CHAPTER 2. GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

2.1. INTRODUCTION

In attempting to understand the environmental mechanisms relating to groundwater quality within the study region, it is important for there to be a clear understanding of the geological structure of the catchment and how this may impact upon water and nutrient transport to, and within, the unconfined aquifer.

Various resource materials are available detailing the geological stratigraphy of the study area, however these are not at the scale necessary for this research. These resource materials were generally developed for differing purposes, such as those references of regional geology (Sprigg 1952, Wopfner and Douglas 1971, Drexel et al. 1993, Drexel and Preiss 1995), reviews on the stratigraphy of individual bores (Ludbrook 1961, Harris 1964), and a number of reports that provide some description of hydrogeology (Cobb and Brown 2000, Walker et al. 2001, Mustafa and Lawson 2002). The work by MacKenzie and Stadter (1981), although brief is the only study that has considered the geological structure of the Coonawarra area in respect to groundwater contamination.

Further, these resource materials have often, by necessity, needed to describe the entire depth of the geology to encompass both the confined and unconfined aquifer, and therefore have not focused upon the upper geological strata. Since the elevated concentrations of nitrate are generally identified within the upper levels of the unconfined aquifer, it was appropriate that greater focus in this area occurred.

This chapter therefore reviews the geology and hydrogeology of the study area, with particular focus upon the upper units of the unconfined aquifer. This review provides a basis for the subsequent assessment of groundwater data quality.

2.2. METHODOLOGY - GEOLOGY

The near-surface geology of the study area, as with the majority of the region, is primarily based upon the interpretation of core samples from constructed wells and, to a lesser degree, from quarrying operations. The region has not been exposed to dramatic structural displacement for a considerable period, and therefore there are few examples of surface exposure of many of the subsurface geological units.

Although other geophysical surveys have been undertaken in the region to delineate deeper deposits and structural features, these were not reviewed as part of this study.

The review of the geological stratigraphy was complicated by the changes in nomenclature since the early studies undertaken over the study area. In an attempt to assist in future reviews, the classification nomenclature adopted in Drexel et al. (1993) and Drexel and Preiss (1995) has been adopted in this thesis.

2.2.1 Interpreting Bore Details

The logging of cores from boreholes is resource intensive for both the drillers and the geologist/palaeogeologist that undertake the sample interpretation. The additional time and cost for this geological logging of bores means that very few bores are logged outside of specific investigation projects.

For the purposes of this research, there were considered to be three levels of review that were available on constructed boreholes for the study area; driller's logs, geological logs and multidisciplinary assessments.

Driller's Logs

A permit is required under the *Natural Resources Management Act 2004* to construct a well (or bore) within South Australia. It is a requirement of this permit that the responsible driller submit to the relevant government department a report on the well construction, including an interpretation of the geological profile. As this reporting was also required in previous legislation, all except very early bores have an available driller's log.

Although this information can be a considerable resource for geological assessments, in practice, the detail within these reports varied considerably within the study area. It is suggested that this limited detail is a result of factors such as the method of bore construction, the varying geological knowledge of the driller, and the gradational nature of the sedimentary deposits in the near-surface geology of the study area.

A review was undertaken on a selection of bores within the centre of the study area (approximately 100 of the estimated 2,200), and although it was confirmed that many did not contain sufficient detail, some of these logs reported upon significant lithological changes identified during bore construction.

Twelve driller's logs considered to be of suitable detail were included in the assessment.

Geological Logs

As a result of a range of different investigative projects, bores are constructed in a manner that allows the collection of relatively undisturbed core samples that are then assessed by professional geologists. For the reasons given above, the number of these reports are limited across the region, although there was a higher than expected number (38) of these reports for bores in the study area.

Given that these assessments are undertaken by individuals with geological experience, and that the assessment is undertaken on the undisturbed core samples, there is high confidence in the accuracy of these available reports.

Multidisciplinary Assessments

The reference to multidisciplinary assessments of geological profiles reflects that the assessment of geological units and age are determined by a combination of investigative methods (e.g. lithological, micropalaeontological, geophysical). This combination of methods provides greater confidence in the reported geological stratigraphy.

There are two bores within the study area that have been assessed using such methods, these being 702302925 (Penola No. 1) (Ludbrook 1961) and 702300632 (Comaum No. 2) (Harris 1964). The detail from these two bores was considered the benchmark reference for other geological logs within the study area.

All collated geological data relating to bores considered in this study are reported in Appendix 1.

2.3. METHODOLOGY - HYDROGEOLOGY

A preliminary assessment of the groundwater characteristics was undertaken to provide a general overview of groundwater within the study area. The assessment was focused upon the unconfined groundwater of the Tertiary and Quaternary formations.

Groundwater (depth) measurements were obtained through the internet application; OBSWELL, that is operated by the Department for Water, Land and Biodiversity Conservation. Departmental files were reviewed for each of the wells used in determining groundwater depths to correct errors within the database of reference (well-head) elevation data.

2.4. RESULTS - GEOLOGY

2.4.1 General

The study area is close to the northern margin of the Gambier Embayment of the Otway Basin (Figure 2.1). This embayment is a geological depression that has been subjected to considerable periods of marine transgression.

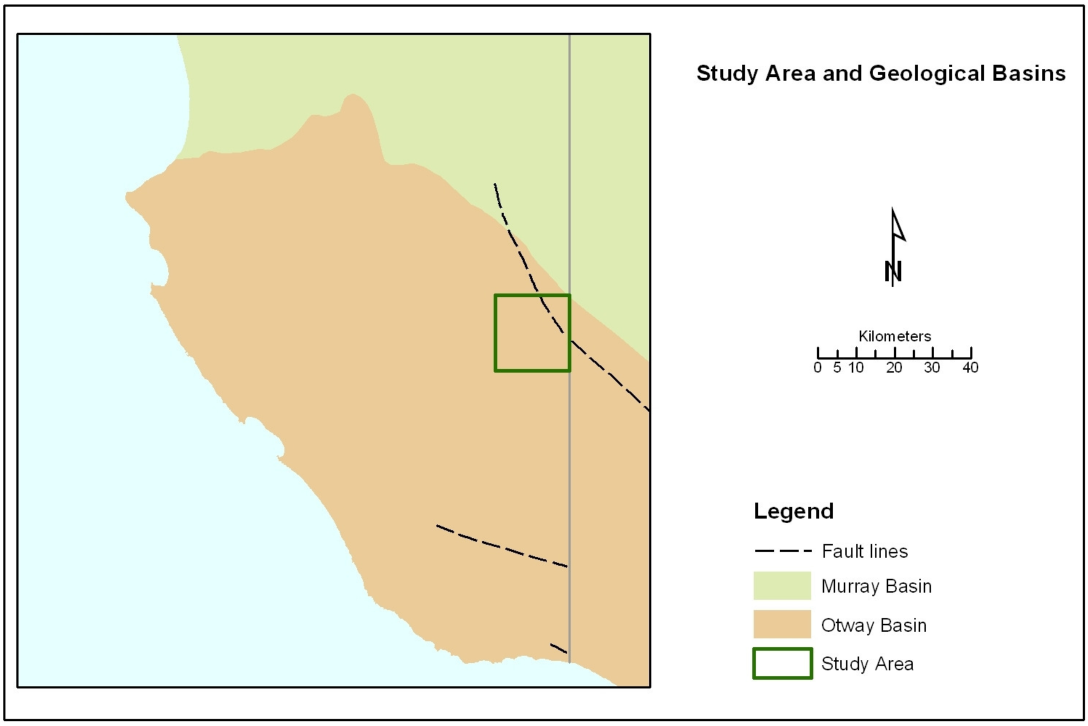


Figure 2.1: The location of the study area within the Otway Basin

The Otway Basin has been described in detail by Wopfner and Douglas (1971). Regional warping has dominated any tectonic displacement within the Gambier Embayment since the Late Cretaceous (Drexel and Preiss 1995), and the Kanawinka Fault running through the north east part of the study area is one of the few defined faults. This subsurface basement fault is expected to have had some influence on the displacement of Tertiary units (Drexel and Preiss 1995), and a review of geological logs separated by the Kanawinka Fault supports this view. This fault controls the northern (as it appears in Figure 2.1) extent of the Gambier Embayment in this area, with the sediments west of this fault dipping down from this lineament. The uplifted north-eastern side of this fault is apparent through the presence of the Naracoorte Ranges that rise 70 metres above the western plains (within the study area). Further east into Victoria, this higher inland plain reaches approximately 300 metres (Cobb and Brown 2000).

