Depositional, diagenetic and mineralogical controls on porosity development in the Ungani Field, Canning Basin

June Then*
Buru Energy
16 Ord Street, West Perth WA 6005
junethen@buruenergy.com

Moyra E.J. Wilson
University of Western Australia
35 Stirling Street, Crawley WA 6009
moyra.wilson@uwa.edu.au

Iain Copp
Good Earth Consulting
Perth WA 6000
iain@goodearthconsulting.com.au

Maja Buschkuehle
buschkuehle@bigpond.com

Ronell Carey
Corescan
1/126 Grandstand Road, Ascot WA 6104
r.carey@corescan.com.au

SUMMARY

A 75 m-thick section of Early Carboniferous Tournaisian Ungani Dolomite reservoir was continuously cored in Ungani Far West 1, an appraisal well 3 km west of the Ungani field located on the southern flank of the Fitzroy Tough in the Canning Basin. The objective of this coring program was to better understand the pore systems, mineralogy, and diagenetic history of the reservoir to allow calibration and extrapolation of the petrophysical evaluation of the reservoir at the Ungani field. Petrography, stable isotopic, XRF, hyperspectral logging, grain density and CT scan studies were conducted on the core. The core consists of a 12m overlying sealing shale and 63 m of vuggy, fractured and dolomitised reservoir. The reservoir is commonly bioclastic-rich but pervasive dolomitisation hinders recognition of earlier depositional features. The upper carbonate facies is interpreted as shallow to moderate depth marine ramp-type deposits while the lower carbonate facies is suggestive of shallow platform top settings with 'reefal' constructing organisms. Bio-mouldic, vuggy, fracture, cavern and inter-crystalline porosity resulting from multistage brecciation, fracturing, dolomitisation and dissolution events are all present and critical to reservoir development. Based on hyperspectral logging and thin section petrography, the reservoir is predominantly dolomite with late phase cements comprising of quartz, calcite, gypsum, anhydrite, chalcedony, dickite and pyrite. Variable grain densities that correspond with porosity have been noted throughout the core but no obvious relationship between the mineralogy and porosity can be established. Shallow to moderate burial and marine or evaporative reflux fluids are likely responsible for the pervasive dolomitisation. Subsequent leaching of calcite is also key to reservoir development.

Key words: Canning Basin, Early Carboniferous, Tournaisian, dolomitisation, carbonate ramp system, diagenesis.

INTRODUCTION

Pre-1990 exploration for high quality reservoirs of the Early Carboniferous Tournaisian Fairfield Group carbonates of the Canning Basin focussed on the platform areas of the Lennard Shelf and to a lesser degree the Jurgurra Terrace (Figure 1). Historically, quality reservoir development largely proved elusive, perhaps unsurprising given that carbonates are considered notoriously heterogenous and unpredictable. Pores are mainly secondary after dissolution, cavity formation, dolomitisation and fracturing, and are on a sub-mm to decimetre scale. Dolomitisation is ubiquitous within the basin with observations from core on the Lennard Shelf showing that dolomitisation is highly variable but is well-developed in inner ramp and shallow restricted subtidal-intertidal facies (Seyedmedhi, 2011). Limestones in the basin are also dolomitised and generally have very poor porosity, likely a result of burial calcite cementation (Wallace, 1990).

The discovery of the Blina oil field in 1981 proved commercial viability with reservoir porosity of up to 30% within the Fairfield Group's Yellow Drum Formation. Blina remained the only commercial success in carbonates of the Canning Basin until the discovery of the Ungani oil field in 2011 within an age equivalent formation. Ungani 1 was drilled by Buru Energy as an on trend follow up to the tight gas, distal Laurel Yulleroo discovery on the Southern Fitzroy Trough Margin. The well instead serendipitously discovered oil within vuggy, fractured dolomite. In the absence of a definitive age dating, the dolomite was informally named the Ungani Dolomite and assigned to the Fairfield Group (Edwards & Streitberg, 2013). Lithostratigraphic units within the Fairfield Group are poorly defined due to limited outcrop exposure, incomplete well sections, and obscured contacts with other formations. In general, however, the Fairfield Group is a mixed carbonate and siliciclastic ramp system that overlies the Late Devonian Windjana/Nullara reef complex, and is overlain by shallow marine to fluvial Late Tournaisian Anderson Formation.

The drilling of six additional follow up wells such as Praslin 1 and Ungani Far West 1 demonstrated that the porous dolomite is laterally extensive. Wells such as Cow Bore 1, Crab Creek 1 and East Crab Creek 1 were revisited and they too support the presence of widespread porosity development in dolomitised moderate to high energy deposits on the southern basin margin (Figure 3). Twenty eight percent log porosity was interpreted in Cow Bore 1 with vuggy, intergranular, 'oolitic and pesolitic' porosity all described from dolomite cuttings (Gulf Oil, 1985).

Studies and analysis of the Ungani Dolomite reservoir based on the core recovered Ungani Far West 1 and comparison and calibration with log data has provided significant insights into the nature and distribution of matrix and secondary porosity and the contribution of each to effective porosity (Long et al, 2018). The integration of the data confirms that the Ungani Dolomite reservoir is bimodal with a predominant background of low matrix porosity (<2%) and subordinate discrete zones of vugs providing excellent reservoir quality with porosities of up to 50%. Correlation with the log and borehole image data from the Ungani 1/ST1, Ungani 2 and Ungani 3 wells shows that the Ungani Dolomite shows a consistent pattern of a 15 m to 20 m thick zone with some excellent quality reservoir at the top, a middle zone of generally poor reservoir quality (30-35 m) and a lower zone with intervals of good to excellent reservoir quality.

