Revision of Oligocene–Miocene Murray Group stratigraphy for geological and groundwater studies in South Australia

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Introduction

The epicratonic Murray Basin covers an area of 300 000 km^2 in southeastern South Australia, northwestern Victoria and southwestern New South Wales (Fig. 1). It contains up to 600 m of freshwater, marine, coastal and continental sediments of Paleocene to Quaternary age (Brown and Stephenson 1991; Rogers et al. 1995).

Tertiary sediments occur in three sequence sets (Rogers et al. 1995):

- *Late Paleocene to Early Oligocene.* Non-marine and minor marginal marine sediments, including the Renmark Group in South Australia.
- *Late Eocene to Middle Miocene.* Transgressive marine sediments, including the Murray Group (subject of this paper), and the upper Renmark Group, which ranges up to Middle Miocene in Victoria and New South Wales.
- *Latest Miocene to Late Pliocene.* Marine, coastal and non-marine sediments.

The Murray Group consists mainly of a shallow marine fossiliferous limestone, with minor clay and silt. Because of its high porosity and permeability, this unit contains huge volumes of groundwater. Close to recharge areas in high-rainfall zones around the basin margins, groundwater salinities are low (below 3000 mg/L) and, consequently, the limestone aquifer is widely developed for agricultural and domestic use. However, at the end of the long flow paths from the recharge areas, the aquifer discharges saline groundwater into the River Murray, a process which causes significant economic impacts to water users in South Australia.

Salt interception schemes are constructed to pump the saline groundwater out of the aquifer before it enters the river. Detailed drilling programs are required to ensure effective scheme design by delineating aquifers and low-permeability aquitards which control groundwater flow. It is also necessary to place these units in a consistent stratigraphic framework to allow correlation throughout the region. To support this work a drillhole transect of five reference stratigraphic holes has been completed near the River Murray between Cadell and Renmark (Australian Water Environments 2003).

After discussions between hydrogeologists from the Department of Water, Land and Biodiversity Conservation (DWLBC), groundwater consultants and PIRSA geologists, a scheme proposed by one of the authors (W Cowley) was accepted for future use. A slightly amended version is presented in Figure 2.

Previous stratigraphic studies

The first stratigraphic scheme to be applied to the marine Oligocene–Miocene rocks of the Murray Basin in South Australia was by Ludbrook (1957, 1961). Figure 2 shows the 1961 scheme, in which the Murray Group encompassed all units between the top of Ettrick Formation and the base of Bookpurnong Beds, namely the Mannum Formation, Finniss Clay, Morgan Limestone and Pata Limestone. The Ettrick Formation and Compton Conglomerate were incorporated in the underlying Glenelg Group, a name which has since fallen from usage.

Lawrence (1966) expanded the concept of the Murray Group, including all the Tertiary units with marine influence in Victoria above the Knight Group, namely the Netherby Marl, Geera Clay, Duddo Limestone and Winnambool Formation, as well as the Pliocene Bookpurnong Beds and Diapur Sandstone. With further work, some of the Victorian units were abandoned in favour of correlative South Australian units defined previously, and Lawrence (1975) presented a revised scheme in which the Murray Group was reduced to exclude the Diapur Sandstone (Parilla Sand).

Subsequently, Lawrence and Abele (1988) removed the Pliocene Bookpurnong Beds from the Murray Group. Brown and Stephenson (1991), in

