Sedimentary Facies of the Coal-bearing Walloon Coal Measures in Tipton Field, Surat Basin

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Abstract: The Walloon Coal Measures(WCM) is the main producing formation in Tipton coalbed methane(CBM) field in the Jurassic Surat basin of the southeast Queensland, Australia. The numerous, thin, pinching out, merging, and splitting coal seams in the WCM show highly variable in the spatial continuity. Accurate determination of the facies, lithological attributes and geometries is important in the CBM exploration and development planning for Tipton field. In the paper, high resolution sequence stratigraphy is used to build an isochronal stratigraphic framework of sublayers and coal plies by utilizing all available data from cores and logs. The key methodology in this procession is to identified single fining-upwards cycles with sandstone at the bottom and coal, siltstone or shale at the top. Five lithologies of coal, shaly coal, sandstone, siltstone and shale are classified by density and gamma ray well logs. Six members, 20 sublayers and 125 single coal plies are picked and correlated for the whole WCM. The distributions and geometries of coal and channel are analysed for each sublayer. The characteristics of the following depositional facies are interpreted: coal swamp and swamp, major channel, minor channel, floodplain, lacustrine. A concept model of sedimentation is reconstructed to emphasize the relationships of major facies which is essential for the further geological modelling, potential sweet spots determining and filed development of the Tipton field.

1 INTRODUCTION

Tipton coalbed methane (CBM) field is in the central part of Surat Basin, Queensland, Australia. It covers an area of 200 km^2 and the structure is a southwest dipping unicline with two near-vertical faults developed in the north area (Figure 1). A total of 167 wells are drilled and most of them have log data such as LSD, SSD, gamma ray. The average well distance is about 600m.

The target formation of the Tipton field is the Walloon Coal Measures (WCM), which is the main coal-bearing formation and CBM producing interval in the Surat basin (Bohacs and Sutter, 1997). WCM is a formation of middle Jurassic underlain by the Eurombah Formation and Hutton Sandstone and overlain by the Springbok Sandstone (Figure 2). Juandah and Taroom are two main sedimentary members of WCM with Tanglooma sandstone in between. The individual seam packages within the Juandah coal measures are Kogan, Macalister, Wambo and Argyle. The Taroom has two recognized coal seams: UpperTaroom and Condamine which is the thicker and deepest seam.

The WCM consists coal-rich mire and a fine-grained meandering fluvial system which develops interbedded sandstone, siltstone, carbonaceous mudstone, shale and coal (Fielding, 1993). The coal is low rank with the vitrinite reflectance of 0.4-0.6% and the net coal thickness is 20-30m deposited in a fluvial sedimentary system. Many coal plies are developed with splitting, merging, pinching out and show highly variable in the spatial continuity. Moreover, not much knowledge except Tangalooma sandstone is known about the sandstone channels in WCM, which have much influenced on the coal beds continuity and the behaviors of CBM.

Due to these complicated geology, the paper uses high resolution sequence stratigraphy to build an isochronal stratigraphic framework of sublayers and coal plies, and identifies five lithologies to analyze the distributions of the coal ply and sandstone. The depositional facies including channel, floodplain, lacustrine, coal swamp and swamp are characterized and the concept depositional model is built to better

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understand the coal heterogeneity and the relationships of these major facies.

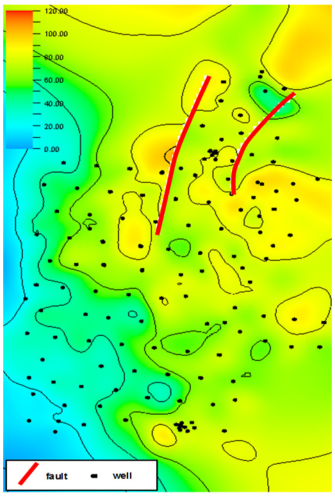

Figure 1: The structure of Tipton field.