Conventional coring was attempted at Ungani 2 but less than 10m of core was recovered from the 90m cored interval. It was questionable how representative of the reservoir the core was since tight carbonates with very poor porosity and permeability were recovered whilst image logs acquired at Ungani 1 and 2 showed chaotic zones of macro-scale irregular, fractured, vuggy-to-cavernous porosity. Until the drilling of Ungani Far West 1, no direct comparison could be made between core and image logs. The 97% core recovery at Ungani Far West was made possible with the use of a retrofitted DDH1 mineral rig with a high RPM.

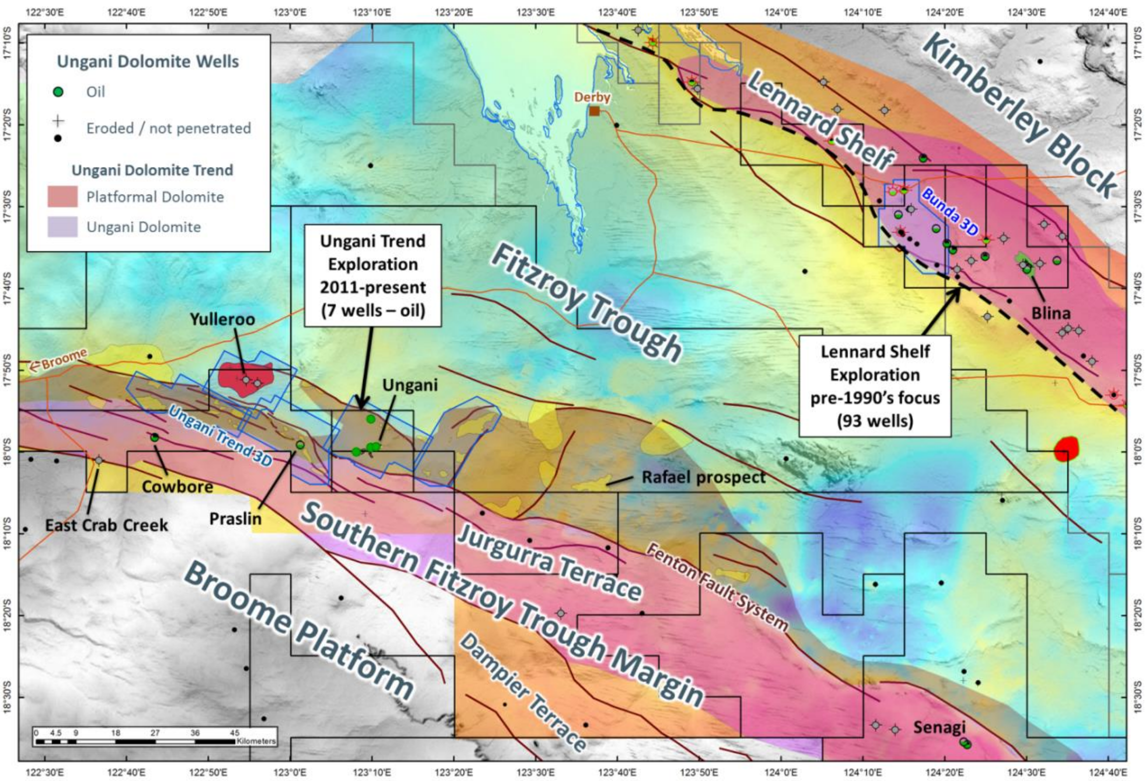

Figure 1. Location map with tectonic elements and Top Dolomite depth map.

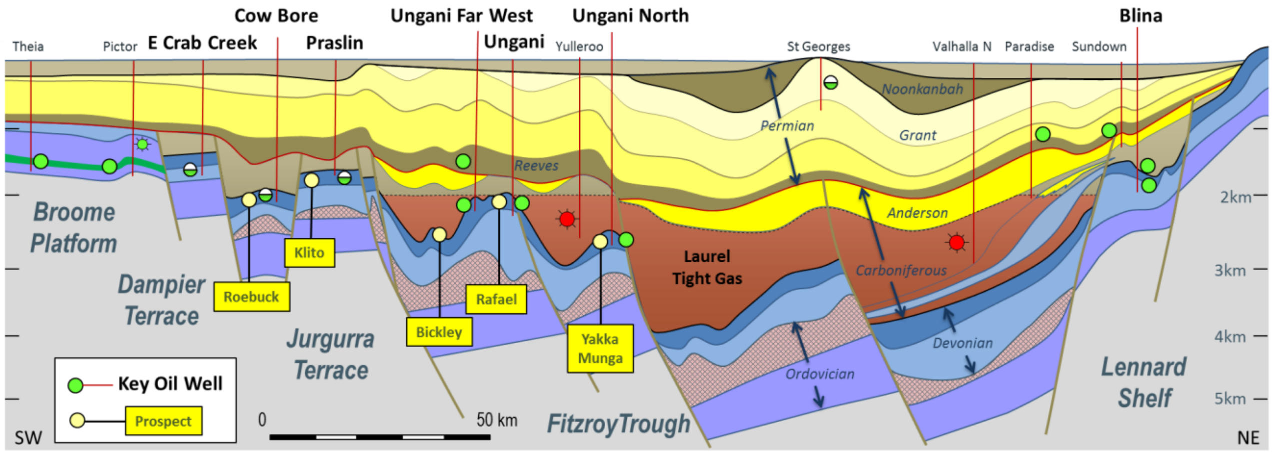

Figure 2. Cross section across the Fitzroy Trough and adjacent terraces.

