SOIL SERIES MAPPING

OF THE

LISMORE REGION

VICTORIAN
VOLCANIC PLAINS

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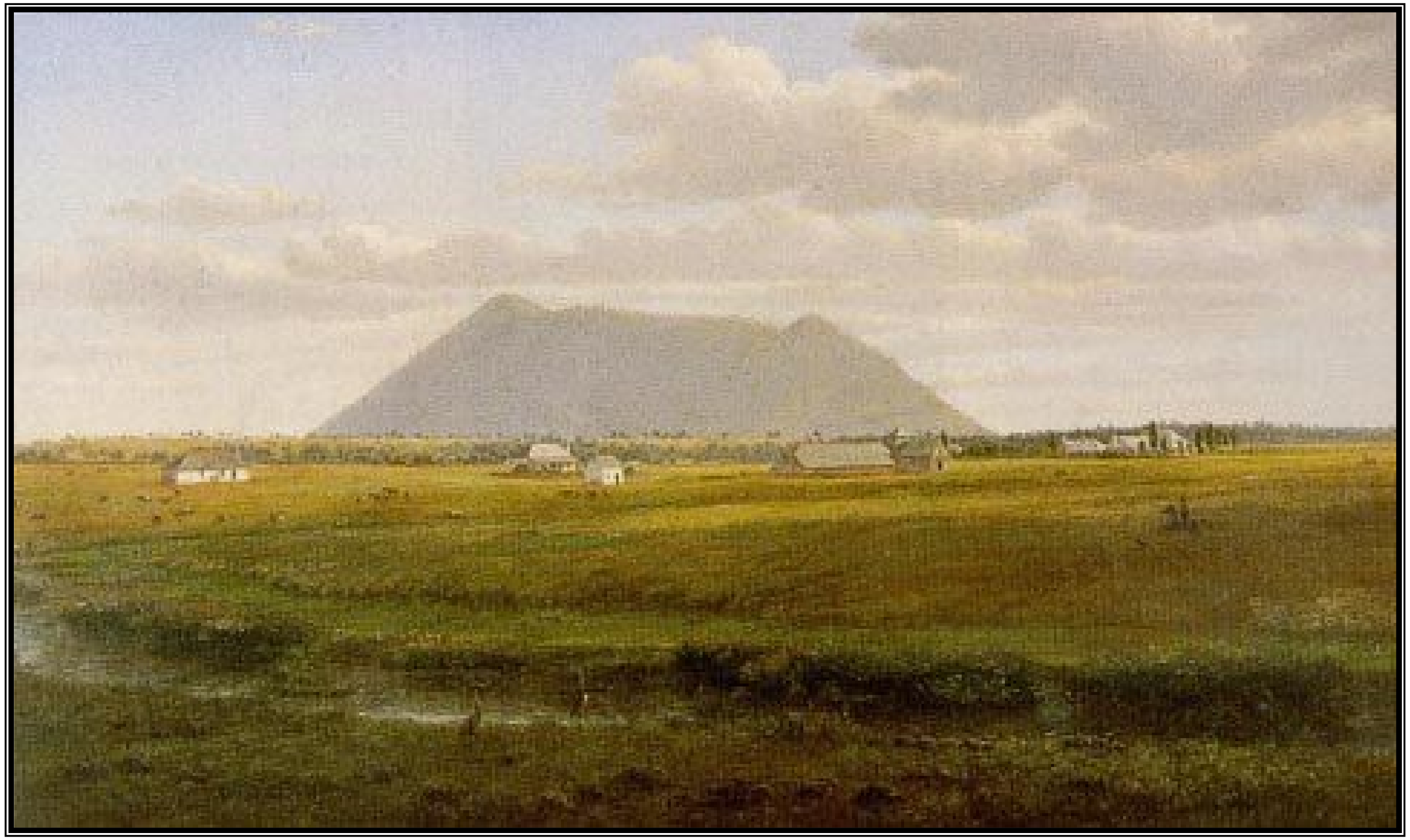

'Larra Homestead, Mt Elephant in distance' Eugene Von Guerard 1857

Abstract

A Soil Series Map of the Lismore Study Area, situated on the Victorian Volcanic Plains of western Victoria, was created through a series of intact soil core extractions, soil chemical and physical testing and profile descriptions. Six soil types were recognised and described in the Lismore Study Area, their spatial distribution mapped, and their suitability to certain agricultural practices discussed. Compaction and waterlogging are the main soil structural limitations to agricultural land use.

Granite outcrops have weathered into the **Granitic Sandy Loams** and are capped in small areas by the **Buckshot Clays**. The Buckshot Clays are recognised as sporadic erosional remnants of marine sediments which are too small and isolated to be included on larger scale maps. Two soil series have been delineated on the volcanic soils. The earlier **Nowra Red Clays** have been exposed in creek lines and patches across the plains. **Lismore Grey Clays** have formed on the intermediate age (3.6 Ma) basalt flows and make up the largest soil type across the Lismore Study Area. **Mundy Gully Black Clays** and **Lunette Clays** are depositional soils and have formed more recently, mainly through wash-off and aeolian sediments, both largely derived from the basalts.

This study fulfils objectives of the Corangamite Soil Health Strategy and provides the Department of Primary Industries and the Corangamite Catchment Management Authority with more accurate soil management advice for landholders, the Lismore Land Protection Group and local farmers.

Key words: soil, soil mapping, Victorian Volcanic Plains, Lismore

Declaration

I hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma in any tertiary institution, and that, to the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Shari L. McConachy

23rd July 2009

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List of Abbreviations

CMA	Catchment Management Authority
DPI	Department of Primary Industries
DSE	Department of Sustainability and Environment
EC	Electrical Conductivity
EVC	Ecological Vegetation Class
LRA	Land Resource Assessment
SHS	Soil Health Strategy
VVP	Victorian Volcanic Plains

1.0 Introduction

The Lismore area is currently experiencing a rapid change in land use between agricultural industries. A shift in farming enterprise from grazing to intensive cropping has placed increased pressure on soil health and led to the requirement of improved management techniques for sustainable farming. This study will assist in identifying areas best suited to particular agricultural practices and how best to manage the land for its long term sustainability.

The creation of a Soil Series Map for the Lismore Study Area based on specific soil chemical and physical characteristics will aid in assessing the agricultural suitability of each soil type, as well as indicating options for better agricultural management practices. The resulting Lismore Soil Series Map (Appendix G Back pocket) will be of use to local farmers and the Lismore Land Protection Group. It will also assist the Department of Primary Industries (DPI) in providing the most appropriate advice on management options of each soil type. This supports the objectives set out in the Corangamite Soil Health Strategy which was completed in 2007 (Clarkson).

1.1 Aim and Objectives

The aim of this research project was the creation of a Soil Series Map for the Lismore Study Area that describes the soil characteristics and the agricultural constraints of each soil unit. To achieve this aim a number of objectives were set including:

- Extract a number of intact soil cores from sites across the Lismore Study Area that represent the geology and landscape variations
- Analyse each soil profile to describe texture, colour, coarse fragments, segregations, mottles, structure, consistence, electrical conductivity and pH
- Delineate soil boundaries using aerial photographs, field observations, terrain and geology
- Sample additional sites as required to better define the boundary between soil types
- Describe each soil agronomically

1.2 Scope of work

This project contributes towards a Bachelor of Applied Science Honours (Geology) program through the University of Ballarat. The Honours program comprises two graduate subjects, a literature review and a major thesis. The program was completed part-time over two and a half years. The research involved field work and laboratory work as described in this thesis.

1.3 Lismore Study Area

The selected Lismore Study Area lies on the Victorian Volcanic Plains (VVP), a broad basalt plain covering approximately 15 000 km^2 of south-west Victoria (Figure 1a). The research area is centred near the township of Lismore, population 513, on the Hamilton Highway approximately 1 hour's drive from each of Geelong, Ballarat, Colac and Warrnambool (Figure 1b). The selected Lismore Study Area covers around 220 km^2 within a square area approximately 15 by 15 kilometres, to be referred to as the Lismore Study Area (Figure 2). The Lismore Study Area is contained within the boundaries of the Lismore South 1:25, 000 topographic map (DSM 1990) which includes Lismore township.

1.3.1 Physiography

The landscape of the Lismore Study Area is generally a low undulating volcanic plain, although more deeply dissected in the drainage lines. Gently rising low hills occur in the northern region where a granite pluton has been more resistant to erosion. Elevations across the Lismore Study Area range from 130 m to 220 m above sea level with the highest elevation of 228 m being an unnamed rise on the granites in the north of the area. The lowest elevation of 130 m occurs in the south along an unnamed drainage line.

The Lismore Study Area is located in the Southeast Coast Drainage Division, Lake Corangamite Basin which covers an area of approximately 13 340 km^2 (BOM 2009b). A broadly spaced drainage pattern has developed across the region with creeks flowing south (Figure 2). These creeks have cut broad valleys ranging from 200 m to 500 m wide and 10 m deep across the Lismore Study Area. Prominent creeks in the Lismore Study Area are Browns Waterholes and Mundy Gully which converge south of Lismore township before flowing into Lake Gnarpurt. Browns Waterholes drains a basin of around 84 km^2 via a network of creeks stretching almost 35 km through the Lismore Study Area. Mundy Gully has a catchment of 85 km^2 with around 27 km of creek line. Before drainage lines were well established the area supported several small swamps and lakes which although now dry are easily recognised by the wind-formed lunettes along their eastern edges.

1.3.2 Climate

Lismore weather data has been recorded at the Post Office since 1919 to the present. Over this period the annual median rainfall has been 620 mm. Although a few gaps exist in the data the record shows greatly fluctuating rainfall totals with the wettest year measuring 903 mm (1964) and the driest 347 mm (1967) (Figure 3).

Climate in the area is described as warm to hot summers and cool winters. Daily average winter temperatures range between 5℃ to 15℃. Most rainfall is received over August, September and October with an average total of 120 mm received over these months. Summer daily average temperatures are relatively warm, ranging between 14℃ and 25℃. Summer rain is not uncommon and is generally not heavy (Figure 4). However summer thunder storms have resulted in the highest recorded daily rainfall event on 8th February 2002 when 122.6 mm fell over a 24 hour period. The wettest month was December 1966 when 175 mm was recorded (BOM 2009a).

However during the last decade (1998 to 2007) the Corangamite Catchment Management Authority (CMA) region experienced average annual temperatures 0.3℃ warmer than the 30 year average (1961 to 1990). The same decade measured a 12% decrease in the region's average rainfall. These trends are predicted to continue with the region expected to receive a 4% reduction in average annual rainfall, the greatest reduction of 7% will be over spring (DSE 2008). The past decade's drier climatic conditions have been conducive to cropping in the Lismore Study Area over, however sufficient spring rainfalls are still required to successfully finish a cropping season.

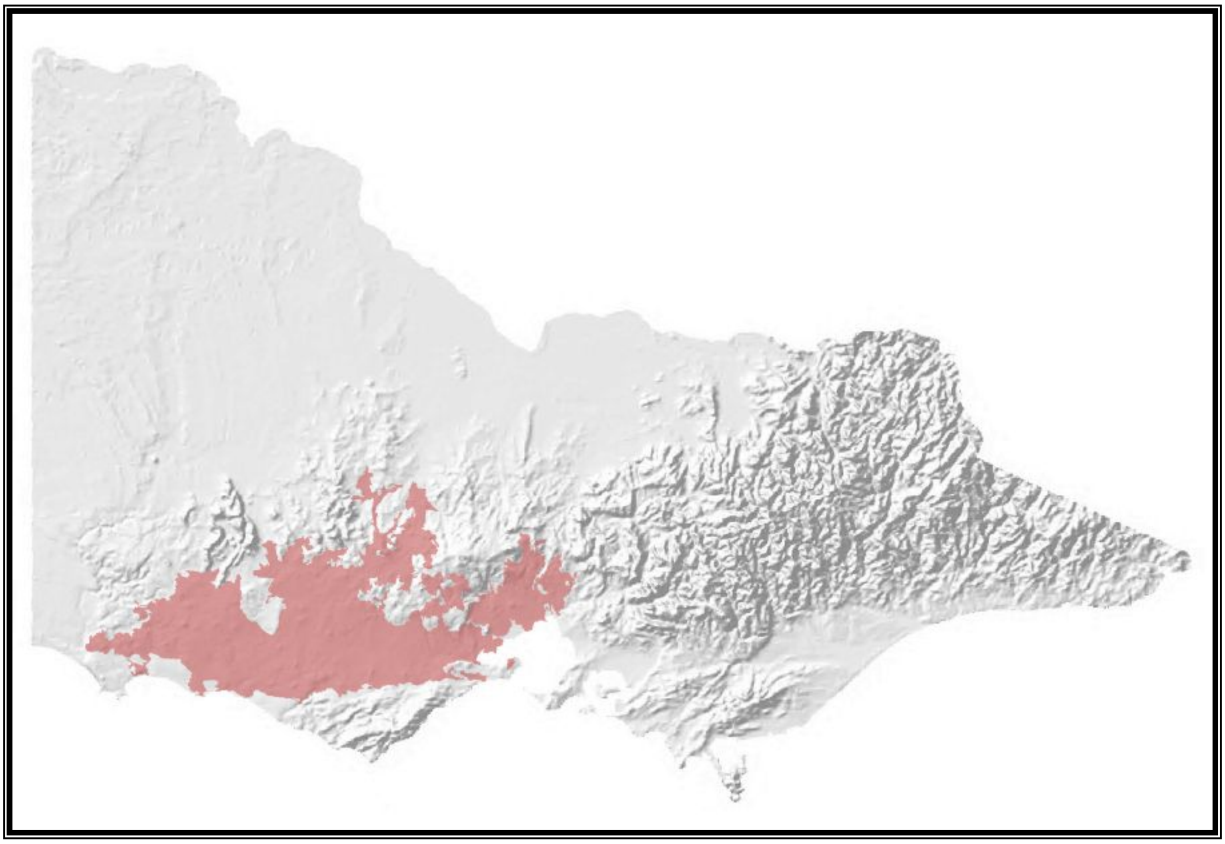

Figure 1a State map showing the extent of the VVP across south-west Victoria (Data source DSE 2004a, scale 1:100, 000).

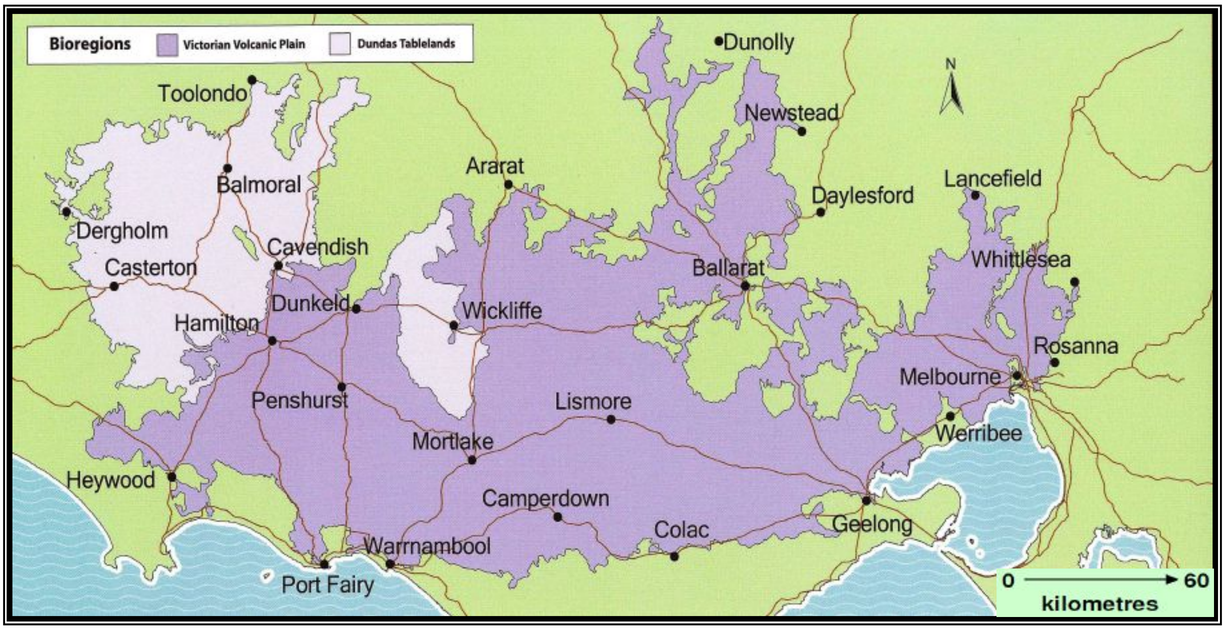

Figure 1b Major regional centres across the VVP in south-west Victoria (CMA 2008a).

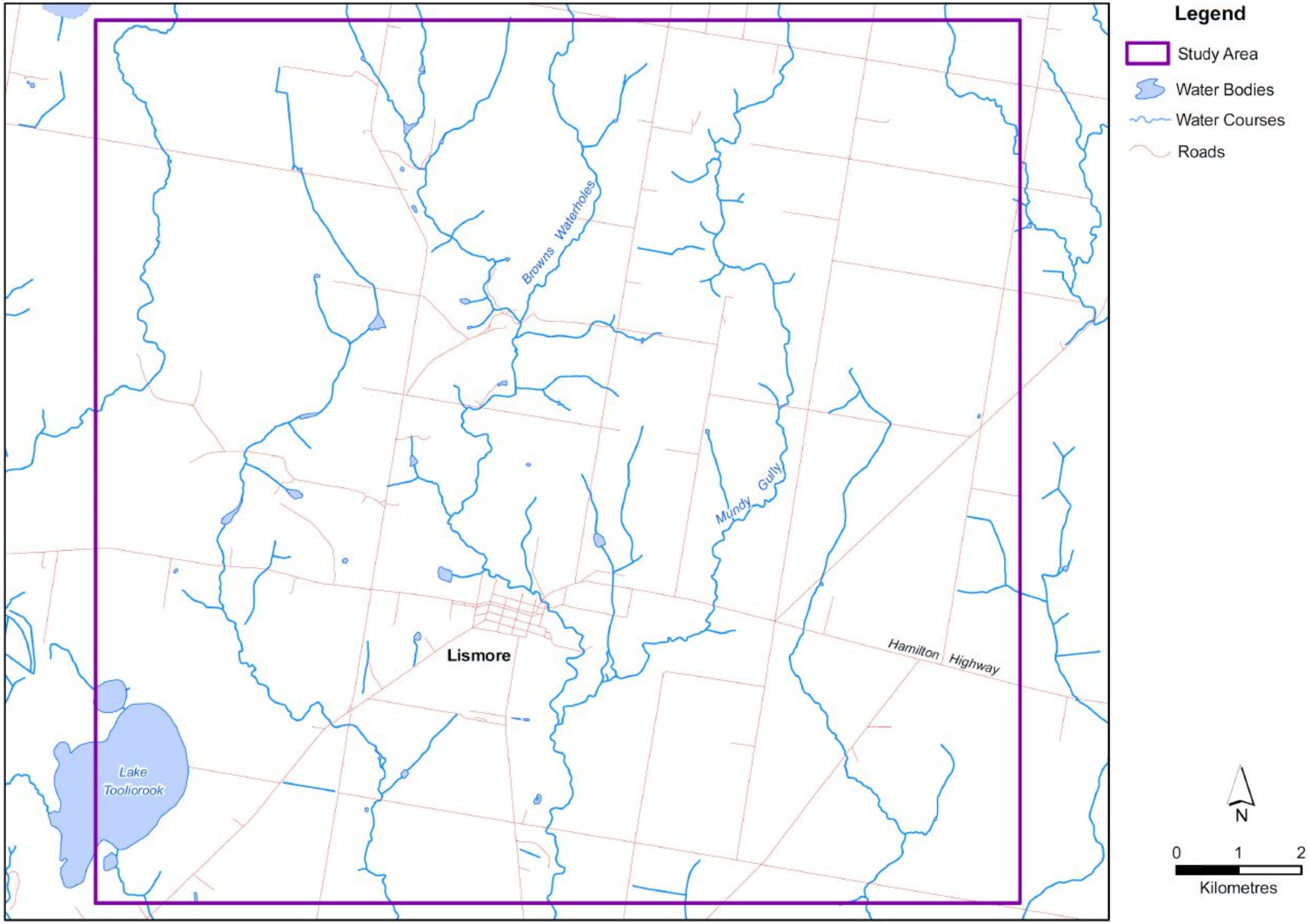

Figure 2 A broadly spaced drainage pattern has developed across the Lismore Study Area with creeks flowing south (Data source DPI/DSE Corporate Library undated, scale 1:25 000).

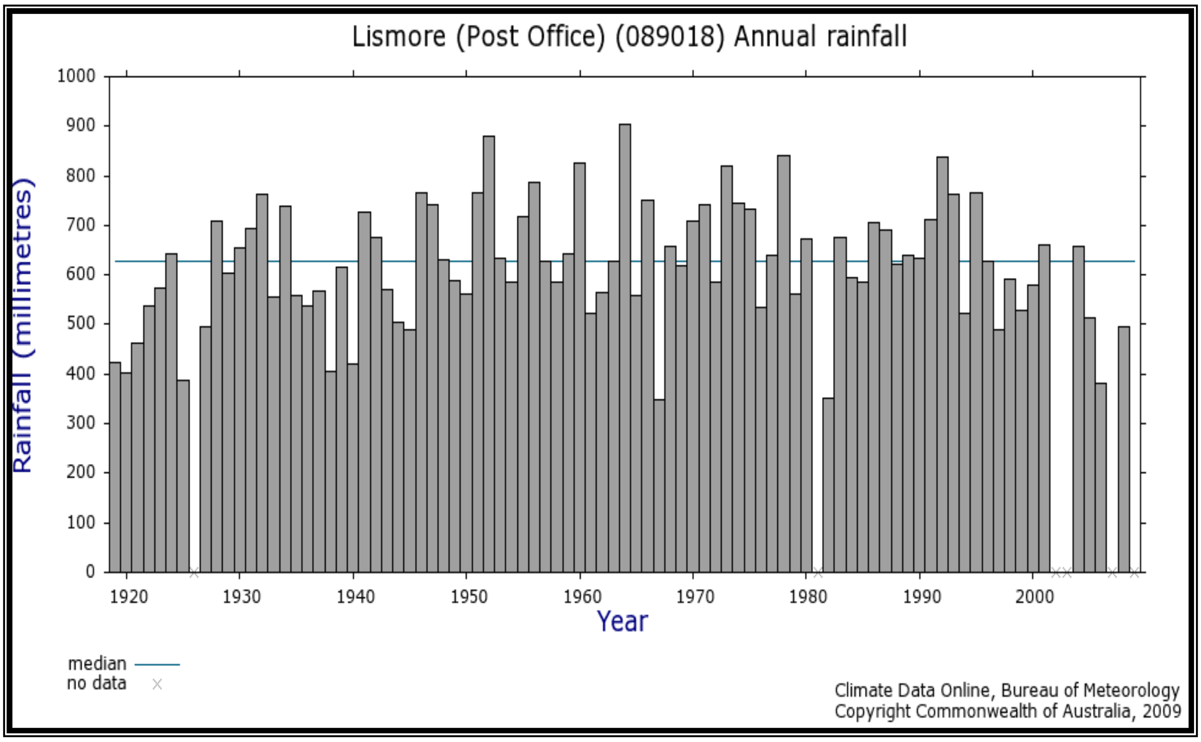

Figure 3 Annual rainfall data for Lismore, Victoria recorded from 1919 to 2008 at the Lismore Post Office (BOM 2009a).

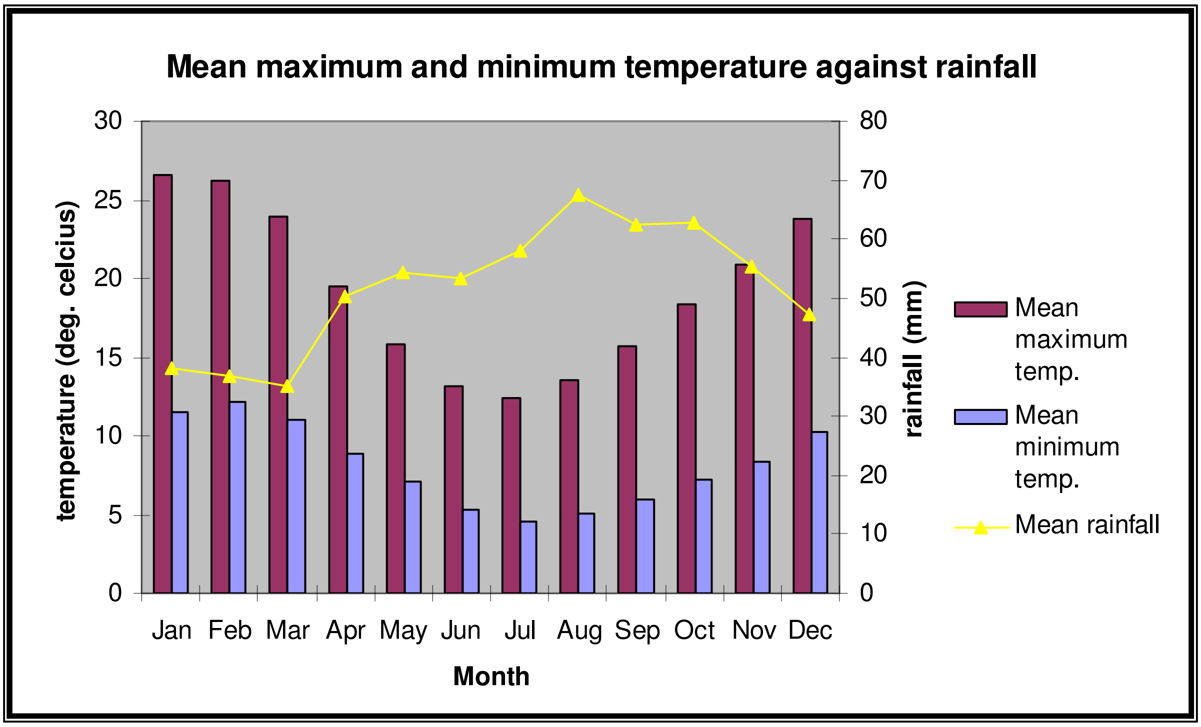

Figure 4 Temperature and rainfall chart for Lismore, Victoria (Data source BOM 2009a).

1.3.3 Flora and fauna

Native grasslands once covered large tracts of the VVP making up many thousands of square kilometres. These grasslands were dominated by a ground layer of tussock-forming perennial grasses mixed with various wild flowers. Very few shrubs and trees were present, if any (DEWHA 1999). The dominant grasses are Kangaroo Grass (*Themeda triandra*), Wallaby Grass (*Austrodanthonia spp.*), Spear Grass (*Austrostipa spp.*) and Common Tussock Grasses (*Poa labillardierei*). Found among the tussocks are herbs and wildflowers such as daisies, lilies, peas and orchids (Vranjic 2008). In June 2008 the Natural Temperate Grasslands of the VVP were listed as a critically endangered ecological community under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (Vranjic 2008). The grasslands support a wide variety of reptiles, birds of prey and ground-dwelling birds. The lakes and wetlands support huge numbers of waterbirds and waders. Eastern Grey kangaroos are one of the few mammal species found on the plains. Over twenty threatened plant species and a variety of nationally threatened animals are supported by these grasslands (Vranjic 2008).

Over 95% of the native grasslands have been destroyed since European settlement. What does remain is highly fragmented and found primarily along road and rail reserves and in cemeteries. Over 75% of shallow freshwater wetlands have been lost or modified through drainage (DEWHA 1999). Riparian vegetation has also been drastically reduced with agricultural activity impacting on the soil and ecological communities right up to the edge of both Mundy Gully and Browns Waterholes. Agricultural practices such as cropping, grazing by sheep and cattle, European pasture establishment, wetland drainage and the use of fertilizers and chemicals, have all contributed to the dramatic decline in this fragile grassland ecosystem.

An Ecological Vegetation Class (EVC) is used to describe the native vegetation of a region (DSE 2007). A single EVC consists of one or a number of floristic communities that appear to be associated with a recognisable environmental niche and can be characterised by a number of their adaptive responses to ecological processes that operate at the landscape scale. Each EVC is described through a combination of its floristic, life-form and reproductive strategy profiles, and through an inferred fidelity to particular environmental attributes. Figure 5 shows the predicted EVC distribution in the Lismore Study Area pre-1750, prior to European settlement.

The clay soil of the Lismore Study Area, similar to much of the volcanic plains of the Western District, was once covered by Plains Grasslands (EVC 132). The granitic soils once supported Plains Grassy Woodlands (EVC 55), described as open eucalypt woodland with the understorey consisting of sparse shrubs over a species-rich layer of grasses and herbs. This vegetation commonly occupies freely draining, infertile soils on flat to gently undulating topography (DSE 2005). Narrow sections of vegetation found along the waterways and lower slopes were classed as Grassy Woodlands (EVC 175) while freshwater swamp areas supported Plains Sedgy Woodlands (EVC 647) (Refer Appendix A for full EVC descriptions).

Agricultural practices have destroyed virtually all remnant EVC's leaving only very small areas of grasslands along roadsides and on stony areas. An aerial photo of the Lismore Study Area (Figure 6) shows that trees and shrubs are few and what does exist is mostly planted vegetation, much of which is not locally indigenous species, occurring along road and rail reserves and in narrow shelterbelts along paddock boundaries.

The present day vegetation comprises mainly fescue and phalaris pasture species with annual crops of barley, wheat and canola commonly grown. Sugar Gum (*Eucalyptus cladocalyx)* plantings began along roadsides in the 1870's and were commonly planted for shelterbelts and timber lots on farms by the 1900's (C. Lang pers. comm. 2009). Today these plantings make up the majority of the vegetation noticeable on the aerial photo in Figure 6.

In more recent years, Landcare plantings have included native species such as Blackwood (*Acacia melanoxylon*), Drooping Sheoak (*Allocasuarina verticillata*), Silver Banksia (*Banksia marginata*), Sweet Bursaria (*Bursaria spinosa*), Black Wattle (*Acacia mearnsii*), Tree Violet (*Hymenanthera dentate*), Manna Gum (*Eucalyptus viminalis*) and Red Gum (*Eucalyptus camaldulensis*) (K. O'Keefe, pers. comm. 2009).

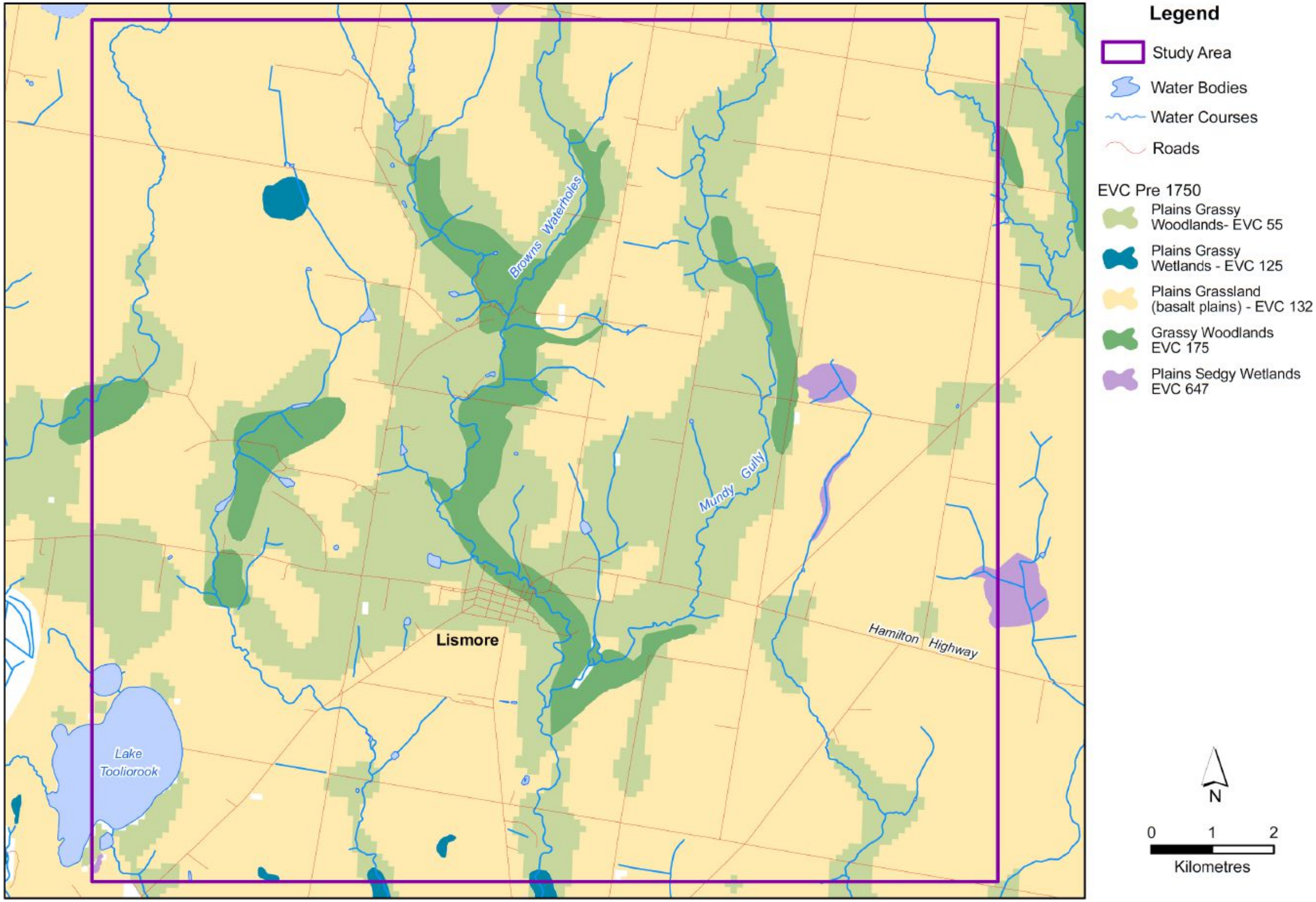

Figure 5 Pre-1750 Ecological Vegetation Classes covering the Lismore Study Area (Data source DSE 2004b).

Figure 6 Aerial photo of the Lismore Study Area showing trees along roadsides and in narrow paddock shelterbelts (Data source Corangamite CMA 2007, scale 35cm pixel size resolution).