Although there is evidence of the recent (7,000 to 28,000 years ago) volcanic activity within the region through the remnant features of Mt Gambier and Mt Schank (Leaney et al. 1995), such activity does not extend to the study area.

The landscape of the study area, and the Gambier Embayment, is dominated by Tertiary and Quaternary sedimentation, particularly influenced by marine inundations. These deposits overlay the older deposits that are discussed to provide a context to the later sedimentary units.

2.4.2 Mesozoic Geology

The study area is on the northern flank of the Robe-Penola trough that comprises thickened Cretaceous sediments that become thinner (within the study area) towards the uplifted Kanawinka Fault. The depth of these Cretaceous sediments within the study area is unclear. Ludbrook (1961) reported possible Upper Jurassic deposits at a depth of 1280 metres, and later suggested that the pink garnet identified at a depth of 1340-1408 metres possibly indicated reworking of Permian sediments (Ludbrook 1971).

The Cretaceous sediments within the Gambier Basin were deposited during the early stages of the rift development between the diverging Australian and Antarctic landmasses. During this time the area was likely to have been subjected to lacustrine, riverine-deltaic and shallow marine deposition environments (Harris 1983). The resulting Cretaceous deposits of interbedded shales, siltstones, minor sands and sandstones are reported in deeper bores within the study area. Harris (1964) reported that there appeared to be little basis for lithological differentiation of the approximately 200 metres of Cretaceous formations encountered in 702300177. The spore assemblages recorded in this bore suggest that this intersected early Cretaceous unit is the Eumeralla Formation of the Upper Otway Supergroup.

To the west of the Kanawinka Fault the Cretaceous deposits (suggested as Eumeralla Formation) are significantly deeper as a result of the downward displacement.

This review could not confirm the presence of the early Cretaceous Pretty Hill Formation, although this may be a result of an absence of deep boreholes. Further, the available information could not confirm the presence of the

Upper Cretaceous Sherwood Group of sediments, and the study area may be beyond the northern extent of this formation.

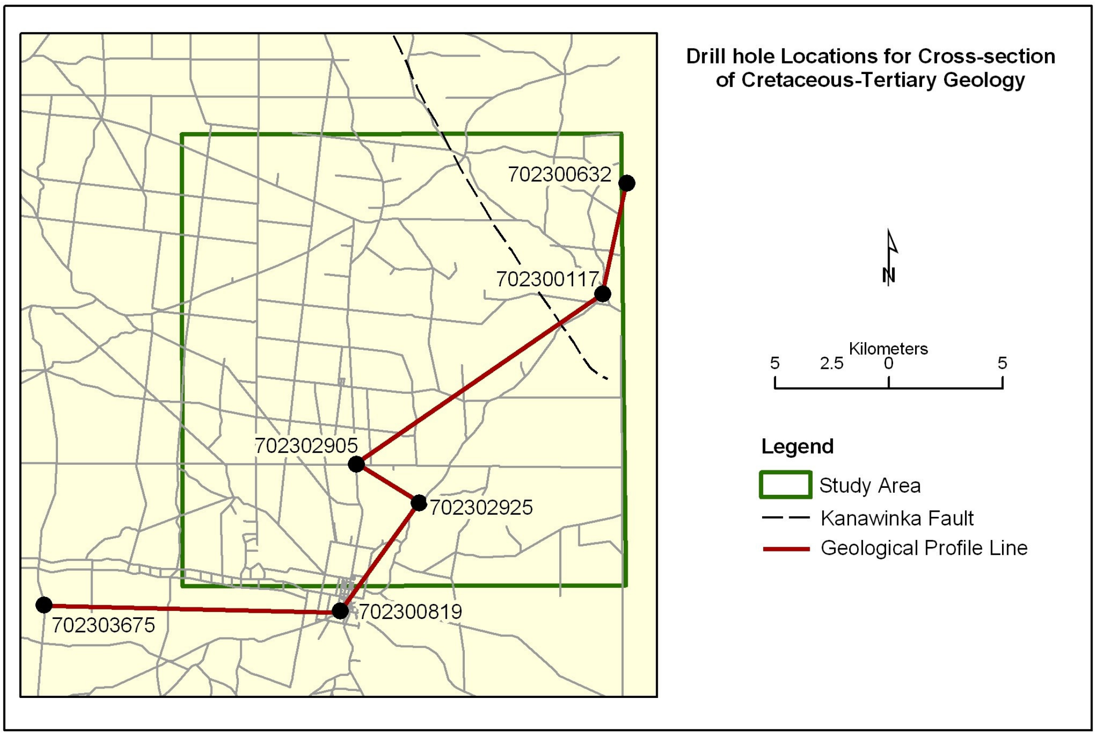
The difficulty in accurately defining these geological units, and their little relevance to the research, resulted in the collective classification as the Otway Group for the Cretaceous deposits within the study area. This classification has been used to develop the small scale geological profile shown in Figure 2.2.

2.4.3 Tertiary Geology

Overlying the Cretaceous Otway Group is the Late Paleocene-Middle Eocene Dilwyn Formation. The sand sediments of the Dilwyn Formation in the study area compromise ferruginous and partly pyritic, silty, fine to coarse-grained sandstone, with carbonaceous and micaceous mudstones and siltstone interbeds, glauconitic pellets and sparse shelly fossils (Drexel and Preiss 1995). This formation generally has an upper layer of brown, carbonaceous clay that has a low permeability (Cobb and Brown 2000).

This formation is regionally important as it contains a confined aquifer that has been generally accessed for industrial, municipal potable supplies and agricultural usage. This has particularly been the case in the west of the region where the aquifer is artesian.

To the west of the Kanawinka Fault, the Dilwyn Formation extends to more than 300 m below the surface, and is likely to be in the vicinity of 200 m thick. However, to the east of the Kanawinka Fault the thickness of the Dilwyn Formation is significantly reduced to less than 50 m in the two bores assessed. Harris (1964) suggested that much of the Eocene portion of the Dilwyn Formation was removed during the erosion periods of the movements of the Kanawinka Fault.



