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Formation of Very Thick Permian Coal Seams, Cooper Basin, Australia

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SUMMARY

The Weena Trough and the Milpera Depression in the SW Cooper Basin contains some unusually thick Permian coal seams. Their development is linked to the Late Carboniferous-Early Permian glacial palaeoclimates, the slow subsidence resulting from their flanking structural location, and the isolation of the peat swamps from the main fluvial drainage systems.

The very thick coals are sub-bituminous to bituminous and have high inertinite:vitrinite ratios with relatively large amounts of semi-fusinite and alginite macerals. This combination of thickness, maceral composition and rank makes them ideal for coal bed methane production notwithstanding their depth.

Key words: Coal bed methane, very thick coal seams, Permo-Carboniferous ice caps.

INTRODUCTION

The Cooper Basin is Australia's main onshore petroleum basin in which conventional petroleum has been produced since the 1960s (Figure 1). In the last decade attention has moved to development of the unconventional resources principally from the coal seams and organic rich shales. The Cooper Basin is an intra-cratonic basin developed during the Late Carboniferous to Triassic and is overlain by the younger Eromanga Basin (Figure 2). The coal seams are mainly Permian and are deeply buried at depths of 1-2km on the flanks and 2-4km in the deep troughs.

The NE-SW depocentres dominate the structural elements of the basin, with secondary NW-SE, and a small number of E-W and N-S structures (Figure 1). Thick coal seams were known for many years from the petroleum drilling, principally in the Patchawarra Trough, while some thick coals had been intersected in other parts of the basin. Recently, some very thick Permian hard coal seams (30-40m thick) were appraised by deep exploration drilling for coal bed methane, within the Weena Trough and Milpera Depression, in the SW part of the Cooper Basin (Figure 1). The consistent thickness, lateral extent and continuity of these coal seams is remarkable. Some of the characteristics of these thick coal seams, including their tectonic and structural location, are similar to other examples of very thick Permian coal seams in Australia (eg Blair Athol). Their structural setting is also similar to the very thick Tertiary Latrobe Valley coal seams but the lithotypes and maceral compositions seem very different.

The controls on the origin and accumulation of these very thick coal seams are not well understood. Some results from recent studies at Curtin University are discussed here aimed at a better understanding of these valuable occurrences.

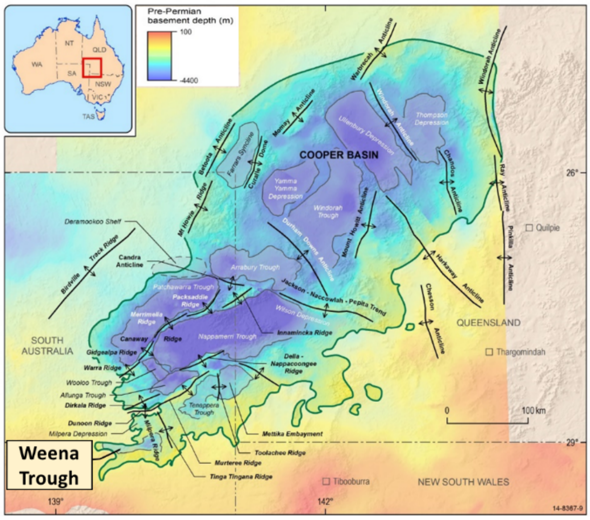

Figure 1: Cooper Basin SW area around Weena Trough (Based on Hall et al., 2016)

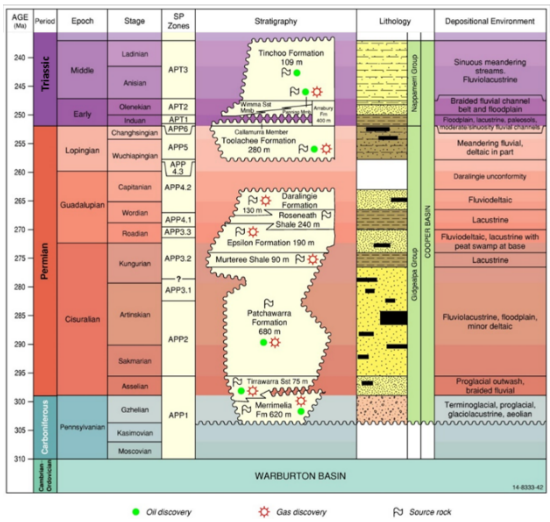

Figure 2: Cooper Basin Lithostratigraphy (Based on Hall et al., 2016)

METHOD

The Cooper Basin is a petroleum basin with extensive deep seismic data, many wells with logs, comprehensive core and cuttings, so the stratigraphy and structural history are well

known. All open file data were used to study the structural and depositional history of the coals. However, the south-west flank of the basin is underexplored, the well spacing is sparse and only 2D seismic is available (Figure 3). Previous exploration concentrated on the conventional plays so the seismic is concentrated on the highs. The area is on the flanks of the Cooper Basin where some formations are not present including most of the Triassic units.

