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Estimating porosity and permeability in the Springbok Sandstone, Surat Basin (Qld), using new wireline log-based workflow

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1. Background

The Walloon Coal Measures of the Surat Basin host some of the most prominent coal seam gas (CSG) resources in Australia. The Walloons are directly overlain by the Springbok Sandstone, historically referred to as a regional aquifer. An increasing number of studies suggest only limited hydraulic connectivity between the formations, due to lithological heterogeneity [1, 2, 3, 4]. Accurate evaluation of the permeability, and continuity of lithological units within the Springbok, is critical in reservoir models that form the basis of reasonable aquifer protection practices and CSG impact prediction.

We present a straightforward wireline log-based workflow that allows estimations of porosities and Klinkenberg permeabilities in identified risk (permeable) zones in the vicinity of targeted coal seams. In this study, we have started to address the scientific challenge of whether the formation at a given location and depth is significantly permeable and thus forms part of an "effective" aquifer.

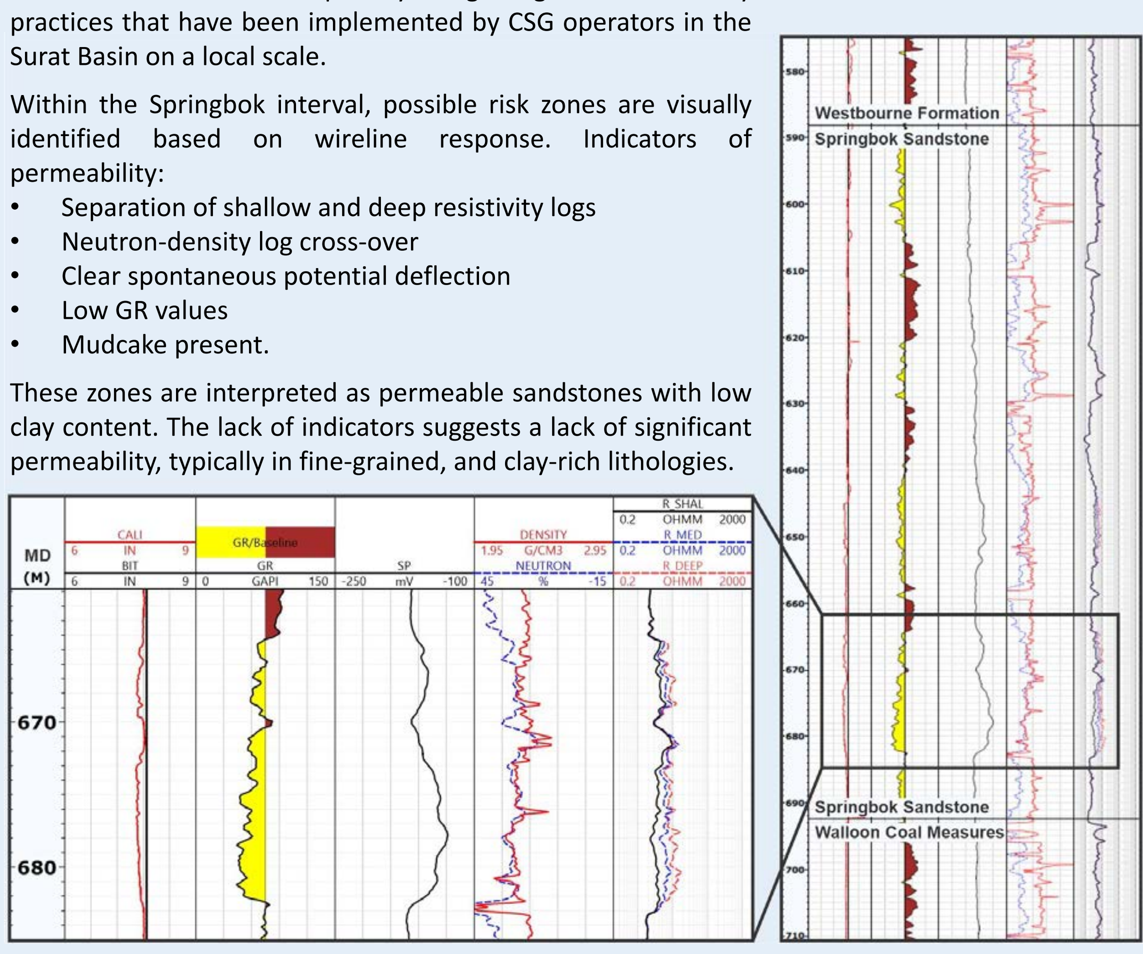
2. Workflow

This workflow was developed by integrating current industry practices that have been implemented by CSG operators in the Surat Basin on a local scale.

Within the Springbok interval, possible risk zones are visually identified based on wireline response. Indicators of permeability:

- Separation of shallow and deep resistivity logs
- Neutron-density log cross-over
- Clear spontaneous potential deflection
- Low GR values
- Mudcake present.

These zones are interpreted as permeable sandstones with low clay content. The lack of indicators suggests a lack of significant permeability, typically in fine-grained, and clay-rich lithologies.



Porosity and permeability values were estimated only for the identified permeable zones where resistivity separation and at least one more indicator were present. Empirical equations by Gaede et al. (2020) [4], developed using Springbok Sandstone core plug data, were used:

Porosity:

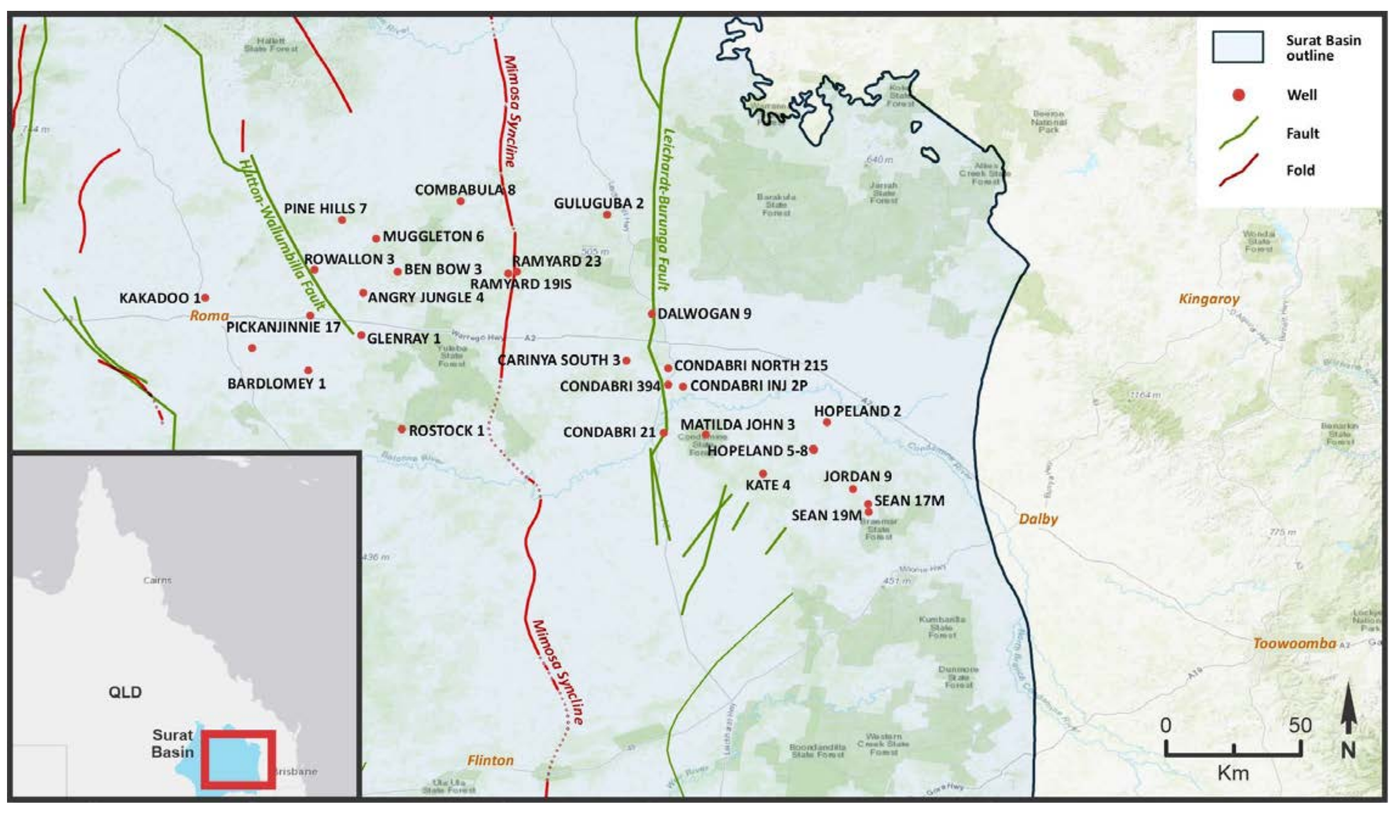
$$\phi_D = \frac{\rho_{log} - \rho_{ma}}{\rho_{fl} - \rho_{ma}}$$

