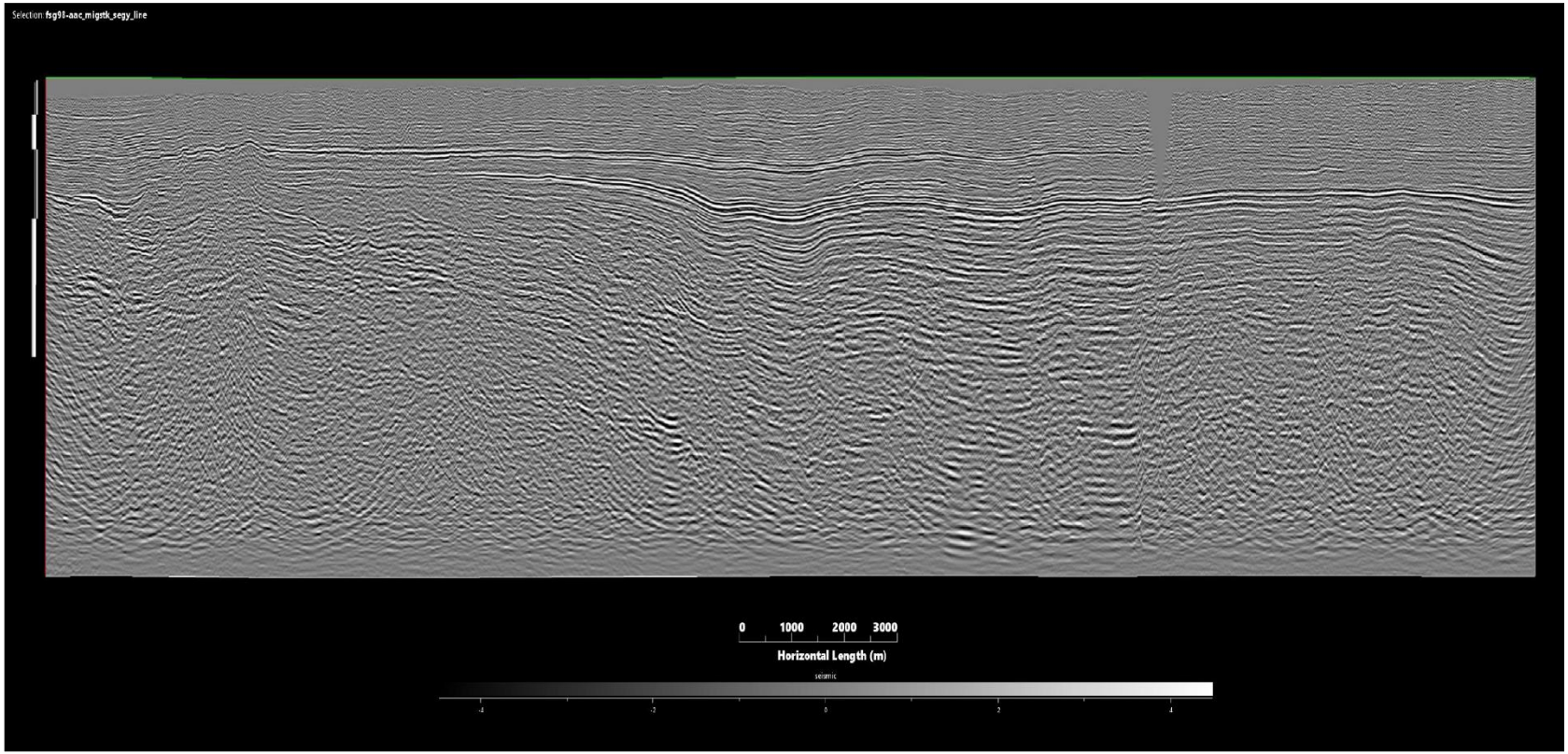


Structure of Gunnedah Basin (modified from Tadros (1996) and Eastern Star (2004))

Seismic line 88q-108 (legacy data, approximately 15 km north of CSG area)

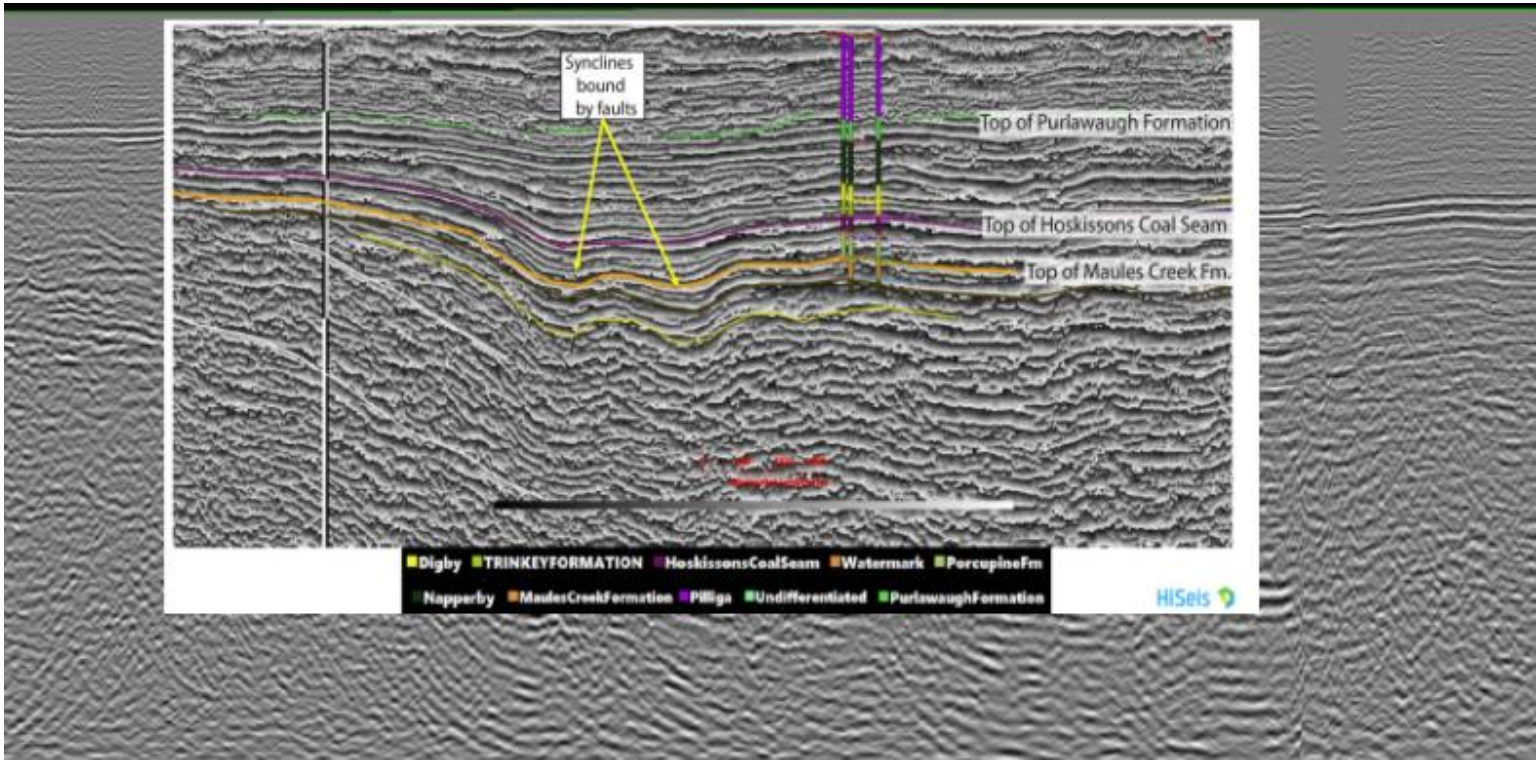


Identification of potential faults/fractures (HiSeis)



