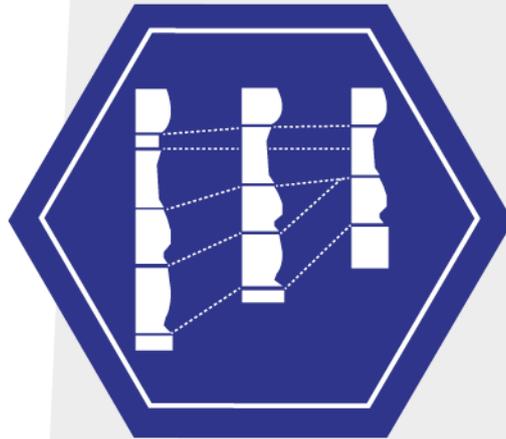




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Report CAu5053-ATP855

Chemostratigraphy of Selected Wells from the Cooper Basin

Prepared for

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Dr T.J. Pearce
Director

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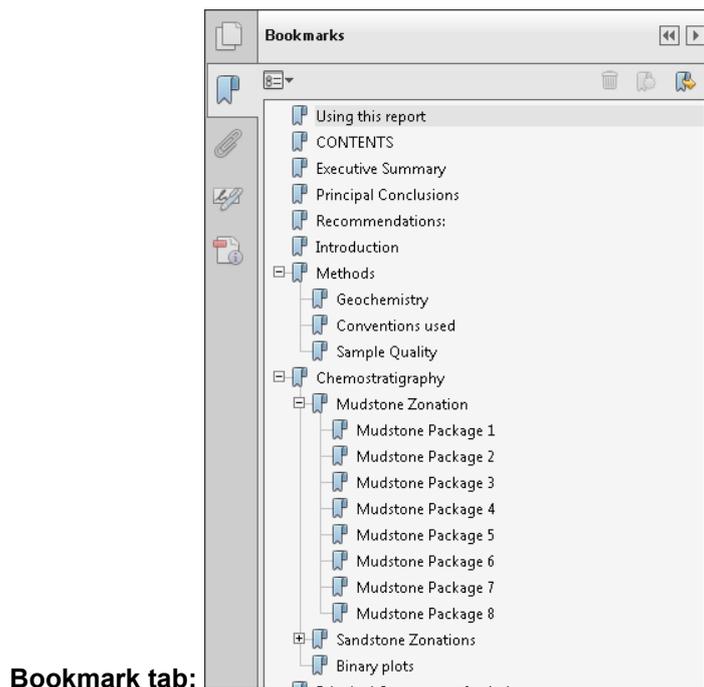
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USING THIS REPORT

- This report has been designed to be used electronically as a PDF. Images and enclosures are intended to be viewed using the zoom tools and so the level of detail of images has been rendered at high resolution.



- The PDF contains a bookmark system that allows you to jump straight to sections of interest.



- This report can be printed on a standard office printer, but it is recommended that the enclosures are printed separately on a large format printer.

EXECUTIVE SUMMARY

- The results and conclusions of a sequence of chemostratigraphic studies undertaken on Permian aged rocks of the Cooper Basin in Southern Australia as encountered in Halifax-1, Hervey-1, Redland-1, Keppel-1 and Geoffrey-1ST1 are presented in this report.
- The sediments of the study interval belong to the Patchawarra Formation, Murteree Shale, Epsilon Formation, Roseneath Shale, Daralingie Formation and the Toolachee Formation and are dominantly lacustrine rocks with some fluvial and deltaic rocks.
- The client supplied wireline log data and formation tops.
- The aim of this study is to define and correlate chemostratigraphic packages between Halifax-1, Hervey-1, Redland-1, Keppel-1 and Geoffrey-1ST to establish a regional stratigraphic scheme.
- All samples were analysed by Inductively Coupled Plasma Optical Emission Spectroscopy and Mass Spectrometry (ICP-OES-MS) and for Total Organic Carbon using a CHNS analyser, a total of 1008.

PRINCIPAL CONCLUSIONS

- Significant and apparently systematic changes in select elements and element ratios within the study interval have allowed all wells to be correlated producing a strong correlation scheme (**Enclosure A**).
- Nineteen chemostratigraphic packages and thirty one chemostratigraphic units have been defined, though only eighteen units are identified in the wells in this project. (**Table 2**)
- The top of Package 14 is identified as a particularly prominent geochemical surface, with significant changes across this boundary. It may represent an unconformable surface.
- The correlation scheme devised for Chemostrat Report CAu1155 is replaced by a scheme initially developed during construction of correlations to Halifax-1, Hervey-1, Keppel-1 and Redland-1, which has been revised and formalised in this report. This zonation and correlation scheme places all wells in a regional and stratigraphic context.
- Principal Component Analysis was used to relate the geochemistry to mineralogy. Six groups of elements were identified and linked to quartz (Si), Zircon (Zr, Hf) drilling fluids (Ba, S, Sr), aluminosilicates, heavy minerals and diagenetic minerals (see PCA section for details).

RECOMMENDATIONS

- **Extension of existing wells:** The extent of the proposed correlation is limited by the extent of the data. Data from the analysis of samples above and below the current data limits will allow the extension of the scheme as well as the testing of the robustness of the proposed scheme.
- **Addition of more wells:** The chemostratigraphic correlation could be tested further by extending the project into adjacent wells.
- **Acquire mineralogical data:** The principal component analysis carried out in the report related elements and element clusters to mineralogy. However, these are only predictions based on statistical analysis. X-Ray diffraction or Fourier Transform InfraRed Spectroscopy could be carried out on samples from all wells to determine more confidently the link between mineralogy and geochemistry. A range of options are available to meet client budgets from using XRD on the entire well, to using FTIR in combination with a small subset of XRD data points for calibration purposes.
- **Geochronology:** The proposed chemostratigraphic correlation scheme is broadly a lithostratigraphic correlation. Various geochronological techniques offered by Chemostrat could allow the subdivision of the strata based on depositional ages.

INTRODUCTION

The results and conclusions of a chemostratigraphic study undertaken on Permian aged rocks of the Gidgealpa Group of the Cooper Basin in Southern Australia as encountered in Halifax-1, Hervey-1, Redland-1, Keppel-1 and Geoffrey-1ST1 are presented in this report (**Figure 1, Table 1**). The sediments of the study interval belong to the **Patchawarra** Formation, the **Murteree** Shale, the **Epsilon** Formation, the **Roseneath** Shale, the **Daralingie** Formation and the **Toolachee** Formation which are dominantly lacustrine rocks with some fluvial and deltaic rocks.

The complex, intracratonic Cooper Basin is a remnant Late Carboniferous to Middle-Triassic depocentre situated at the time in the interior of Gondwana (Gravestock et al., 1998; Jell, 2013). Unlike other remnant basins from Gondwana it contains a continuous Permo-Triassic sequence. The Cooper Basin was formed following cooling of granite batholiths emplaced during the previous epoch (Gravestock et al., 1998). The Cooper Basin is split into a number of large trough systems representing an erosional land surface produced during the Kanimblan and Alice Springs orogenys (Gravestock et al., 1998). It is entirely covered by the Mesozoic Eromanga Basin. Basement of the basin includes Proterozoic gneiss, the early Palaeozoic Warburton Basin, early Palaeozoic Thomson Orogen metamorphics and the Devonian Warrabin Trough (Jell, 2013). The study section includes rocks of the Permian Gidgealpa Group.

The early Permian **Patchawarra Formation** is the oldest formation in the study interval contains interbedded sandstone, mudstone and coal with authigenic quartz, kaolinite and dickite common in the sandstones (Jell, 2013). It interdigitates with the Tirrawarra Sandstone or lies unconformably on the Merrimelia Formation, or the Warburton Basement (Jell, 2013). It is 50-500 m thick

The **Murteree Shale** conformably overlies or interdigitates with the Patchawarra Fm. and contains mudstone and subordinate sandstone deposited in a large freshwater lake with restricted circulation (Jell, 2013). It is less than 80 m thick (Jell, 2013).

The **Epsilon Formation** conformably overlies the Murteree Shale and contains sandstone, mudstone and coal from shoreface, deltaic and lacustrine deposits (Jell, 2013). The Epsilon Formation conformably overlies the Murteree Shale and is 20-100 m thick.

The **Roseneath Shale** conformably overlies the Epsilon Formation or intertongues with the Epsilon Formation in places (Jell, 2013). The Roseneath Shale is lacustrine in origin and ranges in thickness from 20-100 m thick. The Roseneath Shale and Epsilon Formation are known to be laterally variable in thickness (Jell, 2013).

The **Daralingie Formation** conformably overlies the Roseneath Shale and consists of interbedded carbonaceous and micaceous mudstones, coal and minor sandstone with a kaolinitic matrix and occasional carbonaceous inclusions (Jell, 2013). The formation is greater than 95 m in thickness and the upper contact of the Daralingie Formation with the Toolachee Formation is unconformable.

The late Permian **Toolachee Formation** disconformably overlies the Daralingie

formation or unconformably overlies older rocks (Jell, 2013).

Fining upwards cycles represented by the Epsilon Formation to Roseneath Shale and the Daralingie Formation to the Nappamerri Group relate to either periods of uplift of the source area or changes in base level (Jell, 2013).

Study Aims

The aim of this study was to correlate all wells in the project using their geochemistry, understanding that this most likely reflects provenance, climate and weathering of sediments now resident in the basin (Report CAu1155).

A chemostratigraphic zonation and correlation scheme was devised in 2012 (Report CAu1155) based on a study of 209 ICP-OES-MS analyses, however following work (reported as correlation panels) significantly revised this scheme including revision of the elements and element ratios used for correlation and the new scheme is reported herein.

For this study a total of 1008 ICP-OES-MS and TOC analyses were carried out over five additional phases (Proposals CAu1026a, CAu1068, CAu1066a, CAu1076 and CAu1077) (**Table 1**).

Although the chemostratigraphic correlation is objective (independent of other factors) ultimately the value of the data will be maximised by integrating it with other data (biostratigraphy, sequence stratigraphy, seismic data etc.).

