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The University of Queensland Surat Deep Aquifer Appraisal Project (UQ-SDAAP)

Scoping study for material carbon abatement via carbon capture and storage

Supplementary Detailed Report

Palynological analysis of the Precipice Sandstone and Evergreen Formation in the Surat Basin

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1. Executive summary

Seventy-one core samples from nine wells that penetrate the Precipice Sandstone and Evergreen Formation underwent palynological analysis for biostratigraphic and paleoenvironmental purposes.

The results showed that the Precipice Sandstone, by and large, is of Early Jurassic age whereas the Evergreen Formation is of Early to Middle Jurassic.

A few samples also confirm the younger age for the Hutton Sandstone, falling mostly in the Middle Jurassic.

Paleoenvironmental interpretation of spores and pollen suggest a mostly freshwater origin for mudstones, though a proportion of samples indicated marine influence due to the presence of acritarchs and dinoflaggelate cysts. These were distributed in several wells, and at various stratigraphic levels. However, the majority occurred above the Boxvale Sandstone Member and into the Westgrove Ironstone Member.

Combined with the facies analysis from core, which focussed on sedimentology and ichnology, **the results are taken to mean that the depositional environments shifted substantially due to small changes in base level and a topographically flat depositional gradient**.

Large delta systems show a complex arrangement of depositional environments and facies, and these results are reasonably consistent with what is observed in modern systems such as the Mississippi River Delta, USA and Fraser River Delta, Canada.

2. Introduction

Biostratigraphic correlation is one of the most widely utilised methods for determining age-relationships of sediments in geological successions. However, interpreting the age of strata using fossil taxa or groups of fossil taxa contains an inherent degree of error and uncertainty. The uncertainties relate to sample quality, sample size and sampling interval, the resolution of the biostratigraphic zonation, and the fact that the stratigraphic record is incomplete (Cope 1995). Good, clean samples are important for quality biotstratigraphic assessment to avoid the convoluting ages due to caving, reworking, or post-depositional mixing. Sample size and sampling interval have an important control on the resolution of age-determinations. There are stochastic effects related to the size of samples analysed and the amount of effort used to examine them (Cooper et al. 2000). Similarly, the vertical spacing between samples can impart uncertainty related to the lowest and highest occurrence of particular taxa; these never represent their true first and last occurrence. Therefore, good taxonomic understanding of the particular group of fossils being used for biostratigraphy is essential (Cope 1995; Pol & Norell 2006). However, not all time-intervals and groups are understood to the same resolution (e.g. Loydell 1993; Shackleton et al. 2000; Berggren et al. 1995, Kaufmann, 2006). Since biostratigraphy is in essence an indirect dating method, this requires ties to geochronometric datasets at other locations. Finally, the stratigraphic record is incomplete in nature (Miall, 2010), and this probably presents the largest uncertainty in achieving the highest possible resolution in depositional ages.

Another aspect of biostratigraphic analysis is the interpretation of depositional environment. Based on the suite of palynomorphs and their relative proportions, inferences can be made about the types of vegetation that were present in the environment (Farley 1990b; Batten 1974; Frederiksen 1985). These can then lend insights about faunal production, climate and latitude, and be used to help differentiate between subaerial, freshwater, and marine-influenced depositional settings (Czarnecki et al. 2014; Farley 1990a). The main types of palynomorphs recorded include spores, pollen, and algae – these are the most common non-marine forms. On the other hand, marine-indicators generally consist of dinoflagellate cysts, acritarches, copepod eggs, and types of marine algae (de Vernal 2009). Of course, the relationship between palynomorph and environment is much more complicated with numerous other factors affecting the distribution of forms including windblown transport (Andersen 1974; Birks 1981), redeposition and sediment mixing (Davis 1968, Davis 1973), reworking of older palynomorphs, and unstable depositional settings in terms of water table fluctuations, and autogenic shifts in environment. These ultimately mean that interpretations based on palynology need to be couched in the context of other lines of evidence including stratigraphy, sedimentology, and ichnology.

UQ-SDAAP undertook palynological analysis of core from the Precipice Sandstone and Evergreen Formations in the Surat Basin to better refine our stratigraphy and interpretations of depositional environments. The aim was to address uncertainties in the age-relationships between sequence stratigraphic units to ensure our correlations were sound and to better predict lateral continuity of strata. Moreover, the paleoenvironmental information gleaned from the analysis was important for assessing the validity of facies interpretations and the size and distribution of geobodies. Ultimately, by reducing uncertainty, UQ-SDAAP could build better static reservoir models.

3. Methods

A total of 71 core samples from the Chinchilla 4, Condabri MB9-H, Kenya East GW7, Reedy Creek MB3-H, Roma 8, Taroom 17, West Wandoan 1, and Woleebee Creek GW4 wells were processed by MGPalaeo at their Malaga Laboratory in Perth.

The samples were analysed quantitatively with the first 300 specimens in each sample counted and subsequent species simply recorded as present. Details of the palynomorph assemblages are recorded on the StataBugs distribution chart, with each taxon expressed as a percentage of the entire assemblage. From this information, assignments are made to the palynostratigraphic scheme of Price 1997, as shown in Figure 1. The McKellar 1998 zonation is also included here for completeness (Figure 2). In general, it is similar to the (Helby et al. 2004) zonation but is more widely used in the Surat Basin than Helby, Morgan and Partridge. As an example, Figure 1 provides a summary of the results for individual samples from Woleebee Creek GW4.

Paleoenvironmental assessments contained in the report are based on the proportions of marine microplankton (saline algae) to non-marine spores, pollen and freshwater algae, combined with an evaluation of marine microplankton diversity. This enables the interpretation of broad environmental subdivisions giving a general impression of proximity to shoreline, but does not take account extensive cannibalisation and redeposition, by turbidite processes, of non-marine to marginal marine sediments into a more offshore or basinal setting. Where the caving content can be readily distinguished by other means, this is considered.

For this report, the relative abundances of taxa in running text are discussed in the following percentage interval terms:

Rare (R): ≤1%

Frequent (F): 2-4%

Common (C): 5-19%

Abundant (A): 20-49%

Superabundant (SA): ≥50%

Figure 1 Palynological zonation scheme of Price 1997; Helby et al. 2004; Morgan et al. 2002; and MGPalaeo 2014.

