Placing key casing points using wellsite chemostratigraphy in the Ungani Field, Canning Basin, Western Australia

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Abstract

Oil wells in the Ungani Field need to carefully target a casing shoe placement in the top of the Ungani Dolomite reservoir, as close as possible to the boundary with the overlying Laurel Shale seal. This maximises the reservoir interval completed and enables the entire unstable Laurel Shale section to be cased off. X-ray Fluorescence (XRF) elemental analysis was used to identify trends in element concentration and element ratio values in the lower part of the Laurel Shale topseal and the upper part of the Ungani Dolomite reservoir in offset wells. Real-time wellsite application of this technique was then used to predict proximity to the targeted boundary. This method was trialled on two wells, Ungani-4 ST1 and subsequently Ungani West-1. High Fe/Mn values were used to identify penetration into the lower ~20 m of the Laurel Shale while increases in sulphur (S) concentration were used to identify the basal few metres of the Laurel Shale. Subsequently, increased concentrations of Ca, Mg and S were used to identify penetration of the uppermost Ungani Dolomite. The method, combined with controlled drilling rate, was successfully used to place key casing shoes just below the boundary of the Laurel Shale and Ungani Dolomite.

Introduction

The Ungani Oil Field is located on southern flank of the Fitzroy Trough, Canning Basin, Western Australia (Fig. 1) (Edwards & Streitberg, 2013). The Famennian to Tournasian-aged "Ungani Dolomite" (e.g. Edwards & Streitberg, 2013) reservoir is sealed by the 50 to 100 m thick 'Lower Clastic Member of the Laurel Formation' (Edwards & Streitberg, 2013), herein referred to as the 'Laurel Shale' (Figs 2, 3). As the Laurel Shale is prone to splintering and caving into the borehole, elevated mud weights are required while drilling, and casing is preferably set to isolate the entire section (Figs 4, 5). The oil-bearing dolomite reservoir, by comparison, is normally pressured and has a vuggy porosity system with multi-Darcy permeability and does not typically develop a borehole mud cake. As a result, it is ideally drilled with lower mud weights to minimise mud losses and potential formation damage. This was not previously recognised in the initial wells. In Ungani-2 and -3 the production casing was run more than 10 m into the Ungani Dolomite reservoir, whereas Ungani-4 was cased 20 m above the reservoir resulting in borehole completion issues and eventually the need for a side-track. The challenge is therefore to set casing just into the dolomite reservoir but as close as possible to the base of the Laurel Shale. However, pre-drill uncertainty on the depth to top reservoir from seismic interpretation is about ±10 metres, which means the casing point must be selected by appropriate wellsite techniques. The focus in drilling of more recent wells (Ungani West-1, Ungani-5, Ungani-4 ST1) has been to identify and set casing below the base of the shale but not deeper than 5 m into the Ungani Dolomite reservoir.

The Laurel Shale is a monotonous black shale, as seen in core (Fig. 3), and cannot be sub-divided biostratigraphically, occurring entirely within the *G. spiculifera* biozone. In addition, it does not give any reliable indications from cuttings or LWD GR (logging while drilling gamma ray) when nearing the base of the interval (Fig. 3). The uncertainty in depth prognosis based on seismic and other methods, including well correlation, is too large to be used for the purpose of predicting the top of the Ungani Dolomite and precisely selecting the casing point.

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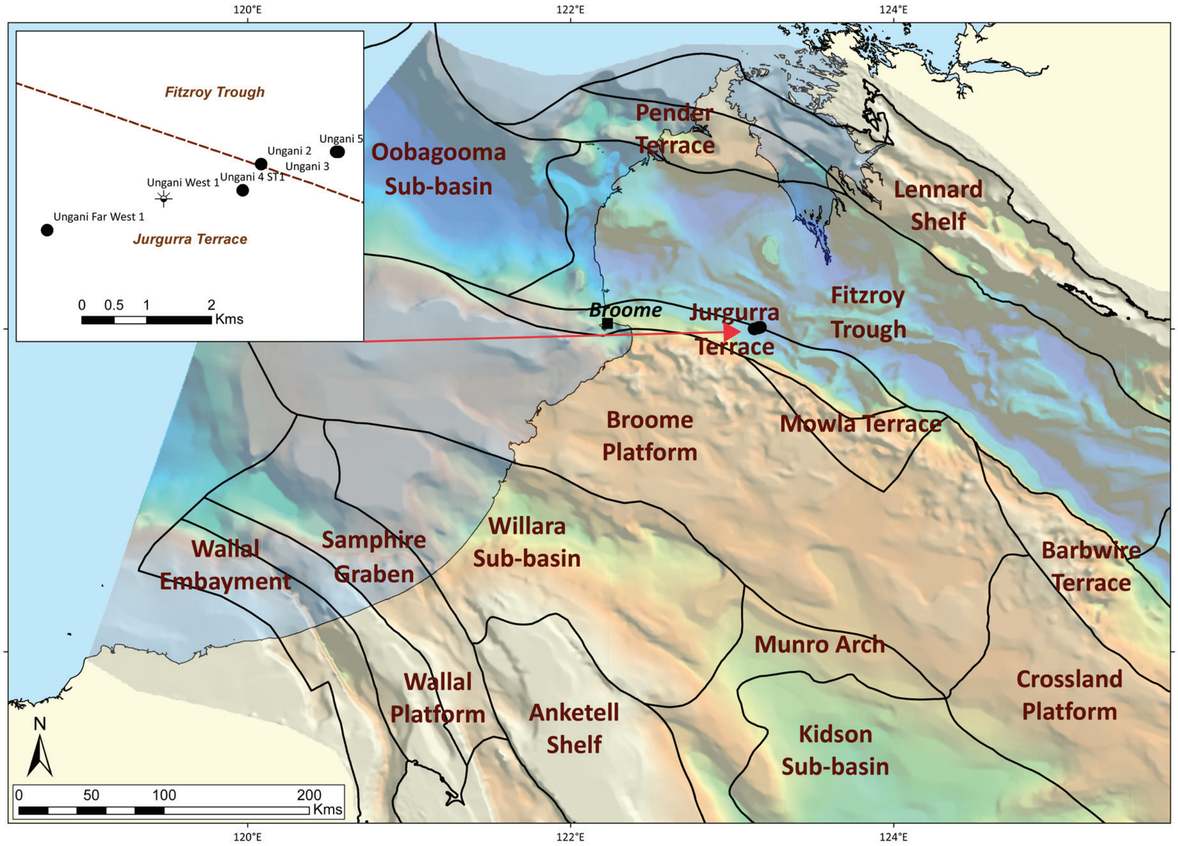