Table 1: Summary of samples analysed in the Cooper Basin projects

Well Name	Top (mD)	Base (mD)	Sample spacing (m)	Sample Interval (m)	ICP samples	TOC	Proposal	Notes
Halifax-1	2859	3630	6	771	176	176	CAu1026a	Correlation panel only
Hervey-1	2652	3306	6	654	110	110	CAu1026a	Correlation panel only
Redland-1	3303	3804	3	501	168	168	CAu1068	Correlation panel only
Keppel-1	3033	3897	6	864	145	145	CAu1026a	Correlation panel only
Geoffrey-1 +ST1	2904	4124	3	1220	409	409	CAu1066a, CAu1076	Report CAu5053 (this phase)
TOTAL					1008	1008		

METHODS

GEOCHEMISTRY

Cuttings and core samples from the above wells were analysed for geochemistry (**Table 1**). Surfaces of core samples were cleaned then hand ground into a powder in a mortar and pestle. Cuttings samples were first washed in a mild detergent to remove surface contamination and to wash away clay grade material. From the remaining material either mudstone (grain size <62.5 µm) or sandstone (grain size >62.5 µm) chips were picked from the sample under microscopic examination (Wentworth Scale). The wireline gamma ray log, provided by the client, was used to guide whether sandstones or mudstones were to be picked at any particular depth. A threshold value of 60 API is applied to subdivide sandstones (<60API units) from mudstones (>60API units) with consideration of carbonates, volcanic and coal lithologies etc. where necessary. Once picked, samples were hand ground in an agate mortar and pestle. The powder from both core and cuttings samples was then dissolved into a solution using an alkali fusion technique and lithium metaborate fusion for geochemical analysis as described in Jarvis and Jarvis (1992).

Element concentration data were acquired using Inductively Coupled Plasma source Optical Emission Spectrometry (ICP-OES) and Inductively Coupled Plasma source Mass Spectrometry (ICP-MS). These analytical methods resulted in data for 50 elements (10 major elements, reported as **oxide percent** by weight (SiO₂, TiO₂, Al₂O₃, Fe₂O₃, MgO, MnO, CaO, Na₂O, K₂O and P₂O₅); 25 trace elements, reported as **parts per million** by weight (Ba, Be, Bi, Co, Cr, Cs, Cu, Ga, Hf, Mo, Nb, Ni, Pb, Rb, Sn, Sr, Ta, Tl, Th, U, V, W, Y, Zn, and Zr); 14 rare earth elements (REE), reported as **parts per million** by weight (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Ho, Dy, Er, Tm, Yb, and Lu)). Precision error for the major element data is generally better than 2%, and is around 3% for the high abundance trace element data derived by ICP-OES (Ba, Cr, Sc, Sr, Zn and Zr) (Ratcliffe *et al.*, 2010).

TOTAL ORGANIC CARBON

TOC values were obtained from selected samples (**Table 1**) using a Thermo Scientific Flash EA1112 combustion analyser after decarbonation with hydrochloric acid to remove any inorganic carbon in the form of carbon dioxide. This instrument uses the flash dynamic combustion method within a high temperature reactor, measuring the amount of carbon dioxide released from the sample as a combustion product. The concentration of organic carbon (TOC) measured is reported in weight percent (%).

CONVENTIONS USED

- For brevity throughout the report, all elements are referred to by their appropriate chemical symbol (**Appendix 1**). For the major elements, all their chemical symbols are taken to imply oxides unless otherwise stated, e.g., K = K₂O, etc.
- For brevity square brackets used to denote concentration are omitted. E.g. [Zr] is shown as Zr and [Zr]/[Hf] as Zr/Hf. Concentration is either percent (%) or parts per million by weight.
- Depths quoted in this report are in mMD unless otherwise stated.
- Cuttings samples for the interval x to y are plotted at depth y, where y is deeper.

SAMPLE QUALITY

Core samples are directly sampled from a known location and so data derived from their measurement are considered a direct measurement of a particular depth, though not capturing well the heterogeneity of the whole interval necessarily. Cuttings samples represent the rocks present over a depth interval and can contain contamination from cavings, drilling additives and LCMs. Cuttings were used in this study and therefore it was necessary to assess how representative they are of the interval sampled. One method to test cuttings representivity is to compare a calculated estimate of the GR value based on the chemical measurements, called chemical gamma (ChemGR), against downhole measured gamma ray data (**Figure 2**). Chemical gamma is calculated using the following formula from Ellis and Singer (2007):

$$\text{ChemGR} = (K_2O * 13.55) + (Th * 3.93) + (U * 8.08)$$

Comparison of the wireline GR data to ChemGR can be used as an assessment of the effectiveness of the picking process and highlight any discrepancies between lithologies expected from the wireline GR, and what was actually picked and measured for geochemistry.

Figure 2 illustrates that overall there is a good match between the ChemGR the chemistry of the picked samples indicating that sample picking was good. Thirteen samples (marked by yellow stars in **Figure 2**) were picked as sandstone instead of mudstone (or vice versa) but this amounts to 1.3% of ICP samples and so is not significant. On these occasions there may not have been chips of the required lithology available in the cuttings samples as indicated by the GR, or sample spacing resolution may have been an issue.

CHEMOSTRATIGRAPHY

Although data for a total of 50 elements are acquired, chemostratigraphic characterisation typically relies upon a relatively small number of these elements, or ratios of elements (Pearce *et al.*, 2005; Ratcliffe *et al.*, 2006; Hildred *et al.*, 2010). These elements and element ratios, termed *key indices*, are used to construct a chemostratigraphic zonation scheme, for which the following chemostratigraphic hierarchy is conventionally applied:

- Package:** A mudstone interval whose geochemical composition can be differentiated from others in the study interval, and whose geochemical characteristics allow them to be recognised and correlated *regionally*.
- Unit:** A second order chemostratigraphic division whose mudstone geochemistry allows it to be differentiated from others within its parent package. These are numbered to reflect their parent package. For example Unit 4_1 is the oldest in Package 4 and Unit 4_5 the youngest in that package. Although their regional lateral extent can be restricted, they often form the basis for detailed *local* chemostratigraphic correlations between relatively closely spaced wells.
- Sand unit:** Intervals that are composed of discrete sand bodies; their nomenclature is often used to reflect their position within the parent package. Two sandstones are only considered chemostratigraphically equivalent and correlative when they occupy the same position in the mudstone-based zonation scheme and have similar chemistry. It is possible for sands to occupy the same position in the mudstone packages and yet have different chemistry, but these sand units may not be correlative but diachronous - i.e. different channel belts in a fluvial setting (Hildred *et al.*, 2010).

Note that these packages and units refer to sediment packages of similar chemical composition. This does not necessarily translate into small scale sedimentary architectural features, such as channel belts, but is more comparable to members and formations.

The geochemical data has been split by lithology (sandstones and mudstones) using the Si/Al ratio (**Figure 3**). The change in scaling seen in **Figure 3** at approximately Si/Al = 6 represents the change from mudstones to sandstones, based on Chemostrat's experience. Specifically, sandstones were defined as having Si/Al ≥ 6 , and mudstones where Si/Al < 6 (**Figure 3**). Data with total major oxide weight percentages less than 80% were classified as coals and were not included in the correlation schemes.

The correlation scheme (**Enclosure A**) is based on mudstone data as the number of samples identified as sandstone through the Si/Al ratio is small in all wells except Geoffrey-1.

MUDSTONE ZONATION

Mudstone data points were then used to create a zonation scheme for Halifax-1, Keppel-1, Hervey-1, Redland-1 and Geoffrey-1 which allowed these wells to be correlated. In Report CAu1155 a zonation scheme was developed which has been revised during work on Halifax-1, Hervey-1 and Keppel-1 (Proposal CAU1026a). In this final phase the zonation and correlation schemes were revised to produce the final scheme presented herein.

Nineteen chemostratigraphic packages and thirty one chemostratigraphic units have been defined. The resulting chemostratigraphic correlation is summarised in **Figure 4** and **Enclosure A**. Tops data are shown in **Table 2**. Package descriptions follow but note that Zr/Nb shows exactly the same trends to Zr/Cr used in previous reports (Chemostrat Report CAu1155) and can be used as a Zr/Cr proxy for comparison purposes.

Table 2: Tops data for the Cooper Basin wells.

Halifax-1					
Mudstone Package	Top/m	Base/m	Mudstone Unit	Top/m	Base/m
Package 18	2864.0L	2913.0	18-2	2864.0	2898.0
			18-1	2898.0	2913.0
Package 17	2913.0	2982.0	17-2	2913.0	2982.0
Package 16	2982.0	3062.5			
Package 15	3062.5	3194.2	15-3	3062.5	3104.0
			15-2	3104.0	3138.0
			15-1	3138.0	3194.2
Package 14	3194.2	3228.8			
Package 13	3228.8	3363.0	13-3	3228.8	3279.0
			13-2	3279.0	3341.0
			13-1	3341.0	3363.0
Package 11	3363.0	3446.4	11-3	3363.0	3446.4
Package 10	3446.4	3549.8	10-2	3479.0	3520.0
			10-1	3520.0	3549.8
Package 9	3549.8	3609.0	9-2	3549.8	3594.0
			9-1	3594.0	3609.0
Package 8	3609.0	3628.4L	8-3	3609.0	3628.4

Hervey-1					
Mudstone Package	Top/m	Base/m	Mudstone Unit	Top/m	Base/m
Package 18	2652.0L	2683.0	18-2	2652.0	2669.0
			18-1	2669.0	2683.0
Package 17	2683.0	2840.0	17-2	2691.0	2768.0
			17-1	2768.0	2840.0
Package 16	2840.0	2888.0			
Package 15	2888.0	2969.0	15-3	2888.0	2937.0
			15-2	2937.0	2969.0
Package 14	2969.0	2981.0			
Package 13	2981.0	3041.0	13-3	2981.0	3002.0
			13-2	3002.0	3022.0
			13-1	3022.0	3041.0
Package 12	3041.0	3080.0			
Package 11	3080.0	3175.0	11-3	3080.0	3175.0
Package 10	3175.0	3251.0	10-2	3215.0	3238.0
			10-1	3238.0	3251.0
Package 9	3251.0	3298.0	9-2	3251.0	3280.0
			9-1	3280.0	3298.0
Package 8	3298.0	3315.0L			

Table 2: (Continued) Tops data for the Cooper Basin wells.