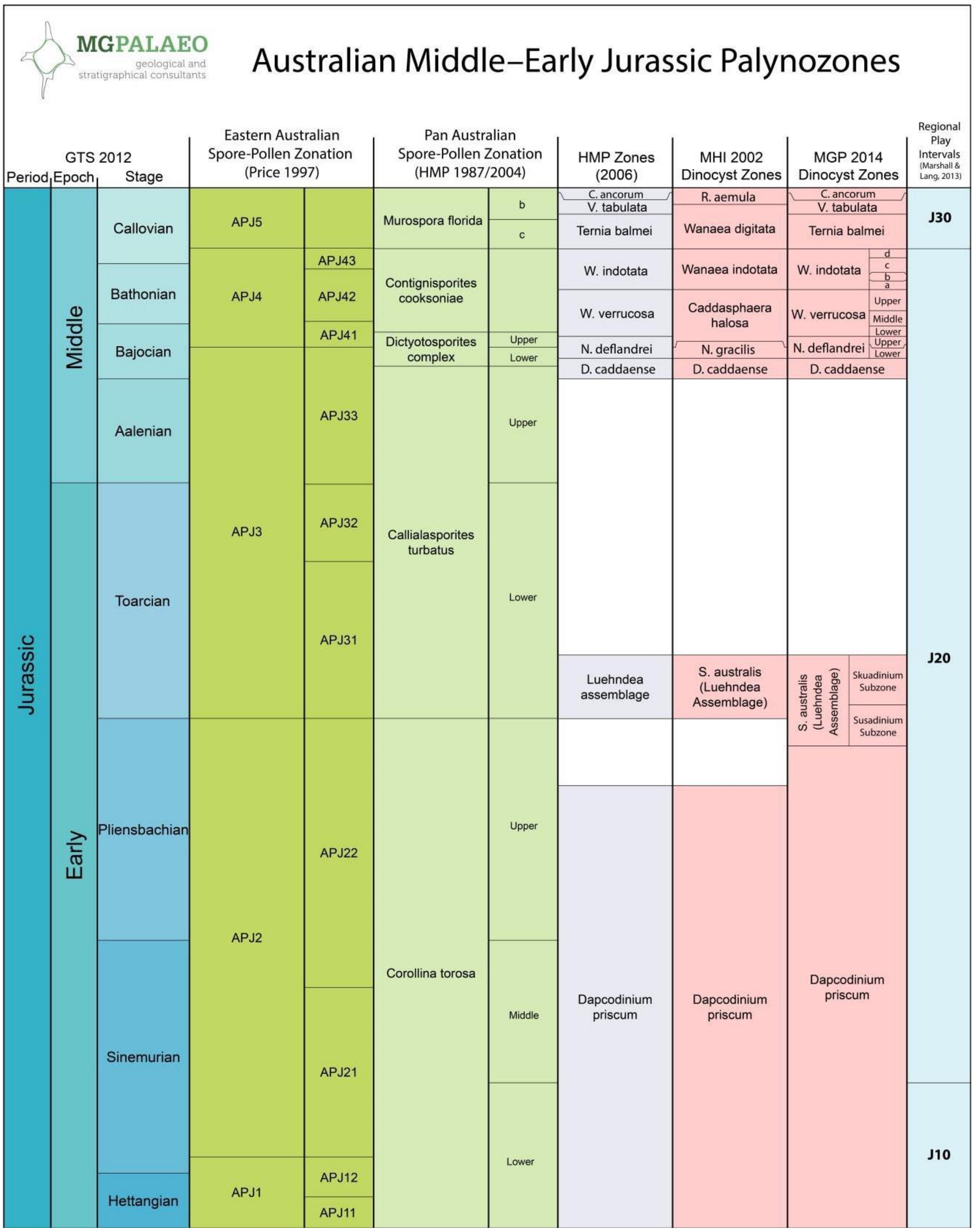
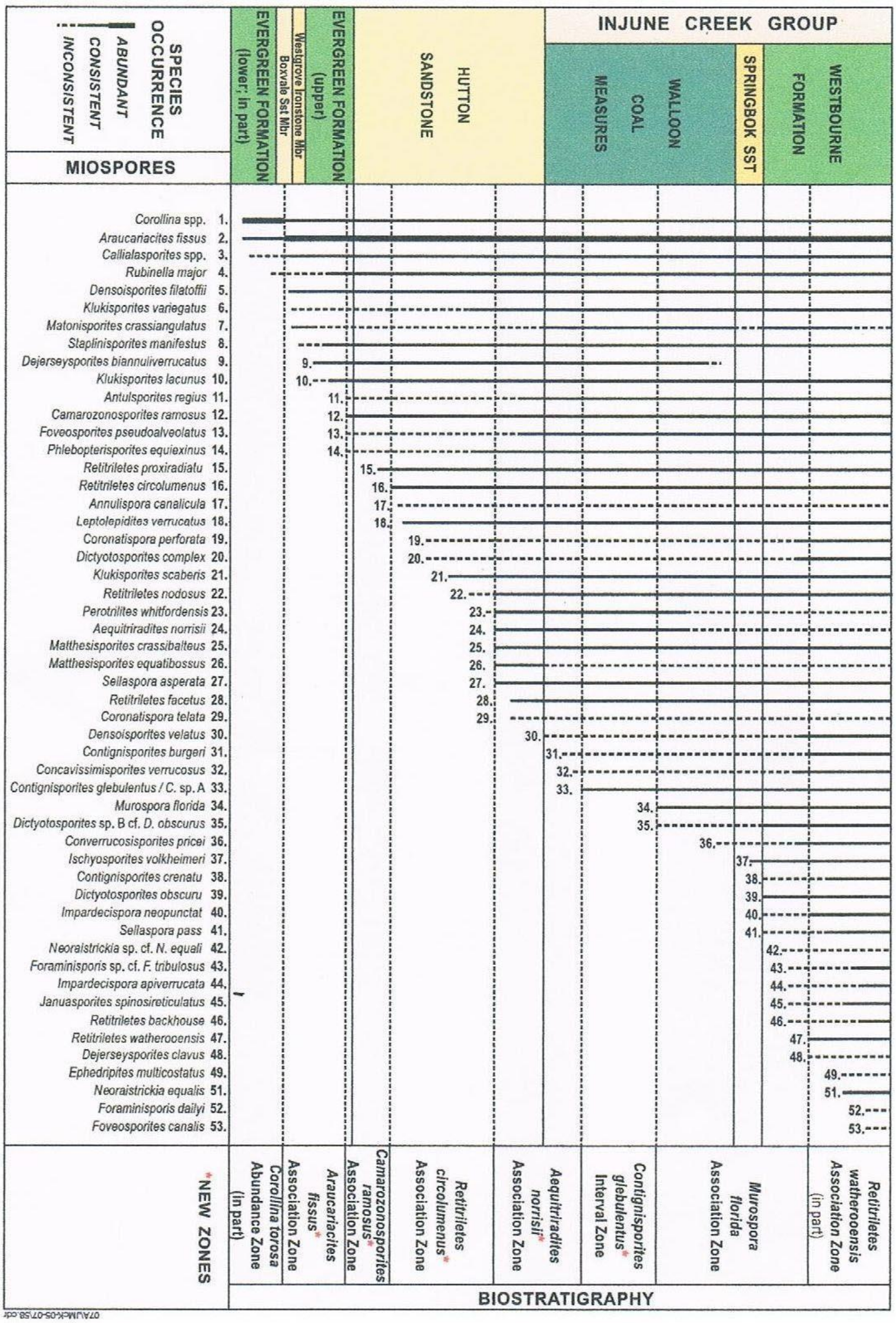


Figure 2 McKeller palynological zonation scheme (McKeller 1998).



4. Results

4.1 Chinchilla 4

Zonal assignment:	**APJ4.2/R. *circolumenus* Zone**
Depth interval:	822.20 m Core (Appendix A)
Stage/Age:	Bathonian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	The presence of *Retitriletes circolumenus* with *Camarozonotriletes ramosus*
Supporting taxa:	The assemblage is dominated by *Retitriletes spp*. Supporting taxa include frequent *Antulsporites saevus* and rare *Trilobosporites antiquus*
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ3.3.1/*A. fissus* Zone**
Depth interval:	936.85 m, 983.00 m and 1017.40 m Core (Appendix A)
Stage/Age:	Aalenian
Palaeoenvironment:	Although no acritarchs were present, Copepod fragments were recorded in the sample at 1017.40 m. In other wells these have been found alongside spinose acritarchs and possible dinoflagellates so this could indicate marine influence. As Copepods can be found in both fresh and salt water, they alone do not indicate marine environments hence a questionable assignment. No marine indicators were recorded in the other two samples
Assignment based on:	The presence of common *Callialasporites turbatus* with *Staplinisporites manifestus* and *Klukisporites lacunus*
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. Supporting taxa include frequent *Trilobosporites antiquus, Callialasporites dampieri* and *Nevesisporites vallatus. Kekryphalospora distincta* was recorded at 936.85m
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ3.1/*A. fissus* Zone**
Depth interval:	1045.45 m Core (Appendix A)
Stage/Age:	Toarcian
Palaeoenvironment:	Although no acritarchs were present, Copepod fragments were recorded. In other wells these have been found alongside spinose acritarchs and possible dinoflagellates so could indicate marine influence. As Copepods can be found in both fresh and salt water, they alone do not indicate marine environments hence a questionable assignment
Assignment based on:	The presence of *Callialasporites dampieri* without younger markers

Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. Other taxa of note include *Kekryphalospora distincta* and *Nevesisporites vallatus*
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ2.2/*C. torosa* Zone**
Depth interval:	1098.65 m Core (Appendix A)
Stage/Age:	Pliensbachian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	Superabundant *Corollina spp*. with *Nevesisporites vallatus*
Supporting taxa:	The presence of frequent *Cadargasporites spp*. with *Polycingulatisporites mooniensis* and *Kekryphalospora distincta* is distinctive and supports a Pliensbachian age
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ2.1/*C. torosa* Zone**
Depth interval:	1126.70 m Core (Appendix A)
Stage/Age:	Sinemurian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	Superabundant *Corollina spp*. with Trisaccate pollen and without *Nevesisporites vallatus*
Supporting taxa:	Other taxa of note include *Cadargasporites baculatus, Perinopollenites elatoides* and *Striatella seebergensis* is distinctive and supports a Pliensbachian age
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ1.2/*C. torosa* Zone**
Depth interval:	1162.08 m and 1199.64 m Core (Appendix A)
Stage/Age:	Sinemurian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	Superabundant *Corollina spp*. with *Ischyosporites crateris, Perinopollenites elatoides* and without trisaccate pollen
Supporting taxa:	The assemblage is dominated by superabundant *Corollina spp*. Other taxa of interest include *Cadargasporites baculatus* and frequent *Anapiculatisporites dawsonensis*
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment: **APJ1/*C. torosa* Zone**

Depth interval: 1217.60 m Core (Appendix A)

Stage/Age: Sinemurian to Hettangian

Palaeoenvironment: No marine indicators were recorded

Assignment based on: Superabundant *Corollina spp*. with *Perinopollenites elatoides* and without trisaccate pollen. *Ischyosporites crateris* (marker for APJ1.2 subzone) was not recorded, which may indicate the APJ1.1 subzone. However, this zonal marker can be rare and the sample was of low diversity, so it was not considered possible to confidently assign any higher resolution than APJ1

Supporting taxa: The assemblage is dominated by superabundant *Corollina spp*. Other taxa of interest include *Cadargasporites baculatus* and frequent *Anapiculatisporites dawsonensis*

Comments Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

4.2 Condabri MB9-H

Zonal assignment: **APJ3.3.2/*C. ramosus* Zone**

Depth interval: 1119.95/1120.04 m and 1135.50/1135.56 m Core (Appendix A)

Stage/Age: Aalenian to Bajocian

Palaeoenvironment: No marine indicators were recorded

Assignment based on: The presence of frequent *Camarozonosporites ramosus* with rare *Klukisporites lacunus*

Supporting taxa: The assemblage is dominated by *Retitriletes spp*. Supporting taxa include frequent to common *Antulsporites saevus* and rare *Trilobosporites antiquus*

Comments: Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment: **APJ3.3.1/*A. fissus* Zone**

Depth interval: 1275.57/1275.62 m and 1326.00/1326.06 m Core (Appendix A)

Stage/Age: Aalenian

Palaeoenvironment: Possible dinoflagellates were recorded. As little is known of the dinoflagellates in this region, and in this part of the stratigraphic section in general; it is not possible to determine a potential environment of deposition

Assignment based on: The presence of common *Callialasporites turbatus* with *Staplinisporites manifestus* and *Klukisporites lacunus*

Supporting taxa: The assemblage is dominated by bisaccate pollen and *Corollina spp*. Supporting taxa include frequent *Trilobosporites antiquus, Callialasporites dampieri* and *Nevesisporites vallatus*

Comments: Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ2.2.2/*C. torosa* Zone**
Depth interval:	1417.56/1417.59 m, 1436.30/1436.37 m, 1445.04/1445.09 m, 1461.20/1461.22 m and 1501.36/1501.40 m Core (Appendix A)
Stage/Age:	Pliensbachian
Palaeoenvironment:	In general, no marine indicators were recorded. However, the sample from 1461.20/1461.22 m contained possible dinoflagellates (Appendix A) and may indicate some marine influence
Assignment based on:	Superabundant *Corollina spp*. with *Nevesisporites vallatus*. The presence of *Foraminisporis spp*. suggests the 2.2.2 subzone
Supporting taxa:	The presence of frequent *Cadargasporites spp*. With *Polycingulatisporites mooniensis* and *Kekryphalospora distincta* is distinctive and supports a Pliensbachian age
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ1.2/*C. torosa* Zone**
Depth interval:	1508/1508.07 m Core (Appendix A)
Stage/Age:	Sinemurian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	Superabundant *Corollina spp*. with *Ischyosporites crateris, Perinopollenites elatoides* and without trisaccate pollen
Supporting taxa:	The assemblage is dominated by superabundant *Corollina spp*. Other taxa of interest include *Polycingulatisporites mooniensis* and *Camarozonosporites rudis*
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

4.3 Kenya East GW7

Zonal assignment:	**APJ3.3.1/*A. fissus* Zone**
Depth interval:	981.35 m Core (Appendix A)
Stage/Age:	Aalenian
Palaeoenvironment:	Possible dinoflagellates were recorded. As little is known of the dinoflagellates in this region, and in this part of the stratigraphic section in general; it is not possible to determine a potential environment of deposition
Assignment based on:	The presence of frequent *Callialasporites turbatus* with *Staplinisporites manifestus* and *Klukisporites lacunus*
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. Supporting taxa include *Trilobosporites antiquus, Callialasporites dampieri, Foraminisporis spp.* and *Nevesisporites vallatus*
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ3.1/*A. fissus* Zone**
Depth interval:	1023.60 m and 1028.60 m Core (Appendix A)
Stage/Age:	Toarcian
Palaeoenvironment:	Although no acritarchs were present, rare possible dinoflagellates were recorded. As little is known of the dinoflagellates in this region, and in this part of the stratigraphic section in general; it is not possible to determine a potential environment of deposition
Assignment based on:	The presence of *Callialasporites dampieri* without younger markers
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*
Comments:	Microfossil yield is high with excellent preservation and a moderately diverse spore pollen assemblage

Zonal assignment:	**APJ2.2.2/*C. torosa* Zone**
Depth interval:	1146.70 m, 1165.30 m, 1181.5m and 1192.70 m Core (Appendix A)
Stage/Age:	Pliensbachian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	Superabundant *Corollina spp.* with *Nevesisporites vallatus*. The presence of *Foraminisporis spp*. suggests the 2.2.2 subzone
Supporting taxa:	The presence of frequent *Cadargasporites spp*. With *Polycingulatisporites mooniensis* and *Kekryphalospora distincta* is distinctive and supports a Pliensbachian age
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

