Reinterpretation of Wire-line Log Data in the Eastern Galilee Basin, Queensland: Stratigraphical and Hydrogeological Implications.

James Hansen*
Water Planning and Coastal Sciences, Science Delivery,
Department of Science, Information Technology and Innovation
Ecosciences Precinct, 41 Boggo Road,
Dutton Park, Queensland 4102
jim.hansen@dsiti.qld.gov.au

Alison Uroda
Water Planning and Coastal Sciences, Science Delivery,
Department of Science, Information Technology and Innovation
Ecosciences Precinct, 41 Boggo Road,
Dutton Park, Queensland 4102
alison.uroda@dsiti.qld.gov.au

SUMMARY

The Bureau of Meteorology (BoM) to meet the role of compiling and delivering Australia's water information under the conditions set out in the Federal Water Act 2007 developed the Australian Water Resource Information System (AWRIS) and the National Groundwater Information System (NGIS) to support AWRIS. Functionality of the NGIS relied on compiling state and territory groundwater databases. Completeness of the data contained in these databases was critical in facilitating data migration to the NGIS and groundwater bores in the Galilee Basin were identified as a priority target for addressing data gaps.

Published wire-line log interpretation information was used to create and map structure surfaces for the Galilee Basin. These structure surfaces were used to create a 3D stratigraphic framework to visualise the basin architecture. Assessment of the 3D stratigraphic framework, structure surfaces and wire-line log interpretations identified numerous inconsistencies with the established basin stratigraphy. This is partially attributed to the large number of interpretation sources, exploration relevance and an incomplete understanding of facies variability. Additional areas of concern that were also identified included inconsistent surface geology mapping and a poor understanding of regional lineaments.

To address these inconsistencies systematic reinterpretation of the published wire-line log data was undertaken to validate or reassign inconsistent existing stratigraphic interpretations in the Galilee Basin. The highest percentage of inconsistent interpretations was concentrated in the eastern Galilee Basin and this area was chosen as the priority focus area. Reinterpretation relied on utilising a suite of wire-line log data from multiple data sources that included stratigraphic drill holes, coal seam gas (CSG), oil and gas exploration drill holes and groundwater bores. The availability of gamma wire-line log data was the minimum data requirement.

Reinterpretation of the wireline log data has resulted in producing revised stratigraphic formation data for the tops of the Moolayember Formation/Base Eromanga Basin, Rewan Group, Dunda beds, Clematis Group, Bandanna Formation/Betts Creek beds, Colinlea Sandstone and Joe Joe Group. This revision has shifted some of these formation tops vertically by up to 300m in some instances leading to significant modification of some structure contour surfaces and the lateral extents of some formations. The Clematis Group, Dunda beds and Rewan Group have undergone the greatest level of modification.

Uncertainty over the internal architecture of the Galilee Basin has significant implications for understanding the hydrogeology of aquifer systems and springs in the basin. Reinterpretation by a single operator has assisted in removing some of this uncertainty and provided a consistent dataset of interpretations.

Key words: Galilee Basin, wireline log data, stratigraphy, hydrogeology.

INTRODUCTION

The Millennium drought and increased demand for water throughout Australia placed the water supply infrastructure of the day under considerable stress. In response the Bureau of Meteorology (BoM) was given the role of compiling and delivering Australia's water information under the conditions set out in the Federal Water Act 2007.

To achieve this the BoM developed the Australian Water Resource Information System (AWRIS) and the National Groundwater Information System (NGIS) to support AWRIS. Functionality of the NGIS relied on compiling and updating state and territory groundwater databases. Completeness of the data contained in these databases was critical in facilitating data migration to the NGIS and groundwater bores in the Galilee Basin (Figure 1) were identified as a priority target for addressing data gaps as part of the Hydrogeologic Unit Mapping Project.

A 3D stratigraphic framework was created using published wire-line log interpretation information to map structure surfaces for the Galilee Basin. Assessment of the 3D stratigraphic framework, structure surfaces and wire-line log interpretations identified numerous inconsistencies with the established basin stratigraphy (Figure 2) in the eastern Galilee Basin (McKellar and Henderson, 2013), particularly for some recent exploration wells. This is partially attributed to the large number of interpretation sources, exploration relevance and an incomplete understanding of facies variability within the Galilee Basin. Additional areas of concern were also identified in the eastern Galilee Basin that include inconsistent surface mapping of geological formation boundaries and the eastern extent of the basin margin, and a poor understanding of regional lineaments.