Keppel-1					
Mudstone Package	Top/m	Base/m	Mudstone Unit	Top/m	Base/m
Package 19	3029L	3095.0			
Package 18	3095.0	3170.0	18-2	3095.0	3141.0
			18-1	3141.0	3170.0
Package 17	3170.0	3317.0	17-2	3170.0	3269.0
			17-1	3269.0	3317.0
Package 16	3317.0	3377.0			
Package 15	3377.0	3553.0	15-4	3377.0	3410.0
			15-3	3410.0	3463.0
			15-2	3463.0	3508.0
			15-1	3508.0	3553.0
Package 14	3553.0	3568.0			
Package 13	3568.0	3671.0	13-3	3568.0	3611.0
			13-2	3611.0	3651.0
			13-1	3651.0	3671.0
Package 12	3671.0	3728.0			
Package 11	3728.0	3773.0			
Package 10	3773.0	3888L	10-2	3820.0	3847.0
			10-1	3847.0	3888L

L denotes limit of data set, not identified package/unit boundary

Redland-1					
Mudstone Package	Top/m	Base/m	Mudstone Unit	Top/m	Base/m
Package 18	3298.0L	3322.0			
Package 17	3322.0	3464.0	17-2	3322.0	3427.0
			17-1	3427.0	3464.0
Package 16	3464.0	3533.0			
Package 15	3533.0	3722.0	15-4	3533.0	3563.0
			15-3	3563.0	3636.0
			15-2	3636.0	3692.0
			15-1	3692.0	3722.0
Package 14	3722.0	3753.0			
Package 12	3753.0	3805.0L			

Geoffrey-1					
Mudstone Package	Top/m	Base/m	Mudstone Unit	Top/m	Base/m
Package 17	2903.0L	2990.0	17-1	2954.0	2990.0
Package 16	2990.0	3055.0			
Package 15	3055.0	3190.0	15-4	3055.0	3083.0
			15-3	3083.0	3156.0
			15-2	3156.0	3190.0
Package 14	3190.0	3246.0			
Package 12	3246.0	3291.0			
Package 10	3452.0	3479.0	10-2	3474.0	3479.0
Package 9	3479.0	3545.0	9-2	3481.0	3503.0
			9-1	3503.0	3545.0
Package 8	3545.0	3608.0	8-3	3545.0	3594.0
			8-1	3594.0	3608.0
Package 7	3608.0	3710.0	7-3	3608.0	3650.0
			7-2	3650.0	3685.0
			7-1	3685.0	3710.0
Package 5	3710.0	3802.0	5-3	3710.0	3733.0
			5-2	3733.0	3763.0
			5-1	3763.0	3802.0
Package 4	3802.0	3902.0	4-2	3802.0	3851.0
			4-1	3851.0	3902.0
Package 3	3902.0	3968.0	3-2	3902.0	3936.0
			3-1	3936.0	3968.0
Package 2	3968.0	4060.0			
Package 1	4060.0	4127.0L			

Package 19

Package 19 is only present in Keppel-1. It is defined by its position above Package 18 and the top is not defined due to limits of the data coverage. The contents define the package which contains low values of Mg/Al, Ga/Rb and Cr/K. No units have been defined for Package 19.

Package 18

Package 18 is present in Halifax-1, Keppel-1, Hervey-1 and Redland-1 although the top of this package is only defined in Keppel-1. The top of this unit is defined by a change in values of Mg/Al and Mn from high in Package 18 to low in Package 19, and Nb from low to high over the same interval. Package 18 contains two units whose contents help to define the package:

- **Unit 18-2:** Contains low values of Mg/Al and Zr/Nb.
- **Unit 18-1:** Contains high values of Mg/Al and Zr/Nb.

Package 17

Package 17 is present in Halifax-1, Keppel-1, Hervey-1, Redland-1 and Geoffrey-1, although the top is not defined in Geoffrey-1. The top of the package is defined by a step change in the values of Fe from low in Package 17 to high in Package 18 and Zr/Nb from high to low over the same interval. Ti/Nb is particularly high in this package. Two units have been defined for Package 17:

- **Unit 17-2:** Contains higher values of Zr/Nb, Fe and Mg/Al.
- **Unit 17-1:** Contains lower values of Zr/Nb, Fe and Mg/Al.

Package 16

Package 16 is present in Halifax-1, Keppel-1, Hervey-1, Redland-1 and Geoffrey-1. The main characteristic defining the top of Package 16 is a rapid drop in Cr/K values from high/higher in Package 16 to lower in Package 17. Accompanying this is a rapid drop in Ga/Rb values from high in Package 16 to lower in Package 17, although this is not present in Geoffrey-1. Cr/K is generally high in Package 16. No units have been defined in Package 16.

Package 15

Package 15 is present in Halifax-1, Keppel-1, Hervey-1, Redland-1 and Geoffrey-1. The top of the package is not as strongly defined as other packages in the project, but is defined by an increase in the value of Cr/K accompanied by a less strong increase in the values of Ga/Rb and Fe locally at the contact. Four units are defined for Package 15:

- **Unit 15-4:** Contains locally low values of Cr/K and Ga/Rb.
- **Unit 15-3:** Identical to Unit 15-2 in composition, but base is defined by the decrease in values of Ga/Rb from a local peak at the top of Unit 15-2.
- **Unit 15-2:** Contains slightly elevated values of Ga/Rb, relative to adjacent units including a peak in Ga/Rb values at the top of this unit.
- **Unit 15-1:** Contains locally high values of Nb.

Package 14

Package 14 is present in all wells and the upper surface is a significant regional marker whereby all parameters on **Enclosure A** show significant changes. The top of Package 14 is defined by strong step change upward increases in values of Ga/Rb, Zr/Nb and Cr/K. Less strongly Ti/Nb shows a similar trend. Fe, Mn and Mg/Al change from higher to lower values. No units have been defined for Package 14.

Package 13

Package 13 is present in all wells except Redland-1 and Geoffrey-1. The upper contact is defined

by a step change in the values of Mg/Al from high values in Package 13 to low values in Package 14 and values of Fe and Mn from high to low. Along with this change is the change in values of Zr/Nb from low to high. Three units have been defined for Package 13:

- **Unit 13-3:** Contains locally high values of Fe.
- **Unit 13-2:** Contains locally low values of Ti/Nb, Mn and Fe.
- **Unit 13-1:** Is poorly defined but exhibits low values of Mg/Al.

Package 12

Package 12 is present in all wells except Halifax-1 with the upper contact contacting either Package 13 or Package 14. Where it contacts with Package 13 the low values of Fe and Mn present in the package are particularly visible in **Enclosure A**, where they define a yellow oval. Where contacting Package 13 the upper contact is defined by a rapid change in Fe and Mn from low values in this package to high values in Package 13 and Zr/Nb which changes from high values to low. Accompanying these changes is a less pronounced step change in the values of Ti/Nb from high in the package to low in Package 13. Low values of Mg/Al and high values of Cr/K and Nb are also present. When the top of Package 12 is in contact with Package 14 the change in Fe and Mn concentrations are less pronounced, though decrease slightly into Package 14. The top surface in this situation shows a step change in the values of Zr/Nb to lower values in Package 14 and a step change in the values of Cr/K to higher values. Data points for sandstones also show a step change in the values of Ga/Rb from lower values in Package 12 to higher values in Package 14, whilst K/Rb values change from higher values to lower values. No units have been defined for Package 12.

Package 11

Package 11 is present only in Halifax-1, Keppel-1 and Hervey-1. The upper contact is particularly strongly defined, relative to other contacts in the project and either contacts with Package 12 or Package 13. The top of Package 11 is defined by a step change from high values of Fe and Mn in the package to low values in Package 13/12. This coincides with a step change in Mg/Al from high to low, and from Zr/Nb and Nb values from lower values in the package to higher values in Package 13/12. The change in Zr/Nb values is particularly strongest in the transition to Package 12. High values of Fe and Mn are present in the package and are particularly clear on the graphical plot in **Enclosure A**. No units have been defined for the wells in this project.

Package 10

Package 10 is present in all wells except Redland-1. The top of the package is defined by a step change in the values of Fe, Mn and Mg/Al from lower values found in the package to higher values in Package 11 and Nb from higher values to lower values. Within the package there is a gradual increase in the values of Ti/Nb, Zr/Nb and Cr/K from low values defined by the top of Package 9.

At the same time the values of Nb gradually decrease in Package 10. This package exhibits varying and lower Fe and Mn concentration with very high Fe and Mn values present. Three units are defined for Package 10:

- **Unit 10-3:** Contains locally high values of Ti/Nb and Zr/Nb.
- **Unit 10-2:** Contains locally intermediate values of Ti/Nb and Zr/Nb with local spikes in Fe values.
- **Unit 10-1:** Contains locally low values of Ti/Nb, Zr/Nb and Fe.

Package 9

Package 9 is present in Halifax-1, Hervey-1 and Geoffrey-1. The top of the package is defined by an increase in the values of Cr/K which occurs in Package 10 more strongly towards the west, with values of Cr/K within the package staying approximately constant throughout. Over the upper contact Nb decreases to lower values, following a decreasing trend, in either a step change or a more gradual trend and values. Package 9 also contains regions of higher Mn and Fe. Two units have been defined for Package 9:

- **Unit 9-2:** Contains low values of Ti/Nb and Zr/Nb and high values of Fe.
- **Unit 9-1:** Contains high values of Ti/Nb and Zr/Nb and low values of Fe.

Package 8

Package 8 is present in Halifax-1, Hervey-1 and Geoffrey-1. The top of this package is defined by an increase in values of Ti/Nb from low values to higher values at the base of Package 9 (Unit 2-1). In Halifax-1, Hervey-1 and Geoffrey-1 this is accompanied by an increase in the values of Zr/Nb, Cr/K and a subtle increase in the values of Ga/Rb in Geoffrey-1, and a decrease in the values of Nb and Fe. In the western wells Ga/Rb is characteristically higher in Package 8 than Packages 9-14. Three units have been defined for all the wells in the project but only 8-3 and 8-1 are identified in Halifax-1 and Geoffrey-1:

- **Unit 8-3:** Contains high Ga/Rb and low Ti/Nb relative to adjacent units.
- **Unit 8-2:** Contains high Ga/Rb and low Ti/Nb relative to adjacent units.