In Ungani Far West 1, several stages of diagenetic, dolomitising and porosity-forming events were identified through petrographic studies. These include early, near syndepositional marine cements (syntaxial overgrowths on echinodermata grains, isopachous to radiaxial cements). Various stages of breccia development, fracturing and dissolution of carbonates are identified, with early brecciation and cavity formation via marine neptunian origin and/or meteoric mechanisms. Pervasive replacement of limestone by dolomite and associated selective leaching of bioclasts occurred in shallow burial settings. Further brecciation and fracturing is a result of compaction of cavity systems as well as some structuration. Some late dolomite cements, fracturing, dissolution and accessory mineral precipitates are linked to deeper burial, and perhaps for the latest stages hydrothermal origins (Wallace & Hood, 2012; Wilson, 2016).

While dolomitisation is widespread in the basin, dolomitisation in the Ungani field wells appears to be more pervasive when compared with other wells that have intercepted dolomite from the Fairfield Group in the basin. A combination of factors may have contributed to this such as original deposition in relatively shallow to moderate water depths under moderate to high-energy settings, multi-stage cavity formation/brecciation and prevalent faulting to allow for passage of significant fluid flow through a porous system which is essential for massive dolomitisation. Further work is being undertaken on the origins of the dolomitising fluids with marine, evaporative reflux and burial sources all considered to be possible mechanisms (Wallace, 1990; Wallace & Hood, 2012; Wilson, 2016). The reservoir from core and sidewall core in Ungani 2 was interpreted to be deposited in a mid to outer ramp environment with an overall waning in energy levels. Interpretation from Ungani Far West 1 attests to a shallower depositional environment with variable energy conditions.

Porosity was formed relatively early while hydrocarbon emplacement is later (hydrocarbons rim partially cemented pore spaces). The long-lived nature of porosity within the Ungani dolomite in part may be linked to the overwhelming dominance of dolomite, but also different phases of pore system development (Wallace, 2012; Wilson, 2016). In limestone successions porosity preservation is commonly short lived due to calcite cementation sourced from pressure solution whereas dolomite is much less susceptible to pressure solution.

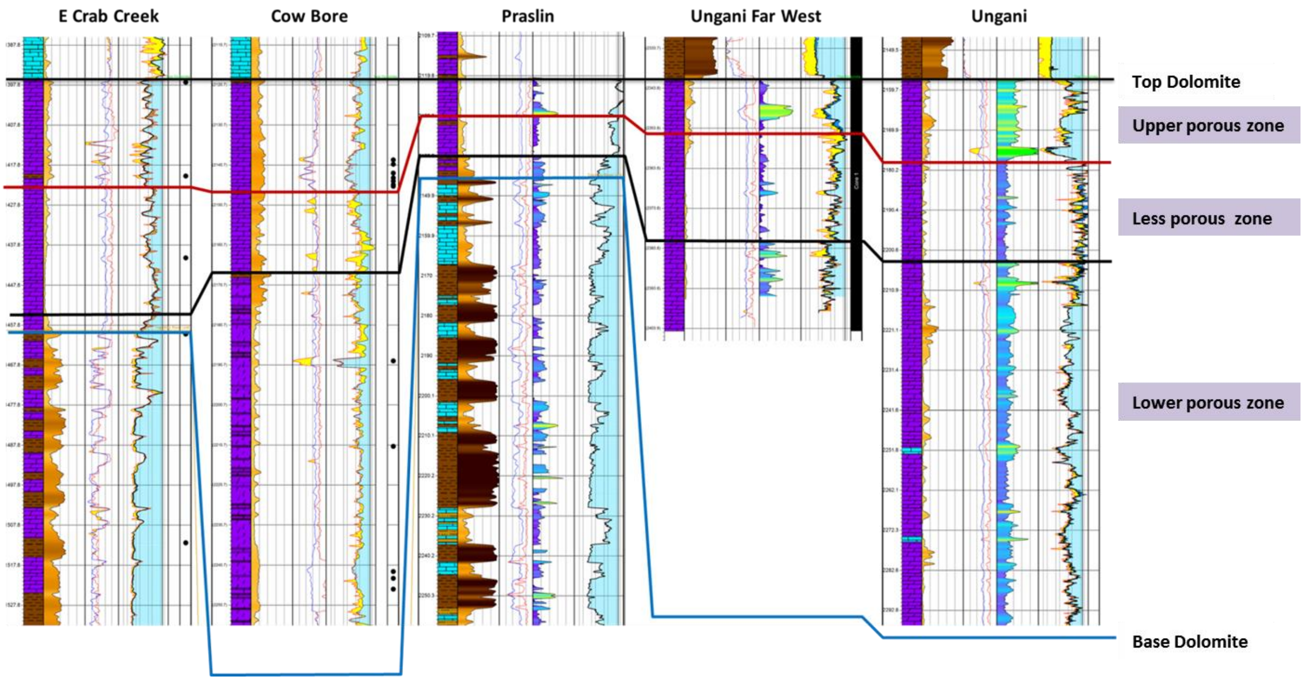

Figure 3. Approximate SW to NE log correlation through wells on the Dampier and Jugurra Terraces on the southern margin of the Canning Basin (See Figures 1 and 2 for well locations and settings).