Klinkenberg gas permeability (mD):

$$k_{Klink} = 0.0014e^{(0.4169\phi D\times 100)}$$

ρ_{log} – density log values [g/cm3] | ρ_{fl} – pore fluid density (1 g/cm3 assumed) | ρ_{ma} – matrix density (2.62 g/cm3 assumed)

Obtained permeability estimates were plotted against depth, and N/G for the Springbok interval was calculated. For the purposes of this study, the formation was considered 'permeable' when k_{Klink} was >1 mD. Note that permeabilities to brine would be much lower and therefore, the 1 mD value is specifically not proposed as any practical cut-off for aquifer definition purposes.

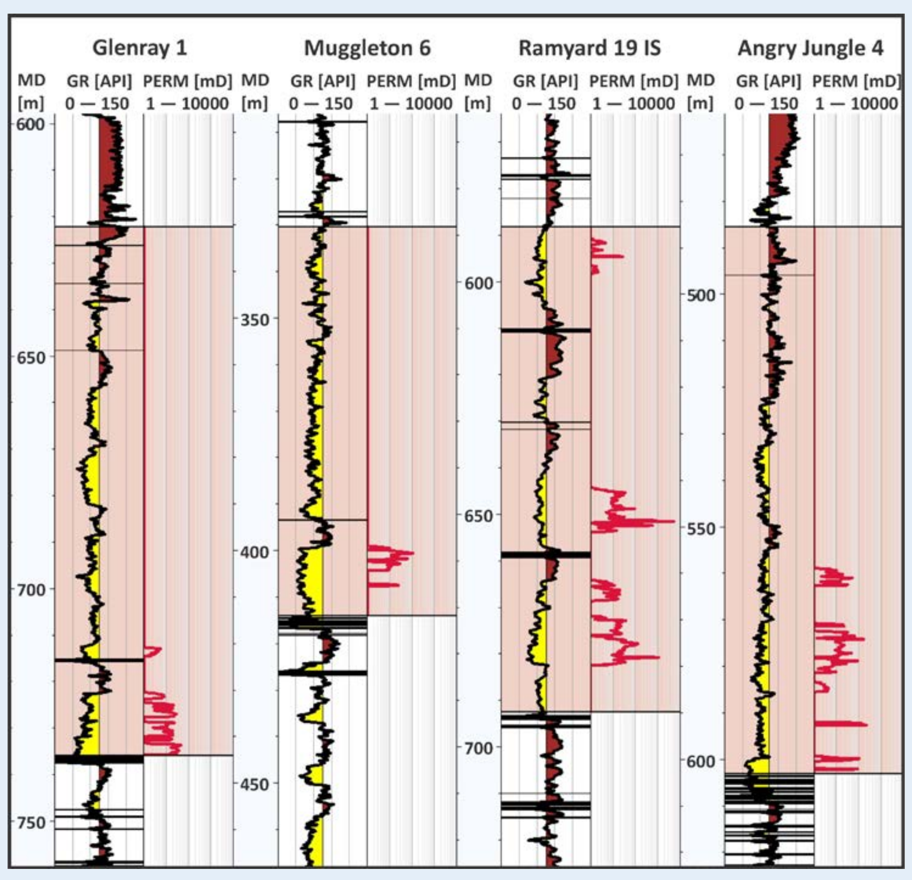


3. Results

The aquifer properties were evaluated from high-quality wireline datasets in 31 wells across the NE Surat Basin. A typical profile shows 2.3-28.5m of permeable formation in the lower third of the Springbok interval, consisting of multiple individual permeable zones 0.1 to 9.5 m thick, separated by nonpermeable siltstone or mudstone horizons. The topmost coal seam of the Walloons is not always in direct contact with a permeable (>1 mD) sandstone within the Springbok. Sometimes, a minor permeable zone is present at the top of the interval.

- N/G for the formation: 1-69%, avg 25%
- Avg permeabilities per well: 0.03-117 mD, avg 22.1 mD
- P10, P50 and P90 (averaged for all analysed wells): 39.9 mD, 4 mD and 0 mD, respectively.

Wells within ~5 km of large fault zones such as the Burunga-Leichardt and Hutton-Wallumbilla faults, tend to have lower average permeabilities and N/G.



Examples of a typical permeability profile in the Springbok Sandstone interval (in pink). Coal beds are shown in black. GR, gamma ray; MD, measured depth; PERM, permeability.

4. Key Conclusions

- At present, CSG companies are required to isolate the Springbok Sandstone 'aquifer' from the Walloons in production wells. Our results show that the hydraulic connectivity within the Springbok and with the underlying coal measures is likely to be relatively limited. This is supported by recent drill core data and numerical modelling [1, 4].