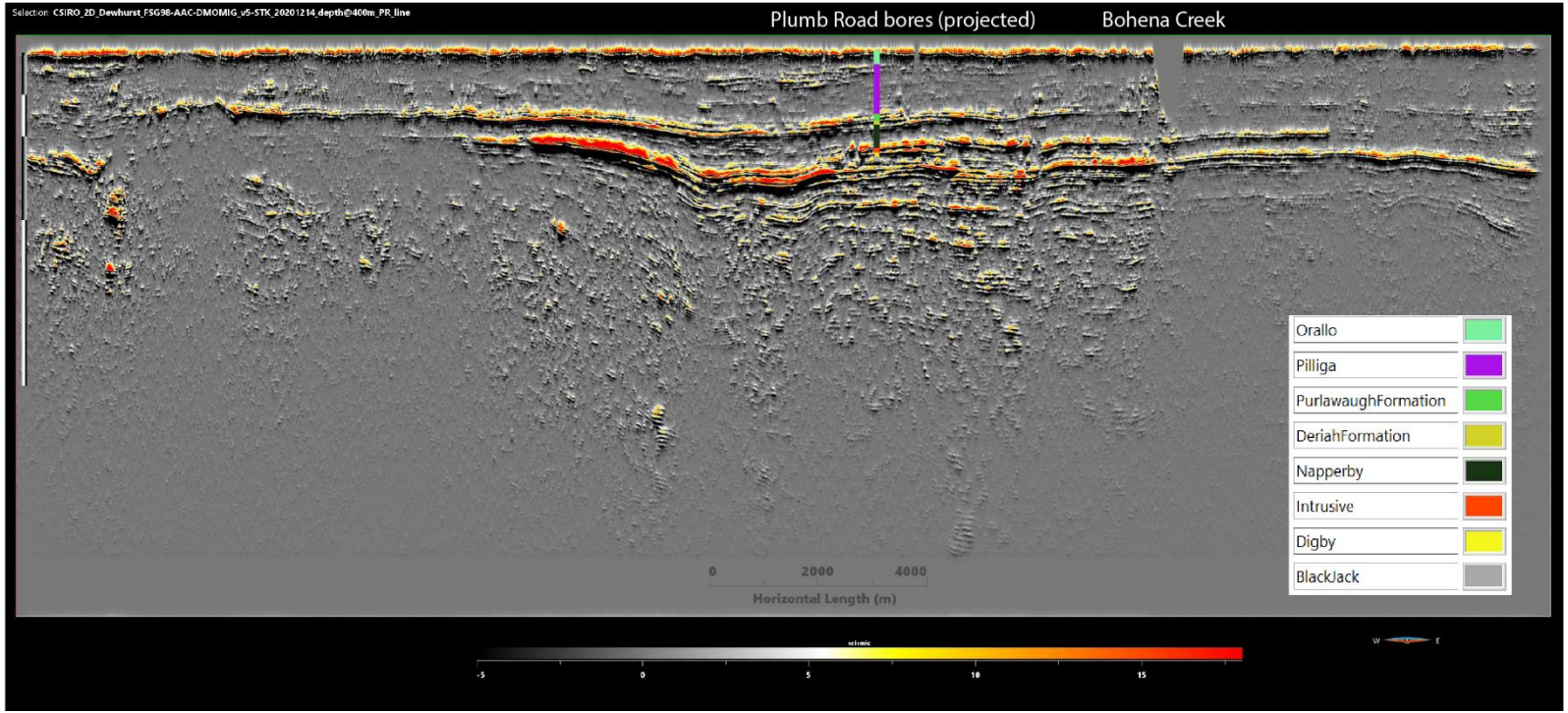
Legacy data FSG98-AAC

Identification of potential faults/fractures

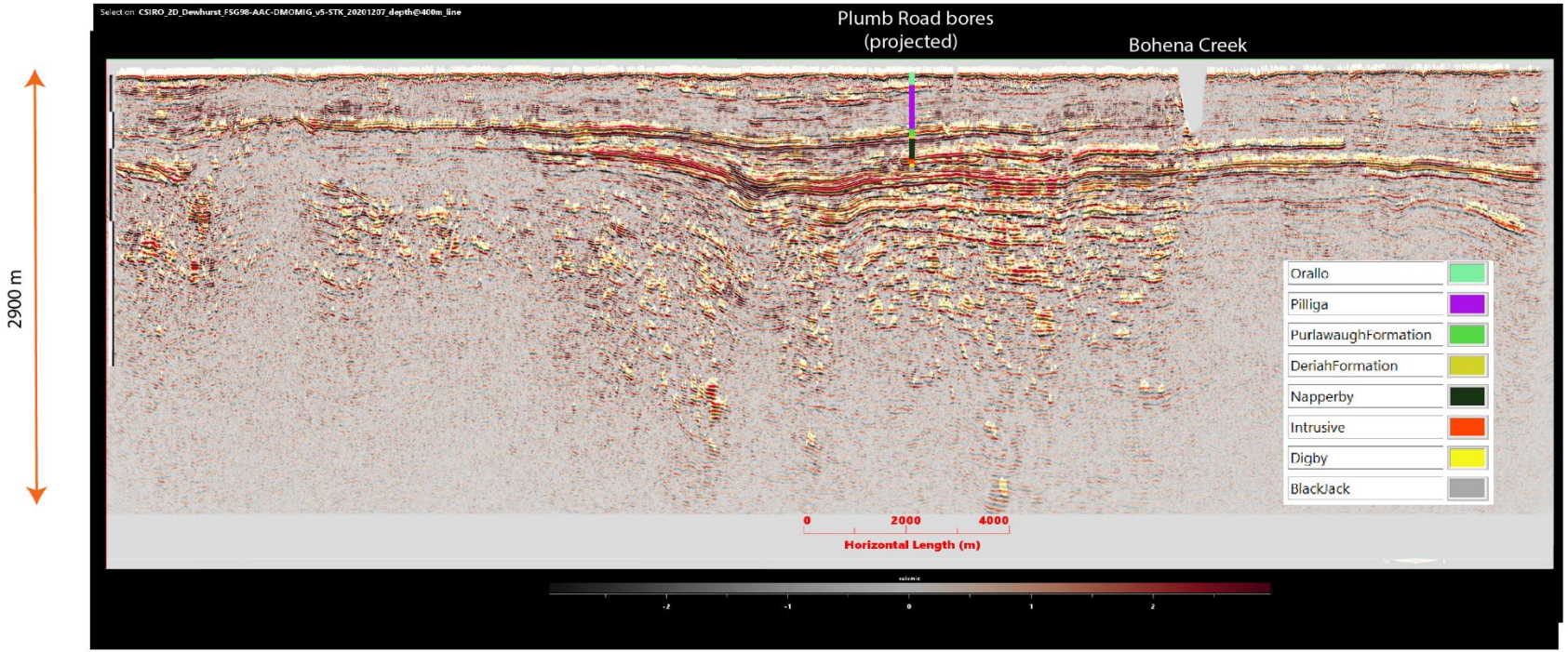


Instantaneous phase: improving continuity of reflectors

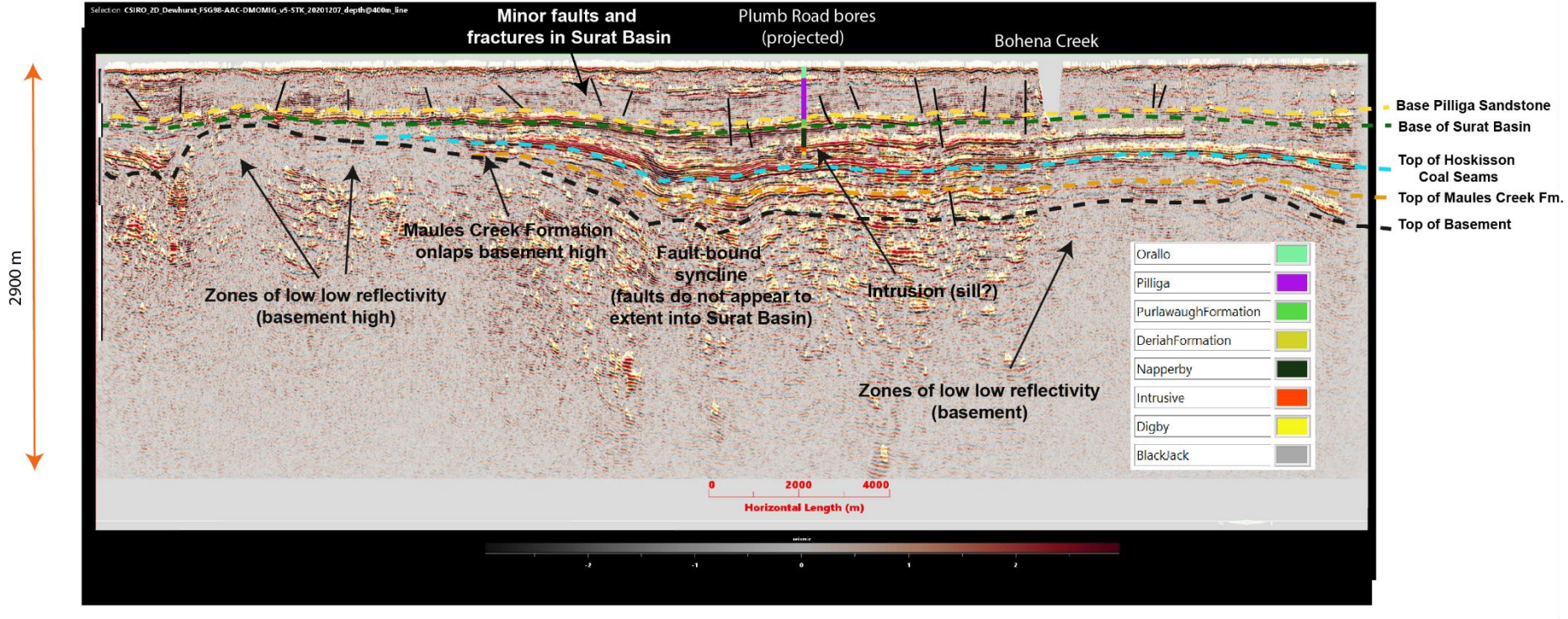
Identification of potential faults/fractures