4.4 Reedy Creek MB3-H

Zonal assignment:	**APJ3.3.1/*A. fissus* Zone**
Depth interval:	1117.17/1117.23 m, 1119.5/1119.52 m Core (Appendix A)
Stage/Age:	Aalenian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	The presence of frequent *Callialasporites turbatus* with *Staplinisporites manifestus* and *Klukisporites lacunus*. The sample from 993.43/993.51 m did not contain a confident *K. lacunus*, but the presence of *Klukisporites spp*. suggests this zone, thus it is assigned only questionably
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. Supporting taxa include *Trilobosporites antiquus, Callialasporites dampieri, Foraminisporis spp.* and *Nevesisporites vallatus*
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ3.2/*A. fissus* Zone**
Depth interval:	1208.3/1208.35 m Core (Appendix A).
Stage/Age:	Toarcian
Palaeoenvironment:	Although no acritarchs were recorded the presence of possible dinoflagellates and Copepod fragments suggest some possible marine influence. As little is known of the dinoflagellates in this region, and in this part of the stratigraphic section in general; it is not possible to determine a potential environment of deposition. Abundant Botryococcus algae may suggest the proximity to standing water
Assignment based on:	The presence of *Callialasporites dampieri* with *Staplinisporites manifestus* and without *Klukisporites lacunus*
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. Supporting taxa include *Foraminisporis spp* and *Nevesisporites vallatus*
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ3.1/*A. fissus* Zone**
Depth interval:	1215.15/1215.17 m Core (Appendix A)
Stage/Age:	Toarcian
Palaeoenvironment:	These samples contained the highest proportion of spinose acritarchs and dinoflagellates of all the samples and an undifferentiated marine environment is interpreted. As little is known of the dinoflagellates in this region, and in this part of the stratigraphic section in general; it is not possible to determine a potential environment of deposition
Assignment based on:	The presence of *Callialasporites dampieri* without younger markers
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. Youngest *Kekryphalospora distincta* supports an age in the earliest part of the Toarcian
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ2.2/*C. torosa* Zone**
Depth interval:	1243.25/1243.3 m and 1270.4/1270.42 m Core (Appendix A)
Stage/Age:	Pliensbachian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	Superabundant *Corollina spp.* with *Nevesisporites vallatus*
Supporting taxa:	The presence *of Cadargasporites spp., Polycingulatisporites mooniensis,* and *Kekryphalospora distincta* is distinctive and supports a Pliensbachian age
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ1/*C. torosa* Zone**
Depth interval:	1326.17/1326.26 m and 1337.62/1337.68 m Core (Appendix A)
Stage/Age:	Sinemurian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	Superabundant *Corollina spp*. with *Perinopollenites elatoides* and without trisaccate pollen
Supporting taxa:	The assemblage is dominated by superabundant *Corollina spp*. Other significant taxa include *Cadargasporites spp.* and *Camarozonosporites rudis* and *Polycingulatisporites mooniensis* (at 1326.17/1326.26 m)
Comments:	Microfossil yield is high with excellent preservation and a Moderately diverse spore pollen assemblage

4.5 Roma 8

Zonal assignment:	**APJ3.1/*A. fissus* Zone**
Depth interval:	956.70 m, 967.87 m, 985.26 m and 995.85 m Core (Appendix A)
Stage/Age:	Toarcian
Palaeoenvironment:	The sample at 967.87 m contained possible dinoflagellates, with Copepod fragments suggesting possible marine influence. Copepod fragments were also recorded in the sample from 956.70 m
Assignment based on:	The presence of frequent *Callialasporites dampieri* and *Callialasporites turbatus* with *Nevesisporites vallatus* and without younger markers
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp.* The presence of *Kekryphalospora distincta* supports an age in the earliest part of the Toarcian
Comments:	Microfossil yield is high with excellent preservation and a generally diverse spore pollen assemblage

Zonal assignment:	**APJ2.2.2/*C. torosa* Zone**
Depth interval:	1011.40 m, 1029.15 m, 1041.00 m and 1042.90 m Core (Appendix A)
Stage/Age:	Pliensbachian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	Superabundant *Corollina spp.* with *Nevesisporites vallatus*. The presence of *Foraminisporis spp.* suggests the 2.2.2 subzone
Supporting taxa:	The presence of *Cadargasporites spp.* with *Polycingulatisporites mooniensis* (at 1011.4 m) and *Kekryphalospora distincta* (at 1041.00 m) supports a Pliensbachian age
Comments:	Microfossil yield is moderate-low to high with excellent preservation and a diverse spore pollen assemblage

4.6 Taroom 17

Zonal assignment:	**APJ3.3.1/*A. fissus* Zone**
Depth interval:	280.66/280.7 m and 297.6/297.65 m Core (Appendix A)
Stage/Age:	Aalenian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	The presence of frequent *Callialasporites turbatus* with *Staplinisporites manifestus* and *Klukisporites lacunus*
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. Supporting taxa include frequent *Trilobosporites antiquus, Callialasporites dampieri* and *Nevesisporites vallatus. Kekryphalospora distincta* was recorded at 280.66/280.7 m
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ2.2/*C. torosa* Zone**
Depth interval:	331.3/331.37 m (sample probably out of place, correct depth most likely to be 421.7/421.8 m), 378.43/378.53 m, 386.35/386.42 m and 397.25/397.35 m Core (Appendix A)
Stage/Age:	Pliensbachian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	Superabundant *Corollina spp*. with *Nevesisporites vallatus*
Supporting taxa:	The presence of frequent *Cadargasporites spp*. With *Kekryphalospora distincta* supports a Pliensbachian age
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ1.2/*C. torosa* Zone (out of place)**
Depth interval:	421.7/421.8 m Core – Likely sample bags have been mislabelled. Suggested correct depth is 483.19-483.25 m (Appendix A)
Stage/Age:	Sinemurian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	Superabundant *Corollina spp.* with *Ischyosporites crateris, Perinopollenites elatoides* and without trisaccate pollen
Supporting taxa:	The assemblage is dominated by superabundant *Corollina spp*
Comments:	Microfossil yield is moderate with moderate preservation and a moderately diverse spore pollen assemblage. Kerogen appears to be degraded

Zonal assignment:	**APJ3.2/*A. fissus* Zone (Out of place)**
Depth interval:	483.19/483.25 m Core. Sample bags likely to be mislabelled. Correct depth likely to be 331.3/331.37 m (Appendix A)
Stage/Age:	Toarcian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	The presence of *Callialasporites dampieri* with *Staplinisporites manifestus*. This sample contained markers much older than the overlying samples. It is likely that this sample is either mislabled or out of place
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. Supporting taxa include *Foraminisporis spp.* and *Nevesisporites vallatus*
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

4.7 West Wandoan 1

Zonal assignment:	**APJ3.3.1/*A. fissus* Zone**
Depth interval:	980.36/980.45 m, 990.67/990.84 m, 993.43/993.51 m Core (Appendix A)
Stage/Age:	Aalenian
Palaeoenvironment:	Spinose acritarchs, such as *Micrhystridium spp*. and *Multiplicisphaeridium spp*. with possible simple dinoflagellate cysts (Appendix A) were recorded that indicate marine conditions. As little is known of the dinoflagellates in this region, and in this part of the stratigraphic section in general; it is not possible to determine a potential environment of deposition
Assignment based on:	The presence of common *Callialasporites turbatus* with *Staplinisporites manifestus* and *Klukisporites lacunus*. The sample from 993.43/993.51 m did not contain a confident *K. lacunus*, but the presence of *Klukisporites spp*. suggests this zone, thus it is assigned only questionably
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. Supporting taxa include *Foraminisporis spp* and *Callialasporites dampieri, Nevesisporites vallatus*
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ3.2/*A. fissus* Zone**
Depth interval:	998.55/998.65 m, 1010.5/1010.56 m Core (Appendix A)
Stage/Age:	Toarcian
Palaeoenvironment:	Spinose acritarchs were not recorded but possible Copepod fragments along with possible dinoflagellates suggest some possible marine influence. As little is known of the dinoflagellates in this region, and in this part of the stratigraphic section in general; it is not possible to determine environment of deposition
Assignment based on:	The presence of frequent *Callialasporites turbatus* with *Staplinisporites manifestus* and without *Klukisporites lacunus*. The sample from 998.55/998.65 m did not

	contain *S. manifestus*, but the presence of the marker in the sample below suggests this subzone
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. Supporting taxa include *Foraminisporis spp*., *Callialasporites dampieri* and *Nevesisporites vallatus*
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ3.1/*A. fissus* Zone**
Depth interval:	1011.8/1011.86 m, 1013.29/1013.4 m Core (Appendix A)
Stage/Age:	Toarcian
Palaeoenvironment:	These samples contained the highest proportion of spinose acritarchs and dinoflagellates of any of the samples in West Wandoan 1, and an undifferentiated marine environment is interpreted. As little is known of the dinoflagellates in this region, and in this part of the stratigraphic section in general; it is not possible to determine a potential environment of deposition
Assignment based on:	The presence of *Callialasporites dampieri* with *Nevesisporites vallatus* and without younger markers
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. A questionable specimen of *Kekryphalospora distincta* at 1011.8/1011.86 m supports an age in the earliest part of the Toarcian
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ2.1/*C. torosa* Zone**
Depth interval:	1027.52/1027.61 m Core (Appendix A)
Stage/Age:	Sinemurian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	Superabundant *Corollina spp*. with *Perinopollenites elatoides*
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. The presence of *Cadargasporites baculatus* and Trisaccate pollen support this age
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ1/*C. torosa* Zone**
Depth interval:	1207.61 m Core (Appendix A)
Stage/Age:	Sinemurian
Palaeoenvironment:	Extremely rare possible simple dinoflagellates were recorded but it was not possible to determine a depositional environment