Package 7

Package 7 is present only in Geoffrey-1. The top of the package is defined by a change from high values of Ti/Nb to low values in Package 8. Accompanying this is a more gradual change from low values of Ga/Rb to higher values in Package 8 and higher values of Cr/K to lower values in Package 8. Three units have been defined for Package 7:

- **Unit 7-3:** Contains locally higher values of Mg/Al and Zr/Nb and low values of Fe.
- **Unit 7-2:** Contains locally high values of Cr/K and Nb, and low values of Ti/Nb.

- **Unit 7-1:** Contains low values of Nb and Zr/Nb and higher values of Fe.

Package 5

Package 5 is present only in Geoffrey-1. The top of the package is defined by a rapid change from low values of Ti/Nb to higher values in Package 7. This is accompanied by a more subtle change from higher values of Ga/Rb in Package 5 to slightly lower values in Package 7. Three units have been defined for Package 5:

- **Unit 5-3:** Contains locally high values of Zr/Nb and Ti/Nb, and low values of Nb, Cr/K and Ga/Rb.
- **Unit 5-2:** Contains a local high peak in Cr/K values.
- **Unit 5-1:** Contains low values of Ti/Nb and Cr/K.

Package 4

Package 4 is present only in Geoffrey-1. The top of the package is defined by a rapid change from low values of Zr/Nb, Mg/Al and Ti/Nb to high values in Package 5, and from high values of Nb to low values in Package 5. Two units have been defined in Package 4:

- **Unit 4-2:** Contains locally lower values of Cr/K and higher values of Zr/Nb relative to unit 4-1.
- **Unit 4-1:** Contains locally higher values of Cr/K and lower values of Zr/Nb relative to Unit 4-2 and Package 3.

Package 3

Package 3 is present only in Geoffrey-1. The top of the package is defined by a rapid change in Cr/K from low values at the top of Package 3 to high values at the base of Package 4, and from high values of Zr/Nb to low values that define the base of Package 4. Two units have been defined in Package 3:

- **Unit 3-2:** Contains locally higher values of Fe and lower values of Ti/Nb and Cr/K.
- **Unit 3-1:** Has low values of Fe and high values of Ti/Nb, Cr/K and Zr/Nb.

Package 2

Package 2 is only present in Geoffrey-1. The top is defined by a step change from lower values of Ga/Rb and Cr/K which makeup Package 2 to higher values in Package 3. No units have been defined for Package 2.

Package 1

Package 1 is present only in Geoffrey-1 and is the oldest package in the study. The base is not

defined and is expressed only as the maximum extent of the data set (denoted “L” in **Table 2**). Its top is defined by a step change from low values of Ga/Rb, Cr/K and Nb to high values in Package 1, and high values of Zr/Nb and Ti/Nb to lower values in Package 2. This package contains high values of Mg/Al and Zr/Nb and low values of Ga/Rb, Ti/Nb, Cr/K and Nb. No units have been defined in Package 2.

TOC DATA

TOC data was acquired for 1008 samples and data is presented in **Enclosure A and Appendix 2**. The values of TOC varied with depth and by well in each chemostratigraphic package. Overall Packages 15 to 17 have higher TOC values than Package 8-14 and Packages 18-19 in Halifax-1, Keppel-1, Hervey-1, Redland-1 and Geoffrey-1. Highest values in Geoffrey-1/ST1 represent coals.

TOC values broadly coincide with package boundaries with the largest step change occurring over the Package 14 – Package 15 boundary where values increase from low to high.

PRINCIPAL COMPONENT ANALYSIS

Following the establishment of a chemostratigraphic correlation based on visual analysis of chemical logs and graphical plots (**Figure 4 and Enclosure A**), statistical approaches such as Principal Component Analysis (PCA) can be used to provide a basic understanding of element - element, and therefore element - mineral relationships. This technique is commonly applied where mineralogical data is absent.

PCA is a statistical test used in many chemostratigraphic studies (e.g. Pearce et al., 2005; Svendsen et al., 2007; Ellwood et al., 2008; Pe-Piper et al., 2008, and Ratcliffe et al., 2010) to assess element – element associations from geochemical data alone. PCA reduces the total variation in a dataset (Aitchison, 1986), which in this case are the element concentrations, to a smaller number of variables termed principal components (PC).

PC1 and PC2 accounts for 62 - 76 % of variation in the entire data set for each well (**Figure 5**). The principal component score assigned to each sample is determined from the Eigenvectors (EV). When the Eigenvector values are plotted against each other, the closer the elements plot to one another in the parameter space, the more closely associated they are to one another in the rocks. Elements associated with certain minerals can then be identified based on mineral chemistry.

Six groups were identified based on PCA analysis of each well individual (**Figure 5 and Table 3**):

- **Quartz – SiO₂**. In PCA plots for all wells SiO₂ sits on its own distant from other elements indicating that Si is related to quartz and is the dominant coarser grade mineral.
- **Zircon – Hf and Zr**. Zirconium is dominantly in Zircon and Hf is commonly found in association with Zr in Zircons as it is in the same group in the periodic table but in period 6 not 5.
- **Drilling additives** – In almost all wells Ba, S and Sr group together. Barium is the most common contamination in the form of barite added to drilling muds to increase density (although every effort is made to avoid including mud additives in samples analysed by ICP). Both sulphur and strontium are closely associate with Ba in PCA plots for all wells (except Halifax-1 where they form part of other clusters) suggesting that they are also contaminants from mud additives. The differences suggest that different drilling mud mixtures were used for the latter two wells.
- **Aluminosilicates** – In most wells Cs, V, Rb, Cr, K, Al, Ga, Sc, Be, Co, Ni, Na and Zn form a distinct cluster which is attributed to aluminosilicate minerals, including clay minerals (e.g. kaolinite group Al₄[Si₄O₁₀](OH)₈) and feldspars (e.g. alkali feldspars (K, Na)[AlSi₃O₈]). However in Keppel-1, Redland-1 and Geoffrey-1 Nb, Ta, light rare earth elements (LREE), middle rare earth elements (MREE),

heavy rare earth elements (HREE), Y, Th, U, Ti and Sn also form part of the group indicating that in these wells aluminosilicates also include these elements. These elements are attributed to heavy minerals in the other wells. Mn, Mg, Fe, P and Cu also rarely plot more closely associated with the aluminosilicate cluster.

- **Heavy minerals** – In all wells except Keppel-1, Redland-1 and Geoffrey-1 Nb, Ta, light rare earth elements (LREE), middle rare earth elements (MREE), heavy rare earth elements (HREE), Y, Th, U, Ti and Sn form a distinct cluster, separate to the aluminosilicate cluster, which is related to heavy minerals such as rutile (TiO₂), anatase (TiO₂) and sphene (a.k.a. titanite, CaTi[SiO₄](O,OH,F)).
- **Diagenetic minerals** – Ca, Mn, Mg, Fe, P, Mo and Cu form a separate cluster which is related to diagenetic minerals such as calcite (CaCO₃), dolomite (CaMg(CO₃)₂), siderite (FeCO₃), pyrite (FeS₂), haematite (Fe₂O₃) and apatite (Ca₅(PO₄)₃(OH,F,Cl)).

Table 3. Element – mineral associations from PCA analysis. The main element – mineral affiliations are shown on the left, with differences shown for each well in the columns.

Element	Main affiliation	Halifax-1	Keppel-1	Hervey-1	Redland-1	Geoffrey-1
Si	Quartz	x	x	x	x	x
Zr	Zircon	x	x	x	x	x
Hf	Zircon	x	x	x	x	x
Ba	Drilling fluids	x	x	x	x	x
S	Drilling fluids	Diagenetic Minerals	x	x	x	x
Sr	Drilling fluids	Not assigned	x	x	x	x
Cs	Aluminosilicates	x	x	x	x	x
V	Aluminosilicates	x	x	x	x	x
Rb	Aluminosilicates	x	x	x	x	x
Cr	Aluminosilicates	x	x	x	x	x
K	Aluminosilicates	x	x	x	x	x
Al	Aluminosilicates	x	x	x	x	x
Ga	Aluminosilicates	x	x	x	x	x
Sc	Aluminosilicates	x	x	x	x	x
Be	Aluminosilicates	x	x	x	x	x
Co	Aluminosilicates	Not assigned	Not assigned	x	x	x
Ni	Aluminosilicates	Not assigned	Not assigned	x	x	x
Na	Aluminosilicates	Not assigned	Diagenetic Minerals	x	x	Diagenetic Minerals
Zn	Aluminosilicates	Not assigned	Not assigned	x	x	Not assigned
Nb	Heavy minerals	x	Aluminosilicates	x	Aluminosilicates	Aluminosilicates
Ta	Heavy minerals	x	Aluminosilicates	x	Aluminosilicates	Aluminosilicates
LREE	Heavy minerals	x	Aluminosilicates	x	Aluminosilicates	Aluminosilicates
MREE	Heavy minerals	x	Aluminosilicates	x	Aluminosilicates	Aluminosilicates
HREE	Heavy minerals	x	Aluminosilicates	x	Aluminosilicates	Aluminosilicates
Y	Heavy minerals	x	Aluminosilicates	x	Aluminosilicates	Aluminosilicates
Th	Heavy minerals	x	Aluminosilicates	x	Aluminosilicates	Aluminosilicates
U	Heavy minerals	x	Aluminosilicates	x	Aluminosilicates	Aluminosilicates
Ti	Heavy minerals	x	Aluminosilicates	x	Aluminosilicates	Aluminosilicates
Sn	Heavy minerals	Aluminosilicates	Aluminosilicates	x	Aluminosilicates	Aluminosilicates
Ca	Diagenetic Minerals	x	x	x	x	x
Mn	Diagenetic Minerals	x	x	x	Aluminosilicates	x
Mg	Diagenetic Minerals	x	x	x	Aluminosilicates	x
Fe	Diagenetic Minerals	x	x	x	Aluminosilicates	x
P	Diagenetic Minerals	x	x	x	x	Aluminosilicates
Mo	Diagenetic Minerals	Not assigned	x	Not assigned	x	Not assigned
Cu	Diagenetic Minerals	Aluminosilicates	Not assigned	Not assigned	Not assigned	x

DISCUSSION

USE OF SI/AL TO LITHOLOGICALLY SUBDIVIDE SAMPLES

As noted earlier, data points were subdivided into sandstone and mudstones based on their Si/Al ratio, where sands are defined when $Si/Al \geq 6$, and mudstones when $Si/Al < 6$ (**Figure 3**). Subdivision of the data set into lithologies is an important step as some elements which are present in higher concentrations in minerals associated with sand grade sediment may be “masked” in the mud grade sediment due to the low concentrations in this grain size fraction. Some elements are particularly useful in subdividing the mudstones leading to the importance of subdividing data by lithology. Whilst this scheme is not perfect it does allow the data to be subdivided in both wells in an objective manner.

