PS Electrofacies Analysis and Shale Gas Potential of the Carynginia Formation (Perth Basin, Western Australia)*

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Abstract

As the unconventional activities in petroleum industry are globally increasing, the importance of evaluating shale gas potentials in different parts of the world becomes crucial. In recent years, shale gas plays of Western Australia are also being carefully looked at and the Permian Carynginia Formation (Perth Basin) is considered as one of the primary targets in the region. There are about 341 wells in the Perth Basin, of which 187 wells penetrate the Carynginia Formation. Thirty-two wells crossing the Carynginia Formation have been studied and about 600 Rock-Eval data were analyzed to reconstruct burial history and develop thermal modeling. The Carynginia sediments show a trend of increasing maturity from north to south, favoring the occurrence of gas shale near the basin's center. After a detailed study of different well logs, well reports and core observations, six wells were selected for shale gas layers identification. Detailed electrofacies studies have been developed, including cluster analysis and its correlation with shale-gas prone lithofacies. Based in burial history and thermal modeling, three Types of wells have been considered. Type 1 includes wells Geelvink 1A, Jurien 1 and Narlinque, with modeled maturation for gas and log data analysis pointing to layers with good potential for gas shale production (high GR, IND, DT and low SP). Type 2 includes wells Cadda 1 and Mt Horner 1, with modeled maturation only for oil, but electrofacies data pointing to layers with shale-gas potential (high GR, IND, DT, and low SP); this situation may be due to the presence of Type III kerogen, more prone to gas generation, even within the late-oil window. Type 3 is represented by Mondara 1 well, with insufficient maturation and no electrofacies characteristics of shale-gas. This study illustrates a case of electrofacies cluster analysis applied to shale gas prone units, as a well log tool to identify and characterize the presence of shale-gas layers.

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Abstract:
Unconventional hydrocarbon resources are becoming increasingly important to keep pace with the global rising energy demands. Identification of reservoir electrofacies plays an important role in petrophysical evaluation of hydrocarbon bearing intervals. In order to provide criteria to highlight the sweet spots for shale-gas in the Perth Basin, electrofacies analysis was done for Carynginia Formation, using cluster analysis techniques. This analysis was carried out by identifying electrofacies from wireline well log responses and from the available core data, focused in 6 selected wells. Three types of situations have been defined, regarding shale-gas potential and characteristic electrofacies identification – Type I, Gas-window wells with shale-gas; Type II, Oil-window wells with shale-gas; Type III, Non-mature wells with no shale-gas. From the 30 identified electrofacies, three appear as more promising in terms of shale-gas bearing layers of the Carynginia Formation. This method may be used to help detecting shale-gas targets based on electrofacies analysis.

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I. GEOLOGICAL FRAMEWORK

a) Perth Basin (Figure. 1)

Perth Basin is an N-S elongated trough, lying in the southwestern part of Australia consisting of a sedimentary succession ranging from the Silurian to the Pleistocene. Nearly one half of the basin is situated onshore and extends from near Murchison River to the south coast covering a distance of 750 km approximately. Perth Basin is a structurally complex basin of about 172 300km2 area which has formed in Permian to Early Cretaceous during the phase of separation of the Greater India and Australia. The initial Permian extension originated a N-S- trending series of deep rift basins, known as Dandaragan Trough and Bunbury Trough. In the northern Perth Basin, Dandaragan Trough is the most important depocenter next to the Darling fault, with nearly 15 km of sediments from Silurian to Cretaceous ages deposited in response to the rifting.

b) Carynginia Formation (Figure 2.)

The Carynginia Formation deposits cover a wide area of the northern Perth Basin. Irwin River Coal Measures underlie the Carynginia Formation conformably, while the upper contact with the Dongara and Wagina sandstones and also Beekeeper Formation corresponds to an angular unconformity. Trace fossils, wave ripples, hummocky cross-stratification and conglomerate lenses have suggested that the formation has been deposited mostly coastal marine environments, under proglacial conditions similar to the setting of the Holmwood Shale. The lower part consists of thinly interbedded siltstone, sandstone and limestone, corresponding to the Shale Member deposited in deeper waters, while the upper part is known as the Limestone Unit, a bioclastic shelf carbonate, deposited in shallower waters. Sandstones are usually thin and discontinuous, sealed by shales and limestones, with stringer-like layers known to produce gas in the area of Dongara.

The permeability values are approximately 5 mD while the porosity varies from 11 to 20% (Cadman et al., 1994). At Woodada field, the Carynginia Limestone presents porosity values up to 15% and permeability is about 134 mD, having produced gas (Cadman et al., 1994).

The Carynginia Formation deposits present reasonably good source potential in its basal marine shales and claystones. The organic material is considered to land plants derived (inertinite) and poor in hydrogen (Kantsler and Cook, 1979) but the TOC has values up to 11.4% and this unit is normally gas prone.

In most of the northern Perth Basin, the Carynginia Formation is found to be overmature and in the window of dry-gas generation. In the area of Dongara Saddle and Beagle ridge flanks, source rocks appear to be less mature and some shaly facies are replaced by shallow water limestones (Cadman et al., 1994).