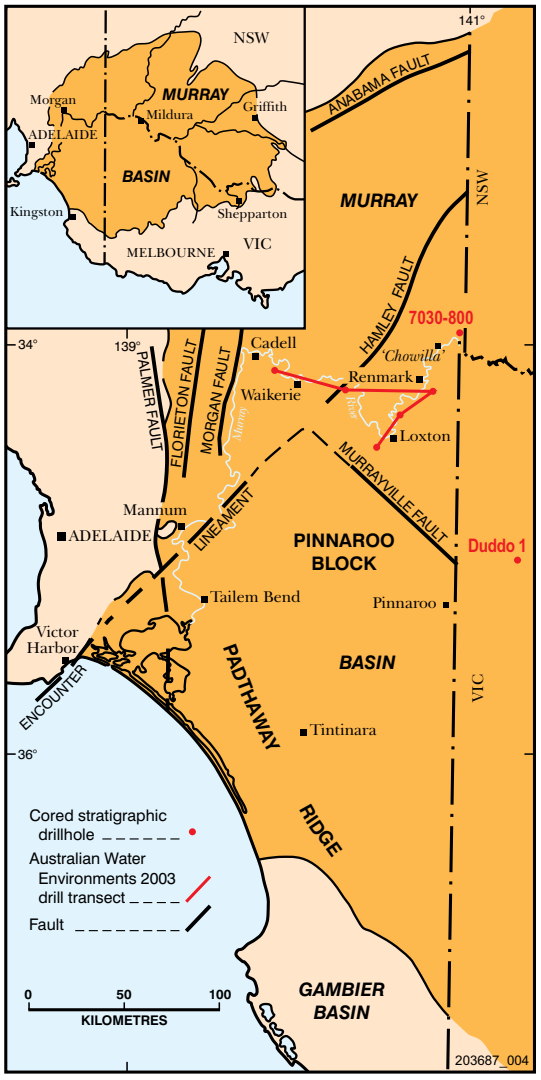


Figure 1 *Location map of the Murray Basin in South Australia showing cored stratigraphic drillholes.*

a comprehensive compilation of the entire Murray Basin, juxtaposed the schemes of Ludbrook and Lawrence and Abele, and presented them together in a time-space diagram (their fig. 45).

Rogers et al. (1995, figs 10.2 and 10.7), summarising the geology of the Murray Basin in South Australia, excluded the Ettrick Formation from the Murray Group (as did Ludbrook) and this was then at odds with Victorian usage. Furthermore, the status of Geera Clay and Winnambool Formation was left ambiguous, and arguably these units may also have been intended to be excluded from the Murray Group. Rogers et al. (1995) also replaced the Mannum Formation, Morgan Limestone and Pata Limestone with the single unit, Mannum Limestone.

The Compton Conglomerate was defined in the Gambier Basin by Ludbrook (1961) but was considered to extend into the Murray Basin, where in more recent studies it has been termed 'Compton Conglomerate equivalent'. The unit in the type area was abandoned by White (1996) and, where it was applied in the Murray Basin, it has been relegated to a basal facies of the Ettrick Formation.

Lukasik and James (1998) carried out a detailed study of the extensive exposures of Murray Group sediments along the River Murray cliffs in South Australia, and introduced a much more finely divided stratigraphic scheme, supported by comprehensive lithological and palaeontological descriptions and careful definitions and redefinitions of a number of stratigraphic units (Fig. 2). They included Ettrick Formation, Geera Clay and Winnambool Formation (but, seemingly, not Duddo Limestone) in their Murray Supergroup, which was elevated from Murray Group. They reinstated Mannum Formation, Finniss Formation and Pata Formation to their original usage, but all as formations, and reinstated and elevated Morgan Limestone to Morgan Group to cover the interval between the Finniss and Pata formations. Additionally, they defined new members within many of the units.

Discussion of Lukasik and James' stratigraphic scheme

Rogers in Rogers, Lukasik and James (1999), although commending Lukasik and James' detailed description and subdivision of the Oligo-Miocene sediments along the River Murray, disagreed with their elevation of the Morgan Limestone to Morgan Group and of the Murray Group to Murray Supergroup. He considered that these changes were unnecessary and did not correspond with nomenclature used for sediment packages of similar magnitude both within the Murray Basin and in other southern Australian Tertiary marine basins. He recommended that the term Murray Group be retained, and the term Morgan Group be abandoned.

Later, Rogers (PIRSA, pers. comm. 2003) observed that the contentious portions of the Lukasik and James scheme had '…not been widely accepted in South Australia. Geologists at PIRSA and hydrogeologists at DWLBC are still using the name Murray Group', and recommended the retention of the term. He further suggested that if Murray Supergroup was not accepted, Murray Group could continue to be used, and Lukasik and James' Morgan Group could be retained but demoted to Morgan Subgroup instead of being abandoned. This would enable the continuation of a well-established and understood name in the literature. Lukasik and James in Rogers, Lubasik and James (1999), although initially refuting Rogers' criticisms, have more recently accepted them (Queen's University, pers. comm. 2004).

Subsequent and continuing work by DWLBC hydrogeologists and groundwater consultants has established the usefulness of the Lukasik and James scheme in defining the stratigraphy close to the River Murray. However, facies changes on a regional scale may make application of this scheme in detail difficult if not impossible, some distance from the studied cliff sections. For instance, whilst the scheme is fully recognisable in five cored drillholes located over an E–W transect of 90 km between Waikerie, Loxton and Renmark (Australian Water Environments 2003), a cored hole which fully penetrated the Murray Group at Chowilla some 30 km north of the transect (well number 7030-800) intersected fine-grained calcareous sediments with only the Pata, Cadell and Mannum formations from the scheme distinguishable. This suggests that the

