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The Queensland Energy Province - The Geology behind Coal, Coal-seam Gas, Oil, Traditional gas, Groundwater, and Carbon Geostorage Opportunities

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Contents

Bowen Basin Overview

The Bowen Basin forms the northern extension of the Bowen-Gunnedah-Sydney Basin system in eastern Australia and the southern part of this basin in Queensland is overlain by the Surat Basin (Figure 1). Sedimentary rocks of shallow marine and terrestrial origin and volcanics of Permian–Triassic age comprise the deposits in the Bowen Basin (Figure 2), which form a sedimentary pile up to 10km in the Taroom Trough. The basin outcrops approximately between latitude 20°S (near Collinsville) and latitude 25°S. The southern section of the Bowen Basin is unconformably overlain by the Surat Basin and the subcrop continues into New South Wales, where it is contiguous with the Gunnedah Basin (Green, 1997).

The Bowen Basin began as an extensive north–south-trending back-arc basin to the west of the continental Camboon Volcanic Arc. Early Permian back-arc extension on the western margin of the Bowen Basin produced a series of half-grabens, such as those of the Denison and Arbroath troughs, where initial deposition commenced (Draper, 1985). A phase of thermal subsidence followed, allowing the incursion of the sea over the arc and westwards across the basin. Deltas persisted into the Late Permian resulting in the formation of coastal swamps and the subsequent accumulation of extensive coal deposits (Fielding & others, 1990a).

During the latest Permian, initial deposition of the volcanolithic alluvial sediments of the Rewan Group was followed by the Middle Triassic Clematis Group. This reflected a change in provenance with sediments being sourced predominantly from the uplifted western craton instead of the arc in the east (Fielding & others,1990a). The Middle Triassic Moolayember Formation is the youngest unit in the Bowen Basin and its lithology reflects a return to sourcing from a volcanic province in the east. Major compressive deformation during the Middle – Late Triassic resulted in regional uplift, folding and the erosion of up to 3000m of section (Fielding & others, 1990b).

Surat Basin Overview

The Triassic – Cretaceous Surat Basin is a fluvial to shallow marine basin, which extends across south-east Queensland and northern New South Wales (Figures 1 and 2). The lower-most Triassic Taroom and Eddystone beds are discontinuous and consist of only remnant pods which unconformably underlie the Lower Jurassic Precipice Sandstone within this basin. The Surat Basin overlies the Permian–Triassic Bowen in the central portion and Palaeozoic sediments to the east. Sedimentation in the Surat Basin halted in the Middle Cretaceous due to a compressional event that uplifted the Bowen and Surat basins. The basin contains important petroleum reserves, as well as forming part of the Great Artesian Basin (Green, 1997). The Precipice Sandstone is the basal unit of the Surat Basin and a major aquifer that can be examined in detail at Carnarvon Gorge over a number of sites.

The purpose of this field trip is to examine the stratigraphy of the Lower Surat Basin and when exposed, sections of the underlying upper Bowen Basin.

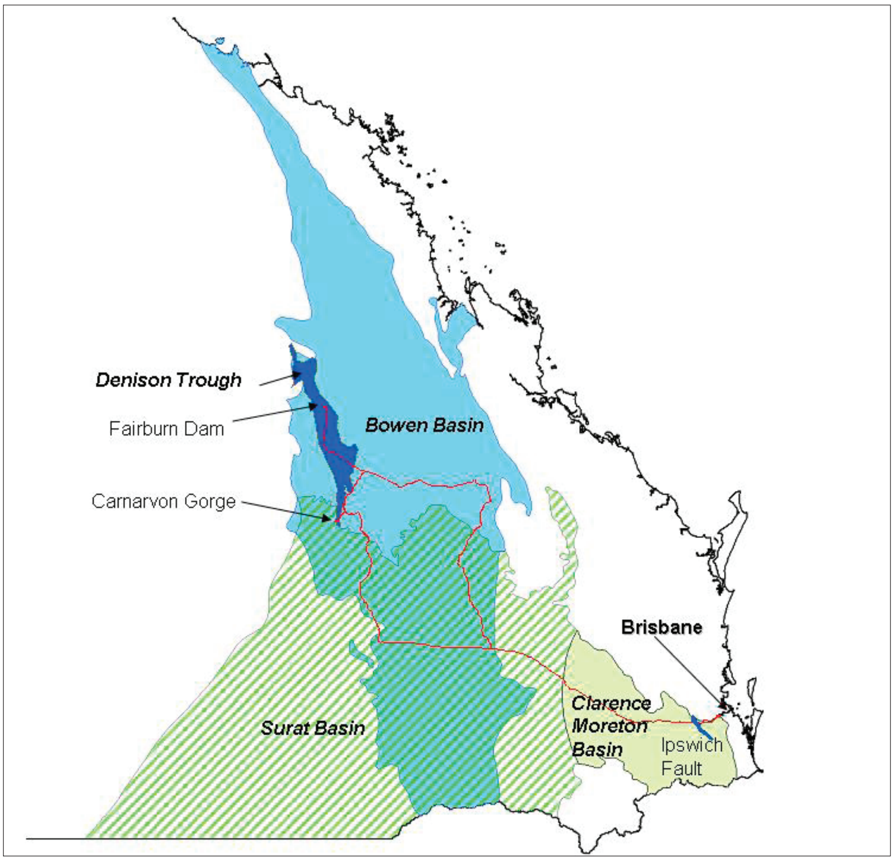

Figure 1. Location of the Permian–Triassic Bowen Basin, and the Triassic–Cretaceous Surat and Clarence-Moreton basins. The red lines depict the roads in relation to basins, structural features and faults.