Figure 1. Map of the study wells in the Ungani Oil Field, Canning Basin, Western Australia, with background from Canning Basin SEEBASE (Frogtech Geoscience, 2017).

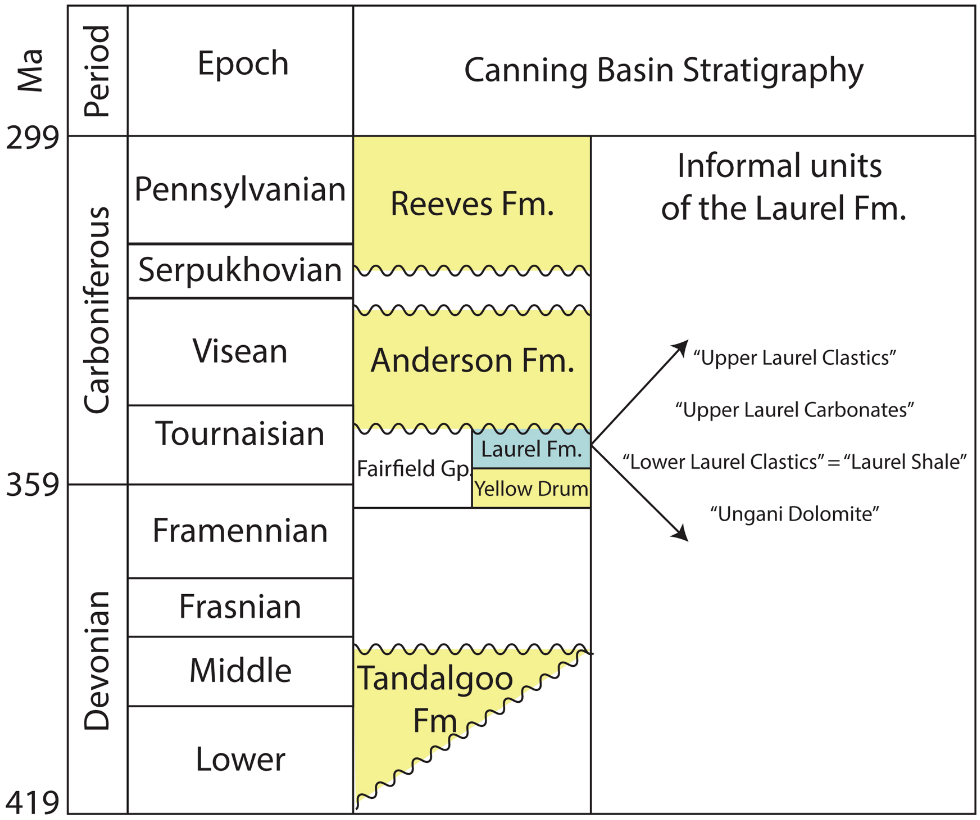

Figure 2. Relevant stratigraphy of Canning Basin, demonstrating the informal units of the Laurel Formation.