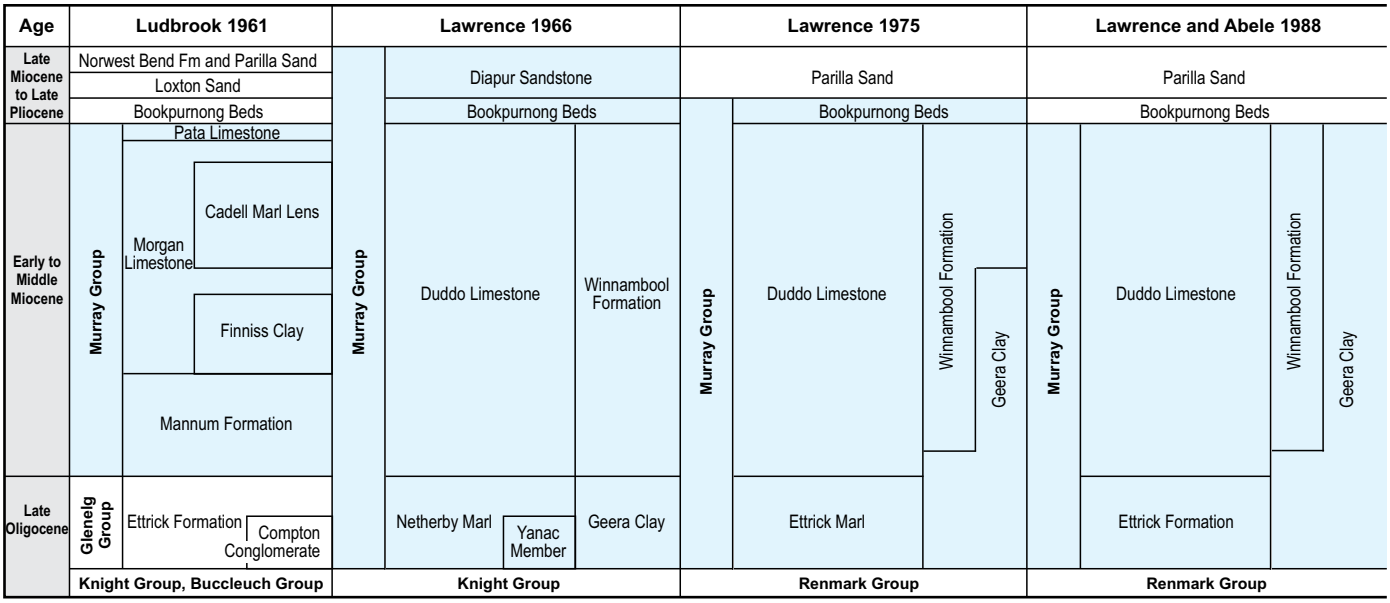


Figure 2 *Evolution of stratigraphic schemes for the Oligo-Miocene rocks of the Murray Basin.*

full Lukasik and James scheme may only be recognisable, on a lithological basis, within a few tens of kilometres north or south of the River Murray, due to the facies changes from south to north representing changes in depositional environments from open marine to marginal marine.

By comparison, Gallagher and Gourley (2007) have used facies, wireline log and foraminiferal studies of drillholes to extend the Lukasik and James units into Victoria and about 130 km south of the River Murray (Duddo 1), but their continued usage of Murray Supergroup and Morgan Group is not followed here. Note that Gallagher and Gourley also incorrectly stated (p. 847) that Lukasik and James (1998) assigned the Finniss and Pata formations to their Morgan Group, and went on to describe the Finniss as the basal unit of the Morgan Group, at odds with their figure 2b.

Gallagher and Gourley (2007) recommended the replacement of the Duddo Limestone with the units from Mannum Formation to Pata Formation; as the Duddo is not known from South Australia, no opinion is expressed herein on this proposal. Additionally, they suggested the Winnambool and Ettrick formations are lithostratigraphically indistinguishable and should be considered a single unit, Ettrick Formation. As the Ettrick Formation in South Australia is Oligocene in age and occurs near the Padthaway Ridge, and the Winnambool Formation is Early to Middle Miocene and is a lateral equivalent of the Murray Group at its northern limit (Brown and Stephenson 1991; Rogers et al. 1995), the two units are retained for now.

Nomenclature of hydrogeological units

Because the focus of the DWLBC hydrogeologists has necessarily been on the aquifers and intervening aquitards contained within the Murray Basin sediments, much discussion was devoted to the fact that aquifers and aquitards can and do cross lithostratigraphic boundaries. Due to the convention of referring to these hydrostratigraphic entities by names taken from stratigraphic units, confusion can arise where the context is ambiguous. Consideration should be given to developing nomenclature for hydrostratigraphic units which is separate from that given to lithostratigraphic units.