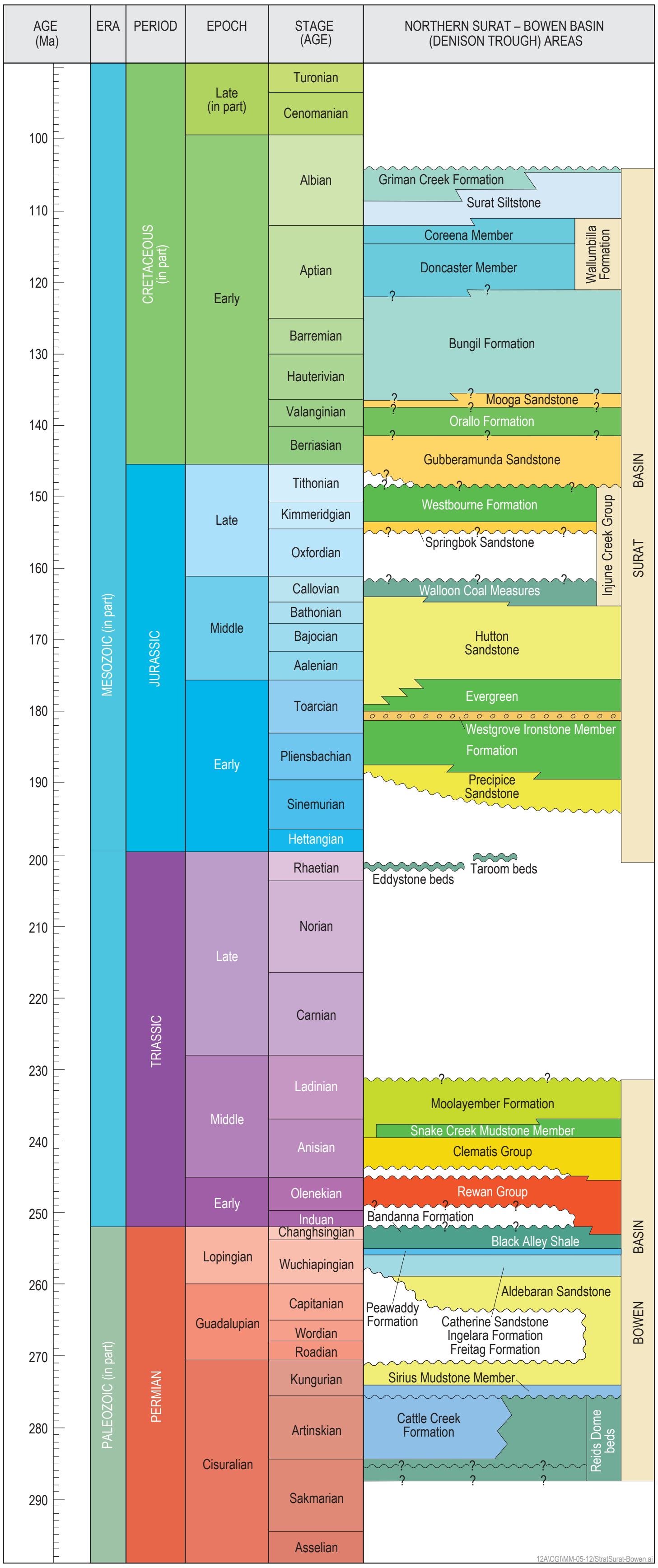

Figure 2. Stratigraphy of the Permian–Triassic Bowen Basin and the Triassic–Cretaceous Surat Basin (John McKellar, GSQ)

Day 1: Brisbane – Theodore

Points to note without a stop:

1. Ipswich Fault where we see the Triassic Ipswich Basin against the Jurassic Clarence-Moreton Basin

2. Further along the road ~15km we can see the Marburg Range which consists of Early to Middle Jurassic sediments of the Clarence-Moreton Basin which are stratigraphically equivalent to the Surat Basin strata. Look out for the Mount Marrow basalt plugs and the Marburg Sandstone road-cuts along the road.

Stop 1: The Orallo Formation outcrop is 5.5 kilometres north of the Gurumundi township (Figure 3). This unit was previously called the "Fossil Wood beds" as petrified wood can be found in this unit. Bentonite is mined from the Orallo Formation and is used in the drilling and the geotechnical engineering industry.