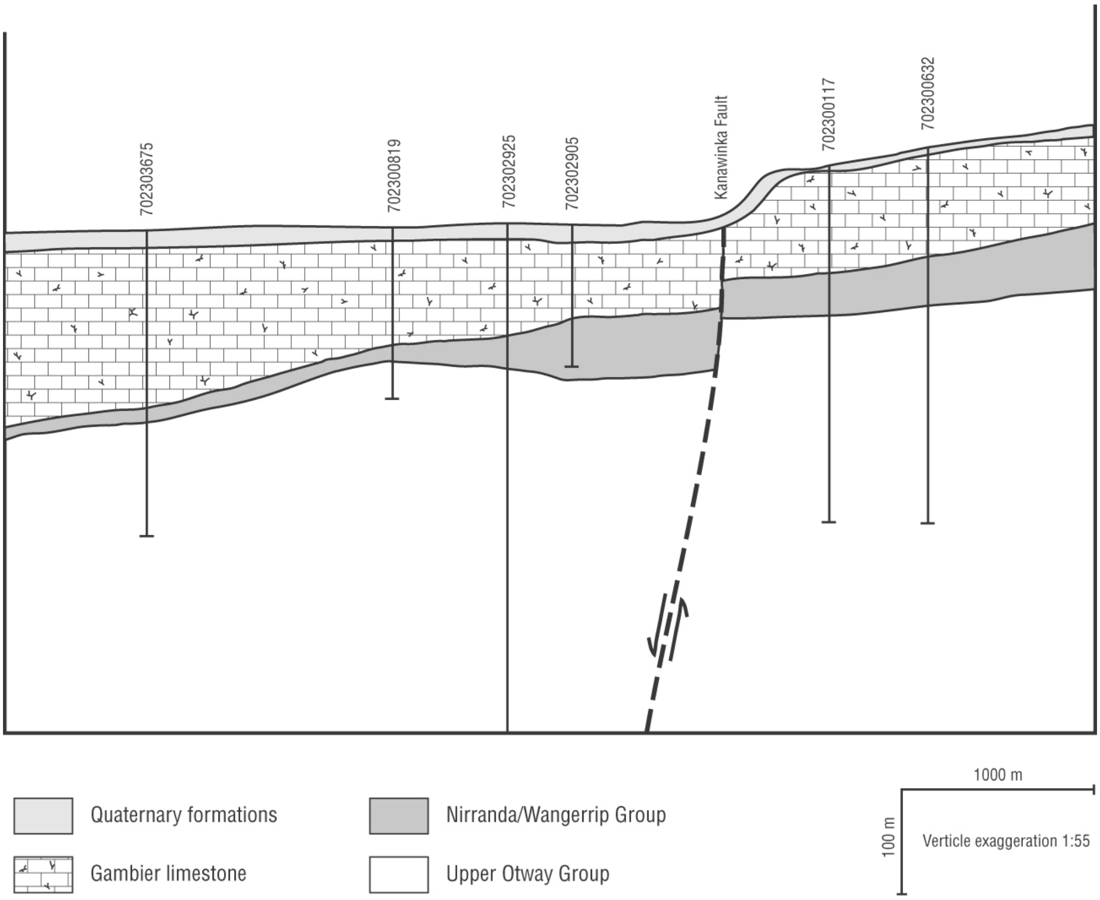


Figure 2.2: A cross-sectional presentation of the Cretaceous-Tertiary geology of study area

Given this reduced thickness of the Dilwyn Formation, and the potential displacement of the units at the Kanawinka Fault, it is possible that this lineament may have significant influence on the confined aquifer that exists throughout this unit. Although this was not of direct relevance to the study being undertaken, it is identified that groundwater exchange may occur between the confined and the unconfined aquifers in this area.

Both of the (Eocene) Nirranda Group units; the Narrawaturk Marl (glauconite marl) and the Mepunga Formation (ferruginous sand) have been reported in drill holes within the study area. However there is only one drill hole (702302905) where both units are reported; depths of 83-85 m for the Narrawaturk Marl, and 85-116 m for the Mepunga Formation. Most drill holes terminate in these formations as access to the confined aquifer (within the Dilwyn Formation) is generally prohibited as conditions of well-construction permits.

East of the Kanawinka Fault, the Nirranda Group units do not appear to be specifically identified. Harris (1964) reported the grey to light brown laminated carbonaceous clays of a similar Upper Eocene age as the Nirranda Group as Unit B of the Buccleuch Formation. Due to data gaps within the drill holes on the western side of the Kanawinka Fault for this corresponding sequence, the lithological equivalence between the Buccleuch and Nirranda Formation were not able to be confirmed. It is indicated however that the Dilwyn Formation is also confined in the study area east of the Kanawinka Fault.

The overlying Gambier Limestone unit is of increasing relevance as it contains the generally unconfined aquifer that was the subject of this research. This formation consists mainly of calcareous limestone deposits from the Late Oligocene to the Middle Miocene (~35 to 15 million years ago). The Gambier Limestone exists throughout the extent of the study area, and is only exposed in the uplifted section east of the Kanawinka Fault.

The classification of the Gambier Limestone includes a range of previously identified lithological units. Although three main units, Greenways Member, Camelback Member and the Green Point Member (the later not present in the study area), have been adopted (Drexel and Preiss 1995), it is expected that there is greater heterogeneity within the Gambier Limestone than this classification suggests. The recent work by Mustafa and Lawson (2002) has reported that there may be up to seven geological units within the Gambier Limestone within the lower South East, with these units having different hydrogeological properties.

The Gambier Limestone in the study area is dominated by bryozoal calcarenite deposits that range from poorly to strongly cemented grey limestone. Interbedded with these deposits are marl, sand, silt and occasional clay layers. It is suggested that the Gambier Limestone within the study area is generally of the Camelback Member. The similarity to the typical bryozoal calcarenite with rare chert (Drexel and Preiss 1995) is noted, as well as its association with the former Compton Conglomerate which has been recorded at the base of the Gambier Limestone within the study area.

The Gambier Limestone varies in thickness from less than 100 m to 150 m across the study area, with the thickness of the formation increasing to the north and west. This is reflective of the basement influence of the Penola-Robe trough and Kanawinka Fault. The Gambier Limestone retains a similar thickness (~100 m) on the eastern margin of the Kanawinka Fault, although this is possibly due to the proximity of the drill holes to the fault.

The depth to the top of the Gambier Limestone throughout the majority of the study area (west of the Kanawinka Fault) is around 20 m from the surface. The surface of the Gambier Limestone is reasonably level throughout the study area, with a slight sloping towards the west (see Figure 2.3). The uplifting of the Gambier Limestone to the east of the Kanawinka Fault is apparent, although it is suggested that the displacement effect of the fault is more abrupt than indicated in Figure 2.3.

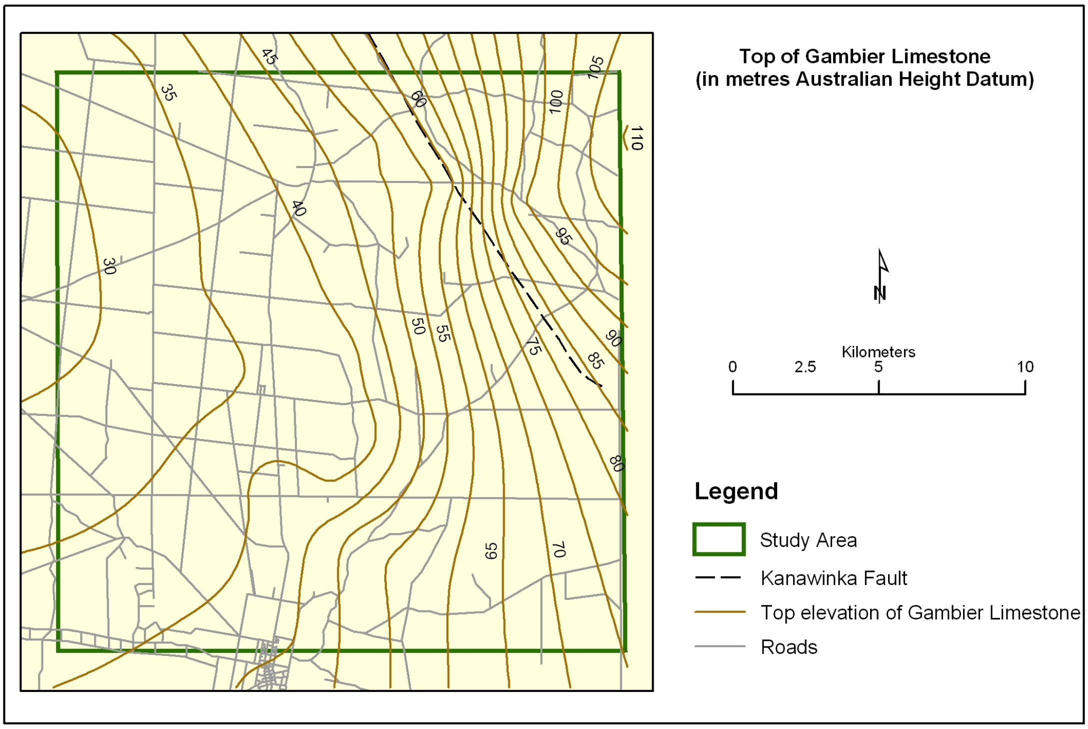


Figure 2.3: Top of the Gambier Limestone unit (mAHD)

2.4.4 Quaternary Geology

The Tertiary Gambier Limestone is overlaid by a variety of Pleistocene and Holocene units that have been deposited as a result of a series of coastal and marine sequences that occurred during the significant changes in climate and sea levels of those periods.