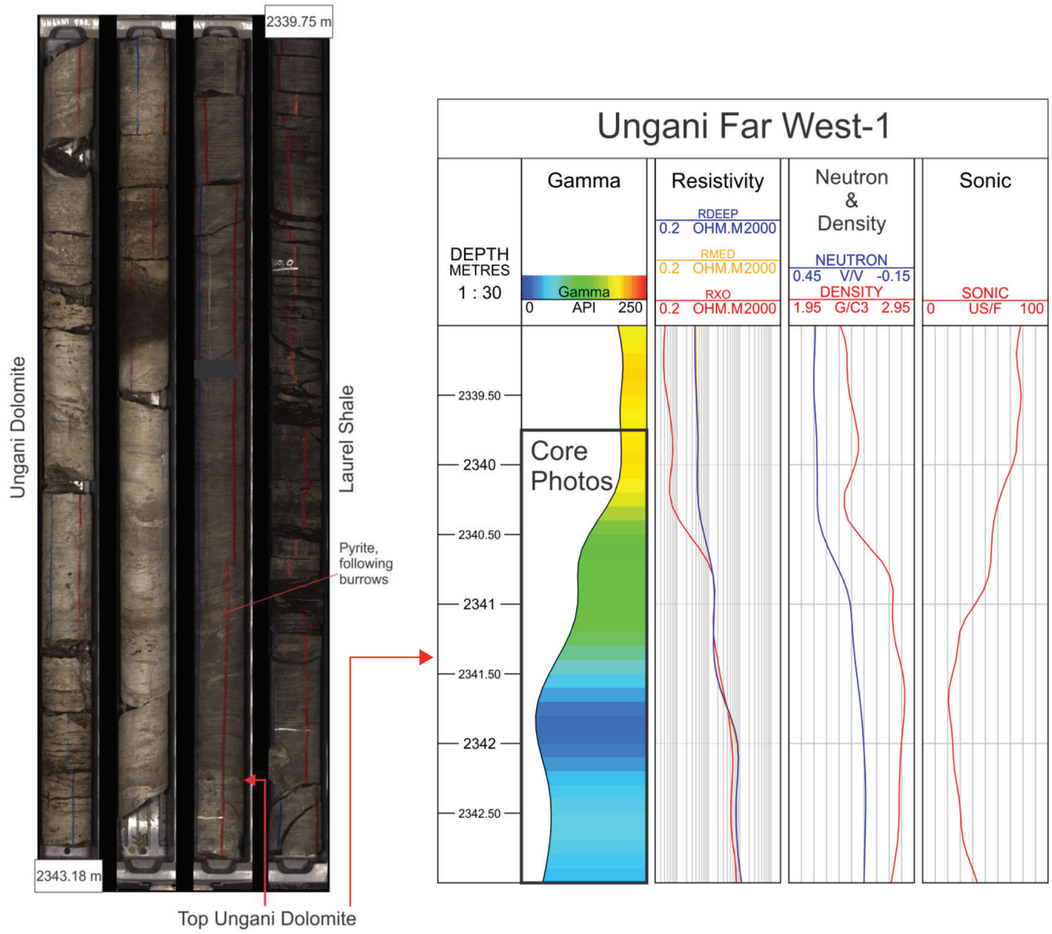

Figure 3. Core photos and Wireline curves from Ungani Far West-1 showing lowermost Laurel Shale and uppermost Ungani Dolomite.

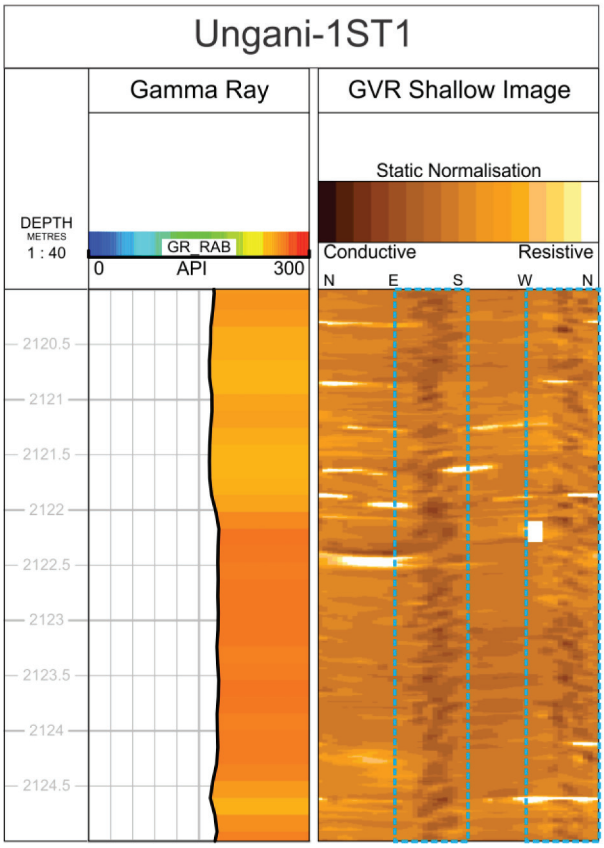

Figure 4. Shallow GVR resistivity image from Ungani-1 ST1 showing borehole breakout (features outlined with blue dashed boxes) in the Laurel Shale.

In addition, the boundary between the Ungani Dolomite and the Laurel Shale is not easy to identify in cuttings samples because cavings from the Laurel Shale contaminate and dominate cuttings samples from the Ungani Dolomite. Furthermore, thin calcite/dolomite beds or nodules present in the lower Laurel Shale can give a false indication of having penetrated the Ungani Dolomite. With the LWD GR tool placed 10 m behind the bit, this tool cannot be used to identify the contact until the bit has penetrated too deep into the Ungani Dolomite. LWD tools placed closer to the drill bit were prohibitively expensive, and often unavailable, and a more cost-effective solution was required.

Chemostratigraphy, the correlation of sediments based on their inorganic elemental geochemistry, was proposed as a potential tool to aid the placement of the casing shoe just below the Laurel Shale/Ungani Dolomite boundary. This paper describes the methods and results of chemostratigraphy performed at wellsite in order to identify this contact.