Figure 3. Road cutting of the Orallo Formation with a bentonite clay layer

Stop 2: Isla Gorge lookout in the north eastern Surat Basin is a Precipice Sandstone outcrop and has been weathered down to form this feature (Figure 4). This is an excellent stop for comparing the Precipice Sandstone in the east with that of the west, which will be observed at Carnarvon Gorge.

The first night we will stay at Theodore, a small town in the Banana Shire, which is a rich farming, grazing and mining region situated in Central Queensland. Coal mining, beef production, power generation, dryland cropping and irrigation cropping (mainly cotton and lucerne) are the local major industries. Nearly 80% of the cotton crop of the shire is grown in the Dawson Valley area. There are abundant supplies of coal bed methane, which could be utilised for power production and other industrial uses.

Figure 4. View at Isla Gorge of the Early Jurassic Precipice Sandstone, Surat Basin

Day 2: Theodore – Springsure

The second day involves driving across the central Bowen Basin, observing mining of the Late Permian coal measures, the Clematis Group, the Staircase Sandstone and the Sirius Mudstone.

Stop 3: The viewing platform of the Dawson open cut coal mine (Figure 5). Late Permian coal in Queensland has been mined extensively for approximately 40 years. Dawson mine is located in the Dawson Valley, at the southern end of the Bowen Basin in Central Queensland. The mine is made up of three operating pits: North, Central and South.

Dawson mine is owned by the Moura Joint Venture, comprising Anglo American Metallurgical Coal Pty Ltd (51%) and Mitsui Coal Holdings Pty Ltd (49%). The mine is operated by Anglo American.

The site has been operating since the 1960s and was the first mine to export coal to Japan in 1961. It was also the first mine to introduce draglines into its operations in 1963 and more recently, was the first mine to commercially extract and sell methane gas in 1996.

Each year Dawson mine produces in excess of 7Mt of coking, soft coking and thermal coal, using open cut and high wall mining methods. The operation has identified

Figure 5. View from the viewing platform at the Dawson coal mine

reserves of 281Mt of coal, with potential for an additional 125Mt. Coal is railed to the port at Gladstone for export to Japan, Korea and Taiwan.

Stop 4: A further 30 kilometres along the road, as we move up section from the Late Permian to the Middle Triassic, we stop to view a road-cut of the Clematis Group (Appendix 1 and Figure 6). This road-cut is undifferentiated Clematis Group, which is a sub-labile to quartzose sandstone.

Figure 6. Road cut showing undifferentiated Clematis Group rocks

Stop 5: Continuing east and moving up-dip we stop at Roundstone Creek, probably named after the Expedition Sandstone, which is exposed in the creek bed below the bridge. The surrounding area is mapped as Moolayember Formation; however, this creek has exposed the underlying Expedition Sandstone (Clematis Group). Pebble bands and cross-bedding is diagnostic of the Expedition Sandstone (Figure 7).

Figure 7. The Conglomeratic sandstones of the Clematis Group. High energy fluvial deposits showing basal pebble lags.

Stop 6: After stop 5, we drive west over the Moolayember Formation for approximately 70 kilometres. This unit is primarily made up of fine-grained sediments, which have weathered to a flat terrain with no outcrops.

Stop 6 is 180 kilometres from stop 5 and the drive west takes us down-dip into the Denison Trough (Figure 1) strata, at the Staircase Range lookout. The Staircase Sandstone is a member of the Cattle Creek Formation (Appendix 1) and it will be examined in more detail when driving back down the range. This formation displays cross-stratification, flame structures, soft sediment deformation, slump folds and dewatering structures (Figure 8). Moving further down the range we stop at a picnic area where we can view the typical 'staircase' morphology of the sandstone. The overlying Sirius Mudstone Member (Figure 9) is seen beside the creek; this unit is the expression of a major marine transgression.

The second night is spent in Springsure, a small town 66 kilometres south of Emerald on the Gregory Highway. Springsure is a pastoral settlement serving cattle farms as well as sunflower, sorghum, wheat and chickpea plantations. The cliff face in the hills surrounding Springsure, which is clearly seen from the town, is known to the area as Virgin Rock, named because it once looked like the Virgin Mary cradling the baby Jesus, although years of erosion have blurred the original resemblance (Figure 10).

Figure 8. Dewatering structure within the Staircase Sandstone Member

Figure 9. Sirius Mudstone Member which overlies the Staircase Sandstone Member

Figure 10. Virgin Rock, Springsure

Day 3: Springsure – Carnarvon Gorge

On leaving Springsure you can view Mount Zamia, which includes Virgin Rock, and is part of the Capricorn Highlands. The excursion continues up section into the Freitag Formation. The best exposure can be seen at Fairbairn Dam which is located 25 kilometres south-west of Emerald in Central Queensland, very close to the Tropic of Capricorn line. Fairbairn Dam was constructed in 1972 across the Nogoa River 'Gap' creating Lake Maraboon, which is Queensland's second largest lake. Maraboon is the Aboriginal word for 'where the black ducks fly'. The primary purpose of this dam is for irrigation; about 300 irrigators are supplied with water for cotton, citrus and other horticultural operations.