METHODOLOGY & RESULTS

The entire Ungani Far West 1 core was scanned using Corescan's Hyperspectral Core Imager Mark III (HCI-3) which is capable of high resolution reflectance spectroscopy, digital core photography and 3D laser profiling. The imager provides high spectral resolution (~3.8nm bandwidth) EM spectra in the 450nm to 2500nm wavelength range. The position and shape of absorption features within this wavelength range are diagnostic of mineral type and reflects compositional changes within specific mineral species. Carbonate, hydrocarbon, kaolinite, dickite, silica, hydrous silica (silica with interstitial water which appears to correspond with the occurrence of radiaxial cements), and compositional changes of the carbonate (purity of carbonate and calcium vs magnesium content were identified and spatially mapped (Figure 5).

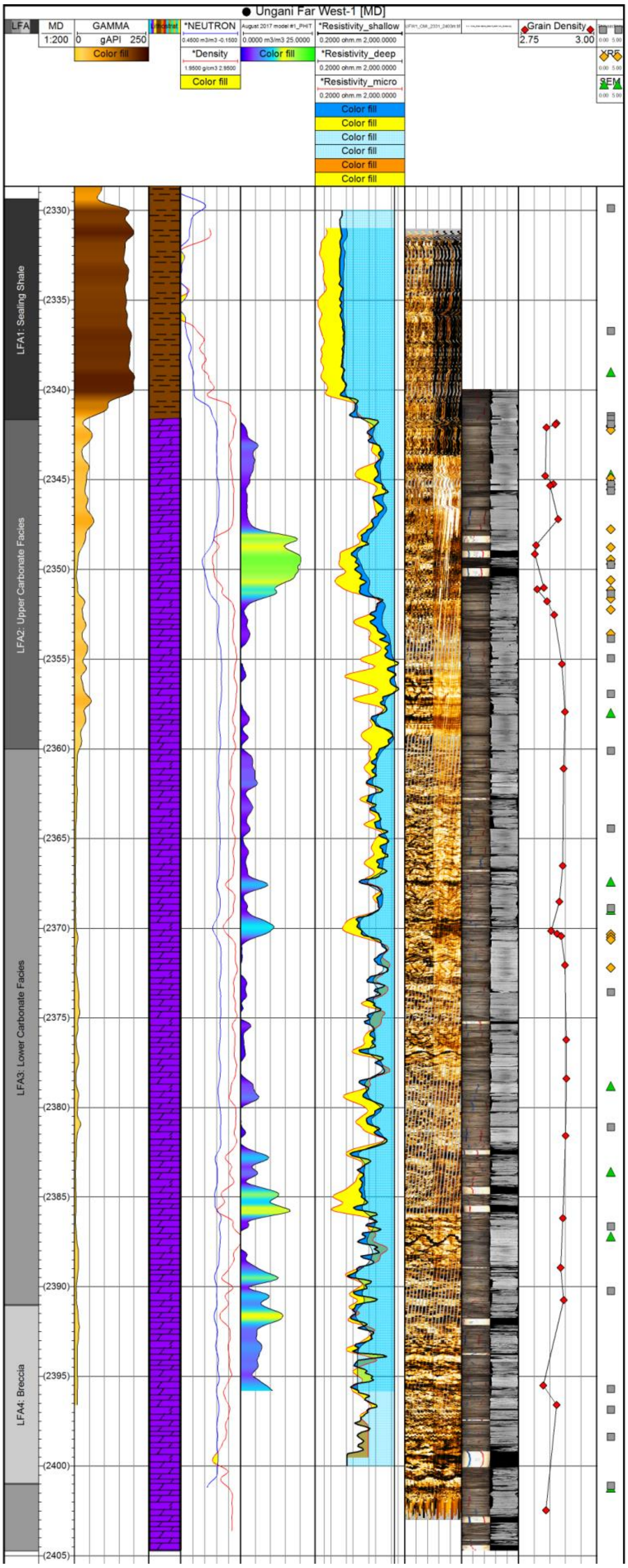

Figure 4. Cored interval at Ungani Far West 1. From left to right: Lithofacies associations, shaded GR, lithology, neutron and density, total porosity calculated from neutron density (0-25%), shallow/deep/micro resistivities, image log (CMI), plain light photography, CT scan, grain densities, and intervals sampled for thin section (square), XRF (diamond) and SEM (triangle).

Eighteen thin sections, 10 of which oversized, were impregnated with blue resin and half stained with Alizarin Red S and potassium ferricyanide to allow for differentiation of dolomite (no stain), ferroan dolomite (stains pale blue), ferroan calcite (stains blue) and non-ferroan calcite (stains pink). These thin sections were selected to best understand variability in the succession based on facies associations and features of interest such as porosity types, lithological boundaries, fractures, breccias, dissolution seams and infills. Five additional polished thin sections from the lower carbonate facies were studied for cathodoluminescence. These samples had predominantly coarser cements and were most likely to yield the most complete cement stratigraphies. Four lithofacies associations were identified from visual core description and petrology:

LFA1: Laurel Fm (sealing shale) — post-carbonate siliciclastic facies

LFA2: Laurel Fm (Ungani dolomite) — upper carbonate facies

LFA3: Laurel Fm (Ungani dolomite) — lower carbonate facies

LFA4: Laurel Fm (Ungani dolomite) — breccia facies.