Assignment based on:	Superabundant *Corollina spp*. with *Perinopollenites elatoides* and without trisaccate pollen
Supporting taxa:	The assemblage is dominated by superabundant *Corollina spp*
Comments:	Microfossil yield is high with excellent preservation and a moderately diverse spore pollen assemblage

Zonal assignment:	**APT3.3/*T. playfordii* Zone**
Depth interval:	1237.89/1237.94 m Core (Appendix A)
Stage/Age:	Anisian
Palaeoenvironment:	No marine indicators were recorded and a non-marine environment has been interpreted
Assignment based on:	Abundant *Aratrisporites parvispinosus* with *Falcisporites australis* and *Ashmoripollis reducta*
Supporting taxa:	*Cadagarsporites senectus, Calamospora spp.* and *Protohaploxypinus spp*. support a Middle Triassic age
Comments:	Microfossil yield is high with excellent preservation and a moderately diverse spore pollen assemblage

4.8 Woleebee Creek GW4

Zonal assignment:	**APJ3.3.1/*A. fissus* Zone**
Depth interval:	1275.85 m and 1310.6 m Core (Appendix A)
Stage/Age:	Aalenian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	The presence of common *Callialasporites turbatus* with *Staplinisporites manifestus* and *Klukisporites lacunus*
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. Supporting taxa include *Callialasporites dampieri, Trilobosporites antiquus, Kekryphalospora distincta* (at 1275.85 m) and *Nevesisporites vallatus*
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ3.1/*A. fissus* Zone**
Depth interval:	1336.7 m and 1356.75 m Core (Appendix A)
Stage/Age:	Toarcian
Palaeoenvironment:	*Multiplicisphaeridium spp., Micrhystridium spp*. and possible dinoflagellates were recorded in the sample from 1336.7 m indicating marine influence. As little is known of the dinoflagellates in this region, and in this part of the stratigraphic section in general; it is not possible to determine a potential environment of deposition. No marine indicators were noted in the sample from 1356.75 m

Assignment based on:	The presence of *Callialasporites dampieri* with *Nevesisporites vallatus* and without younger markers
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp*. The presence of *Kekryphalospora distincta* supports an age in the earliest part of the Toarcian
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ2.2/*C. torosa* Zone**
Depth interval:	1382.25 m, 1391.25 m, 1422.55 m Core (Appendix A)
Stage/Age:	Sinemurian
Palaeoenvironment:	No marine indicators were recorded
Assignment based on:	Superabundant *Corollina spp.* with *Perinopollenites elatoides*
Supporting taxa:	The assemblage is dominated by bisaccate pollen and *Corollina spp.* The presence of *Cadargasporites baculatus, Polycingulatisporites mooniensis* (at 1382.25 m), *Camarozonosporites rudis* and Trisaccate pollen support this age
Comments:	Microfossil yield is high with excellent preservation and a diverse spore pollen assemblage

Zonal assignment:	**APJ1/*C. torosa* Zone**
Depth interval:	1489.55 m Core (Appendix A)
Stage/Age:	Sinemurian
Palaeoenvironment:	Extremely rare possible simple dinoflagellates were recorded but it was not possible to determine a depositional environment
Assignment based on:	Superabundant *Corollina spp*. with *Perinopollenites elatoides* and without trisaccate pollen
Supporting taxa:	The assemblage is dominated by superabundant *Corollina spp*
Comments:	Microfossil yield is high with excellent preservation and a moderately diverse spore pollen assemblage

5. Summary and conclusions

Core samples from the Precipice Sandstone and Evergreen Formations were palynologically analysed from nine wells in the Surat Basin by MGPalaeo. The first 300 specimens from each sample were counted and used to determine the palynostratigraphic zonation for the sample as well as make paleoenvironmental interpretations. Special care was taken to note any potential marine-indicators within samples. In total, 71 samples were looked at.

The results of the analysis showed that by and large the Precipice Sandstone fits into the APJ2 spore-pollen zone of Price (1997) or *C. torosa* Zone of Helby, Morgan, and Partridge 2004suggesting that it ranges from Hettangian to Pleinsbachian in age (Early Jurassic). The Evergreen Formation shows palynozonation within the APJ3 spore-pollen zone (Price 1997) or the *A. fissus* Zone (Helby, Morgan & Partridge 2004) with an age varying between Toriacian to Bajocian (Early to Middle Jurassic). The few samples collected from higher stratigraphic intervals (i.e. the Hutton Sandstone) generally fit into the APJ3 zone (Price 1997) placing it within the Middle Jurassic, but younger than the Evergreen Formation.

Paleoenvironmental interpretations of the samples showed an overall dominance of freshwater-continental origin for the mudstones. However, a proportion of the samples suggested subtle marine influence on deposition due to the presence of acritarchs and dinoflaggelate cysts. These are scattered between wells and stratigraphic levels, though show an overall concentration above the J20 unconformity and upwards into the Westgrove Ironstone Member and Upper Evergreen Formation. The results do not necessarily contravene interpretations based upon sedimentology and ichnology, as there are many possible explanations for the distribution of palynomorphs. In fact, it is thought that these results support the idea that depositional environments shifted substantially due to small changes in base level and a very shallow dipping depositional gradient. These palynological results are not dissimilar to what is observed in modern large-scale delta systems such as the Mississippi River Delta, USA (Chmura 1994; Darrell 1973) and the Fraser River Delta, Canada (Czarnecki et al. 2014).

6. References

Andersen ST (1974), Wind Conditions And Pollen Deposition In A Mixed Deciduous Forest I. Wind Conditions And Pollen Dispersal, *Grana,* vol 14**,** pp 57-63.

Batten RJ (1974), Wealden Palaeoecology From The Distribution Of Plant Fossils, *Proceedings Of The Geological Association,* vol 85**,** pp 433-458.

Berggren WA, Kent DV, Swisher CC & Aubry MP (1995), A Revised Cenozoic Geochronology And Chronostratigraphy. *In:* Berggren WA, Kent DV, Swisher CC & Aubry MP (Eds.), *Geochronology, Time Scales And Global Stratigraphic Correlation* Sepm.

Birks HJB (1981), Long-Distance Pollen In Late Wisconsin Sediments Of Minnesota, U.S.A.: A Quantitative Analysis, *New Phytologist,* vol 87**,** pp 630-661.

Chmura GL (1994), Palynomorph Distribution In Marsh Environments In The Modern Mississippi Delta Plain, *Geological Society Of America Bulletin,* vol 106**,** pp 705-714.

Cooper RA, Crampton JA, Raine JI, Gradstein FM, Morgans HEG, Sadler PM, Strong CP, Waghorn D & Wilson GJ (2000), Quantitative Biostratigraphy Of The Taranaki Basin, New Zealand: A Deterministic And Probabilistic Approach, *AAPG Bulletin,* vol 85**,** pp 1469-1498.

Cope JCW (1995), High Resolution Biostratigraphy. *In:* Hailwood EA & Kidd RB (eds), *High Resolution Stratigraphy,* Geological Society.

Czarnecki JM, Dashtgard SE, Pospelova V, Matthewes RW & Maceachern JA (2014), Palynology And Geochemistry Of Channel-Margin Sediments Across The Tidal-Fluvial Transition, Lower Fraser River, Canada: Implications For The Rock Record, *Journal Of Marine And Petroleum Geology,* vol 51**,** pp 152-166.