***Stop** 7*: The Freitag Formation (Appendix 1) is seen as a series of beach ridges which can be seen when viewed at a distance (Figure 11). This stop will require us to climb down a steep rock face. A copy of the section (Fielding & McLoughlin, 1992) will be given out.

The Fairbairn Dam Spillway (Figure 11) is approximately 50m high and 200m wide, and has been mapped previously by Fielding and McLoughlin (Fielding & McLoughlin, 1992). They interpreted this section as part of a coastal setting, including four main depositional environments: major distributary channel, interdistributary bay, beach ridge and tidal inlet deposits. They tentatively interpreted it as equivalent with the Late Permian Freitag Formation. The GSQ regional mapping has this mapped as the underlying Aldebaran Sandstone.

Figure 11. Spillway cut into the Freitag Formation at Fairbairn Dam

After we see the dam wall, we move 215 kilometres to the south going up section through the Denison Trough. Heading toward Carnarvon Gorge, we turn down Rewan Road. The sandstone bluffs observed along the way are Clematis Group. Further on Early Permian Reid's Dome Beds can be seen forming a breached syncline.

If time permits, two further stops will be conducted within 4 kilometres of the Carnarvon Gorge Wilderness Lodge to see the Peawaddy Formation and the Black Alley Shale. These units are well exposed in the tributary of Carnarvon Creek.

Stop 8: The Peawaddy Formation (Appendix 1 and Figure 12) conformably underlies the Black Alley Shale (next stop). This outcrop is the uppermost sand of the Peawaddy Formation and occurs as coarse labile sandstone, with large cross-beds. No fossils have been recorded from this locality; however, numerous very large vertical escape burrows can be seen. There are no Mantuan Productus beds at this locality as these are not prevalent over the whole extent of the Peawaddy Formation (Gray, 1976).

A further 500 metres towards the lodge we do a short walk along a creek bed to see the Black Alley Shale.

Stop 9: The Black Alley Shale (Appendix 1) outcrop is about 40 metres up the creek. The section seen above the creek bed is of dark marine mudstones with thin beds of light coloured tuff. Bioturbation is common and particularly apparent in some of the light coloured beds (Figure 13).

Figure 12. Peawaddy Formation outcrop displaying shallow marine features

Figure 13. Outcrop of the Black Alley Shale with tuffaceous beds within black mudstone

Day 4: Carnarvon Gorge

The Carnarvon Gorge National Park is 550 kilometres west north-west of Brisbane. The gorge is part of the Queensland's central highlands and formed through the erosion of the lower Surat Basin (Figure 14).

Figure 14. Geological map of Carnarvon Gorge (Willmott, 2006)

Stop 10: The main stratigraphic unit that will be observed in Carnarvon Gorge is the Precipice Sandstone, which forms the greater majority of the cliff faces in the gorge. The best location to see the braided fluvial sedimentary structures within the Precipice Sandstone is in the 'Amphitheatre' (Figure 15). Cross stratification and channelling can be easily observed.

The cross-stratification within the Precipice Sandstone is typical of that produced by transverse bar migration in a braided stream system (Figure 16). This unit is younger on the western side of the Surat Basin than the eastern, and it was sourced from the north-west during the early Jurassic. Deposition transgressed westward and, as the basin gradient reduced, the Precipice Sandstone was covered by the fluvial-lacustrine deposits of the Evergreen Formation (Martin, 1980).

The unconformable contact surface with the underlying Moolayember Formation can be clearly seen in both the Amphitheatre and the Moss Garden. This represents a forty million year depositional hiatus and is the divide between the Bowen Basin and the overlying Surat Basin (Figures 17 and 18).

Figure 15. Cross-stratification within the Precipice Sandstone in the Amphitheatre at Carnarvon Gorge