1.3.4 Land use

Prior to European settlement the VVP region was inhabited by indigenous peoples of seven different aboriginal language groups. Two of these language groups, the *Wathaurong* and the *Djargurd Wurrong* intersected across the Lismore Study Area. The Aboriginal name for the area was *Bongerimennin* (Art & Hamilton undated). These indigenous inhabitants were largely nomadic family groups who lived on the natural resources available in the landscape. Apart from regularly burning the native vegetation, their impact on the land was minimal (CMA 2008b).

The area was first claimed by Europeans in 1840 when pastoralist John Brown recognised the land's potential and decided to settle, giving the location its initial name of Browns Waterholes. The open grasslands and fertile soils proved ideal for sheep grazing and by 1853 a settlement had begun to develop. Later the town was renamed Lismore after a village in Ireland (Oman & Lang 1980). The earliest documented grazier to the region was Charles Synott who, in 1848, bought 8,000 sheep to run on his 19,107 acre parcel near Berrybank (Bergin unpublished). Early squatters to the VVP, between 1836 and 1851, carried out low intensity grazing of the native grasslands. During the 1860's an increase in boundary fencing and the installation of bores, allowed stocking rates to rapidly increase. The use of super-phosphate fertiliser began around the 1890's and became common practice after World War II (Morcom & Martin 1998). Around mid-1910 rabbits were introduced near Geelong and by the outbreak of World War I rabbits were widespread causing large losses to the agricultural industry, as they still do today (CRP 2008). The increased grazing pressure from introduced stock as well as rabbits and the increasing use of fertilisers led to a rapid decline in native pastures. These pressures on native grasslands continue today.

The Lismore region was primarily used for sheep grazing into the 1980's as its rainfall and clay soils made waterlogging a limitation when cropping. However, with the development of raised-bed cropping (drainage furrows every 2 m so crops are sown on raised beds) and a recent run of drier years, cropping has been on the rise (I. McConachy, pers. comm. 2007). The VVP region is undergoing a rapid land use change. Traditional sheep grazing enterprises fell by 29% between 1991 and 2006 while cereal and oilseed cropping has increased 103% over the same period. Not only have the number of hectares under crop increased, so has the productivity, with cereal yields rising from 2 t/ha in 1991 to 2.92 t/ha in 2006. Dairy farming and blue gum plantations have also increased significantly (Schirmer *et al.* 2008). Today the primary land use is a combination of grazing and cropping. A wide variety of crops are grown in the region with a common rotation including wheat and barley, with canola as a break crop. Although some beef cattle (71 800 head) are farmed, sheep (496 000 head) are the main grazing enterprise in the wider Lismore region (Schirmer *et al.* 2008). Settlement across the western plains today is generally sparse. The 4404 km^2 of the Corangamite Shire, which includes Lismore township, has an estimated population of 17 270 living across the Shire at 30^{th} June 2008 (ABS 2009), making a population density of 1 person per 4 km^2. Cereal cropping is the most profitable farming enterprise in the region with gross margin figures of $1291/ha compared to grazing (sheep and cattle) and wool production which all return a gross margin between $217/ha and $257/ha (DPI 2009).

2.0 Regional geology and geomorphology

2.1 Geological evolution of the Lismore region

The soils and geomorphology of the Lismore region of western Victoria have evolved over the past 500 million years (Ma) through a series of continent building phases that included extensive marine sedimentation, granitic intrusions, major uplift, erosion and the effects of more recent changing sea levels, volcanic activity and weathering.

The following section describes these processes according to geological time periods and has been compiled using the following main resources: Birch (2003), Cochrane *et al*. (1999), Joyce (1999 and 2004), Ollier & Joyce (1986), Ollier (1971), Robinson *et al*. (2003), and White (1994). Numerical ages listed are from Gradstein *et al.* (2004). Where specific details are included the references are cited in the text.

2.1.1 Palaeozoic 545-251 Ma

During much of the Palaeozoic most of Victoria was below sea level where a thick (2-5 km) and extensive (800 km present width) pile of quartz-rich turbidites was being deposited. These have been interpreted as constituting both a continental margin sediment prism and a back-arc basin sequence that developed in collisional interactions along the Gondwana continental margin.

Sub-oceanic basaltic volcanicity produced volcanic cones that were subsequently eroded by wave action and accumulated on the ocean floor along with the sediments. These are exposed today as Cambrian greenstones along fault-bounded slices outside the Lismore Study Area, at Mt Stavely south of the Grampians and in the Barabool Hills near Geelong.

During the Late Cambrian - early Ordovician (500-470 Ma), a series of movements caused uplifting of parts of Victoria, including the far west which is known as the Delamerian Highlands. Extensive erosion of these Highlands was a major source of sediments deposited in the Western Basin. Ordovician mudstones and sandstones, locally rich in graptolite fossils, are distributed widely across the Ballarat region, north of the Lismore Study Area.

Several orogenies were experienced over this period causing compression of the region by 60-70% (Birch 2003). The result of this extensive folding and faulting was the formation of several mountain ranges which built up additional land on the eastern edge of Australia. The rocks consist of sandstone, shale and siltstone layered and were folded into a series of steeply dipping anticlines and synclines which strike north-south. During this mountain-building event, silica-rich hydrothermal fluids squeezed into rock cracks and subsequently cooled to form quartz veins, some of which are gold-bearing such as those found near Ballarat.

By the late Devonian (~ 370 Ma) sea level had retreated enough to expose most of the State of Victoria for the first time. This was also a period of intrusive and extrusive activity. The Palaeozoic sediments of the Lismore Study Area were intruded by granitic magma which cooled slowly around 5 km below the surface. Following these intrusions there was a long period of weathering, lasting around 200 million years, which eroded between 2 and 5 km of overlying rock. This erosive period exposed the granites, outcrops of which can be seen today in the centre of the Lismore Study Area. The exposed granites consist of a coarse-grained hornblende biotite granodiorite and porphyritic biotite granite (Thost & Stuart-Smith 2000).

During the Late Carboniferous-Permian (318-260 Ma) the landmass of Gondwana was close to the South Pole and much of it, including Victoria, was covered by glaciers. By the early Permian the glaciers had retreated to the south which left the region exposed to active erosion. Glacial pavements and tillites are well preserved in the Bacchus Marsh area north-east of Lismore.

2.1.2 Mesozoic 251-65 Ma

Near the end of the Permian (~ 253 Ma) the landmass of Gondwana began to break up. It was not until Early Cretaceous (~ 140 Ma) that the Australia and Antarctica separation began as north-south tension resulted in crustal thinning and normal faulting. This split created an east-west trough along the southern edge of Victoria which slowly filled with sediments as the mountain ranges either side eroded. These Late Cretaceous freshwater mudstones and sandstones are rich in plant fossils and other evidence of life at this time, including insects, fish, dinosaur and even bird feathers and small mammal fossils, which lived in Polar latitudes when this part of the Australian continent was south of the Antarctic circle. A global abrupt cooling and major extinction event marked the end of the Mesozoic.

The break-up of Australia and Antarctica caused such stresses that during the Late Cretaceous (~80 Ma) the rift valley which had filled with kilometres of Early Cretaceous sediments was mildly folded, faulted and uplifted to form mountain ranges. Local examples of this are the Otway Ranges and the Barrabool Hills near Geelong.

2.1.3 Cainozoic 65 Ma to present time

During the Palaeogene (65-23 Ma) climatic conditions in southern Australia generally changed to high rainfall and humid conditions conducive to weathering. It was during this time that local Devonian granites were weathered deeply to the economically important kaolin clays which are mined north of the Lismore Study Area near Pitfield. Palaeozoic sedimentary rocks around Ballarat were also deeply weathered and exposed at this time.

Australia became an island continent in the mid-Eocene (45 Ma) after complete separation from Antarctica. With accelerated (6-7 cm/yr) northerly drifting the climate changed from wet to arid conditions and Australia became the driest vegetated continent on Earth (White 1994). Glacial climate cycles in the Tertiary peaked at 35 Ma, at 15 Ma with the formation of the southern ice cap, at 6 Ma with the Terminal Miocene event and 2.4 Ma with the formation of the northern ice cap (White 1994). The severity of glacial stages varied, as indicated by differing sea level falls, down to 180 m below current sea level. Similarly the degree of warmth and wetness of interglacial stages varied with some warmer and wetter than the present. This very arid phase relating to the development of the northern ice cap affected climates worldwide. A pattern of glacial cycles meant increased aridity and windiness as well as lower temperatures. Rainfall had lessened during these cold episodes and the rate of weathering slowed. Soil formation, weathering and erosion features of the Lismore area are a direct consequence of this late Pliocene, Pleistocene and Holocene climate history.

Late in the Neogene (10-3 Ma) sea levels rose again covering much of south-west Victoria with a shallow sea reaching up to the southern margin of the Western Uplands. Extensive limestone deposits were laid during this time and now outcrop around Port Campbell. With the final retreat of the sea the landscape drained south from the Uplands covering a vast area of land with a thin deposit of alluvial sands. As the retreating sea moved south, erosion exposed the clays and marls which today make up many of the soils of the Heytesbury region. Deposited sands weathered into a group locally known as the Hanson Plain Sands which are exposed in small windows in the Lismore Study Area on the Devonian granites.

The Cainozoic saw two main periods of volcanic activity across Victoria. The first major period of activity occurred from 40-7 Ma, known as the *Older Volcanics*, and the second from 7 Ma almost to the present day known as the *Newer Volcanics*. The Older Volcanics were concentrated in Gippsland and east of Melbourne. Most activity of the Newer Volcanics occurred between 4.5 Ma and 20 000 years ago (Rosengren 1994) in the south west of the State. The Newer Volcanics cover an area of 15 000 km^2 of western Victoria stretching from Bendigo in the north, as far south as Portland, from Melbourne's east and through to Mt Gambier in the west and are known as the Victorian Volcanic Plains. The region now covered by the VVP is bordered in the south by the Mesozoic rocks of the Otway Ranges and the Cainozoic sediments of the Coastal Plains (Figure 1a).

Along the southern margin of the plains on a line between Port Fairy and Colac, rising magma met with ground water and moisture-rich limestone, resulting in violent explosions which produced the maars and tuff rings seen today, particularly around Camperdown.

Basalt flows across the VVP can be broken down into three phases according to their ages, determined using K-Ar dating. The oldest, also referred to as first phase basalts, according to Joyce (2003) are dated at 5-3 Ma, with intermediate dates between 3-1 Ma and the newest, young phase basalts, being less than 1 Ma. Oldest flows (5-3 Ma) have weathered into deep soil profiles of kaolinitic clay, often deeper than 10 m. The mottling and iron nodules in these profiles indicate a Neogene climate which was favourable to deep weathering. Deeply incised valleys were cut into the landscape during this time.

Weathering of the earlier basalt flows (5-3 Ma) indicates a warm and wet climate while a cooler climate over the past 3 Ma has meant weathering of the more recent basalt flows (3-1 Ma) has been significantly slower.

Intermediate flows (3-1 Ma) have weathered to greyish brown clays with shrink-swell properties, generally with a depth of 1-2 metres. These shrink-swell properties have resulted in a landscape of gently undulating plains with relatively few rocky outcrops. Gilgai, small hummocks and hollows formed by wetting and drying cycles of cracking clays, are common in this landscape (Young & Young 2001). Particularly good examples are found around Lake Bolac, approximately 70 km north-west of the Lismore Study Area. Due to the shorter period of weathering, the valleys formed are narrow and shallow, with lakes and swamps still present as seen around Vite Vite area, north-west of Lismore.

The youngest flows dated at less than 1 Ma, with some as recent as 20 000 years (Joyce 2003), show well-preserved flow features and are noted by the presence of stony rises and non-uniform surfaces where relief can vary by up to 10 m. Numerous lakes and swamps are found throughout the stony rises, due to the disruption caused to drainage patterns when basalt flowed over the landscape. Excellent examples of stony rises are seen between Camperdown and Colac, south of the Lismore Study Area.

Gray and McDougall (2009) have completed the most recent research into dating the basalts of the VVP using K-Ar dating and geological evidence. These studies showed Newer Volcanics activity began in the Pliocene at 4.6 Ma, continuing almost to the present day with most activity peaking between 3.0 to 1.8 Ma. The stony rises, characterised by abundant near-surface fresh rock, have been dated to 1.5 Ma while lava flows of 3.5 Ma are now present as thick weathered profiles. The Lismore Study Area is situated in the eastern sector of the Western Plains sub province of the Newer Volcanic Province of Victoria. Gray and McDougall (2009) show there is a progression in the basalt composition from tholeiitic to alkalic at the same time as the strontium ratio decreases. They observe this progression is typical of intraplate volcanism, such as in Hawaii. This implies that the most recent phase of Cenozoic volcanic activity in Victoria is coming to a close.

2.2 Structural geology

The underlying Palaeozoic sediments of Victoria are part of the much larger north-south trending Tasman Orogenic System. The southern section which makes up Victoria's basement is called the Lachlan Fold Belt. This belt formed during the Palaeozoic (>400 Ma). Victoria is divided into nine structural zones. The Lismore Study Area lies in the Stawell structural zone which is bounded to the west by the Moyston fault, an east-dipping thrust west of Ararat and to the east by the Ararat fault (Birch 2003).

2.3 Geomorphology

Volcanic eruptions and the subsequent emplacement of basalts and disruption to drainage have been the main processes in shaping the landscape seen today. Across the VVP, the most noticeable features of the landscape are the 400 hills, including scoria cones and lava shields, which mark the eruption points (Joyce 2003). Lava shields were produced when low-viscosity lava spilled from a single eruption point, creating a low smooth hill of basalt, Wallinduc Hill near Pitfield is one such example (Rosengren undated). Scoria cones formed when gaseous magma was ejected and settled to form a high steep-sided cone, often building higher on the east rim due to westerly winds. Mt Elephant at Derrinallum is one of the best preserved scoria cones of the VVP.

The lava which flowed across the VVP was low in silica and therefore quite fluid and generally producing a basalt layer of only 2-10 m thick (Robertson *et al.* 2003). This was assisted by the already flat nature of the marine landscape and resulted in deep basalt profiles only occurring where lava had followed a creek valley, known as a constricted or valley flow (Jones 2001). Constricted flows would often travel great distances, such as the Mt Eccles flow which has been traced for 50 km (Ollier & Joyce 1964). These flows are now often found with a lateral stream or two, following the flanks of the lava. Long constricted flows are not found in the Lismore Study Area although shorter flows can be identified using total magnetic imagery (Figure 7).   Total magnetic imagery helps identify varying thickness of basalts in shade from blues and greens for shallow basalts into reds where thick flows are found. Figure 7 shows constricted flows of lava which displaced drainage and created lateral streams.

Lateral streams along the edge of a basalt flow cut into the softer rock beside the basalt, often leaving a basalt plateau (Gibbons & Gill 1964). Water courses which did cut through the basalt have revealed earlier rock types such as older basalts, Cainozoic and Palaeozoic sediments and granitic rocks (Jones 2001). Earlier basalts have been exposed in Mundy Gully where deeply weathered red soils can be seen under basalt rock on the river bed. Original water courses can sometimes be located by a series of swamps and ponds on the lava plains which have occurred when old river beds have sagged (Hills 1975).   The geology map in Figure 8 highlights where creeks have cut through basalts to expose the underlying granites in the north of the Lismore Study Area.

Lava flows often blocked and altered drainage lines creating extensive swamps and large lakes, such as Lake Corangamite (Rosengren 1994). An earlier alternative view by Hills (1975) was that Lake Corangamite formed when large shallow depressions were created by the sinking of the land when a magma chamber emptied. Volcanic activity has also created the saline lakes, found particularly in the Corangamite region, by creating isolated basins when water bodies and drainage were blocked. Many are fed by ground water and so are not regularly flushed out by streams (Hills 1975).

The thin veneer of basalt did not form a continuous blanket over the VVP but left windows of Neogene sediments visible in small areas. These outcrops have formed soils with sandy loam topsoil and mottled clay subsoils, often with abundant buckshot gravel (Joyce 2004). In the Lismore Study Area these soils are found capping the granitic sands and are regionally known as the Hanson Plain Sands.

The type of landscape formed is influenced by the composition of the magma's parent material. While some, such as the higher-silica andesitic magmas, are very explosive, the low-silica olivine-rich basalt of the VVP erupted gently producing large flat plains (Ollier 1971). Some of the landforms resulting from these eruptions across the VVP are discussed below.

Sheet flows were common across the VVP resulting in broad flat plains formed by very fluid lava. Extraction of cores revealed most of the plains to be an average of only 8 m thick and composed of many thin individual flows, between 0.5-2 m in depth, overlapping each other (Ollier & Joyce 1964).

The youngest of the features produced by volcanic activity are the locally named stony rises. These uneven stony piles with their 10 m relief were most commonly formed by the lava draining unevenly from beneath the solidified surface of a lava flow. This resulted in sagging and depressions of the lava surface. Stony rises may also have formed when narrow fingers of lava continued to flow out from a larger lava flow. An example of this can be found along the southern edge of Lake Corangamite (Ollier & Joyce 1964).

Scoria cones are the most noticeable features of volcanic activity. Cones can be singular or multiples with straight, steep sides and a large crater. Mt Elephant at Derrinallum (Figure 9) is one of the best examples on the plains, rising to a height of 250 m above the surrounding landscape, while most other cones are less than 160 m (Ollier 1971).

Maars, large circular craters with low walls, formed when rising magma met groundwater as it moved toward the surface. This meeting produced an explosion violent enough to blast material out and form a crater. Maars are often 1-1.5 km in diameter and many contain lakes. Maars with flat floors or swamps have been filled with considerable amounts of sediment (Ollier 1971). Some of the best examples of maars are around Camperdown, such as Lake Bullen Merri.

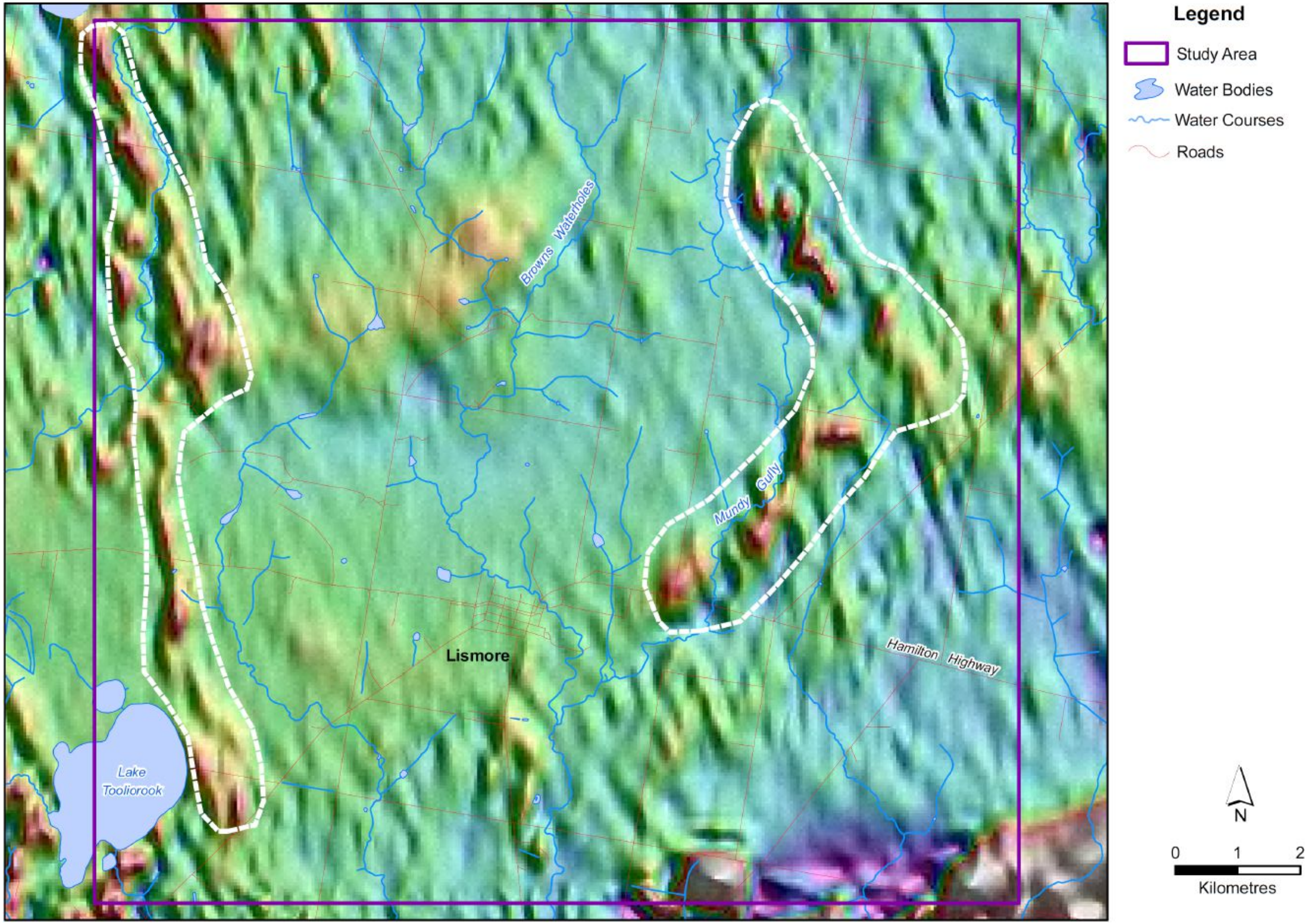

Figure 7 Total magnetic imagery can be used to identify basalt thickness and the presence of constricted flows (circled) (Data source GeoScience Australia 2007, grid cell size 50cm).

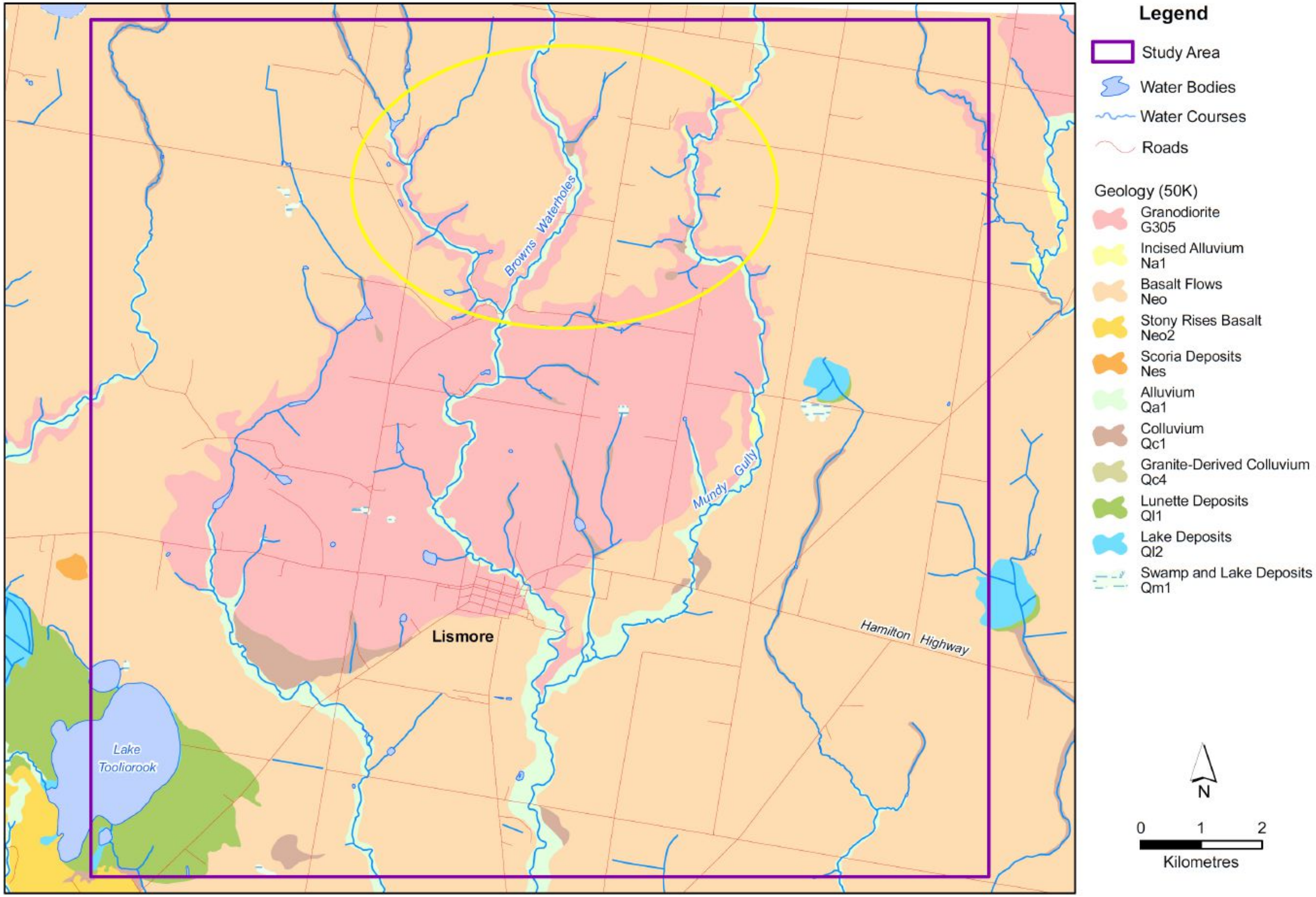

Figure 8 Geology map of the Lismore Study Area where stream erosion has cut through basalt into underlying granites (circled) (Data source GeoScience Australia 2007, scale seamless 1:50 000 series).

Figure 9 Aerial view of the Mt Elephant scoria cone rising above the surrounding basalt plains (Photograph S. McConachy).

2.3.1 Geomorphology of the Lismore Study Area

The Lismore Study Area is dissected by two main streams, Mundy Gully and Browns Waterholes, both flow south and join before entering Lake Gnarpurt.

Both Mundy Gully and Browns Waterholes begin to the north of the Lismore Study Area at an elevation of 200 m and fall 58 m to the point of junction of the two, at 142 m. Mundy Gully has cut its channel between the east flank of the granite and the edge of a basalt flow. The valley averages 10 m deep and between 200 m and 500 m wide. Browns Waterholes begins on the basalt plains north of the Lismore Study Area. The stream has progressively cut down through the basalt into the underlying granites, then flows through the middle of the granite where it has cut a broad valley averaging 30 m deep and up to 1 km wide from ridge to ridge. After the two creeks junction the valley becomes even broader, spanning an area of up to 750 m while the channel averages 10 m deep. Other small unnamed drainage lines flow south through the Lismore Study Area resulting in a well-drained landscape with few swamps and marshes.

Exposed rocks in the area include the Devonian granites which outcrop as scattered boulders on the edge slopes of the granite derived soils and in large boulders in the channel cut by Browns Waterholes (Figure 10). The granites form the highest point in the

Lismore Study Area at an elevation of 228 m. Erosion has stripped material off the slopes and deposited older alluvial sand silt and clay materials in small alluvial terraces down Mundy Gully. More extensive alluvial terraces are most likely covered by more recent stream alluvium.

Several flows of different ages ranging from 3.6 Ma to 0.89 Ma are responsible for the basaltic soils seen today (Gray & McDougall 2009). This is apparent in the Lismore Study Area by the deeply weathered red soil patches which show through the predominant grey clay soil. These soils could be termed palaeosols as it is likely they formed under different climatic conditions than are currently experienced. These red soils have also been exposed in the lower reaches of Mundy Gully (Figure 11). The smaller patches (< 5 ha) of red clay soils that exist across the basalt soils have not been mapped, as they cannot be managed as a separate soil type by landholders whose paddock sizes are typically around 40 ha in area. Soil variability at a paddock scale is particularly prominent on the basaltic soils (Figure 12).

Although drainage is now well developed, the presence of lunettes indicates the historical wetting and drying cycles which occurred in wetlands and lakes. The largest lunette in the Lismore Study Area occurs on the eastern bank of Lake Tooliorook (Figure 13), south-west of Lismore township. Prevailing westerly winds built a lunette rising approximately 14 m above the surrounding plains, whose elevation averages 164 m (DSM 1990). Lake terraces to the north of Lake Tooliorook indicate the much higher levels the lake once reached. Several smaller lunettes have also formed around lakes and swamps that are now dry.

Figure 10 Browns Waterholes has cut a broad valley into the granitic sands (Granitic Sandy Loams) exposing granite boulders on the valley edges (circled) (Photograph S.McConachy).

Figure 11 Deeply weathered red soils (Nowra Red Clays) exposed at the base of Mundy Gully (Photograph P. McConachy).

Figure 12 Soil variability at a paddock scale as seen on the cultivated basaltic soils above Mundy Gully (Photograph S. McConachy).

Figure 13 The lunette at Lake Tooliorook rises 14 m above the surrounding plains with Mt Elephants scoria cone in the distance (Photograph S. McConachy).

3.0 Soil formation and previous mapping

Regolith is described as unconsolidated rock material, which includes debris of all kinds, and the soil which overlies it (Ollier & Joyce 1986). A soil, however, can be defined differently depending on a person's objectives. This thesis is concerned with mapping and describing the soils used for agriculture so a further definition is required.

In this context soil is described as the layer of weathered material used for agricultural production which generally accounts for the top one metre. The soil profile and its chemical and physical properties which influence agricultural production will be focused on in this thesis.

3.1 Weathering and soil formation

Weathering is the alteration of rock minerals into smaller particles when exposed to the atmosphere (Corbett 1969). Hills (1975) classifies a rock as having weathered to form soil when a plant establishes itself. Plant matter then decomposes to form humus which, along with rain water, promotes further chemical changes. The rate at which a rock weathers is largely determined by its permeability and porosity (Ollier & Pain 1996). The ease with which water can enter a rock and create a weathered product determines to a large extent the style and rate of weathering. While weathering is the process, there are several factors which influence the resulting soil profile.

The colour of a soil is partly determined by the compounds being weathered in the parent material. Organic carbon compounds produce black and brown colours, while reds and yellows are derived from parent rock with minerals rich in iron compounds. Soils that are pale or white have been influenced by lime, salts, quartz or pure clays (Corbett 1969) or may have been leached of mineral material by long periods of elluviation, creating a bleached layer.

A soil's texture is largely determined by the leaching processes and the lateral movement of water, acting on the soil. Leaching produces horizontal differentiation by transporting certain constituents of the soil, including clay particles, down the profile. This differentiation process results in different horizons in a soil profile and is responsible for the texture-contrast soils commonly found across the VVP. A texture-contrast soil, noted by its very distinct texturally different soil horizons, is an indication of a well-weathered soil. Fine minerals and clays have been elluviated from the upper profile and illuviate in the lower profile, accumulating in the subsurface and forming a heavier clay below. Drainage also influences soil colour by influencing the aeration of the soil. Well-drained soils (aerobic conditions) show rich, bright reds and browns whereas waterlogged soils (anaerobic conditions) result in dull, pale or bluish grey soil.

The rate at which a parent material will weather into a soil profile depends on the strength of the bonds that cations form with the negative sites on clay particles and humus. Sodium and potassium form weak bonds; calcium, magnesium and iron form stronger bonds; aluminium bonds are stronger again and silicon forms the strongest bonds, with bonds that are twice as strong as aluminium (Paton 1978). This means that low-silica basalts and sediments weather to produce a soil profile at a faster rate than a granite outcrop with its high-silica content. It is these chemical differences which have exposed the granite plutons in the Lismore Study Area as the Palaeozoic sediments eroded around them at a faster rate.

Because the minerals found in basalt are not strongly resistant to weathering the resulting soil is uniform with fine-grained clays and hydroxides, usually of iron and aluminium, which result from the breakdown of feldspars and iron-magnesium minerals (Paton 1978). In contrast, the granite sands formed from the weathering of granites are coarse-grained and have high levels of coarse fragments largely consisting of orthoclase and quartz.

Minerals with low resistance to weathering are known as *primary minerals,* they weather into cations, anions and small crystals which form clays. The higher the rate of weathering, the higher the clay content (Corbett 1969). High clay content can lead to poor drainage due to a lack of macropores between soil aggregates which often results in waterlogging. These fine clays can also be transported down the profile and accumulate in the B horizon, sometimes forming a hard pan (Ollier 1969). A susceptibility study of waterlogging in the Corangamite CMA (DPI 2008) region ranked the majority of the Lismore Study Area as having a low or low-moderate risk of waterlogging. An area around the southern edge of the granitic sands is classed as being a moderate-high risk (Figure 14).

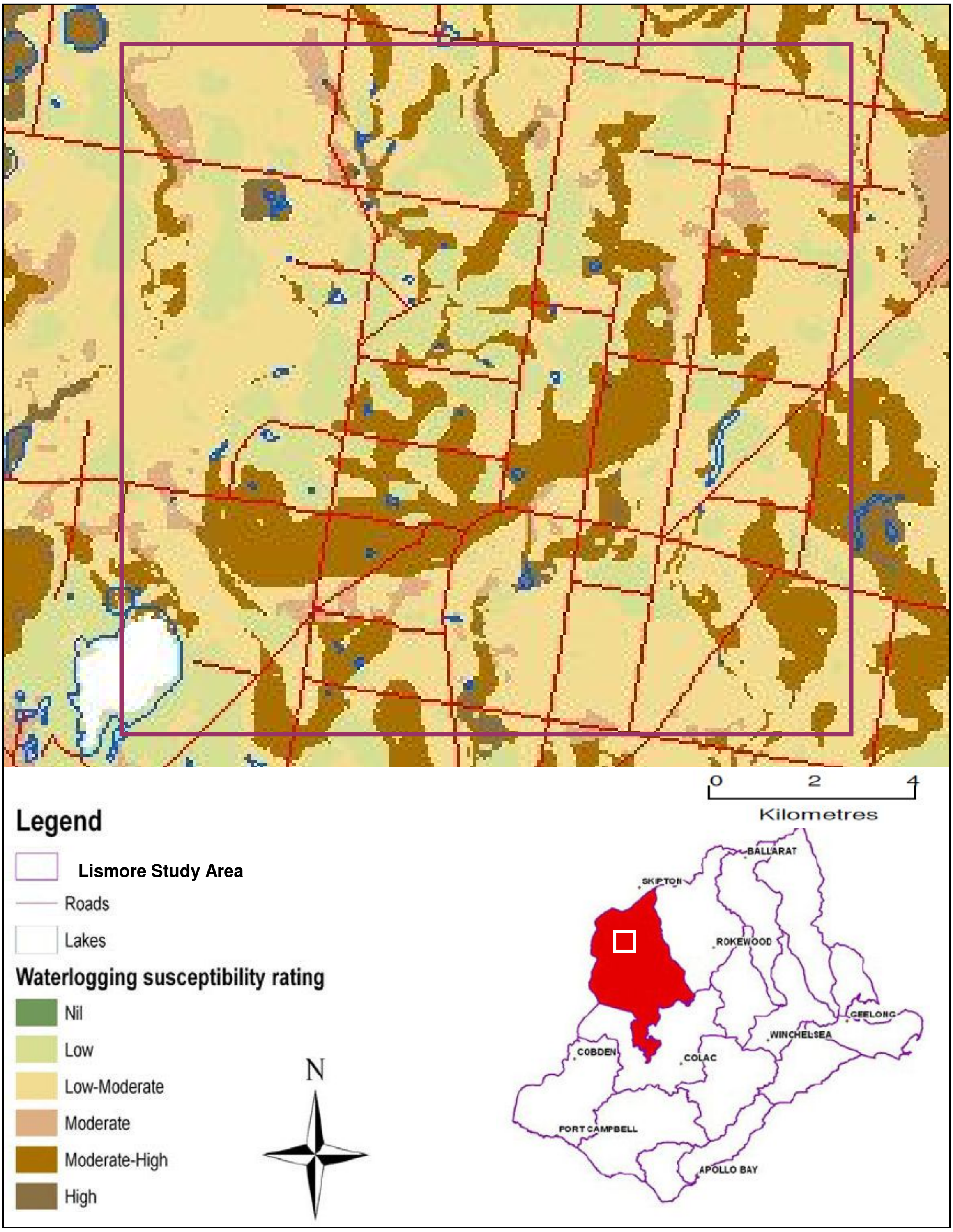

Figure 14 Waterlogging susceptibility mapping of the Lismore Study Area shows moderate to high susceptibility around the granitic sands (DPI 2008).