- The proportion of clean sandstone within the Springbok is much lower than previously thought, and the formation is lithologically heterogeneous. Fine-grained, non-permeable lithologies are significantly more continuous, and likely more connected than channel sandstone bodies. Contrary to the formations' names, the Walloon Coal Measures are mostly not coal and the Springbok Sandstone is mostly not sandstone.
- Where permeability *is* indicated, the estimated values are orders of magnitude lower than those typical of "regional aquifers" (e.g., Precipice Sandstone).
- Given these results, the Springbok Sandstone displays characteristics of what might be described qualitatively as an interbedded aquitard.
- The future scope of this research will include broader basin coverage, calibrating the permeability estimates with core data, calculating brine permeabilities, and refining the formula. A better understanding of the degree and distribution of permeability in the formation may result in changes to the way it is modelled in the future.

Complexity and challenge in classification are increasingly being recognised [1, 2, 4]. For now, the "Springbok Sandstone" remains modelled as an aquifer in QLD Government groundwater flow models, which estimate impact of CSG production on groundwater resources. If there were an overestimation of the connectivity between the gas-producing Walloon Coal Measures and permeable zones in the Springbok Sandstones, this might have a significant impact on drawdown *predictions* for groundwater users, as well as for the assessment of the State's gas resources [1, 4, 5]. This research study aims to help improve the science underlying groundwater protection practices and optimise recovery of the State's gas resources.

5. Declaration of funding

This work was funded by the Centre for Natural Gas at The University of Queensland and its industry partners: Arrow Energy, Australia Pacific LNG and Santos. Energ*i* Simulation provided partial funding. This research was conducted in accordance with UQ policies and procedures relating to research conduct and integrity.

6. References

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