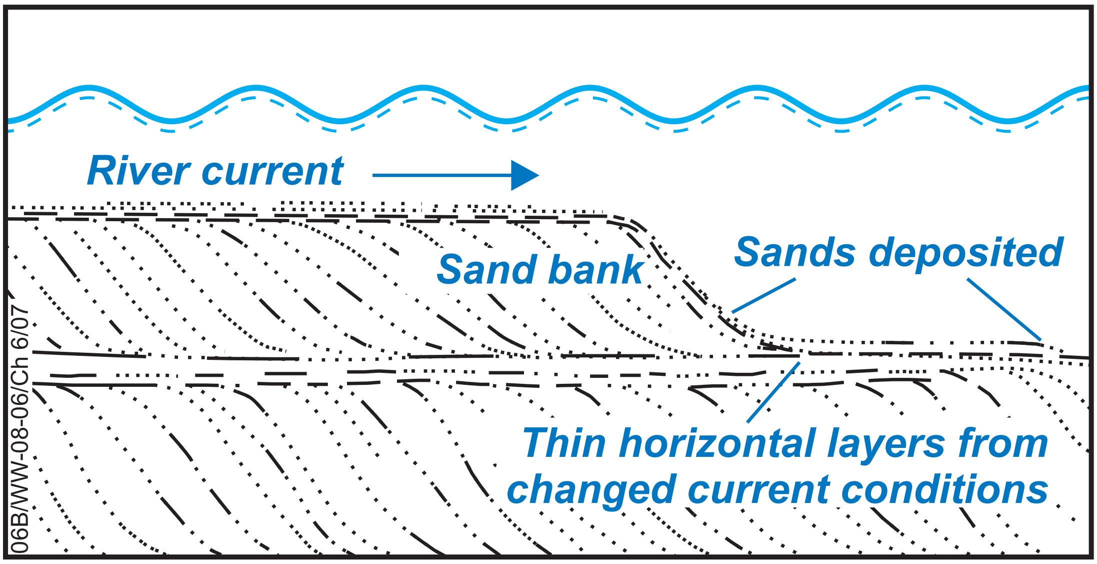

Figure 16. Diagram of cross-bedding (Willmott, 2006)

The Evergreen Formation overlying the Precipice Sandstone can be seen during the 400 metre climb up Boolimba Bluff. The back-stepping Evergreen Formation overlying the white Precipice Sandstone cliff shows differential erosion within the unit. The siltsonte and shale of the Evergreen Formation is underlain by the Boxvale Sandstone Member which, at Carnarvon Gorge, is then capped with basalt from the Buckland volcano of Oligocene age (27Ma.). To the left, the erosion pattern on the hills is most likely the bedding plane of the underlying Bowen Basin strata, which forms an angular unconformity with the Surat Basin (Figure 19).

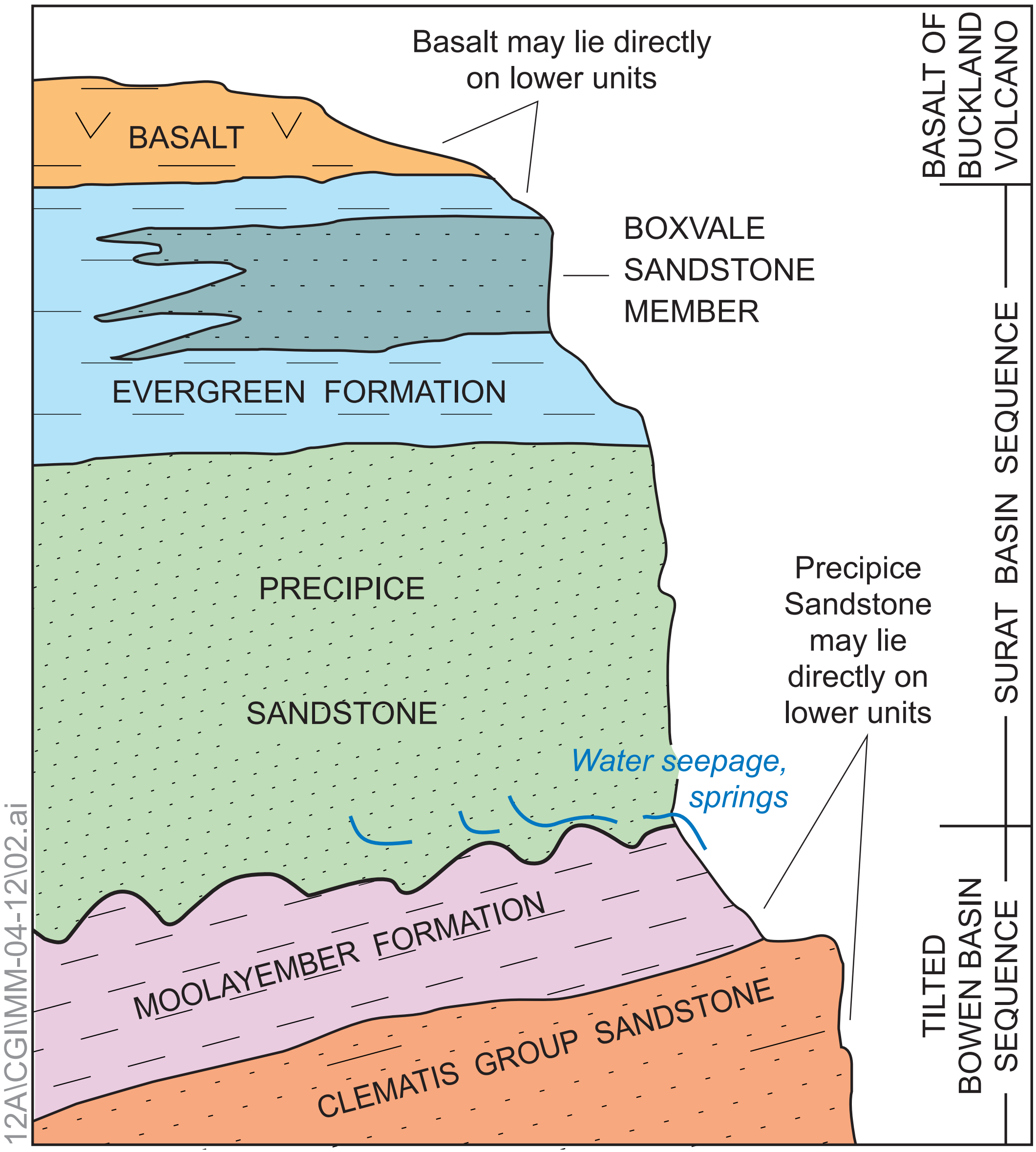

Figure 17. Schematic diagram of the stratigraphy which can be observed from Boolimba Bluff (modified from Willmott, 2006).