An important point to note is that the GR file, provided by the client, was used to guide which lithology was picked from the samples available at each depth interval. If mudstones were identified on the GR for that depth interval then mudstone fragments were picked. The Si/Al ratio should then relate to the picked sample lithology, and not necessarily the dominant lithology in the formation. This is an important point because when comparing the lithology determined by the Si/Al ratio to other records of lithology (which may be more generalised over an interval) they do not always exactly match. Comparing lithology determined from the Si/Al ratio and well data show that there is a good match for all wells and so picking has generally been successful (**Figure 2**). Where mudstones were picked where the GR has suggested sandstones were present (or vice versa), this probably reflects a problem with the sample not containing enough of the desired lithology in these samples.

Note that Keppel-1 did not have a GR file available so picking a lithology guided by the GR was not carried out for this well. Instead the dominant lithology in each sample bag was picked.

NOTES ON THE CORRELATION

Chemostratigraphy has been successfully applied to the Cooper Basin wells to produce a confident zonation and correlation for these fluvial-lacustrine sediments. Chemostratigraphy has previously been successfully applied to the correlation of terrestrial strata in both low and high accommodation fluvial and fluvial-lacustrine systems (Hildred et al., 2010; Ratcliffe, Wilson et al., 2014) giving confidence to this interpretation.

An important point to note is that chemostratigraphic “surfaces” can be either virtual, reflecting a change in composition, or real reflecting an unconformable surfaces such as an erosional unconformity. Chemostratigraphic surfaces also need not be chronostratigraphic (and by default should be considered diachronous like lithostratigraphy) but in many cases they can be chronostratigraphic. One surface of note is the large step change in a large number of key

indices that occurs at the top of Package 14 which makes this a significant regional surface. The most likely explanation for this is a regional unconformity. The close association between Package 14 top surface and the top of the Daralingie Formation indicate that this package boundary is most likely an unconformity at the top of the Daralingie Formation, identified very clearly in the geochemistry. This is corroborated by the wireline GR trace which shows a lithostratigraphic boundary approximately at this location which is consistent with this interpretation. To determine if the chemostratigraphic subdivision is chronostratigraphic further analyses are required in order to date sediments, tuffs or organic components within the sediment.

The combinations of features used to define packages and units means that some packages and units have unique properties allowing them to be identified precisely in the well e.g. Package 12. In other places the zonation is less well defined because of the lack of data coverage particularly at the upper and lower bounds of the data sets. In these cases the limits of the packages or units are placed above or below the last data point available and do not reflect true chemostratigraphic boundaries.

SANDSTONE SUBDIVISION

Subdividing and correlating the sandstones within the study interval was not attempted due to the lack of data coverage and the segmented nature of the sandstone data point clusters. Additionally, the GR plot (**Figure 2**) indicates that many of the sandstones are thin beds (<5 m thick) in heterolithic sequences. Ideally in fluvial strata we would want to try and correlate individual channel belts (>10 m thick), or channel belt complexes (*sensu* Wilson et al., 2014), but in general using chemostratigraphy we attempt to correlate at a much higher order – on the member or formation level (e.g. >50 m thick) (e.g. Ratcliffe, Wilson et al., 2014). At this level we are most likely detecting the change in provenance over much longer timescales than the processes governing fluvial deposition and defining these small scale features (e.g. avulsion). Correlating sandstones is always more difficult when they are subordinate, such as here, and the best that is usually obtainable is to place the sandbodies within the scheme defined by the mudstone data. If high resolution subdivision of the sandstone dominated regions is required then an extension to the project using high resolution sampling and possibly heavy mineral provenance techniques is recommended.

INTERPRETATION OF KEY ELEMENTS AND ELEMENT RATIOS USED FOR ZONATION AND CORRELATION

Mn, Fe, Mg/Al, Ga/Rb, Ti/Nb, Zr/Nb, Cr/K and Nb were used to define the mudstone zonation scheme which was used to correlate the eight wells. The construction of a zonation scheme requires the use of elements or element ratios that show features, or signal, and these can be any elements or combinations of elements. Specific ratios are not chosen based on direct links between elements and minerals or any processes. The meaning of the elements used for correlation is explored here:

- **Mn:** Mn is present in a wide variety of rocks but in siliciclastic rocks it has similar affinities to Fe and Mg i.e. chloritic clay minerals and biotite. It is also associated with authigenic carbonate nodules and cements including siderite, ankerite, calcite and dolomite.
- **Fe:** Iron is very common in sedimentary rocks and occurs in higher abundances in Fe-bearing carbonate minerals. Numerous factors can govern the distribution of Fe in sedimentary sequences, which makes the interpretation of Fe data acquired for chemostratigraphic studies quite difficult. Fe is extremely common in a wide range of minerals and rock types including chlorite, pyrite, Fe-oxyhydroxides, siderite, calcite, dolomite, and minerals occurring in volcanic rocks e.g. pyroxene and olivine. Its distribution can be influenced to a great extent by redox and pH conditions - Fe is present in the form of Fe^{2+} in oxidising conditions and as Fe^{3+} in reducing conditions. In the geochemical datasets obtained by Chemostrat Australia Pty Ltd, Fe concentrations are expressed as Fe_2O_3^T , which represents the total Fe content from both redox states so comment on the redox conditions present at the time of deposition cannot be made from the geochemical data alone.
- **Mg/Al:** Magnesium may be present in minerals of detrital or authigenic origin. Mg is primarily associated with the clay minerals, including chlorite and smectite, mica as well as dolomite, ankerite and magnesium calcite. Al is primarily related to the abundance of clay minerals.
- **Ga/Rb:** Ga can replace Al in kaolinite, and Rb with K in illite. Thus Ga/Rb is considered to model the amount of kaolinite and illite present in the rock. Kaolinite is the stable product of the weathering series which includes illite. This ratio is therefore interpreted to represent the amount of chemical weathering, where high values of the ratio reflect intense hydrolytic weathering (hot and humid conditions) and low values reflect less weathering (cool, dry climate).
- **Ti/Nb:** Ti is found in a diverse assemblage of minerals including illite, chlorite, mica and heavy minerals (rutile, sphene, brookite, anatase etc.) as well as opaque minerals

(ilmenite, titanomagnetite and magnetite) although it is most common in mudstones. Niobium is also associated with Ti-bearing minerals. Thus a change in this ratio reflects a change in the dominant type of Ti-bearing mineral, and so a likely change in provenance in the mudstone component.

- **Zr/Nb:** Zirconium has a strong affinity with the heavy mineral zircon whilst Niobium is associated with the heavy minerals rutile, anatase and sphene. Trace amounts of Nb are also found in biotite, chlorite and clay minerals. Anatase can also occur as an authigenic cement. This ratio principally reflects the composition of heavy minerals i.e. provenance.
- **Cr/K:** Cr is related to the abundance of heavy minerals e.g. Cr-spinel, and may also be found in clay minerals (e.g. chlorite). K is a very common element in siliciclastic rocks in the form of K-feldspars, glauconite, mica, clay minerals and also as evaporitic minerals as chlorides.
- **Nb:** Niobium is associated with Ti-bearing minerals (see Ti/Nb above). Trace amounts of Nb are also found in biotite, chlorite and clay minerals. Anatase can also occur as an authigenic cement.

In most cases where the geochemistry relates to detrital mineralogy, it is the changes in provenance which we interpret to be the cause of variations in the values of key elements and indices as seen in **Figure 4** and **Enclosure A**. Only certain key indices, such as Ga/Rb, are related to palaeoclimatic variations which are inferred to produce variations in clay minerals present in the basin through chemical weathering.

CONCLUSIONS

- Significant and apparently systematic changes in select elements and element ratios within the study interval have allowed all wells to be correlated producing a strong correlation scheme (**Enclosure A**).
- Nineteen chemostratigraphic packages and thirty one chemostratigraphic units have been defined, though only eighteen units are identified in the wells in this project. (**Table 2**)
- The top of Package 14 is identified as a particularly prominent geochemical surface, with significant changes across this boundary. It may represent an unconformable surface.
- The correlation scheme devised for Chemostrat Report CAu1155 is replaced by a scheme initially developed during construction of correlations to Halifax-1, Hervey-1, Keppel-1 and Redland-1, which has been revised and formalised in this report. This zonation and correlation scheme places all wells in a regional and stratigraphic context.
- Principal Component Analysis was used to relate the geochemistry to mineralogy. Six groups of elements were identified and linked to quartz (Si), Zircon (Zr, Hf) drilling fluids (Ba, S, Sr), aluminosilicates, heavy minerals and diagenetic minerals (see PCA section for details).

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Chemostrat Reports:

- Report CAu1155 (November 2012). Chemostratigraphy of Cooper Basin wells.

FIGURES

Figure 1: Map of wells indicating line of section taken by Enclosure A

Five wells are investigated in this project (large red circles): Halifax-1, Keppel-1, Hervey-1, Redland-1 and Geoffrey-1.