Identification of potential faults/fractures



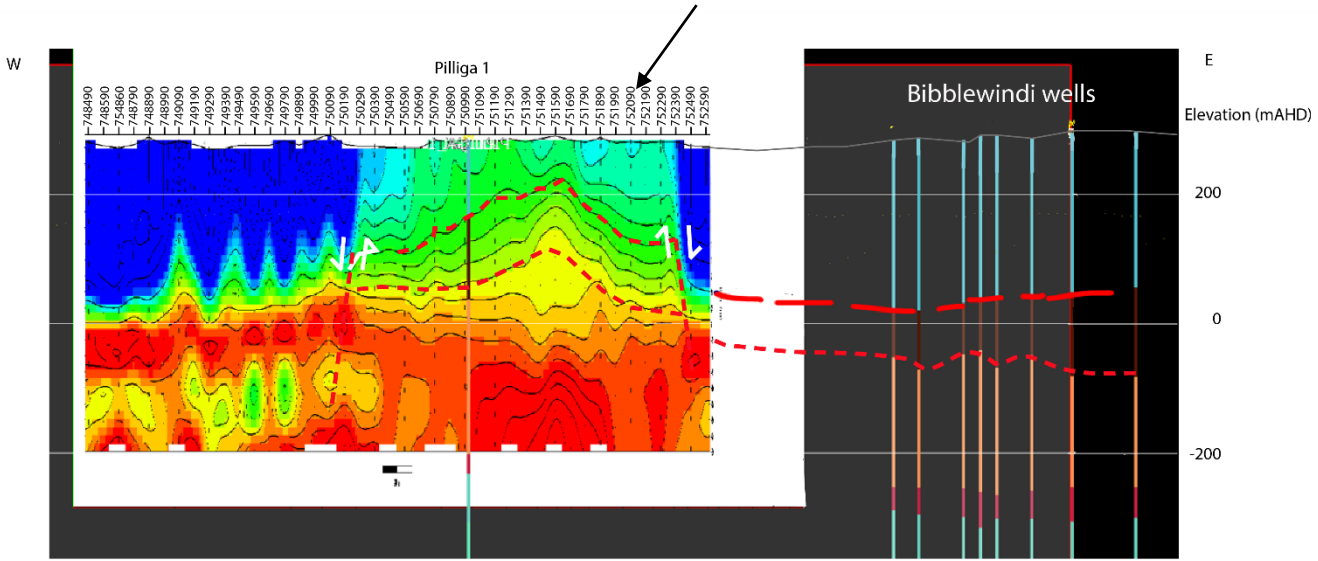
Identification of potential faults/fractures



Time domain electromagnetics (TEM) (upper ~400-600 m, Zonge Engineering)

Time domain electromagnetics (TEM) (upper ~400 - 600 m)

Each coordinate corresponds to a 100 m loop



Stratigraphic logs
- Pilliga Sandstone
- Purlawaugh Formation (Base of Surat Basin)
- Napperby Formation
- Digby Formation
- Black Jack Group

Resistivity ohm-m
10000
1000
100

High resistivity
- Lack of Clays
- Low Saturation
- Fresh pore water
- Impervious fresh rock

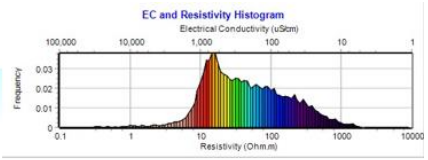
Low resistivity
- Clays
- High Saturation
- Saline pore water
- Weathered rock

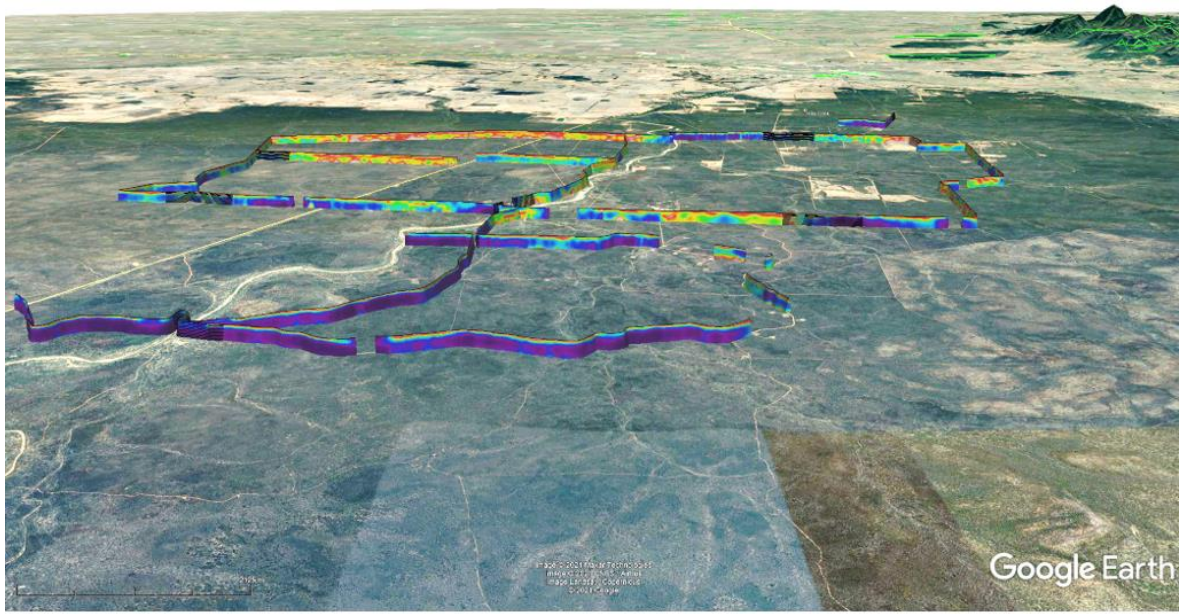
Caution: Ambiguous results, one of multiple possible model realisations and additional work may be required

AgTEM (Groundwater Imaging) (upper ~60-80 m)

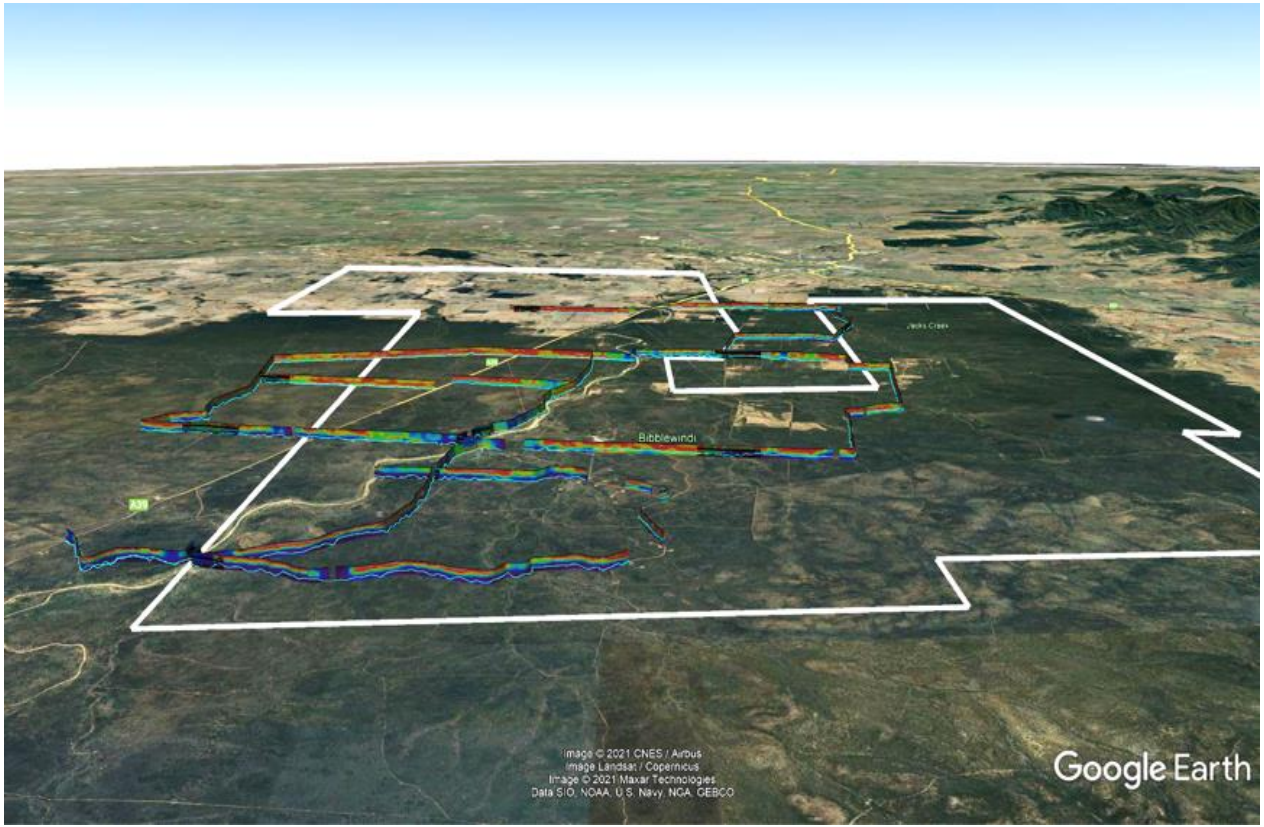
AgTEM (Groundwater Imaging, Dr. David Allen)

Modelled Resistivity on a Linear depth scale to 60m deep.