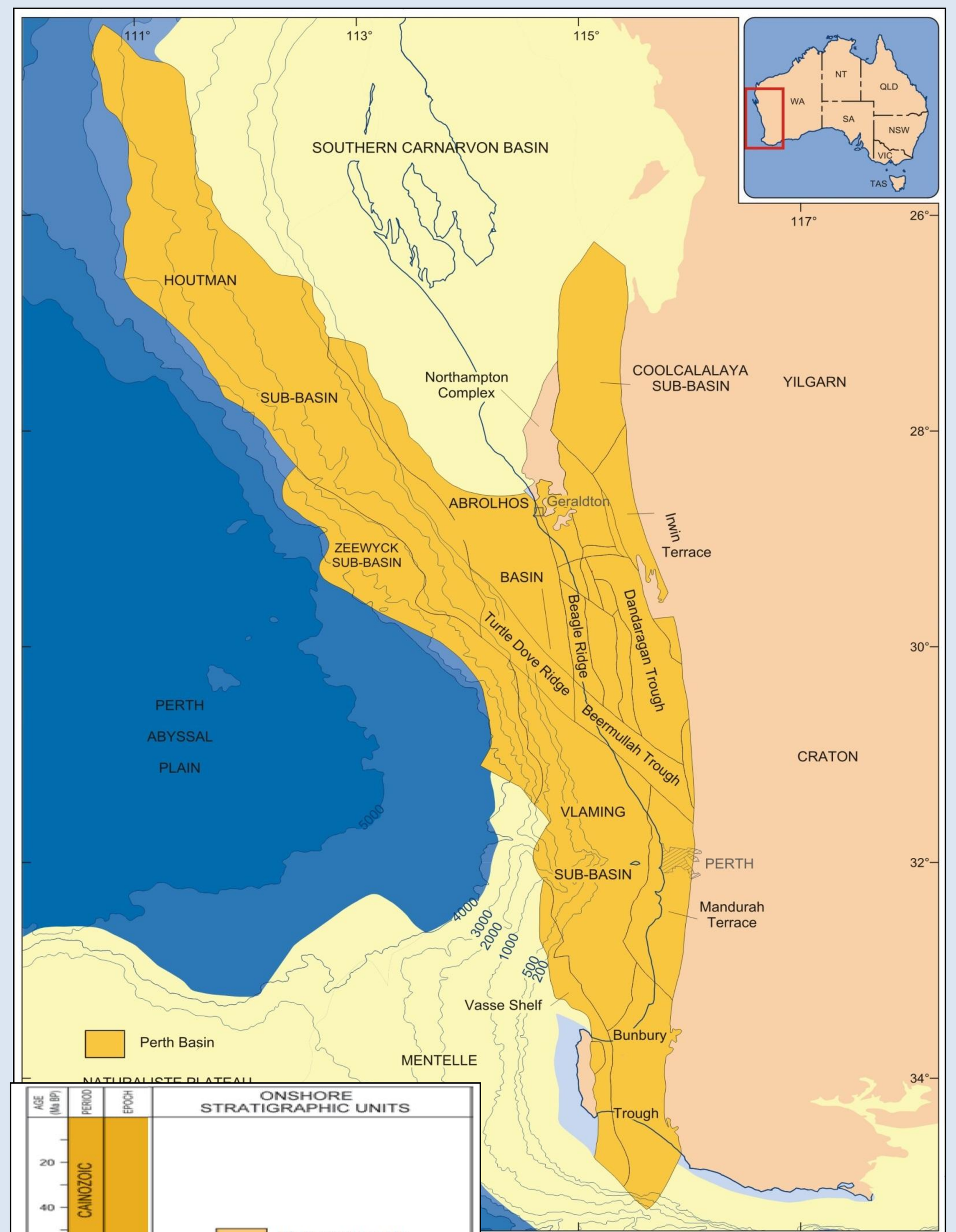

Figure 1. Location map of the studied area (in Geoscience Australia, 2012).

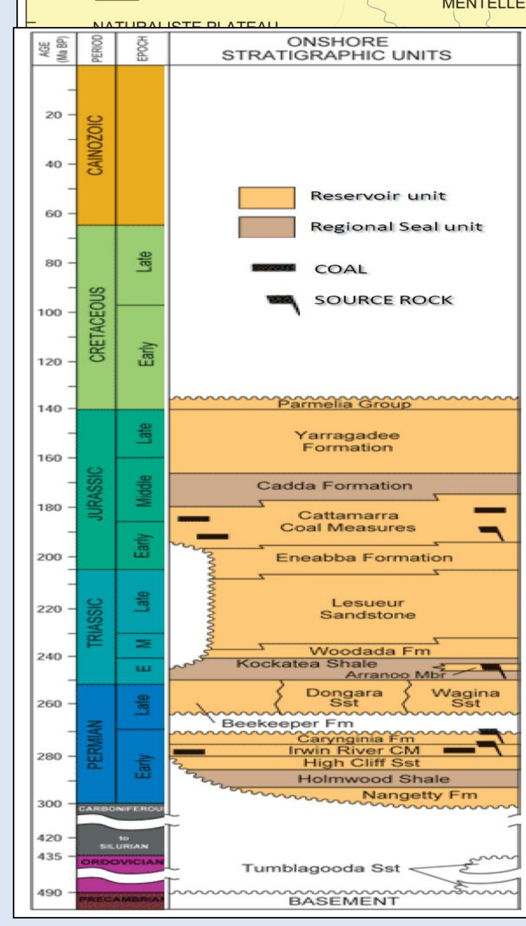

Figure 2. Stratigraphic column of the Perth Basin (in Geoscience Australia, 2012)

II. METHODOLOGY

Six selected wells have been studied in detail, based on stratigraphic and geochemical data, used to model burial history and thermal modeling. Cluster analysis technique was applied to group data and to define or identify electrofacies.

An important step in any clustering analysis is to select a distance measure, which will determine how the similarity of two elements is calculated. This will influence the shape of the clusters, as some elements may be close to one another, according to one distance, and further away, according to another. Euclidean distance has been used. The next step is to extract a dendrogram of data based on the linkage data, consistsing of many U-shaped lines connecting objects in a hierarchical tree. The Lines connect two clusters with minimum distance and the procedure continues until all the groups come together as a single cluster.

Well log data were introduced as primary data into MATLAB software, used to calculate the “distances” between them. The processed log data (i.e., GR, DT, IND, and SP) were loaded as an input matrix (x) and the most used distance function. Euclidean distance, was applied to calculate “distances” between data. The linkage function takes the generated “distance” information generated by the “pdist function” and links pairs of objects that are close together into binary clusters (clusters made up of two objects). The linkage function then links these newly formed clusters to each other and to other objects, to create bigger clusters, until all the objects in the original data set are linked together in a hierarchical tree. This is an important step in data clustering which determines primary grouping in data and prepares input data for cluster tree or dendrogram generation for the next stage.

The “cophenetic correlation coefficient” has been used to examine the reliability of the applied method (Scott et al., 2004). In other words, one way to measure how well the cluster tree generated by the linkage function reflects data is to compare the “cophenetic distances” with the original distance data, generated by the Euclidean function. If the clustering is valid, the linking of objects in the cluster tree should have a strong correlation with the distances between objects in the distance vector. The “Cophenet function” compares these two sets of values and computes their correlation, returning a value called the “cophenetic correlation coefficient”. In the next step the matrix of input distance data was linked through a linkage function known as weighted average distance. The closer the value of the “cophenetic correlation coefficient” is to 1, the more accurately the clustering solution reflects the data distribution.

C = Cophenet (Z,Y) where Z is the matrix output by the linkage function and Y is the N distance vector output by the “pdist function”.

The “cophenetic correlation coefficient” for the present study is determined as high as 0.94, which reflects a good accuracy of the applied method.

III. RESULTS

a) Burial History and Thermal Modeling

From the several wells drilled in the Perth Basin, six wells crossing the Carynginia Formation were selected for this study, based on existent geochemical data, burial history and thermal modeling. Organic matter maturation has been modeled based on Lopatin's time-temperature index of maturity (TTI) (Lopatin, 1971; Waples, 1980), using MATLAB software. From this modeled maturation, equivalent Vitrinite Reflectance values have been deduced and plotted against depth.