Figure 18. Contact between the Moolayember Formation and the Precipice Sandstone as seen in the 'amphitheatre'. Rip-up clasts of Moolayember Formation within the Precipice Sandstone are clearly visible above the contact. At this point ground water from the Precipice Sandstone trickles out from above the less permeable Moolayember Formation

Figure 19. Precipice Sandstone cliffs overlain by the Evergreen Formation and Boxvale Sandstone Member capped with basalt

Day 5: Carnarvon Gorge – Brisbane

Depart as early as possible from Carnarvon Gorge wilderness Lodge.

A number of short roadside stops will be conducted on the way to observe Bowen and Surat basin strata. The time duration of these stops will be dependant on available time as there is approximately nine hours of driving to Brisbane.

An observation of the Rewan Group can be made without disembarking from the bus, approximately 25km from the Lodge at Carnarvon Creek on Wyseby Road.

Stop 11: The Rewan Group (Arcadia Formation), overlaid by the Clematis Group (Glenidal Formation) (Appendix 1), can also be seen a further 40km along the road. This site will be observed from a distance due to the gradient of the cliff face.

Stop 12: The Clematis Group (Expedition Sandstone) (Appendix 1) can be viewed a further 1km along the road. The upper formation of the Clematis Group, the Expedition Sandstone is generally coarser than the underlying Glenidal Formation, and is described as quartzose to sub-labile sandstone with conglomerate and siltstone (Figure 20).

Figure 20. Outcrop of the Expedition Sandstone (Clematis Group), with a palaeosol overlaid by conglomeratic sandstone.

The Moolayember Formation (Appendix 1) road-cut, which is a further 6km south of the Expedition Sandstone road-cut, will be pointed out but we will not stop. Due to the fine grained nature of this unit outcrop exposes are not common. This unit generally weathers to a flat terrain.

Stop 13: The Boxvale Sandstone Member (part of the Evergreen Formation) is more prominent in the northern Surat Basin. This sandstone is a quartzose sandstone, which differs from the other sandstone within the Evergreen Formation which is lithic-feldspathic(Hoffmann & others, 2009). This sandstone member is considered at this point as an incised valley fill due to a drop in base level and hence an increased gradient (Vic Ziolkowski, personal communication). Fielding (1989) suggests this sandstone member indicates a prograding lacustrine delta system.

Stop 14: The Hutton Sandstone (Appendix 1) is a widely used aquifer in the Great Artesian Basin (GAB). The formation is partly arkosic and further south, the lower unit has a higher proportion of siltstone and shale. The Hutton Sandstone is the most geographically widespread Jurassic unit in the GAB and is continuous into, and forms the upper part of, the Marburg subgroup in the Clarence-Moreton Basin to the east and extends west into the Eromanga Basin. Deposition of the Hutton Sandstone represents the start of the second major sedimentary cycle in the Surat Basin (Green, 1997) (Figure 21).

More detail on the Triassic–Jurassic sedimentary evolution of the south-eastern Queensland sedimentary basins can be found at the Queensland Geological Survey website http://mines.industry.qld.gov.au/geoscience/products-services.htm.

Figure 21. The Hutton Sandstone road-cut, where bedding and structures can be observed.

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Appendix 1

Bowen Basin

Reid's Dome Beds (Early Permian)

The Reid's Dome Beds occur in the Denison Trough and the western part of the Bowen Basin. The lithology varies from place to place and includes carbonaceous sandstone, grey siltstone, shale and coal above thick dark shale with anhydrite, dolomite, coal, sandstone and siltstone. Thick volcanolithic pebble conglomerate and volcanolithic sandstone occur in places (Dickens & Malone, 1973).

The Reid's Dome Beds were deposited during the initial subsidence of the trough (Gray, 1980); they have abundant Glossopteris/Gangamopteris flora and the rare marine fossils indicate marine incursions (Dickens & Malone, 1973).

Cattle Creek Formation (Early Permian)

The Cattle Creek Formation consists of marine, fossiliferous, conglomeratic and silty sandstone, with thin interbeds of limestone and calcareous sandstone. Its deposition represents a change from non-marine to more widespread marine conditions in the Denison Trough (Gray, 1976).