3.2 Soil development

In 1941 Hans Jenny created an equation to describe the factors influencing soil development, now know as the Jenny Equation:

$$s = f(cl,o,p,r,t)$$

Soil = function (climate, organisms, parent material, relief, time) (Jenny 1941).

The influence of each of these five functions on the formation of a soil profile is discussed below.

3.2.1 Climate

Climate is an aspect of the above equation that cannot be controlled. Temperature and rainfall, the main aspects of climate, vary over regions and have varied greatly over the thousands of years of soil formation. It is the climate that, to some degree, influences not only the rate of soil formation but can also give rise to certain dominant soil types (Ollier & Pain 1996).

Hot, wet conditions promote rapid decomposition of organic matter and the formation of deep soil profiles. High temperatures speed up chemical reactions further enhancing soil formation, therefore soil depth and rate of development will increase as rainfall and temperature increase. Soil profiles formed under hot, wet conditions are generally high in iron minerals as most other minerals and nutrients have been leached. If high levels of organic matter are present it may often mask the red and yellow staining of the iron (Corbett 1969).

Rainfall impacts the rate and type of soil profile developed by influencing the depth of leaching. Water moving through the soil carries both dissolved compounds (e.g. salts) and particles suspended in solution, creating a more deeply weathered soil with better defined profiles than would occur in an arid climate (Young & Young 2001).

The precipitation to evaporation ratio is also important. In regions where precipitation exceeds evaporation, ions will be lost from the soil through leaching and in surface runoff. Where precipitation is less than evaporation the soil accumulates salts such as carbonates and sulphates (Ollier & Pain 1996). In dry climates organic matter accumulates throughout the soil profile, especially in the A horizon. If conditions are extremely cold and waterlogged, organic matter accumulates faster than it can break down and forms a peat soil (Corbett 1969). When humus breaks down slowly, such as in these conditions, humic acid accumulates, resulting in a fall in pH and the production of an acid soil. In contrast, the rapid decomposition of humus in warm, moist climates means humic acid is destroyed so pH is not lowered and an alkaline soil results.

The past and present climate of the VVP has been conducive to the relatively rapid decomposition of the basalts primary minerals to form clays.

Paton (1978) divides the soils of basalt origin into two main types:
a) Red brown materials where kaolinitic minerals (1:1 clays) and iron oxides dominate
b) Dark coloured material where 2:1 clays dominate

Describing clays as 1:1 and 2:1 refers to the arrangement of their tetrahedral and octahedral sheets. A 1:1 clay mineral contains one tetrahedral and one octahedral sheet per clay layer while 2:1 clay minerals contain two tetrahedral sheets with an octahedral sheet between them (Leeper & Uren 1993).

Initial thinking on the difference between the two basalt soils proposed by Paton (1978) was related to the weathering and leaching processes the soils had been exposed to, forming the 2:1 clays first and later converting to 1:1 kaolinite clay with time and further weathering.

Sherman (1952) also believed that rainfall was an important factor in the type of soil that formed from weathered basalt. Sherman's research showed that in regions which received less than 1000 mm annual rainfall, montmorillonite (2:1 clay) formed as the dominant clay. Rainfall between 1000-1500 mm annually resulted in kaolinitic-dominant clays (1:1 clay) and above 2000 mm annual rainfall the soils that developed contained hydroxides of iron and aluminium.

This theory, however, has been abandoned since the two soils can be found in such close proximity that the influence of different climates could not be the main factor in their development (Paton 1978). Although, as Jones (2001) points out, soils over a small area can vary due to local drainage patterns. As Ollier & Joyce (1964) found, the basalt from a single eruption point can form a range of soils, including reddish brown soil and black soil.

With this in mind the degree of soil formation cannot be used as an accurate guide to the age of a profile or the underlying basalt.

Since the formation of the VVP, Pleistocene (1.6 Ma-10 000 yrs) glacial cycles may have been the most significant influence on rock weathering, erosion by water and wind and the formation of soils in this area. The cycle of climate change established in the Pleistocene remains active today. Warm interglacials take up only about 15% of the cycles, with 85% of the time encompassed by intervals which are cooler and drier, and glacials that are much cooler, much drier and much windier (White 1994). As a consequence, the timing and rate of major weathering and soil formation episodes will be periodic and will be accelerated during the interglacial phases.

When considering the relationship between soils and their climate, it is important to remember that many soils were formed in past climates which vary greatly from the climate experienced today.

3.2.2 Organisms

Many texts focus on vegetation as the key organism involved in soil development. Paton (1978) discusses the large impact that vegetation cover, type and distribution have on the rate of weathering. Vegetation cover slows the detachment, transportation and deposition of material from a weathering surface. Roots also act to bind material together. Grasslands are particularly effective at this due to their thick mass of fine, deep roots compared to treed areas, where roots are large and fewer. Vegetation can also release or form hydrogen ions (acidic conditions) which accelerate weathering and creates an acidic pH (Paton 1978).

More recent works such as by Ollier & Pain (1996) acknowledge that while vegetation does have an influence on the types of soil formed, soil organisms, both macro and micro, play important roles as decomposers, sorters and mixers. Macro-organisms such as earthworms and ants assist in creating a gradational soil profile by mixing materials. Organisms prefer an aerobic environment in moist but well-drained, highly fertile soil (Young & Young 2001). In acid soils where few earthworms live, a clear boundary between the A and B horizons is maintained. Organisms are also required to mobilise and convert nutrients to plant-available forms.

Young & Young (2001) take the discussion on organisms one step further and include human activity as a factor influencing soil formation. Many human activities impact in ways that can substantially alter a soil in a relatively short period of time. Removal of natural vegetation, sowing monoculture crops, altering natural rainfall with irrigation, mixing and declining soil structure through cultivation and adjusting fertility with fertilisers all have significant impacts on the formation of a soil.

3.2.3 Parent material

The third component of Jenny's equation is parent material. The type of soil produced during the weathering process is largely determined by the texture, porosity, drainage and mineral composition of the parent material. If a rock is porous and well-drained, soil will develop more rapidly as opposed to a dense parent material. It is then logical that soil formation will be more rapid on a partly weathered parent material than a solid rock.

The mineralogy of the parent material has many influences on its associated soil, one of these is soil texture. Rocks with easily weathered minerals form clay soils, while minerals that resist weathering will form sandy soils with coarse fragments. The grain size and silica content of the material also plays a large role. Silica-rich materials such as granites produce sandy, acid, low-fertility soils with low clay content. Basalts on the other hand form clay rich, low-silica content, fertile soils (Young & Young 2001). Different clays will be formed depending on the composition of the parent rock. Rocks rich in cations such as calcium and magnesium produce montmorillonite 2:1 clays, while rocks poor in these cations but rich in potassium will form kaolinite 1:1 clays (Ollier & Pain 1996).

Mineral content of the parent material also influences soil fertility. Fertile soils arise from rocks such as basalt which is made up of the primary minerals olivine, augite and plagioclase feldspars. These primary minerals weather down to release macro-elements such as potassium, calcium and phosphorus, and trace elements such as iron, manganese and copper. Granites on the other hand are formed of the primary minerals quartz, potassic, calcic and sodium feldspars, hornblende and biotite, most of which weather to produce acidic, low-fertility soils (Leeper & Uren 1993).

The influence of the parent material is much more significant on a young soil type and it is often quite easy to determine the parent material, whether it be basalt, granite or limestone for example. With age however, the climate will be more influential in determining soil type (Hills 1975).

3.2.4 Relief

The topography of a landscape influences the distribution of soil through both mechanical movement and leaching of particles. Mechanical movement relates to water runoff over the surface, while leaching relates to water movement through the profile.

The crest of a slope receives rainfall and, due to the little relief, it seeps into the soil weathering the profile below. As relief increases, so does water flow velocity. High velocity water does not allow for much seepage into a soil profile and instead removes loose surface material causing erosion, that is, mechanical movement. At the base of the slope the removed material from above is deposited, along with the water that transported it. A depositional environment is created through sedimentation and is often waterlogged (Young & Young 2001).

Leaching occurs when upper slopes receive rainfall which seeps into the soil, transporting salts and nutrients down the profile which are then moved by through-flow to lower slopes in a concentrated solution. Water then evaporates, depositing salts and excess nutrients in the lower slope (Ollier & Pain 1996). Waterlogging of the lower slopes results in a yellow and grey profile due to iron in the soil remaining wet, rather than creating an oxidised red soil which occurs if the profile is freely draining, such as in upper slopes (Figure 15).

Waterlogging of iron rich soils creates an environment favouring chemical reduction and the formation of Fe^{2+}. Drying cycles expose the Fe^{2+} rich soil water allowing it to be converted into insoluble Fe^{3+} through oxidation and acid hydrolysis, creating brightly coloured particles of iron oxide in the profile. After long periods of wetting and drying, Fe begins to accumulate and forms iron nodules, commonly know as buckshot, or cemented layers, know as coffee rock, which can restrict root growth and drainage (Peverille *et al.* 1999).

3.2.5 Time

Soil development is influenced by a region's climate, the organisms present, mineralogy of the parent material and the relief of the landscape but all this occurs over varying periods of time.

Some sandy soils have been found to form a bleached horizon in less than 10 years (Ollier & Pain 1996). This is a relatively quick formation and the soils derived from heavy, impermeable clays, such as those found on basalt parent material, take much longer. The process of soil development is longer still when weathering from fresh rock. As Leeper *et al.* (1936) point out, with the current understanding of the age of the basalts there is a time frame of over 1-5 million years during which different flows occurred and began to weather into regolith. This must clearly lead to a difference in soils from different areas of the Newer Volcanic region.

This study will use these understandings to discuss the soil profiles that have developed across the Lismore Study Area under the variable climatic conditions, on different parent materials and with different relief and management practices.

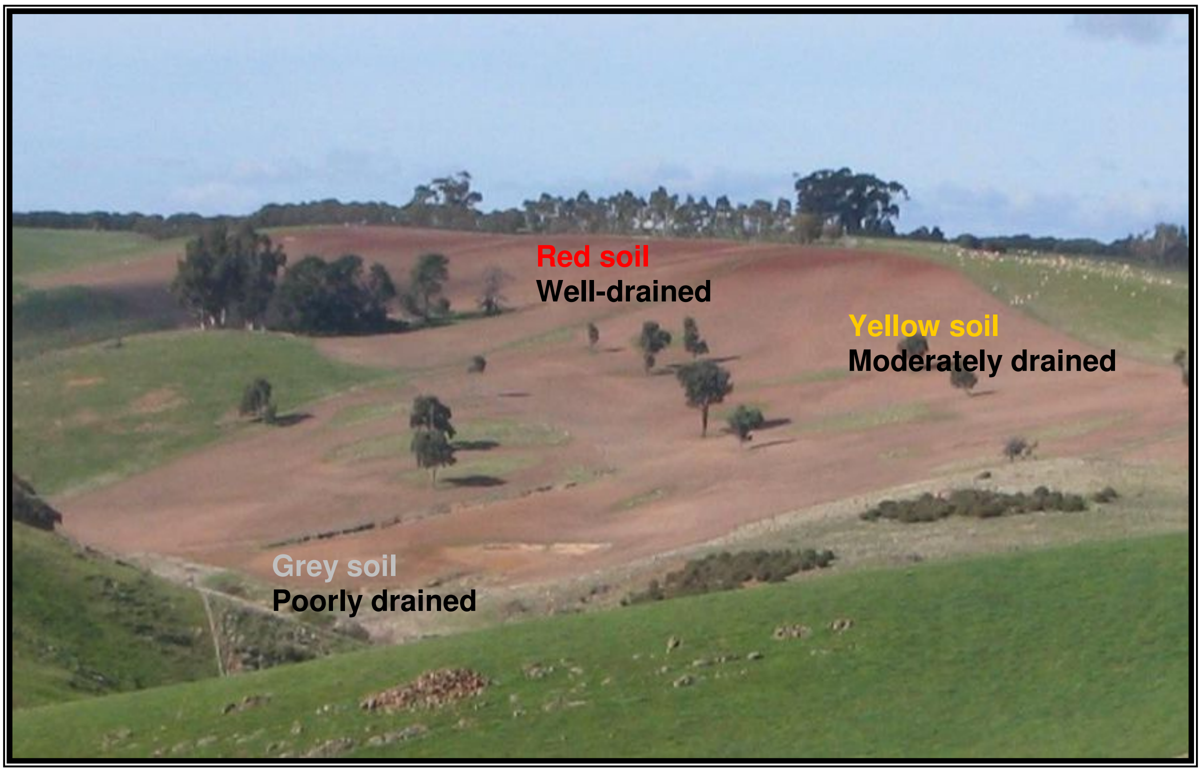

Figure 15 A cultivated paddock exposes the variation in soil colour down the slope indicating changes in drainage (Photograph S. McConachy).

3.3 Dating soil surfaces

It is of great interest to geologists to be able to put in order a sequence of events. Dating soil surfaces is one technique used to help date the age of various lava flows and other materials. Two methods are primarily used; *direct dating* which aims to identify the age of a specific material and *relative dating* which places materials in an historical framework by establishing the succession of their formation.

3.3.1 Direct dating methods

The steady rate of decay of certain radioactive elements allows the absolute age of minerals found in soil to be dated to the time of formation. In igneous rocks this radiometric "clock" indicates the time the magma cooled and crystallized. Potassium (K) is a common element found in micas and clay minerals. Its long half-life allows it to be used to calculate absolute ages of samples more than a few thousand years old to billions of years. This form of dating is based on the fact that the radioactive isotope, potassium-40, decays at a steady rate into argon-40 with a half life of 1.25 billion years (Pitman 2001).

When using this method, some basic assumptions are made (Pitman 2001):

- The beginning conditions and the initial ratio of daughter to parent isotopes is known
- There has been a constant rate of decay
- No parent or daughter isotopes have been leached
- The above assumptions are valid for billions of years

The radioactive elements potassium (K), uranium (U) and thorium (Th) are particularly useful in dating flows because they change at a known and steady rate over time (Joyce 2003). Basalt soils of various ages can be distinguished from one another by the comparison of their levels of K, U, and Th to that of the parent basalt. Basalt soils contain up to 50% less K compared to levels present in the parent basalt, while levels of U increase by as much as four times and levels of Th double as the basalt weathers (Joyce 1999). An example of radioactive potassium levels measured for the Lismore Study Area is shown in Figure 16 where yellow, red and white indicates high levels of K such as in new basalts and in granites, and greens indicate lower levels of radiometric potassium on the thickly weathered basalts.

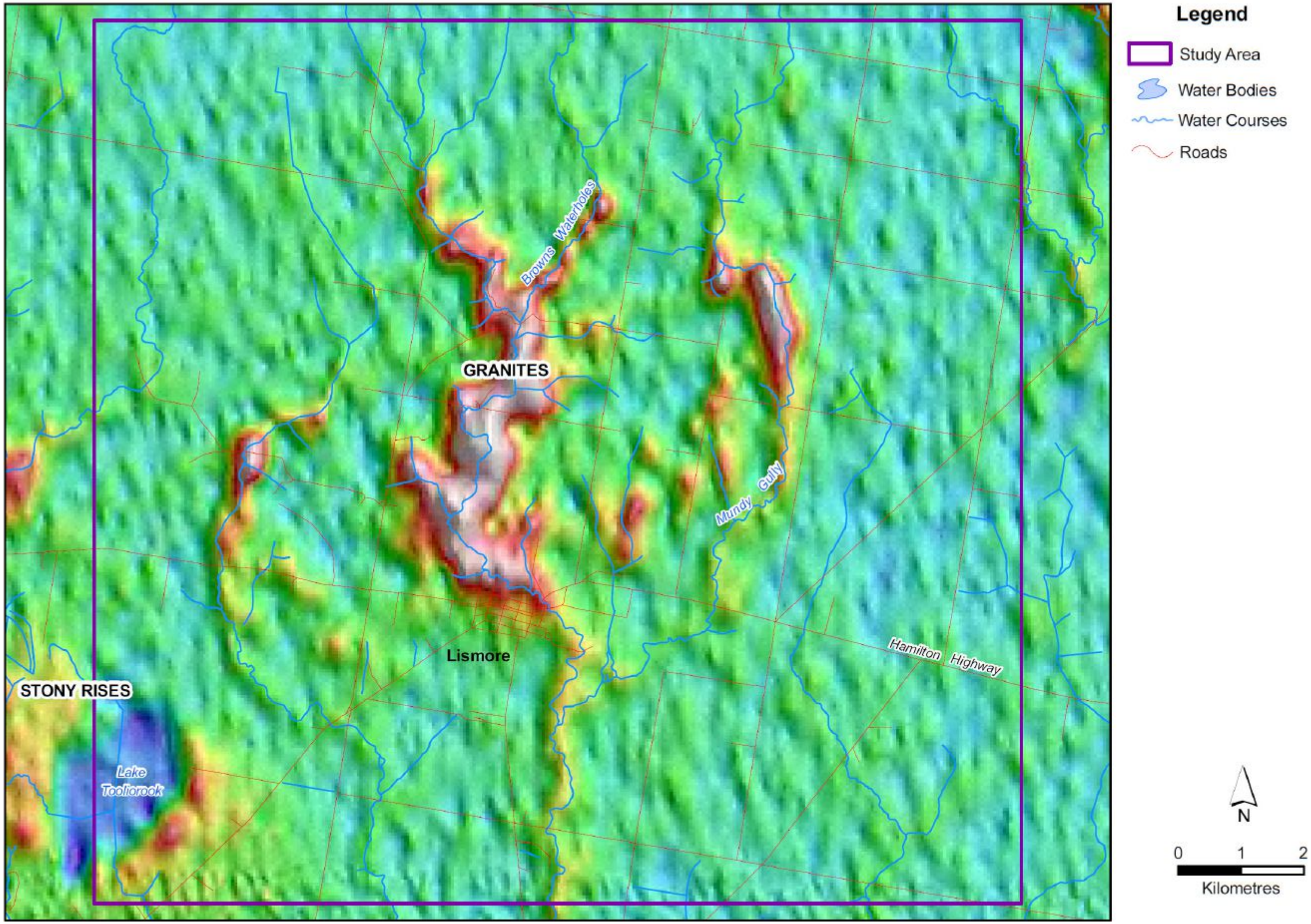

Figure 16 Radioactive potassium (K) helps identify areas of concentrated granites and the location of newer basalt such as the stony rises (labelled) (Yellow, red and white indicate high K levels, greens indicate low K levels) (Data source GeoScience Australia 2007, grid cell size 50cm).

3.3.2 Relative dating methods

Several techniques can be used to identify and determine the sequence of individual basalt flows. Methods such as fine resolution terrain models, satellite imagery, radiometric and geophysical imagery can all be used, often in conjunction with one another, to distinguish different basalt flows.

Radiometrics

Unstable parent elements decay to a more stable daughter element at a known and fixed rate. The half-life of the parent material and daughter material can be measured to determine the age of a sample. Radiometric techniques are useful on large lava flows of more than 1 Ma in age (Stone *et al.* 1997). Airborne radiometric technology uses the degree of weathering, the rock outcrop and the soil type formed on a surface to distinguish between and date lava flows. One limitation of using radiometric dating is that the parent basalts from flows of different ages may not all have the same original mineral composition of lava. If this was the case then the dates derived from the weathered material would be incorrect (Joyce 2003). This is particularly relevant given Gray and McDougall (2009) conclusions on basalt petrogenesis.

LiDAR Digital Elevation Model

Light Detection and Ranging (LiDAR) Digital Elevation Model (DEM) allows the measurement of distance, speed, rotation, chemical composition and concentration of a specific object such as a tree or a tractor (Speirs 2004). When used to date soils the measurements of distance and chemical composition are the important elements of LiDAR.

LiDAR data is captured from a low flying aeroplane firing high speed laser pulses at the earth. A sensor on the instrument measures the time taken for a pulse to bounce back which allows the instrument to calculate the distance between itself and the target (CSIRO 2008). The data is then used to generate a three-dimensional map of the terrain and landscape features (Figure 17a, 17b). This is delivered with a vertical accuracy of 0.1 m and horizontal accuracy of 0.3 m (Turton 2008). The high amount of detail makes LiDAR a useful tool for mapping basalt flows and landscapes (Gibson *et al.* 2005).

LandSat

LandSat is a remote sensing satellite program developed by the US during the exploratory time of space travel. Since 1972 LandSat satellites have been providing specialised digital photographs of Earth with enough resolution to depict human-scale works such as highways (NASA 2009). LandSat imagery often identifies vegetation and land uses of an area by distinguishing them in different colours. It can also be useful in showing aspects of lithology, structure and broad geomorphic regions (Joyce 1999).

Magnetics

Paleomagnetic dating measures the orientation of magnetic materials in the soil, such as iron oxides in basalt, and compares these to the Earth's magnetic field as it was orientated at certain periods over time. The technique provides several broad time ranges over the last 100 Ma in which the material must have crystallised/solidified (Young & Young 2001). Total magnetic imagery was used in this thesis to help identify thick areas of basalt, for example valley flows, and areas where magnetism was weak such as the granite sands. This information was useful in determining likely changes in soil type when creating the Lismore Soil Series Map (Figure 7).

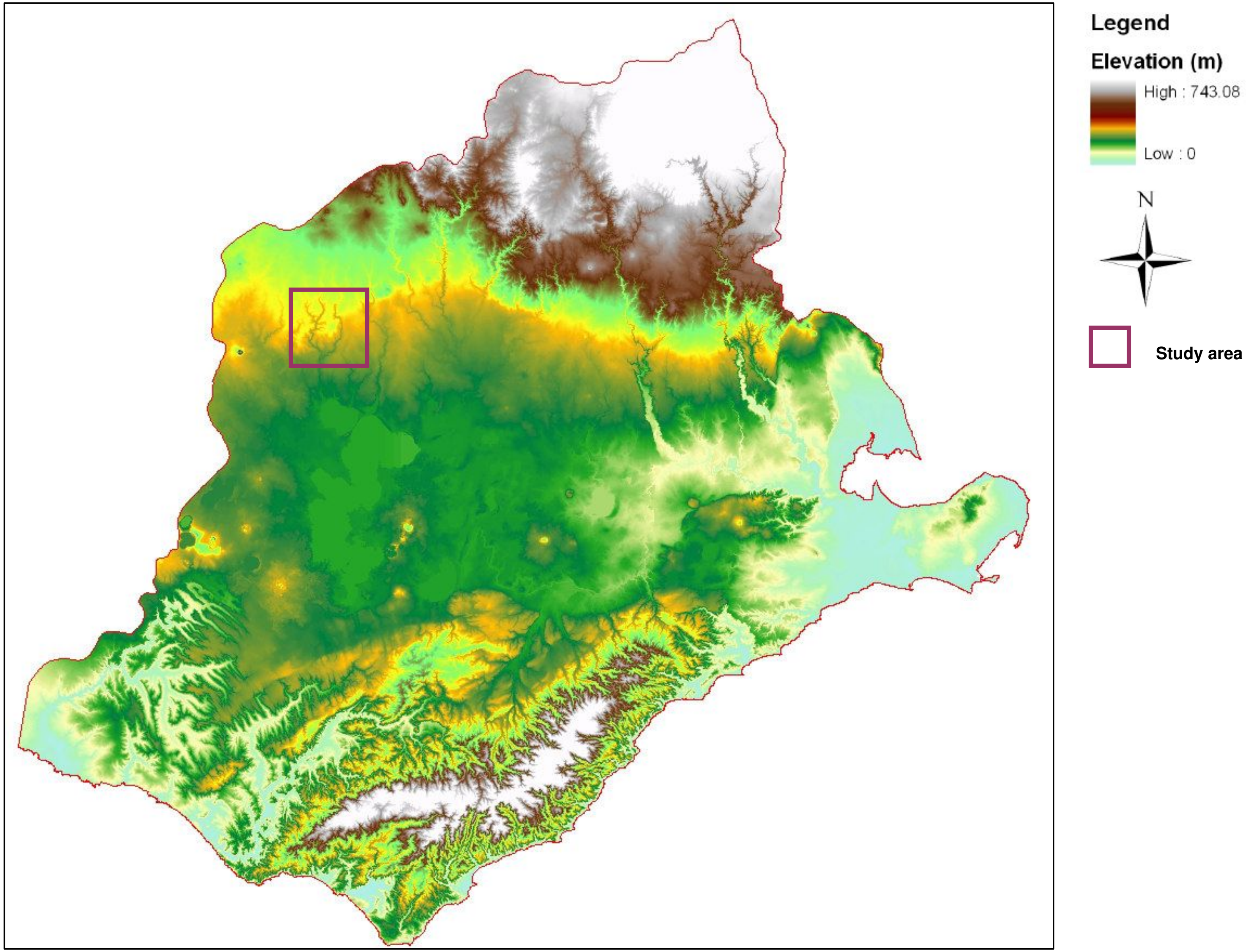

Figure 17a LiDAR DEM displaying elevation for the Corangamite CMA region showing terrain and landscape features (Data source DPI 2008).

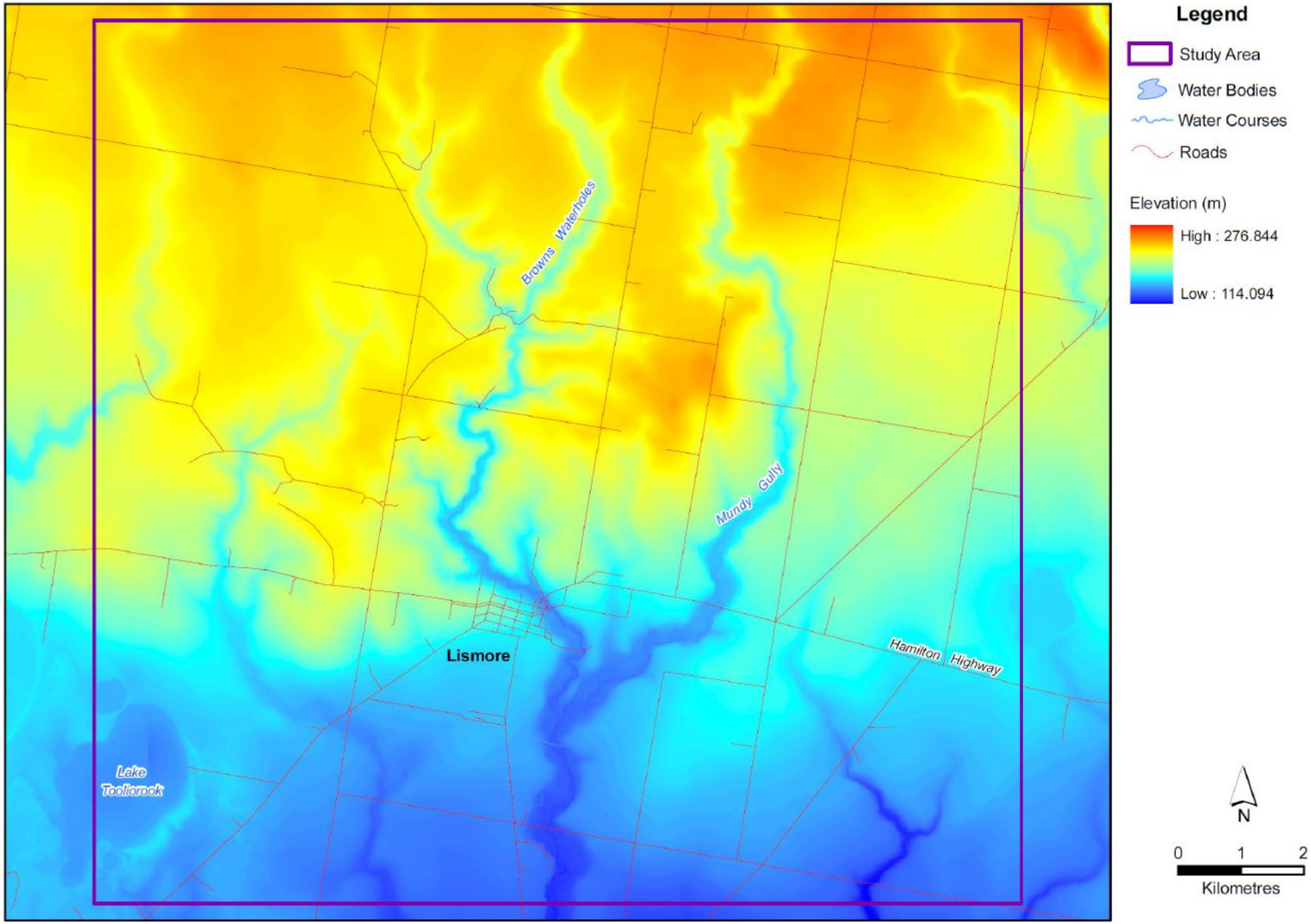

Figure 17b LiDAR DEM displaying elevation for the Lismore study area showing terrain and landscape features (Data source Corangamite CMA 2003, grid cell size 1m).

3.4 Previous mapping of soils in the region

Several studies have been completed which describe the soils formed across the VVP. The following are discussed in chronological order. A summary table is presented in Appendix B.

3.4.1 Soil Studies of the Mt Gellibrand Area

In 1936 Leeper *et al.* conducted a survey of the soils around Mt Gellibrand, near Colac. The study divides the soils into the following components:

Soils of the plains, which includes

- *Soils with Surface Drainage (Stony Rises, Thistle Zone, Lower Slopes)*
- *Swampy Soils*

S*oils of the Mountain*

This division will be continued here for the purpose of the discussion.

Soils of the Plains – Soils with Surface Drainage: This area includes the soils of the *Stony Rises* which have been classified according to soil depth. Stony Rise Brown Loam is the newest soil around Mt Gellibrand, being only 0.2 m deep, high in organic matter and very fertile with abundant basalt rock throughout. Stony Rise Clay still shows basalt outcrops but the rocks are further apart and a flat surface has formed over time. The soils formed here are darker and have a higher clay content.

Leeper describes a *Thistle Zone*, where a crop of thistles grows on a clay loam over heavy clay with mottling and calcium carbonate found in the heavy clay. Leeper links the growth of thistles here to the high lime content, the good fertility and the cracking property of the clays, all of which are conducive to thistle growth.

The *Lower Slopes* support two main soil types which are the predominant soils of the area. A lighter soil with a sandy loam surface leading into heavy clay subsoil is found extensively over the gentle slopes associated with Mt Gellibrand and Mt Pleasant. The second soil of the lower slopes is slightly heavier then the first and is described as a loam to light clay texture over a heavy clay subsoil. A steady line of transition was noted between the two soils of the slopes.

The second class of *Soils on the Plains* according to Leeper is the *Swampy Soils*. These soils have developed under conditions of periodic waterlogging to form grey clays.

Seasonal wetting and drying cycles create a self-mulching soil as the clays shrink and swell. This feature has produced the effect known as gilgai on these *Swampy Soils*.

Soils of the Mountain have formed a dark chocolate clay loam to a clay which is friable and rich in organic matter with calcareous clay found at depth. These soils are highly permeable and quite young due to continual erosion of the topsoil on the slope (Leeper 1936).

3.4.2 Regolith Terrain Units of the Hamilton 1:100 000 sheet area, Western Victoria

Ollier & Joyce (1986) completed a 1:100 000 scale regolith terrain map of Western Victoria which divided the soils of the Lismore Study Area into three groups. The bulk of the area was classed as Class 31, *basalts around the Lismore-Skipton area*. These soils evolved from Pliocene lava flows 5-3 Ma with lateritic profiles up to 10 m deep of kaolinitic weathering with mottled clay and nodular ironstone.

A small section of the Lismore Study Area was covered by Class 33, the *stony rises*. The granite hills were Class 43, *erosional hills of granite*. The granite hills formed uniform coarse sand on steep slopes and a red duplex over silica-rich hard pan on the gentler slopes. Grus could be found on the flanks of the granites at varying depths up to 100 m. Grus is a term given to clastic sediment composed of hard, often abrasive granules of a size range between sand and pebbles, typically from exfoliation of granitic bedrock.

3.4.3 Soil and Landforms of south-western Victoria

Maher & Martin (1987) completed a land assessment of the volcanic plains using aerial photography and field work. The survey divides the region's soils into six main classes then further into subclasses. The entire Lismore basalts are classed by Maher & Martin (1987) as soil class *Ab*: *hard, mottled yellow duplex soils, with partial subsurface bleach*.

According to Maher and Martin, the upper A horizon is commonly a dark greyish brown to dark brown fine sandy clay loam, ranging most often to a clay loam. The lower A horizon shows scattered areas of bleaching, an indication of intermittent waterlogging. High levels of buckshot are commonly found at the boundary between the A and B horizons. Distinct texture-contrast soils such as these show a prominent boundary between the lighter-textured A horizons over a clay-rich subsoil. These are often the dominant soils of the basalt plains. The granite sands have been classed as soft to firm, mottled yellow duplex soils with prominent subsurface bleach.