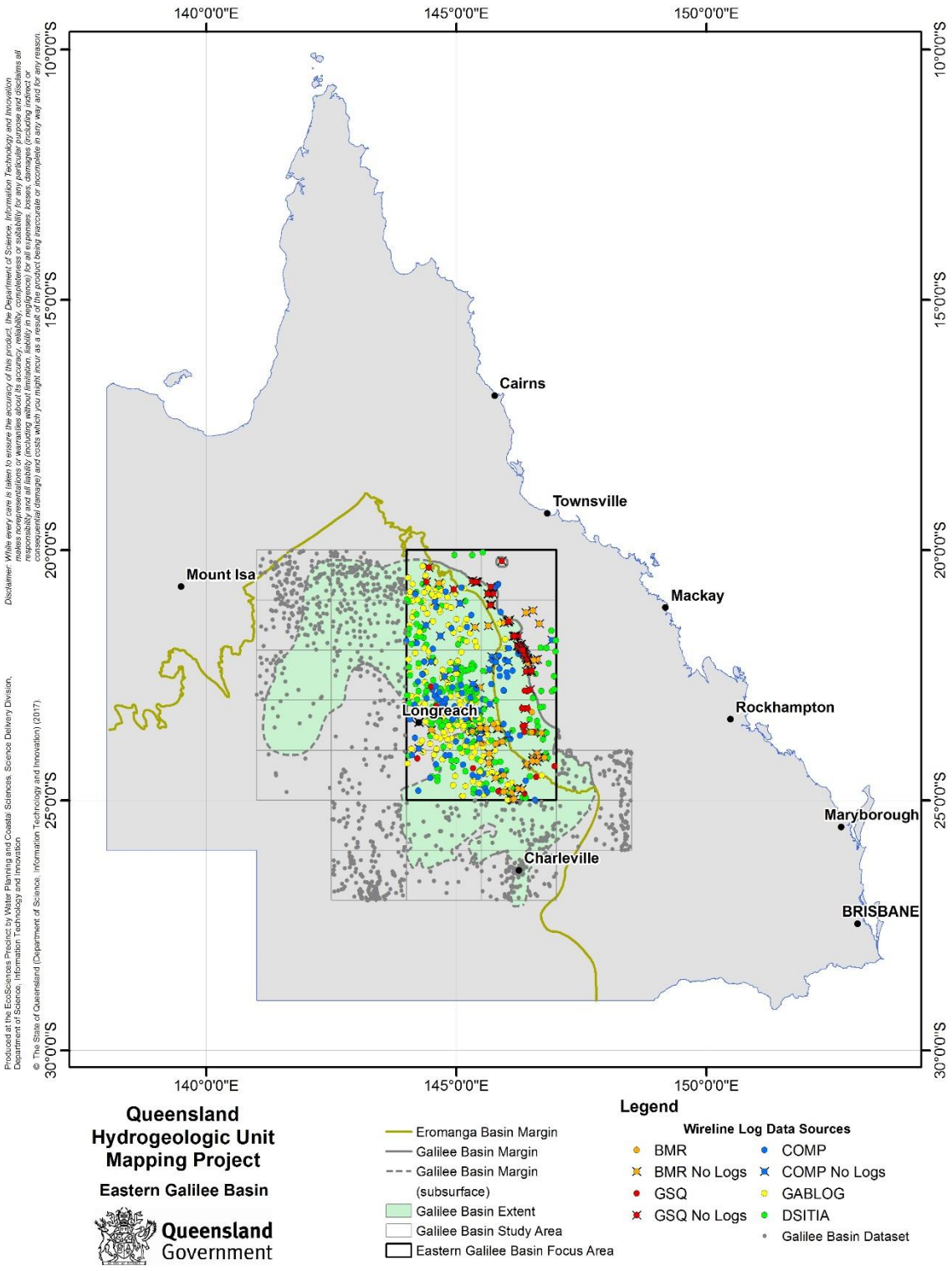

Figure 1: Extent of the Galilee Basin and overlying Eromanga Basin (DNRM, 2012), location of the Galilee Basin Hydrogeologic Unit Mapping Project area and Galilee Basin wire-line log dataset, location of the eastern Galilee Basin focus area and location of eastern Galilee Basin wire-line log data points displaying data sources.

Systematic analysis of the published wire-line log data has been undertaken to validate or reassign inconsistent existing stratigraphic interpretations in the eastern Galilee Basin. The focus area of this work in the eastern Galilee Basin covers the Hughenden, Charters Towers, Tangorin, Buchanan, Muttaburra, Galilee, Longreach, Jericho, Blackall and Tambo 1:250,000 scale map sheet areas (Figure 1). The ultimate outcome of this work is to reinterpret wire-line log data across the full extent of the Galilee Basin with a view to developing a revised stratigraphic framework and hydrogeological conceptualisation for the basin.