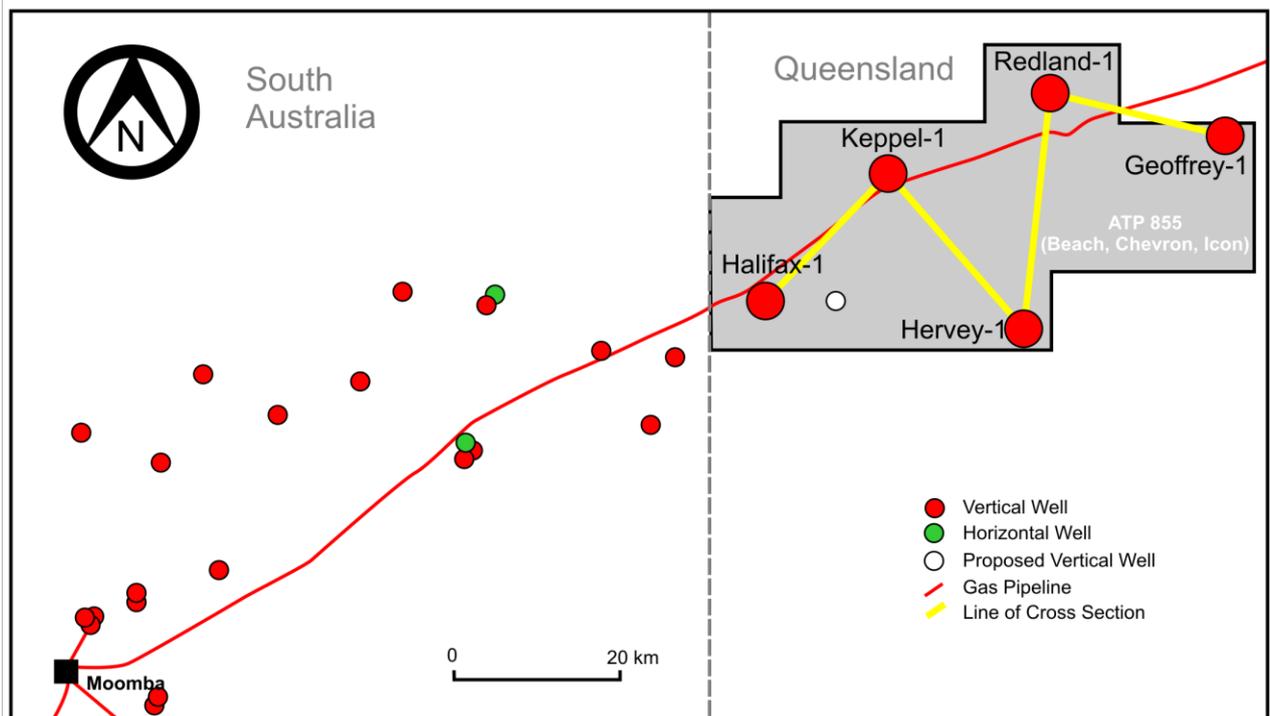


Figure 2: Sample distribution

Mudstone samples are shown as black squares, sandstone samples as yellow squares. Also shown in "ChemGR" which is a synthetic gamma ray trace calculated from the geochemistry (see main text for details). Red stars indicate positions where the wrong lithology has been picked (based on GR).

(Thumbnail view below please refer to attached PDF)

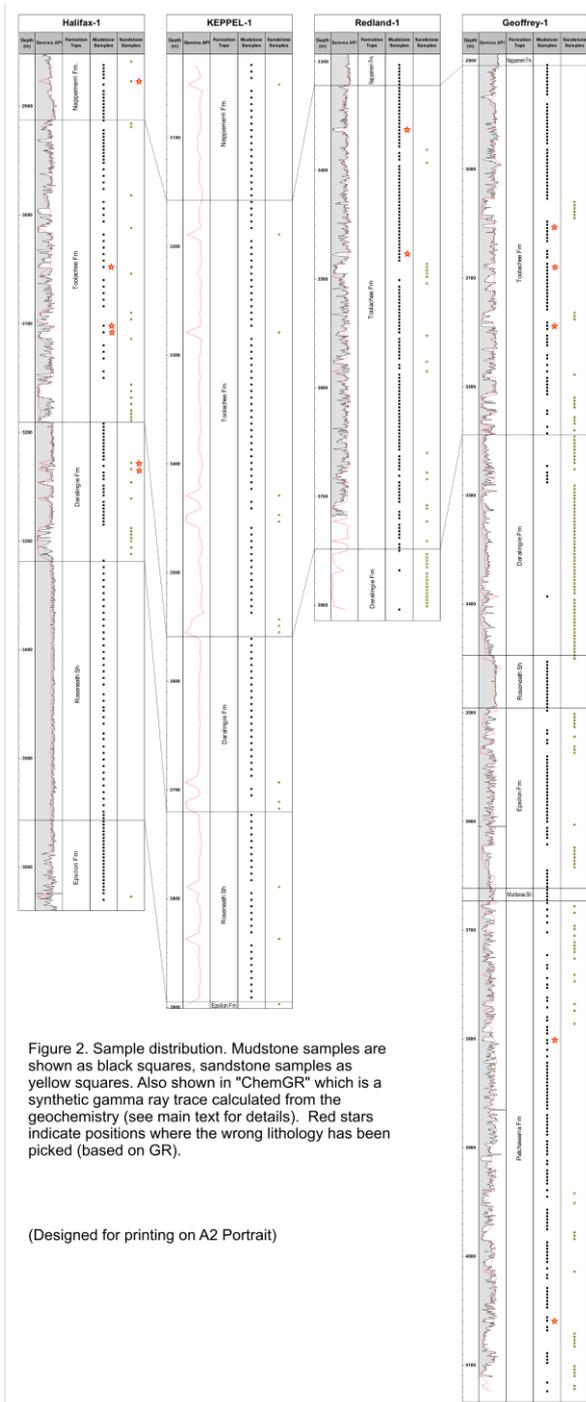


Figure 2. Sample distribution. Mudstone samples are shown as black squares, sandstone samples as yellow squares. Also shown in "ChemGR" which is a synthetic gamma ray trace calculated from the geochemistry (see main text for details). Red stars indicate positions where the wrong lithology has been picked (based on GR).

(Designed for printing on A2 Portrait)

Figure 3: Subdivision of samples into mudstone and sandstone based on Si/Al ratios.

Samples were subdivided into mudstone and sandstone based on their Si/Al values, where a value of 6 marks the change in scaling on a stacked curve. Experience by Chemostrat indicates that this scaling change marks the subdivision of mudstone and sandstone samples.

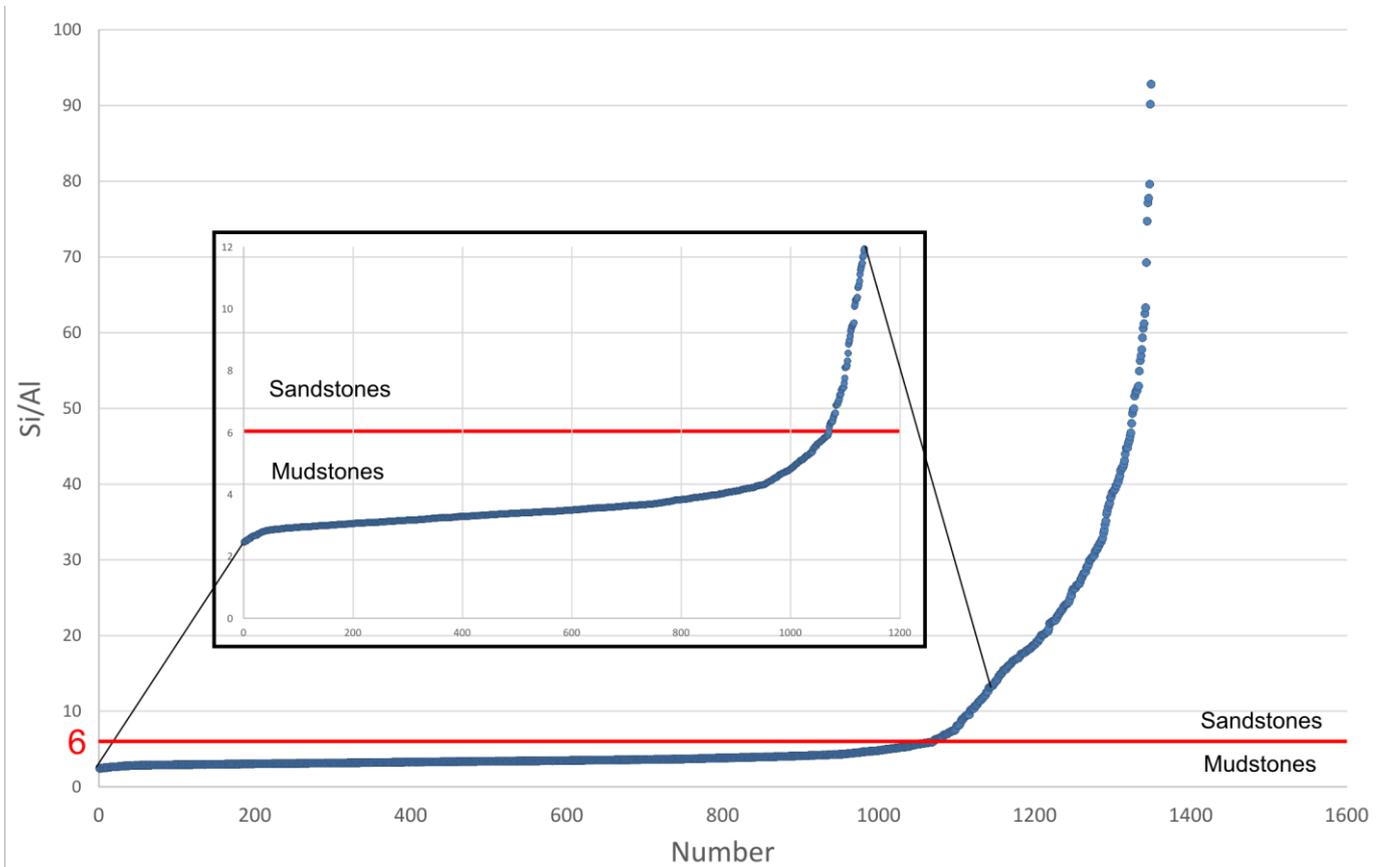


Figure 4: Summary of correlation scheme

Chemostratigraphic packages, based on mudstone data, are shown as coloured fills.