The key cementing diagenetic phases identified are listed below. These are 'interspersed' and partly contemporaneous with brecciation, fracturing and leaching events:

1. Z1 – early cements: syntaxial overgrowths on echinoderm material and marine bladed to radiaxial cements preipitated oxidising conditions (these phases are subsequently replaced by dolomite)
2. Z2 – replacive dolomitisation and growth of dolomite mosaic cements mainly under shallow burial conditions
3. Z3-5 – Precipitation of planar to xenotopic dolomite cements under increasing burial conditions, as well as further precipitation of additional mineral phases

Ten samples were selected for scanning electron microscopy (SEM) work and 49 samples were micro-drilled from counterpart slabs of thin sections for stable carbon and oxygen isotopic analysis to evaluate a range of cement and component types. Stable oxygen isotopes reflect the relative roles of marine, meteoric, burial or mixed fluids and potential temperature of precipitation while carbon isotopes are related to the original seawater and soil-derived carbon.

Specific targeted features were:

1. clastic bioclasts and cements from siliciclastics overlying the dolomite (n=5),
2. dolomitised bioclasts (n=1),
3. dolomitised matrix (n=15),
4. grey dolomitised matrix to crinoidal/siliciclastic units (n=8),
5. dolomitised syntaxial overgrowth cements on crinoids (n=2),
6. dolomitised radiaxial to bladed cements (n=3),
7. hypidiotopic/xenotopic dolomite mosaics within dolomitised matrix (n=5),
8. hypidiotopic to xenotopic banded dolomite cements (n=4),
9. hypidiotopic to xenotopic cements in fractures/veins (n=3)
10. late calcite cement after dolomite (n=3).

Stable isotopic results from the targeted micro-drilling of rock components fall into four groups:

1. Moderately negative $\delta^{18}O$ and positive $\delta^{13}C$ V-PDB values
2. Strongly negative $\delta^{18}O$ and weakly positive $\delta^{13}C$ V-PDB values
3. Highly negative $\delta^{18}O$ and weakly negative $\delta^{13}C$ V-PDB values
4. Moderately negative $\delta^{18}O$ and negative $\delta^{13}C$ V-PDB values

Grain densities were sampled through the dolomite and variations were noted and compared to other Ungani field wells. No obvious relationships could be drawn between the grain densities and mineralogy.