Geelvink 1A (Figure 3.) - Maximum burial of the Carynginia Fm reached 3053 m. Modeling based on geochemical data (TMax), burial history and thermal maturation (TTI), show that this unit reached the oil generation window in late Cretaceous and gas generation window in early Tertiary.

Mondarra 1 (Figures 4. and 5.)- Maximum burial of the Carynginia Fm reached 3062 m. Modeling based on geochemical data (Tmax) and burial history, show that this Unit reached the oil window in middle Jurassic and the wet gas generation window in late Cretaceous. However, geochemical data (Tmax and IH) shows that the deposits are immature for oil.

Narlingue 1 (Figure 5.)- Maximum burial of the Carynginia Fm reached 2130 m. Data from burial history and thermal modeling (TTI, Easy Ro) show that this Unit did not reach oil generation. However, geochemical data (Tmax and HI) show that the oil-window has been reached .

Jurien 1 (Figure 6.) - Maximum burial of the Carynginia Fm reached 1026 m. Data from burial history and thermal modeling (TTI, Easy Ro) show that this Unit did not reach hydrocarbon generation. But geochemical data modeling (Tmax, HI) show that it reached the wet gas window (Figure. 10). This Fact points to up-lift and erosion affecting burial history curve.

Mount Horner 1 (Figure 7.)- Maximum burial of the Carynginia Fm reached 2252 m. Vitrinite reflectance data (Ro%) show that this Unit it reached the oil generation window (Figure. 11).

Cadda 1 (Figure 8) - Maximum burial of the Carynginia Fm reached 2794 m. Burial history and thermal modeling (TTI) show that this Unit gradually entered the oil generation window during the whole Jurassic.

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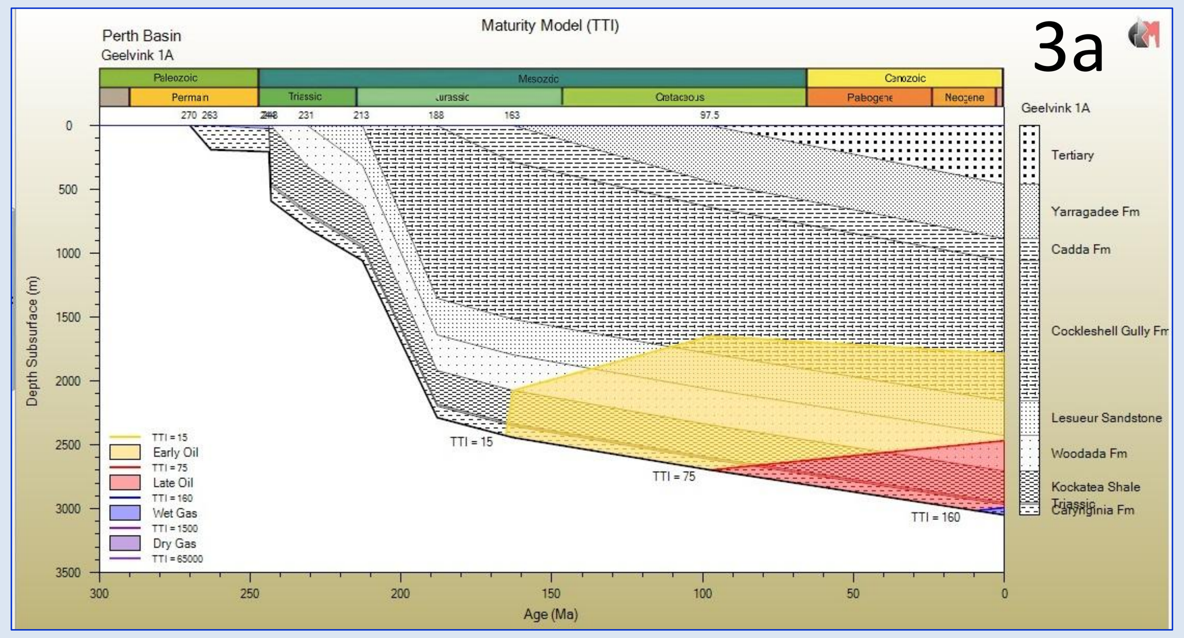

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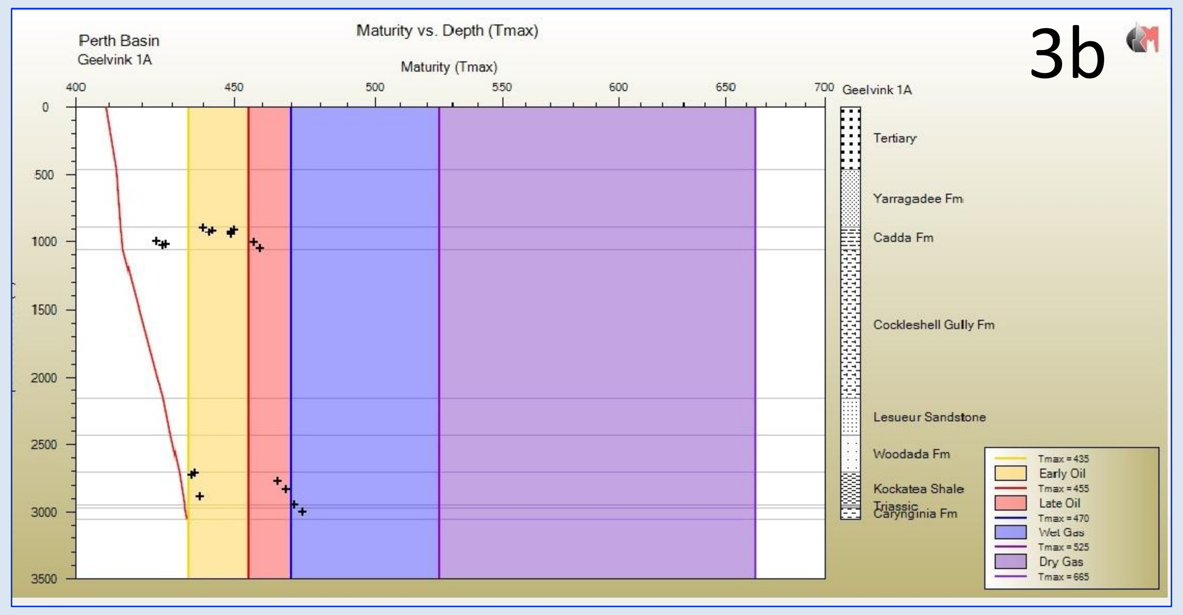