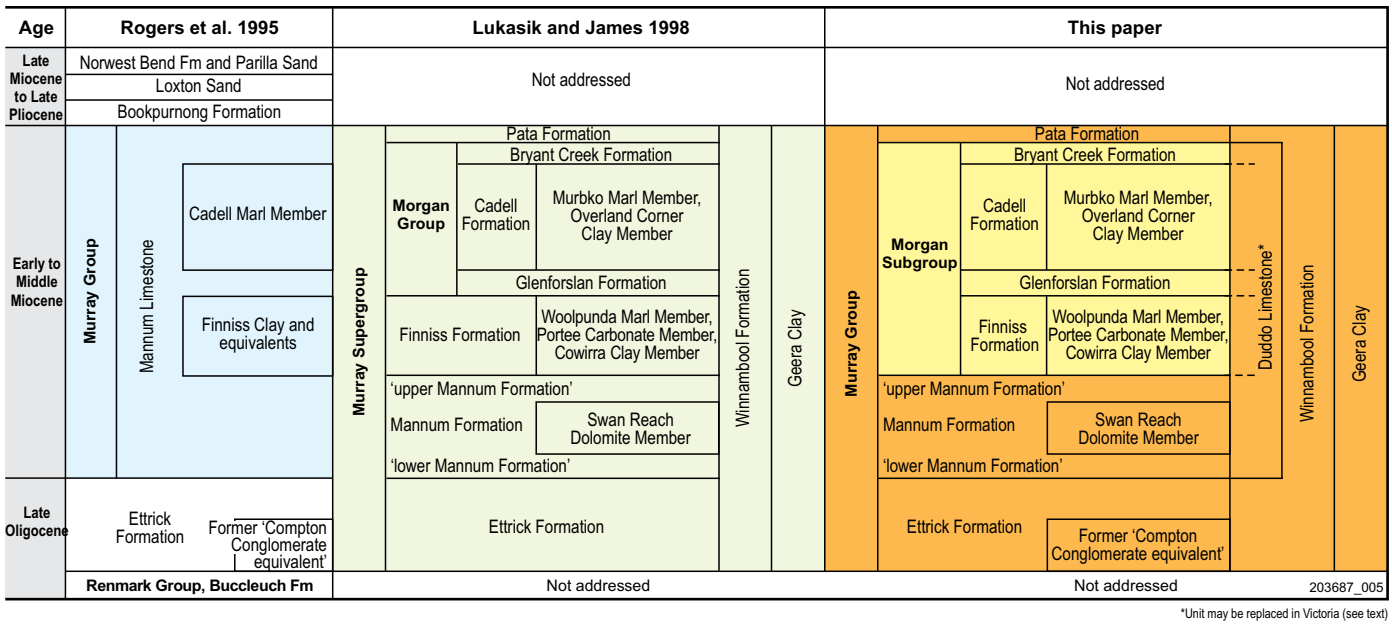
Recommended stratigraphic scheme

Figure 2 illustrates the evolution of the stratigraphic nomenclature for the Oligo-Miocene rocks of the Murray Basin, culminating in the recommendation of this paper. Essentially, the scheme is that of Lukasik and James, but with Rogers' unpublished 2003 modifications. Further, the Finniss Formation has been included in the Morgan Subgroup on the recommendation of Dr B McGowran (University of Adelaide, pers. comm. 2007) on the basis that the base, not the top, of the Finniss represents the commencement of the Middle Miocene transgression (Li and McGowran 1999). This reverts to the original concept of the base of Ludbrook's (1961) Morgan Limestone (Fig. 2).

Key features of the recommended scheme (Fig. 2) are:

- reinstatement of Murray Group in place of Murray Supergroup
- replacement of Morgan Group with Morgan Subgroup
- inclusion of the Finniss Formation in the Morgan Subgroup
- retention of Lukasik and James' new and reinstated formations and members
- confirmation of inclusion of Ettrick Formation, Winnambool Formation, Duddo Limestone (or informal 'Murray Group limestone') and Geera Clay in the Murray Group for South Australia
- compatibility with the stratigraphic terminology used in Victoria and New South Wales (Lawrence and Abele 1988; Gallagher and Gourley 2007).

The stratigraphic architecture of the western Murray Basin, incorporating the recommended scheme of this paper, is shown in Figure 3 and is based on figure 45 of Brown and Stephenson (1991). Note that the time span of the Morgan Subgroup and Pata Formation in Figure 3 has been reduced from that shown in Brown and Stephenson (1991) based on information in Gallagher and Gourley (2007, their fig. 2b).