The Cattle Creek Formation is subdivided into five member units named Mostydale Mudstone Member, Riverstone Sandstone Member, Moorooloo Mudstone Member Staircase Sandstone Member and the Sirius Mudstone Member (Price, 1997). The Staircase Sandstone Member is light grey, fine to very coarse and pebbly, mostly medium, fairly and poorly sorted, sub-labile to labile with a mostly argillaceous matrix, in part siliceous and calcareous. Carbonaceous plant fragments, shale clasts and scattered quartz pebbles occur throughout. Some sandstones are silty with bedding being bioturbated. Fossil shells occur in the uppermost few metres (Gray, 1976).

The Sirius Mudstone Member consists of laminated and thinly bedded, light to dark grey siltstone, shale, mudstone and fine to very fine labile sandstone. Some plant fragments and pyrite are present. Fossil shells and calcareous veins occur (Gray, 1976).

Freitag Formation (Late Permian)

The Freitag Formation contains interbedded sandstone, in part pebbly, siltstone and sandy mudstone; wavy, irregular bedding and bioturbation are common. The unit is transgressive and its deposition represents a return to marine conditions in the Denison Trough (Gray, 1980).

Peawaddy Formation (Late Permian)

The Peawaddy Formation consists of:

- thinly interbedded and inter-laminated micaceous grey siltstone and dark carbonaceous mudstone, with abundant plant debris, worm burrows, gypsum and jarosite on bedding planes

- lithic sandstone predominant in the upper half of the unit

- fossiliferous coquinitic siltstone and sandstone of the Mantuan Productus beds at the top in places.

The Peawaddy Formation was deposited over a much greater extent than the Denison Trough and marine conditions existed for at least part of the deposition time.

Black Alley Shale (Late Permian)

The Black Alley Shale consists of shale, siltstone, tuff and coal with minor sandstone. Shale is grey to black, silty, tuffaceous, abundantly carbonaceous and may grade into coal. The shale is generally micaceous with minor pyrite. Siltstone is grey to black or brown, micaceous, carbonaceous and commonly pyritic. Tuff is commonly white to cream and soft (Green, 1997).

Mollan & others (1969) suggest that depositional conditions were variable. Acritarchs at the bottom of the formation suggest initial deposition was in a large basin with limited direct access to the sea, providing brackish-marine conditions. Final deposition was in a restricted freshwater lake.

Rewan Group (Late Permian – Early Triassic)

The Rewan Group is dominated by red-brown, green and khaki mudstones interbedded with green and khaki siltstones and fine- to medium-grained, labile sandstones, and includes the Sagittarius Sandstone and the Arcadia Formation.

The Sagittarius Sandstone comprises light green-grey, calcareous, fine- to medium-grained, rarely very coarse-grained, lithic sandstones interbedded with green to brown mudstones and siltstones with scattered carbonaceous plant material. The sandstone contains numerous shale and siltstone clasts at some depths (Jensen, 1975).

The overlying Arcadia Formation consists dominantly of red-brown mudstone and silty mudstone interbedded with lesser amounts of green siltstone and very fine to medium-grained sandstone. The boundary with the underlying Sagittarius Sandstone is taken at the change upwards from dominantly sandstone to thick beds of red-brown mudstone.

Clematis Group (late Early Triassic – early Middle Triassic)

In the Glenidal Formation (lowest Clematis Group), sandstone is more common than siltstone and mudstone. The sandstone is white to dark brown, very fine to medium-grained, and sub-labile. Mudstone is generally red or red-brown and in part yellow-green or grey, and carbonaceous. Siltstone is grey, mottled brown and red, laminated, generally micaceous and in part carbonaceous. The formation is characteristically thinly bedded.

The overlying Expedition Sandstone consists mainly of pale grey to white, medium- to very coarse-grained, sub-labile to quartzose sandstone, conglomeratic in part, interbedded with lesser amounts of fine-grained lithic and sub-labile sandstone, siltstone and mudstone. The finer grained rocks are generally grey with some red siltstone and mudstone interbedded in the lower part.

Jensen (1975) interpreted that sediments of the Glenidal Formation were deposited by meandering streams in a floodplain environment and those of the Expedition Sandstone by braided streams.

Moolayember Formation (Middle Triassic)

The Moolayember Formation in its type area consists dominantly of interbedded olive, green-brown and green-grey mudstones and lithic to sub-labile, medium to coarse-grained sandstones. Other rock types include grey to black carbonaceous shale, siltstone, mudstone, coal, conglomerate and minor tuff and limestone. The Snake Creek Mudstone Member on the Roma Shelf dominantly comprises dark grey to black mudstone with minor laminae and thin beds of very fine-grained quartzose sandstone (Hogetoorn, 1970).

The Moolayember Formation was deposited in a dominantly fluvial-lacustrine environment in an internally drained basin (Mollan & others, 1972). The Snake Creek Mudstone Member is interpreted by most workers to have been deposited under lacustrine conditions; interbedded coarse-grained sandstones with megaripples may reflect an estuarine or tidal channel environment (Alcock, 1969). Butcher (1984) interpreted a marginal marine or tidal flat environment of deposition for this member.

On the western side of the basin, acritarchs in abundances of up to 5% have been reported in the upper part of the Moolayember Formation in the Carnarvon Range area (Alcock, 1969), which provides evidence that at least brackish conditions prevailed during deposition of some horizons.