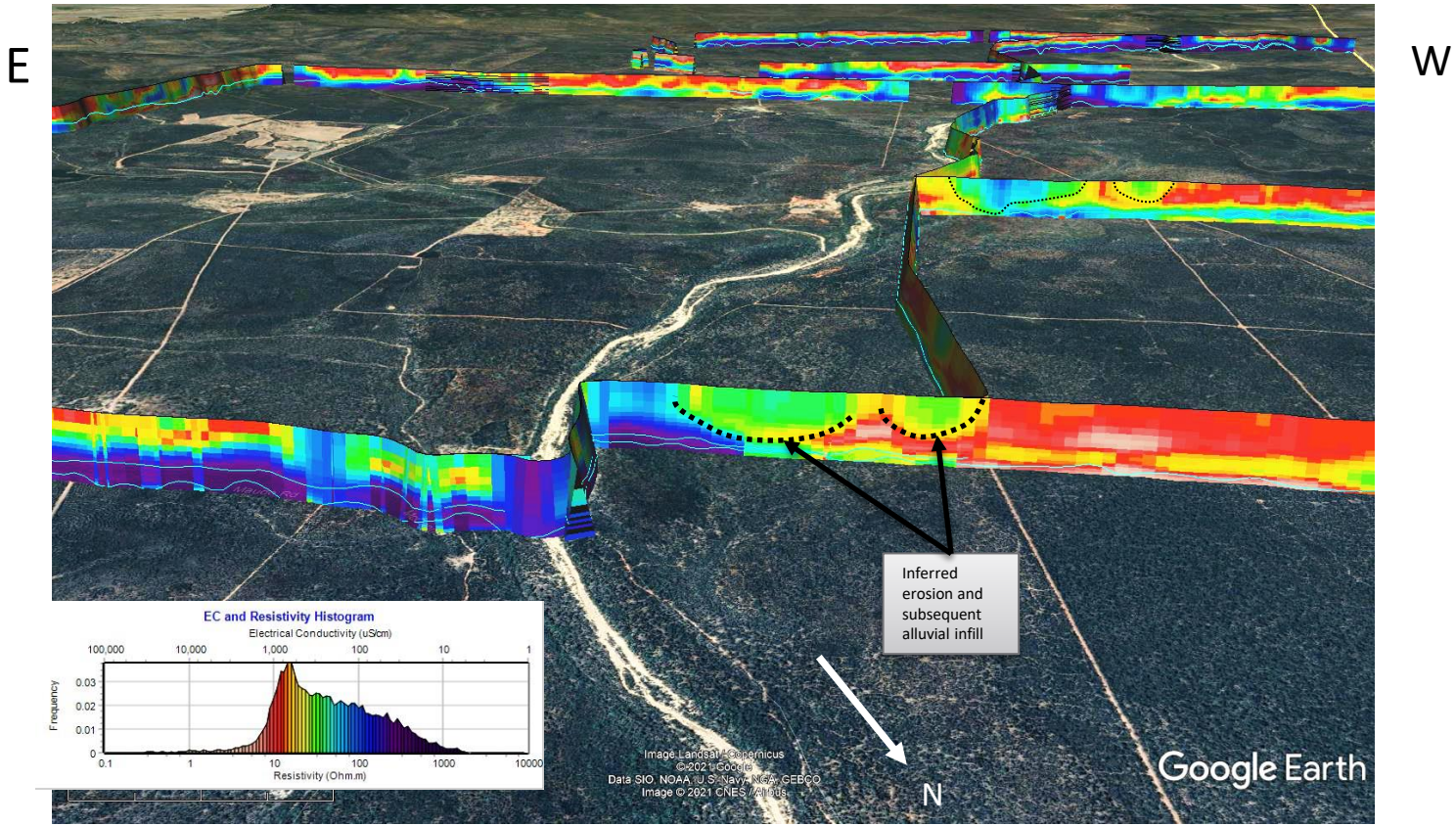


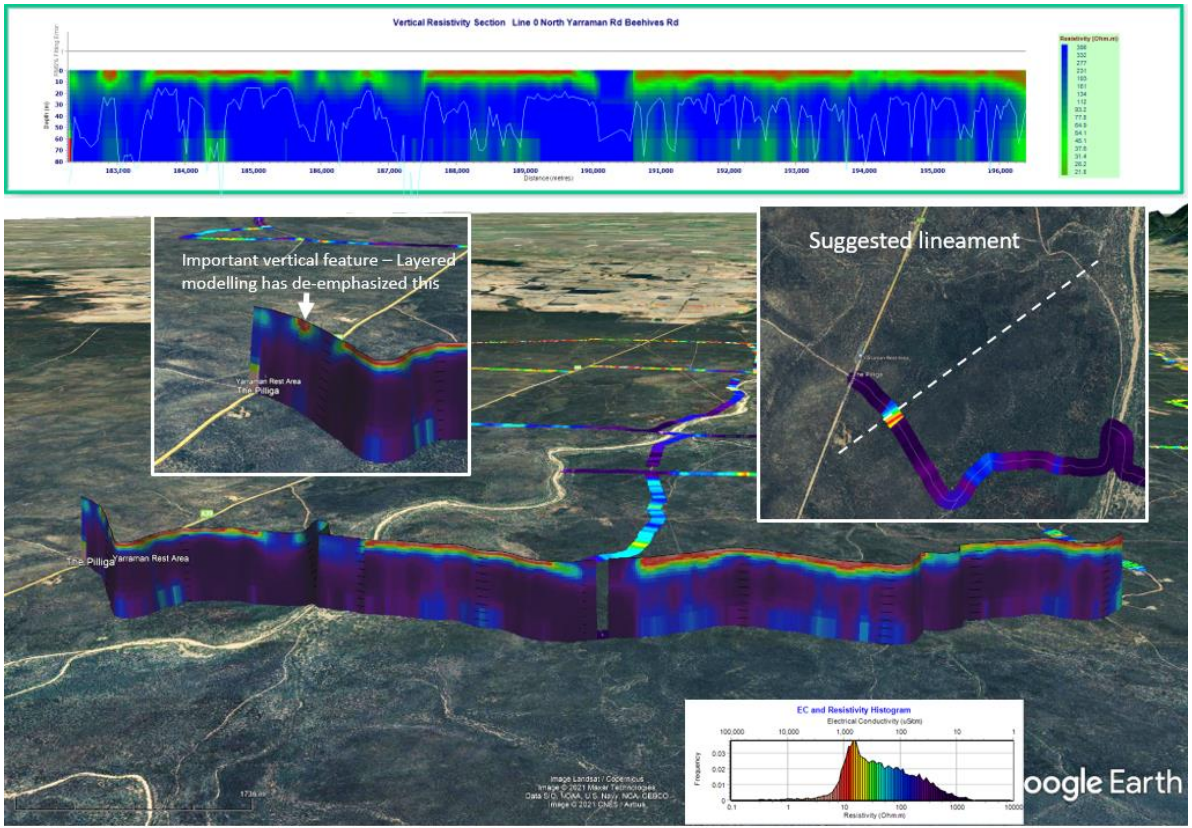


AgTEM (Groundwater Imaging, Dr. David Allen)



Pilliga AgTEM Slingram modelled resistivity – Logarithmic depth scale from 2m to 80m