Darrell JHI (1973), Statistical Evaluation Of Palynomorph Distribution In The Sedimentary Environments Of The Modern Mississippi River Delta, Ph.D, Louisianna State University.

Davis MB (1968), Pollen Grains In Lake Sediment: Redeposition Caused By Seasonal Water Circulation, *Science,* vol 162**,** pp 796-799.

Davis MB (1973), Redeposition Of Pollen Grains In Lake Sediment, *Limnology And Oceanography,* vol 18**,** pp 44-52.

De Vernal A (2009), Marine Palynology And Its Use For Studying Nearshore Environments, *Iop Conference Series: Earth And Environmental Science,* no 5.

Farley MB (1990a), Palynological Facies Fossils In Nonmarine Environments In The Paleogene Of The Bighorn Basin, *Palaios,* vol 4**,** pp 565-573.

Farley MB (1990b), Vegetation Distribution Across The Early Eocene Depositional Landscape From Palynological Analysis, *Palaeogeography, Palaeoclimatology, Palaeoecology,* vol 79**,** pp 11-27.

Frederiksen NO (1985), Review Of Early Tertiary Sporomorph Paleoecology, *American Association Of Startigraphic Palynologists Contribution Series,* vol 15**,** pp 1-92.

Helby R, Morgan R & Partride AD (2004), *Updated Jurassic – Early Cretaceous Dinocyst Zonation, Nws Australia*, Geoscience Australia Publication.

Kaufmann B (2006), Calibrating The Devonian Time Scale: A Synthesis Of U–Pb Id–Tims Ages And Conodont Stratigraphy, *Earth-Science Reviews,* vol 76**,** pp 175-190.

Loydell DK (1993), Worldwide Correlation Of Telychian (Upper Llandovery) Strata Using Graptolies. *In:* Hailwood EA & Kidd RB (Eds.), *High Resolution Stratigraphy,* Geological Society.

Mckellar JK (1998), Late Early To Late Jurassic Palynology, Biostratigraphy And Palaeogeography Of The Roma Shelf Area, Northwestern Surat Basin, Queensland, Australia, PhD, University Of Queensland.

Miall AD (2010), *The Geology Of Stratigraphic Sequences,* Berlin Heideberg, Springer-Verlag.

Morgan RP, Hooker N & Ingram B (2002), Towards Higher Palynological Resolution In The Australian Mesozoic.

Pol D & Norell MA (2006), Uncertainty In The Age Of Fossils And The Stratigraphic Fit To Phylogenies, *Systematic Biology,* vol 55**,** pp 512-521.

Price PL (1997), Permian To Jurassic Palynostratigraphic Nomenclature Of The Bowen And Surat Bains. *In:* Green PM (Ed.), *The Surat And Bowen Basins, Southeast Queensland.* Brisbane, Queensland: Queensland Department Of Mines And Energy.

Shackleton NJ, Hall MA, Raffi I, Tauxe L & Zachos J (2000), Astronomical Calibration Age For The Oligocene-Miocene Boundary, *Geology,* vol 28**,** pp 447-450.

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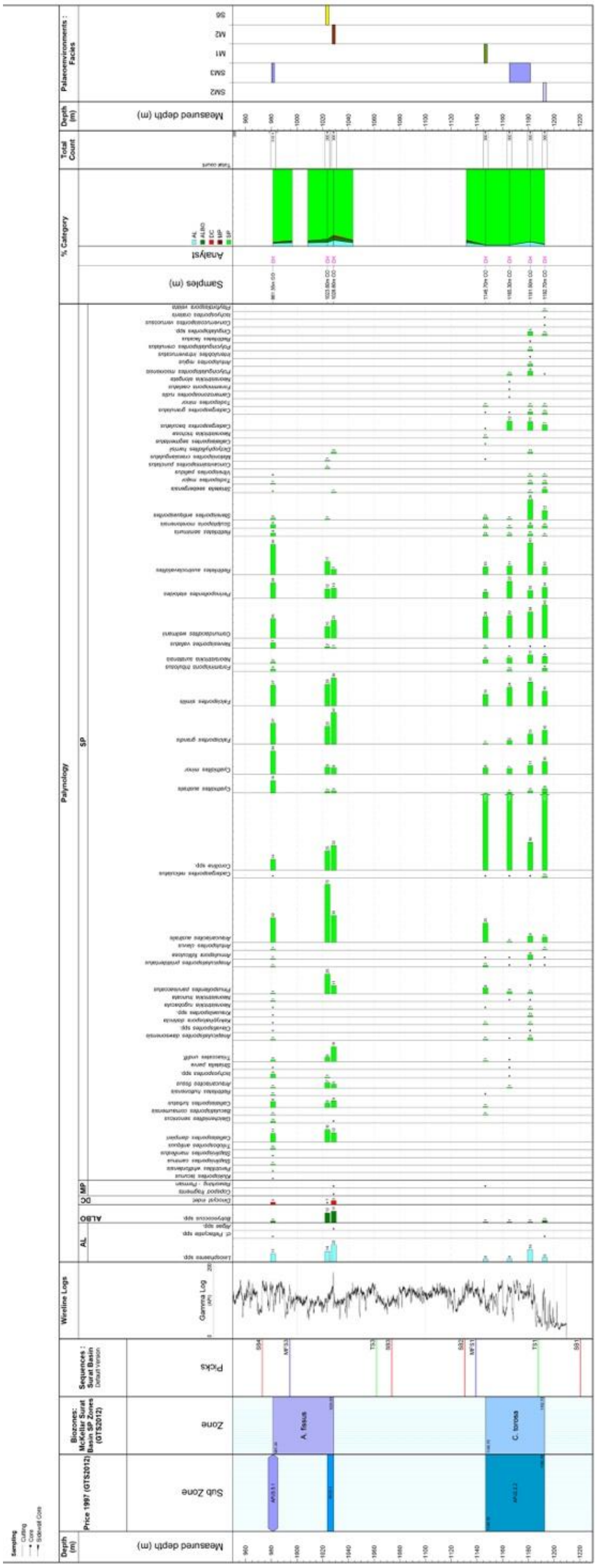
7. Appendices

7.1 Appendix A

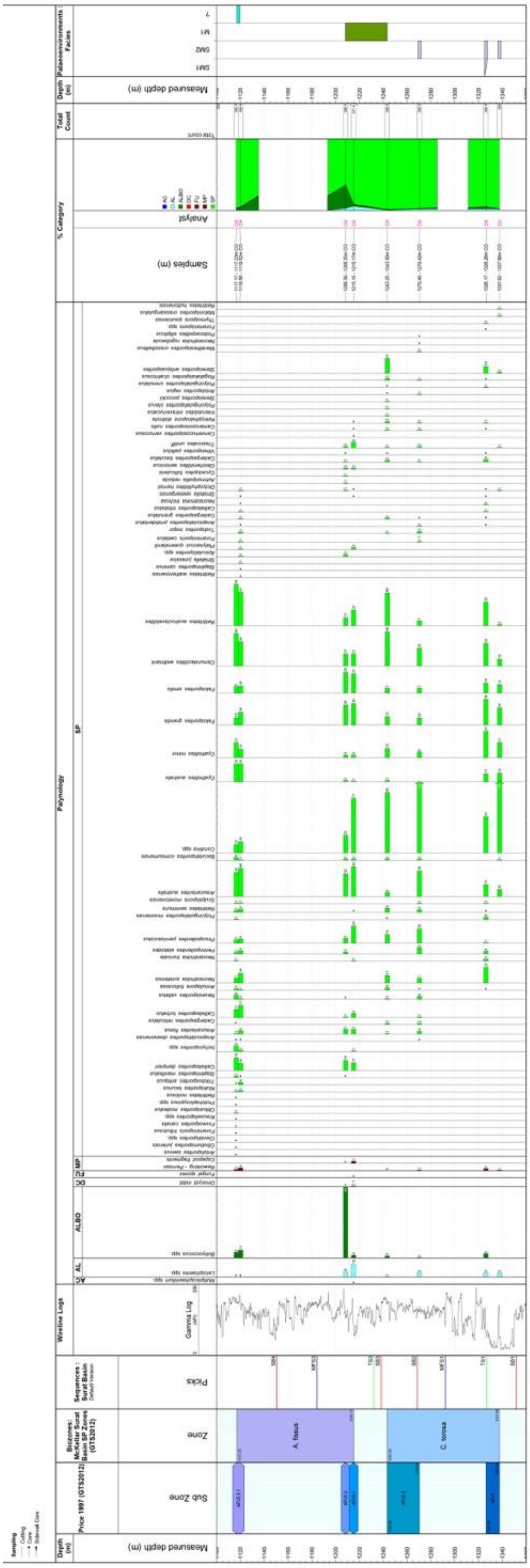
Detailed range chart for the Chinchilla 4 well showing the palyno-zonation, along with the corresponding proportion of the various palynomorph types observed in samples. Note: for palynomorph categories AC=acritarchs, AL=algae, ALB=Botryococcus algae, DC=dinoflaggelate cysts, FU=fungi, MP=miscellaneous palynomorphs, and SP=spores and pollen. Other abbreviations include +=taxa present, but outside of the count, rw=reworking, and cv=cavings.