Figure 5. Splintered shale cuttings from 2170 mMD in Ungani-1.

Methods

The instrument chosen for chemostratigraphic analysis on wellsite was a handheld X-Ray Fluorescence device (XRF; Thermo Niton XL950). It was selected due to its portability and rapid measurement capability. The XRF measures the elemental abundances of a specific set of elements in a sample.

Approximately 4–5 grams of washed and dried cuttings were placed into a plastic measuring cup with polypropylene film on the base. These were then placed into the sample holder/ radiation shield with the polypropylene film in contact with the XRF aperture. Measurement time was 2.5 minutes.

Samples were analysed directly after they were collected from the shakers, washed and dried. The data were output into Microsoft Excel and major elements (Si, Al, Ca, Mg, Fe, Mn, Ti, K) were calculated into their oxide weight % from the elemental parts per million (ppm). Trace elements (S, P, Cl, Ba, Cr, Nb, Ni, Rb, Sr, Th, U, V, Zn, Zr, Cu, Mo) were measured in ppm. A synthetic GR (ChemGR, Jarvis & Jarvis, 1992a,b) was calculated based on the concentrations of K, Th and U. Selected individual elements and element ratios were plotted by depth and compared between reference wells for correlation (Fig. 6).

Results of wellsite analysis

Pre-drill calibration

In preparation for real-time wellsite analysis, cuttings from the Laurel Shale and Ungani Dolomite in offset wells were analysed using the XRF instrument in an identical manner to that which would be used during the wellsite analysis. The wells available for pre-drill analysis were Ungani-1, Ungani-4 and Ungani-5. Analyses were conducted at 5–10 m spacing.

Data were examined to determine which elements and element ratios were best suited to subdividing the Laurel Shale. Our focus was on determining proximity of the drill bit to the

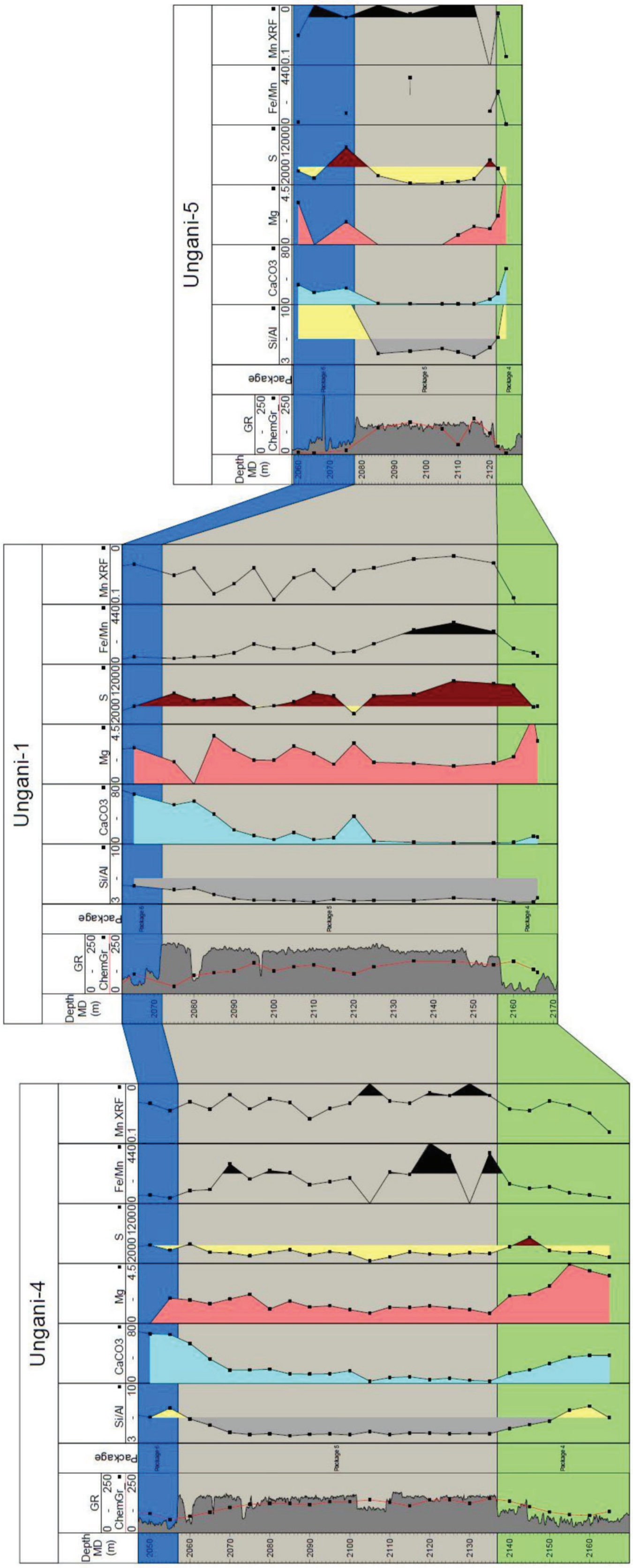

Figure 6. Pre-drill XRF analysis of existing cuttings on Ungani-4, -1 and -5. Package 5 (green) is the Ungani Dolomite, Package 6 (grey) in the Laurel Shale and Package 7 (blue) is the Upper Laurel Carbonate.

top of the Ungani Dolomite when drilling through the lower section of the Laurel Shale.