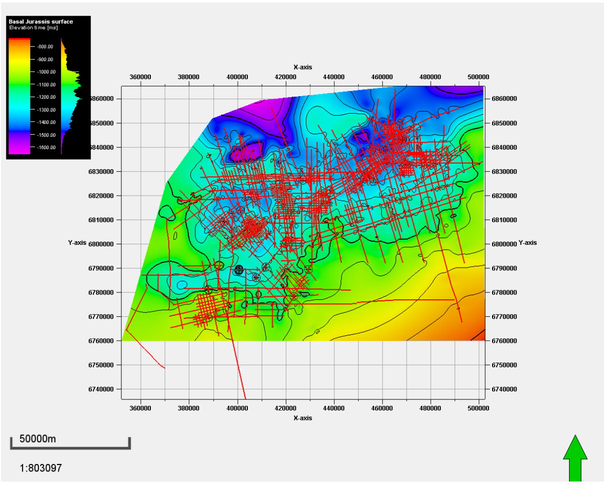

Figure 3. Location of the Seismic Surveys and wells on the Basal Jurassic Unconformity structure map.

The interpretation was done in Petrel (Schlumberger software). The main formations and coal seams were correlated between the wells using the well completion reports to guide the stratigraphic picks. The seismic horizons were tied to the wells, interpreted throughout the study area, and depth converted using the well velocity data though most wells do not have checkshot surveys. A structural model was made using the faults, horizons and wells.

The main horizons interpreted through the study area include: the pre-Permian basement which lies unconformably below the base of the Permo-Carboniferous section (mainly Cambro-Ordovician strata part of the Warburton Basin); the top of the Early Permian Patchawarra Formation; the near base Late Permian (essentially the top of the Epsilon Formation); the Base Jurassic; and the Cadna-owie Formation. The Toolachee Formation can be mapped over parts of the study area (eg in the Milperra Depression) although commonly the Jurassic rests unconformably on the Permian. The coals are correlated between closely spaced wells but it is difficult to map them confidently on seismic between the widely spaced seismic lines and given the uncertainty in precise well ties.

RESULTS AND DISCUSSION

The very thick coal seams result from three main controls on their development and the inter-actions between them: the Permo-Carboniferous palaeolatitude and climate prevailing in the south-west part of the Cooper Basin; the structural and burial history; and the sedimentary facies of the area relative to the main depocentres.

Palaeoclimate Control

In the Late Carboniferous most of Antartica and much of southern-central Australia were covered by an enormous ice cap (Figure 4). The main ice-cap began to retreat in the Early Permian into separate sheets. The combination of cold temperatures and abundant meltwaters are ideal for peat development including their growth, lateral extent and continuous preservation over long periods of time. This is analagous to the recent present day post-glacial period, in which the majority of long lived and laterally extensive peats occur in very high northern latitudes adjacent to the Arctic ice-sheets, over northern Siberia, Scandinavia and Canada.

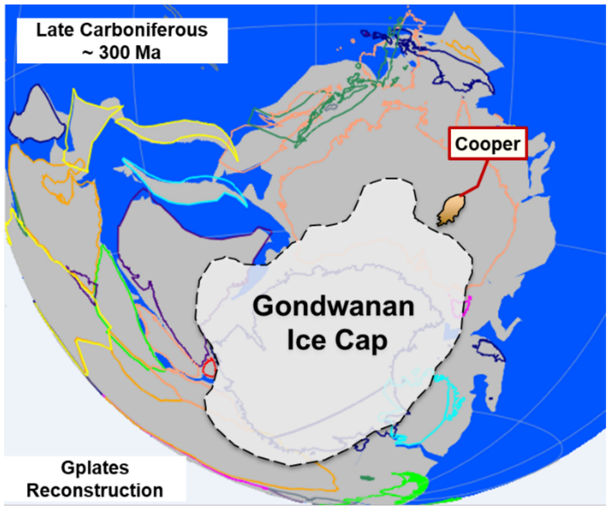

Figure 4. Gplates reconstruction of Gondwana showing Antartica-Australia in the Late Carboniferous (~300Ma).

The Permian coals have unique maceral compositions that result from the associated palaeoclimate and sedimentary environments. They consist of vitrinite with high amounts of inertinite (especially semi-fusinite) and minor liptinite (mainly sporinite and cutinite) as shown in Figure 5. They are conspicuous in having high semi-fusinite to vitrinite ratios and some clarain bands contain alginite (especially Bottryococcus sp.) interbedded with the vitrinite as shown in Figure 6. This is consistent with peat development under alternating subaqueous and subaerial water table conditions (Hunt and Smyth, 1989) and may correspond with waxing and waning of the glaciers.