Directly overlaying the Gambier Limestone in the study area is the Early Pleistocene Coomandook Formation. This formation is extensive throughout much of the lower South East region, and consists of varying lithologies of marine sandy limestone, calcareous sandstone and shelly sandstone and clay (Drexel and Preiss 1995). The reworking of Gambier Limestone that is extensive through the Gambier Embayment is also reported in drill holes within the study area.

The later Bridgewater Formation consists of bioclastic barrier shoreline deposits and has surface expression through the series of sub-parallel dunal ridges throughout the region (Drexel and Preiss 1995). Although the two formations have different attributed facies; shallow marine sediments for the Coomandook Formation, and coastal aeolian for the Bridgewater Formation, it is difficult to differentiate these formations based upon existing information. Although it is suggested that both formations are present, no differentiation is attempted (the collective naming adopted by MacKenzie and Stadter (1981) is also used in this thesis). This collective naming approach is considered reasonable as both formations are expected to have similar hydraulic properties.

The Coomandook-Bridgewater Formation is present throughout the study area west of the Kanawinka Fault (it does not exist to the east of the fault), and ranges from 1.5 to 18.5 m thick (averages approximately 11 m).

At the base of the Coomandook-Bridgewater Formation exists a grey-black, plastic clay sediment that contains delicate shell fragments, molluscs, gastropods, and some subrounded quartz sands and gravels. This unnamed clay unit is restricted to the centre of the study area, similar to the depressed surface area identified in the top of the Gambier Limestone (Figure 2.3). It is possible that this unit represents a transitional deltaic period during the early Pleistocene. MacKenzie and Stadter (1981) suggested that this unit may confine the Gambier Limestone aquifer where it exists, and this view is supported. The unit is not specifically reported across the area of its occurrence, and therefore may not be continuous. This unit ranges to a maximum thickness of 3.5 m, and occurs at a depth of 16 to 20 m. The extent of this unnamed clay unit is provided in Figure 2.4.

Discontinuously overlaying the Coomandook-Bridgewater Formation (and the unnamed clay unit where it exists) is a limestone unit that has generally been classified as the Padthaway Formation. This formation is distinguished from the Bridgewater Formation as the sedimentation occurred within ephemeral lacustrine environments associated with the former shorelines (Drexel and Preiss 1995). Within the study area the Padthaway Formation consists of white to cream limestone with some quartz that is generally well cemented, with interbedded clay layers. The unit is generally within one metre of the

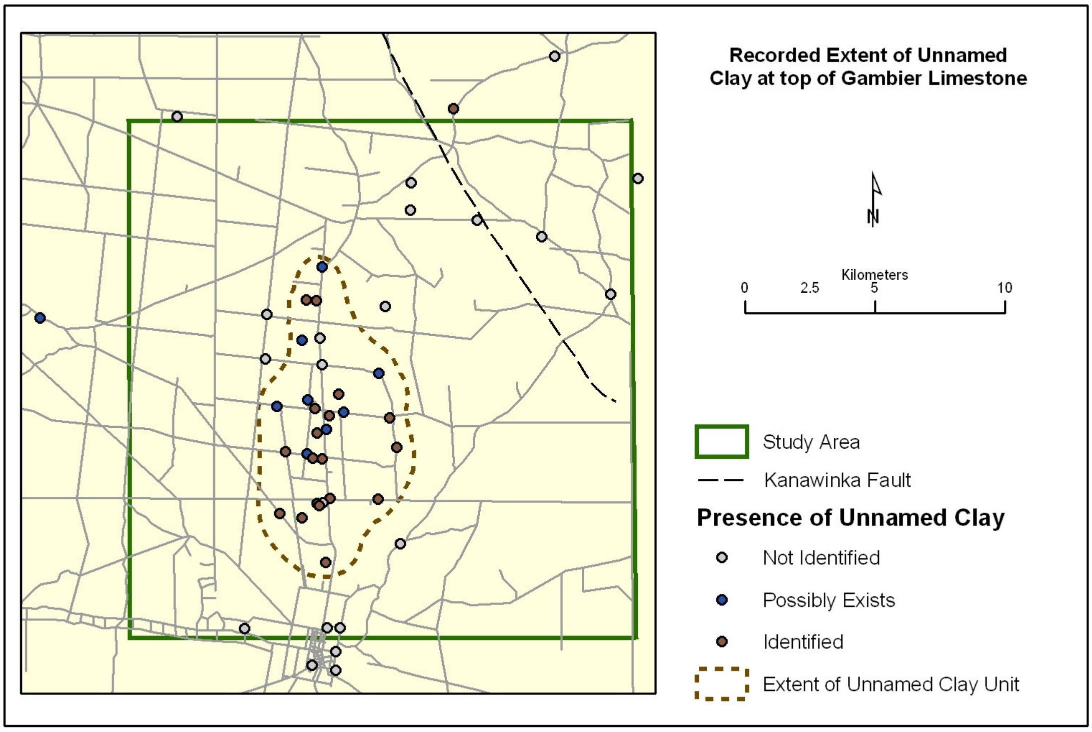


Figure 2.4: The recorded extent of the unnamed clay unit based upon reinterpretation of drillhole information

surface and approximately five metres thick. To the west and north of the study area, the Padthaway Formation is recorded to be up to 23.5 m thick.

On the eastern upthrow of the Kanawinka Fault, the quartzite Parilla Sand formation overlays the Gambier Limestone. This is probably the result of the different depositional (and erosion) environments that occurred east of the exposed Kanawinka Escarpment. In addition, Molineaux Sand deposits are also reported at the surface through mapping. These non-marine aeolinate quartz sand deposits are of the late Pleistocene – Early Holocene.

A summary of the surface and Quaternary geology of the study area is shown in Figure 2.5.

2.4.5 Soils of the Study Area

The soils of the region and the study area have been described within a number of reference text, such as Blackburn (1959, 1964) and