Fe/Mn was determined to be a key element ratio in identifying the lower portion (~15–20 m) of the Laurel Shale (Fig. 6). In addition, increases in Mg, Ca and S clearly demonstrate when the well first penetrates the Ungani Dolomite (which can be uncertain from other wellsite methods, as described above). The Mg concentrations encountered are close to the detection limits of the instrument, but repeatable, which is sufficient for the purposes of this work. Consistent trends in chemical signature established in offset wells gave confidence in applying the chemostratigraphy technique to determine the precise stratigraphic level in future wells. This successful pre-drill trial led to implementation at the wellsite.

Ungani-4 ST1 wellsite analysis

During drilling of Ungani-4 ST1 the data were primarily compared to the analysis of Ungani-4. Once the high Fe/Mn was detected, indicating that the well had intersected the lower ~10–20 m of the Laurel Shale, the drilling speed was kept constant to monitor for any drilling breaks and cuttings samples were collected every 1 m to the section TD giving a higher resolution data set. Clear increases in Mg, Ca and S values indicated that the uppermost 4 m of the Ungani Dolomite had been penetrated.

Section TD was tentatively called when this dolomite signal was first identified in the cuttings sample at 2132 m. The well circulated bottoms up and the additional cuttings samples were analysed, confirming the top of the Ungani Dolomite had been intersected and section TD was confirmed.

The top of the Ungani Dolomite (Package 4) in this well is anomalously high in siliciclastic material with high Si and Al values compared with dolomite in other wells. Si/Al values are high indicating the quartz-rich nature of this siliciclastic material compared to the overlying Laurel Shale. This was later confirmed to be silt-grade material rich in quartz (Omma & Benedictus, 2019). The quartz-rich nature of the cuttings at the top of the Ungani Dolomite was initially interpreted as 'calcareous sandstone' from the wellsite cuttings description, which caused confusion about the exact stratigraphic nature of this section. However, XRF data were able to confirm that the Ungani Dolomite had been intersected.

The high-resolution cuttings XRF analysis of the lower Laurel Shale in Ungani-4 ST1 allowed identification of increased S values in the basal 12 m, and very high S values in the basal 4 m of the Laurel Shale (Package 5, Fig. 7). This had not been identified previously due to the signal having been lost in the larger (5 m) cuttings intervals used for the pre-drill analysis.