3.4.4 A New Regolith Landform Map of the Western Victorian Volcanic Plains

In 1999, Joyce completed a paper on the regolith landform map of Western Victoria. From his research of aerial photos, LandSat imagery and radiometric imagery Joyce divided the basalt soils of the VVP into three ages according to their degree of soil cover and the degree of stream incision. Joyce's first bracket of basalt flows included those between 5-3 Ma as dated by K-Ar dating methods. These basalts have produced flat to gently undulating landscapes with continuous soil cover and commonly support scattered Red Gum eucalypt growth. Creeks have cut deeply incised channels on the flanks of lava flows as well as into the surface of flows. The regolith produced consists of deeply weathered kaolinitic profiles often more than 10 m deep, with mottled clay and nodular ironstone.

The middle-aged flows are dated between 3-1 Ma and have formed an undulating and less dissected landscape with many swamps and depressions, as drainage systems are not well formed. Some lunettes have formed on the eastern rims of lakes and swamps that have been seasonally wet and dried.

The youngest flows dated as less than 1 Ma form the stony rise country. This highly undulating country often has changes in relief of more than 20 m from the piles of stony rubble and the surrounding plains. These areas are characterised by stony surfaces, thin soil coverage and a scattering of trees and shrubs. Soil is deepest in the depressions where shallow brown to black clay has formed. Swamps are common in the depressions.

3.4.5 Victoria's Geomorphological Framework

A Geomorphological Framework for the State has been developed on a three tier hierarchical approach based on the initial works of E. Sherbon Hills and primarily based on morphology of the area. The framework divides Victoria into seven first tier geomorphic zones, twenty-seven geomorphology units and a further seventy-seven third tier units. This revised framework, designed by the Victorian Geomorphological Reference Group, is a revised scheme building on the work of Hills (1975) and Jenkin & Rowan (1987).

The use of new technologies such as gamma radiation imaging (radiometrics), digital elevation models (DEM's), recent geological mapping of regolith and structure along with soil surveys has provided new insights into the distribution of land types, their genesis and their behaviour under different external forces (DPI 2007).

The Lismore Study Area comes under the first tier division of *Western Plains*. This division and its subsequent second and third tiers are discussed in section 3.4.6 of this report and in Appendix C. The Land Resource Assessment for Corangamite (Robinson *et al.* 2003) follows this Framework.

3.4.6 A Land Resource Assessment of the Corangamite Region

Robinson *et al.* (2003) completed a detailed study into the landforms of the Corangamite CMA. The Land Resource Assessment (LRA) discusses soil groups of the geomorphic unit *Western Plains* where the three tier system of the Victorian Geomorphological Framework was adopted (Appendix C).

The *Western Plains* geomorphic unit is further divided into *Volcanic Plains, Sedimentary Plains* and *Palaeozoic Inliers* each containing several soil groups. Three of the soil groups of the *Volcanic Plains,* one from *Sedimentary Plains* and one from *Palaeozoic Inliers* occur in the Lismore Study Area (Figure 18) and are discussed here.

The three soil groups of the *Volcanic Plains* represented in the Lismore Study Area are:

- *Plains with well-developed drainage*
- *Plains with poorly developed drainage*
- *Alluvial terraces and flood plains, lakes, swamps and lunettes*

The soil group from the *Sedimentary Plains* is:

- *Plains and plains with low rises*

The soil group form *Palaeozoic Inliers* is:

- *Granitic hills*

Basalts erupting during the early Pliocene have evolved into *Plains with well-developed drainage*. Wetlands are uncommon on these plains and thicker soils have developed. Soil types are predominantly black and brown sodic mottled texture-contrast soils with buckshot in the lower A horizon. A distinct change then occurs into dark, hard-setting heavy clay with mottles. Few rocks are found here due to the age of the basalts.

Stony rises cover approx 680 km^2 of the Corangamite CMA although they do not occur in the Lismore Study Area. The youngest dated stony rises (59 000 years) occur around Mt Porndon near Camperdown. Over time, the stony rise country will evolve into *Plains with poorly developed drainage*, as already occurs across a large proportion of the basalt plains in the Corangamite CMA including the Lismore Study Area. These plains were formed in the Pliocene-Pleistocene and their associated soil profiles are texture-contrast soils and some gradational soils. A dark organic fine sandy loam to clay loam often overlies a bleached iron-rich clay loam layer over a medium clay. Wetlands are commonly found on these plains.

Many lake complexes once existed across the plains, creating an array of lunettes from rising and falling water levels. These have developed into black or grey self-mulching clays, black sodic soils and dark loams and are described as soil group *Alluvium terraces, floodplains, swamps and lunettes*.

The soil group of the *Sedimentary Plains* which occurs in the Lismore Study Area is that of *Plains and plains with low rises*. These included undissected sand plains which includes the Hanson Plain Sands. Soils are typically mottled texture-contrast soils with coffee rock at depth and can be sodic or non sodic.

Granitic hills have been derived from the granites outcropping within the Lismore Study Area and surrounds. These hills are covered by a thin veneer of sandy colluvium on the western slopes which merges with the Pliocene sands. The associated soils are sandy loam to sandy clay loam over a bleached horizon where coarse fragments are found in variable amounts. This overlies mottled yellowish brown medium clay.

Robinson *et al.* (2003) classified 204 soil landform units across the Corangamite CMA. Five of these occur in the Lismore Study Area. Full descriptions are found in Appendix D.

- Alluvial floors
- Undulating low hills derived from granite outcrops
- Quaternary basalt plains
- Neogene sands
- Swamps and depressions

Alluvial floors (landform unit 57) formed where creeks have dissected valleys through lava plains, sediments and granites, so they are found on a range of geologies. They generally produce black cracking clay soils with dark brown uniform texture on the plains. Yellowish brown texture-contrast soils occur on the terraces and lower slopes. These landform units are subject to waterlogging and flooding.

Undulating low hills derived from granite outcrops (landform unit 143) are featured in the Lismore Study Area. They contain a partially remaining veneer of Neogene sedimentary material. Uniform sandy soils (Tenosols) or sands over clays are common on the upper slopes. Mid to lower slopes have produced strongly sodic, mottled brown, grey and yellow texture-contrast soils (Sodosols). These soils can be susceptible to sheet and rill erosion because of their terrain and loose, sandy texture.

Quaternary basalt plains (landform unit 136) make up the largest proportion of the Lismore Study Area and have formed gently undulating plains which retain some basalt stones on the surface. They have generally produced mottled, clay loam texture-contrast soils often with a strongly sodic or heavy clay subsoil.

The soils formed on the *Neogene sands* (landform unit 172) have low fertility and low waterholding capacity. These grey, yellow and or red sandy mottled texture-contrast soils are also prone to gully erosion because of their weak texture. Swamps and closed depressions scatter the dissected VVP and appear to be associated with certain basalt flows. The grey or black cracking clays are prone to waterlogging and compaction if controlled traffic methods are not used. Topsoils are often self-mulching and subsoils can be sodic.

Numerous *swamps and depressions* (landform unit 156) scatter the basalt plains and seem to be associated with certain basalt flows. Soils are generally grey or black cracking clays. In more recent years many of these swamps have dried and are now used for agriculture. Extensive drainage of the swamps has also occurred.

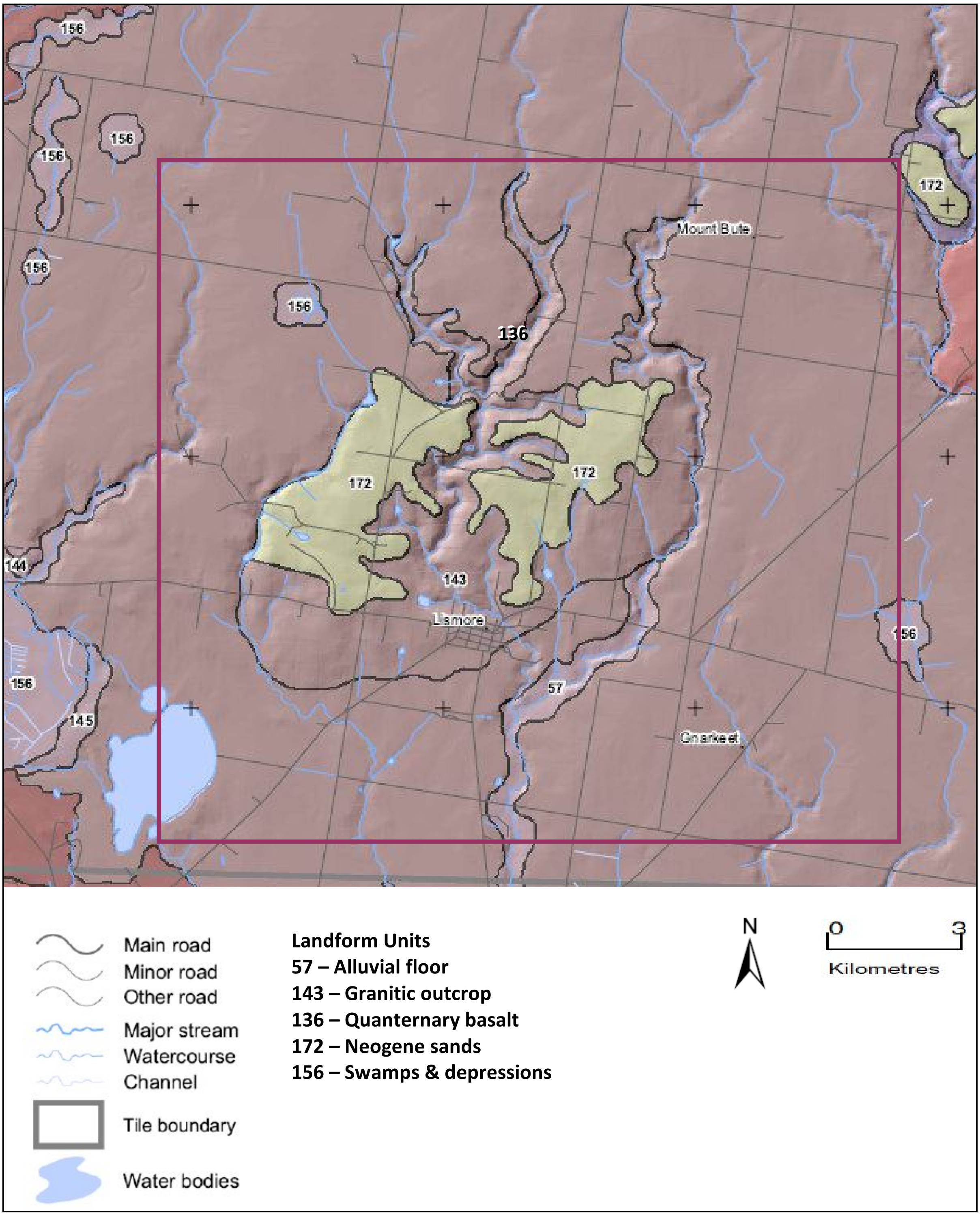

Figure 18 Five broad landform units were mapped across the Lismore Study Area by Robinson *et al.* (2003).

3.4.7 Distribution of Plio-Pleistocene Basalts and Regolith around Hamilton, Western Victoria, and their relationship to Groundwater Recharge and Discharge

The work of Bennett *et al.* (2003) is similar to that of Joyce (1999) in that it describes three distinct phases of volcanics, each producing noticeably different regoliths. In particular it details soils of the Hamilton region and divides the three phases according to periods of activity: ~ 4 Ma, ~ 2 Ma and less than 0.5 Ma.

First phase basalts of around 4 Ma have deeply weathered profiles with buckshot formations. A typical profile consists of a reddish brown clay loam overlying a light brown A_2 horizon. A subsoil of yellowish red clay is followed by kaolinitic clay with mottling. Profiles formed on 2 Ma basalts differ markedly from the 4 Ma flows as they are missing the iron nodule and tiger mottling formations. A general profile shows a brown silty loam followed by a brown clay loam to complete the A horizon. A sharp transition into a yellow clay B horizon then occurs. The youngest of the three phases occurred within the last 0.5 Ma and is distinguished by the irregular ground surface of the stony rises, due to basalt rock outcropping. The soils around the boulders have weathered into reddish brown earths in places and commonly into black clays and peaty soils in depressions and swamps (Bennett *et al.* 2003).

3.4.8 Revisiting a Leeper survey and a Volcano or two

In 2004 Imhof *et al.* completed a follow-up survey of Leeper *et al.'s* 1936 work on Mt Gellibrand and redefined some of the soil types. The lower slopes of the stony rises around Mt Gellibrand were classed as black Vertosols. This is the depositional area for material eroded off the stony barriers. The surface soil is black medium clay which shows surface cracking. There is a clear change to a subsoil of very dark greyish brown clay of medium to heavy texture. The clay content increases down the profile, giving rise to heavy clay with some calcium carbonate found at depth. Significant shrinking and swelling occurs in these soils which produces surface cracking. On the flats associated with older flows, but near the stony rises, a black Sodosol soil was found. The surface soil consists of dark greyish brown sandy loam with some mottling visible in a bleached layer in the lower A horizon. The subsoil is a dark grey clay of medium texture and is described as being a very deep profile with calcium carbonate deposits at depth.

The lower slope of Mt Gellibrand supported a grey Sodosol that is suspected to have originated from Tertiary quartz-rich marine sediments. A very fine surface material, classing as a sandy clay loam, is present. Mottling is found in the lower A horizon. A dark greyish brown heavy clay subsoil follows, which also showed mottling. There was a strong textural contrast between the surface and the subsoil. The basalt scoria crest of Mt Gellibrand has weathered to a black Dermosol. This profile shows dark grey medium texture clay surface soil over a black heavy clay subsoil which shows mottling. The clay content gradually increases down the profile into a well-structured subsoil (Imhof *et al.* 2004).

3.5 Summary of Literature Review

Volcanic activity occurred across the Victorian Volcanic Plains, spanning a period from the Pliocene beginning at 4.6 Ma to the Holocene possibly as recent as 20 000 years, covering the land with a thin veneer of basalt lava. The scoria cones which are a prominent feature of the landscape were produced in the later eruptive phases.

Volcanic activity and subsequent erosion and weathering have been the main factors shaping the landscape and the soils of the Lismore Study Area as it is seen today. Fluid lava formed the plains by filling in shallow valleys and depressions. Lava flows blocked and diverted rivers, altering drainage patterns on a regional scale and resulting in large lake systems and a poorly drained landscape. Drainage systems are still developing in the more recently active areas such as the stony rises.

Several factors influence the soil profile that will form from these basalt plains. The most influential factors are climate, organisms, parent material, relief and time. Several soil types across the plains have been described and discussed by various authors. Soils commonly found on the volcanic plains include rich reddish brown soils, black cracking clays with a self-mulching surface and soils with sodic subsoils. The soil types in the region vary with drainage patterns and location in the landscape and age of the basalt flow.

When considering volcanic soils it must be remembered that, to our current knowledge, the flows over the plains have occurred over a period of almost 5 million years. This leaves a large variation in time where weathering and climatic changes have influenced the resulting soil profiles.

4.0 Methods

4.1 Mapping

Soil series mapping and map production utilised ESRI ArcView3.3 Geographic Information System (GIS) software made available by Department of Primary Industries (DPI). The relevant layers that were used in producing the Lismore Soil Series Map were aerial photography, geology, waterways, topography, LiDAR-derived digital elevation model (DEM) and Total Magnetic Intensity. The layers were combined initially to select potential sites for soil profile investigations.

Aerial photography (Corangamite CMA 2007)

- 2007 orthophotomosaic registered to a geographic co-ordinate system (Map Grid of Australia (MGA) zone 54).
- Supplied by the Corangamite CMA to DPI
- 35cm pixel resolution

Light Detetction and Ranging (LiDAR) (Corangamite CMA 2003)

- Flown by AAM in 2003 in the Victorian Volcanic Plains bioregion
- Gridded to 1m x 1m with a vertical accuracy of +/- 0.3m and a horizontal accuracy of +/- 3
- Projection is MGA zone 54
- Datum: Geocentric Datum of Australia 1994 (GDA 94)
- Raw data supplied by the Corangamite CMA and processed by the University of Ballarat

Geophysical data (GeoScience Australia 2007)

- Total Magnetic Intensity (TMI) and Radiometric K, Th and U.
- Raw data sourced from GeoScience Australia, processed by Linderman Geophysics Pty Ltd for Dahlhaus Environmental Geology Pty Ltd 2007
- Grid cell size 50m

Base Mapping (DSE/DPI digital corporate data library undated)

- Roads (TR_ROAD), Streams (HY_WATERCOURSE), Lakes (HY_WATER_AREA_POLYGON)
- Scale 1:25 000

Bioregions (DSE 2004a)

- Extract made for the Victorian Volcanic Plains (VBIOREG100)
- Department of Sustainability and Environment (DSE) 2004
- Scale 1:100 000

EVC (DSE 2004b)

- Ecological Vegetation Class dataset Native Vegetation Modelled 1750's (NV1750_EVCBCS)
- DSE 2004

4.1.1 Core site selection

To achieve good representation in the Lismore Soil Series Map it was essential to collect core samples from across the 220 km^2 Lismore Study Area. Aerial photography, geological maps and LiDAR DEM were all used to determine core extraction sites. These three tools allowed ideal core extraction sites to be determined which were then matched with landholders wanting to participate in the project. Further detail was then gained from discussions with the landholders on soil type boundaries and best locations to extract cores. This information resulted in a spread of thirty-four cores sites across the Lismore Study Area covering all mapped geologies (Figure 19).

4.2 Field work

Thirty-four intact soil cores were extracted across the Lismore Study Area using a trailer-mounted Pengo-type drill (Figure 20) which produced 1 m deep soil cores with a 0.1 m diameter. Photographs show the surrounding landscape and GPS points were recorded for each core location. Extracted cores were described, sealed and labelled for transportation back to the laboratory at University of Ballarat for further analysis (Figure 21). Once in the laboratory each core was unsealed and carefully picked back to expose a fresh, undisturbed face of the soil's profile. A profile description was completed using the methods outlined below, while the remaining soil was bagged in calico bags, labelled and transported to the DPI soil laboratory at Bendigo were electrical conductivity (EC) and $pH_{(w)}$ were measured. Intact soil cores were supplemented by hand augering at eight locations to best define the soil boundaries and confirm suspected soil types. These samples were described in the field and not retained or analysed.

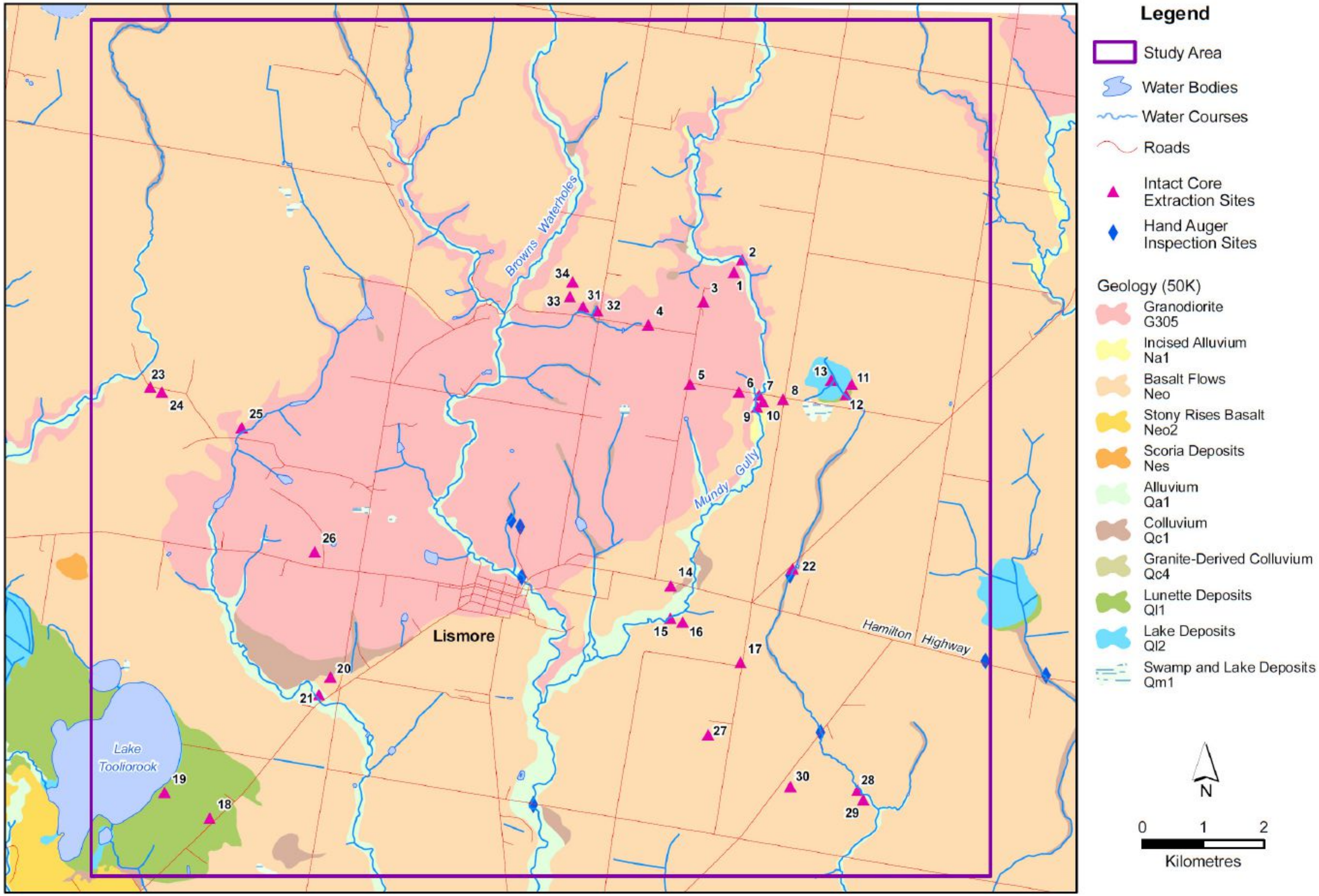

Figure 19 Geology of the Lismore Study Area showing intact core extraction and hand auger locations (Data source GeoScience Australia 2007, scale seamless 1:50 000 series).

Figure 20 A trailer-mounted Pengo-type drill was used for the extraction of intact soil cores (Photograph S McConachy).

Figure 21 Soil profiles were described before being sealed for transportation to the laboratory (Photograph G. Wallis).

4.3 Laboratory analysis

A soil series is defined or delineated by similar pedology, such that soils with similar profiles, colour, texture, structure, consistence and composition are grouped together. These properties are further used to discuss the soil's agricultural applications. Laboratory analysis involved full profile descriptions for each core, using the Australian Soil and Land Survey: Field Handbook (McDonald *et al.* 1990). The methods used have been summarised below. Full details of the standard analytical methods used to determine particle size, pH and electrical conductivity are set out in Laboratory Methods: for the Land Evaluation Group (Jones unpublished a).

4.3.1 Horizons

Soil profiles are described in terms of their horizons as assessed in this study. Soil horizons are distinguished by properties or appearance that differs from the soil above and below it. In this study each horizon has been measured in centimetres and documented according to the standard procedure (McDonald *et al.* 1990). The soil profile comprises the soil horizons and pedological characteristics.

4.3.2 Munsell soil colour chart

Colour provides an easily recognisable indication of a soil's fertility and drainage and often relates to position in the landscape. Colour may also indicate soil parent material. The Munsell system determines soil colour by comparing the freshly broken surface of a moist soil aggregate (moisten if dry) to the colour chart. The soil's hue, value and chroma are taken from the chart and recorded in the following form *10YR3/3*. The chart also provides a name for this colour, for example *dark brown*. If an exact match can not be found the closest match is used.

4.3.3 Mottles

Mottles are blotches or streaks of colour different to the base colour of the soil ped and indicate the presence of past waterlogging. Mottles are a consequence of reduction/oxidation chemical reactions of iron. The type, size, abundance and contrast of mottles are recorded along with their colour. The Munsell Soil Colour Chart is used to determine the colour of any blotches or streaks that are a different colour from the base soil colour previously determined.

4.3.4 Texture

Texture is a measure of the proportions of sand (2–0.02 mm), silt (0.02–0.002 mm) and clay (<0.002 mm) in a soil. This is useful for estimating a soil's waterholding capacity and its ability to retain nutrients, known as the Cation Exchange Capacity (CEC). Changes and trends in texture down a profile are also used to classify soil types. Field texture is described by McDonald *et al.* (1990) as "a measure of the behaviour of a small handful of soil when moistened and kneaded into a ball and then pressed out between thumb and forefinger". Soil is passed through a 2 mm sieve to remove roots, coarse fragments and segregations which would impede the hand texture test. A small amount of soil is then gradually moistened and worked by hand to form a bolus (ball of soil). This bolus is then manipulated to feel for sands and silts and a ribbon is produced by pressing out between thumb and forefinger to determine clay content. These observations are used to determine a field texture for the soil, for example *silty clay loam.*

4.3.5 Coarse fragments

Coarse fragments are described by Jones (unpublished b) as "particles coarser than 2 mm. They include stones, gravel and unattached rock fragments, but do not include segregations of pedogenic origin." Coarse fragments are described according to their abundance, size, shape, lithology and their distribution throughout the soil profile. These are all estimated by eye, using charts provided in the Australian Soil and Land Survey: Field Handbook (McDonald *et al.* 1990).

4.3.6 Structure

Structure is the way soil particles are arranged and bound together and so determines profile hydrology and the ease with which roots will penetrate. To reliably describe soil structure, a vertically exposed soil profile or intact soil core is required so an undisturbed profile can be viewed. Recording a soil's structure requires identifying the individual soil peds and describing their overall grade, size and shape in each horizon. Charts are provided in the Australian Soil and Land Survey: Field Handbook (McDonald *et al.* 1990) to assist with determining the shape of peds and descriptions help to determine the peds grade and size. The consistence is a measure of the strength and coherence of a soil which provides an indication of the ease with which roots will penetrate individual aggregates, the permeability of the soil for water movement and how well a soil will maintain its structure when cultivated for agricultural use.

4.3.7 Segregations of pedogenic origin

Segregations include buckshot and carbonate deposits. High proportions (>50%) of buckshot or hard rock fragments, especially when within 0.5 m of the surface, greatly reduce the effective soil volume of a profile and are highly abrasive to tillage implements. Reduced effective soil volume means there is physically less soil to store water and nutrients which can severely limit plant growth. High proportions of carbonates, depending on the composition, also impede drainage and restrict root growth. Concentrations of certain constituents in the soil can form segregations, usually through chemical or biological means. These segregations are assessed according to their abundance, size, strength, shape and the nature of their material. For example a "calcareous" segregation is made up of carbonate minerals and a "ferruginous" segregation is formed from iron minerals.

4.3.8 Water repellence

Some soils, commonly sandy soils, have waxes attached to sand grains which prevent water moving quickly into the soil. The field test for water repellence is simply measuring the time taken for a droplet of water to be absorbed into the soil.

4.3.9 Effervescence of carbonate

The presence of carbonates influences soil pH and, depending on the form and size of the carbonate segregations, may influence water movement through the profile. To determine whether a soil contains calcareous fractions a few drops of 1-molar hydrochloric acid is added and any visible or audible effervescence is noted.

4.3.10 Boundary

The type of boundary between each horizon is described according to its width, whether it is a sharp or gradual change, and the shape.

4.3.11 Field and laboratory pH

Soil pH is the measure of acidity or alkalinity on a scale of 0 to 14 measuring the concentration of hydrogen ions in a soil. An ideal pH for agricultural use is between pH $5.6_{(w)}$ and pH $7_{(w)}$. Parent material and agricultural practices both influence soil pH. All pH measurements discussed in this report are pH in water. A field pH test kit was used to determine a pH value and gives a reading in water accurate to within 0.5 of a unit. pH in water was also tested at the DPI soil laboratory at Bendigo.

4.3.12 Electrical Conductivity

Additional analysis was completed at Bendigo DPI for EC which measures the salt content of a soil. Following the standard procedure, the electrical conductivity of a mix of one part soil to 5 parts water is measured and recorded. Soils with a high electrical conductivity usually contain high levels of salts.

4.3.13 Particle Size Analysis

Particle size analysis was undertaken by "Farmworks" at Meredith where the Bouyoucos method (Bouyoucos 1936), which divides particles into the following ranges, was followed.

Coarse sand: 2-0.2 mm

Fine sand: 0.2-0.02 mm

Silt: 0.02-0.002 mm

Clay: <0.002 mm

The basic method used for this procedure is as follows:

- Weigh sample, oven dry, weigh again. This gives gravimetric moisture content of the soil
- Sieve out fractions larger than 2 mm
- Put 90-100 g of soil (weighed to 0.01 g) in 1 litre water
- Disperse for minimum 8 hrs on end-over-end shaker
- Put dispersed suspension in 1 litre measuring cylinder
- Measure with hydrometer after 4 minutes (clay and silt fractions)
- Measure with hydrometer after 2 hours (clay fraction)
- Sand percentage is measured by rinsing and draining repeatedly (until suspension is clear after 4 minutes) then oven dry remainder
- Results are checked by adding the sand, silt and clay fractions which should total 100.

5.0 Results and Discussion

The results of this study, mapping at 1:25 000, identified six soil series which were delineated by their profiles through the extraction of soil cores and hand augering combined with the study of aerial photos and geological maps. Robinson *et al.* (2003), the most recent and detailed soil series map covering the Lismore Study Area, identified only five soil landform units within this Lismore Study Area when mapping at a regional scale of 1:100 000.

Based on the soil profile, physical and chemical data of the various geological and topographic locations, the following Soil Series were delineated by this study:

- Granitic Sandy Loams
- Buckshot Clays
- Nowra Red Clays
- Lismore Grey Clays
- Mundy Gully Black Clays
- Lunette Clays

These are described in detail in the following sections.

Differences between soil series mapping by Robinson *et al.* (2003) and this study are represented in Table 1 and further described below.

Table 1 Differences between soil series mapped by Robinson *et al.* (2003) and those delineated by this study for the Lismore Study Area.

Robinson *et al.* 2003	**Lismore Study Area**
Granites, landform unit 143	Granitic Sandy Loams
Neogene Sands, landform unit 172	Buckshot Clays
Basalt, landform unit 136	Nowra Red Clays
	Lismore Grey Clays
Alluvium, landform unit 57	Mundy Gully Black Clays
Swamp & depressions, landform unit 156	
Lunette, landform unit 145 (Not mapped in the Lismore Study Area)	Lunette Clays

The soil mapping for this thesis confirms that the Neogene sands and their derived soils, the Buckshot Clays, are far less extensive than shown in the Corangamite LRA map (Figure 18) (Robinson *et al.* 2003) but do exist in patches of < 5 Ha. They are no longer shown on the most recent 1:50 000 seamless geological maps (DPI 2008). Basalts (landform unit 136) have been divided into two soils *cf* Robinson *et al.* (2003) based on distinct differences in colour, structure and degree of weathering which is interpreted to reflect differences in age of basalt flows. Alluvium (landform unit 57) and the swamps and depressions (landform unit 156) have been grouped into Mundy Gully Black Clays based on common characteristics of being black cracking clays (Vertosols) with carbonate deposits. From an agricultural perspective these are a single soil type. Lunette Clays were not distinguished by Robinson *et al.* (2003) at Lake Tooliorook and on other smaller depressions in the area however lunettes (landform unit 145) are recognise elsewhere in the Corangamite CMA. Stony rises are absent from the Lismore Study Area.

Agricultural cropping occurs across all six delineated soil types in the Lismore Study Area. The suitability of each soil type to cropping is dependent on soil moisture retention. The Lismore Study Area receives an average growing season rainfall (measured from April to November) of 463 mm (BOM 2009a). In years experiencing low growing season rainfall the Nowra Red Clays and Lismore Grey Clays perform best, while in high rainfall years the Lunette Clays are most productive due to being more freely drained. The Mundy Gully Black Clays are ideal for cropping in moderate years. Higher moisture levels are required to wet the soil profile and stimulate germination but excessive soil moisture renders these soils untrafficable as they become waterlogged in very wet years. Raised-bed cropping is increasingly being adopted to overcome waterlogging by improving drainage through more rapid water flow. In addition, controlled machinery trafficking to the furrows prevents soil compaction on the raised beds.

The pH of the studied soils ranged from pH 5 to pH 9 with an average of pH 6.5. Soils developed on the granites showed a greater acidity than those on the basalts and so require higher lime inputs to maintain production. Textures ranged from sandy loam to clay loam sand on the Lunette Clays and Granitic Sandy Loams but clay texture soils were much more widely spread across the remaining soils. The alluvial deposition soils of the Mundy Gully Black Clays showed the highest clay content, followed by the Lismore Grey Clays. All results are appended (Appendix E). Salinity is known to exist around the Lismore region. Chemical analysis showed no immediate salinity issues in the upper horizons. Salinity levels did increase down the profile of all sampled soils and reached levels unfavourable to agriculture on the soils with heavier clay subsoils such as Lismore Grey Clays and Mundy Gully Black Clays.

5.1 Mundy Gully Black Clays

Figure 22a Representative landscape where Mundy Gully Black Clays are found along creek flats (core site 15) (Photograph S. McConachy).

Figure 22b Representative landscape where Mundy Gully Black Clays are found in swamp sites (core site 13) (Photograph S. McConachy).

General features

Mundy Gully Black Clays are dark grey to black, medium to heavy clay soils with soft carbonate deposits occurring around 1 m. They typically occur along broad creek flats and in old swamp beds due to their alluvial depositional origin (Appendix F, Core 2, 8, 9,13,15, 21 and 28).

Description and Agricultural implications

Heavy clay soils with shrink-swell properties class these soils as typical black Vertosols according to the Australian Soil Classification (Isbell 1998). Shrink-swell properties create a semi-self-mulching topsoil and forgiving soil structure that overcomes compaction issues when large, deep cracks form over summer.

The profile shows a generally weak A_1 horizon overlying a firm to very firm lower A horizon and subsoil (B horizon). Hard, firm or very firm consistence restricts water movement and root penetration through the profile. Most sites in this soil reached firm to very firm material at only 0.1 m depth, indicating that plant vigour would be restricted. Tap root plants with strong root development may penetrate harder horizons especially utilising soil cracks. Typical profiles show medium textured clay A_1 horizon, although where erosion has deposited soils from up-slope a loam A_1 is found over the medium to heavy clay. Textures indicate high proportions of clay present in the profile giving the soil a high waterholding capacity and good nutrient retention ability. Clay soils have a higher CEC compared to lighter-textured soils.