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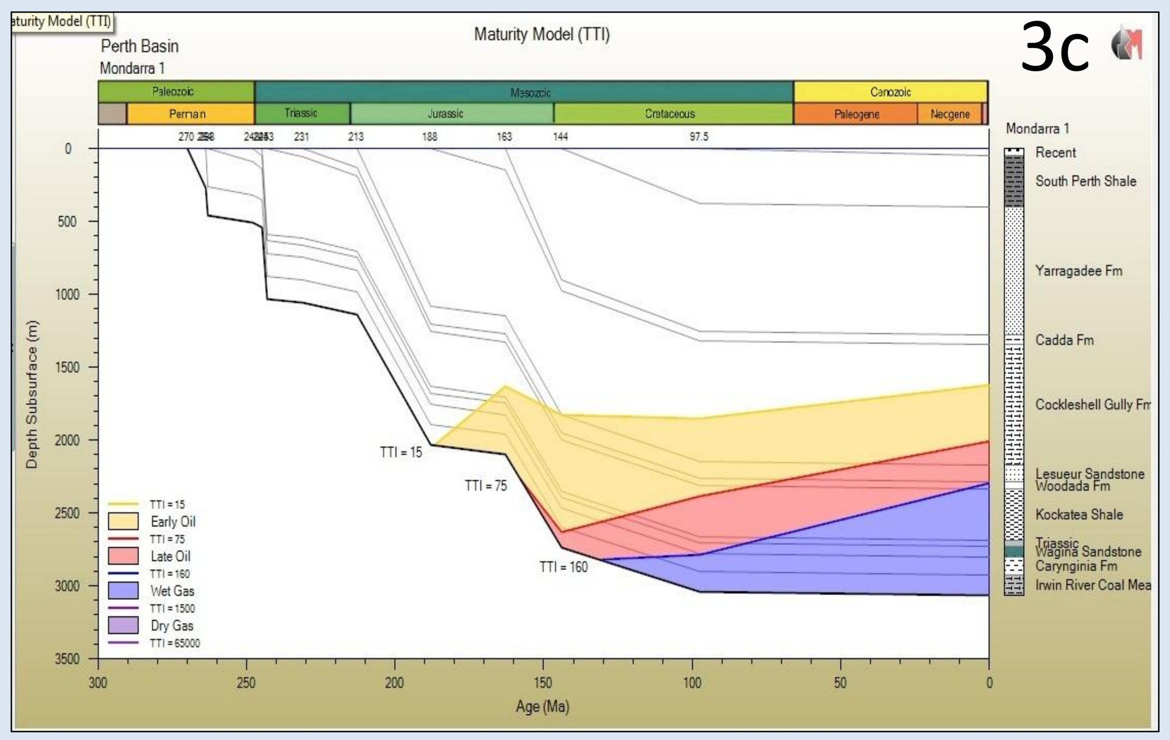

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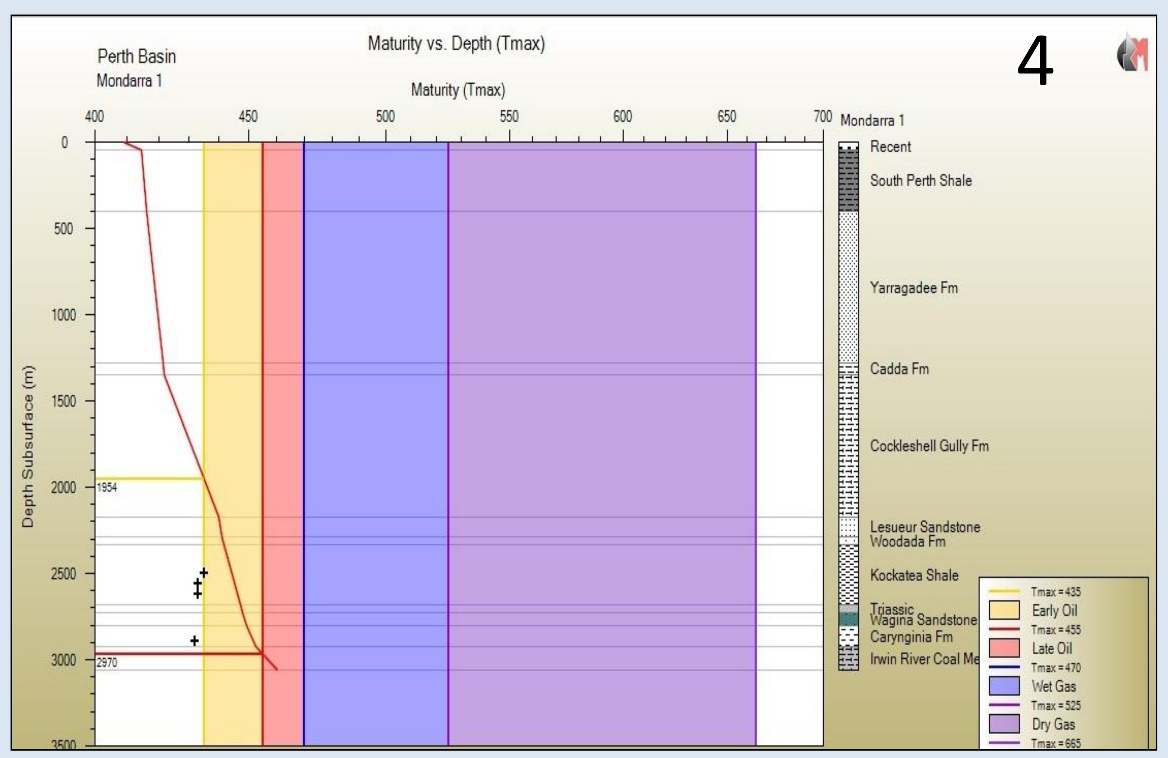

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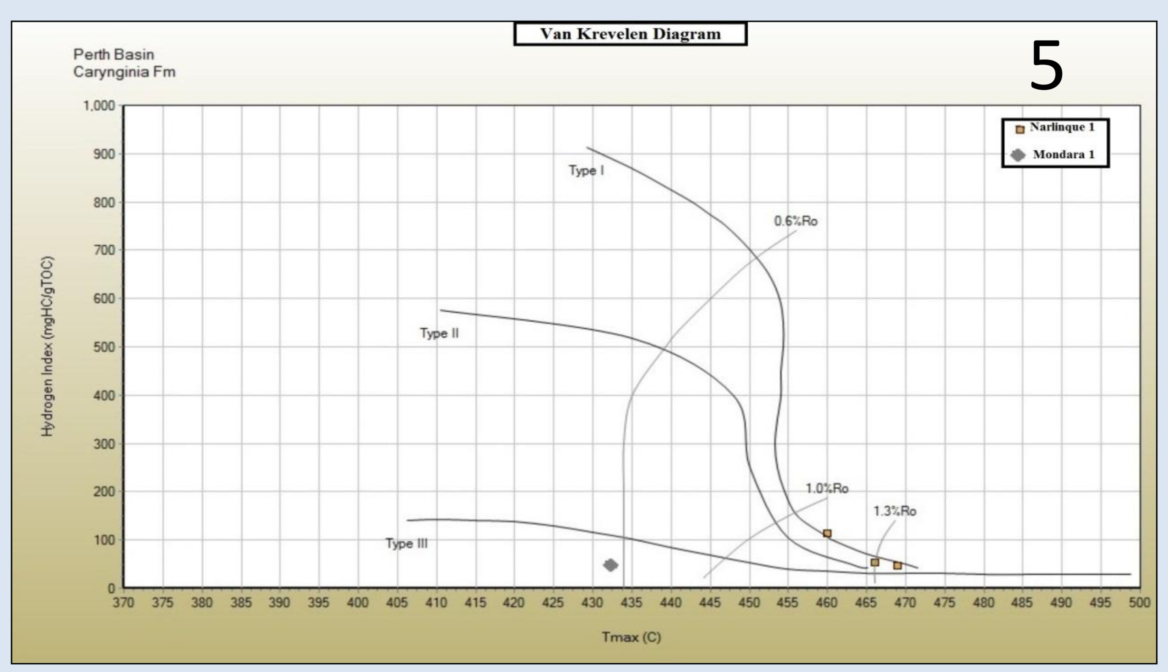