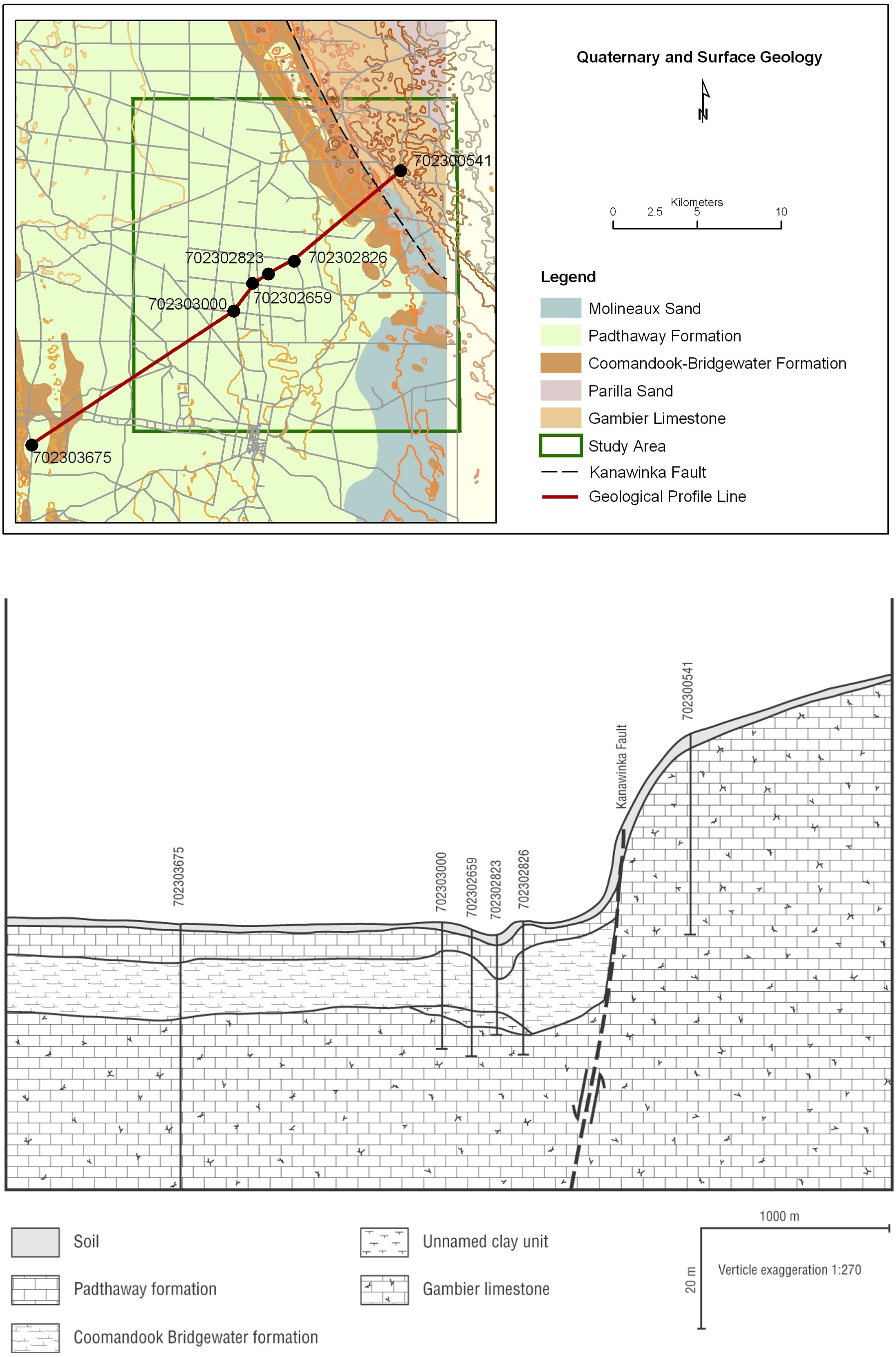


Figure 2.5: A cross-sectional presentation of the Quaternary geology of study area

De Silva (1994), and have been incorporated into digital landscape data resources (DWLBC 2004).

It is not unexpected that the soil characteristics vary considerably across the study area, and reflect the differing depositional and erosion environments experienced. It is therefore with caution that the dominant soils are presented for the study area in Figure 2.6.

Figure 2.6 illustrates that although there is variability in the dominant soil types, there is a clear graduation from the deep aeolian sands and sandy clays in the eastern part of the study area, associated with the Parilla and Molineaux Sand deposits, grading to the red-brown clays and loams overlaying limestone in the centre of the study area, and the dark heavier clays and loams in the west of the study area. This is shown in greater clarity in Figure 2.7 that shows dominant soil textures for the study area.

Scattered throughout the study area, particularly in the areas east and north west of the Coonawarra township area, the soils (and topography) can be locally dominated by lunette deposits of calcareous sands and clay. The origin of these soils are primarily from marine, deltaic and aeolian processes.

The depth of soil within the study area varies considerably, with many areas within the centre of the study area having a soil depth of less than one metre (Figure 2.8). The depth of soil is likely to influence both recharge and leaching of nitrogen into underlying groundwater systems. Accurate data on the depth of soil across the study area does not exist, however the reviewed bore logs suggest that soil depth throughout most of the study area is very shallow (less than one metre), with depths increasing towards the north east (approximately two metres), and increasing further east of the Kanawinka Escarpment. The soil and sand deposits across this escarpment are substantial and exceed 10 metres in thickness (Kneeling 1983a, 1983b).

Examples of available profiles of soil within the study area are presented in Figures 2.8 and 2.9 and illustrate the shallow soil depth.