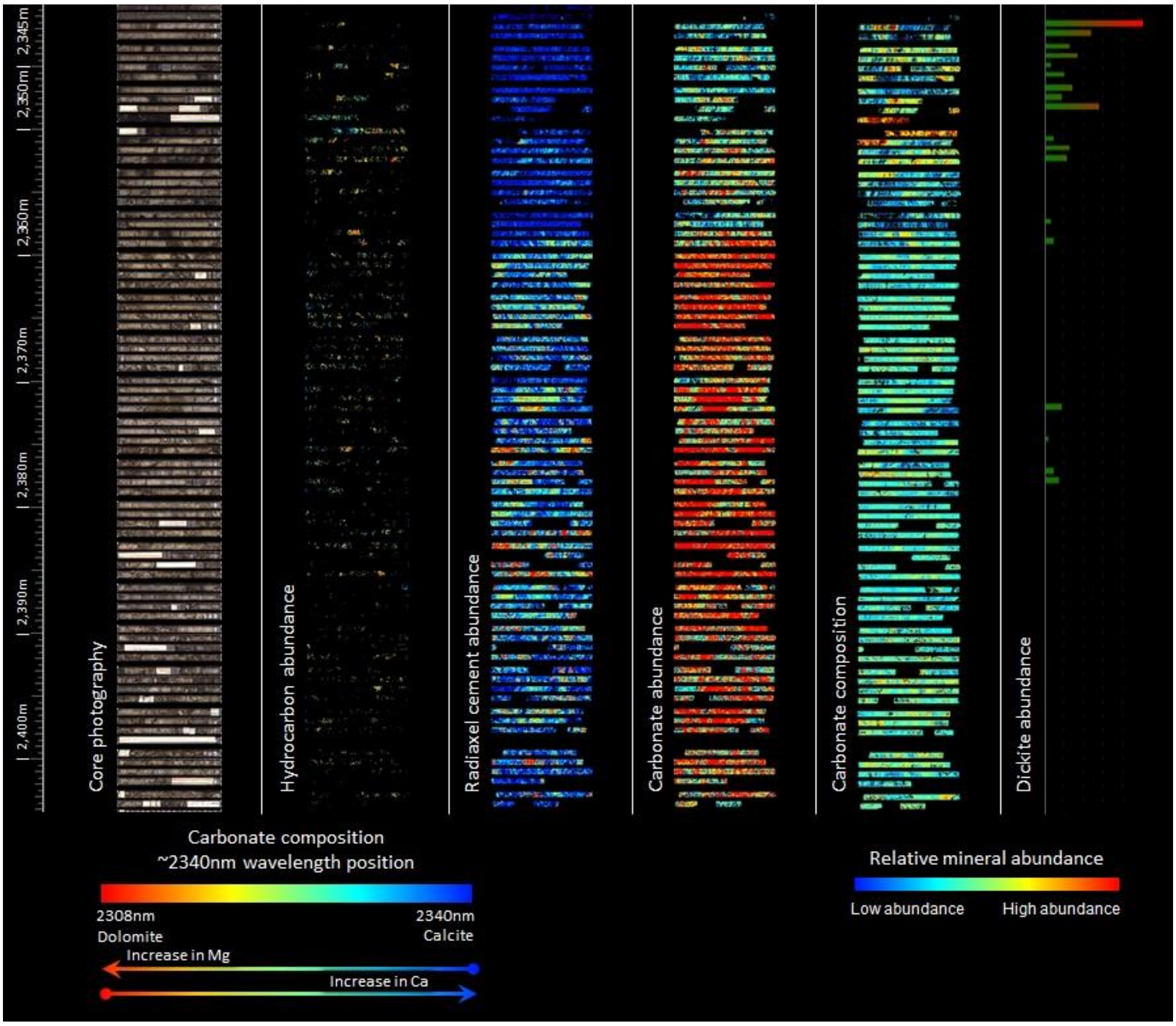

Figure 5. Core photography and hyperspectrally mapped features by Corescan. A marked change can be noted at 2360m, coinciding with the change from upper to lower carbonate facies. From left to right: Hydrocarbon abundance, hydrous silica (radiaxial cement) abundance, carbonate abundance and composition, and dickite abundance.

LFA1: Laurel Fm (sealing shale) — post-carbonate siliciclastic facies

Sealing shale comprises of dark, finely-laminated mudstone and siltstone, indicative of normal, transgressive marine conditions. The shale contains abundant clays, mainly illite and perhaps kaolinite and chlorite, and minor pyrite. The contact between the sealing shale and dolomite is abrupt and pyritised indicating the upper surface of the dolomite may have been a hiatal marine hardground or karstified surface and the overlying shale may not have been always sealing in the past. Such sudden termination of the carbonate system could be due to a rapid rise in sea level or rapid increase in subsidence. The upper carbonate section does, however, contain a siliciclastic fraction suggestive of some terrestrial influence in the upper part.

Bed-parallel ferroan calcite veins with cone-in-cone structures are common, suggesting precipitation during dilation and some shear with abundant fluid movement, and perhaps fluids derived from carbonate units below. Stable isotopes from the calcitic cements have negative $\delta^{13}C$ values suggestive of soil zone or organic influence. Iron for both the pyrite and ferroan calcite may in part be derived from siliciclastics.

LFA2: Laurel Fm (Ungani dolomite) — upper carbonate facies

The upper ~20m of the core is assigned to the upper carbonate facies. It is light grey, crinoidal-rich with variable sub mm to cm-scale pore development (biomouldic, intraparticle, shelter and intercrystalline). Textures ranging from mudstones to pack-rudstones and grain-rudstones, and possible boundstone are present. There is an abundance of reworked bioclastic debris such as crinoids and shells with probable stromatoporoids. Preservation of partial stacks of crinoid ossicles attests to rapid deposition and/or minor transportation. Quartz silt is prevalent in the darker units and commonly disseminated throughout this facies.

This facies is interpreted as shallow to moderate depth marine ramp-type deposits with probable crinoid meadows and other bioclastic facies that are perhaps nutrient and clastic-influenced. It was originally described as a microbial boundstone but thin section petrography revealed dolomitised bioclastic packstone and crinoidal float-stone/rudstone. Much of the early depositional fabrics have been obliterated by pervasive replacive dolomitisation together with dissolution and cementation by dolomite.

Hyperspectral and GR logs, and XRF data support the presence of siliclastics in this facies. Prismatic quartz cement post-dating dolomite formation and partially coeval with chemical compaction features are common in the upper carbonate, likely to be associated with remobilisation of silica during burial dissolution. Dickite is present in fractures, possibly temperature-altered from terrigenous-derived kaolinite (Figure 5). Stable isotopes from near the upper carbonate surface are suggestive of higher temperatures and/or fresher waters, consistent with the upper hiatal surface of the carbonate being linked to subaerial exposure, and or derivation from terrigenous material.

A brecciated and fractured zone is recorded between 2348.7-2351.5m. The primary breccias appear to be in place before dolomitisation as either a depositional breccia or perhaps through dissolution and collapse. Brecciation may have been enhanced through probable compaction or tectonic fracturing. Negative carbon isotope excursions associated with breccia infills and fractures may also support a potential organic carbon and/or fresh water influence. Longer retention of open pore networks such as through the brecciated intervals may have also enhanced later fluid movements and associated higher temperature diagenesis during burial.

LFA3: Laurel Fm (Ungani dolomite) — lower carbonate facies

At 2360m, a marked boundary was noted in the core facies, spectral and GR log data (Copp, 2016). The lower facies has light grey to creamy mottling, is notably heavier to handle and cleaner on GR. Crinoids and mouldic porosity after crinoids are less common than in the upper carbonate facies. Early textures in the lower carbonate facies have similarly been masked or obliterated by strong dolomitisation, making it challenging to determine primary depositional features. However, there is common evidence for bioclasts such as probable sponges, stromatoporoids, possible corals, shells and some crinoids forming bound to floatstone fabrics as well as wackestone to packstone, grainstone and locally rudstone textures. Many of the bioclasts are leached out and their presence is inferred from the shape and sizes of biomoulds. Stromatactis-like features are locally present, and although their origins are difficult to determine due to overprinting dolomite, dissolution of bioclasts and early cementation may play a role. Crinoids, although present, are less noticeable than above 2360m in the upper carbonate. Siliclastics are generally absent and only occur as breccia infills. Hyperspectral and gamma logs reveal cleaner carbonate than in the upper carbonate (Figure 5).