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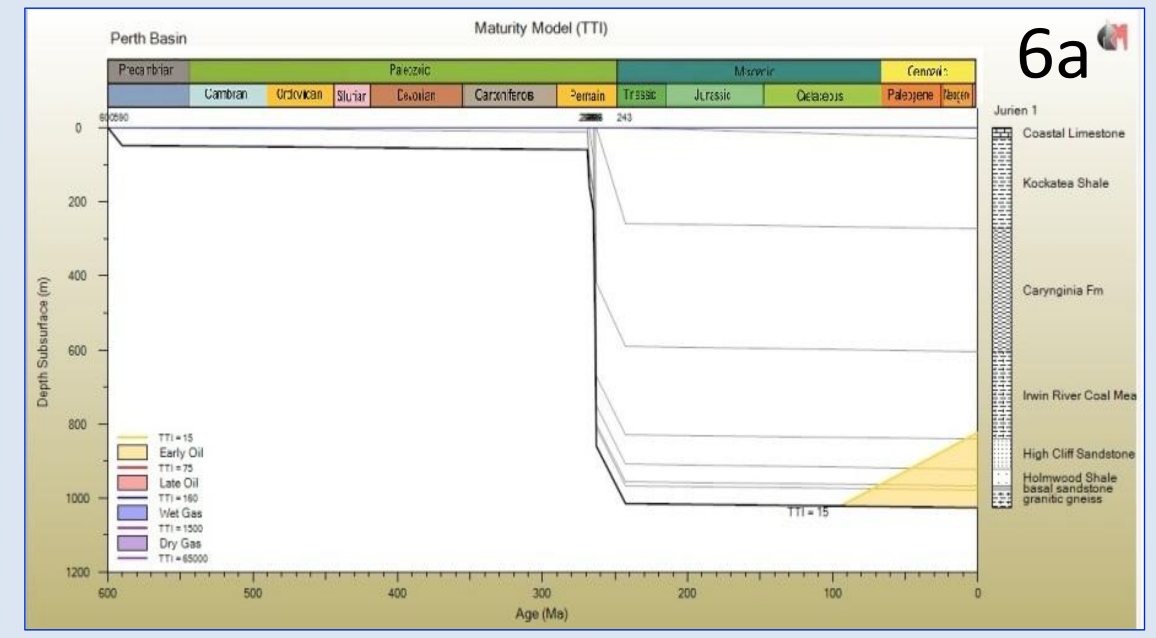

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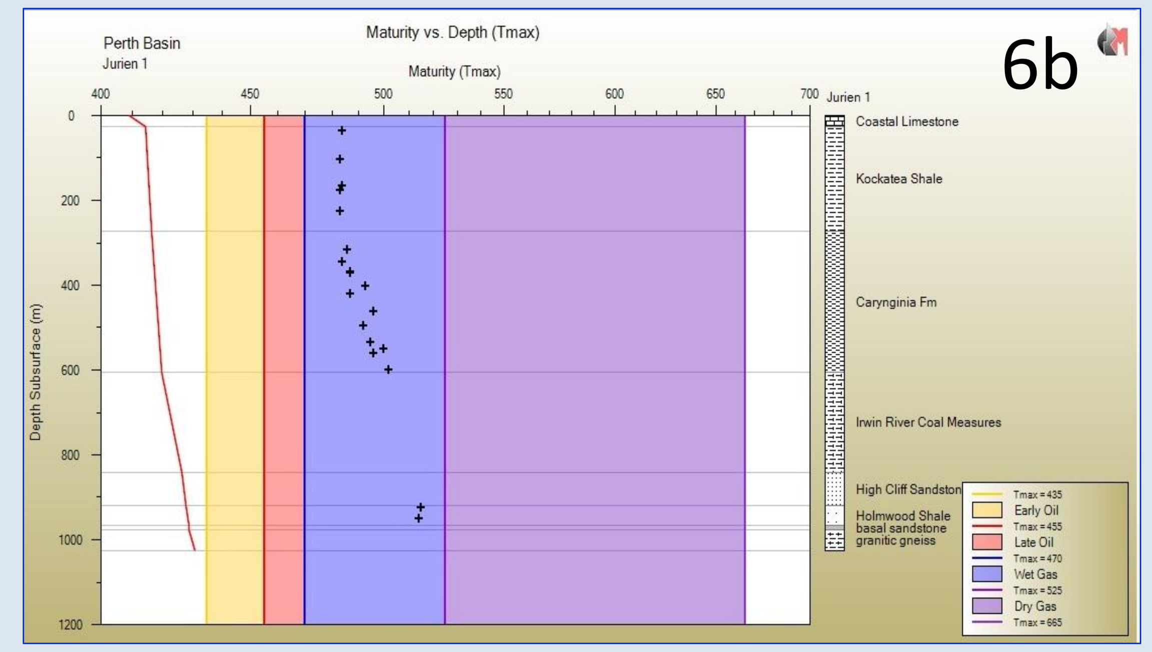