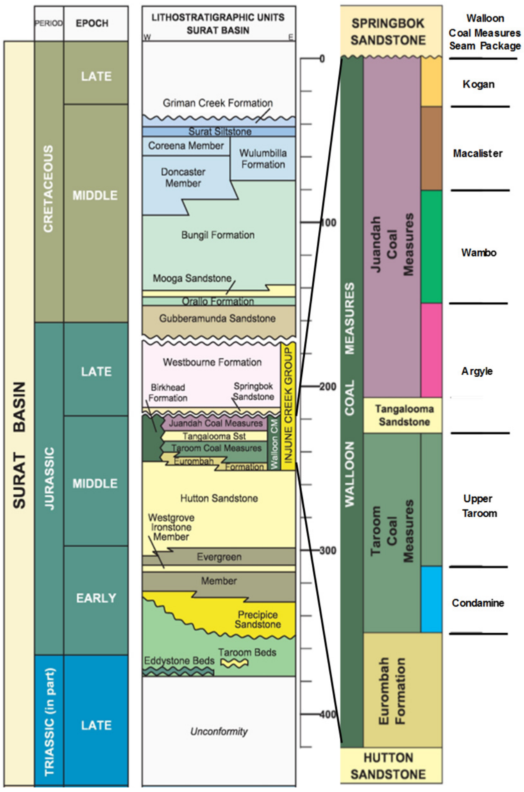

Figure 2: WCM formation of Surat basin.

2 METHODOLOGY

This methodology constitutes a systematic and effective workflow to delineate the characteristics of the coal ply and sandstone, and the distribution of the depositional facies.

Firstly, all wells in the gas field are investigated, including core data analysis, depth shifting, logs normalization, lithology and facies interpretation.

Then the ply and sandstone are correlated and the isochronal stratigraphy framework is built. The correlation is based on the fining-up sequence cycle, in which the sandstone bodies are the fluvial channels at the base then the flooding plains of siltstones upwards and then the development of the lacustrine clays and coal swamps. The roof and floor of the coal plies are manually picked in well section in order to descript the splitting and merging of the coal plies in areal and vertical directions. The boundaries of the sandstone are also picked in order to better improve channel description quality.

Based on the core descriptions, photographs and logs of all wells, lithologies and sedimentary facies are studied to describe the fluvial depositional system in the gas field. The horizontal distributions of the coal ply and sandstones are mapped. The geometry parameters such as the coal thickness, the area of coal distribution, the width, orientation, amplitude, wavelength of the channel belts are studied.

Then finally, the concept depositional model is generated in which channel, floodplain, lacustrine, coal swamp and swamp are integrated to describe the interrelationships of these facies and to improve the understanding of swamp heterogeneity in fluvial system.

3 WCM THREE-ORDER CORRELATION AND ISOCHRONAL STRATIGRAPHIC FRAMEWORK

Correlation within the WCM package are complex with an absence of marker beds and significant lithological variations across small aerial distances (Zhou, 2017). Individual seams are generally not easy to be correlated due to the very high frequency of seam pinches, swells, coalescence and truncations.

For WCM isochronal correlation, a three–order cycle correlation methodology is used to complete the work guided by sequence stratigraphy theory. The correlations in three-order cycle are made on the basis of log comparison, using similar coal seams to correlate over short distances and fining upward packages to correlate over longer distances. The first order is the correlation of wells between coal members, and then the sublayers. The third order is the correlation of wells of single coal ply and sandstone within each sublayer.

For the coal member division, the best markers are the Macalister and Condamine which are considered massive and relatively continuous (Hamilton, 2014). There is often a gamma baseline shift between the Macalister and Wambo seam packages, with an increase in gamma response in the Wambo. The Tangalooma sandstone at the base of Argyle can also be regarded as a marker for its relative lateral continuity.

The Kogan package which is the uppermost of WCM generally contains one to three coal seams. The Macalister package generally consists of one or two well-developed seams and the highest percentage of coal with a number of smaller stringers. The Wambo generally consists of thin, poorly correlatable coal seams. The Argyle package usually consists of one or two major coaly intervals with banded coals and muds, and Tangalooma sandstone is at the base of Argyle which may be continuous and consists of individual sand lenses in some area. The Upper Taroom package is generally a thick zone of thin coal seams, and forms a relatively thick and continuous single seam at the base. The Condamine is occasionally present as a well-developed single seam up to 10m thick.

Sublayer is the general result of one fluvial decrease period. The sandstone bodies are the fluvial channels at the base then the flooding plains of siltstones upwards and then the development of the lacustrine clays and coal swamps. For sublayer correlation, the typical single fining upwards cycle with coal, clay or siltstone at the top and sandstone at the base. The total of 20 sublayers are picked and correlated for the whole WCM.

A ply refers to an individual depositional coal seam and often quickly splits, merges or pinches out laterally due to the sedimentary complexity. A total of 125 coal plies, 54 sandstones are divided and correlated in all 20 sublayers of the six members. Figure 3 shows the plies correlation in sublayer3 of Wambo member. Four fining upwards cycles (in red triangular) are identified with the normalized density and gamma ray logs. In each cycle sandstones are divided and plies are picked for correlation. Three sandstones are picked and the only lowest seems continuous. The six correlated coal plies show the high degree changing of lateral heterogeneity.