The biota present is suggestive of relatively shallow water depths, under mostly stenohaline and perhaps variable energy conditions. Early cementation of primary porosity through radiaxial cementation is normally indicative of flushing of marine waters through the sediment. Some of the cemented cavities were primary shelter pores between large bioclasts whereas some are infilled after bioclasts or their biomoulds while the rest are less clear. The abundance of micrite suggestive of low to moderate energies alongside evidence of extensive early flushing of fluids through the sediment more indicative of higher energies is enigmatic.

Porosity in these facies is generally after leaching of bioclastic material, in fractures and in dolomite cement-lined vugs, and intercrystalline porosity. Porosity is on a cm to sub-mm scale. Many of the primary pores, such as shelter pores and probable intergranular pores, are occluded by early radiaxial to bladed and sometimes possible blocky cements that formed prior to dolomitisation. Overall, porosity mainly results from dissolution during dolomitisation, fracturing, remnant primary and secondary porosity and some possible late leaching.

Pyrite occurs locally as cement concentrated along fractures. Thick radiaxial to fibrous, bladed cements are common in primary porosity between precursor grains that may originally have been stromatoporoids, sponges or perhaps corals and in shelter porosity locally resembling stromatactis-like cavities. Stable isotopic data collected here is supportive of very shallow-burial marine diagenesis.

LFA4: Laurel Fm (Ungani dolomite) — breccia facies

The first and main phase of breccia formation occurred prior to dolomitisation but after precipitation of radiaxial marine cements. Dark grey sediment infill is also inferred to be of marine origin as it is commonly crinoidal-rich. Potential causes for the primary origin of breccia could be marine or karstic collapse cavities, or dissolution of underlying strata such as evaporites. Although no evidence was seen for early evaporites in the core, evaporative and sabkah deposits are known to occur in the basin. Frome Rocks 1, for example, penetrated a thick section of Ordovician salt

Figure 6 2396.7m Core image (left) and whole thin section scan in XPL of dolomitised multiphase breccia with varied clast which is mainly pale dolomite but also now dolomitised radiaxial cements (upper right) and dark, siliciclastic and crinoidal-rich packstone (TS horizontal field of view 4 cm). Many of the clasts show additional later fracturing and silica cements mostly post-date late fracturing.

POROGENESIS

Pre-dolomitisation

Primary porosity in the Ungani carbonates included intergranular, intragranular and shelter porosity. Primary intergranular porosity on a mm to sub-mm-scale was best developed in grainstone/rudstone units, such as crinoidal grainstones, that are most prevalent in the upper carbonate section, but sub-mm to micro-scale porosity would also have occurred in finer grained to micritic units. Intragranular, shelter and intergrain primary porosity on a cm-, to mm-scale was well developed in the lower carbonate section associated with a range of now diagenetically altered potential framework building organisms including stromatoporoids and corals.

Much of this primary porosity has been occluded by early cements including syntaxial overgrowth cements prevalent in echinodermata-rich grainstones, as well as isopachous/bladed to radiaxial cements prevalent in the lower carbonate unit. Initial phases of breccia development, dissolution of some bioclasts, cavity formation and some fracturing, all post-date radiaxial cement formation but pre-date dolomitisation. As described above, dark grey crinoid-rich sediments partially infill some cavernous porosity. Retention of some primary porosity, together with secondary cavity formation and linked fracture networks are thought to provide pathways for significant throughput of Mg-rich fluids resulting in massive dolomitisation.

Dolomite-associated and post-dolomitisation

Burial dolomites form in the subsurface at the onset depths of burial compaction effects at depths as shallow as 100 to 200m. In these very shallow burial environments, a range of fluids may be the dolomitising agent and different terminology may also be applied, e.g. dolomitisation by marine fluids in shallow burial depths could also be termed marine dolomitisation (Machel, 2004). The dolomites can either precipitate directly as cement or form as replacements in permeable intervals flushed by magnesium-rich fluids, such as seawater, evaporative or connate/burial brines (Al-Awadi et al, 2009).

To cause massive dolomitisation of the ~60+ m of dolomites present at the Ungani field significant volumes of Mg-rich fluid must have circulated through the deposits. The onset of dolomitisation is likely to have occurred in relatively shallow to moderate burial depths at temperatures around <50-60ºC on the basis of the predominantly planar form of dolomite preserved. There is also a relative paucity of high temperature non-planar dolomites. Planar dolomites are replacive, commonly altering and including ghost traces or inclusions of micritic matrix, bioclastic to peloidal sediments. These planar dolomites are partially contemporaneous with a phase of significant dissolution of remaining calcite elements linked to understaturation of calcium carbonate as dolomitisation continues (Machel, 2004).

Fluids of marine and perhaps evaporative reflux origins are potential dolomitising fluids for the early replacive to planar dolomites with further work is required to better understand dolomitising mechanisms and fluid origins. There is also potential for subaerial exposure perhaps resulting in drawdown and then pumping of seawater through the platform thus enhancing dolomitisation after re-flooding.

Non-planar dolomite cements are cementing phases in Ungani Far West formed at temperatures in excess of 60-70ºC and partially occlude some pore spaces (Wilson, 2016). Given the temperatures, dolomite cementation is inferred to have occurred under increasing burial depths. Further compaction together with structuration resulted in additional breccia formation. Saddle dolomite and sulphides have been described as pore-filling materials in a suite of wells in the Canning Basin both in the Fairfield Group and underlying Devonian reef complex. The Fairfield carbonates are, however, not as strongly overprinted with higher temperature, late pore occluding non-planar dolomite cements when compared with the Devonian carbonates, suggesting some form of fluid migration barrier between the two formation, and/or lower temperature setting for the Fairfield carbonates. Pyrite, gypsum, quartz, chalcedony, kaolinite and dickite are all seen as late fracture and cavity filling cements in Ungani that partially occlude pore space.