Colour ranges between black, dark grey and very dark grey indicating the presence of organic matter in the profile as expected due to their depositional origin. Their heavy clay texture and position in the landscape make these soils prone to waterlogging in wet years. Waterlogged horizons are indicated by the presence of faint orange mottling in a greyish matrix in the lower profile, particularly in the swamp soils. Mottles indicate a prolonged phase of anaerobic conditions that occurs when a soil is saturated for extended periods. Waterlogging leaves only a small window of opportunity for these soils to be trafficked without causing extensive compaction. This issue has lead to the adoption of raised beds which allow cropping in wet years to fully utilise these fertile soils. These deep clay profiles are generally well structured with a strong to massive grade of sub angular blocky to angular blocky peds. Ped size is generally 10–20 mm or less until a massive structure and larger peds are reached at around 0.7–1 m depth, generally at a B_{22} or B_{23} horizon.

At sites adjacent to the Granitic Sandy Loams, coarse fragments of granite are found throughout the profile such as at core sites 2 and 9 due to wash off. Soft segregations of calcium carbonate are generally found around 1 m, sometimes as shallow as 0.65 m. The presence of carbonates gives the lower profile an effervescent reaction to hydrochloric acid. The proportions of segregations and coarse fragments found are small (<10 %) and so do not adversely affect overall effective soil volume. Waterholding capacity and nutrient retention is not reduced. When high proportions of fine calcium carbonates are present in a profile, such as at core sites 2, 9, and 15, drainage and root growth are impeded at that depth.

Alkalinity increases down the profile ranging from an acidic topsoil (pH 5.5 – pH 6) gradually changing to an alkaline subsoil (pH 9 – pH 10), particularly where carbonates are present.

Occurrence

The Mundy Gully Black Clays are depositional material largely derived from weathered basalt. These soils are typically found on the broad alluvial plains where creeks have cut through the basalt and also in the beds of past swamps. In the Lismore Study Area these soils occur along wide stretches of Mundy Gully and lower reaches of Browns Waterholes but have only formed narrow stretches along smaller drainage lines. They also make up the soils of the several small swamps that are marked by lunettes on their eastern edges.

Extensive shrinking and cracking makes these soils unable to support the growth of trees and large shrubs, leaving grasses, tussocks and herbs as the primary vegetation (Plains Grasslands, EVC 132) (T. D'Ombrian pers. comm. 2008). The native grasslands have long since been grazed out during early settlement and more recently the dry years and use of raised beds have allowed these flats to be cultivated and cropped where it historically would be too wet.

Swamp sites once supported Plains Sedgy Wetlands (EVC 647) which included many of the grasses and herbs found on the grasslands, but also sedgy-herbaceous vegetation and occasionally scattered paperbark shrubs in wetter areas. This vegetation class preferred seasonally wet, fertile, and silty to heavy clay soils (DSE 2005). These swamps are now commonly used for grazing in dry years and show few signs of the original vegetation.

Representative soil - Mundy Gully Black Clays

General description of the soil

Medium to heavy grey or black clay profile with carbonates at depth. Common to broad alluvial plains of Mundy Gully and lower reaches of Browns Waterholes. Also found in swamp areas.

Distribution:	Alluvial flats, flood plains and dry lake beds
Typical land use:	Grazing or cropping in dry years
Common variants:	Depth to carbonates and clay content
Other names	Black Vertosol

Environment and location of the example profile

Landform:	Flat, low lying
Parent material or substrate:	Alluvial
Drainage class:	Poor, water logging common in winter
Surface condition:	Friable, self mulching
Site disturbance:	Cultivated and sown to crop
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map

Mundy Gully Black Clays

Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Coarse fragments	Segregations	Boundary
A1	0.0-0.13	Black	-	Medium clay	Strong	Sub angular blocky	10-20mm	Firm (mod moist)	-	-	Clear
B21	0.13-0.34	Black	-	Heavy clay	Massive	Angular blocky	-	Very firm (moist)	-	-	Clear
B22	0.34-0.64	Black	-	Heavy clay	Strong	Sub angular blocky	20-50mm	Firm (mod moist)	-	-	Abrupt
B23	0.64-1.05	Black	-	Heavy clay	Massive	-	-	Firm (mod moist)	-	<2% medium calcareous soft segregations	-

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm	Particle Size Analysis Sand %	Silt %	Clay %	Determined texture
A1	0.0-0.13	6	-	6.04	365.00	33.4	19.2	47.4	Clay
B21	0.13-0.34	7	-	7.20	196.00	29.9	16.7	53.4	Clay
B22	0.34-0.64	8	-	8.05	311.00	23.8	15.6	60.6	Clay
B23	0.64-1.05	9	Moderate	9.42	803.00	27.1	13.2	59.7	Clay

5.2 Lismore Grey Clays

Figure 23 Representative landscape on which the Lismore Grey Clays are found (core site 14) (Photograph G. Wallis).

General features

Very dark grey to greyish brown medium to heavy clay makes up the most common soil occurring across the volcanic plains of the Lismore Study Area and is classified as a brown Sodosol (Isbell 1998). Concretions of buckshot, also referred to as pisoliths, are common and carbonates are often found at depth (Appendix F, cores 6, 8, 14, 17, 24, 27 and 30)

Description and Agricultural implications

Consistence is usually weak down the profile, indicating no restrictions to root penetration or water movement. Consistence increases in dry peds, while being weak in wet peds. However, sites where compaction occurs in the A horizon and into the upper B horizon have firm to strong consistence. Root growth is inhibited through these horizons, causing stunted early growth of plants. Such horizons also impede drainage after heavy rainfall as water moves slowly through the upper profile.

The high clay content (>50%) of these soils provides a good CEC, allowing one-off fertiliser applications to occur without risk of high nutrient losses through leaching. Waterholding capacity is also good. Profiles with the lighter texture A_1 horizons still have adequate clay content to retain water and nutrients.

Colours range from greyish brown in the A_1 and upper B horizons down to yellowish brown and olive brown in the lower B horizon. Greyish brown colours indicate moderate organic matter build-up in the soil and moderate fertility. The increasingly pale colours down the profile indicate that leaching of nutrients and organic matter has occurred over time. Structural grade is moderate to strong consisting of polyhedral or sub-angular blocky peds. Roots and water have difficulty moving into peds so root growth and drainage of these soils is reduced. The presence of some mottling in various horizons identifies repeated wetting and drying cycles causing the oxidation of iron in the soil. Raised-bed cropping is widely used across the Lismore Grey Clays to overcome reduced drainage.

Lismore Grey Clays contain around 2% buckshot, generally in the B horizon. Coarse fragments of granite are found in small amounts (<2%) throughout profiles taken in close proximity to the Granitic Sandy Loams, while cores extracted in other sites show no coarse fragments. Such small amounts of both segregations and coarse fragments have no impact on the soil's waterholding capacity or total soil volume.

Lower profiles effervesce to hydrochloric acid indicating the presence of carbonates accumulating at depth. Soil pH becomes increasingly alkaline down the profile ranging from pH 5.5 to pH 6 in the A_1 and up to pH 9 in the subsoil. The acidic topsoil requires the addition of lime for productive agriculture and gypsum is often applied to improve structure and drainage of the clay. Salinity levels increase down the profile, possibly due to the poor drainage and the eluviations of salt from the upper horizon and illuviation to the lower horizons. Common variations within the Lismore Grey Clays are the distribution of buckshot and mottles in the profile and the depth to carbonates.

Occurrence

The Lismore Grey Clays are the most widely found soil type across the Lismore Study Area, forming from intermediate basalt flows from around 3.6 Ma (Gray & McDougall 2009). Lava flowed across the landscape from several small unknown eruption points forming relatively thin sheets. These soils are found across the flats, sometimes forming gentle undulations and may be cut by drainage lines which have followed along basalt flow margins.

The landscape of the Lismore Grey Clays is generally planar and is used widely for both grazing and cropping. Similar to other heavy clay soils these areas did not support vegetation larger than the grasses, tussocks and herbs that were found across the VVP (Plains Grasslands, EVC 132) (DSE 2005).

Representative soil - Lismore Grey Clays

General description of the soil

Dark grey brown, lighter textured A horizon over heavy clay subsoil. Some segregations throughout profile with carbonates at depth. Cores extracted near Granite Sandy Loams include coarse fragments from washoff.

Distribution:	Found extensively across basalt plains
Typical land use:	Cropping and grazing
Common variants:	Depth to and amount of carbonates
Other names	Brown Sodosol

Environment and location of the example profile

Landform:	Flat to gently undulating
Parent material or substrate:	Basalt
Drainage class:	Moderate
Surface condition:	Slight compaction
Site disturbance:	None
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map

Lismore Grey Clays

Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Coarse fragments	Segregations	Boundary
A1	0.0-0.14	Very dark grayish brown	-	Clay loam, sandy	Strong	Sub angular blocky	5-10mm	Very weak (moist)	<2% small granite pebbles	<2% medium FeMg concretions	Abrupt
B1	0.14-0.44	Gray	<2% fine, faint orange	Heavy clay	Moderate	Polyhedral	10-20mm	Weak (moist)	-	2-10% coarse FeMg concretions	Abrupt
B21	0.44-0.76	Grayish brown	-	Heavy clay	Moderate	Polyhedral	20-50mm	Weak (moist)	<2% small granite pebbles	<2% medium FeMg concretions	Clear
B22	0.76-1.00	Light yellowish brown	-	Heavy clay	Moderate	Polyhedral	20-50mm	Weak (moist)	<2% small granite pebbles	<2% fine FeMg concretions	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm	Particle Size Analysis Sand %	Silt %	Clay %	Determined texture
A1	0.0-0.14	5.5	-	5.87	256.00	42.9	17.0	40.2	Clay
B1	0.14-0.44	7	-	6.61	298.00	38.8	17.8	43.4	Clay
B21	0.44-0.76	8.5	Moderate	8.39	722.00	30.4	12.3	57.3	Clay
B22	0.76-1.00	9	High	8.82	1242.00	27.7	13.1	59.2	Clay

5.3 Nowra Red Clays

Figure 24 Representative landscape in which the Nowra Red Clays are found (core site 16) (Photograph S. McConachy).

General features

Friable dark brown to very dark brown clay soil appearing red in the broader landscape. Typically exposed where drainage lines have cut through Lismore Grey Clays exposing older, underlying basalts. Carbonates found at depth create an increasingly alkaline lower profile. Classed as red or brown Ferrosols (Isbell 1998) (Appendix F, cores 10, 16, 23 and 29).

Description and Agricultural implications

The firm consistence of individual peds in the A_1 and upper B horizons limits the ease with which roots access water and nutrients stored within aggregates. Consistence is firmest when peds are dry. As moisture content increases down the profile ped strength weakens.

Texture is light clay A_1 horizon to around 0.25 m depth, with a gradual change into medium to heavy clay subsoil. Colour ranges from dark brown to very dark brown although appears distinctly red in the landscape. Such colours indicate a well-drained soil with good aeration and organic matter accumulation in the A_1 horizon. Iron in the soil gives the reddish brown appearance and can fix phosphorus by binding it to the iron, making it inaccessible to plants (Peverille *et al.* 1999).

Nowra Red Clays are generally well-structured, moderate to strong grade blocky peds, creating a freely drained and well aerated soil with good waterholding capacity. Roots can grow with ease down the profile, with many fine roots found down to 0.6 m depth. The friable structure makes an excellent seed bed and raised beds are not essential on the Nowra Red Clays although this form of controlled-traffic farming is considered best practice to maintain soil structure.

Pockets of buckshot occur in some profiles and fragments of weathered basalt parent material are found at varying depths depending on location. In shallower profiles soft calcareous nodules are found as a weakly structured mass. Depths to parent material and carbonate deposits are common variants across these soils. Typical of carbonate-rich clays soil pH becomes alkaline down the profile beginning at pH 5 to pH 6 in the A horizon and reaching pH 8.5 in the lower B (B_{22} or B_{23}). Lime is often applied to soils with a topsoil of this pH range to allow maximum production but pH is generally adequate (P. McConachy, pers. comm. 2009).

Occurrence

The Nowra Red Clays are correlated with the weathered remnants of earlier volcanic activity of the VVP dated to around 3.6 Ma (Gray & McDougall 2009). It is probable that these soils were formed under warmer and wetter climatic conditions which were more conducive to deep weathering. Alternatively, the mineralogy of the parent material and longer time for soil formation could influence the resulting soil profile (refer to section 3.2). The soils are found along slopes above the Mundy Gully Black Clays, where creeks have cut their paths. Sections are also exposed in the creek bed of Mundy Gully. Nowra Red Clays can also be found on the plateau surrounded by Lismore Grey Clays where later lava flows were thin and have subsequently been eroded, exposing patches of Nowra Red Clays.

The botany occurring on this soil group is not distinguished from the Lismore Grey Clays on EVC maps. It is likely that it supported Plains Grasslands (EVC 132) (DSE 2005).

Representative soil - Nowra Red Clays

General description of the soil

Light clay A_1 with clay content increasing down profile. Carbonate accumulations found past 0.80m. Core extracted from red bank on the edge of basalt plateau above Mundy Gully.

Distribution:	Exposed on slopes beside creek valleys and in small patches on plains
Typical land use:	Cropping or grazing
Common variants:	Depth to carbonates
Other names	Nowra Red Clay, Brown or red Ferrosol

Environment and location of the example profile

Landform:	Moderate slope on edge of plateaux
Parent material or substrate:	Basalt
Drainage class:	Excellent
Surface condition:	Friable
Site disturbance:	Cultivated and sown to crop
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map

Nowra Red Clays

Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Shape	Size	Consistence	Course fragments	Segregations	Boundary
A1	0.0-0.25	Very dark brown	-	Light clay	Strong	Sub angular blocky	5-10mm	Very firm (dry)	<2% small quartz pebbles	10-20% fine FeMg concretions	Gradual
B1	0.25-0.42	Very dark brown	-	Light medium clay	Moderate	Sub angular blocky	2-5mm	Firm (mod moist)	-	-	Gradual
B21	0.42-0.67	Very dark brown	2-10% fine faint orange	Medium clay	Moderate	Sub angular blocky	10-20mm	Firm (moist)	-	-	Gradual
B22k	0.67-0.89	Brown	-	Heavy clay	Weak	Sub angular blocky	10-20mm	Weak (moist)	-	20-50% course calcareous nodules	Clear
B23k	0.89-0.94	Brown	-	Heavy clay	Weak	Sub angular blocky	2-5mm	Weak (moist)	-	>50% med. to course calcareous nodules	-

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm	Particle Size Analysis Sand %	Silt %	Clay %	Determined texture
A1	0.0-0.25	6	-	6.28	267.00	49.8	14.1	36.1	Clay
B1	0.25-0.42	7	-	6.05	389.00	33.3	18.2	48.5	Clay
B21	0.42-0.67	7.25	-	6.39	274.00	29.5	17.5	53.0	Clay
B22k	0.67-0.89	7.5	-	8.18	402.00	42.4	10.8	46.8	Clay
B23k	0.89-0.94	8.5	High	8.36	506.00	48.5	6.9	44.6	Clay

5.4 Granitic Sandy Loams

Figure 25 Representative landscape on which the Granitic Sandy Loams are found (core site 1) (Photograph S. McConachy).

General features

A brown to yellow, sandy clay soil formed on weathered granite, suitable for grazing and is successfully cropped. Granite outcrops are exposed mid slope in some locations. Classed as brown or grey Sodosol (Isbell 1998) (Appendix F, cores 1, 4, 5, 20, 25, 26, 31 and 32).

Description and Agricultural implications

Consistence of the Granitic Sandy Loams is generally weak and although this indicates root penetration and permeability is not restricted, it leaves soils susceptible to compaction. Paddocks worked under undesirable soil moisture conditions, when soils are too wet, result in degradation of the soil's structure. Surface compaction of the A_1 horizon, generally to 0.2 m is not uncommon in grazed paddocks, even where cultivation has not occurred. Consistence becomes firm as clay content increases down the profile.

Texture is a clay sand or sandy clay loam. High proportions of sand can reduce fertility levels due to a reduced CEC. In management terms, split fertiliser applications should be considered as the soil has a lower capacity to bind to and store nutrients, compared to high clay content soils. Sandy textured soils are generally well-drained. However the higher clay content of the subsoil reduces water movement, creating a perched watertable in wet years, resulting in waterlogging issues. This issue was identified in the waterlogging susceptibility study of the Corangamite CMA (DPI 2008) and its susceptibility map (Figure 14). Anecdotal evidence shows areas of the Granitic Sandy Loams are known for their 'spewy' soils when the profile is saturated making them suited to cropping in dry to moderate years as long as crops are sown while the soils are still traffickable (P. McConachy pers. comm. 2009). Structure grade varies between sites, but the majority of samples show weakly graded structure of small (2-10 mm) peds of various shapes and very weak soil consistence, explaining the soil's lack of structure when wet. In terms of profile hydrology and ease of root penetration this soil's structure allows a relatively freely draining A horizon and roots easily grow down the profile unless other barriers to growth exist.

Colours vary from brown or dark brown to yellowish dark brown, but the overall appearance is brownish A horizon over a yellowish subsoil. Brown topsoil indicates the accumulation of small amounts of organic matter. Mottling, an indication of waterlogging, occurs in the subsoil as clay content increases. Pockets of buckshot (10-50%), an indicator of prolonged seasonal waterlogging, are found in some profiles while small amounts (2-20%) of coarse granite fragments are prominent in those on the mid to lower slopes. Soils with the higher amounts (50%) of buckshot have reduced effective soil volume, resulting in a lowered waterholding capacity and CEC. Generally the coarse fragments and segregations are not found in such high proportions in the A_1 horizon so the abrasive effect on equipment is not significant. However this also leaves the A_1 horizon open to compaction from trafficking, as has occurred in some locations.

Soil pH is acidic and varies only slightly between pH 5 to 5.5 at A_1 and pH 6 to 6.5 at B2. Lime is required annually to maximise agricultural production.

Occurrence

The Devonian granite being more resistant to weathering and erosion than the surrounding material was left as rocky outcrops which, at their higher elevation, were not covered by later basalt extrusions. Subsequently the surface of these granite plutons has weathered to form the Granitic Sandy Loams which cover the gently undulating hills rising from the basalt plains.

Unlike the heavier clays these lighter soils sustained woody vegetation such as drooping she-oaks and prickly wattles which grew scattered across the grasslands (Plains Grassy Woodlands EVC 55) (DSE 2005).

Representative soil - Granitic Sandy Loams

General description of the soil

A sandy loam A horizon susceptible to compaction. Extensive buckshot material in a fine sandy loam matrix in the A_3 horizon overlying a higher clay content subsoil which may impede drainage.

Distribution:	Capping weathered granite
Typical land use:	Grazing, some cropping
Common variants:	Depth of compaction, depth to clay subsoil
Other names	Brown or grey Sodosol

Environment and location of the example profile

Landform:	Ridge above Browns Waterholes
Parent material or substrate:	Granite
Drainage class:	Moderate
Surface condition:	Loose material, some compaction
Site disturbance:	None
Native vegetation:	None present (originally Plains Grassy Woodlands EVC 55)

Location map

Granitic Sandy Loams

Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Course fragments	Segregations	Boundary
A1	0.0-0.24	Brown	-	Sandy loam	Weak	Platy	20-50mm	Very weak (dry)	-	10-20% medium FeMg concretions	Clear
A3	0.24-0.43	Brown	-	Sandy loam	Massive	Polyhe-dral	5-10mm	Weak (dry)	-	>50% coarse FeMg concretions	Abrupt
B2	0.43-0.72	Dark yellowish brown	<2% fine faint red	Clay loam sand	Moder-ate	Polyhe-dral	5-10mm	Firm (dry)	-	2-10% medium FeMg concretions	-

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Repel-lence	Lab. pH (w)	EC uS/cm	Particle Size Analysis Sand %	Silt %	Clay %	Determined texture
A1	0.0-0.24	5	-	yes	5.02	116.50	78.4	10.5	11.1	Sandy Loam
A3	0.24-0.43	5.5	-	-	5.64	139.00	79.1	8.0	12.9	Sandy Loam
B2	0.43-0.72	6.5	-	-	6.18	141.90	39.1	9.0	51.9	Clay

5.5 Lunette Clays

Figure 26 Representative landscape on which the Lunette Clays occur (core site 12) (Photograph S. McConachy).

General features

Crescent-moon-shaped features termed lunettes have formed along the eastern rim of swamps, built up by wind-blown material. Texture is silty clay loam, with underlying swamp deposits found at depth. They are classed as brown Vertosol (Isbell 1998) (Appendix F, cores 11, 12, 18 and 19).

Descriptions and Agricultural implications

Consistence is weak and due to their good permeability and ease of root penetration the Lunette Clays are commonly used for growing deep-rooted species that have a low tolerance to waterlogging, such as lucerne. On sites where cores reached the black clay there is firm consistence, so root penetration is restricted and some waterlogging occurs at this level. Core 12 shows evidence of waterlogging where mottling is recorded throughout the B horizon, with 20-50% of medium size mottles occurring in the B_1 horizon.

Lunettes are well-drained due to the high proportion of sands and silts in a clay matrix making up the sandy clay loam or silty clay loam texture. High proportions of sand in a soil ensure ample macro-pores exist for fast drainage. Depending on proportions of clay and silt in the profile, waterholding capacity can be reduced due to the limited micro-pores which are required for water storage within aggregates. Colours ranged from very dark greyish brown to dark brown A horizon to a black subsoil where clay had been reached. Browns and dark browns indicate the accumulation of some organic matter in the upper profile but also the origin of the sediments.

Soil structure varied between sites with some showing loose material with weakly structured lenticular shaped peds. Others were strongly graded polyhedral shaped peds, often around 20-50 mm in size. As structure influences the hydrology and root penetration of a profile, water and root movement will occur freely through the weakly structured profiles. Weak structure can leave soil susceptible to compaction. Small proportions, generally less than 10%, of buckshot are found in the A horizon. Small amounts of buckshot such as this, along with the absence of any coarse fragments, would have no bearing on the soil's waterholding capacity or CEC.

Lunette material is quite acidic with pH 5 - pH 5.5 common down the profile with lime being required for agricultural use. Only in profiles where black clays are encountered did pH increase, presumably carbonates would be found below this. Salinity levels also increase down the profile, particularly where black clays are found at depth.

Occurrence

The lakes and swamps across the VVP have been through many wetting and drying cycles. As lakes dried, prevailing westerly winds eroded lake beds depositing fine sands and silts along the eastern rim. These lunettes are found on several swamps in the Lismore Study Area. Texture varied between sites with a higher clay content found on the lunette of Lake Tooliorook, the most significant lunette in the Lismore Study Area. Studies by Bowler (1983) showed that sand lunettes are formed alongside freshwater swamps, whereas clay lunettes are formed adjacent to salt water swamps.

EVC maps do not distinguished the vegetation of the lunettes from the swamps so lunettes are classed as having supported Plains Sedgy Wetlands vegetation (EVC 647).

Representative soil - Lunette Clays

General description of the soil

Brown to greyish A horizon of clay loam sand texture with a clear change into a saline black clay subsoil. Flakes of quartz and chert from aboriginal tools found on the lunette.

Distribution:	Lunettes, found on eastern edges of past and present lakes
Typical land use:	Grazing, some cropping on larger lunettes
Common variants:	Depth to clay subsoil
Other names	Brown Vertosol

Environment and location of the example profile

Landform:	Lunette ridge
Parent material or substrate:	Aeolian lake sediments
Drainage class:	Well drained
Surface condition:	Compacted to 0.26m
Site disturbance:	None
Native vegetation:	None present (originally Plains Sedgy Wetlands EVC 647)

Location map

Lunette Clays

Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Coarse fragments	Segregations	Boundary
A1	0.0-0.26	Dark brown	-	Clay loam sandy	Moderate	Platy	20-50mm	Weak (mod moist)	-	<2% med. FeMg concretions	Gradual
A21	0.26-0.40	Dark greyish brown	-	Clay loam sandy	Moderate	Polyhe-dral	10-20mm	Weak (mod moist)	-	20-50% coarse FeMg concretions	Sharp
A22	0.40-0.51	Brown	20-50% Med. distinct red	Silty clay loam	Strong	Polyhe-dral	20-50mm	Firm (mod moist)	-	-	Abrupt
A23	0.51-0.65	Dark grey	2-10% Med. faint yellow	Silty clay loam	Moderate	Polyhe-dral	20-50mm	Weak (dry)	-	-	Clear
B21	0.65-0.92	Black	<2% medium faint yellow	Medium heavy clay	Massive	Polyhe-dral	10-20mm	Firm (mod moist)	-	-	Gradual
B22	0.92-1.06	Black	-	Heavy clay	Massive			Firm (mod moist)	-	-	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm	Particle Size Analysis Sand %	Silt %	Clay %	Determined texture
A1	0.0-0.26	5.5	-	5.18	142.10	74.3	10.5	15.2	Sandy Loam
A21	0.26-0.40	6	-	6.05	149.90	74.9	9.0	16.1	Sandy Loam
A22	0.40-0.51	6.5	-	7.20	132.50	54.7	9.7	35.6	Clay
A23	0.51-0.65	7	-	6.69	427.00	48.5	12.3	39.2	Clay
B21	0.65-0.92	8.5	-	8.21	931.00	24.4	8.5	67.1	Clay
B22	0.92-1.06	9.5	-	7.99	989.00	25.3	13.0	61.7	Clay

5.6 Buckshot Clays

Figure 27 Representative landscape on which the Buckshot Clays are found (core site 3) (Photograph S. McConachy).

General features

A friable, well-drained medium clay soil with abundant buckshot throughout and coffee rock reached at depth. Classed as brown Chromosol (Isbell 1998) (Appendix F, core 3).

Description and Agricultural implications

The weak consistence found throughout this profile indicates that crops and pastures will not experience barriers to growth from rigid peds. Light clay A_1 horizon with a clear transition into bleached A_2 horizon followed by brown medium clay subsoil. Although soils with such clay levels generally have excellent waterholding capacity and the ability to retain high amounts of nutrients, these properties are reduced by the large quantities of buckshot present. Such high proportions or buckshot, over 50% in the B horizon, reduce the effective soil volume of these profiles. With a reduced CEC these soils need to be treated similarly to sandy soils and receive split fertiliser applications to reduce the leaching of excess nutrients. Buckshot is very abrasive on tillage equipment. Large and high density segregations of coffee rock are encountered at 0.8 m preventing a full core extraction. Coffee rock forms by indurations and cementation of the lower profile by iron-rich water infiltrating from the upper horizons and transporting iron sesquioxides.

Colour varies slightly from dark brown A_1 horizon, where most organic matter has accumulated, into a predominantly brown profile. Fine orange mottling is common through the profile, giving the soil an overall reddish orange appearance. The reddish colour and the slightly bleached A_2 horizon indicate how freely draining the soil is and the high presence of iron in the soil. Such colours also indicate the soil's natural fertility. While most of the profile is well-drained a layer of coffee rock found at depth may result in a perched water table after high rainfall events. Mottles above this layer indicate that waterlogging has been an issue here historically.

Structure is difficult to observe in soil with such high proportions of buckshot. Platy peds are found in the A_1 indicating some compaction may have been caused where only 10-20% buckshot is present. Soil pH increases gradually down the profile from pH 5.5 in the A_1 to neutral pH 7 where coffee rock is met. The soils are generally very friable and well-drained due to high proportions of buckshot and are suited to either cropping or grazing.

Occurrence

Marine transgression occurred during the Pliocene and as the sea retreated a thin but extensive sheet of sand was deposited across the plains. Subsequent volcanic activity occurred between 3.6 Ma to 20, 000 years ago. In the Lismore Study Area almost the entire deposit of this thin layer of sand from the Pliocene sea was covered by lava flows or eroded off the granite hills. All that remains are small pockets of the Pliocene sand (Buckshot Clays) that indicate what once covered the broad plains. In the Lismore Study Area, small scattered caps of these Buckshot Clays are found on the gently undulating Granitic Sandy Loam hills.

The Buckshot Clays have not been distinguished on previously mapped geology in this region and the EVC is listed as Plains Grassy Woodlands (EVC 55). The Buckshot Clays have not been mapped on the Lismore Soil Series Map in this thesis due to only one small (<5ha) area being positively identified. The extent of these caps is unknown as they are not obvious in the landscape. They are also not identifiable from the geophysical or terrain data

Representative soil - Buckshot Clays

General description of the soil

Dark brown, light clay top soil over a bleached A_2 horizon followed by medium clay subsoil. Segregations of iron manganese abundant throughout profile. Coffee rock formation reached at depth.

Distribution:	Small patches capping Granitic Sandy Loams
Typical land use:	Cropping or grazing
Common variants:	Percentage of buckshot and depth to coffee rock
Other names	Brown Chromosol

Environment and location of the example profile

Landform:	Mid slope on gentle undulation
Parent material or substrate:	Neogene marine sands known as Hanson Plain Sands
Drainage class:	Moderate
Surface condition:	Friable
Site disturbance:	Cultivated and sown
Native vegetation:	None present (originally Plains Grassy Woodlands EVC 55)

Location map

Buckshot Clays

Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles (Mussel)	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Coarse fragments	Segregations	Boundary
A1	0-0.19	Dark brown	<2% fine orange	Light clay	Strong	Platy	5-10mm	Weak (dry)	-	10-20% coarse FeMg concretions	Clear
A2	0.19-0.44	Gray	<2% fine orange	Medium clay	Strong	Lenticular	5-10mm	Very weak (mod. Moist)	-	20-50% coarse FeMg concretions	Abrupt
B21	0.44-0.55	Dark gray	20-50% medium orange	Medium clay	Moderate	Sub-angular blocky	10-20mm	Weak (mod. Moist)	-	>50% coarse FeMg concretions	Clear
B22	0.55-0.69	Brown	10-20% fine orange	Medium clay	Moderate	Sub-angular blocky	10-20mm	Weak (mod. Moist)	-	>50% coarse FeMg concretions	Abrupt
C	0.69-0.78	Brown	10-20% fine orange						-	>50% coarse FeMg concretions	

Soil chemical and physical properties

Horizon	Depth (cm)	pH (w)	CaCO3 test	Repellence	Lab. pH (w)	EC uS/cm	Particle Size Analysis Sand %	Silt %	Clay %	Determined texture
A1	0-0.19	5.5	-	-	5.27	285.00	50.4	21.1	28.5	Clay Loam
A2	0.19-0.44	6	-	-	6.58	122.50	55.8	17.4	26.8	Clay Loam
B21	0.44-0.55	7	-	-	7.20	292.00	40.9	3.2	55.9	Clay
B22	0.55-0.69	7	-	-	5.88	200.10	51.5	6.3	42.2	Clay
C	0.69-0.78	7	-	-	7.80	270.00	45.2	7.1	47.7	Clay

5.7 Lismore Soil Series Mapping

The Lismore Soil Series Map was developed from existing maps, field verification, soil profile analysis and landholder interviews.

The most recent seamless geology 1:50 000 map (GeoScience Australia 2007) was used as a primary source for lithological boundaries. Topography maps and ortho-rectified aerial photos were used to further delineate soil boundaries from lithology. Features such as the Mundy Gully Black Clays were easily visible when observing ortho-rectified aerial photography. Extensive field work was carried out to confirm or deny boundaries delineated from existing maps. This involved visual inspection of changes in topography and identifying landform boundaries. Intact soil core extraction and hand augering, as described in the Methods, were then carried out to improve the accuracy of soil boundaries. Mapping data was recorded on aerial images at a maximum of 1:25 000 but many sites were mapped in more detail and so carry a higher level of confidence (Figure 28).

Landholder interviews proved very useful in delineating soil boundaries on individual properties. Cropping farmers in particular have an excellent knowledge of soil boundaries on their properties and their interview information was used to extrapolate boundaries across neighbouring farms.

5.8 Limitations to study

Dry conditions experienced prior to the second round of intact core extraction in April 2009 resulted in cores of a lower quality compared to the first round of coring completed in May 2008. With the profile completely dry it made a full core extraction to 1m generally unachievable hence most cores were 0.7-0.8 m in depth. The extremely dry profiles were more fragile and did not travel as well back to the laboratory, resulting in slightly disturbed profiles being used for analysis.

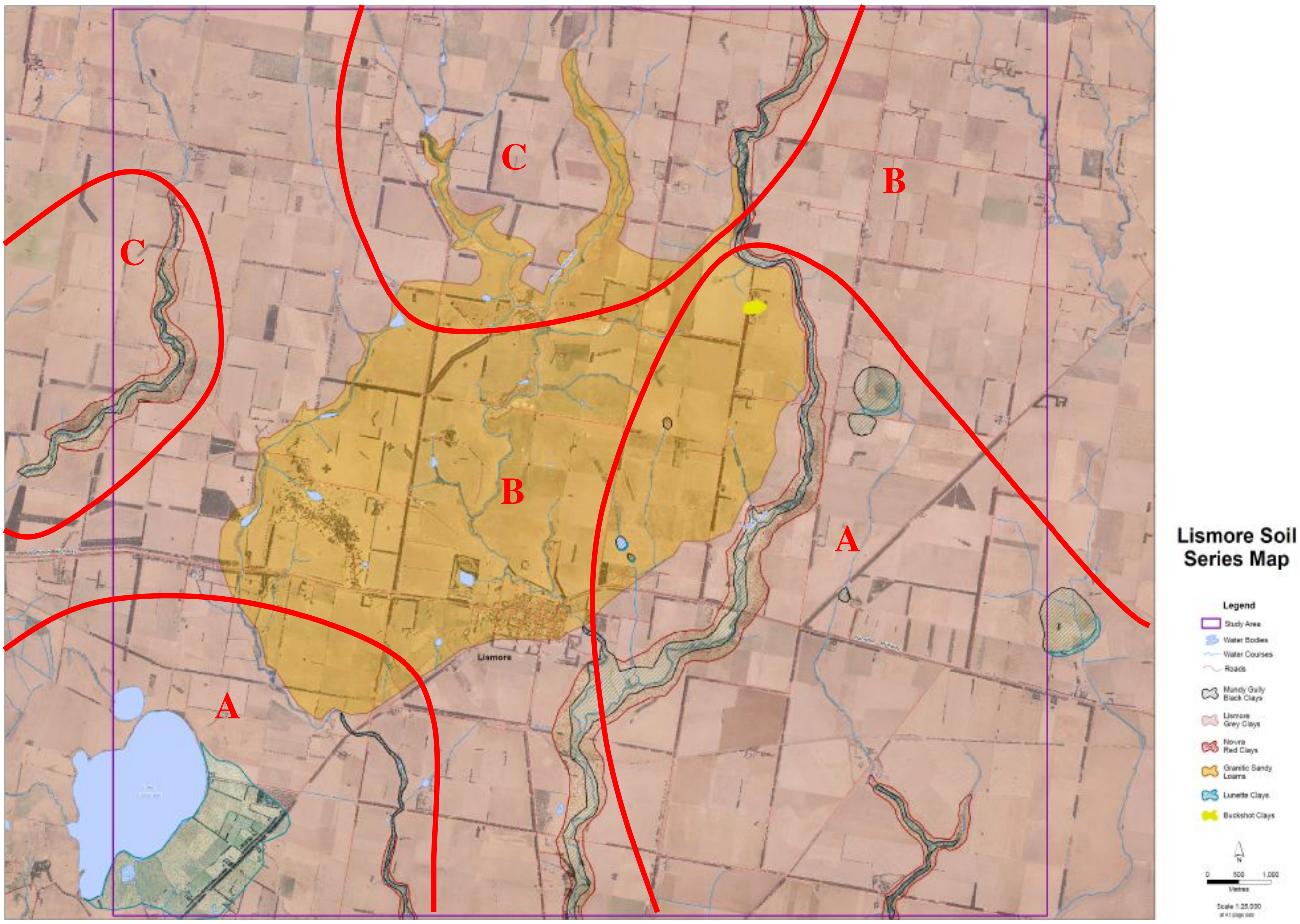

Figure 28 Map of confidence of soil boundaries.