Precipice Sandstone (Early Jurassic)

The Precipice Sandstone consists of fine- to coarse-grained, pebbly quartzose sandstone with minor lithic sub-labile sandstone, siltstone and argillite. Exon (1976) sub-divided the Precipice Sandstone into a Lower and Upper unit with the Lower Precipice Sandstone being coarser grained.

Martin (1980) interpreted that the Precipice Sandstone was deposited in transverse bars in a braided stream system, with stream flow being from west to east. Palynofloras from the Precipice Sandstone are indicative of deposition in a continental environment. The unit is conformably overlaid by the Evergreen Formation.

Evergreen Formation (upper Early Jurassic – early Middle Jurassic)

Below the Boxvale Sandstone Member, the Evergreen Formation comprises green-grey labile and sub-labile, fine to medium-grained sandstone, carbonaceous mudstone and argillite and minor carbonaceous siltstone, shale and coal. The Boxvale Sandstone Member commonly consists fine to coarse-grained, cross-bedded, quartzose sandstone with some argillaceous clay matrix. The Upper Evergreen Formation comprises of dark green to black mudstone (laminated with sandstone, siltstone and shale) and fine-grained sub-labile to labile sandstone. The Westgrove Ironstone member forms the lower part of this interval and consists of interbedded mudstone and chamositic mudstone with pelletal or oolitic structure with sideritic cement and minor labile sandstone (Green, 1997).

The Evergreen Formation below the Boxvale Sandstone Member is interpreted as being deposited in freshwater lakes (Mollan & others, 1972) or by meandering streams in coastal plains and deltas (Exon, 1976), whilst another interpretation suggests it was deposited as part of a prograding lacustrine delta system (Fielding, 1989). There are suggestions that the Westgrove Ironstone Member was deposited under shallow marine conditions as this coincides with a global sea-level high in the middle Toarcian (Vic Ziolkowski, personal communication). Above the Boxvale Sandstone Member the sedimentation continued in a lacustrine system of deposition.

The Evergreen Formation is Pliensbachian–Toarcian in age and it conformably underlies the Hutton Sandstone.

Hutton Sandstone (Middle Jurassic)

The Hutton Sandstone consists mainly of sub-labile to quartzose sandstone with interbedded siltstone, shale, minor mudstone and coal. The sandstone is white to light grey, fine- to medium-grained, well-sorted, partly porous with some pebble bands with shale-siltstone clasts in the lower part (Green, 1997).

The siltstone and shale is light to dark grey, micaceous, carbonaceous and commonly interlaminated with very fine-grained sandstone. The Hutton Sandstone was deposited by meandering streams on a broad floodplain with generally quartz rich sediments (Exon, 1976).

Orallo Formation (Late Jurassic – Early Cretaceous)

The Orallo Formation consists mainly of friable, medium- to coarse-grained, sub-labile to labile sandstone, in part calcareous, and lesser interbedded carbonaceous siltstone, silty mudstone, bentonite and coal. Fossil wood commonly is included in the sandstones and in some areas; conglomerates also are interbedded within the sandstones. Bentonite occurs at the top of the formation, north of Jackson (Gray, 1972) and it is mined commercially north and south of Miles.

Day (1964) interpreted that the depositional environment for the Orallo Formation was fluvial with local ponding. The presence of coals and interbedded tuff indicate a lacustrine environment with periods of volcanic activity, particularly during deposition of the uppermost beds.

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Appendix 2

Stop	Details of Way Points along route	Latitude	Longitude
	Ipswich Fault	-27.580111	152.725194
	Marburg Range	-27.564889	152.563972
1	Orallo Formation	-26.365611	150.076667
2	Isla Gorge lookout	-25.191111	149.972361
3	Dawson open-cut coal mine	-24.616639	150.047861
4	Clematis Group	-24.619528	149.813889
5	Roundstone Creek - Expedition Sandstone	-24.623028	149.788667
	Basalt Quarry	-24.577583	149.265389
6a	Sirius Mudstone and Staircase Sandstone	-24.226108	148.233595
6	Staircase Range lookout	-24.211936	148.195803
	View point for Mount Zamia	-24.093417	148.097306
7	Fairbairn Dam	-23.647750	148.06825
	Clematis Group overlying Rewan Group	-24.742778	148.405833
	Clematis Group - Ridge	-24.821056	148.37225
8	Peawaddy Formation	-25.083806	148.276111
9	Black Alley Shale	-25.080361	148.272778
10	Carnarvon Gorge Wilderness Lodge	-25.070806	148.25525
	Rewan Group Carnarvon Creek crossing	-24.976972	148.390389
11	Rewan Gp and Clematis Gp	-25.167556	148.566222
12	Clematis Group (Expedition SS)	-25.175917	148.563861
	Moolayember Formation	-25.223278	148.601750
	Precipice Sandstone	-25.294917	148.659639
13	Boxvale Sandstone Member	-25.436333	148.640778
14	Hutton Sandstone	-25.751000	148.656833

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