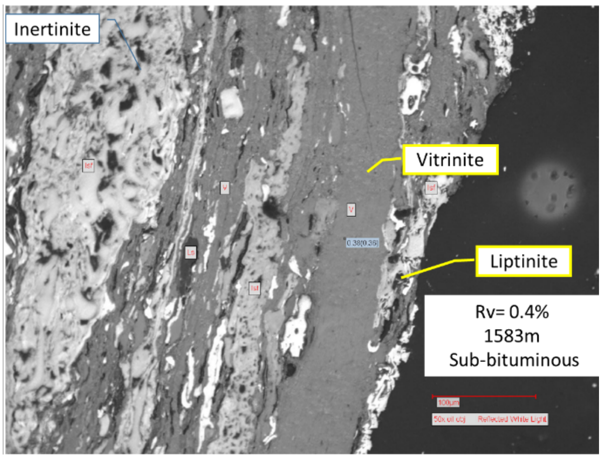

Figure 5. Coal photomicrograph, reflected white light, 1583mMD, from Le Chiffre 1 Well Completion Report, Petrographic Report (E. Barcelona, 2014).

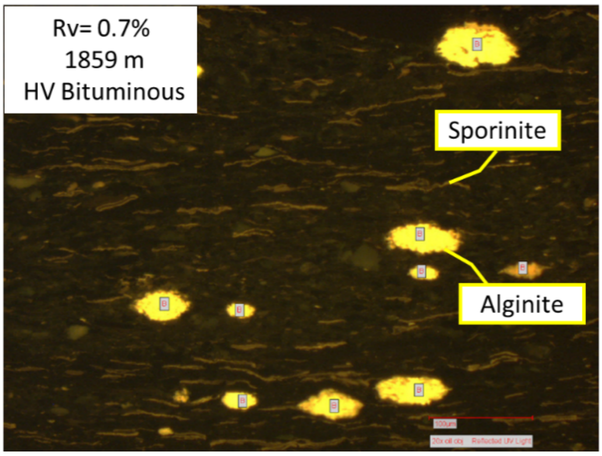

Figure 6. Coal photomicrograph, fluorescent light, 1859mMD from Le Chiffre 1 Well Completion Report, Petrographic Report (E. Barcelona, 2014).

Structural Control

The main structures in the Cooper Basin are strongly influenced by the NE-SW and E-W basement structural trends from the Warburton Basin (Kulikowski and Amrouch, 2018). These trends controlled the development of a relict glacial palaeotopography in the Late Carboniferous, when southern-central Australia was shaped by the ice-sheets and glaciers ploughed their way radially outward (Figure 7). The Late Carboniferous and Early Permian sediments largely filled these glacial valleys, beginning with the glaciogene Merrimelia Formation (Kantsler et al., 1984) and proglacial, Tirrawarra Formation, overlain by the Patchawarra Formation comprising thicker fluvial- lacustrine floodplain successions, in which coarse clastics still dominate but coals are common (Figure 8).

The sides of these glacial valleys were being eroded further as these earliest sediments filled the palaeotopography, with accommodation mostly by further cut and fill controlled by continued movement on the inherited normal faults and compaction. Base level was probably also affected by isostatic uplift as the ice caps melted. The Weena Trough and Milpera Depression are reasonably symmetric when restored which is consistent with an intracratonic basin structural style and they do not show clear evidence of asymmetric growth more typical of an extensional basin.

The younger Permian sediments are mixed sand, mudstone and coal successions suggesting lower base level grades and slower accumulation rates. These sequences spill out of the more confined valleys and onlap onto the adjacent basement highs (Figure 9). The basement flanks of these old glacial valleys probably only had a thin cover of late Permian sediments, though some may have been eroded by the uplift associated with the Hunter-Bowen orogeny. Hence, the flanks were probably not covered by thick sediments until deposition of the overlying Mesozoic sediments of the Eromanga Basin.

The old Permian faults were overprinted by approximately NW-SE compressional stress and some strike-slip movements in the Late Permian, with E-W compression in the late Triassic (Hunter-Bowen movement), followed by the E-W compression in the late Cretaceous-present day (Kulikowski and Amrouch, 2018). These movements have produced monoclinal folds over reverse faults and widespread erosion especially over the basement related highs.