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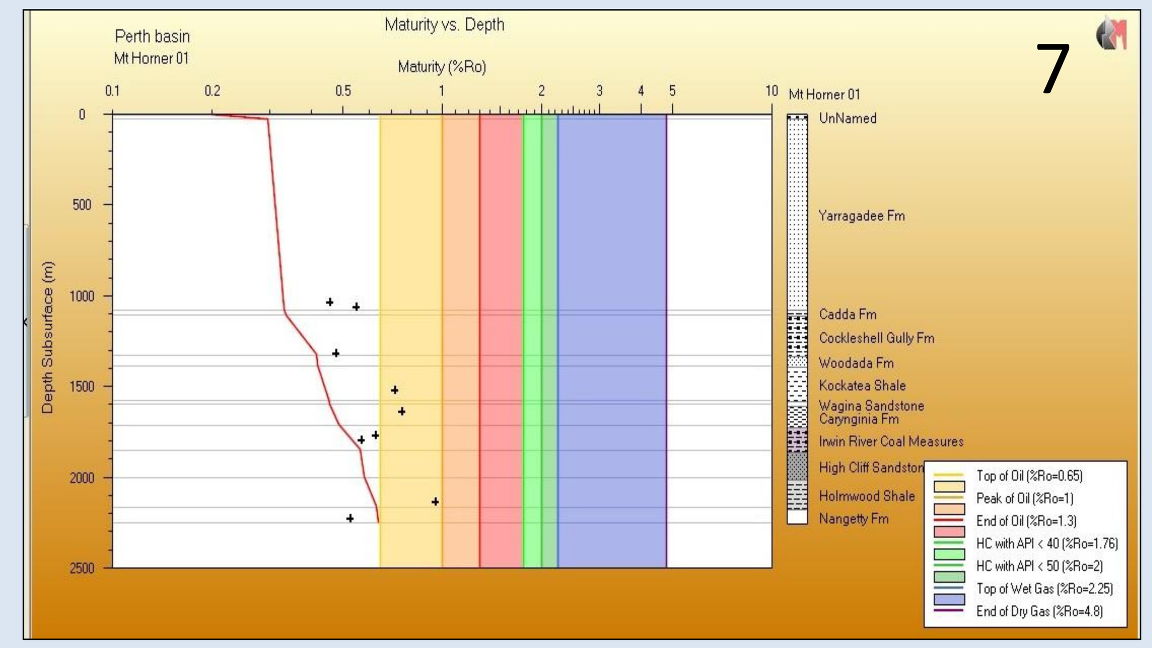

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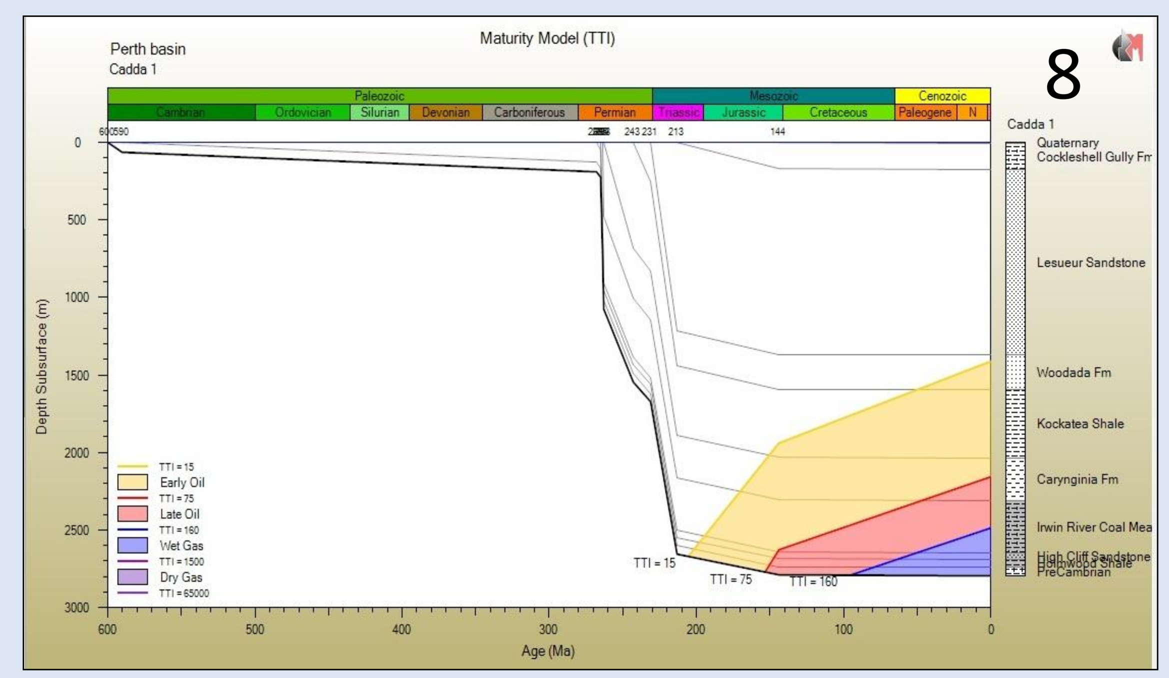

***Figure 3**. Geelvink 1A well. a) Burial-history curve; b) Maturity versus Depth, based on TTI and Ro; c) Maturity versus Depth, based on Tmax.*
***Figure 4**. Mondarra 1 well. Maturity versus Depth, based on Tmax.*
***Figure 5**. Van Krevelen Diagram for Mondarra 1 and Narlinque 1 wells.*
***Figure 6.** Jurien 1 well. a) Burial-history curve; b) Maturity versus Depth, based on Tmax.*
***Figure 7.** Mount Horner 1 well. Maturity versus Depth, based on Ro.*
***Figure 8.** Cadda 1 well. Burial-history curve.*

***Figure 9.** Electrofacies dendrogram for the studied wells in the Perth Basin. X-axis represents the 30 defined electrofacies and Y-axis represents the hierarchic degrees of distinctness.*

***Figure 10.** Petrophysical properties for the three electrofacies associated with shale-gas layers, recognized in the reservoir.*