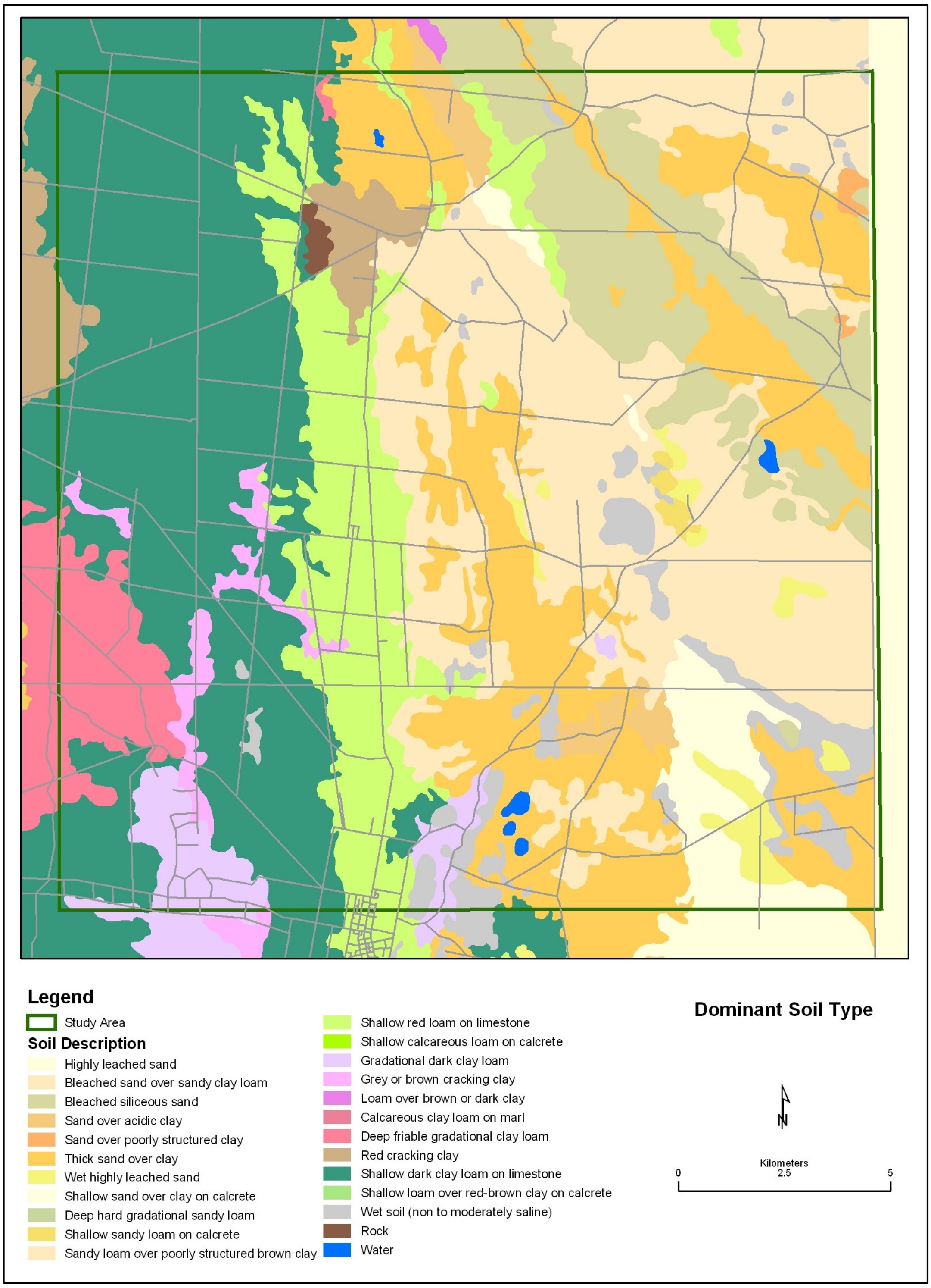


Figure 2.6: The dominant soils types within study area

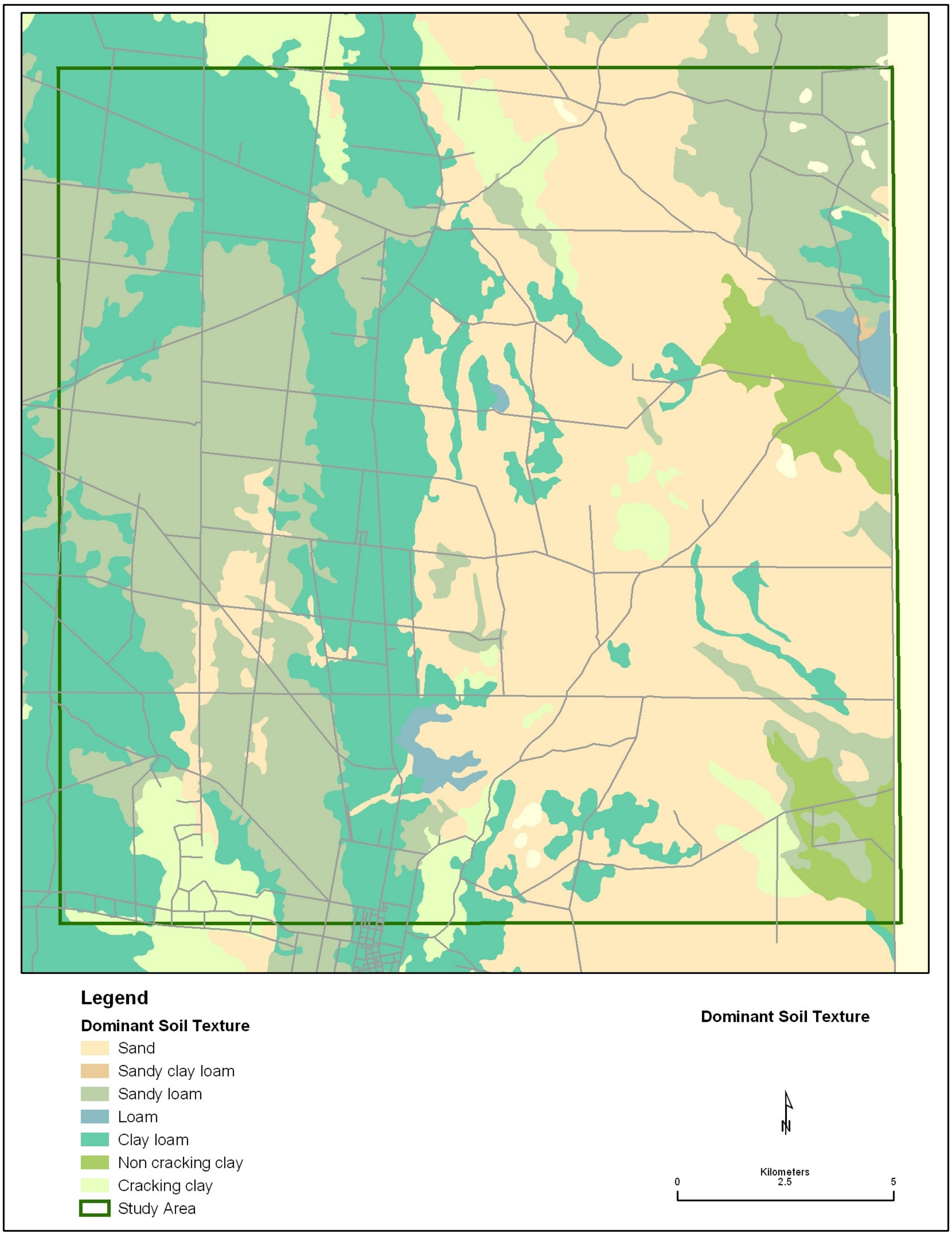


Figure 2.7: The dominant soil textures within study area

Figure 2.8: An example of the depth of soil within the study area (Coonawarra township)

Figure 2.9: An example of the depth of soil within the study area (western part of study area)

2.5. RESULTS - HYDROGEOLOGY

2.5.1 Confined Aquifer

The confined aquifer exists within the interbedded sands of the Dilwyn Formation. The top of the confined aquifer is at least 130 m below the surface throughout the study area west of the Kanawinka Escarpment, and possibly within 110 m east of the escarpment. Regional groundwater flow for the confined aquifer is generally towards the western and southern coasts, with the major recharge source of the water being the elevated areas in the Dundas Plateau in western Victoria (Cobb and Brown 2000).

Although there is no previous evidence that the confined aquifer has substantial interactions with the unconfined aquifer within the study area, there is the possibility that there is exchange between the confined and unconfined aquifers in the vicinity of the Kanawinka Fault.

The water level of the unconfined aquifer is higher (in elevation) than the potentiometric level of the confined aquifer, suggesting that any exchange between these aquifers will be dominated by percolation of water from the unconfined aquifer to the confined. Approximately 20 kilometres south of the study area, a dramatic thinning of the overlying clay aquitard has resulted in localised recharge of the confined aquifer and an associated water level depression in the unconfined aquifer (Brown et al. 2006). The absence of substantial water table depressions within the study area suggest that any downward percolation of groundwater to the confined aquifer is likely to be minimal.

Although the confined aquifer is regionally significant, it was not further investigated in this project.

2.5.2 Unconfined Aquifer

Within the study area, the unconfined aquifer is shallow and exists within the Gambier Limestone and the overlaying Coomandook-Bridgewater Formation.

The average depth to the top of the unconfined aquifer derived from 44 bores with data across the 2000-2004 period illustrates that it decreases from east to west within the study area (Figure 2.10). Across the study area the thickness of the unconfined aquifer may be up to 100 metres.

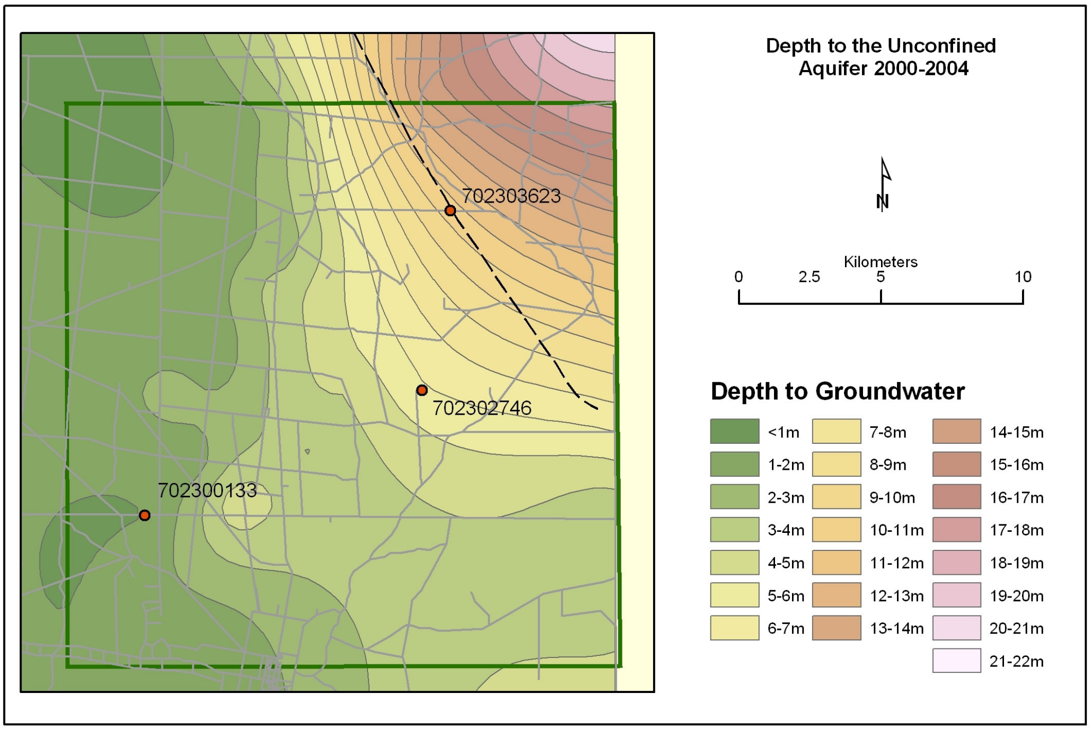


Figure 2.10: The shallow depth to groundwater of the unconfined aquifer as modelled from groundwater measurements from 44 wells between 2000 and 2004

The phreatic surface of the unconfined aquifer is flat within the western side of the study area, and rises towards the north east. The significant rise in elevation beyond the Kanawinka Escarpment is not reflected in a dramatic increase in the water table (Figure 2.11). This suggests that the Kanawinka Fault complex may not significantly retard unconfined groundwater flow in the same way as is reported for the Tartwaup Fault (Brown, et al. 2006).