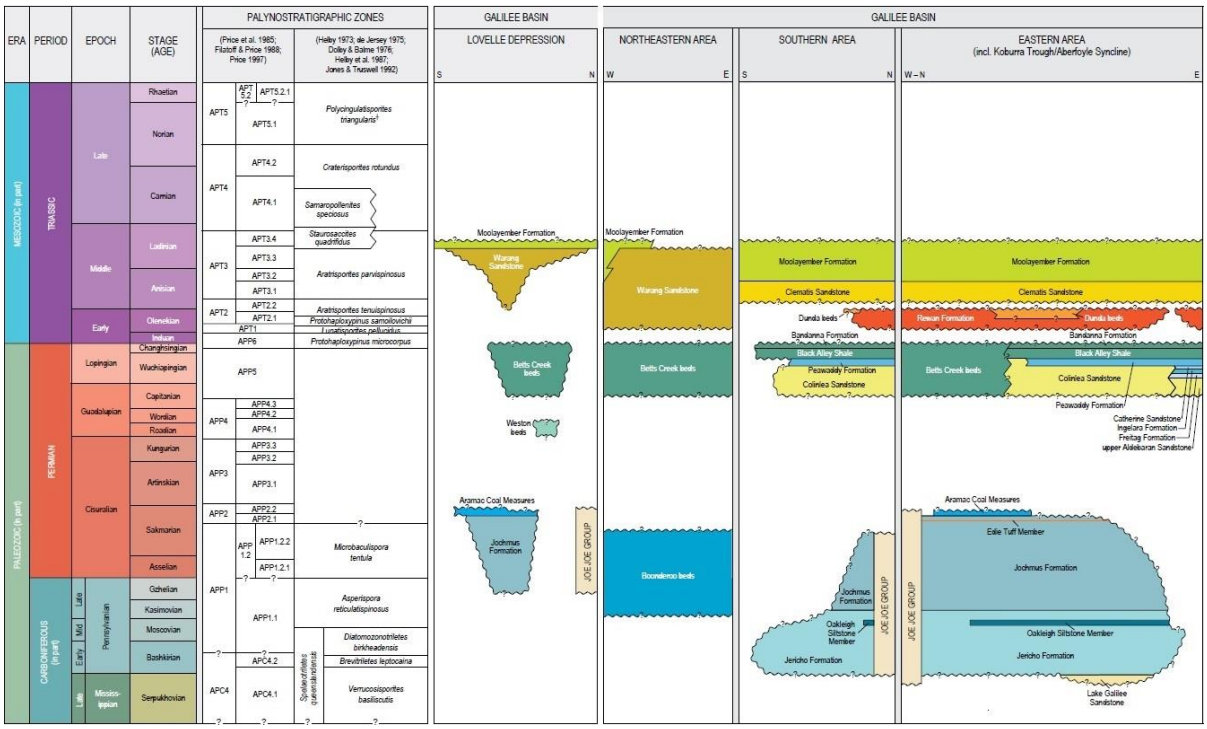

Figure 2: Established stratigraphic and palynostratigraphic relationships of the Galilee Basin (McKellar and Henderson, 2013).

METHOD

All available wire-line log data was collated from multiple sources across the entire surface and subsurface extent of the Galilee Basin (Figure 1). These data sources were;

- Bureau of Mineral Resources (BMR) stratigraphic drill holes,
- Geological Survey of Queensland (GSQ) stratigraphic drill holes,
- GSQ coal exploration drill holes,
- Oil and gas exploration drill holes,
- CSG exploration drill hole,
- Groundwater bores;
  - GABLOG: Geoscience Australia Great Artesian Basin wire-line logged borehole database,
  - DSITI Great Artesian Basin Sustainability Initiative (GABSI) wire-line logging (unpublished data).

An initial review of the published wire-line log interpretation information identified the following suit of wire-line log data as being most desired for undertaking systematic reinterpretation. These were, gamma and neutron, density and 3-5' compensated sonic, spontaneous potential, point resistivity and/or conductivity, and shallow or deep laterolog wire-line log data. Due to a combination of factors primarily relating to the age of the drill hole, the availability of relevant wire-line logging technologies and drill hole data source, not all drill holes have this suite of wire-line logs available for assessment. The availability of gamma wire-line log data was set as the minimum data requirement. Digital data in the form of LAS files or text files was the preferred data medium for assessment. Hard copy wire-line log data in the form of scanned composite logs was also utilised if this was the only available data.

Composite logs for all drill holes selected for assessment were created using the EarthFX ViewLog LS software package. The composite logs displayed the available wire-line log data, lithology descriptions or the location of Permian coal seams, stratigraphic data, aquifer details and casing details. Reinterpretation was performed using direct drill hole to drill hole correlation. Formation tops interpreted by the GSQ (DEEDI, 2011) on a selection of stratigraphic and exploration drill holes formed the control dataset from which all reinterpretations were correlated. The GSQ coal exploration drill holes were also used to assist with performing reinterpretations and followed the method of assigning the A and B seams to the Bandanna Formation, and assigning the C, D, E and F seams to the Colinlea Sandstone (DEEDI, 2011; Phillips et al., 2017a). The validity of these reference stratigraphic interpretations were also reassessed utilising the increased dataset created by more recent exploration drilling programs.