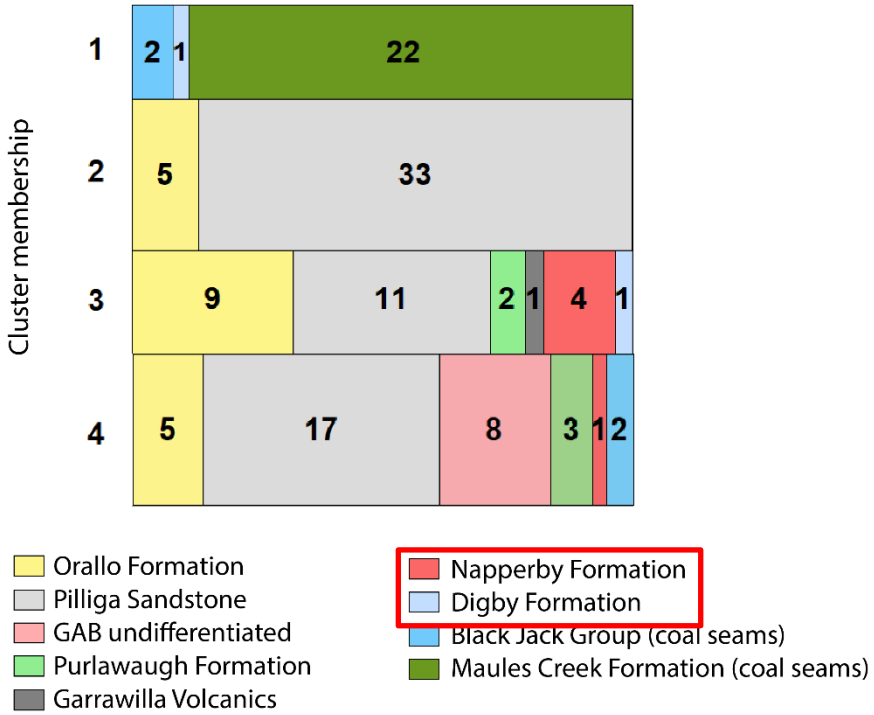


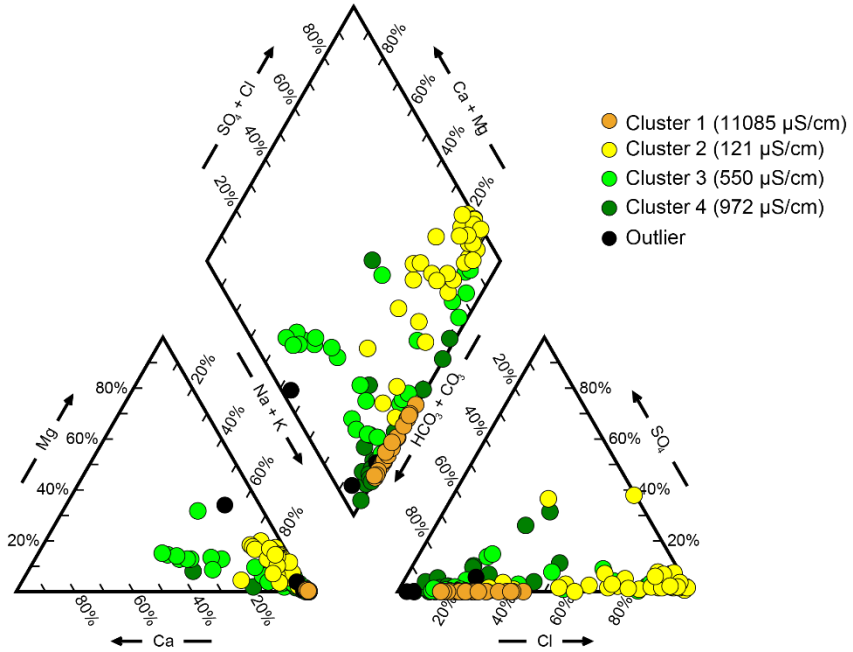

Vertical Resistivity Section Line 0 North Yarraman Rd Beehives Rd
Important vertical feature – Layered modelling has de-emphasized this
Suggested lineament
Yarraman Rest Area
Tee Pilliga
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
Frequency
Resistivity (Ohm.m)
oogle Earth

Summary of subsurface geometry and potential pathways assessment

- Seismic legacy data and re-processing of seismic data confirmed that some fractures and faults and dykes (in the north in proximity to the Nandewar Volcanic Centre) are present within the upper 400 m of the subsurface (Surat Basin);
- However, the continuity of major reflectors suggests that displacements of shallower faults appear to be small and that most deeper faults are not reactivated into Surat Basin;
- Some Gunnedah Basin formations terminate against basement ridge at FSG98-AAC (with primary CSG target Maules Creek Formation appearing to sub-crop at depth);
- TEM indicates possible presence of subsurface structure (possible anticline) in south, but on-going ambiguity with regards to the degree of possible displacement of Surat Basin strata;
- AgTEM also suggested presence of minor shallow faulting, and identifies Bohena Creek palaeochannels (possible evidence of former lineaments);

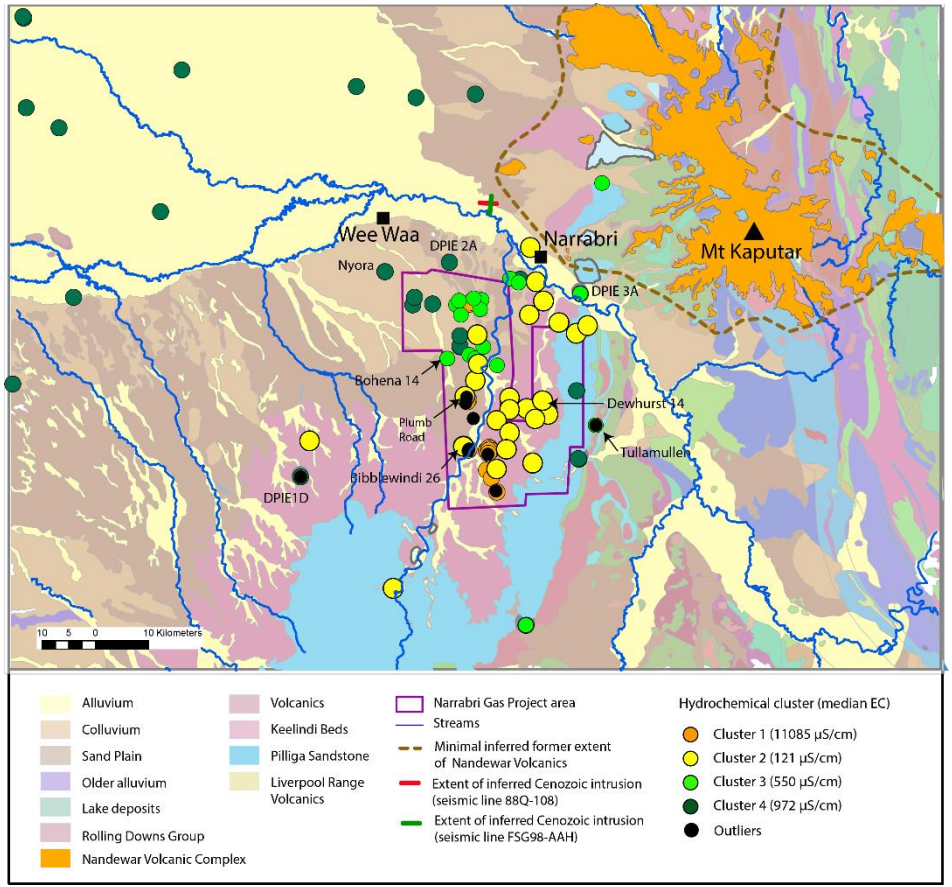
Hydrochemical patterns – multivariate statistics





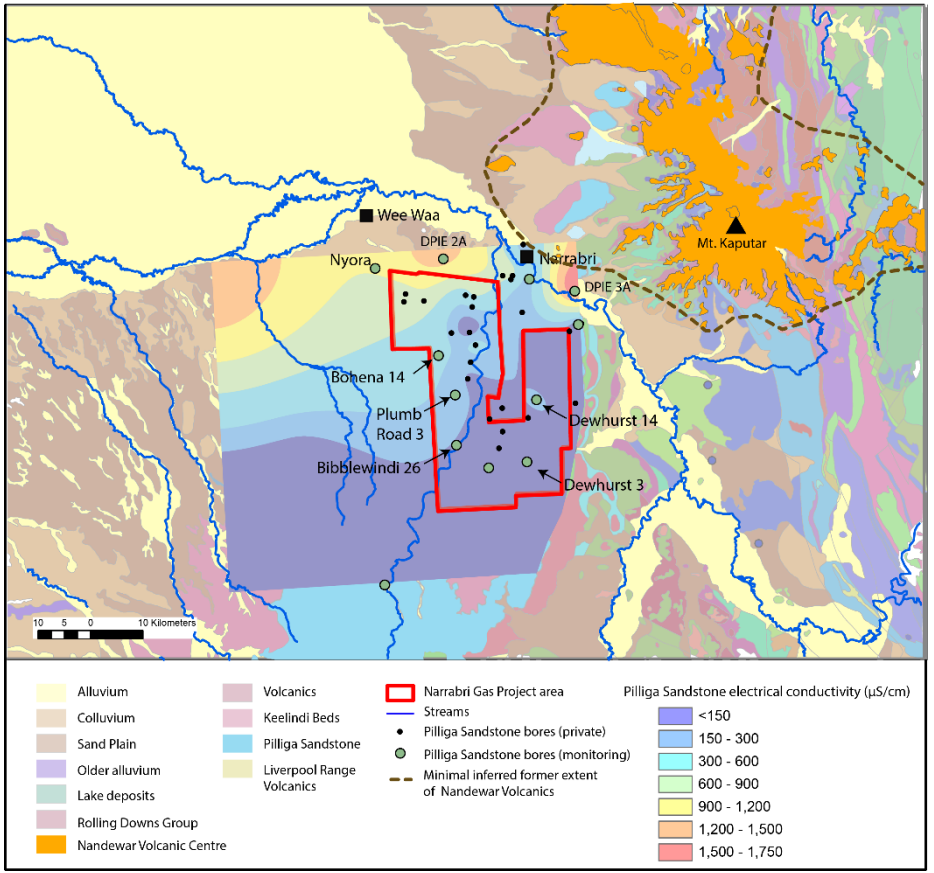
Spatial patterns

- Very fresh groundwater in Pilliga Sandstone in south, east and centre
- Very high salinity in Maules Creek Formation and other Gunnedah Basin formations
- Increase of salinity in Pilliga Sandstone towards north-west