From members, sublayers to plies, the three-order sequence stratigraphy correlation framework are built for the whole WCM in Tipton field.

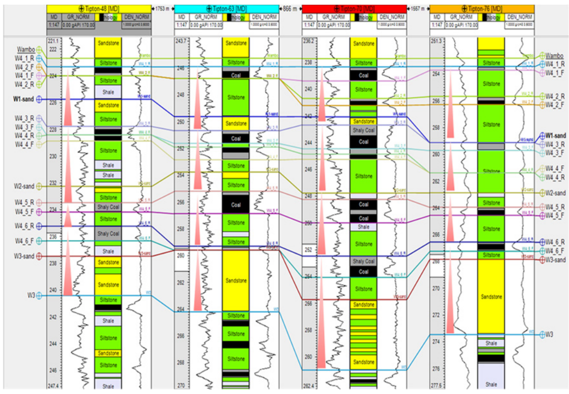

Figure 3: Coal ply and sandstone correlation.

4 COAL AND SANDSTONE DISTRIBUTION

Based on the isochronal stratigraphic framework, the thickness of each ply in each sublayer at well points are summarized. The main thickness of coal plies is about 0.5m, and only a few coal plies have the thickness larger than 5m in WCM of Tipton field (Figure 4). The horizontal thickness surfaces of each ply are mapped with the coal ply thickness point data. From these surfaces the maximum coal ply thickness and the areal coal area can be picked. Thus the correlation between coal ply thickness and the extension area is established (Figure 5). It can be seen that the coal seam area increases with the ply thickness.

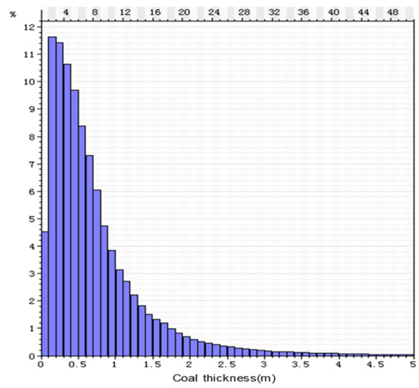

Figure 4: Histogram of coal ply thickness.

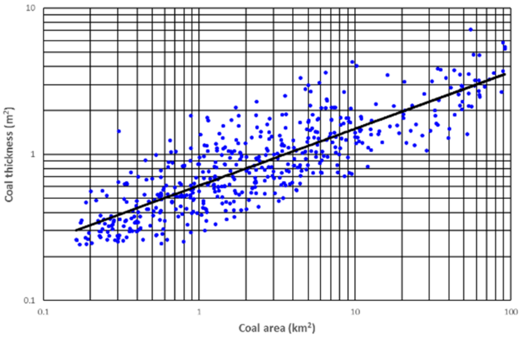

Figure 5: Relationship between coal area and ply thickness.

The sandstone thickness surfaces are also created using the thickness from well points. From these surfaces the channel belts can be identified. Figure 6 is the thickness surface of M1-sand. The red lines show the major channel, the brown lines the minor channel and yellow lines the crevasse splay. The red arrows are the provenance direction. Then the key parameters such as the amplitude, orientation, width and wavelength of the channel belts can be obtained. Table 1 is the parameter summary of major sandstones in each sublayer of Tipton field. The main orientation of the channel is from north to south, and the width is 700- 1500m. The channel amplitude is 800-1900m, and the wavelength is 1400-4000m. These channel geometry parameters are important inputs for the facies object modelling in the future research.

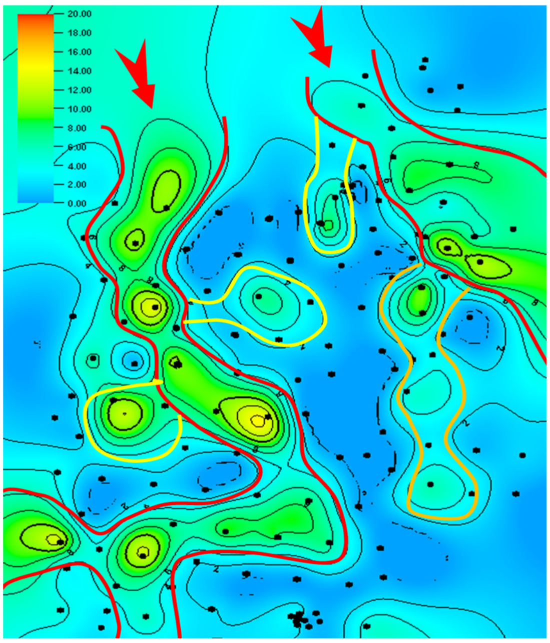

Figure 6: The sandstone thickness surface of M1-sand.