As part of this investigation the surface geology of the eastern Galilee Basin was also assessed to validate mapped formation boundaries and the eastern margin of the Galilee Basin. This assessment utilised a combination of regional scale geophysics, satellite imagery, current surface geology mapping by the GSQ and coal exploration companies, and drill hole data. The focus of this work was not to perform detailed surface remapping of the eastern Galilee Basin but to provide a synthesis of available surface geology information to create a consistent regional solid geology based on the established basin stratigraphy to assist in providing more reliable surface control.

SOLID GEOLOGY REVISION

Validating and refining the geology in the eastern Galilee Basin was essential in providing more reliable surface stratigraphic control for reinterpreting the wire-line log data, mapping of updated formation extents and developing structure contour surface. The surface geology mapping in the eastern Galilee Basin is complicated by the presence of extensive Quaternary and Tertiary cover sediments and deep weathering profiles that mask the original character and structure of the older sediments.

The most complete regional surface geology mapping for the eastern Galilee Basin is the GSQ Queensland Geology 2012 Edition (DNRM, 2012). This was compared with older GSQ 250K sheet area mapping, more recent GSQ 100K mapping, and publically available local scale coal exploration company mapping across the China Stone (Hansen Bailey PTY LTD, 2015), Carmichael (Adani Mining PTY LTD, 2012), Kevin's Corner (Hancock Galilee PTY LTD, 2011), Alpha Coal (Hancock Prospecting PTY LTD, 2010) and Galilee Coal (Waratah Coal PTY LTD, 2011) mine and exploration lease areas.

Examination of the more recent GSQ 100K scale mapping for the entire Buchanan and eastern thirds of the Galilee and Jericho 250K sheet areas combined with drill hole data revealed that mapping of the eastern margin of the Galilee Basin required significant modification. Based on this more recent mapping data when combined with regional geophysical datasets, the eastern margin of the Galilee Basin was moved between approximately 5 and 30km to the east of the previously mapped margin in an area extending north from Alpha (Figure 3). Minor modification to the basin margin was also made in the area extending southeast from Pentland.

In the absence of field mapping for this investigation, the existing surface geology mapping of outcrop areas was used as the foundation for solid geology mapping of areas where there is extensive Cainozoic cover. The solid geology underlying the Cainozoic cover was mapped using information from drill holes. When combined with the existing surface geology this created revised solid geology formation boundaries (Figure 3). The key solid geology formation boundaries that were created were for the top of the Moolayember Formation/Base Eromanga Basin, Clematis Group, Dunda beds, Rewan Group, Bandanna Formation/Betts Creek beds, Colinlea Sandstone and Joe Joe Group. Creation of the solid geology formation boundaries has assisted with removing some of the inconsistencies identified in the earlier phase of this work.

The presence and role of structural features in the eastern Galilee Basin is problematic. Local scale coal exploration company mapping has identified some significant structural features. Typically, these structural features that have been interpreted primarily from seismic data have only been mapped at a local scale and the extent of these features beyond lease boundaries is not clearly understood. The role these know structural features on influencing the local hydrogeology and groundwater flow systems is also currently not clearly understood.

Due to a number of factors, it was beyond the scope of this study to assess seismic data in relation to defining structural features. Several regional linear features, commonly marked by down-dip, lateral offsetting of stratigraphic formations were identified (Figure 3). The relationship of these regional linear features to identified regional structural features along with their potential influence on the stratigraphy and hydrogeology of the eastern Galilee Basin is currently not clear.

WIRE-LINE LOG REINTERPRETATION

Reinterpretation of wire-line log data in the eastern Galilee Basin has assessed 585 stratigraphic and exploration drill holes and groundwater bores of which 224 intersect sediments of the Galilee Basin. While the majority of wire-line log interpretations did not require any or only minor revision, a significant number did require revision to address inconsistencies with the established basin stratigraphy (McKellar and Henderson, 2013). These inconsistencies can be attributed to multiple interpretation sources, exploration relevance and an incomplete understanding of facies variability.

Multiple exploration leases holders have operated in the eastern Galilee Basin since the turn of the 20th century. While these operators have all subscribed to the establish basin stratigraphy (Figure 2) as defined by the Geological Survey of Queensland, the widespread and often isolated exploration drilling locations has contributed to a number of inconsistencies observed in the some of the wire-line log interpretations. The issue of these inconsistencies is compounded by the use of multiple geophysical wire-line logging contractors that bring their own subtle variations in interpreting the data collected for an individual drill hole.

Exploration relevance is a major factor in generating inconsistent interpretations. With the exception of exploration and stratigraphic holes drilled during the initial greenfields exploration phase in the Galilee Basin, more recent drilling has targeted coal seams in the Bandanna Formation, Colinlea Sandstone, Betts Creek beds and Aramac Coal Measures. Typically data collection for the interval containing these formations has been thorough and includes a comprehensive suite of wire-line logs. For the stratigraphic intervals above and below these coal bearing strata, data collection has not been as thorough for some of these more recent exploration drill holes. With regard to wire-line log data, gamma logs are often the only wire-line log data available and in some rare instances no wire-line logs were run.