Detailed range chart for the Condabri MB9-H well showing the palyno-zonation, along with the corresponding proportion of the various palynomorph types observed in samples. Note: for palynomorph categories AC=acritarchs, AL=algae, ALB=Botryococcus algae, DC=dinoflaggelate cysts, FU=fungi, MP=miscellaneous palynomorphs, and SP=spores and pollen. Other abbreviations include +=taxa present, but outside of the count, rw=reworking, and cv=cavings.

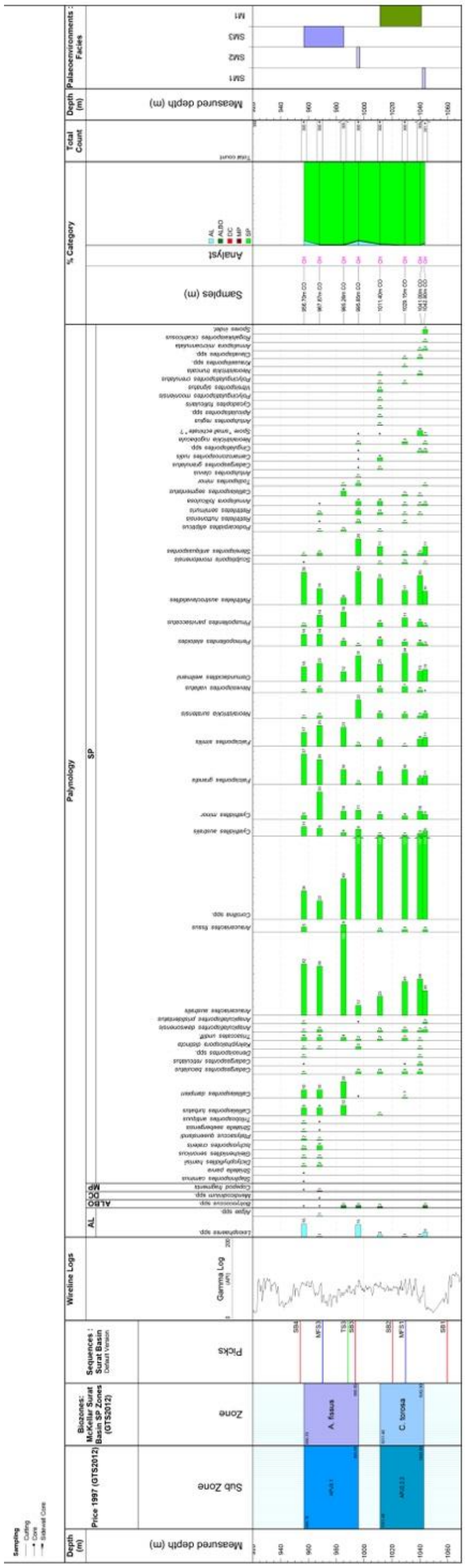
Detailed range chart for the Kenya East GW7 well showing the palyno-zonation, along with the corresponding proportion of the various palynomorph types observed in samples. Note: for palynomorph categories AC=acritarchs, AL=algae, ALB=Botryococcus algae, DC=dinoflaggelate cysts, FU=fungi, MP=miscellaneous palynomorphs, and SP=spores and pollen. Other abbreviations include +=taxa present, but outside of the count, rw=reworking, and cv=cavings.



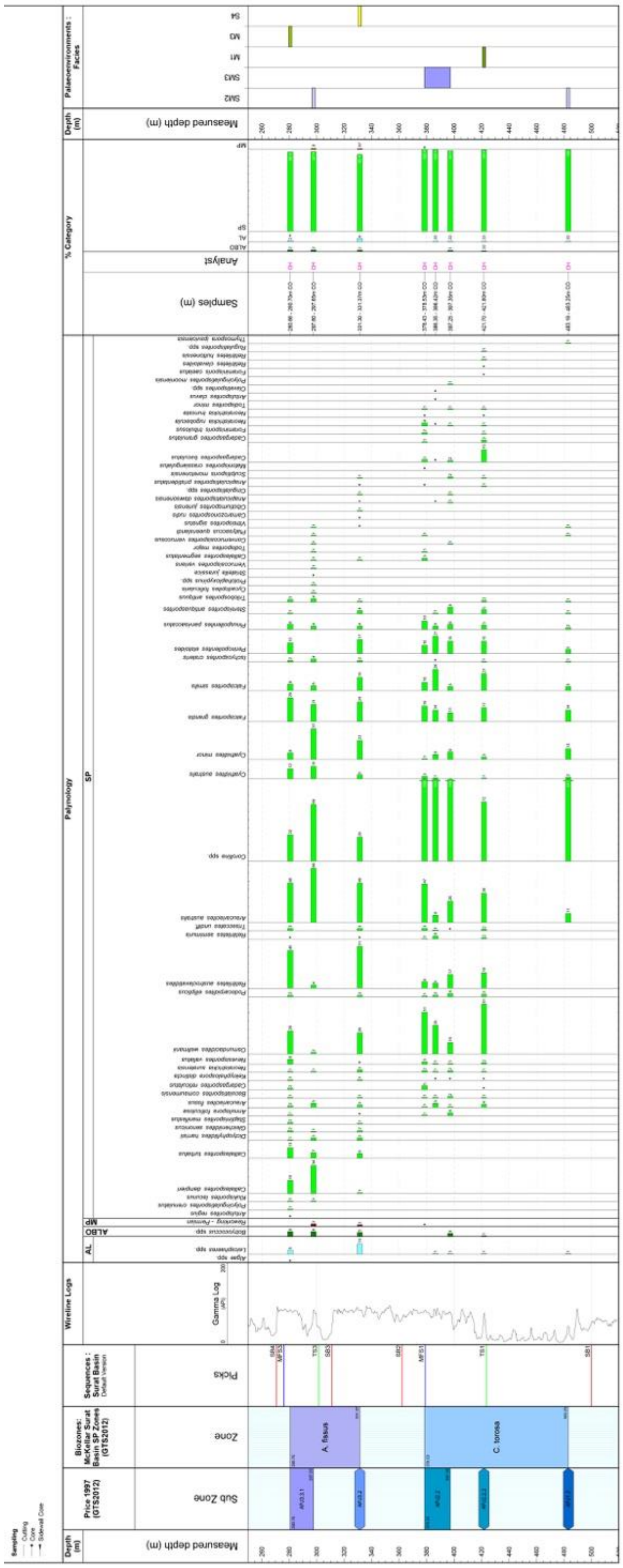
Detailed range chart for the Reedy Creek MB3-H well showing the palyno-zonation, along with the corresponding proportion of the various palynomorph types observed in samples. Note: for palynomorph categories AC=acritarchs, AL=algae, ALB=Botryococcus algae, DC=dinoflaggelate cysts, FU=fungi, MP=miscellaneous palynomorphs, and SP=spores and pollen. Other abbreviations include +=taxa present, but outside of the count, rw=reworking, and cv=cavings.