*Unit may be replaced in Victoria (see text)

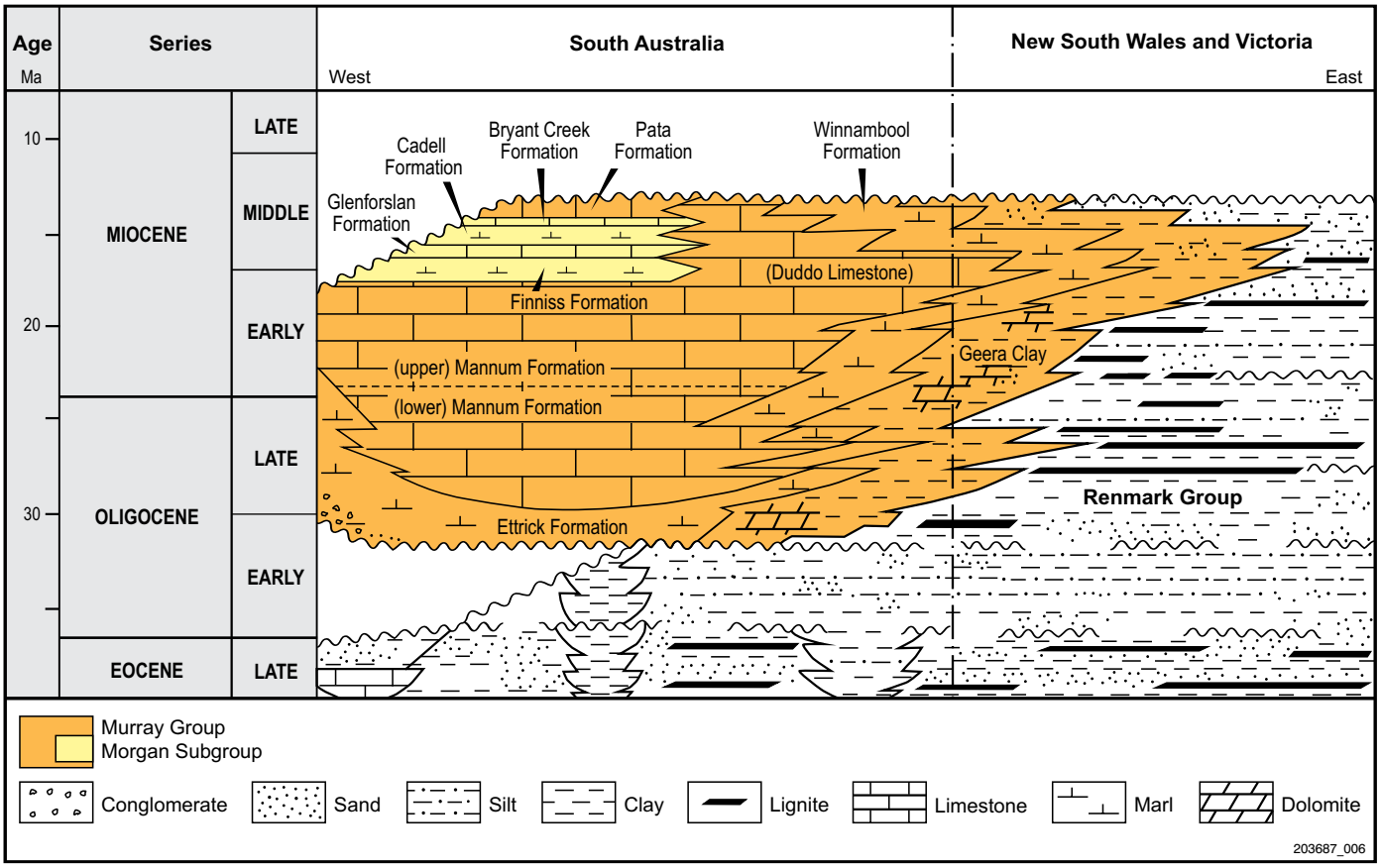


Figure 3 *Stratigraphic architecture of the Murray Group (adapted from Brown and Stephenson 1991, and Gallagher and Gourley 2007).*

Further work required

The latest Miocene–Pliocene stratigraphy of the Murray Basin in South Australia has also been under consideration. A number of informal units introduced by DWLBC hydrogeologists and groundwater consultants in the course of their investigations for the Loxton Salt Interception Scheme need to be formalised and an agreed stratigraphic scheme erected. Such a scheme would also need to address difficulties introduced by Pufahl et al. (2004), who have proposed the extension of the Norwest Bend Formation downwards so that it correlates not only with the Late Pliocene Parilla Sand (as is presently the case) but additionally with the Early Pliocene Loxton Sand.

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