Another issue that relates to exploration relevance is the level of quality assurance/quality control (QA/QC) that has been applied to these non-coal bearing intervals for exploration drill holes with less comprehensive data collection regimes. The lack of comprehensive data does not facilitate the application of greater QA/QC protocols when defining downhole stratigraphy. The Triassic successions of the Galilee Basin including the overlying Eromanga Basin are most impacted by poor QA/QC.

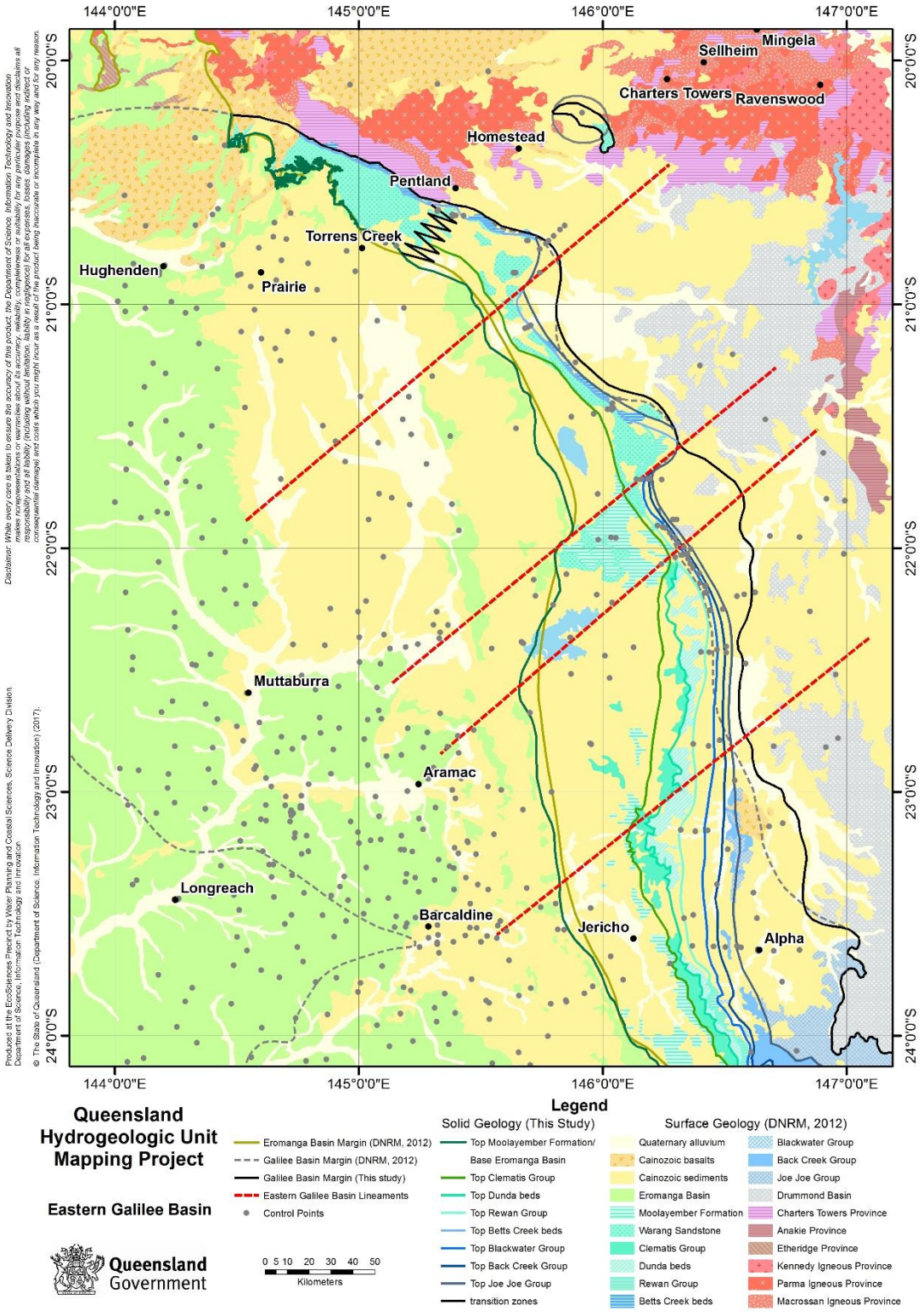

Figure 3: Surface geology of the eastern Galilee Basin focus area and Galilee Basin margin (DNRM, 2012), modified Galilee Basin margin boundary, modified solid geology formation boundaries, and regional lineaments.

The widespread and isolated distribution of drill holes in the Galilee Basin places limitations on understanding facies variation. All of the factors outlined in the preceding paragraphs place a further limitation on defining facies variation particularly for the non-coal bearing intervals. Defining facies variations has significant implications for defining the downhole stratigraphy and ultimately establishing formation extents. Understanding facies variation is key in resolving relationships within the Triassic successions of the Galilee Basin, specifically equating facies variability in the Warang Sandstone to the Moolayember Formation, Rewan Group, Dunda beds and Clematis Group.