A – Areas of high confidence which used extensive field verification, soil coring and landholder interviews.

B – Areas of medium confidence which used field verification, soil coring, map and aerial photo interpretation

C – Areas of lower confidence which used map and aerial photo interpretation

6.0 Conclusions

The Lismore Study Area has been included in various previous soil mapping projects across the Victorian Volcanic Plains, most classed all basalts as a single soil type and the granites as a separate type. This study recognises two soil series on the granite outcrop. The granite outcrop has weathered into the Granitic Sandy Loams and is capped in small areas by the Buckshot Clays. The Buckshot Clays are recognised as sporadic erosional remnants of marine sediments. However these are too small and isolated to be included on the larger scale maps. Two soil series have been delineated on the volcanic soils. The earlier Nowra Red Clays have been exposed in creek lines and patches across the plains. Lismore Grey Clays have formed on the intermediate age basalt flows and make up the largest soil type across the Lismore Study Area. Basalt ages for the Lismore area are now recognised as being around 3.6 Ma. Mundy Gully Black Clays and Lunette Clays are depositional soils and have formed more recently, mainly through wash-off and aeolian sediments, both largely derived from the basalts. These soils were sampled and described to create a Soil Series Map (Appendix G back pocket) for the Lismore Study Area which will be useful on a paddock scale for farmers and other land managers when planning paddock production, management and land class fencing.

The completion of this thesis raised awareness of variations in soils both at a property scale and the wider Lismore area. Discussions with landholders covered the application of the Corangamite Soil Health Strategy to land managers and the variation of soil types and appropriate management techniques. This information will be applied by DPI extension staff when providing advice on best soil management options. Groups involved with the completion of the thesis included landholders, the Lismore Land Protection Group (LLPG) and DPI staff. Landholders who made their properties available for intact soil core extraction will benefit directly from the results. Soil type descriptions and test results will be discussed and interpreted for each participating landholder to help improve agricultural management options. This aligns directly with the aims of DPI Soil and Salinity extension program. Intact soil core and chemical analysis is of benefit to landholders in identifying subsoil barriers to growth such as acid or saline subsoils and depth to coffee rock or clay pans.

The completion of the Lismore Soil Series Map has stimulated the LLPG to undertake a soil coring project which involves extracting and preserving intact soil cores from the main soil types across the LLPG's area. Each core will be chemically analysed and a full profile description completed with the results displayed alongside the preserved cores. These will be used for educational purposes at field days and other Landcare events.

6.1 Recommendations for future work

- Salinity has previously been mapped at a catchment scale in the Corangamite CMA region. Further deep soil coring would quantify salinity patterns across the landscape and within the soil profile. This information would contribute to the creation of a localised salinity map to build upon the Lismore Soil Series Map. Profile analysis would identify the horizons affected by salinity levels and allow landholders to adopt better management practices to minimise the impact of salinity on agricultural production.
- Cropping yield-limiting constraints of different soil types can be identified by using grain yield contour maps. Anecdotal evidence suggests that grain yields do vary across the Lismore Soil Series and the opportunity of quantifying this for production agriculture would be of benefit to farmers and catchment managers.
- A recent study on land use change has identified a rapid shift from grazing to cropping around the Lismore Study Area. Monitoring the effect of this enterprise change on soil properties over the long term would further build on the modification of management practices to maintain long term sustainability.
- Further coring would determine variation across deeply weathered basalt flows thus further improving our understanding of soil structural variation and its relationship to geology.

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Appendices

Appendix A Pre-1750 Ecological Vegetation Classes

Descriptions of the pre-1750 Ecological Vegetation Classes mapped in the Lismore Study Area

EVC	Description
132 – Plains Grasslands	Treeless vegetation mostly < 1 m tall dominated by largely graminoid and herb life forms. Occupies cracking basalt soils prone to seasonal waterlogging in areas receiving < 500 mm annual rainfall.
55 – Plains Grassy Woodlands	An open, eucalypt woodland to 15 m tall occurring on a number of geologies and soil types. Occupies poorly drained, fertile soils on flat or gently undulating plains at low elevations. The understorey consists of a few sparse shrubs over a species-rich grassy and herbaceous ground layer.
175 – Grassy Woodlands	A variable open eucalypt woodland to 15 m tall over a diverse ground layer of grasses and herbs. The shrub component is usually sparse. It occurs on sites with moderate fertility on gentle slopes or undulating hills on a range of geologies.
647 – Plains Sedgy Wetlands	Sedge-dominated wetland vegetation of lowland plains, with conspicuous and potentially diverse herbaceous component, including species characteristically associated with wet sites on fertile soils. Moisture supply appears to be more reliable (e.g. associated with springs/seepage) than for sites supporting Plains Grassy Wetland.
125 – Plains Grassy Wetlands	Usually treeless, but in some instances can include sparse River Red Gum (*Eucalyptus camaldulensis*) or Swamp Gum (*Eucalyptus ovata)*. A sparse shrub component may also be present. The characteristic ground cover is dominated by grasses and small sedges and herbs. The vegetation is typically species-rich on the outer verges but is usually species-poor in the wetter central areas.
203 – Stony Rises Woodlands	Eucalypt woodland to 15 m tall on stony rises. Soils are fertile and well-drained but shallow or skeletal. Limited soil development outside of rock-cracks and dry summers promote annuals and deep-rooted perennials.

(Data source DSE 2009)

Appendix B Table comparing nomenclatures of previous soil studies

Part 1

Parent rock	Age		Soil classification	Description	Landform	Location	Author
Mixed		Holocene	Dark clays & loams	Black or grey self-mulching clay topsoil over black sodic soils and dark loams	Alluvium terraces, floodplains, swamps and lunettes	Corangamite region	Robinson *et al* (2003)
Basalt	Pliocene – Pleistocene	Young phase basalts < 1 Ma Mt Porndon, near Camperdown dated at 59,000 years Mt. Napier, near Hamilton dated at 32,000 years	*'Soils of the mountain'* Black Dermosol	Dark chocolate clay loam to clay High organic matter Calcium carbonates present in subsoil	Scoria cone	Scoria crest of Mt Gellibrand	Leeper (1936) Imhof *et al* (2004)
			'Soils of the Plains *- Soils with Surface drainage'* Black Vertosols	Stony Rise Brown Loam High organic matter, high fertility, abundant basalt rocks Stony Rise Clay Fewer basalt outcrops, darker soils, higher clay content	Stony rise country	Mt Gellibrand	Leeper (1936) Imhof *et al* (2004)
			Class 33 – Stony Rises	Stony Rises		Lismore	Ollier & Joyce (1986)
			Stony Rises	Dark, gradational and self-mulching topsoil. Dark mottled subsoil with calcium carbonate present High fertility and often sodic at depth		Corangamite region	Robinson *et al* (2003)
			'Thistle Zone'	Clay loam over heavy clay Mottling and calcium carbonate in heavy clay subsoils High lime content, good fertility, often alkaline		Mt Gellibrand area	Leeper (1936)
			Stony Rises	Soils around boulders have weathered into red-brown earths Black clays and peaty soils in depressions and swamps		Hamilton region	Bennett (2003)
		Mid-phase basalts 1 - 3Ma	*'Soils on the Plains* *- Swampy Soils'*	Grey clays prone to waterlogging, self-mulching topsoil with shrink - swell properties Gilgai formations common	Undulating, less dissected landscape	Mt Gellibrand area	Leeper (1936) Imhof *et al* (2004)
			'Plains with poorly developed drainage'	Fine sandy loam to clay loam often overlying a bleached Iron-rich clay loam layer over a medium clay subsoil Wetlands are commonly found on these plains		Corangamite region	Robinson *et al* (2003)
			2 Ma basalts	Iron nodule and tiger mottling formations absent Brown silty loam to a clay loam A horizon Yellow clay subsoil		Hamilton region	Bennett (2003)
				Swamps and depressions common across the landscape Lunettes have formed		Western Victoria	Joyce (1999)

Table comparing nomenclatures of previous soil studies

Part 2

Parent rock	Age		Soil classification	Description	Landform	Location	Author
Basalt	Pliocene	First phase basalts 5–3 Ma	4 Ma	Red brown clay loam topsoil over yellow red clay subsoil which overlies kaolintic clay Mottling and iron nodule present		Hamilton region	Bennett (2003)
			Basalt Soils	Deeply weathered kaolinitic profile Mottled clay and nodular ironstone at depth		Western Victoria	Joyce (1999)
			'Basalts on plains and rises'	Hard, mottled yellow duplex soils with partial subsoil bleach Brown fine sandy clay loam with high buckshot content	Flat to gently undulating landscape	Western Victoria	Maher & Martin (1987)
			'Plains with well developed Drainage'	Black and brown sodic mottled texture contrast soil with iron nodules Dark, heavy clay subsoil with mottling		Corangamite region	Robinson *et al* (2003)
			Class 31 *Basalt soils derived from lava flows 5-3 Ma*	Lateritic profiles weathered with up to 10m deep of kaolinitic clays Mottling and nodular ironstone present		Lismore	Ollier & Joyce (1986)
Sedimentary Plains quartz-rich marine sediments	Tertiary	Early to Late Pliocene	Hanson Plain Sands	Mottled texture contrast soils with coffee rock at depth and can be sodic or non sodic Low fertility and low water holding capacity	Plains and plains with low rises. These included undissected sand plains	Corangamite region	Robinson *et al* (2003)
			Tenosols	Uniform sandy soils (Tenosols) or sands over clays are common on the upper slopes of granites		Corangamite region	Robinson *et al* (2003)
			Sodosols	Strongly sodic, mottled brown, grey and yellow texture contrast soils formed on the mid to lower slopes		Corangamite region	Robinson *et al* (2003)
			'Lower slopes' Grey sodosol	Sandy clay loam over heavy clay subsoil with a steady transition into loam to light clay over heavy clay subsoil		Mt Gellibrand	Leeper (1936) Imhof *et al* (2004)
Granite	Devonian			Mottled yellow duplex soils with prominent subsurface bleach	Erosional hills of granite	Western Victoria	Maher & Martin (1987)
			Class 43 *Erosional hills of granite*	Uniform coarse sands on steep slopes and a red duplex over silica-rich hard pan on the gentler slopes		Lismore area	Ollier & Joyce (1986)

Appendix C Geomorphological Framework for Corangamite

Breakdown of the geomorphic units of the Corangamite CMA as described by Robinson *et al.* (2003), adapted from the Victorian Geomorphological Framework.

Geomorphological framework for Corangamite

The physiography of the Corangamite CMA region reflects the underlying geology and landscape evolution processes.

The three first tier geomorphic units of the Corangamite CMA region are (Figure 29):

- Western Uplands
- Southern Uplands
- Western Plains

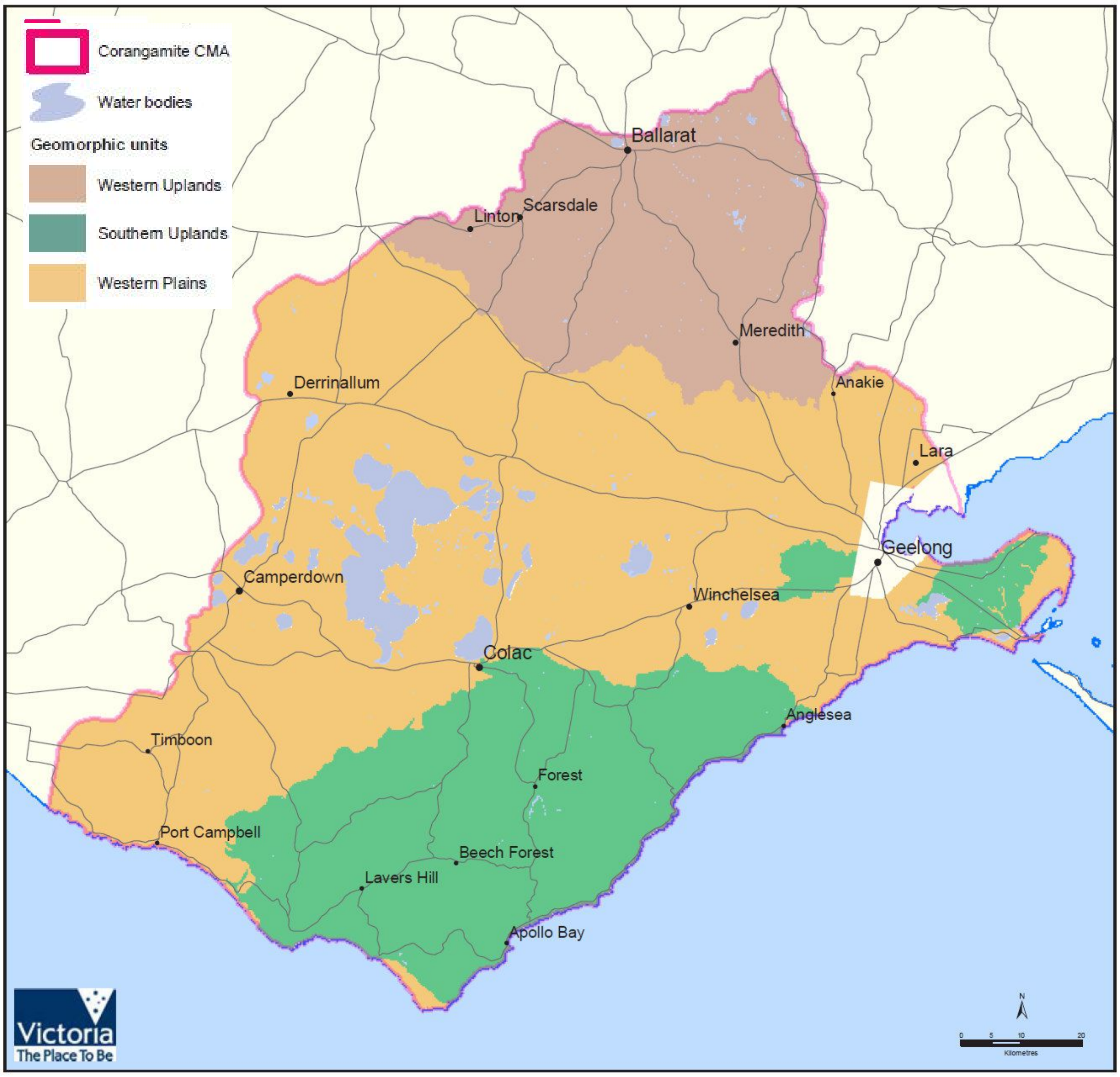


Figure 29 First tier geomorphic units of the Corangamite CMA region.

First tier geomorphic units are divided into a range of second tier geomorphic units which are subsequently further divided into a larger range of third tier geomorphic units. The geomorphic tiers of the *Western Plains* unit are as follows:

Western Plains

▪ **Volcanic plains**

- Eruption points, including maars, scoria cones and lava shields (e.g. Mount Elephant)
- Stony rises (e.g. Pomborneit)
- Plains with poorly developed drainage (e.g. Wingeel)
- Plains with well developed drainage (e.g. Werneth)
- Alluvium, terraces, floodplains, lakes, swamps and lunettes (e.g. Lower Woady Yaloak River, Lake Corangamite)

▪ **Sedimentary plains**

- Dissected plains (e.g. Heytesbury)
- Karst plains with depressions (e.g. Port Campbell)
- Plains and plains with low rises (e.g. Duck Hole Plain)
- Alluvium, alluvial terraces, floodplains and coastal plains (e.g. Moolap Sunklands)

▪ **Palaeozoic inliers**

- Granitic hills (e.g. Mount Kinross)

Appendix D Soil Landform Units

Descriptions for the soil landform units found across the Lismore Study Area, taken from the Corangamite Land Resource Assessment by Robinson *et al.* (2003).

Landform unit 143 (Granite)
Landform unit 172 (Neogene Sand)
Landform unit 136 (Basalt)
Landform unit 57 (Alluvium)
Landform unit 156 (Swamp)
Landform unit 145 (Lunette) *

* Lunettes have been included although are not mapped in the Lismore Study Area by Robinson *et al.* (2003)

Soil-landform unit 143

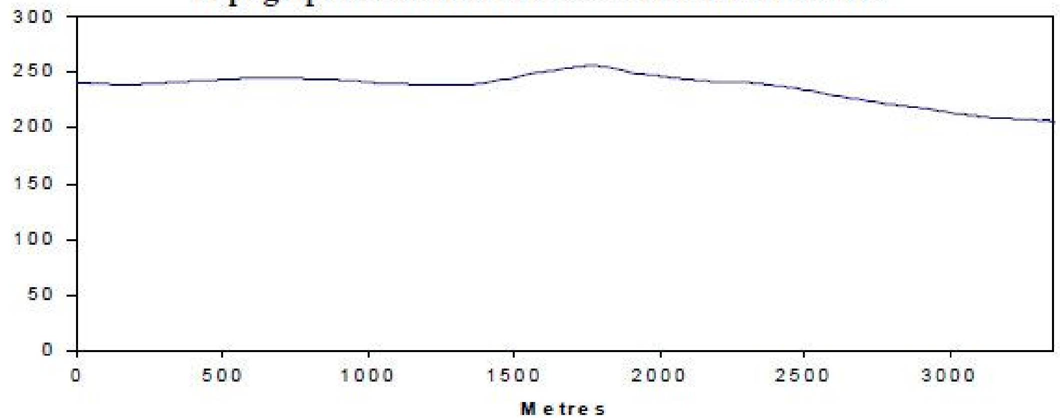
Area: 4530 ha
0.34% of CMA region

This unit of undulating low hills is derived from residual granitic outcrops on the Western Plains.
This single unit lying north-east of Lismore near Wallinduc, consists of granitic outcrop with a partially remaining veneer of Neogene (colluvial) sedimentary material. Unit components include rocky and sandy crests, upper, mid and lower slopes. This unit is surrounded by basaltic plains (Units 136 and 117) and a small sedimentary area (Unit 172). The soils are uniform sands (Tenosols) or sands over clay on the upper slopes, while strongly sodic mottled brown, grey and yellow texture contrast soils (Sodosols) are found on the mid and lower slopes. Land use is mainly grazing (sheep). The sloping terrain in conjunction with loose sandy surface soils means this unit is susceptible to sheet and rill erosion and nutrient decline. It is also susceptible to gully erosion on the lower slopes with the strongly sodic subsoils and coarse sand fraction.

Dissected residual granitic slopes of the Lismore Granodiorite

Mount Kinross, south-east of Pitfield

Topographical section of the soil-landform unit 143



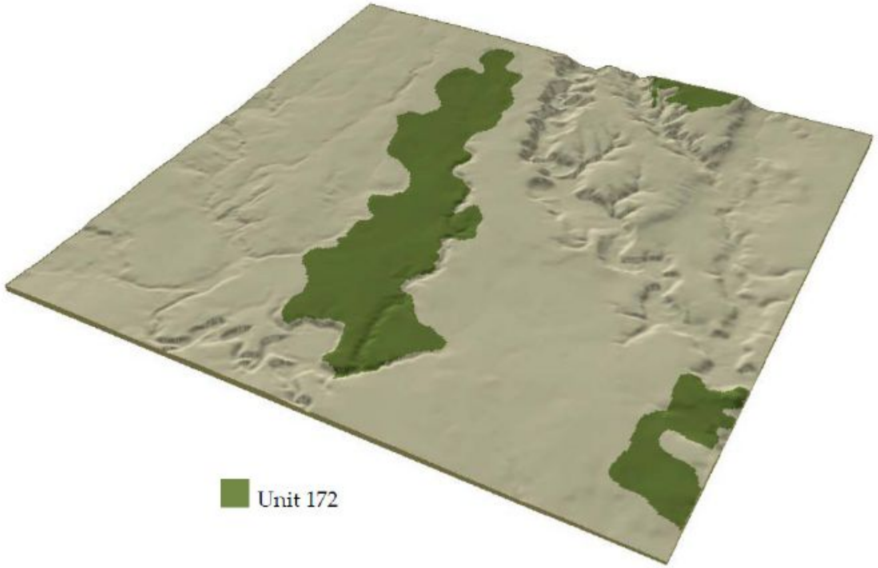
Soil-landform unit 172

Area: 9944 ha
0.74% of CMA region

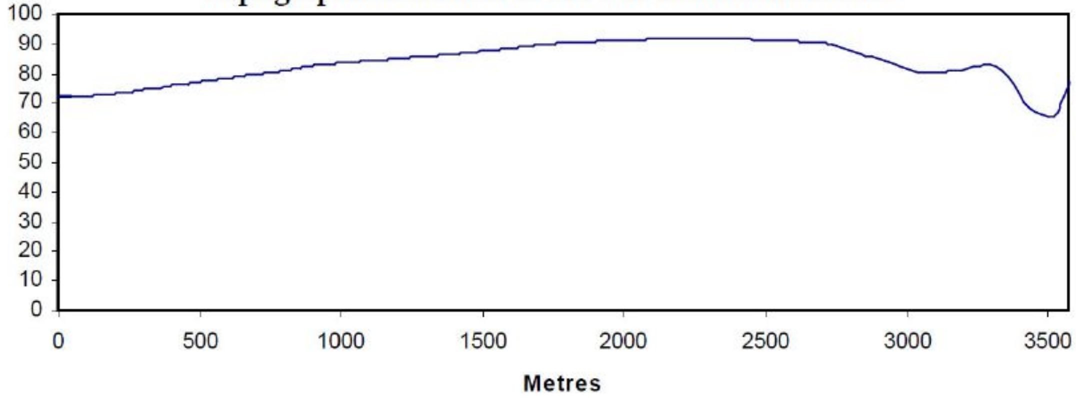
These gently undulating plains occur as envelopes of Neogene fluvio-marine sand overlying various geologies in a number of areas across the region including Bannockburn, Torquay, Gheringhap, Maude and Lismore. These sedimentary plains of the dissected Western Plains support a wide range of vegetation classes including Plains Grassy Woodland, Plains Grassland/Plains Grassy Woodland Mosaic and Coastal Dune Scrub Mosaic. The dominant species vary from area to area along with the density and occurrence of vegetation classes. The low fertility and the low water holding capacity of the soils is an inherent limitation. Soils include an association of bleached brown, grey, yellow and/or red sandy mottled texture contrast soils or unbleached equivalents in better drained areas. Heavier surface textured soils may occur in drainage lines. These soils are prone to gully erosion which is minor to moderate in severity in some cleared areas along with sheet and rill erosion and waterlogging in wet seasons.

Gently undulating sedimentary plains of a remnant plateau located north-east of Torquay

The gently undulating plains have been extensively cleared and now support mainly grazing



Topographical section of the soil-landform unit 172



Red highly ferruginised texture contrast soils exposed in a dam east of Torquay

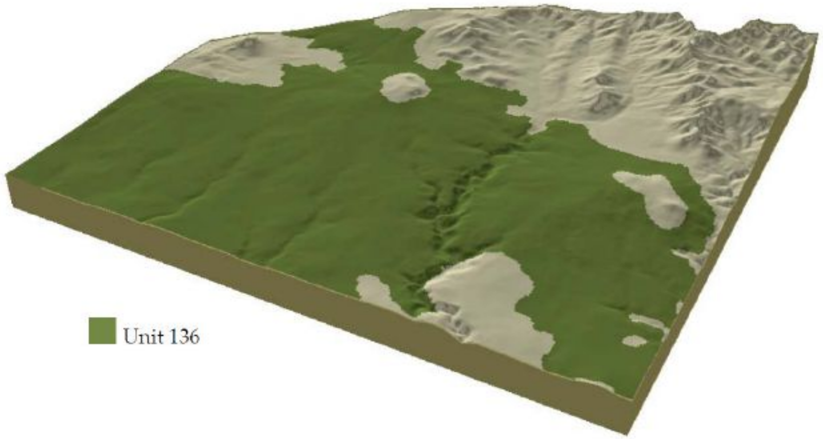
Soil-landform unit 136

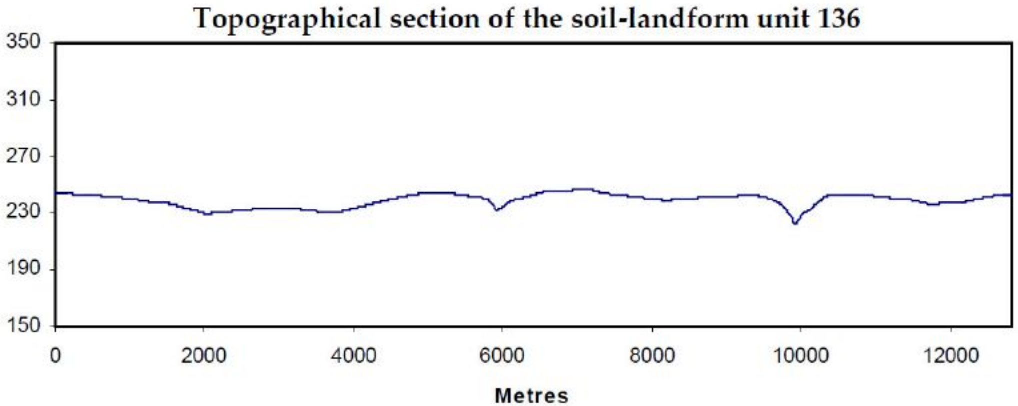
Area: 58 432 ha
4.38% of CMA region

The gently undulating plains that exist between Lismore and Skipton have well developed regolith profiles on Quaternary basalt within the Western Plains. These gently undulating plains may have some stone on the surface on the gentle crests and upper slopes. The soils are texture contrast with variable depth surface horizons that are often shallow with sporadically bleached subsurfaces over strongly sodic medium or heavy clay subsoils. Local relief is low with a sparse drainage network and depressions generally having similar soils to the slopes. This drainage network does become more pronounced further south towards Lismore. The only significant vegetation class of these plains is the Plains Grassland/Plains Grassy Woodland Mosaic (0.9%). This is a large unit with few outliers, surrounded by other basaltic areas (including stony rises) and granite to the north. This unit surrounds a granitic unit (Unit 143) centred to the north of Lismore. The land use is extensively cropping and grazing (mainly sheep). Land degradation issues include waterlogging and overland due to the low relief and sometimes hardsetting sufaces.

The gently undulating plains have a greater density and depth of dissection further south near Lismore. Above is an example of the broad drainage depressions undulating across the plains

Crops are extremely productive on these gentle plains with deeply developed regolith





Much of these plains are cropped and grazed in rotations

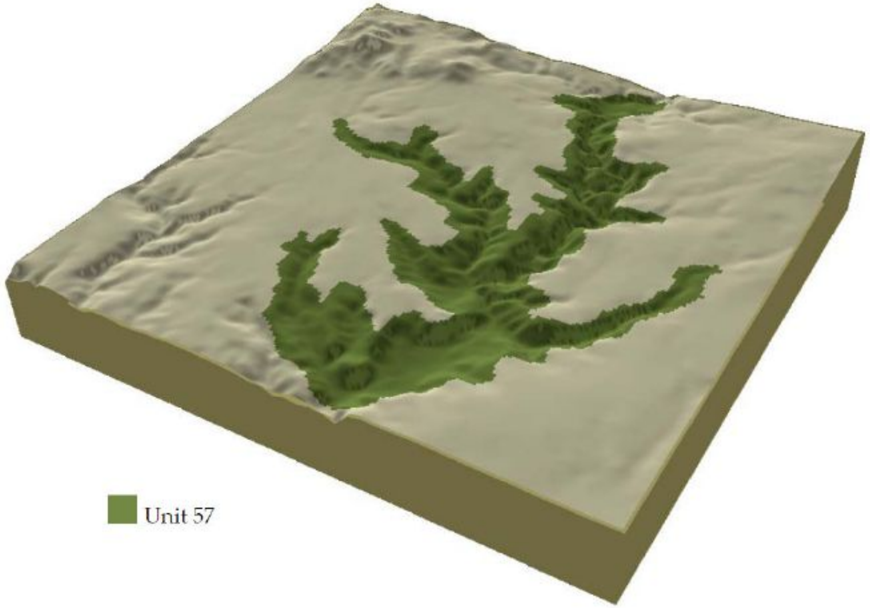
Soil-landform unit 57

Area: 26 302 ha
1.97% of CMA region

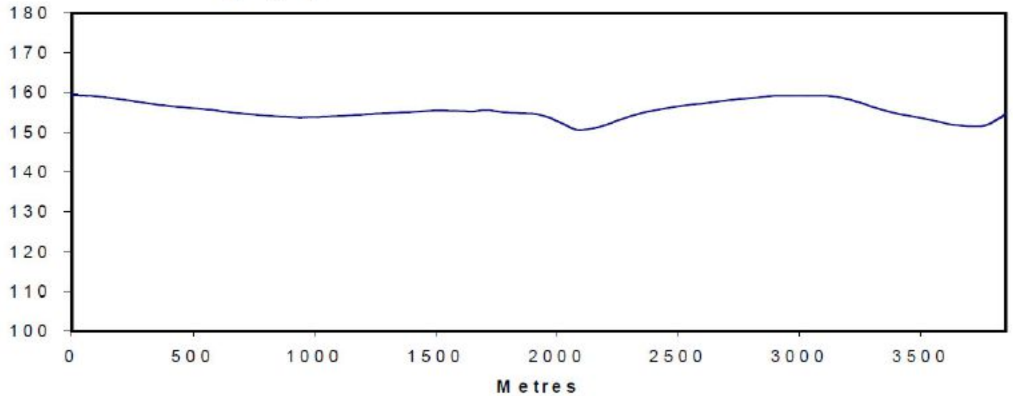
Dissection of the lava plains, sediments and granites of the Western Uplands and plains of the Corangamite region has led to the development of dissected entrenched valleys with narrow to broad alluvial floors. This unique landscape includes the Moorabool River in the east and minor streams on the basalt plains in the west. The entrenched valley and valley floor supports the vegetation classes of Grassy Dry Forest, Valley Grassy Forest, Stream-bank Shrubland, Floodplain Riparian Woodland and Plains Grassy Woodland. Importantly the vegetation differs considerably from the Moorabool River to the basalt streams of the west. The main soil type of the unit is the black cracking clays with dark brown uniform soils of the alluvial plains. Terraces and lower slopes support yellow and brown texture contrast soils while the steep slopes and valley sides have black clays with some red gradational or texture contrast soils and some sandy areas (soils here can be quite variable depending on the host geology). Land use is quite variable and includes water supply, grazing, cropping, horticulture and nature conservation. Erosion hazards are high on the scarps and steep slopes, which have a high susceptibility to soil loss. Landslip and rock falls are also hazards of the steeper terrain. Areas with shallow soils are susceptible to leaching of nutrients, and compaction is a problem on the alluvial plains along with waterlogging and flooding in wet seasons.

The entrenched valleys and slopes of the upper Moorabool River are prominent landforms of the dissected volcanic and sedimentary plains

The vegetation differences reflect soil and water availability differences



Topographical section of the soil-landform unit 57



Minor streams of the basalt plains congregate in the upper catchment to eventually drain into Lake Corangamite

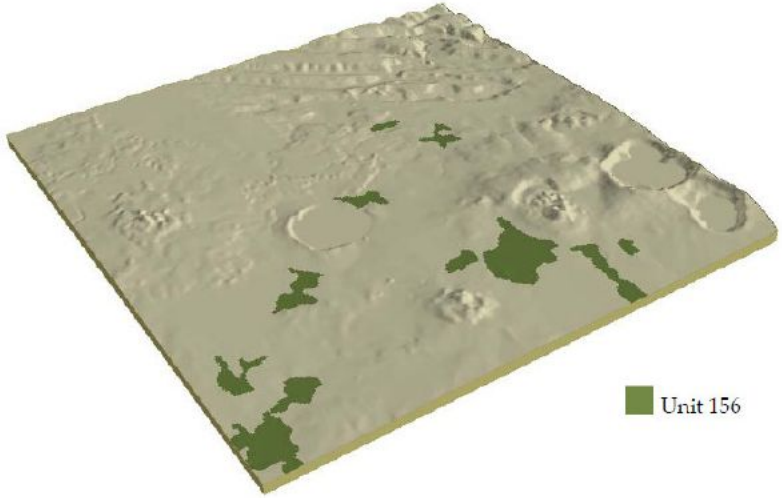
Soil-landform unit 156

Area: 13 580 ha
1.02% of CMA region

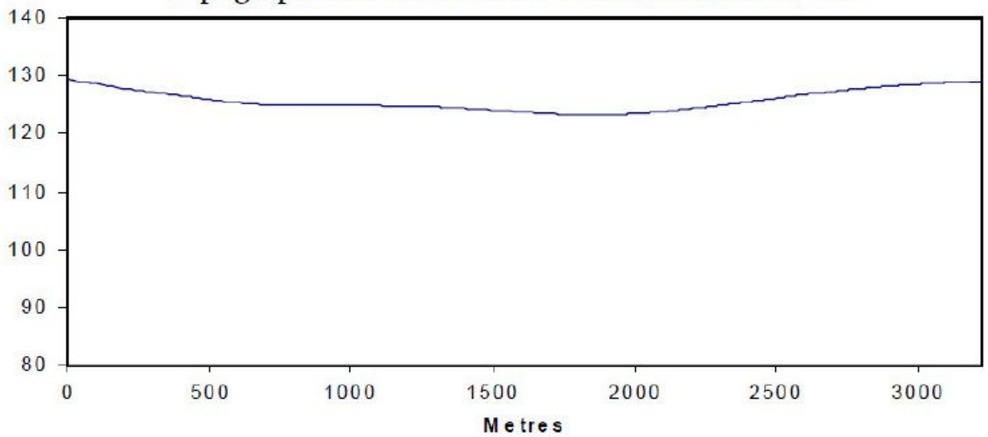
Across the dissected basalt plains of the Western Plains are numerous swamps and closed depressions that host a wide variety of flora and fauna. These swamps have been derived on Quaternary basalt, alluvial clay, sand and gravels and tend to be associated within two regions of the Western Plains. The reasoning for this is not entirely understood, but it would appear there is a high correlation of swamps with certain basalt flows. Most of the land has been cleared where these swamps were, or have been developed with drainage to remove excess surface water. Remnant vegetation classes on these plains include plains Sedgy Wetland, Stony Rises Herb-rich Woodland and Aquatic Herbland / Plains Sedgy Wetland Mosaic. Land use is mainly restricted to grazing owing to the waterlogged state of soils in most years, however cropping is quite productive when annual rainfall is below average. Soils include the grey cracking clays on the lava plains and black cracking clays associated with swamps and depressions of the stoney rises. While waterlogging is the major limitation, soil compaction may also be a limitation for production without adequately controlled traffic.