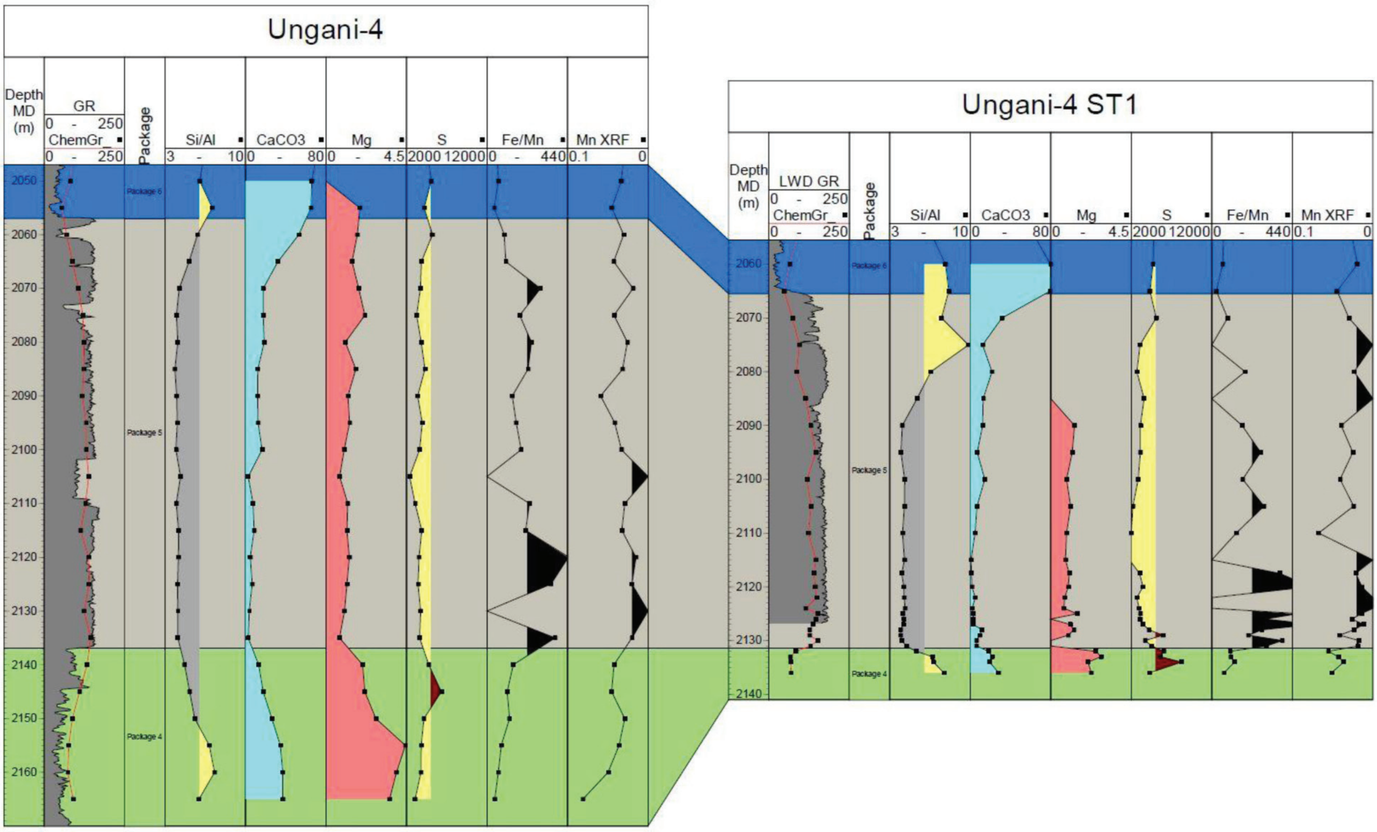

Figure 7. Ungani-4 ST1 wellsite XRF analysis data with Ungani-4 for comparison. High Si/Al in the Ungani Dolomite (Package 4) indicates the quartz-rich nature of the siliciclastic material present in this well.

Ungani West-1 wellsite analysis

Prior to drilling Ungani West-1, but after the Ungani-4 ST1 wellsite XRF analysis had been completed, core from Ungani Far West-1 was analysed using the same technique and instrument. The core covers the lower part of the Laurel Shale and the upper part of the Ungani Dolomite (Copp, 2016). Its analysis allowed for high resolution sampling over the interval, similar to the 1 m planned cuttings samples to be collected in Ungani West-1. Additionally, the Ungani Far West-1 core provided a control point to the west of the Ungani Field, with Ungani West-1 to be drilled between Ungani Far West-1 and the Ungani Field (Fig. 1).

The data from the Ungani Far West-1 core also demonstrated increasing S values in the lower Laurel Shale, with high values above 4000 ppm in the basal 11–12 m, and very high values above 8000 ppm in the basal ~4–5 m which coincides with a zone of pyrite (Copp, 2016). The XRF analysis on core causes some offsets in the data values versus measurements made on cuttings (Fig. 8). This is due to the different measurement geometry resulting from placing the XRF directly on the core.

An increase in Fe/Mn values in Ungani West-1 indicated that the lower portion of the Laurel Shale had been penetrated. At this point drilling parameters were held constant to monitor for drilling breaks and cuttings samples were collected at 1 m intervals. Subsequently, slight increases in S values to greater than 3500 ppm were identified, confirming the lower portion of the Laurel Shale had been intersected.

When S values increased further, to greater than 5000 ppm, it was predicted that this sample was within 5 m of the top Ungani Dolomite based on a trend established in offset wells. Subsequent high Ca, Mg and S values indicated that the Ungani Dolomite had been penetrated after a further 3 m and section TD was called. Two subsequent cuttings samples also had high Ca, Mg and S values, confirming penetration of the Ungani Dolomite.

Discussion

Controls on sediment geochemistry

The causes of the variations in the geochemistry are simple to explain in some cases. Increases in Ca and Mg are related to the lithology change from shale to dolomite. Elevated S concentrations, which are a critical wellsite indicator, are associated with the presence of pyrite and minor amounts of other sulphides (e.g. sphalerite which is identified by high Zn concentrations from XRF data). Sulphur (pyrite) appears to concentrate at the top of the dolomite and the lower < 5 m of the overlying Laurel Shale. Above this S values decrease to background levels over approximately 10–15 m from the top