An example of the issues encountered during the reinterpretation process can be best displayed in CSG exploration drill hole QER Solomon 1-1A (Figure 4). Existing formation top interpretations in QER Solomon 1-1A (Bayrak, 2010) were correlated with FPN Koburra 1 and AAE Towerhill 1 (DEEDI, 2011). This hole displays the broadest range of revisions and these are:

1. Revised base of Eromanga Basin pick – approximately 120m lower that previously interpretation,
2. Revised Eromanga Basin stratigraphic formation picks;
3. Revised top of Clematis Group pick – approximately 50m lower than previous interpretation,
4. Interpretation of Dunda beds – previously included as part of the Rewan Group,
5. Revised top of Rewan Group pick – approximately 100m lower than previous interpretation,
6. Revised Bandanna Formation/Betts Creek beds pick,
7. Subdivision of Betts Creek beds into Bandanna Formation and Colinlea Sandstone,
8. Revised top of Jochmus Formation pick – approximately 25m lower than previous interpretation.

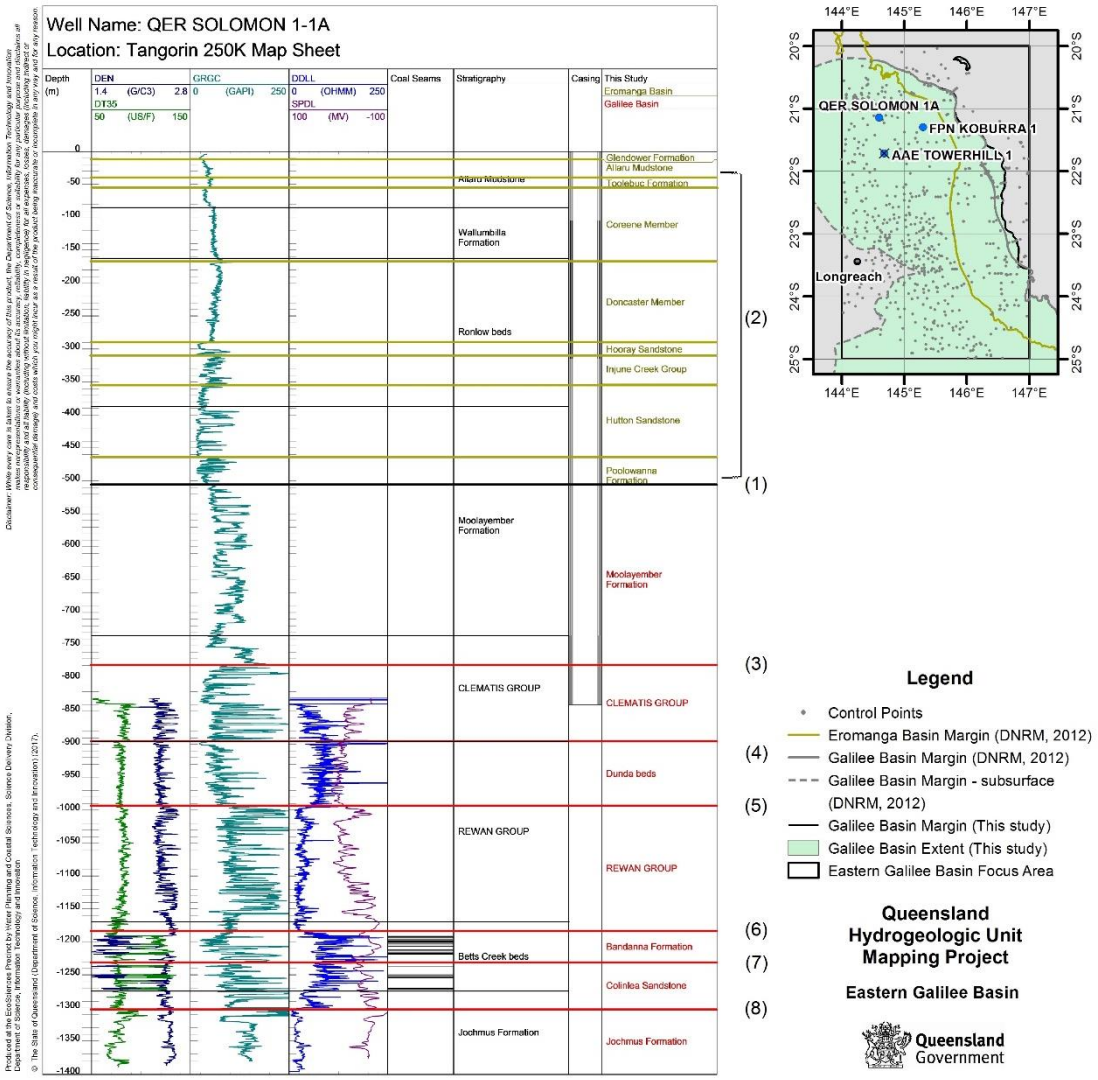

Figure 4: Example composite log for QER Solomon 1-1A displaying the original (Bayrak, 2010) and revised stratigraphy illustrating the more common revisions identified during the reinterpretation process. The revised stratigraphy was based on correlation with AAE Towerhill 1 and FPN Koburra 1 (DEEDI, 2011).