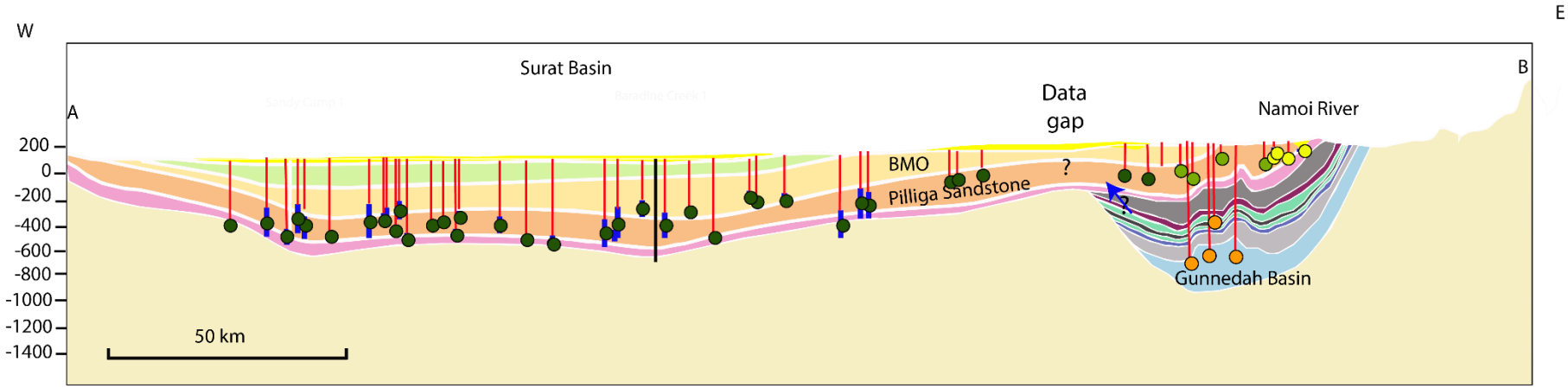


Spatial distribution of electrical conductivity in Pilliga Sandstone

- Very low salinity in the centre, south and south-east
- Increase of salinity towards north and north-west (although still relatively low salinity), starting approximately at Plumb Road
- Lack of data west of proposed CSG development area
- Interaction with over- or underlying formation likely as Pilliga Sandstone is a clean, quartzose sandstone



Hydrochemistry changes along the flow path



Surat Basin
- Alluvium
- Rolling Downs Group
- Bungil, Mooga and Orallo (BMO)
- Pilliga Sandstone
- Purlawaugh Formation (Base of Surat Basin)

Gunnedah Basin
- Napperby Formation
- Digby Formation
- Black Jack Group
- Hoskissons Coal (secondary CSG target)
- Watermark Formation
- Porcupine Formation
- Maules Creek Formation (primary CSG target)
- Pre-Surat/Pre-Gunnedah basins strata undifferentiated

- Groundwater Bore
- Groundwater Bore Screen
- Exploration/stratigraphic well

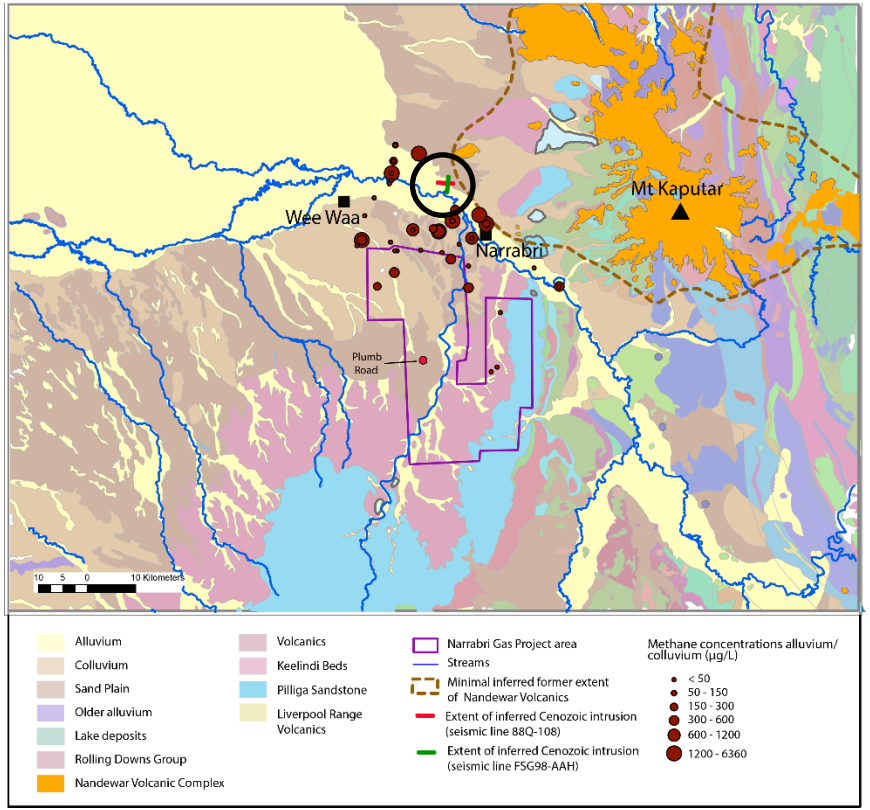
Hydrochemical cluster (median EC)
- Cluster 1 (11085 µS/cm)
- Cluster 2 (121 µS/cm)
- Cluster 3 (550 µS/cm)
- Cluster 4 (972 µS/cm)

Pilliga Sandstone is a relatively clean, quartzose sandstone

Methane concentrations - alluvium

Methane can be an indicator of connectivity.

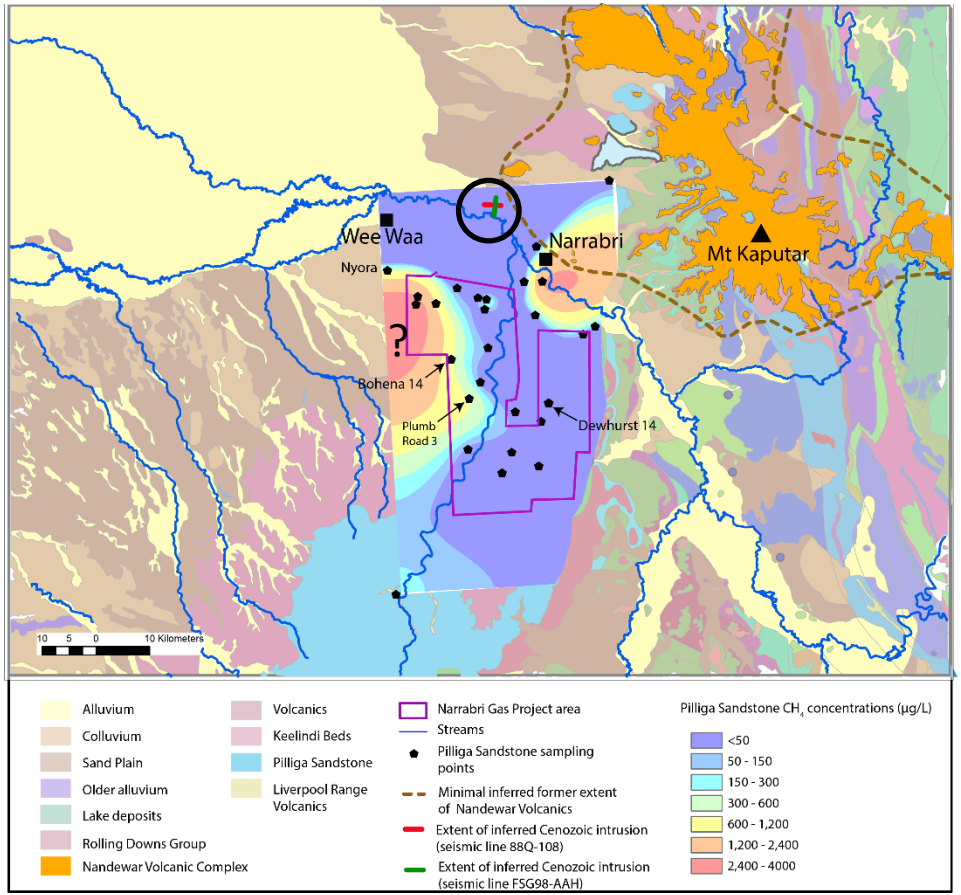
- Shallow bores (at nested bore sites) mostly with very low concentrations
- Deeper bores with elevated concentrations