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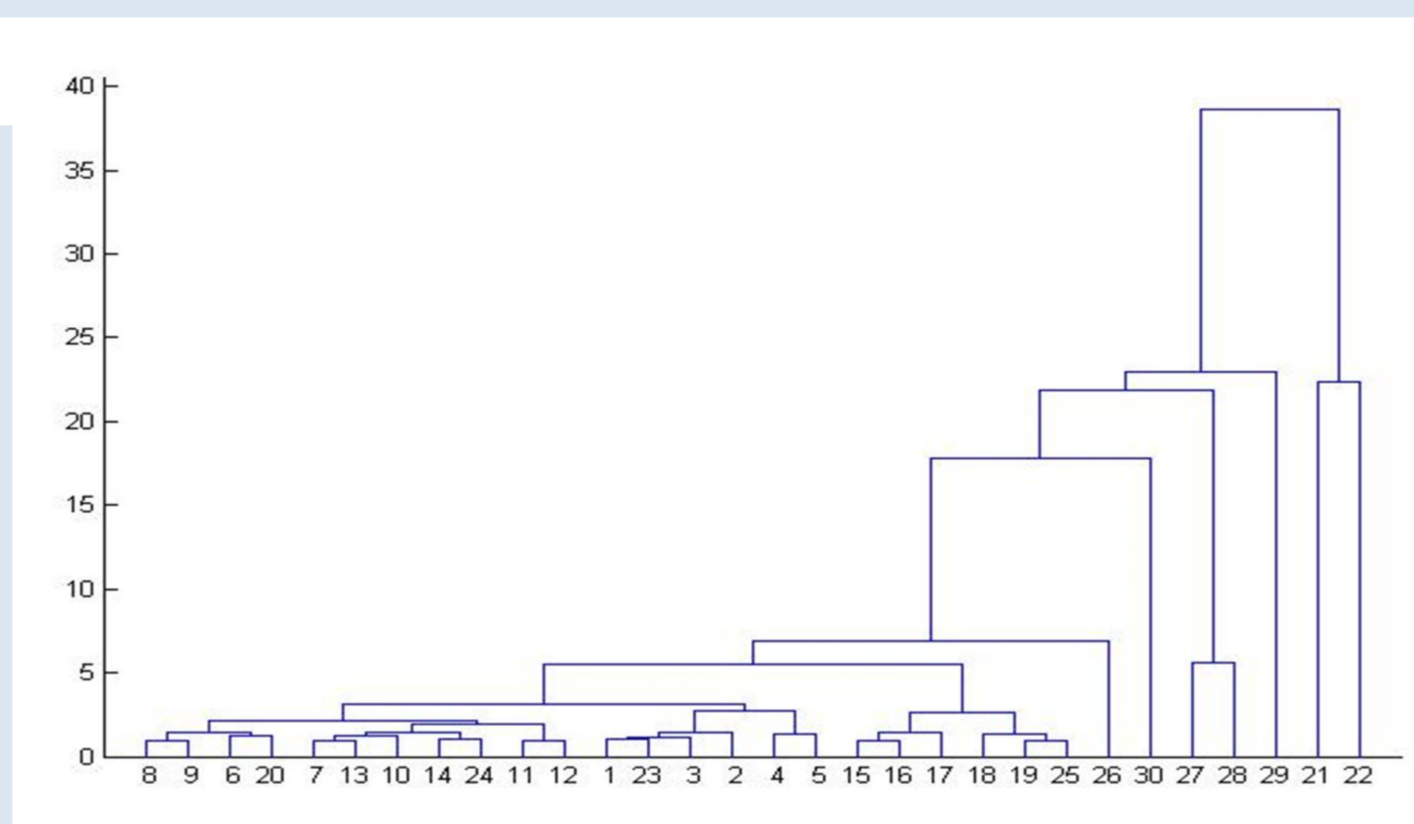

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Electrofacies		DT	GR	IND	SP
	Max	99.64803	151.1755	26.77935	69.05875
2	Avg	85.10241	101.0881	13.15367	53.60963
	Min	72.10945	57.10865	4.342141	37.62114
	Max	105.478	180.7834	18.54953	106.0379
5	Avg	85.76923	143.138	10.30295	92.2712
	Min	74.29083	71.84818	4.117763	81.7836
	Max	111.3895	209.2214	17.57589	92.02628
18	Avg	89.99543	143.4255	8.565839	66.09357
	Min	72.51421	89.58122	2.163138	54.53049

b) Electrofacies and Shale-gas potential (Figure 11.)

The study focused on wireline well logs - DT, GR, IND and SP – as well as on Electrofacies cluster-analysis. In well logs, characteristic properties for shales containing gas are: i) high to very high gamma ray, over 150 g/API; ii) high resistivity, over 15 ohm; iii) high sonic porosity; iv) low SP (Alexander et al., 2011).

In order to approach the relations of petrophysical and electrofacies with shale-gas potential, each of these six wells has been classified in terms of "yes/no" and "oil/gas" generation, based on the presented burial and thermal modeling.

Type I corresponds to wells in which, according to modeling, the Caryngínia Shale may have reached gas-window.

Type II corresponds to wells in which, according to modeling, the oil-window has been reached and some potential for shale-gas may eventually exist.

Type III corresponds to wells in which, according to modeling, no maturation for hydrocarbons has been reached, and therefore no potential for shale-gas exists.

Type I: Gas Window wells

Geelvink 1A (Figure 11a.) –According to the presented modeling, the Caryngínia Shale reached the gas window. Based on wireline log data, electrofacies 5, presenting high DT, GR, IND and low SP, has a good potential for shale gas production.

Jurien 1 (Figure 11b.) - According to the presented modelings, the Caryngínia shale reached the gas-window. Based on wireline log data, electrofacies 2 and 18, both with high DT, GR, IND and low SP, were identified as having good shale-gas production potential.

Narlinque 1 (Figure 11c.) - According to the presented modelings, TTI show that this Unit reached the oil generation window, whereas the geochemical data show that it may have reached the gas window. This situation may eventually be due to higher heat-flow then the one considered as input-value for the modeling software. Based on well log data, electrofacies 2 and 18, both with high DT, GR, IND and low SP, show good potential for shale-gas production.

Type II: Oil-window wells

Cadda 1 (Figure 11d.) - According to TTI data modeling, oil generation window has been reached. Based on wireline well-log data, electrofacies 5 and 18, both with high DT, GR, IND and low SP, have a potential for shale-gas generation and accumulation.

Mount Horner 1 (Figure 11e.) - According to Ro% data, the Unit reached the oil generation window, but geochemical data do not confirm it. Based on wireline well log data, electrofacies 2 and 18 present the best shale-gas potential in this well.

Type III: Non-productive wells

Mondarra 1 (Figure 11f.) - According to TTI modeling, the gas generations window has been reached, although the geochemical data do not confirm it. Also based on wireline well log data, there is no potential for shale-gas in this well.