Table 1: The parameters of the channels of each sublayer

Member	Sand name	Orientation	Amplitude (m)	Wavelength (m)	Width (m)	Thickness (m)
Kogan	K2-sand	NE, E	1000	1800	1000-1500	3-12
	K1-sand	NW, N	1200-1800	1900-4000	1200-1500	3-20
Macalister	M3-sand	NW, N	1000-1200	2000-3000	1000-1200	2-15
	M2-sand	N	1200-1500	2500-2700	1000-1400	2-10
	M1-sand	N, NW	1100-1300	1800-2700	1300-1500	5-20
Wambo	W4-sand	N, NW	900-1000	1900-2000	1000	2-10
	W3-sand	N	1000	2400	800	4-10
	W2-sand	N, NW, NE	1000	2400-2600	1200	2-12
	W1-sand	NE, NW, N	1000	2200-2400	900-1200	4-15
Argyle	A4-sand	NE, NW	1000	2000-2200	1000-1200	3-15
	A3-sand	NE, N	1000	2000-2600	800-1200	4-12
	A2-sand	NE, N	800-900	1900-2200	700-900	4-12
	A1-sand	NW, N	800-1500	2000-2100	700-900	3-16
Upper Taroom	T4-sand	NW, N	1000-1900	1800-3000	900-1000	4-17
	T3-sand	N	1000-1300	1600-2100	1000-1300	3-16
	T2-sand	N	800-1000	2200-2500	800-1000	2-16
	T1-sand	NW,NE	900-1200	1900-2400	1000-1200	4-16
Condamine	C3-sand	N	900-1000	2300-2600	1100-1200	4-16
	C2-sand	N, NE	1000	1400-2000	800-1200	2-13
	C1-sand	N, NE	800-900	2400	1100-1200	1-10

5 MAJOR FACIES FEATURES AND GEOLOGICAL CONCEPT MODEL

The calibrated facies features of coal-bearing fluvial system are summarized by combination of core sample data, lithology log, mud log description, lithology report and normalization logs (Hoffman, 2009). Six depositional facies are interpreted as major channel, minor channel, floodplain, coal swamp, swamp and lacustrine. The lithologies of coal, shaly coal, siltstone and shale are approximately corresponded the facies of coal swamp, swamp, floodplain, lacustrine, respectively. The sandstone is for the facies of major channel and minor channel considering the thickness (Martin, 2013). Major channel thickness is usually large than 5m. Note that some thick crevasse splays could have been interpreted as minor channel. Figure 7 is the well section interpreting the distribution of the facies between wells. The red star is the eroded coal by channel, and the red triangular is the coal overlain on the abandoned channels. The coal plies severely vary in lateral with the splitting, merging, pinching out, or erosion by channels.

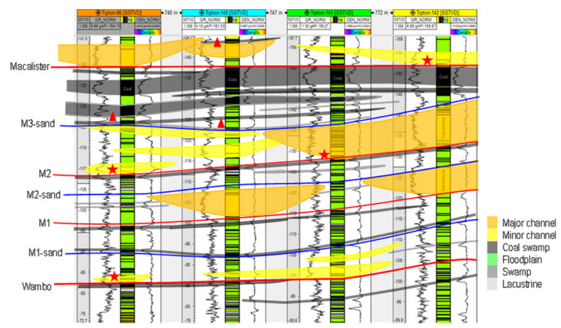

Figure 7: Geological concept model of coal-bearing environment.

5.1 Coal Swamp and Swamp

Coal swamp and swamp are deposited in the flooding plain. Coal swamp was relative pure coal and swamp was the coal with shaly or siltstone which may be more influenced by major or minor channel system than coal swamp. The coal swamp facies formed sheet-like deposits which rarely exceeded 3m in thickness and usually ranged from 0.1 to 2.0m. They are usually underlain by shallow water, and in some instances they are interbedded with each other to form coal seams which may occasionally exceeded 5m in thickness. Channel system usually has great influence on the geometry of the coal swamp and swamp (Stuart, 2014). Usually the coal seams are eroded by the channels, and coal can also deposit in the abandoned channels.