(Thumbnail view below please refer to attached PDF)

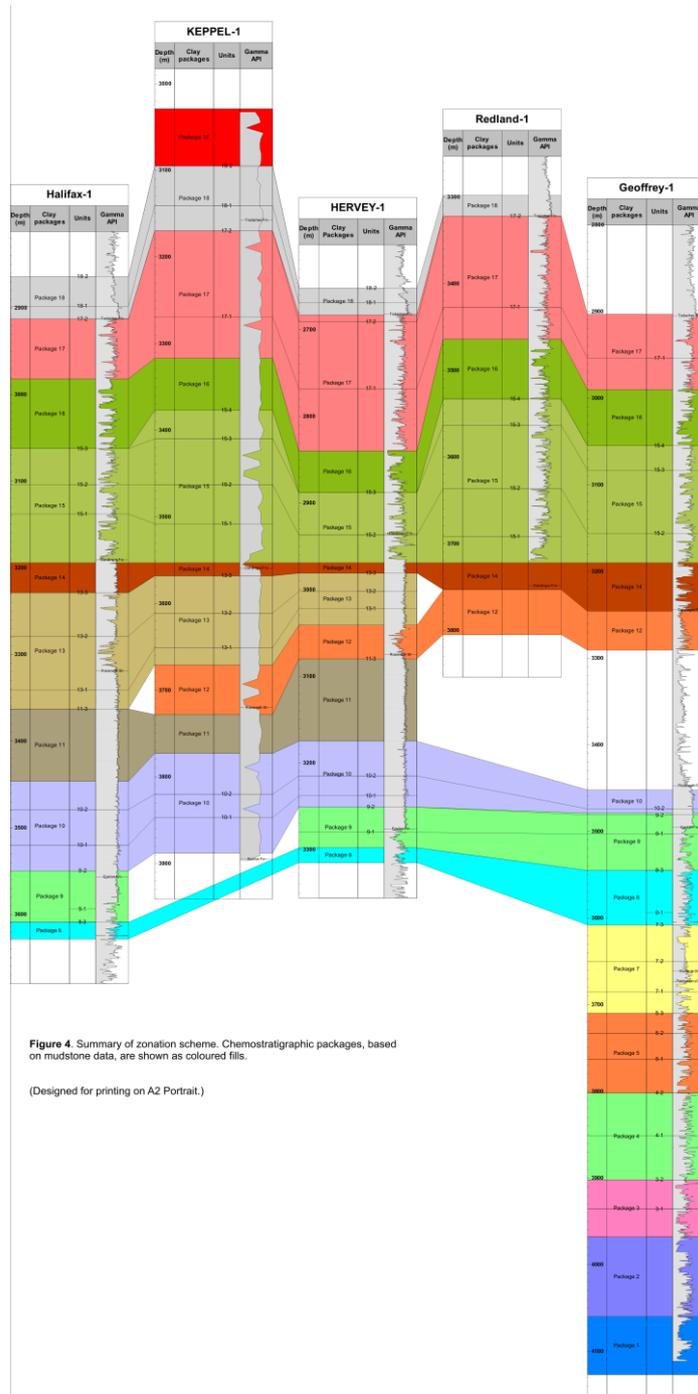
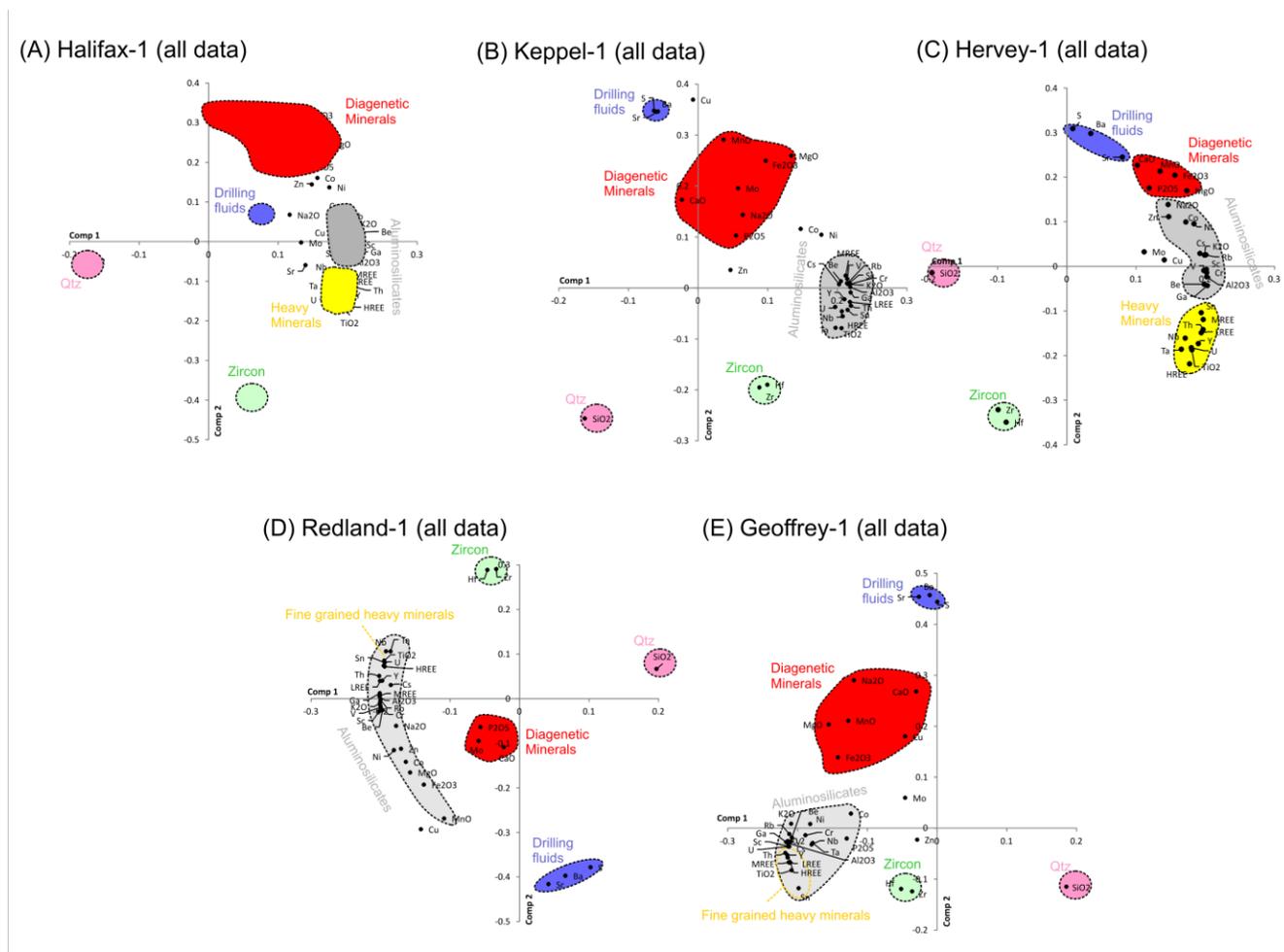


Figure 5: Results from Principal Component Analysis of geochemical data by individual wells.

Clustering of data points indicates that clustered elements are more associated with each other in the cluster than other elements in the data set. Interpretations of the various clusters in terms of mineralogy is indicated by coloured regions. Six element mineral associations are identified, see text for details.



ENCLOSURES

Enclosure A: Full correlation panel

APPENDICES

APPENDIX 1: ELEMENTS AND THEIR CHEMICAL SYMBOLS

Symbol	Atomic Mass	Element	Analysis	Symbol	Atomic Mass	Element	Analysis
Si	28	Silica	ICP/XRF	Ti	48	Titanium	ICP/XRF
Al	27	Aluminium	ICP/XRF	Fe	56	Iron	ICP/XRF
Mg	24	Magnesium	ICP/XRF	Mn	55	Manganese	ICP/XRF
Ca	40	Calcium	ICP/XRF	Na	23	Sodium	ICP/XRF
K	39	Potassium	ICP/XRF	P	31	Phosphorus	ICP/XRF
Be	9	Beryllium	ICP	Ba	137	Barium	ICP/XRF
Co	59	Cobalt	ICP/XRF	Ce	140	Cerium	ICP/XRF
Cs	133	Caesium	ICP	Cr	52	Chromium	ICP/XRF
Dy	163	Dysprosium	ICP	Cu	64	Copper	ICP/XRF
Eu	152	Europium	ICP	Er	167	Erbium	ICP
Hf	179	Hafnium	ICP/XRF	Ga	70	Gallium	ICP/XRF
La	139	Lanthanum	ICP/XRF	Gd	157	Gadolinium	ICP
Nb	93	Niobium	ICP/XRF	Ho	165	Holmium	ICP
Ni	59	Nickel	ICP/XRF	Lu	175	Lutetium	ICP
Rb	86	Rubidium	ICP/XRF	Nd	144	Neodymium	ICP
Sm	150	Samarium	ICP	Pr	141	Praseodymium	ICP
Sr	88	Strontium	ICP/XRF	Sc	45	Scandium	ICP/XRF
Tl	204	Thallium	ICP	Sn	119	Tin	ICP
Th	232	Thorium	ICP/XRF	Ta	181	Tantalum	ICP/XRF
U	238	Uranium	ICP/XRF	Tb	159	Terbium	ICP
W	184	Tungsten	ICP/XRF	Tm	169	Thulium	ICP
Yb	173	Ytterbium	ICP/XRF	V	51	Vanadium	ICP
Zn	65	Zinc	ICP/XRF	Y	89	Yttrium	ICP/XRF
Zr	91	Zirconium	ICP/XRF	Pb	207	Lead	ICP/XRF
Bi	209	Bismuth	ICP/XRF	Mo	42	Molybdenum	ICP/XRF
S	32	Sulphur	XRF	Cl	35	Chlorine	XRF