Triassic Stratigraphic Successions

In the eastern Galilee Basin the Triassic successions have undergone the greatest degree of modification, particularly the Warang Sandstone, Clematis Group, Dunda beds and Rewan Group. The Dunda beds based on the established basin stratigraphy (Figure 2) have historically been regarded as minor formation in the stratigraphic succession that forms a sandier facies variant at the top of the Rewan Group. The Warang Sandstone is regarded as being the stratigraphic equivalent to the lower part of the Moolayember Formation, Clematis Group, Dunda beds and Rewan Group (McKellar and Henderson, 2013). Initially the entire Triassic succession was grouped together when developing regional stratigraphic surfaces to accommodate the Warang Sandstone (Evans, 1980). More recently, the Warang Sandstone has been grouped with the Clematis Group (RPS, 2012).

Historical wire-line log interpretations undertaken during the initial greenfields exploration phase in the basin often identified the Dunda beds. Wire-line log interpretations undertaken more recently quite commonly do not identify the Dunda beds. The Dunda beds are most often grouped with the Rewan Group as with the example of OER Solomon 1-1A although there are exceptions. In other cases, the Dunda beds are grouped with the Clematis Group while in a number of other drill holes the Dunda beds is split across both the Clematis Group and Rewan Group (Figure 4).

Based solely on the original GSQ interpretations for the Dunda beds (blue circles – Figure 5a) the historical extent of the Dunda beds shows many similarities with the revised extent (Figure 5b). The distribution of wire-line log interpretation data assigned by exploration companies (Figure 5a) clearly illustrates the misconceptions that can be made regarding the extent of the Dunda beds.

Reinterpretation of wire-line log data has refined the extent of the Dunda beds (Figure 5b). The new reinterpretation dataset shows that the Dunda beds still have the greatest formation thickness occurring along the main axis of the Koburra Trough. Significantly, the Dunda beds are absent across the Barcaldine Ridge between Barcaldine and Jericho. In the northern part of the Galilee Basin subdivision of the Warang Sandstone has resulted in significant modification of the northern extent of the Dunda beds.