Swamps and waterbodies are prominent along the western boundary of the catchment. Many of these swamps in recent season have been dry and productive

The cracking clays provide valuable soil moisture and nutrients that have resulted in good harvests over the last few seasons



Topographical section of the soil-landform unit 156



These soils are prone to soil compaction and waterlogging if managed poorly

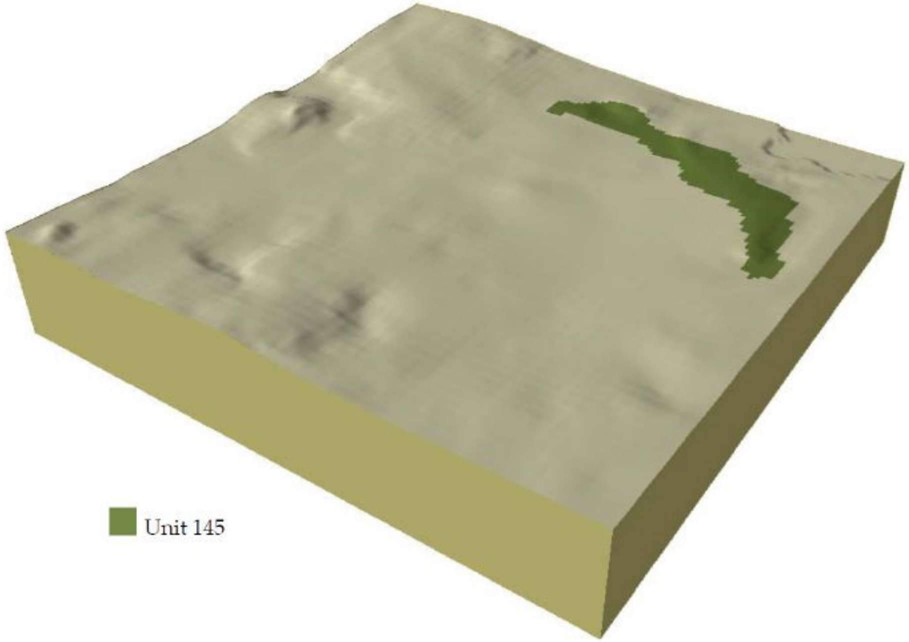
Soil-landform unit 145

Area: 214 ha
0.02% of CMA region

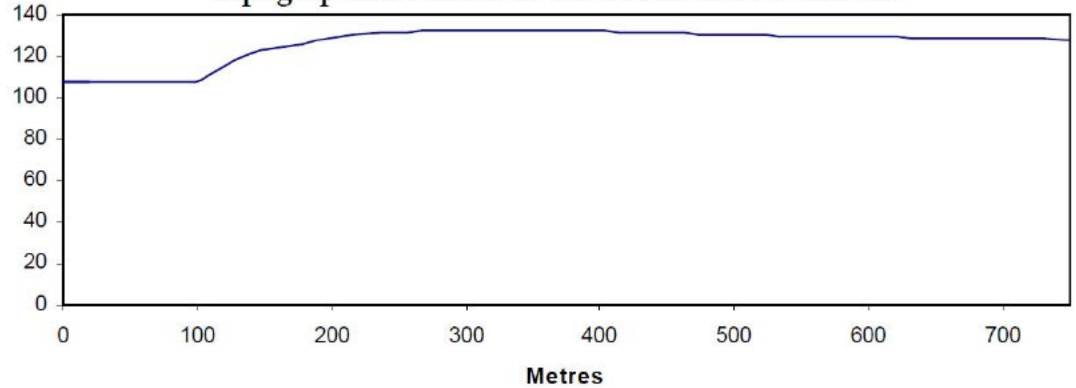
The lunettes that occur near Derrinallum and on the north-east shore of Lake Corangamite near Lake Martin represent a few of many lunettes across the dissected volcanics of the Western Plains. The gently undulating lunettes represent wind blow sands and clays from swamps and lakes indicating the major prevailing wind direction over time. Lake Corangamite and the swamp of Lake Martin provide waterbodies and wetlands for a variety of flora and fauna. No remnant vegetation occurs on these lunettes which have been cleared owing to their highly fertile deep black self-mulching clays on the slopes and crest. Cereal production is a prominent land use along with grazing. These expansive clay soils are strongly structured with moderate site drainage. Subsoils are likely to be calcareous and sodic with depth.

Lunettes near Lake Martin


Dairy farming is a land use of these lunettes



Topographical section of the soil-landform unit 145



Appendix E Particle Size Analysis results

	Particle Size					
	2-0.02mm	0.02-0.002mm	<0.002mm	2-0.2mm	0.2-0.02mm	
Sample ID	%Sand	%Silt	%Clay	%Coarse sand	%Fine Sand	Texture*
Core 1 McDonald A1 0-25cm	74.8	12.3	12.9	53.7	21.1	Loam
Core 1 McDonald A2 25-40cm	82.0	8.8	9.2	64.7	17.3	Loamy Sand
Core 1 McDonald B21 40-48cm	80.5	6.0	13.4	63.8	16.7	Sandy Loam
Core 1 McDonald B22 48-55	59.2	7.5	33.3	43.0	16.2	Clay
Core 3 McDonald A1 0-19cm	50.4	21.1	28.5	20.3	30.1	Clay Loam
Core 3 McDonald A2 19-44cm	55.8	17.4	26.8	27.0	28.8	Clay Loam
Core 3 McDonald B21 44-55cm	40.9	3.2	55.9	29.3	11.6	Clay
Core 3 McDonald B22 55-69cm	51.5	6.3	42.2	40.1	11.4	Clay
Core 3 McDonald B33 67 69-78cm	45.2	7.1	47.7	26.0	19.2	Clay
Core 4 McDonald A1 0-7cm	63.9	21.8	14.3	25.9	37.9	Loam
Core 4 McDonald A21 7-20cm	60.9	18.1	21.0	28.3	32.7	Loam
Core 4 McDonald A22 20-37cm	58.1	13.5	28.4	30.3	27.9	Clay Loam
Core 4 McDonald B2 37-80cm	5.5	7.0	87.5	1.1	4.4	Clay
Core 6 Camerons Ln A1 0-31cm	27.7	8.5	63.8	15.9	11.8	Clay
Core 6 Camerons Ln A3 31-68cm	36.5	9.9	53.5	22.6	13.9	Clay
Core 6 Camerons Ln B2 68-106cm	41.1	12.1	46.8	20.6	20.5	Clay
Core 12 Massey A1 0-26cm	74.3	10.5	15.2	30.4	43.9	Sandy Loam
Core 12 Massey A2 26-40cm	74.9	9.0	16.1	36.6	38.3	Sandy Loam
Core 12 Massey B1 40-51cm	54.7	9.7	35.6	19.0	35.6	Clay
Core 12 Massey B21 51-68cm	48.5	12.3	39.2	12.7	35.8	Clay
Core 12 Massey B22 68-92cm	24.4	8.5	67.1	5.6	18.8	Clay
Core 12 Massey B23 92-106cm	25.3	13.0	61.7	5.2	20.1	Clay
Core 14 'Nowra' A1 0-14cm	42.9	17.0	40.2	20.0	22.8	Clay
Core 14 'Nowra' B1 14-44cm	38.8	17.8	43.4	17.0	21.8	Clay
Core 14 'Nowra' B21 44-76cm	30.4	12.3	57.3	15.5	14.9	Clay
Core 14 'Nowra' B22 76-100cm	27.7	13.1	59.2	10.5	17.1	Clay
Core 15 'Nowra' A1 0-13cm	33.4	19.2	47.4	6.7	26.7	Clay
Core 15 'Nowra' B21 13-34cm	29.9	16.7	53.4	5.5	24.4	Clay
Core 15 'Nowra' B22 34-64cm	23.8	15.6	60.6	4.6	19.2	Clay
Core 15 'Nowra' B23 64-105cm	27.1	13.2	59.7	6.2	20.9	Clay

*Texture derived using Texture Auto Lookup (TAL) 2.8 for Excel, using International Society of Soil Science textural classes.

Sample ID	2-0.02mm	0.02-0.002mm	<0.002mm	2-0.2mm	0.2-0.02mm	
	%Sand	%Silt	%Clay	%Coarse sand	%Fine Sand	Texture*
Core 16 'Nowra' A1 0-25cm	49.8	14.1	36.1	32.3	17.4	Clay
Core 16 'Nowra' B1 25-40cm	33.3	18.2	48.5	13.3	19.9	Clay
Core 16 'Nowra' B21 42-67cm	29.5	17.5	53.0	10.0	19.5	Clay
Core 16 'Nowra' B22K 67-80cm	42.4	10.8	46.8	23.3	19.1	Clay
Core 16 'Nowra' B23K 80-94cm	48.5	6.9	44.6	31.1	17.4	Clay
Core 19 Cook A1 0-24	21.1	16.5	62.4	1.4	19.7	Clay
Core 19 Cook A2 24-56	7.4	10.2	82.4	0.7	6.7	Clay
Core 19 Cook A3 56-74	9.8	12.7	77.5	0.9	8.9	Clay
Core 25 Lang A1 0-9	77.1	10.8	12.1	50.7	26.4	Sandy Loam
Core 25 Lang A21 9-53	80.1	9.7	10.2	56.4	23.7	Sandy Loam
Core 25 Lang A22 53-61	80.4	9.1	10.4	51.5	29.0	Sandy Loam
Core 25 Lang B2 61-100	33.4	5.0	61.6	18.4	15.0	Clay
Core 26 Lang A1 0-24	78.4	10.5	11.1	44.2	34.2	Sandy Loam
Core 26 Lang A3 24-43	79.1	8.0	12.9	48.5	30.6	Sandy Loam
Core 26 Lang B2 43-72	39.1	9.0	51.9	17.0	22.0	Clay
Core 32 'Gala' A1 0-30	60.0	17.7	22.3	25.6	34.4	Loam
Core 32 'Gala' A21 30-46	64.8	11.5	23.6	45.9	19.0	Clay Loam
Core 32 'Gala' A22 46-58	61.8	14.4	23.8	27.7	34.1	Clay Loam
Core 32 'Gala' B2 58-93	5.7	3.6	90.7	2.0	3.8	Clay

*Texture derived using Texture Auto Lookup (TAL) 2.8 for Excel, using International Society of Soil Science textural classes.

Appendix F Intact soil cores

Index of cores followed by soil profile descriptions of intact cores

Core number	Location	GPS Co-ordinates	Soil type
Core 1	McDonald	709 497 E, 5801 689 N	Granitic Sandy Loams
Core 2	McDonald	709 730 E, 5802 022 N	Mundy Gully Black Clays
Core 3	McDonald	709 096 E, 5801 335 N	Granitic Sandy Loams
Core 4	McDonald	708 172 E, 5800 936 N	Granitic Sandy Loams
Core 5	Cameron's Road	708 996 E, 5799 976 N	Granitic Sandy Loams
Core 6	Cameron's Road	709 803 E, 5800 027 N	Lismore Grey Clays
Core 7	Cameron's Road	710 015 E, 5799 807 N	Mundy Gully Black Clays
Core 8	Cameron's Road	710 390 E, 5799 745 N	Lismore Grey Clays
Core 9	Marquand	710 093 E, 5799 679 N	Mundy Gully Black Clays
Core 10	Marquand	710 086 E, 5799 687 N	Nowra Red Clays
Core 11	Massey	711 642 E, 5800 170 N	Lunette Clays
Core 12	Massey	711 431 E, 5799 819 N	Lunette Clays
Core 13	Massey	711 200 E, 5800 061 N	Mundy Gully Black Clays
Core 14	'Nowra'	708 511 E, 5796 689 N	Lismore Grey Clays
Core 15	'Nowra'	708 529 E, 5796 116 N	Mundy Gully Black Clays
Core 16	'Nowra'	708 820 E, 5796 065 N	Nowra Red Clays
Core 17	'Nowra'	709 674 E, 5795 379 N	Lismore Grey Clays
Core 18	Cook	701 136 E, 5793 013 N	Lunette Clays
Core 19	Cook	700 363 E, 5793 430 N	Lunette Clays
Core 20	Cook	703 085 E, 5795 339 N	Granitic Sandy Loams
Core 21	Cook	702 849 E, 5795 057 N	Mundy Gully Black Clays
Core 22	McMillan	710 681 E, 5797 170 N	Mundy Gully Black Clays
Core 23	Lang	700 108 E, 5800 147 N	Nowra Red Clays
Core 24	Lang	700 294 E, 5800 011 N	Lismore Grey Clays
Core 25	Lang	701 621 E, 5799 443 N	Granitic Sandy Loams
Core 26	Lang	702 782 E, 5797 416 N	Granitic Sandy Loams
Core 27	Henderson	709 295 E, 5794 383 N	Lismore Grey Clays
Core 28	Slee	711 765 E, 5793 505 N	Mundy Gully Black Clays
Core 29	Slee	711 851 E, 5793 328 N	Nowra Red Clays
Core 30	Slee	710 652 E, 5793 542 N	Lismore Grey Clays
Core 31	'Gala'	707 238 E, 5801 435 N	Granitic Sandy Loams
Core 32	'Gala'	707 474 E, 5801 360 N	Granitic Sandy Loams
Core 33	'Gala'	707 012 E, 5801 596 N	Granitic Sandy Loams
Core 34	'Gala'	707 060 E, 5801 842 N	Granitic Sandy Loams

Core 1 - McDonalds

General description of the soil

Brown clayey sand A horizon showing severe compaction to 0.25m, over a sandy clay loam subsoil. Granite rock outcrop 100m from core site. Rock hit at 0.55m preventing full core extraction.

Distribution:	Upper and mid slopes of granite sands
Typical land use:	Sheep grazing, occasional cropping
Common variants:	Depth of compacted layer and depth to bedrock
Other names	Granitic Sandy Loam, Brown Sodosol

Environment and location of the example profile

Landform:	Mid slope, gentle undulations
Parent material or substrate:	Granite
Drainage class:	Moderately well drained
Surface condition:	Surface compaction to 0.25m
Site disturbance:	Stock and machinery traffic, no cultivation
Native vegetation:	None present (originally Plains Grassy Woodlands EVC 55)

Location map

Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles (Munsell)	Texture	Structure			Consistence	Coarse fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.25	Brown	-	Clayey sand	Weak	Polyhedral	20-50mm	Weak (dry)	10-20% sub-angular med. Pebbles, granite	-	Abrupt
A2	0.25-0.40	Brown	-	Clayey sand	Weak	Granular	2-5mm	Very weak (dry)	2-10% sub-angular small pebbles, granite	20-50% medium size, FeMg concretions	Clear
B21	0.40-0.48	Dark yellowish brown	-	Sandy clay loam	Single grain	Granular	<2mm	Very weak (dry)	<2% sub-angular small pebbles, granite	10 –20% medium size, FeMg concretions	Clear
B22	0.48-0.55	Dark yellowish brown	-	Sandy clay loam	Single grain	Granular	<2mm	Very weak (dry)	2-10% sub-angular small pebbles, granite	20-50% coarse size, FeMg concretions	-

Soil chemical and physical properties

Horizon	Depth (m)	Field pH (w)	CaCO3 test	Repellence	Lab. pH (w)	EC uS/cm	Particle Size Analysis			Determined texture
							Sand %	Silt %	Clay %	
A1	0.0-0.25	5	-	yes	5.02	116.50	74.8	12.3	12.9	Loam
A2	0.25-0.40	5.5	-	yes	5.64	139.00	82.0	8.8	9.2	Loamy Sand
B21	0.40-0.48	6	-	-	6.18	141.90	80.5	6.0	13.4	Sandy Loam
B22	0.48-0.55	6.5	-	-	5.44	498.00	59.2	7.5	33.3	Clay

Core 2 – McDonalds

General description of the soil

Medium black clay topsoil gradually changing into a greyish, heavy clay subsoil with carbonates at depth. Extracted from Mundy Gully alluvial flats, boarded by granite sands to the south and basalt to the north.

Distribution:	Alluvial creek flats and broad flood plains
Typical land use:	Cropping in dry years on broad flood plains or grazing
Common variants:	Depth to carbonates
Other names	Mundy Gully Black Clays, black Vertosols

Environment and location of the example profile

Landform:	Flat, low lying
Parent material or substrate:	Alluvial
Drainage class:	Poor
Surface condition:	Compacted
Site disturbance:	None
Native vegetation:	None present (originally Grassy Woodlands EVC 175)

Location map

Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles (Munsell)	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Coarse fragments	Segregations	Boundary
A1	0.0-0.11	Black	-	Medium clay	Strong	Subangular blocky	5-10mm	Weak (moist)	2-10% small, subrounded granite pebbles	-	Gradual
A2	0.11-0.66	Black	-	Heavy clay	Strong	Subangular blocky	10-20mm	Weak (mod. moist)	2-10% medium, subrounded granite pebbles	-	Clear
B21	0.66-0.95	Dark grey	-	Heavy clay	Strong	Subangular blocky	10-20mm	Weak (mod. moist)	-	10-20% medium calcareous soft nodules	Abrupt
B22	0.95-1.05	Greyish brown	-	Heavy clay	Massive	-	-	Weak (mod. moist)	-	20-50% coarse calcareous soft nodules	-

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Repellence	Lab. pH	EC
A1	0.0-0.11	7	-	-	7.84	479.00
A2	0.11-0.66	7.5	-	-	8.04	430.00
B21	0.66-0.95	9	Highly calcareous	-	9.29	666.00
B22	0.95-1.05	9	Highly calcareous	-	9.09	827.00

Core 3 - McDonalds

General description of the soil

Dark brown, light clay top soil over a bleached A2 horizon followed by medium clay subsoil. Segregations of iron manganese abundant throughout profile. Coffee rock formation reached at 0.7m

Distribution:	Small (<5ha) patches on the Granitic Sandy Loams
Typical land use:	Cropping or grazing
Common variants:	Percentage of buckshot and depth to coffee rock
Other names	Buckshot Clays, Brown Chromosol

Environment and location of the example profile

Landform:	Mid slope on gentle undulation
Parent material or substrate:	Neogene sands
Drainage class:	Moderate
Surface condition:	Friable
Site disturbance:	Cultivated and sown
Native vegetation:	None present (originally Plains Grassy Woodlands EVC 55)

Location map

Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles (Mussel)	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Coarse fragments	Segregations	Boundary
A1	0-0.19	Dark brown	<2% fine orange	Light clay	Strong	Platy	5-10mm	Weak (dry)	-	10-20% coarse FeMg concretions	Clear
A2	0.19-0.44	Gray	<2% fine orange	Medium clay	Strong	Lenticular	5-10mm	Very weak (mod. Moist)	-	20-50% coarse FeMg concretions	Abrupt
B21	0.44-0.55	Dark gray	20-50% medium orange	Medium clay	Moder-ate	Sub-angular blocky	10-20mm	Weak (mod. Moist)	-	>50% coarse FeMg concretions	Clear
B22	0.55-0.69	Brown	10-20% fine orange	Medium clay	Moder-ate	Sub-angular blocky	10-20mm	Weak (mod. Moist)	-	>50% coarse FeMg concretions	Abrupt
C	0.69-0.78	Brown	10-20% fine orange						-	>50% coarse FeMg concretions	

Soil chemical and physical properties

Horizon	Depth (cm)	pH (w)	CaCO3 test	Repel-lence	Lab. pH (w)	EC uS/cm	Particle Size Analysis Sand %	Silt %	Clay %	Determined texture
A1	0-0.19	5.5	-	-	5.27	285.00	50.4	21.1	28.5	Clay Loam
A2	0.19-0.44	6	-	-	6.58	122.50	55.8	17.4	26.8	Clay Loam
B21	0.44-0.55	7	-	-	7.20	292.00	40.9	3.2	55.9	Clay
B22	0.55-0.69	7	-	-	5.88	200.10	51.5	6.3	42.2	Clay
C	0.69-0.78	7	-	-	7.80	270.00	45.2	7.1	47.7	Clay

Core 4 - McDonalds

General description of the soil

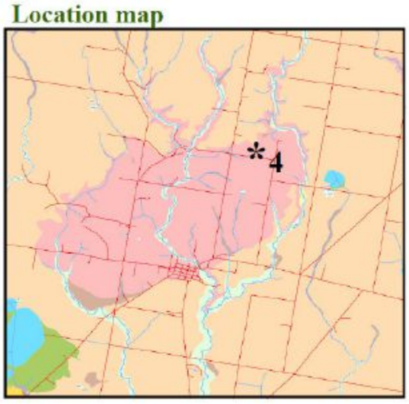
Brown sandy clay loam A horizon with a gradual change to yellowish brown heavy clay. Increasing buckshot through lower profiles.

Distribution:	Plateau and upper slopes of the granites
Typical land use:	Cropping and grazing
Common variants:	Depth to heavy clay
Other names	Granitic Sandy Loams, Brown Sodosol

Environment and location of the example profile

Landform:	Flat to gently undulating on granitic sand ridge
Parent material or substrate:	Granite
Drainage class:	Moderate
Surface condition:	Friable, dry
Site disturbance:	Cultivated and sown
Native vegetation:	None present (originally Plains Grassy Woodlands EVC 55)

Location map



Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles (Munsell)	Texture	Structure			Consistence	Coarse fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.07	Dark brown	-	Sandy clay loam	weak	Subangu-lar blocky	5-10mm	Very weak (mod moist)	-	-	Clear
A21	0.07-0.20	Brown	-	Sandy clay loam	weak	Polyhedral	5-10mm	Very weak (mod moist)	-	2-10% medium size FeMg con-cretions	Clear
A22	0.20-0.37	Dark brown	-	Sandy clay loam	mod-erate	Polyhedral	10-20mm	Weak (mod moist)	-	10-20% coarse size FeMg con-cretions	Gradual
B2	0.37-0.80	Yellowish brown	10-20% medium size, red	Heavy clay	weak	Polyhedral	10-20mm	Weak (dry)	-	20-50% coarse size FeMg con-cretions	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm	Particle Size Analysis			Determined texture
						Sand %	Silt %	Clay %	
A1	0.0-0.07	5	-	6.50	1040.00	63.9	21.8	14.3	Loam
A21	0.07-0.20	5.5	-	5.40	524.00	60.9	18.1	21.0	Loam
A22	0.20-0.37	5.5	-	5.82	465.00	58.1	13.5	28.4	Clay Loam
B2	0.37-0.80	6	-	5.72	226.00	5.5	7.0	87.5	Clay

Core 5 - Cameron's Road

General description of the soil

Brown clayey sand over brown to medium clay subsoil. Core extracted from road side, rock hit at 0.6m preventing full core extraction

Distribution:	Upper and mid slopes on granite sands
Typical land use:	Grazing or cropping
Common variants:	Compaction layer depending on land-use
Other names	Granitic Sandy Loam, Brown Sodosol

Environment and location of the example profile

Landform:	Moderate slope
Parent material or substrate:	Granite
Drainage class:	Moderate
Surface condition:	Slight compaction
Site disturbance:	Some roadside edge disturbance
Native vegetation:	None present (originally Plains Grassy Woodlands EVC 55)

Location map

Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure			Consistence	Coarse fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.17	Dark yellowish brown	-	Clayey sand	Medium	Platy	>5mm into 5-10mm	Weak (dry)	10-20% small granite pebbles	10-20% coarse FeMg concretions	Abrupt
B21	0.17-0.31	Brown	10-20% medium size, red	Medium clay	Strong	Angular blocky	5-10mm	Firm (dry)	-	-	Gradual
B22	0.31-0.60	Brown	10-20% medium size, red	Medium clay	Strong	Angular blocky	5-10mm	Firm (dry)	-	-	-

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm
A1	0.0-0.17	5.5	-	4.83	151.20
B21	0.17-0.31	5	-	5.92	323.00
B22	0.31-0.60	5.5	-	4.95	816.00

Core 6 – Cameron's Road

General description of the soil

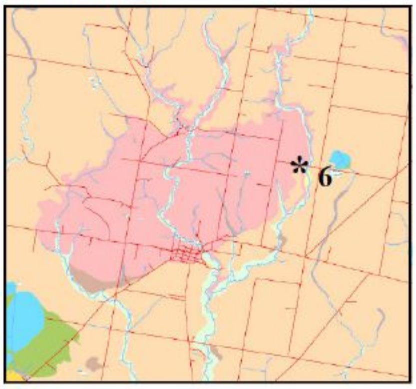
Organic matter thatch over brown, medium clay profile. Course fragments of granite origin present due to granite wash off. Minor carbonate deposits at depth.

Distribution:	Found extensively across basalt plains
Typical land use:	Cropping and grazing
Common variants:	Depth to and amount of carbonates
Other names	Lismore Grey Clays, Brown Sodosol

Environment and location of the example profile

Landform:	Moderate slope
Parent material or substrate:	Basalt with granite wash-off
Drainage class:	Moderate
Surface condition:	Thick organic matter thatch
Site disturbance:	None - road side
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map



Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Coarse fragments	Segregations	Boundary
A1	0.0-0.31	Dark greyish brown	2-10% fine orange	Medium clay	Strong	Angular blocky	5-10mm	Strong (mod moist)	-	-	Gradual
A3	0.31-0.68	Dark greyish brown	<2% fine grey	Medium clay	Strong	Angular blocky	10-20mm	Strong (dry)	<2% small granite pebbles	<2% small FeMg concretions	Gradual
B2	0.68-1.06	Brown	<2% fine yellow	Heavy clay	Strong	Sub-angular blocky	10-20mm	Strong (mod moist)	<2% small granite pebbles	2-10% calcareous soft	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm	Particle Size Analysis Sand %	Silt %	Clay %	Determined texture
A1	0.0-0.31	6	-	7.14	3.12	27.7	8.5	63.8	Clay
A3	0.31-0.68	7	-	7.81	467.00	36.5	9.9	53.5	Clay
B2	0.68-1.06	8	-	8.73	1064.00	41.1	12.1	46.8	Clay

Core 7 - Cameron's Road

General description of the soil
Reddish brown light clay topsoil of basalt origin over a medium to heavy clay alluvial subsoil. Band of sand and organic matter observed between 0.38 - 0.4m, possibly a buried horizon.

Distribution:	Creek flats, slopes below Nowra Red Clay
Typical land use:	Cropping and grazing
Common variants:	Depth of basalt topsoil above heavy clay
Other names	Mundy Gully Black Clays, Black Vertosols

Environment and location of the example profile

Landform:	Creek flats
Parent material or substrate:	Alluvial material from granite and basalts
Drainage class:	Poor
Surface condition:	Organic matter thatch
Site disturbance:	Some past disturbance
Native vegetation:	None present (originally Plains Grassy Woodlands EVC 55)

Location map

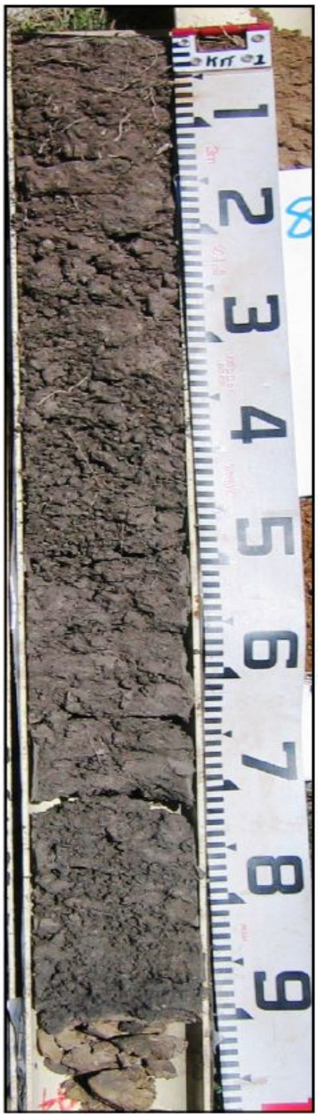
Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure			Consistence	Coarse fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.08	Reddish brown	-	Light clay	Moder-ate	Polyhe-dral	5-10mm	Weak (mod moist)	-	-	Clear
B21	0.08-0.35	Very dark grey	-	Medium heavy clay	Moder-ate	Angular blocky	10-20mm	Weak (moist)	<2% small angular quartz	-	Clear
B22	0.35-0.63	Very dark grey	-	Heavy clay	Weak	Angular blocky	20-50mm	Weak (moist)	<2% small angular quartz	2-10% fine FeMg concretions	Clear
B23	0.63-0.83	Light olive brown	20-50% fine, distinct, yellow & gray	Medium clay	Mas-sive			Weak (moist)	-	2-10% fine FeMg concretions	Gradual
B24k	0.83-1.05	Greyish brown		Medium clay	Mas-sive			Weak (moist)	-	2-10% coarse calcareous segregations	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm
A1	0.0-0.08	6.5	-	6.83	853.00
B21	0.08-0.35	7.5	Slight	7.62	460.00
B22	0.35-0.63	7.5	-	7.17	476.00
B23	0.63-0.83	8.5	-	8.24	683.00
B24k	0.83-1.05	8.5	Moderate	7.97	905.00



Core 8 - Cameron's Road

General description of the soil

Shallow loam topsoil over dark grey, heavy clay profile. Basalt outcrops nearby and many small stones through out the paddock. Weathered basalt parent material hit at 0.93m preventing full core extraction.

Distribution:	Found extensively across plains of newer basalt
Typical land use:	Cropping and grazing
Common variants:	Depth to and presence of carbonates
Other names	Lismore Grey Clays, brown Sodosol

Environment and location of the example profile

Landform:	Gentle slope
Parent material or substrate:	Basalt
Drainage class:	Moderate
Surface condition:	Generally friable
Site disturbance:	None
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map

Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mot-tles	Texture	Structure			Consistence	Coarse fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.06	Very dark greyish brown	-	Loam	Weak	Polyhedral	<2mm	Very weak (mod moist)	-	-	Abrupt
B21	0.06-0.25	Very dark greyish brown	-	Heavy clay	Massive	-	-	Firm (mod moist)	-	-	Clear
B22	0.25-0.50	Very dark grey	-	Heavy clay	Weak	Angular blocky	10-20mm	Weak (mod moist)	-	-	Clear
B23	0.50-0.75	Very dark grey	-	Heavy clay	Massive	-	-	Weak (moist)	-	-	Gradual
B24	0.75-0.93	Very dark grey	-	Heavy clay	Weak	Sub angular blocky	2-5mm	Weak (moist)	-	<2% medium FeMg concretions	Sharp

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm
A1	0.0-0.06	5.5	-	6.60	150.50
B21	0.06-0.25	6.5	-	7.10	229.00
B22	0.25-0.50	7.0	-	6.95	248.00
B23	0.50-0.75	7.5	-	7.81	381.00
B24	0.75-0.93	7.5	-	7.98	499.00

Core 9 - Marquand

General description of the soil

Brown loam basalt derived topsoil over black, medium to heavy clay alluvial material with carbonates at depth. Extracted form creek flats flanked by basalt to the east and granite sands to the west.

Distribution:	Along river flats and alluvial flood plains
Typical land use:	Cropping and grazing
Common variants:	Depth to heavy clay layer and drainage
Other names	Combined core of Nowra Red Clay and Mundy Gully Black Clays

Environment and location of the example profile

Landform:	Very gentle slope to flat
Parent material or substrate:	Alluvial with wash off from basalts and granites
Drainage class:	Poor to moderate
Surface condition:	Slightly compacted
Site disturbance:	Minimal
Native vegetation:	None present (originally Plains Grassy Woodlands EVC 55)

Location map

Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Coarse fragments	Segregations	Boundary
A1	0.0-0.09	Dark brown	-	Loam	Moderate	Sub angular blocky	2-5mm	Weak (mod moist)	<2% fine granites	-	Abrupt
A2	0.09-0.28	Very dark greyish brown	-	Clay loam	Strong	Sub angular blocky	5-10mm	Firm (dry)	<2% fine granites	-	Abrupt
B1	0.28-0.38	Very dark greyish brown	-	Medium clay	Strong	Sub angular blocky	10-20mm	Very firm (dry)	2-10% fine granites	-	Clear
B21	0.38-0.57	Black	-	Medium clay	Strong	Polyhedral	20-50mm	Very firm (dry)	<2% fine granites	-	Gradual
B22	0.57-0.69	Black	-	Heavy clay	Moderate	Polyhedral	50-100mm	Very firm (mod moist)	<2% fine granites	-	Gradual
B23	0.69-1.03	Black	-	Heavy clay	Moderate	Polyhedral	50-100mm	Firm (mod moist)	<2% fine granites	-	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm
A1	0.0-0.09	4.5	-	5.03	434.00
A2	0.09-0.28	5.5	-	6.70	276.00
B1	0.28-0.38	6	-	7.18	296.00
B21	0.38-0.57	7	-	6.95	295.00
B22	0.57-0.69	7	-	8.04	431.00
B23	0.69-1.03	7.5	Very high	8.12	880.00

Core 10 - Marquand

General description of the soil

Organic mat over friable light clay with increasing clay content down profile. Weathered basalt parent material and auger refusal at 0.70m. Core extracted from slopes above Mundy Gully, scattered basalt rock present.