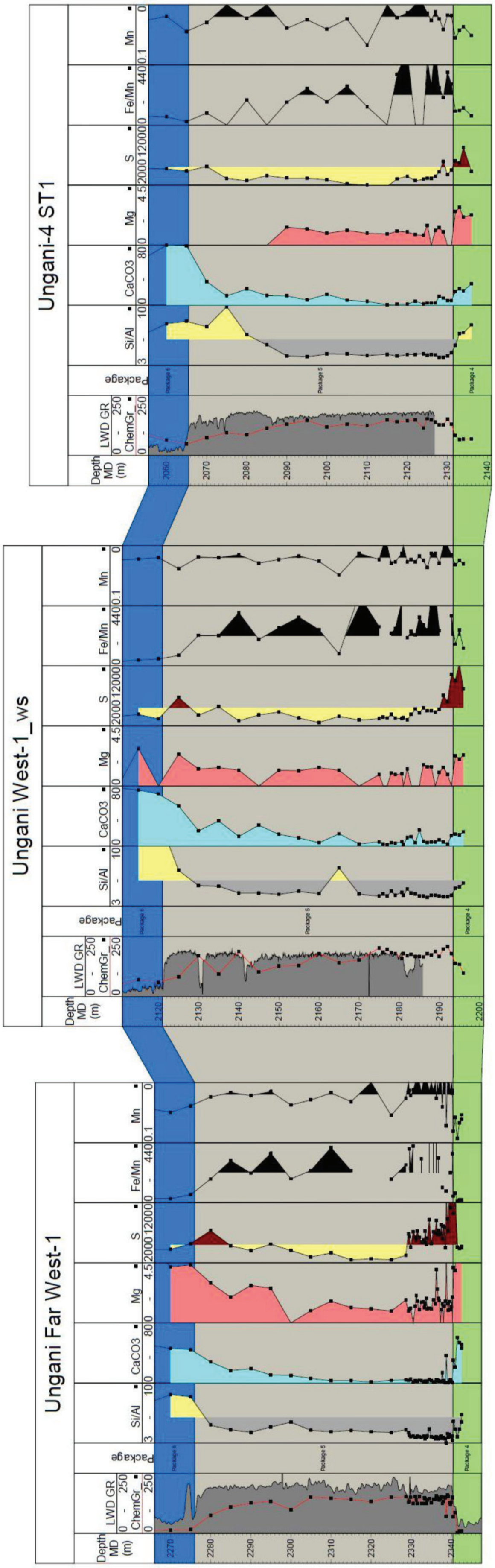

Figure 8. Wellsite XRF analysis data from Ungani West-1 and Ungani-4 ST compared with cuttings and core XRF analysis from Ungani Far West-1. Analysis of the core is higher resolution but results in a systematic offset compared to the cuttings.

of the dolomite. These upward decreases in S are postulated to be controlled by the limited extent of penetration of diagenetic fluids from below into the low permeability Laurel Shale. While pyrite presence due to precipitation during or shortly after sediment deposition in an anoxic setting is possible, the extremely high S concentrations and high Zn concentrations in places strongly suggests some type of later sulphide diagenesis instead. Perhaps something analogous to the sulphide mineralization seen in the Lennard Shelf in the Canning Basin (e.g. Wallace et al., 2002).

The changes in the Fe/Mn values within the Laurel Shale are difficult to explain. Both elements have similar affinities (e.g. clays and Fe-rich carbonates), and the high Fe/Mn values in the lower part of the Laurel Shale are caused by low Mn values. The Mn concentrations may be used as a geochemical indicator for the lower Laurel Shale (Figs 6, 7, 8). However, the Fe/Mn ratio is used in an attempt to remove any significant lithology controls on the Mn concentration, focusing on *relative* Mn enrichment or depletion.

The low Mn values may be caused by changes in the abundance of carbonates within the lower part of the Laurel Shale (where Mn is related to carbonates) or due to changes in the composition of the clays in the upper parts of the Laurel Shales. Mn may be related to the palaeoredox conditions. Less Mn is typically preserved in more reducing conditions due to its solubility in its reduced state, suggesting more reducing conditions in the lower part of the Laurel Shale (e.g. Calvert & Pedersen, 1993).

Key learning points

Pre-analysis of the critical lithological section in nearby wells was a key factor in successful application of the technique at wellsite. Knowing what geochemical signals to expect, and having confidence in their stratigraphic position, resulted in more confident decisions on the wellsite.

Washing and drying of samples was important in obtaining good quality data from the XRF. This took 10–20 minutes on wellsite. Added to this, lag times of the cuttings samples of approximately 30–40 minutes meant that a sample at the bit at any moment may take up to 60 minutes to be analysed (Fig. 9). In other words, by the time a sample is analysed another 60 minutes worth of drilling may have occurred. Depending on the rate of penetration (ROP), this could represent a significant interval.