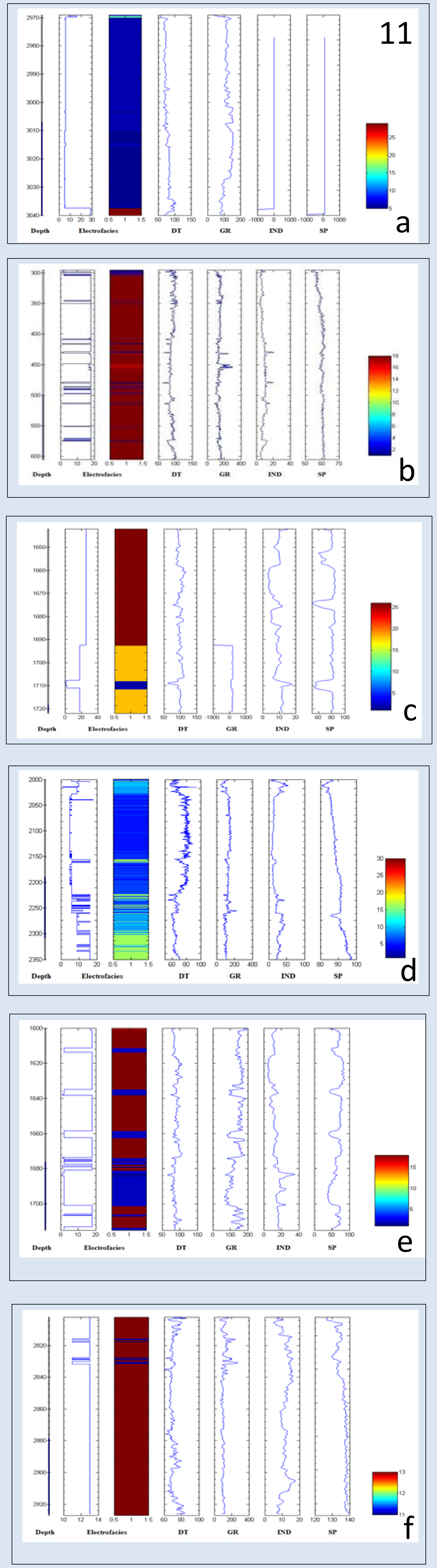
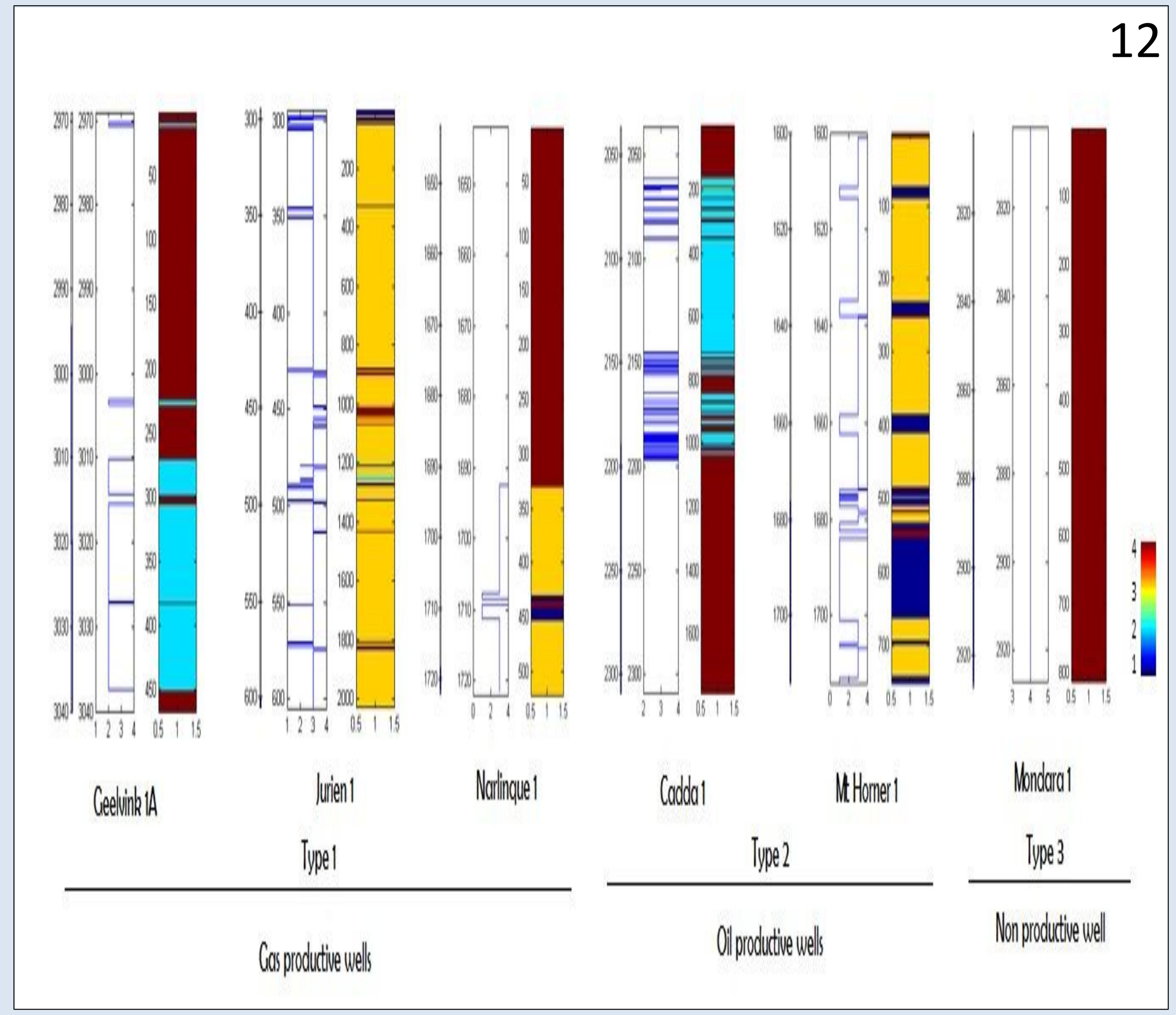


Figure 11. *Electrofacies and petrophyscs for the six selected Perth Basin's wells. a) Geelwink; b) Jurien 1; c) Narlinque 1; d) Cadda 1; e) Mount Horner 1 f) Mondarra 1. For each well, the graded color-bars represent the electrofacies numbers, identified in that well.*

Figure 12. *Electrofacies and petrophysics for the six selected Perth Basin's wells. Electrofacies have been re-colored and re-numbered, from 1 to 4: Dark blue (1) corresponds to electrofacies 2; Light blue (2) corresponds to electrofacies 5; Yellow (3) corresponds to electrofacies 18; Brown (4) corresponds to all the other electrofacies which have been considered as having low to no shale-gas potential.*



Conclusions

Six wells of the Perth Basin were studied, based on log data and modeled burial history and maturation. Three Types of situations have been defined, regarding shale-gas potential and characteristic electrofacies identification (Figure 12.).

Type 1 includes wells Geelvink 1A, Jurien 1 and Narlinque, showing maturation stage for gas production, based on of burial history and thermal modeling, while log data analysis point to layers with good potential for gas shale production (high GR, IND, DT and low SP), corresponding to electrofacies 2, 5 and 18.

Type 2 includes wells Cadda 1 and Mt Horner 1, showing maturation only for oil, based on of burial history and thermal modeling, but petrophysical data show layers with shale-gas potential (high GR, IND, DT, and low SP), corresponding to electrofacies 5 and 18. This situation may be due to the presence of Type III kerogen, more prone to gas generation, even within the late-oil window.

Type 3 is represented by Mondarra 1 well, with insufficient maturation and no electrofacies characteristics of shale-gas.

From this study, it may be concluded that electrofacies data and cluster analysis may be an interesting contribution to support the identification of shale-gas layers and the potential for shale-gas production.

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