Creswell (2014), Iverach et al. (2020), GISERA

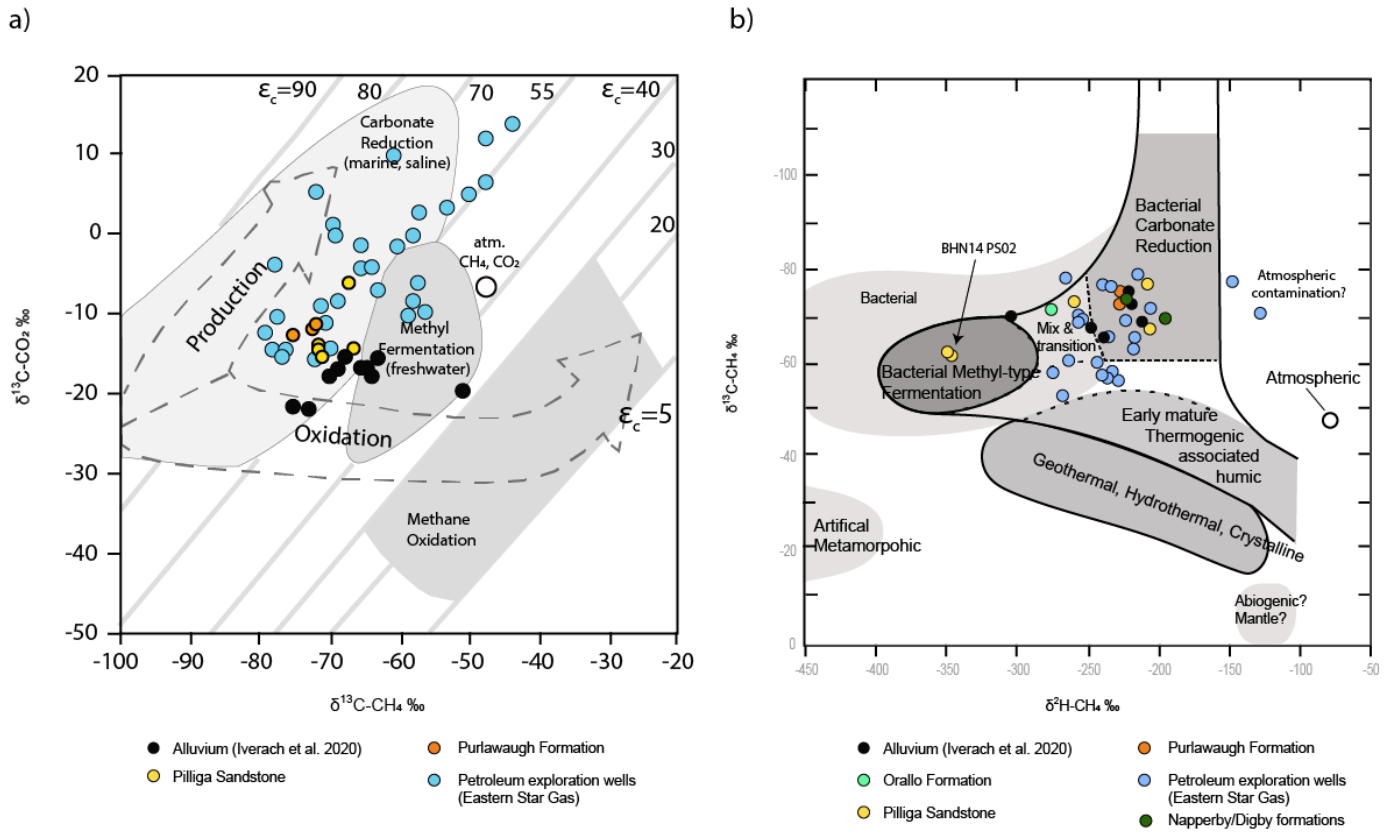
Methane concentrations in Pilliga Sandstone

- Very low methane concentrations in south and east (below reporting limit (10 µg/L), except Dewhurst 14)
- Increase of methane concentrations towards west/north west
- Increase also possibly towards north (but based on few samples only)



Creswell (2014), Iverach et al. (2020), GISERA

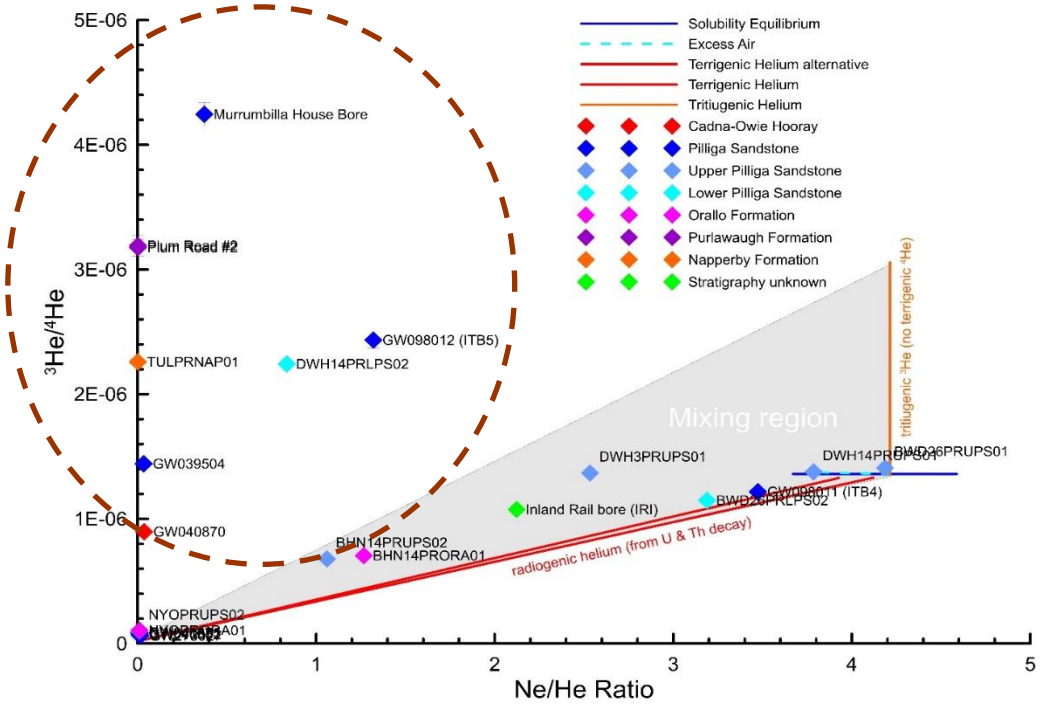
Isotopes of methane as a source indicator



Eastern Star Gas, Iverach et al. (2020), GISERA

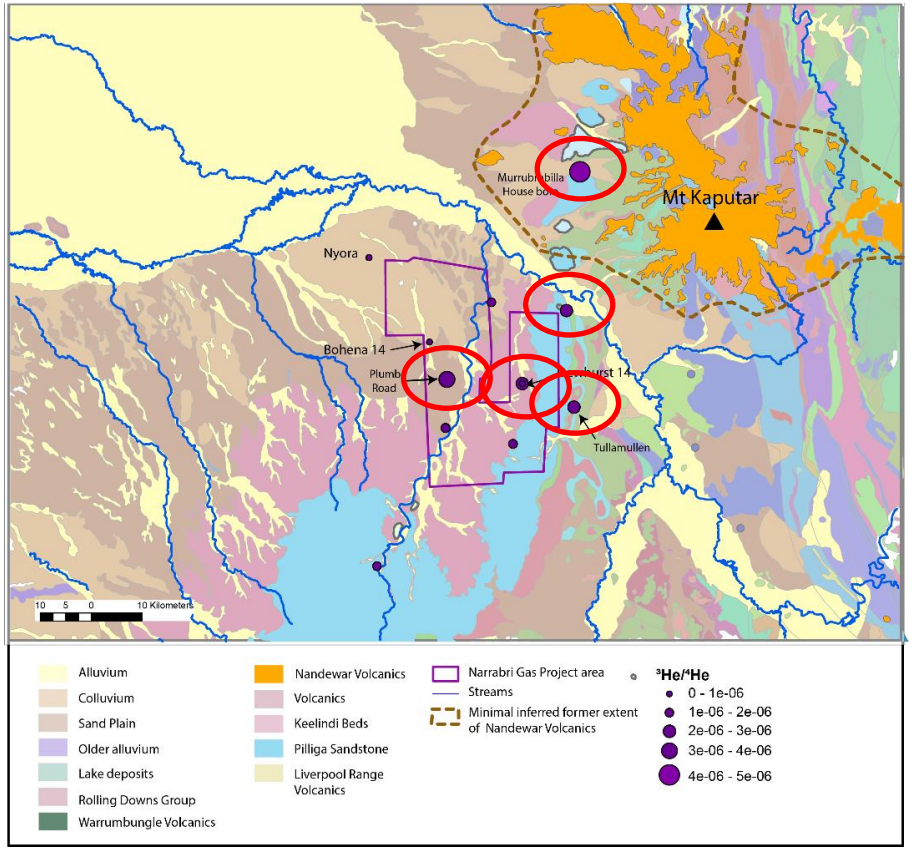
Noble gases as a source indicator

- Inert gases, mostly unaffected by chemical reactions
- Elevated $^{3}He/^{4}He$ ratios indicate possible deep mantle helium (transported by intrusions, as suggested for gas fields in North America)