According to Wallace and Hood (2012), the stable isotopic geochemistry at Ungani 2 (particularly for the late phase of dolomite cements) appears to be similar to that found in Devonian rocks in the Barbwire Terrace, with similar origins suggested. The geochemical and petrographic character of the Ungani dolomite was also described as similar to regional burial dolomites found in Mississippi Valley-type (MVT) lead-zinc provinces worldwide. Christiansen et al. (1995) concluded that mineralising fluids were derived from the dewatering of underlying Devonian shales and Warren and Kempton (1997) suggest faults may have acted as conduits for dolomitising fluids to enter shallow-water carbonates. A minor phase of late dissolution had minor impact corroding some of the late cements.

CONCLUSIONS

The substantial section of core recovered from the Ungani Dolomite at Ungani Far West 1 allowed thorough investigation of the relative timing and potential origins of diagenetic features and their impacts on pore systems development to be conducted via varied techniques including core study, hyperspectral scanning, microscopy and stable isotopic analysis. The Ungani carbonate system developed as part of the Fairfield Group on faulted highs of the Jurgurra Terrace along the southern margin of the Canning Basin. The lower carbonate deposits in the Ungani Far West 1 are interpreted as clean, shallow platform deposits with evidence of framework building organisms, whereas the upper carbonate deposits are bioclastic and commonly crinoidal-rich deposits with some storm influence and siliciclastic influx.

Dolomitisation pervasively replaces carbonates in Ungani Far West 1 and commonly affects many of the carbonate successions from both the southern and northern margins of the Canning Basin. Biomouldic, vuggy, fracture, cavern and inter-crystalline porosity resulting from multistage brecciation, fracturing, dolomitisation and dissolution events are all critical to reservoir development. Porosity is best developed in brecciated units and is generally more common in the cleaner, lower carbonate section where biomouldic, shelter and fracture porosity is more common.

ACKNOWLEDGMENTS

Discussions and research over the years since the discovery of Ungani by Moyra Wilson, Iain Copp, Maja Buschkuele, Zahra Seyedmedhi and Malcolm Wallace have hugely contributed to this paper. Special thanks to Neil Goodey and Ronell Carey from Corescan and Anne Forbes from Chemostrat for collaborating with Buru Energy, Derek Winchester at CSIRO for excellently preparing the thin sections and David Long for his continual support and encouragement.

REFERENCES

Al-Awadi M. et al, 2009. Dolomite: Perspective on a Perplexing Mineral. Schlumberger Oilfield Review. Autumn 21 No. 3.

Copp, I.A. 2016. Ungani FW 1 core description: Jurgurra Terrace, Canning Basin: Good Earth Consulting for Buru Energy, 50p (unpub.).

Christensen J.N., Halliday A.N., Vearncombe J.R., Kesler S.E., 1995. Testing models of large-scale crustal fluid flow using direct dating of sulfides; Rb-Sr evidence for early dewatering and formation of mississippi valley-type deposits, Canning Basin, Australia. Economic Geology 90:877-884.

Edwards, P.B. & Streitberg E., 2013. Have we deciphered the Canning? Discovery of the Ungani Oil Field. *West Australian Basins Symposium IV.*

Gulf Oil, 1985, Well Completion Report Cow Bore 1 EP114, Gulf Oil Australia Pty. Ltd.

Druce E. C. & Radke B. M. 1979. The Geology of the Fairfield Group, Canning Basin, Western Australia. Bureau of Mineral Resources Bulletin 200.

Long, D., Millar, A., Weston, S., Esteban, L., Forbes, A. and Kennedy, M., 2018. Ungani Oil Field, Canning Basin – Evaluation of a Dolomite Reservoir in this volume (unpub.).

Machel, H. G. 2004. Concepts and models of dolomitization: a critical reappraisal. Geological Society, London, Special Publications, 235, 7-63.

Seyedmehdi, Z., 2011. Depositional history and reservoir characterisation of the latest Devonian-Early Carboniferous Fairfield Group, northwestern Lennard Shelf, Canning Basin, Western Australia. Ph.D. thesis. School of Earth and Environment, University of Western Australia.

Trewin, N.H., 1982. The Yellow Drum Formation – Sedimentology and diagenesis. Australian Occidental Pty. Ltd.

Wallace, M.W., 1990, Origin of dolomitization on the Barbwire Terrace, Canning Basin, Western Australia. *Sedimentology*, 37, 105–122.

Wallace, M. & Hood, A., 2012. Stable isotope geochemistry on samples from well Ungani 2 (Depth interval 2242 to 2328m Cores 1 & 2). Internal report for Buru Energy.

Warren, J.K., & Kempton, R.H. 1997. Evaporite Sedimentology and the Origin of Evaporite-Associated Mississippi Valley-Type Sulfides in the Cadjebut Mine Area Lennard Shelf, Canning Basin, Western Australia. SEPM 57, 55-67.

Wilson, M.E.J. 2016. Microscopy and stable isotopic study of Ungani Far West 1 as a follow-up to earlier core logging: Jurgurra Terrace, Canning Basin. Confidential report for Buru Energy, 90 p.