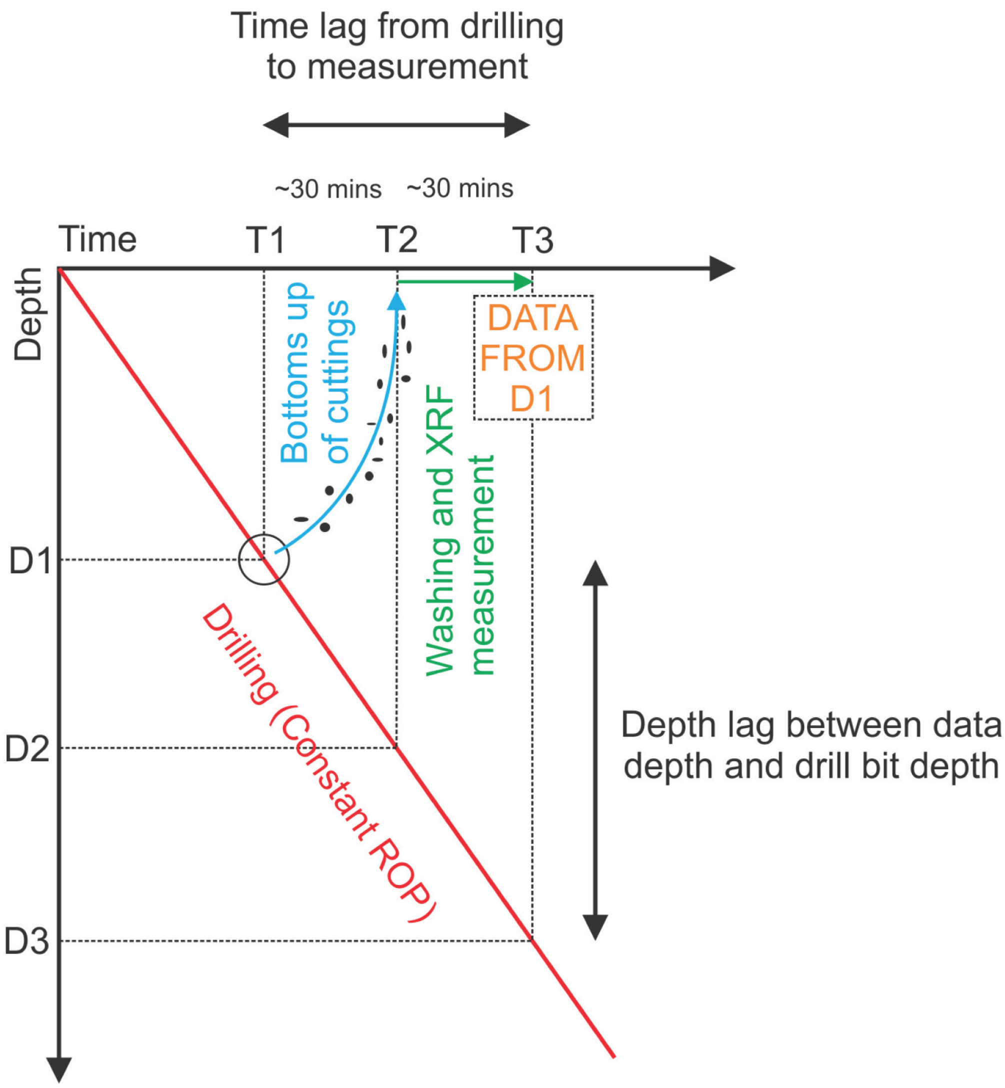

Figure 9. Wellsite analysis timings, demonstrating lag time and sample processing time while drilling.

Fixed drilling parameters and monitoring ROP for drilling breaks, which could indicate a change in lithology near the base of the Laurel Shale, was key in picking the top Ungani Dolomite contact. This allowed time to circulate bottoms up and analyse the cuttings samples, because of the time associated with sample processing and lag times. While pausing to circulate added time (and cost) to the well, it enabled analysis of cuttings without overshooting the desired section TD point. The high resolution (1 m) cuttings samples were invaluable to the success of the project, allowing for identification of the increasing S concentration in the lower 5–10 m of the Laurel Shale. This signal was occasionally visible in the 5 m cuttings samples in some previously analysed wells, but unclear and inconsistent, likely due to the averaging effect of the larger cuttings intervals.

Conclusions

Wellsite XRF analysis of cuttings samples in near real time enabled optimal selection of key casing points in two wells in the Ungani oil field in the Canning Basin. Identification of geochemical trends 20 m (high Fe/Mn), 10–15 m (increased S) and ~3–5 m (high S) above the targeted casing point were used to identify when to keep drilling parameters constant and to predict the depth of the contact between the Laurel Shale and the Ungani Dolomite, which was targeted for the casing point. In addition, the elemental data were used to identify quartz-rich siliciclastic material in the reservoir in Ungani-4 ST1, using Si/Al values.

Collection of high-resolution cuttings samples (1 m spacing) was important in more clearly recognising subtle and localised trends in the geochemical signals in what is otherwise a geochemically monotonous shale.

A pilot project analysing previous penetrations of the Laurel Shale and its contact with the underlying Ungani Dolomite was key to the success of the project.

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Biographies

Anne Forbes has a BA Hons and a Masters in Geology from the University of Cambridge, UK, and a PhD in Volcanology from The Open University, UK. Her PhD involved geochemical studies, analysis of rock fractures, and extensive field work in Iceland. Anne joined Chemostrat in Perth in 2014. She has worked on chemostratigraphy projects across all major basins of the North West Shelf, as well as recent projects in the Otway and Canning basins. She is a member of PESA and the Geological Society of London.

David Long joined Buru in July 2013 and has 26 years of technical and managerial experience in exploration and production. He was previously located overseas with Shell International, Premier Oil and PDO in the UK, Eastern Europe, Pakistan, Netherlands, Indonesia, and Oman. On emigrating to Australia in 2004, David spent six years with Woodside working on international and Australian exploration opportunities, followed by two years with Apache on Asia-wide new business. He is a Geophysicist with a Masters degree from Imperial College, London.

Fionna McNee graduated with a BSc Hons in Geology from The University of Glasgow, UK, in 2015. She then completed a Masters Degree in Basin Analysis and Petroleum Geoscience at Curtin University in 2016. After an internship at Transerv in Perth, she joined Buru in 2016 as a Geophysicist, where she has been participating in exploration, wellsite operations and development activities.

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Andrew Wilson gained BA (Hons) and MSci degrees in Geological Sciences from the University of Cambridge in 2005. He then went on to complete his PhD in Geology at Cambridge in 2009. Moving to Liverpool University Andy joined the STRAT Group as a researcher studying the stratigraphic architecture and sedimentology of the fluvial Beaufort Group in the Karoo Basin of South Africa. In 2013 Andy moved to Perth to take up the position of Geological Manager with Chemostrat Australia. He then worked as a borehole image interpreter and sedimentologist for some years before founding ImageStrat.