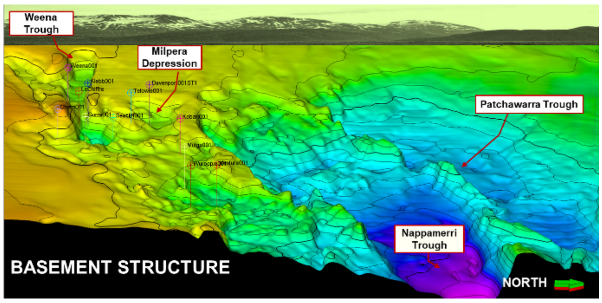

Figure 7. 3D depth model view of Basement structure looking to south-west into Weena and Milpera Depression, with glacial highlands behind indicative of the palaeotopography in the Early Permian.

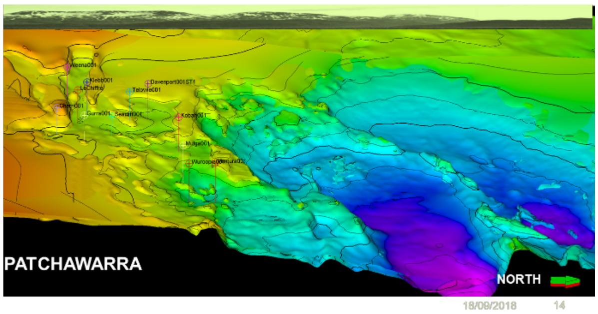

Figure 8. 3D depth model view of top Patchawarra structure looking to south-west into Weena and Milpera Depression, showing the Late Carboniferous – Early Permian fill of the original palaeotopography.

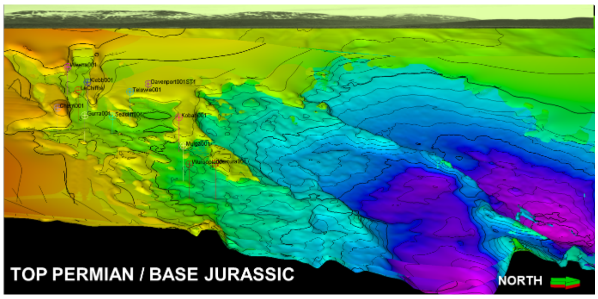

Figure 9. 3D depth model view of top Permian-Base Jurassic structure looking to south-west into Weena and Milpera Depression, showing the Late Carboniferous – Permian fill has spilt over most of the of the original palaeotopography.

Sedimentary Control

The coal measures developed in three main formations: the Patchawarra (early Permian), Epsilon (mid Permian) and Toolachee (late Permian), each separated by shale dominated formations (Figure 1). The earliest glacial valley fill can be differentiated into the glaciogene coarse clastics of the Merrimelia Formation (Kantsler et al., 1984) and the proglacial, braided fluvial sediments in the Tirrawarra Formation. The overlying Patchawarra Formation mainly comprises fluvial, lacustrine and floodplain successions in which coals are common for the first time. However, thick coals are also developed in the Epsilon and Toolachee formations, though the latter is not present furthest south where it probably has been eroded.

The palaeocurrent directions are mainly from the SW to the NE with the main drainage directed along the large Patchawarra and Nappamerri troughs, where deposition is dominated by fluvial channel belts and floodplains. There the coal seams are typically thin in the order of several metres and in most areas make up <5% of the sediment thickness. Some thick coal seams occur in the Patchawarra Trough. The coals consist of vitrinite with high amounts of inertinite (especially semi-fusinite) and minor liptinite (mainly sporinite and cutinite). Overall the coals vary in rank from sub-bituminous to semi-anthracite in the deeply buried areas (Kantsler et al., 1984).

The very thick laterally extensive coal seams are found in the Milpera Depression and Weena Trough to the SW of the Cooper Basin closest to the ice-sheets (Figure 1). These troughs are east-west asymmetric graben in which the rate and overall subsidence and sedimentation was much less than in the main basin centres. The development of these seams can be tracked through time on the seismic, which shows that they began on the flanks of the troughs away from the main streams. They subsequently moved out into the troughs in a series of jumps between intervening periods of non-accumulation, becoming more extensive as the troughs fill.

The net coal isopach relative to sand and shale is much higher with coal making up over 25%. The coals are also high inertinite to vitrinite coals but they have conspicuous amounts of semi-fusinite and alginite (especially Bottryococcus sp.). The lower burial has produced sub-bituminous to bituminous coal ranks. These coals are excellent methane reservoirs because they have a high semi-fusinite content and lie within optimum coal ranks for microporosity preservation and development. The high connected porosity, combined with open cleat development, produces good permeability. The high alginite content and moderate ranks also boosts wet gas content that is important for economic value.

CONCLUSIONS

The structural and depositional controls in the south-west of the Cooper Basin produced a combination of coal rank, coal thickness, extent and petrographic composition that makes these coals excellent coal-bed-methane producers. They appear to be mainly the product of a post glacial climate, the structural and burial history of small troughs flanking the main basin troughs; and the sedimentary facies of an area away from the main depocentres.

ACKNOWLEDGMENTS

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