Groundwater flow is towards the west of the study area (Figure 2.11), and is dominated by localised recharge from vertical percolation of rainfall.

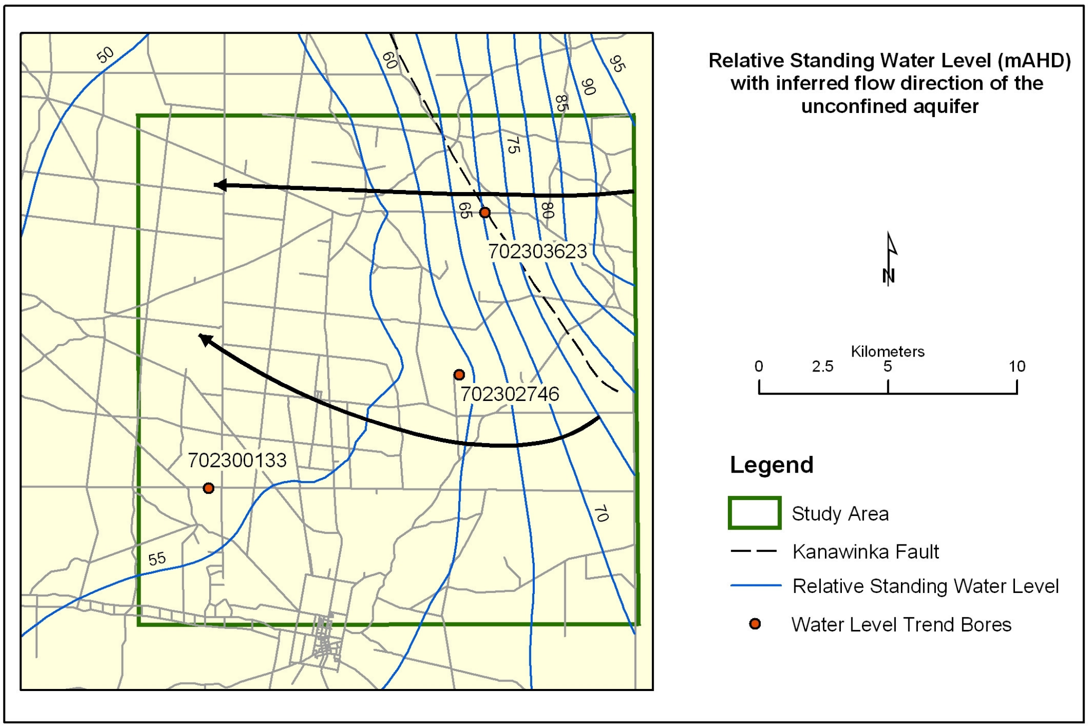


Figure 2.11: Water level elevation of the unconfined aquifer and inferred groundwater flow directions

The seasonal groundwater fluctuations reflected across the study area demonstrate an intra-annual response time (and magnitude ~0.2-2 m) of groundwater level changes that reduce with increased depth to the unconfined aquifer (Figure 2.12). The locations of the bores in Figure 2.12 are indicated on Figures 2.10 and 2.11, with the complex local topography, particularly east of the Kanawinka Fault, being responsible for the apparent difference in depth to groundwater between the modelled (Figures 2.10 and 2.11) and actual depths to water presented (Figure 2.12).

There is some evidence of karstification of the Gambier Limestone in the study area (G. MacKenzie, DWLBC, pers. comm. 2005), and this may be more common in the vicinity of the Kanawinka Fault. The development of large karstic features have previously been reported within the region in association with structural features. The presence of the Naracoorte Caves environments north of the study area (collocated with the Kanawinka Fault)

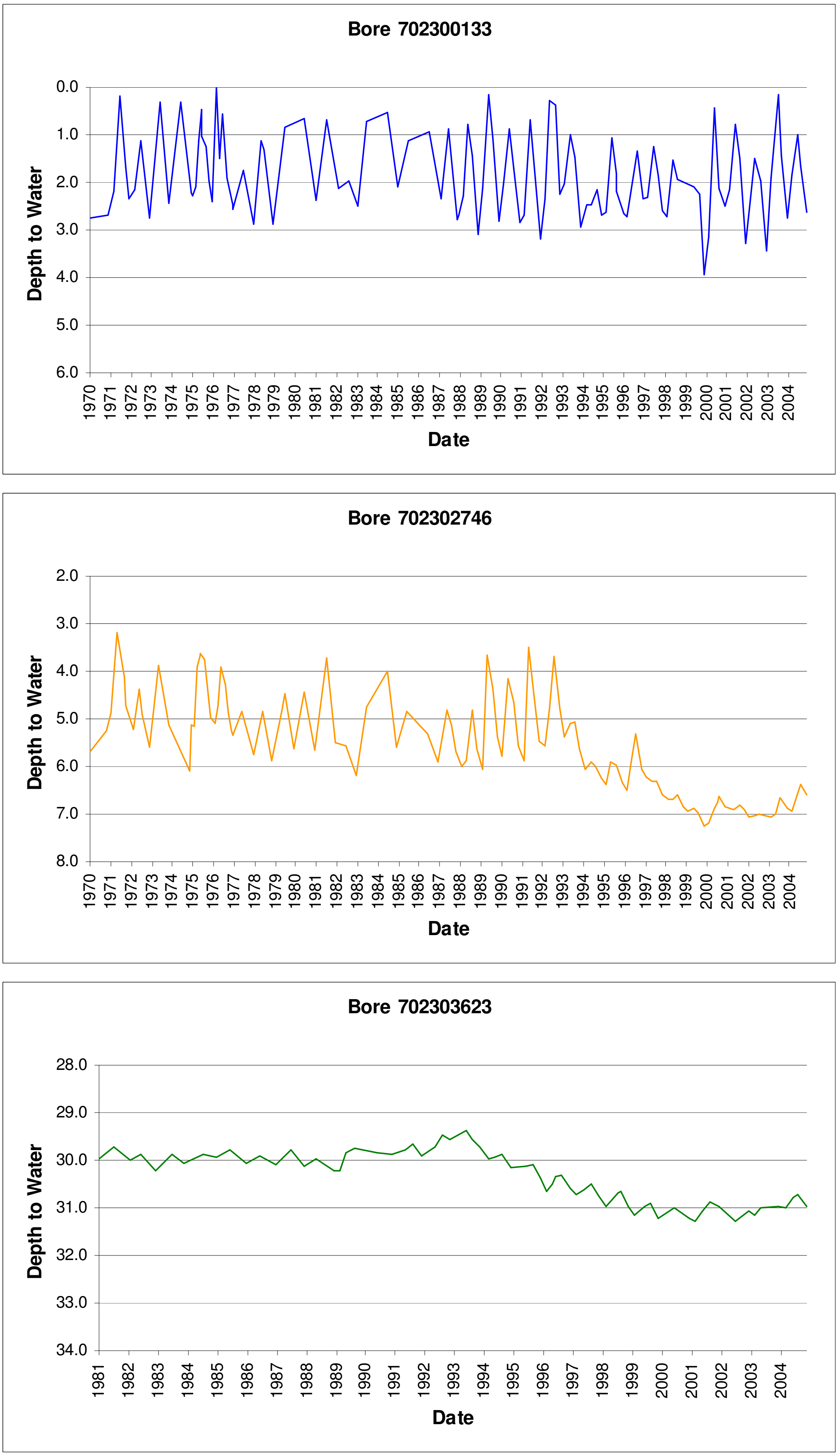


Figure 2.12: Depth and seasonal responses in the unconfined aquifer in selected bores

supports this view. Solution features within the calcareous sediments are reported by MacKenzie and Stadter (1981).

MacKenzie and Stadter (1981) suggested that the unnamed clay unit confined the Gambier Limestone where it existed within the study area. It is difficult to confirm this based upon the available information, although the Gambier Limestone aquifer is locally confined in other parts of the South East region. A number of drilling records (where the unnamed clay layer exists) report that the final water level in the constructed bores were above the original water cut. In some cases the final water level was two metres above the depth of water intersection (such as 702301637). This recovery of the water level could be explained by the Gambier Limestone aquifer being confined within these areas.