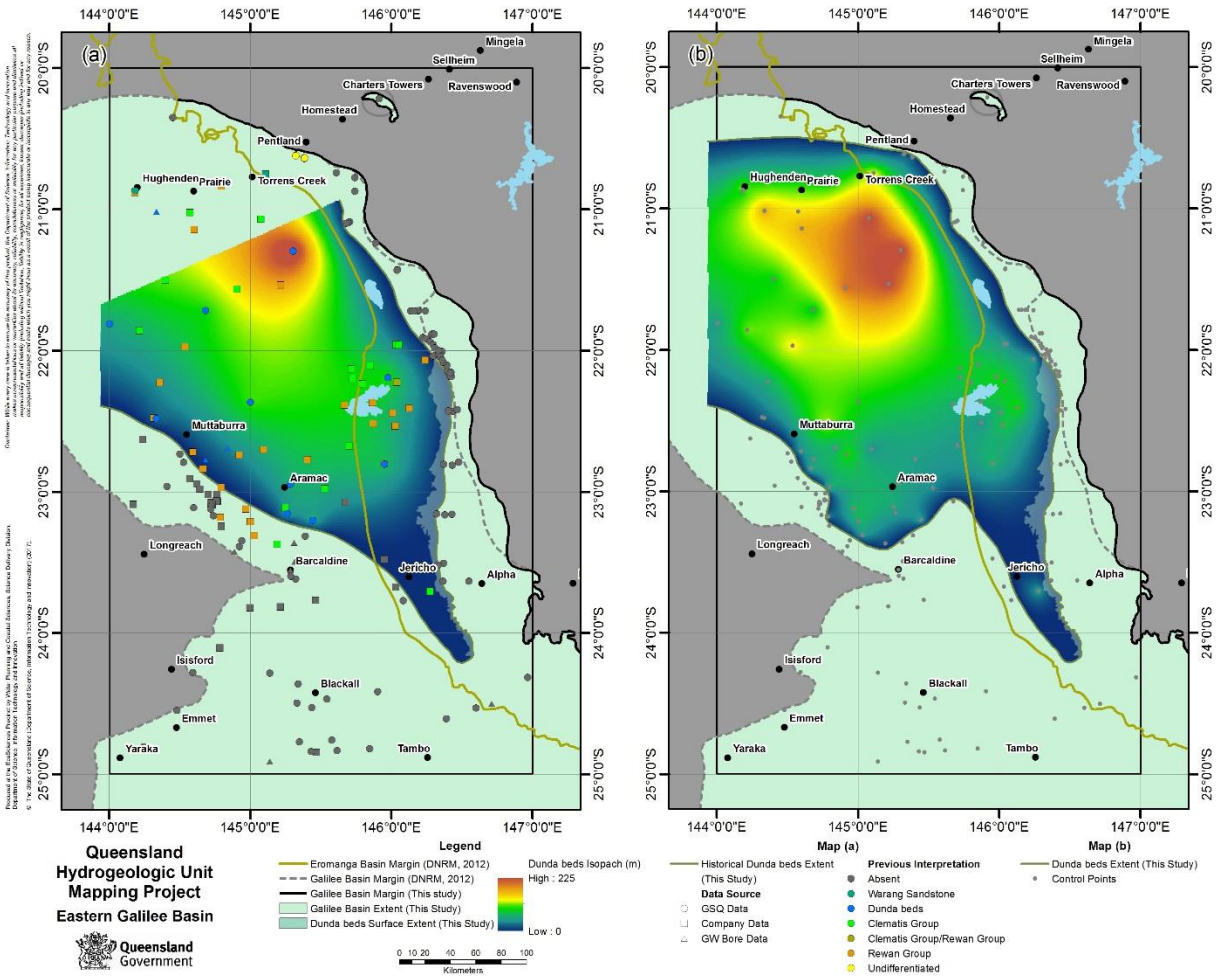

Figure 5: Mapped extents and isopachs for the Dunda beds in the eastern Galilee Basin. (a). Pre-reinterpretation of wire-line log data illustrating the historical extent of the Dunda beds and isopach data based on GSQ interpretations, and previously assigned stratigraphy based on exploration company interpretations. (b). Post reinterpretation of wire-line log data illustrating the revised extent of the Dunda beds and revised isopach data.

Permian and Carboniferous Stratigraphic Successions

Reinterpretation of the wire-line log data has to date allowed for the subdivision of the Betts Creeks beds into the Bandanna Formation and Colinlea Sandstone in the deeper part of the Galilee Basin. It is currently unclear at this stage if this subdivision of the Betts Creek beds can be extended further west into the basin or in relation to recent investigations (Phillips et al., 2017b) how this subdivision correlates with mapped surface exposures of the Betts Creek beds in the north of the Galilee Basin.

Inconsistencies were also identified in the Joe Joe Group and relate to the subdivision and identification of the Jochmus Formation and Jericho Formation, including their respective intra-formation members the Edie Tuff Member and Oakleigh Siltstone. Identification of the youngest Joe Joe Group formation, the Aramac Coal Measures is complicated by close lithological, sedimentological and geophysical similarities between it and the overlying Colinlea Sandstone (McKellar and Henderson, 2013). Resolving these inconsistencies is more problematic due to the small number of drill holes that penetrate the full succession of the Joe Joe Group.

CONCLUSIONS

The results of the wire-line log reinterpretation have highlighted inconsistencies with established basin stratigraphy that exist in the current published stratigraphic datasets for the Galilee Basin. These inconsistencies are most numerous in the eastern Galilee Basin that is the focus of proposed coal mining developments and CSG exploration. The key outcome of this work is the creation of revised stratigraphic dataset that utilises consistently applied wire-line logs interpretations systematically performed by a single operator.

The revised stratigraphic dataset assist in creating more refined structure contour surfaces. The development of more refined structure contour surfaces for the stratigraphic units in the Galilee Basin is a critical step in creating a 3D stratigraphic framework to visualise the basin architecture. Refining the basin architecture has important implications for improving the stratigraphic knowledge base in the Galilee Basin and identifying knowledge gaps that still remain. Some of the more significant knowledge gaps identified through this work include:

- Inconsistent surface geology and structural mapping,
- Incomplete understanding of structural features and their role in influencing basin development and depositional environments,
- Incomplete understanding of facies variability and the role of sediment provenance on this variability,
- Incomplete understanding of basin compartmentalisation and its influence on groundwater flow,
- Incomplete understanding of the Triassic stratigraphic relationships,
- Incomplete subdivision of the Betts Creek beds into the Bandanna Formation and Colinlea Sandstone,
- Incomplete subdivision of the Joe Joe Group,

While these knowledge gaps remain unresolved, the development of a 3D stratigraphic framework for the Galilee Basin to assess the basin architecture will potentially continue to show inconsistencies. The main implication being that until these inconsistencies are addressed, the aquifer characteristics and hydrogeology of the Galilee Basin will remain incompletely defined. Without a complete understanding of aquifer characteristics and the hydrogeology of the Galilee Basin, particularly for the Clematis Group and Dunda beds, the role of aquifer systems in the eastern Galilee Basin on influencing the mechanisms driving spring genesis will continue to remain a potentially contentious issue.

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