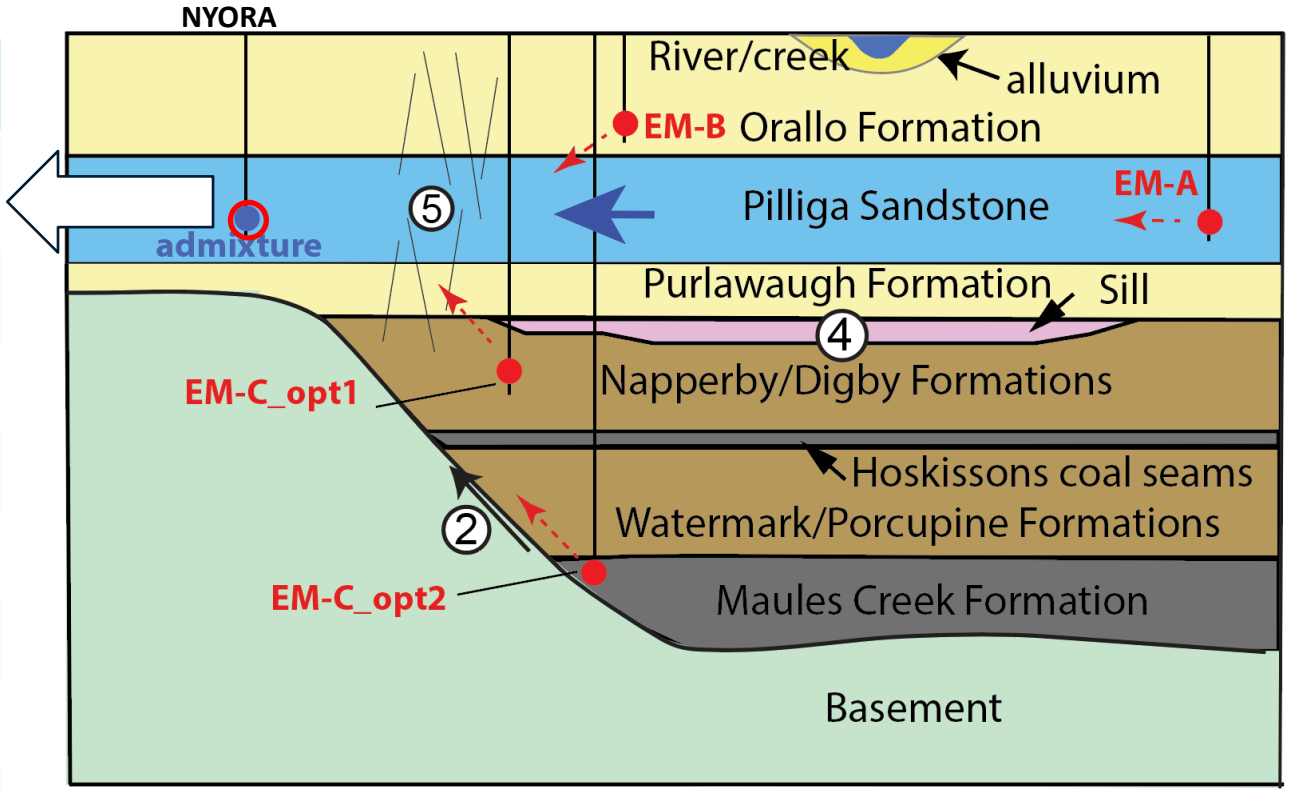
Noble gases as a source indicator

- Inert gases, mostly not affected by chemical reactions
- Elevated $^{3}He/^{4}He$ ratios indicate possible deep mantle helium (possibly related to intrusions, as suggested for gas fields in North America)
- More data fromGunnedah Basin formations would be beneficial



Hydrochemical mixing models to assess Pilliga Sandstone groundwater evolution

Admixture example NYORA station (% contribution to chemical mixing)	
End-members / Cl-Sr	% input
OPTION 1 (NYO_PS02)	
EM-A (Pilliga up-gradient)	72
EM-B (Orallo Fm overlying)	0
EM-C (Digby Fm underlying)	28
OPTION 2 (NYO_PS02)	
EM-A (Pilliga up-gradient)	92
EM-B (Orallo Fm overlying)	8
EM-C (Maules Creek)	0

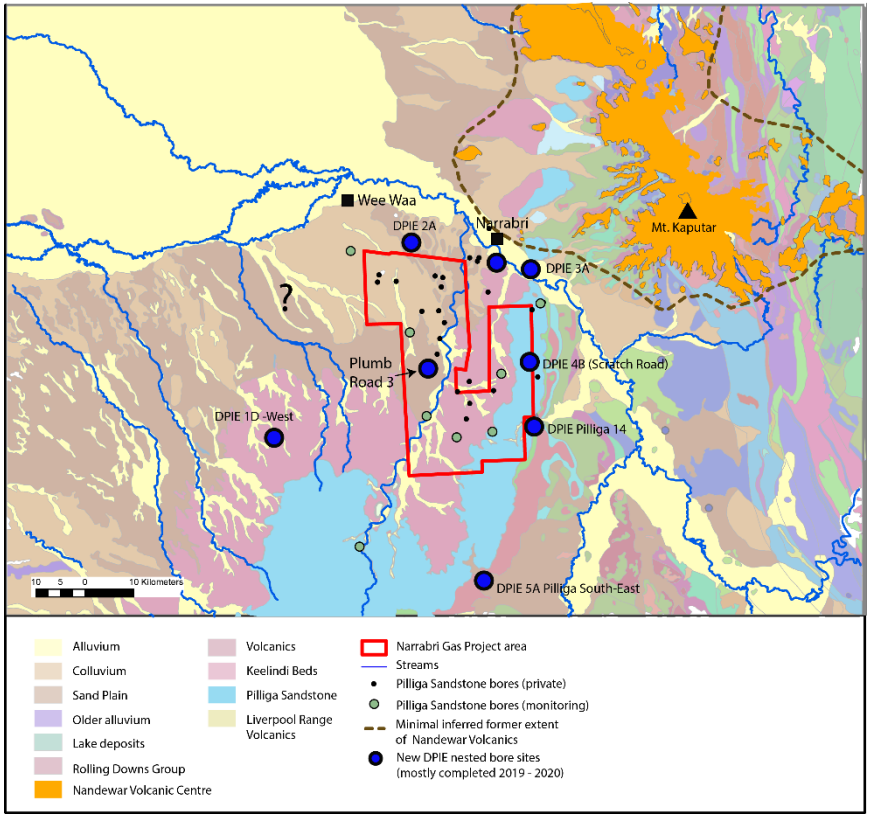


Summary

- Geophysics indicate presence of dykes, stratigraphic contacts at basin margin and some faults and fractures (with minor displacements) as potential pathways
- Hydrochemistry and tracers (e.g. methane and salinity) indicate that throughout the east and south of the proposed CSG development area, aquitards limit vertical connectivity
- Hydrochemistry and tracers indicate that some geological structures (faults, dykes or pinching out of Gunnedah Basin against basement high) likely form local connectivity pathways in north-western part of proposed development area;
- Mixing calculations suggest that increase of salinity in Pilliga Sandstone is more likely due to mixing with Digby Formation than with coal seams; however, more data of these formations would be beneficial.

Opportunities for further research

- Collect samples from new DPIE nested monitoring sites (hydrochemistry and environmental tracer suite)
- Conduct Airborne Electromagnetic (AEM) survey to obtain a more spatially continuous picture of upper 400 m of subsurface
- Re-sample selected alluvial bores with elevated methane concentrations near proposed CSG area and CSG wells for noble gases
- Analyse groundwater samples for microbiology to determine source of methane in shallower aquifers



Thank you

CSIRO Land and Water
Matthias Raiber
Senior Research Scientist

+61 07 3833 5758
Matthias.Raiber@csiro.au