There have been a variety of regional studies undertaken to assess the geological structure of the unconfined aquifer, and these have identified a greater level of geological complexity than previously considered. Although production from wells can be up to 150 L/s, the hydraulic properties of the various unconfined units within the study area are not known (MacKenzie and Stadter 1981).

Bradley et al. (1995) undertook a major hydrological review that included the study area and reported transmissivity values of the Tertiary Gambier Limestone from four wells in or near the study area ranging from 464 to at least 2650 m^2/day. This same research estimated that recharge within the study area ranged from 20 mm/yr in the elevated north eastern corner of the study area to 100 mm/yr in the plains on the western side of the study area.

2.5.3 Hydrostratigraphy

Based upon the review of existing geological records for the study area, and reference material from Drexel and Preiss (1995), Mustafa and Lawson (2002), and Walker et al. (2001), a summary of the hydrostratigraphy for the study area is presented in Figure 2.13.

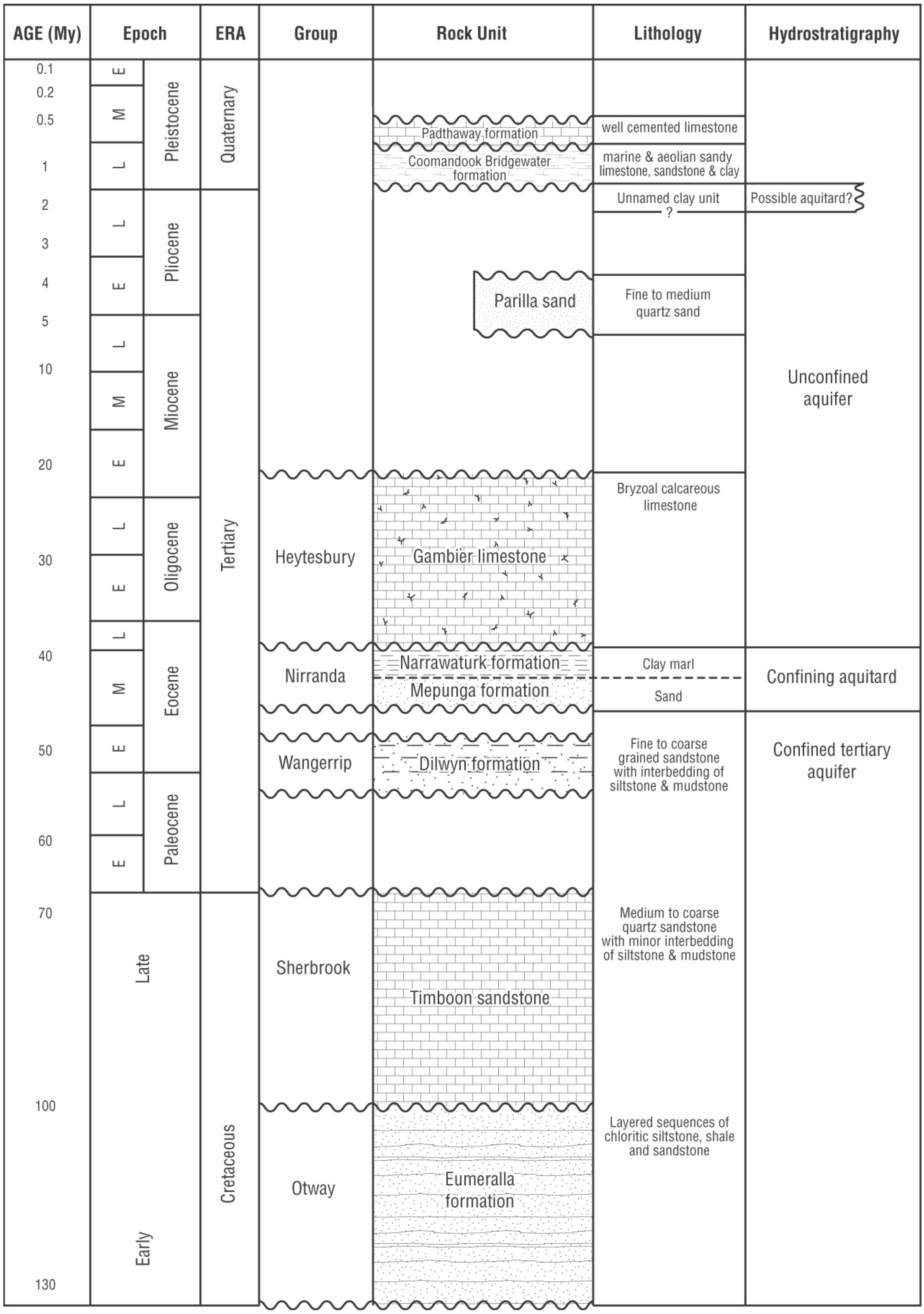


Figure 2.13: The presented hydrostratigraphy of the study area

2.6. DISCUSSION

The geological environment of the study area is dominated by the sedimentary and aeolian deposits that have continued until the late Pleistocene – Early Holocene period. The study area is now characterised by a relatively flat topography, with shallow soils overlaying a (generally) unconfined permeable limestone aquifer that is likely to display dual porosity (water flow between porespaces as well as macrofeatures). The shallow nature of the groundwater and the responsiveness of the hydrographs shown in this chapter indicate that vertical recharge occurs quickly in some parts of the study area.

These environmental factors indicate that the unconfined aquifer is likely to rate high in groundwater pollution vulnerability assessments (Aller et al. 1987, Doerfliger and Zwahlen 1998, Ceplecha et al. 2004, Greene et al. 2005). However this can be suggested for many areas in the South East region that do not display the elevated nitrate concentrations observed through the study area. Therefore other unexplained geological conditions, or landuse impacts are responsible for the nitrate contamination of the unconfined aquifer.

Geological sources of nitrate contamination have been reported in South Africa, Australia and the USA (Tredoux 1993). Nitrate can be present in high concentrations in geological strata and may occur through evaporative processes (such as arid environment salt pans), through volcanic processes or as a result of accumulation of nitrate from natural ecosystem processes such as accumulation in termite mines (Alderman 1973, Marrett et al. 1990, Bolger and Stevens 1999, Harrington 1999). The study area was not subjected to these environments, and therefore geological sources are not expected. Waterhouse (1977) observed that nitrogen is not a major constituent of the Gambier Limestone and concluded that nitrogen in groundwater was not from geological sources.

The subsurface interbedded clay layers observed in the upper parts of the unconfined aquifer may control vertical mixing in some areas. However the widely spaced groundwater contours, the large reported groundwater yields and the high transmissivity values suggest that horizontal flow is relatively high across the study area. This means that landuse mapping to apportion sources needs to be undertaken with care. In addition, it can also mean that point source contamination may spread differently than an unconfined aquifer with uniform hydraulic conductivity over its thickness.

Although there are a variety of soils within the study area (e.g. deep leached sands, terra rossa clays, cracking clays), these soils are found in a variety of other locations in the region and are not unique to the study area (Blackburn 1959, 1964). The research by Mee et al. (2004) indicated that the terra rossa soil in the study area originated from aeolian processes and not from bedrock weathering processes as can result in other terra rossa soils. However the arguments presented by Mee et al. (2004) are applicable to the South East region and therefore this does not present a unique geological condition for the study area.

2.7. CONCLUSION

The geological and hydrological setting for the study area has been presented to provide context for the later conclusions relating to the sources of nitrate into the unconfined aquifer. Importantly, there has been no evidence that geological sources of nitrate occur within the study area that could be contributing to the observed nitrate concentrations.

The hydrogeology of the area results in the unconfined groundwater system being vulnerable to nitrate contamination, however when compared to the remainder of the South East region, this situation is not unique to the study area.

The review of the geology, hydrogeology and soil environments of the study area does not identify any unique environmental factor that could be responsible for the elevated nitrate concentrations in the groundwater within the study area.