APPENDIX 2: WHOLE ROCK GEOCHEMICAL DATA, TOC DATA AND STRATIGRAPHIC TOPS SUPPLIED IN XLS FORMAT

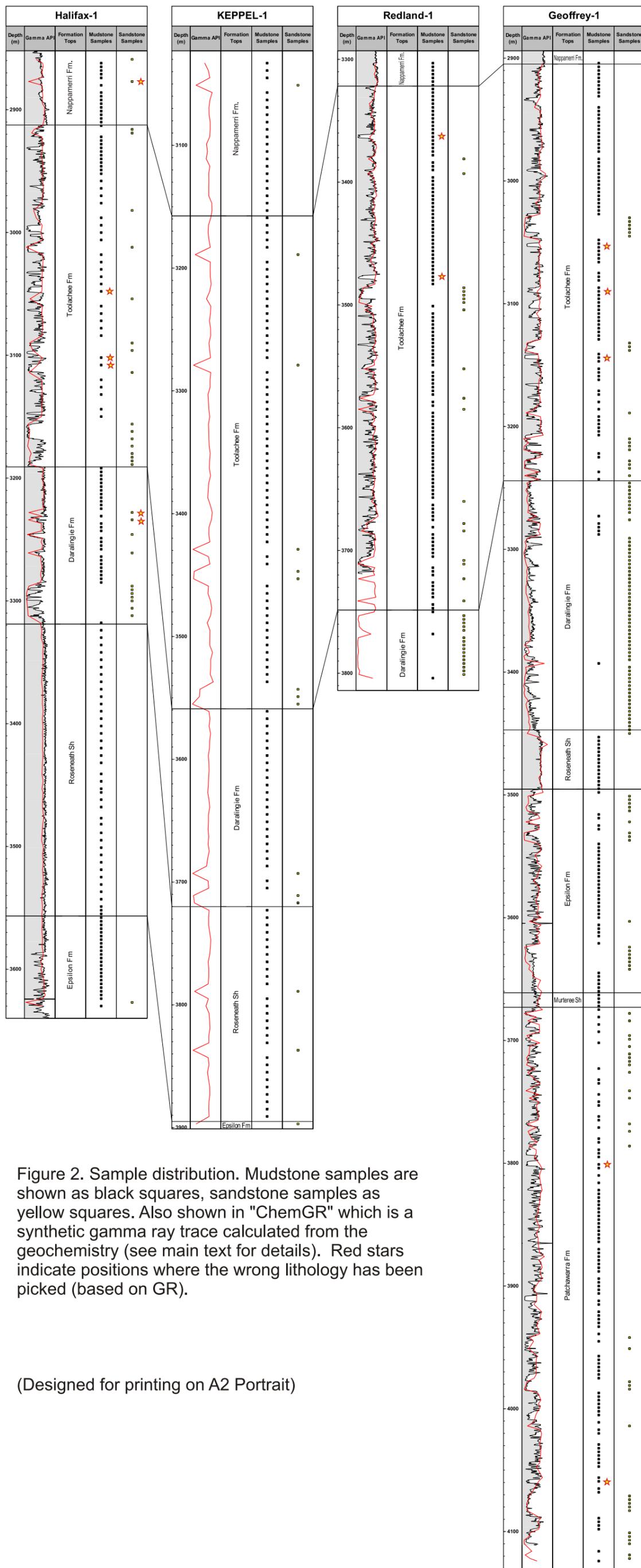


Figure 2. Sample distribution. Mudstone samples are shown as black squares, sandstone samples as yellow squares. Also shown in "ChemGR" which is a synthetic gamma ray trace calculated from the geochemistry (see main text for details). Red stars indicate positions where the wrong lithology has been picked (based on GR).

(Designed for printing on A2 Portrait)

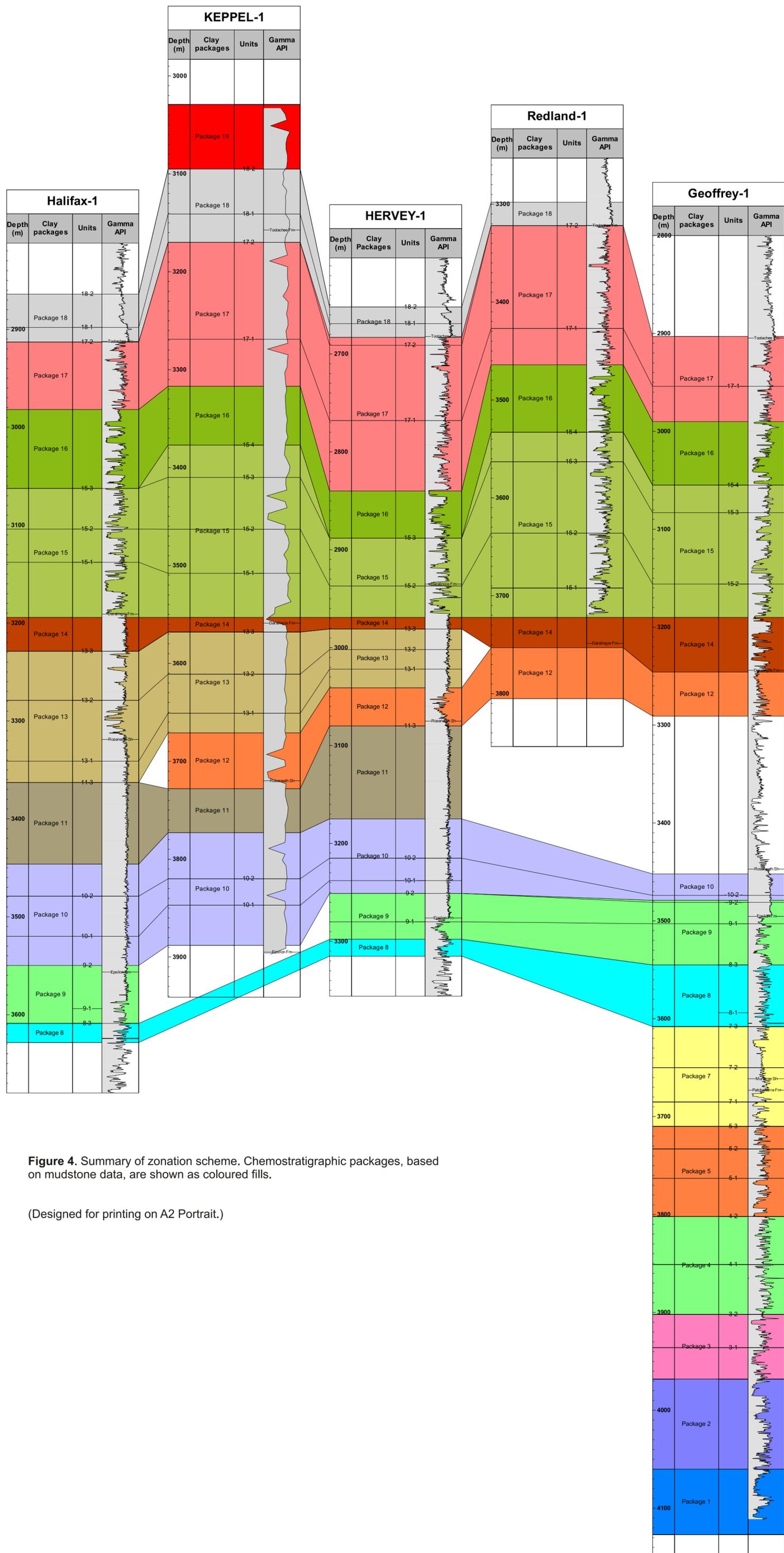
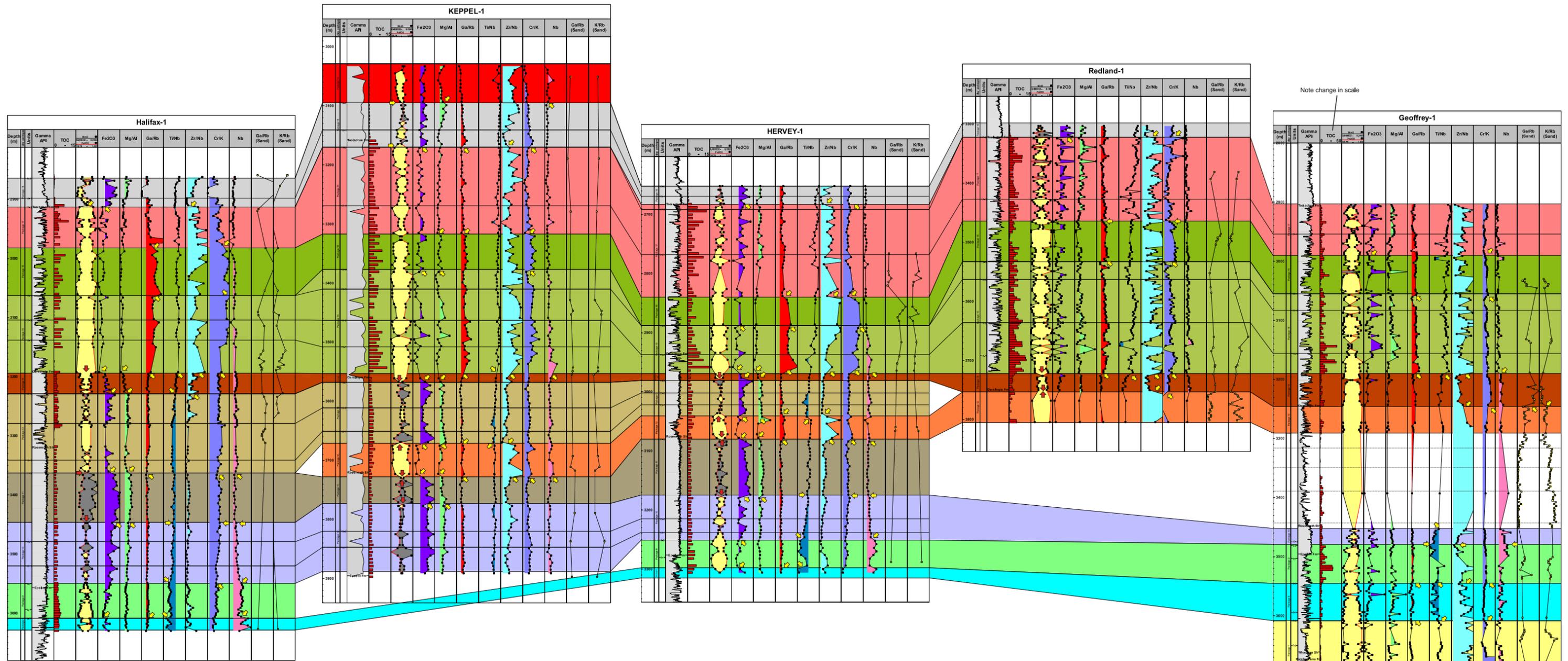


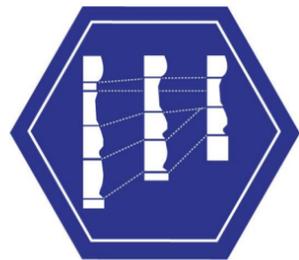
Figure 4. Summary of zonation scheme. Chemostratigraphic packages, based on mudstone data, are shown as coloured fills.

(Designed for printing on A2 Portrait.)



Report CAu5053-ATP855 Chemostratigraphy of selected wells in the Cooper Basin

Enclosure A: Full correlation panel



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