5.2 Channel

Channel deposits in WCM of Tipton field are dominated mostly by sandstones which form long belts tens of kilometers long from the north direction, with typically 700- 1500m wide, mostly in 1000-1200m width and 2- 20m thick, although they may occasionally exceed these dimensions (Shields and Esterle, 2015). Major channels usually has the thickness larger than 5m and sandstone is dominating. Minor channel refers to the thickness larger than 2m and sandstone is major. In Tipton field the sandstone in both channels is generally fine grained, and sometimes medium to coarse sandstones may present. The major and minor channels may include crevasse splays and levee bank with relatively fine sandstone, which are difficult to separate them from channels.

5.3 Floodplain

The floodplain is the background facies including commonly fine-grained siliciclastic rocks such as siltstone, mudstone, shale. Even levee bank and crevasse splay which are not easy to separated are also included in the floodplain facies. Sometimes thin and isolated shaly coal is also included in some places in the Tipton field.

5.4 Lacustrine

Dark, gray shale, claystone or siltstone in shallow water are the main lithologies in the lacustrine. The sedimentation rates and energy are low, and the sediments generally occur as sheets which ranged from a few centimeters to a few meters in thickness.

The organization of the major facies of the WCM depositional environment is summarized in Figure 8, which is a simplification and synthesis of geological concept facies models. Major channels of variable sinuosity are the main pathways of sediment dispersal across the floodplain. These major channels feed a hierarchy of minor channels, crevasse splays and levee bank, depositing sediments in floodplain. Sediments infilling the shallow water, abandoned channel systems and floodplain enable conditions to be established in which coal could form and develop.

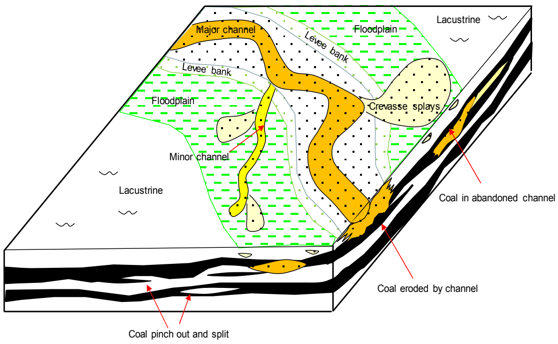

Figure 8: Geological concept model of coal-bearing environment.

6 CONCLUSIONS

The isochronal stratigraphic framework of sublayers and coal plies in WCM of Tipton field is built using high resolution sequence stratigraphy, and the geometries, distributions and interrelationships of the coal plies and channels are obtained to better reveal the lithology heterogeneity and continuity. A number of sedimentary facies have been identified and geological concept model is built which would enhance the understanding of the depositional environments of Tipton field.

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REFERENCES

Bohacs K and Sutter J 1997 Sequence stratigraphic distribution of coaly rocks: fundamental controls and paralic examples. *AAPG Bull* **81 (10)** 1612-1639

Fielding C R 1993 The middle jurassicWalloon Coal Measures in the type area, the rosewood Walloon coalfield, SE Queensland. *Aust. Coal Geol* **9** 4-15

Hamilton S K, Esterle J S and Sliwa R 2014 Stratigraphic and depositional framework of the Walloon Subgroup, eastern Surat Basin, *Queensland. Aust. J. Earth Sci.* **61(8)** 1061-1080

Hoffman K L, Totterdell J M, Dixon O, Simpson G A, Brakel A T, Wells A T and McKellar J L 2009. Sequence stratigraphy of jurassic strata in the lower Surat Basin succession, Queensland. *Aust. J. Earth Sci.* **56** 461-476.

Martin M A, Wakefield M, MacPhail M K, Pearce T and Edwards H E 2013 Sedimentology and stratigraphy of an intra-cratonic basin coal seam gas play: Walloon Subgroup of the Surat Basin, *eastern Australia. Pet. Geosci.* **19** 21-38.

Shields D and Esterle J 2015 Regional insights into the sedimentary organisation of the Walloon Subgroup, Surat Basin, Queensland. Aust. *J. Earth Sci.***62** 949-967.

Stuart J, Moundney N P,McCaffrey W D, Lang S and Collinson J D 2014. Prediction of channel connective and fluvial style in the flood basin successions of the Upper Permian Rangal Coal Measures (Queensland). *AAPG* **98(2)** 191-212.

Zhou F, Shields D, David T, Tyson S and Esterle J 2017 Understanding the geometry and distribution of fluvial channel sandstones and coal in the Walloon Coal Measures, Surat Basin, *Australia. Marine and Petroleum Geology* **86** 573-586