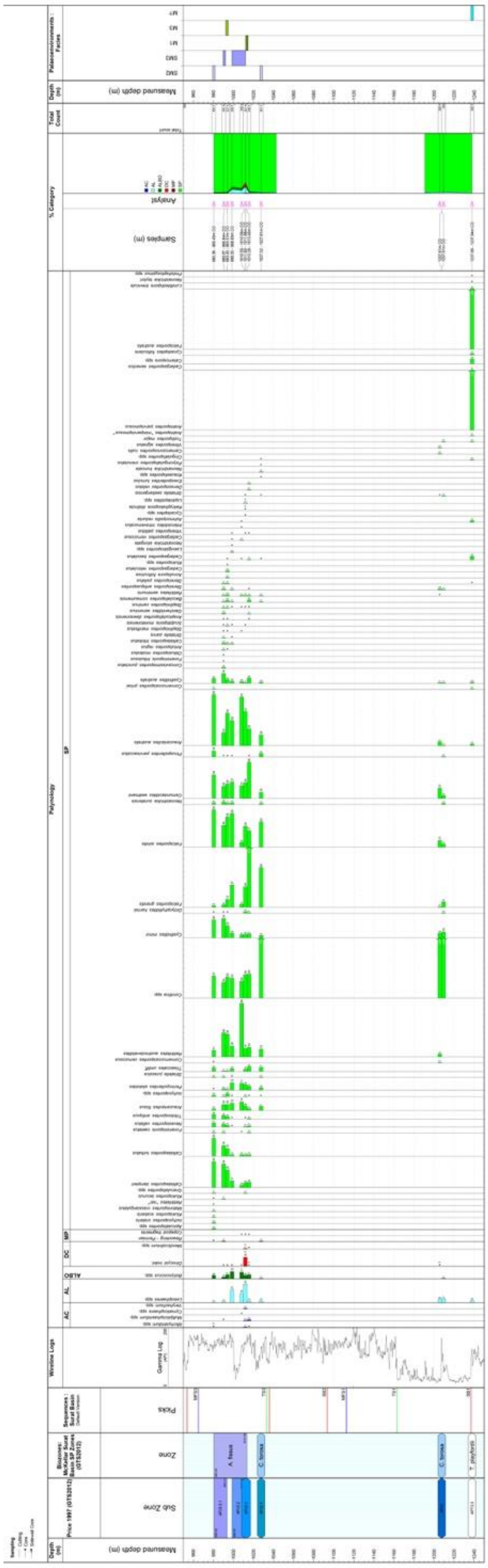
Detailed range chart for the Roma 8 well showing the palyno-zonation, along with the corresponding proportion of the various palynomorph types observed in samples. Note: for palynomorph categories AC=acritarchs, AL=algae, ALB=Botryococcus algae, DC=dinoflaggelate cysts, FU=fungi, MP=miscellaneous palynomorphs, and SP=spores and pollen. Other abbreviations include +=taxa present, but outside of the count, rw=reworking, and cv=cavings.



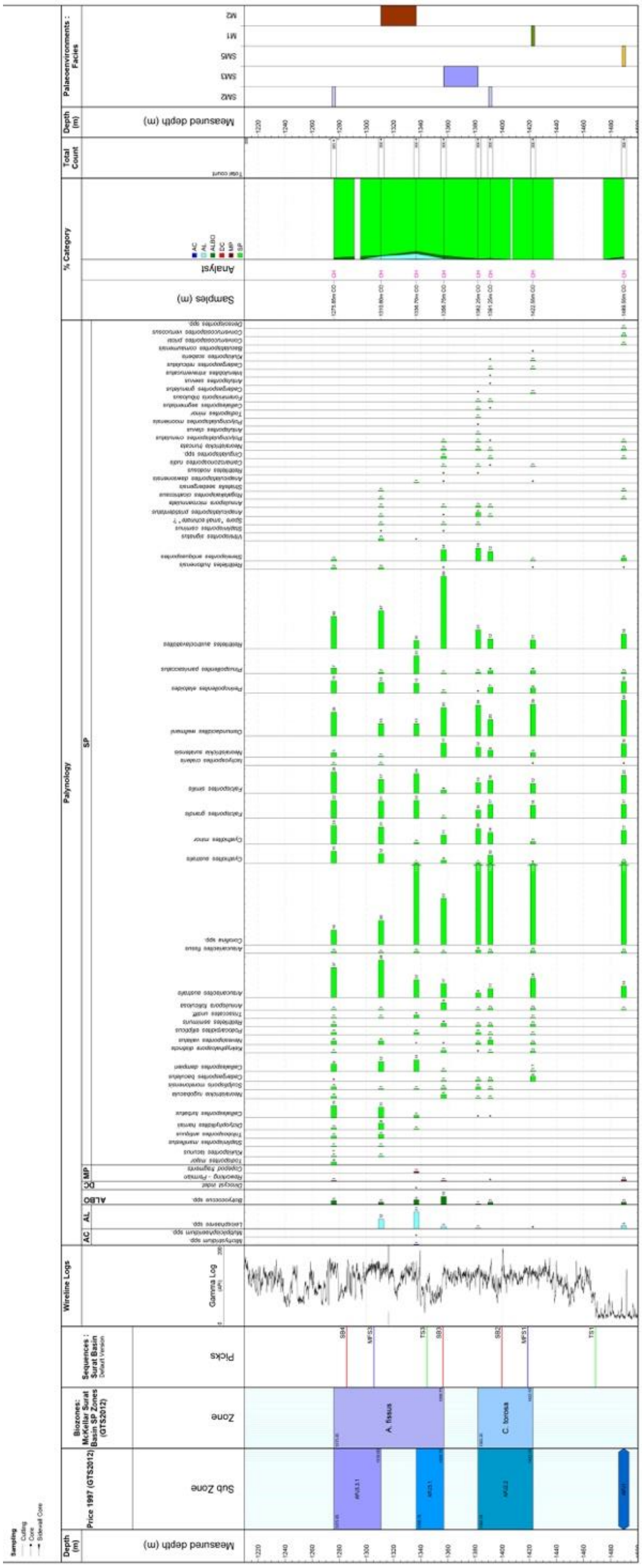
Detailed range chart for the Taroom 17 well showing the palyno-zonation, along with the corresponding proportion of the various palynomorph types observed in samples. Note: for palynomorph categories AC=acritarchs, AL=algae, ALB=Botryococcus algae, DC=dinoflaggelate cysts, FU=fungi, MP=miscellaneous palynomorphs, and SP=spores and pollen. Other abbreviations include +=taxa present, but outside of the count, rw=reworking, and cv=cavings.



Detailed range chart for the West Wandoan 1 well showing the palyno-zonation, along with the corresponding proportion of the various palynomorph types observed in samples. Note: for palynomorph categories AC=acritarchs, AL=algae, ALB=Botryococcus algae, DC=dinoflaggelate cysts, FU=fungi, MP=miscellaneous palynomorphs, and SP=spores and pollen. Other abbreviations include +=taxa present, but outside of the count, rw=reworking, and cv=cavings.



Detailed range chart for Woleebee Creek GW4 showing the palyno-zonation, along with the corresponding proportion of the various palynomorph types observed in samples. Note: for palynomorph categories AC=acritarchs, AL=algae, ALB=Botryococcus algae, DC=dinoflaggelate cysts, FU=fungi, MP=miscellaneous palynomorphs, and SP=spores and pollen. Other abbreviations include +=taxa present, but outside of the count, rw=reworking, and cv=cavings.



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