Distribution:	Exposed on slopes above creek valleys but below plateaus
Typical land use:	Cropping and grazing
Common variants:	Depth to bedrock, presence of carbonates
Other names	Nowra Red Clay, red Ferrosol

Environment and location of the example profile

Landform:	Slopes above Mundy Gully on edge of basalt plateau
Parent material or substrate:	Basalt
Drainage class:	Excellent
Surface condition:	Friable
Site disturbance:	None, permanent pasture
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map

Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles (Munsell)	Texture	Structure			Consistence	Coarse fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.22	Dark brown	-	Light clay	Strong	Polyhedral	5-10mm	Firm (mod moist)	-	-	Gradual
B21	0.22-0.42	Dark brown	-	Heavy clay	Moderate	Sub angular blocky	10-20mm	Weak (moist)	-	-	Diffuse
B22	0.42-0.65	Dark brown	-	Heavy clay	Moderate	Sub angular blocky	10-20mm	Weak (moist)	10-20% Medium basalt	-	Abrupt
C	0.65-0.75	Very dark brown	-	Weathered basalt parent material							

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm
A1	0.0-0.22	5	-	6.17	272.00
B21	0.22-0.42	6	-	6.08	316.00
B22	0.42-0.65	6.5	-	6.46	192.40
C	0.65-0.75	7	-	6.53	414.00

Core 11 - Massey

General description of the soil

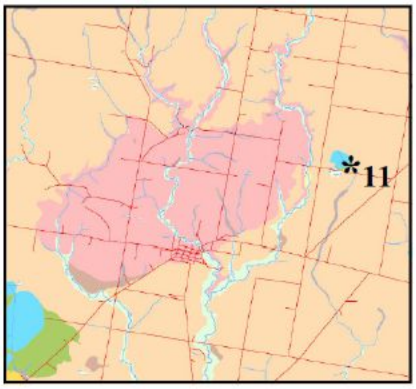
Greyish brown sandy clay loam top soil over clayey sand lower A horizon. Rocks hit at 0.55m preventing full core extraction.

Distribution:	Lunettes, found along eastern edges of lakes
Typical land use:	Grazing, some cropping on larger lunettes
Common variants:	Depth to rock or clay
Other names	Lunette Clays, brown Vertosol

Environment and location of the example profile

Landform:	Lunette ridge
Parent material or substrate:	Aeolian lake sediments
Drainage class:	Moderate
Surface condition:	Organic matter thatch
Site disturbance:	Possibly old house site
Native vegetation:	None present (originally Pains Sedgy Wetlands EVC 647)

Location map



Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mot-tles	Texture	Structure			Consistence	Coarse fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.14	Very dark greyish brown	-	Sandy clay loam	Weak	Sub angu-lar blocky	5-10mm	Very weak (Moist)	-	<2% medium FeMg concretions	Clear
A21	0.14-0.40	Dark brown	-	Clayey sand	Weak	Lenticular	5-10mm	Firm (dry)	-	10-20% medium FeMg concretions	Clear
A22	0.40-0.60	Dark greyish brown	-	Clayey sand	Mod-erate	Lenticular	5-10mm	Weak (dry)	-	<2% medium FeMg concretions	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm
A1	0.0-0.14	5.5	-	5.60	280.00
A21	0.14-0.40	5.5	-	5.60	97.30
A22	0.40-0.60	5	-	6.00	155.90

Core 12 - Massey

General description of the soil

Brown to greyish A horizon of clay loam sand texture with a clear change into a saline black clay subsoil. Flakes of quartz and chert from aboriginal tools found on the lunette.

Distribution:	Lunettes, found on eastern edges of past and present lakes
Typical land use:	Grazing, some cropping on larger lunettes
Common variants:	Depth to clay subsoil
Other names	Lunette Grey Clays, Brown Sodosol

Environment and location of the example profile

Landform:	Lunette ridge
Parent material or substrate:	Aeolian lake sediments
Drainage class:	Well drained
Surface condition:	Compacted to 0.26m
Site disturbance:	None
Native vegetation:	None present (originally Plains Sedgy Wetlands EVC 647)

Location map

Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Coarse fragments	Segregations	Boundary
A1	0.0-0.26	Dark brown	-	Clay loam sandy	Moderate	Platy	20-50mm	Weak (mod moist)	-	<2% medium FeMg concretions	Gradual
A21	0.26-0.40	Dark greyish brown	-	Clay loam sandy	Moderate	Polyhe-dral	10-20mm	Weak (mod moist)	-	20-50% coarse FeMg concretions	Sharp
A22	0.40-0.51	Brown	20-50% medium distinct red	Silty clay loam	Strong	Polyhe-dral	20-50mm	Firm (mod moist)	-	-	Abrupt
A23	0.51-0.65	Dark grey	2-10% medium faint yellow	Silty clay loam	Moderate	Polyhe-dral	20-50mm	Weak (dry)	-	-	Clear
B21	0.65-0.92	Black	<2% medium faint yellow	Medium heavy clay	Massive	Polyhe-dral	10-20mm	Firm (mod moist)	-	-	Gradual
B22	0.92-1.06	Black	-	Heavy clay	Massive			Firm (mod moist)	-	-	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm	Particle Size Analysis Sand %	Silt %	Clay %	Determined texture
A1	0.0-0.26	5.5	-	5.18	142.10	74.3	10.5	15.2	Sandy Loam
A21	0.26-0.40	6	-	6.05	149.90	74.9	9.0	16.1	Sandy Loam
A22	0.40-0.51	6.5	-	7.20	132.50	54.7	9.7	35.6	Clay
A23	0.51-0.65	7	-	6.69	427.00	48.5	12.3	39.2	Clay
B21	0.65-0.92	8.5	-	8.21	931.00	24.4	8.5	67.1	Clay
B22	0.92-1.06	9.5	-	7.99	989.00	25.3	13.0	61.7	Clay

Core 13 - Massey

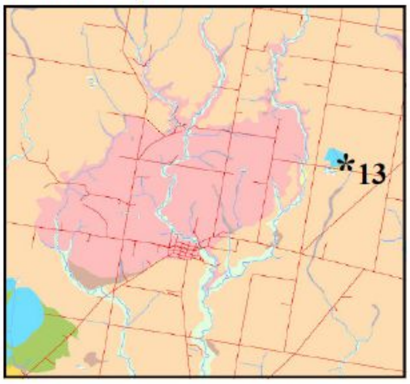
General description of the soil
Dark grey medium clay topsoil increasing to a heavy clay subsoil with orange mottles throughout profile. Core extracted from old swamp bed. Some salt indicator species present.

Distribution:	Lakes, swamps and wetlands
Typical land use:	Grazing in dry years
Common variants:	Depth to heavy clays and salinity levels
Other names	Mundy Gully Black Clays, black Vertosol

Environment and location of the example profile

Landform:	Swamps and depressions in the landscape
Parent material or substrate:	Alluvial
Drainage class:	Poor, covered with water in wet years
Surface condition:	Firm with self mulching surface
Site disturbance:	None
Native vegetation:	None present (originally Plains Sedgy Wetlands EVC 647)

Location map



Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure			Consistence	Coarse fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.09	Dark grey	2-10% distinct, fine, orange	Medium clay	Moderate	Sub angular blocky	2-5mm	Weak (dry)	-	-	Clear
B21	0.09-0.29	Dark grey	2-10% faint, fine, orange	Medium clay	Moderate	Sub angular blocky	5-10mm	Very firm (dry)	-	-	Gradual
B22	0.29-0.81	Dark grey	2-10% faint, fine, orange	Heavy clay	Moderate	Angular blocky	5-10mm	Firm (mod moist)	-	-	Clear
B23	0.81-1.04	Dark grey	2-10% faint, medium, orange	Heavy clay	Massive	-	-	Very firm (moist)	-	-	-

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm
A1	0.0-0.09	5.5	-	6.00	259.00
B21	0.09-0.29	6	-	6.38	277.00
B22	0.29-0.81	6	-	6.35	700.00
B23	0.81-1.04	7	-	6.35	700.00

Core 14 - Nowra

General description of the soil

Dark grey brown, lighter textured A horizon over heavy clay subsoil. Some segregations throughout profile with carbonates at depth. Wash-off from near by granites resulting in coarse fragment of granite origin .

Distribution:	Found extensively across plains of newer basalt
Typical land use:	Cropping and grazing
Common variants:	Depth to and amount of carbonates
Other names	Lismore Grey Clays, brown Sodosol

Environment and location of the example profile

Landform:	Flat to gently undulating
Parent material or substrate:	Basalt
Drainage class:	Moderate to poor
Surface condition:	Slight compaction
Site disturbance:	None
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map

Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Coarse fragments	Segregations	Boundary
A1	0.0-0.14	Very dark grayish brown	-	Clay loam, sandy	Strong	Sub angular blocky	5-10mm	Very weak (moist)	<2% small granite pebbles	<2% medium FeMg concretions	Abrupt
B1	0.14-0.44	Gray	<2% fine, faint orange	Heavy clay	Moderate	Polyhedral	10-20mm	Weak (moist)	-	2-10% coarse FeMg concretions	Abrupt
B21	0.44-0.76	Grayish brown	-	Heavy clay	Moderate	Polyhedral	20-50mm	Weak (moist)	<2% small granite pebbles	<2% medium FeMg concretions	Clear
B22	0.76-1.00	Light yellowish brown	-	Heavy clay	Moderate	Polyhedral	20-50mm	Weak (moist)	<2% small granite pebbles	<2% fine FeMg concretions	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm	Particle Size Analysis Sand %	Silt %	Clay %	Determined texture
A1	0.0-0.14	5.5	-	5.87	256.00	42.9	17.0	40.2	Clay
B1	0.14-0.44	7	-	6.61	298.00	38.8	17.8	43.4	Clay
B21	0.44-0.76	8.5	Moderate	8.39	722.00	30.4	12.3	57.3	Clay
B22	0.76-1.00	9	High	8.82	1242.00	27.7	13.1	59.2	Clay

Core 15 - Nowra

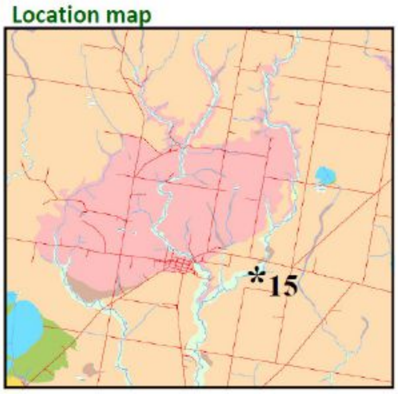
General description of the soil
Medium to heavy black clay profile with carbonates found at depth. Extracted from broad alluvial plains along Mundy Gully and lower reaches of Browns Waterholes.

Distribution:	Creek flats and flood plains
Typical land use:	Grazing or cropping in dry years
Common variants:	Depth to carbonates
Other names	Mundy Gully Black Clays, Black Vertosol

Environment and location of the example profile

Landform:	Flat, low lying
Parent material or substrate:	Alluvial
Drainage class:	Poor, water logging common in winter
Surface condition:	Friable, self mulching
Site disturbance:	Cultivated and sown to crop
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map



Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure			Consistence	Coarse fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.13	Black	-	Medium clay	Strong	Sub angular blocky	10-20mm	Firm (mod moist)	-	-	Clear
B21	0.13-0.34	Black	-	Heavy clay	Massive	Angular blocky	-	Very firm (moist)	-	-	Clear
B22	0.34-0.64	Black	-	Heavy clay	Strong	Sub angular blocky	20-50mm	Firm (mod moist)	-	-	Abrupt
B23	0.64-1.05	Black	-	Heavy clay	Massive		-	Firm (mod moist)	-	<2% medium calcareous soft segregations	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm	Particle Size Analysis			Determined texture
						Sand %	Silt %	Clay %	
A1	0.0-0.13	6	-	6.04	365.00	33.4	19.2	47.4	Clay
B21	0.13-0.34	7	-	7.20	196.00	29.9	16.7	53.4	Clay
B22	0.34-0.64	8	-	8.05	311.00	23.8	15.6	60.6	Clay
B23	0.64-1.05	9	Moderate	9.42	803.00	27.1	13.2	59.7	Clay

Core 16 - Nowra

General description of the soil

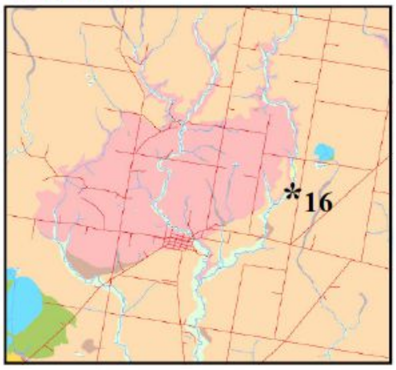
Light clay A_1 with clay content increasing down profile. Carbonate accumulations found past 0.80m. Core extracted from red bank on the edge of basalt plateau.

Distribution:	Exposed on slopes above creek valleys but below plateaus
Typical land use:	Cropping or grazing
Common variants:	Depth to carbonates
Other names	Nowra Red Clay, red Ferrosol

Environment and location of the example profile

Landform:	Moderate slope on edge of plateau
Parent material or substrate:	Basalt
Drainage class:	Excellent
Surface condition:	Friable
Site disturbance:	Cultivated and sown to crop
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map



Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Course fragments	Segregations	Boundary
A1	0.0-0.25	Very dark brown	-	Light clay	Strong	Sub angular blocky	5-10mm	Very firm (dry)	<2% small quartz pebbles	10-20% fine FeMg concretions	Gradual
B1	0.25-0.42	Very dark brown	-	Light medium clay	Moderate	Sub angular blocky	2-5mm	Firm (mod moist)	-	-	Gradual
B21	0.42-0.67	Very dark brown	2-10% fine faint orange	Medium clay	Moderate	Sub angular blocky	10-20mm	Firm (moist)	-	-	Gradual
B22k	0.67-0.89	Brown	-	Heavy clay	Weak	Sub angular blocky	10-20mm	Weak (moist)	-	20-50% course calcareous nodules	Clear
B23k	0.89-0.94	Brown	-	Heavy clay	Weak	Sub angular blocky	2-5mm	Weak (moist)	-	>50% med. to course calcare-ous nodules	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm	Particle Size Analysis Sand %	Silt %	Clay %	Determined texture
A1	0.0-0.25	6	-	6.28	267.00	49.8	14.1	36.1	Clay
B1	0.25-0.42	7	-	6.05	389.00	33.3	18.2	48.5	Clay
B21	0.42-0.67	7.25	-	6.39	274.00	29.5	17.5	53.0	Clay
B22k	0.67-0.89	7.5	-	8.18	402.00	42.4	10.8	46.8	Clay
B23k	0.89-0.94	8.5	High	8.36	506.00	48.5	6.9	44.6	Clay

Core 17 - Nowra

General description of the soil

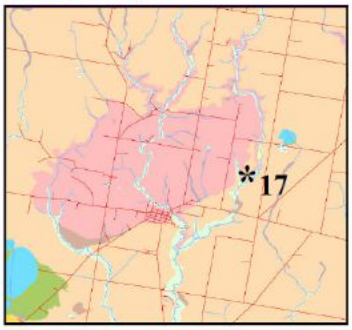
Shallow fine sandy clay loam topsoil over a profile of increasing clay content down profile with carbonate accumulation at depth. Core extracted from an undisturbed corner of a cropped paddock on the top of a basalt plateau.

Distribution:	Found extensively on basalt plains
Typical land use:	Cropping pr grazing
Common variants:	Depth to carbonates

Environment and location of the example profile

Landform:	Flat
Parent material or substrate:	Basalt
Drainage class:	Moderate
Surface condition:	Root mat/ organic matter thatch
Site disturbance:	None at core extraction site
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map



Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure			Consistence	Coarse fragment	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.09	Dark greyish brown	-	Fine sandy clay loam	Weak	Polyhedral	5-10mm	Firm (dry)	-	-	Abrupt
B1	0.09-0.30	Dark greyish brown	2-10% fine faint orange	Light medium clay	Strong	Angular blocky	10-20mm	Very firm (mod moist)	-	-	Clear
B21	0.30-0.60	Brown	10-20% medium distinctive brown	Medium clay	Moderate	Angular blocky	10-20mm	Firm (mod moist)	-	-	Gradual
B22	0.60-0.75	Dark grey	-	Medium clay	Strong	Prismatic	50-100mm	Weak (moist)	-	-	Clear
B23k	0.75-0.90	Greyish brown	-	Medium heavy clay	Moderate	Polyhedral	10-20mm	Weak (moist)	-	10-20% medium FeMg concretions	Clear
B24k	0.90-1.05	Light olive brown	<2% medium prominent brown	Medium clay	Weak	Polyhedral	2-5mm	Weak (moist)	-	<2% medium FeMg concretions	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Lab. pH (w)	EC uS/cm
A1	0.0-0.09	6	-	6.40	266.00
B1	0.09-0.30	6	-	7.20	171.00
B21	0.30-0.60	6.5	-	7.82	682.00
B22	0.60-0.75	7	-	7.84	1133.00
B23k	0.75-0.90	8	Slight	8.15	1753.00
B24k	0.90-1.05	8	High	8.59	1792.00

Core 18 - Cook

General description of the soil

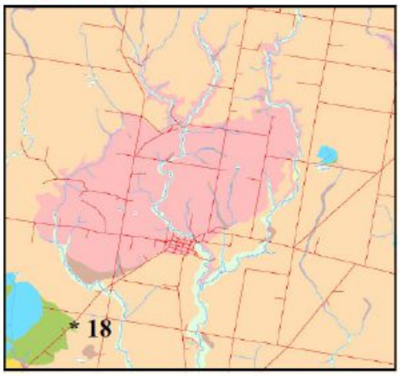
Very dark greyish brown soil with clay content increasing down the profile. Drainage may be impeded by increasing clay content. Generally a fertile soil due to the depositional origin.

Distribution:	Lunette material around eastern rim of past and present lakes
Typical land use:	Cropping or Grazing
Common variants:	Depth to clay
Other names	Lunette Clays, brown Vertosol

Environment and location of the example profile

Landform:	Flat to very gently sloping
Parent material or substrate:	Aeolian lake material
Drainage class:	Moderate to poor
Surface condition:	Friable with some compaction below
Site disturbance:	Cultivation and grazing
Native vegetation:	None present (originally Plains Sedgy Wetlands EVC 647)

Location map



Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Coarse Frag.	Segregations	Boundary
A1	0.0-0.10	Very dark greyish brown	-	Sandy clay loam	Medium	Platy	50-100mm	Weak	-	2-10% medium FeMg concretions	Clear
B1	0.10-0.27	Very dark greyish brown	-	Light clay	Medium	Blocky	5-10mm	Strong	-	<2% fine FeMg concretions	Clear
B2	0.27-0.70	Black	<2% fine faint orange	Light to medium clay	Medium	Blocky	10-20mm	Strong	-	-	Clear
B3	0.70-0.84	Very dark greyish brown	-	Light clay	Medium	Blocky	50-100mm	Very firm	-	-	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test
A1	0.0-0.10	4.5	-
B1	0.10-0.27	5	-
B2	0.27-0.70	6.5	-
B3	0.70-0.84	8.5	-

Core 19 - Cook

General description of the soil

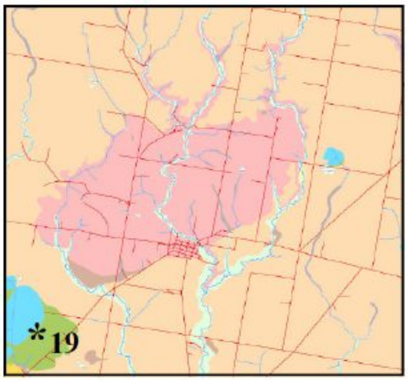
A friable, well structured black, clay dominant profile. Core was extracted on top of Lake Tolliorook's large lunette.

Distribution:	Lunettes, found on eastern edges of past and present lakes
Typical land use:	Grazing, cropping on larger lunettes
Common variants:	Clay content
Other names	Lunette Clays, brown Vertosol

Environment and location of the example profile

Landform:	Lunette ridge
Parent material or substrate:	Aeolian lake sediments
Drainage class:	Moderate
Surface condition:	Friable
Site disturbance:	Cropping
Native vegetation:	None present (originally Plains Sedgy Wetlands EVC 647)

Location map



Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure			Consistence	Course fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.24	Black	-	Light medium clay	Strong	Polyhedral	5-10mm	Very weak (dry)	-	-	Clear
A2	0.24-0.56	Black	-	Medium heavy clay	Strong	Polyhedral	10-20mm	Very weak (mod. Moist)	-	-	Gradual
A3	0.56-0.74	Dark grey	-	Light clay	Strong	Polyhedral	5-10mm	Weak (dry)	-	-	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test	Particle Size Analysis			Determined texture
				Sand %	Silt %	Clay %	
A1	0.0-0.24	5.5	-	21.1	16.5	62.4	Clay
A2	0.24-0.56	6.5	-	7.4	10.2	82.4	Clay
A3	0.56-0.74	7.5	-	9.8	12.7	77.5	Clay

Core 20 - Cook

General description of the soil

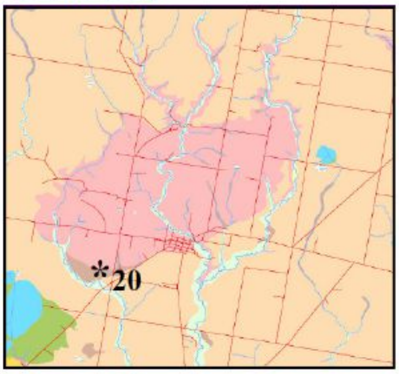
A weakly structured, light textured A horizon with a bleached A22 found over medium clay subsoil. Moderate sand content found through A horizon and small amounts of iron-manganese buckshot throughout.

Distribution:	Small areas of wash off adjacent to the granite sands
Typical land use:	Grazing, some cropping
Common variants:	Depth to clay subsoil
Other names	Granitic Sandy Loam, grey Sodosol

Environment and location of the example profile

Landform:	Gentle slope
Parent material or substrate:	Granite derived colluvium
Drainage class:	Moderate to poor
Surface condition:	Dry, loose material
Site disturbance:	None
Native vegetation:	None present (originally Plains Grassy Woodlands EVC 55)

Location map



Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Course fragments	Segregations	Boundary
A1	0.0--0.11	Greyish brown	-	Sandy loam	Weak	Blocky	2-5mm	Very weak	-	2-10% medium FeMg concretions	Clear
A21	0.11-0.28	Brown	-	Sandy clay loam	Weak	Lenticu-lar	10-20mm	Very weak	-	2-10% coarse FeMg concretions	Clear
A22	0.28-0.51	Light greyish brown	-	Sandy loam	Weak	Blocky	10-20mm	Weak	-	10-20% coarse FeMg concretions	Sharp
B2	0.51-0.84	Yellowish brown	20-50% me-dium promi-nent orange	Medium clay	Me-dium	Polyhe-dral	10-20mm	Weak	-	<2% very coarse FeMg concretions	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test
A1	0.0--0.11	4.5	-
A21	0.11-0.28	4.5	-
A22	0.28-0.51	5.5	-
B2	0.51-0.84	7	-

Core 21 - Cook

General description of the soil

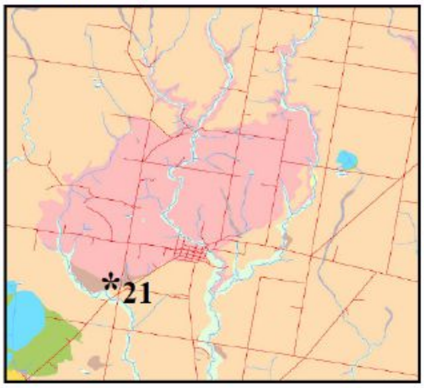
Extremely dry profile prevent fully core extraction and resulted in clay profile with a blocky structure. Surface cracks were evident across the area.

Distribution:	Alluvial creek flats and flood plains
Typical land use:	Cropping of grazing
Common variants:	Depth to or presence of carbonates
Other names	Mundy Gully Black Clays, black Vertosol

Environment and location of the example profile

Landform:	Flats
Parent material or substrate:	Basalts with some wash off from granite sands
Drainage class:	Poor
Surface condition:	Compacted
Site disturbance:	None
Native vegetation:	None present (originally Plains Sedgy Wetlands EVC 647)

Location map



Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure			Consistence	Course fragments	Segregations	Boundary
					Grade	Shape	Size				
A	0.0-0.45	Black	-	Medium clay	Strong	Blocky	20-50mm	Very strong (dry)	<2% small quartz pebbles	-	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test
A	0.0-0.40	6.5	-

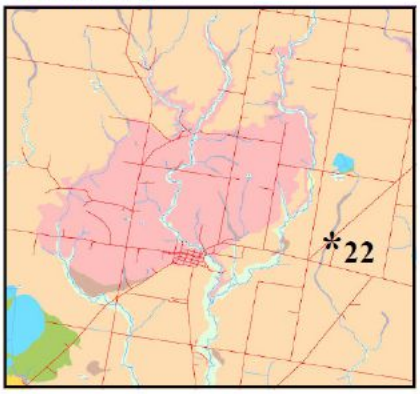
Core 22 - McMillan

General description of the soil	
Black loam topsoil over a subsoil of increasing clay content with carbonates found at depth. Quartz pebbles found through due to wash off from granites	
Distribution:	Shallow drainage lines through basalts and granites
Typical land use:	Grazing
Common variants:	Depth to carbonates and amount of coarse fragments, depends on location

Environment and location of the example profile

Landform:	Drainage lines, shallow depressions
Parent material or substrate:	Alluvial material from basalt and granite wash-off
Drainage class:	Poor
Surface condition:	Very dry
Site disturbance:	Probably due to location of core on roadside drain
Native vegetation:	None present (originally

Location map



Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Course fragments	Segregations	Boundary
A1	0.0-0.10	Black	-	Loam	Medium	Blocky	10-20mm	Firm	10-20% small quartz pebbles	-	Clear
B21	0.10-0.55	Very dark greyish brown	2-10% faint fine orange	Light Clay	Medium	Blocky	10-20mm	Very firm	10-20% small quartz pebbles	-	Clear
B22	0.55-0.80	Dark brown	-	Medium clay	Medium	Blocky	20-50mm	Very firm	10-20% small quartz pebbles	-	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test
A1	0.0-0.10	6	-
B21	0.10-0.55	6	-
B22	0.55-0.80	7.5	Moderate

Core 23 - Lang

General description of the soil

Friable, generally well structured clay profile which appears red in colour. Basalt rock hit at depth preventing a full core extraction.

Distribution:	Exposed in slopes above creek valleys, below plateaus of Lismore Clay
Typical land use:	Cropping or grazing
Common variants:	Presence of carbonates and depth to basalt rock
Other names	Nowra Red Clays, brown Ferrosol

Environment and location of the example profile

Landform:	Beginning of slope above creek and below Lismore Clay plateau
Parent material or substrate:	Basalt
Drainage class:	Good
Surface condition:	Friable
Site disturbance:	None
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map

Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure			Consistence	Course fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.19	Very dark grey	-	Loam	Moder-ate	Polyhe-dral	10-20mm	Very firm	-	-	Gradual
B2	0.19-0.38	Very dark brown	-	Medium clay	Strong	Blocky	5-10mm	Strong	-	-	Gradual
B3	0.38-0.58	Very dusky red	-	Heavy clay	Weak	Blocky	2-5mm	Strong	-	> 50% very coarse partly weathered ba-salt chunks	-

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test
A1	0.0-0.19	4.5	-
B2	0.19-0.38	5.5	-
B3	0.38-0.58	6	-

Core 24 - Lang

General description of the soil

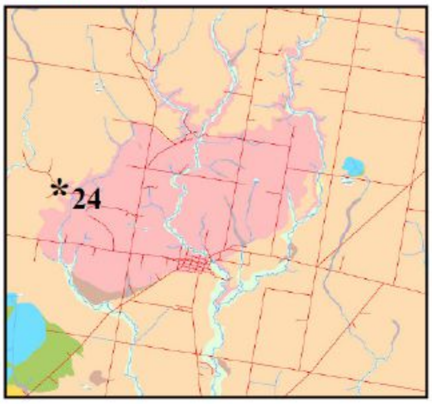
Extremely dry conditions produced a structure of polyhedral shaped peds of strong consistency. A dark grey-ish brown loam A horizon over a dark grey, medium clay B horizon.

Distribution:	Extensively found across the plains of newer basalts
Typical land use:	Cropping or grazing
Common variants:	Clay content, presence of and depth to carbonates
Other names	Lismore Grey Clays, brown Sodosol

Environment and location of the example profile

Landform:	Flat
Parent material or substrate:	Basalt
Drainage class:	Moderate to poor
Surface condition:	Very hard and dry
Site disturbance:	2.5T lime spread the previous day
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map



Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure			Consistence	Course fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.38	Dark greyish brown	-	Loam	Strong	Polyhedral	20-50mm	Very strong (dry)	-	-	Clear
B1	0.38-0.58	Dark grey	-	Medium clay	Strong	Polyhedral	10-20mm	Strong (dry)	-	-	Clear
B2	0.58-0.70	Dark grey	-	Medium clay	Strong	Polyhedral	20-50mm	Very firm (dry)	-	-	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test
A1	0.0-0.38	5.5	-
B1	0.38-0.58	6.5	-
B2	0.58-0.70	7.5	-

Core 25 - Lang

General description of the soil

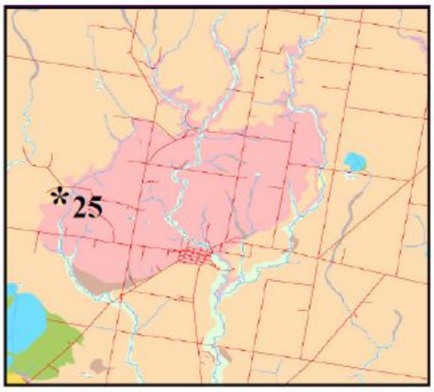
Clay sand A horizon with a sharp change into a heavier B horizon. Compaction of the upper profile was evident from the platy structure.

Distribution:	Weathered granite sand ridges and slopes
Typical land use:	Sheep grazing, occasional cropping
Common variants:	Depth to parent material or heavier clay
Other names	Granitic Sandy Loams, brown Sodosol

Environment and location of the example profile

Landform:	Mid slope of moderate gradient
Parent material or substrate:	Granite
Drainage class:	Moderate
Surface condition:	Compacted
Site disturbance:	Grazing only
Native vegetation:	None present (originally Plains Grassy Woodlands EVC 55)

Location map



Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Course fragments	Segregations	Boundary
A1	0.0-0.09	Light olive brown	-	Loamy sand	Me-dium	Suban-gular blocky	2-5mm	Very weak	2-10% small quartz pebbles	-	Clear
A21	0.09-0.53	Brown	-	Clay sand	Weak	Platy	50-100mm	Weak	2-10% small quartz pebbles	-	Abrupt
A22	0.53-0.61	Brown	-	Clay sand	Weak	Suban-gular blocky	2-5mm	Weak	2-10% small quartz pebbles	-	Sharp
B2	0.61-1.00	Dark brown	2-10% fine faint red	Clay loam sand	Weak	Polyhe-dral	10-20mm	Strong	Small quartz fragments <2mm	-	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test
A1	0.0-0.09	5	-
A21	0.09-0.53	4.5	-
A22	0.53-0.61	6	-
B2	0.61-1.00	6	-

Core 26 - Lang

General description of the soil

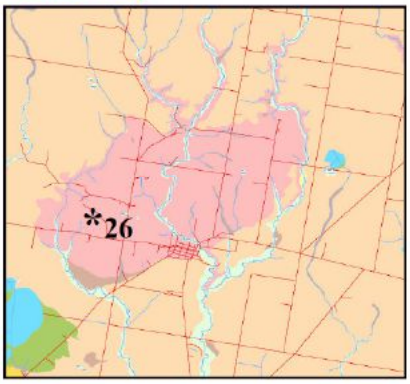
A sandy loam A horizon with compaction hard pans found in A1 and extensive buckshot material in a fine sandy loam matrix in A3. This overlies a higher clay content subsoil which would impede drainage.

Distribution:	Plateau and upper slopes of the granites
Typical land use:	Grazing, some cropping
Common variants:	Depth to clay subsoil
Other names	Granitic Sandy Loams, brown Sodosol

Environment and location of the example profile

Landform:	Edge of plateau before moderate slope begins
Parent material or substrate:	Granite
Drainage class:	Moderate to poor
Surface condition:	Loose material
Site disturbance:	None
Native vegetation:	None present (originally Plains Grassy Woodlands EVC 55)

Location map



Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure			Consistence	Course fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.24	Brown	-	Sandy loam	Weak	Platy	20-50mm	Very weak (dry)	-	10-20% medium FeMg concretions	Clear
A3	0.24-0.43	Brown	-	Sandy loam	Massive	-	-	-	-	>50% coarse FeMg concretions	Abrupt
B2	0.43-0.72	Dark yellowish brown	<2% fine faint red	Clay loam sand	Moder-ate	Polyhe-dral	5-10mm	Firm (dry)	-	2-10% medium FeMg concretions	

Soil chemical and physical properties

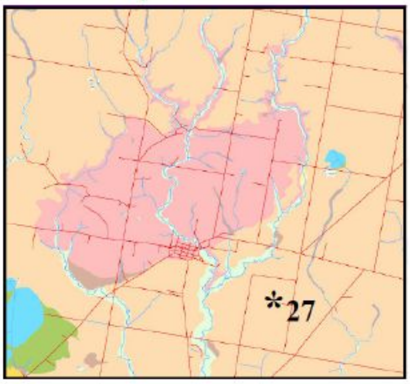
Horizon	Depth (m)	pH (w)	CaCO3 test
A1	0.0-0.24	5	-
A3	0.24-0.43	5.5	-
B2	0.43-0.72	6.5	-

Core 27 - Henderson

General description of the soil	
Grey clay profile typical of the basalt plains across the area. Waterlogging can occur due to increasing clay content down the profile. Carbonates just reached at depth of core	
Distribution:	Found extensively across plains of newer basalt
Typical land use:	Cropping or grazing
Common variants:	Depth to and amount of carbonates
Other names	Lismore Grey Clays, brown Sodosol

Environment and location of the example profile	
Landform:	Flat
Parent material or substrate:	Basalt
Drainage class:	Moderate to poor
Surface condition:	Thick root mat with slight compaction below
Site disturbance:	None
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map



Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Course fragments	Segregations	Boundary
A1	0.0-0.20	Dark greyish brown	-	Light clay	Weak	Poly-hedra.l	2-5mm	Strong (dry)	-	>50% medium FeMg concretions	Abrupt
B1	0.20-0.28	Dark greyish brown	-	Medium clay	Massive	Poly-hedra.l	50-100mm	Rigid (dry)	-	10-20% medium FeMg concretions	Abrupt
B21	0.28-0.58	Dark grey	-	Medium clay	Moder-ate	Poly-hedra.l	5-10mm	Strong (dry)	-	10-20% medium FeMg concretions	Clear
B22	0.58-0.90	Grey	-	Medium heavy clay	Strong	Blocky	10-20mm	Firm (moist)	-	20-50% medium FeMg concretions	

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test
A1	0.0-0.20	5	-
B1	0.20-0.28	6.5	-
B21	0.28-0.58	7	-
B22	0.58-0.90	7.5	Slight

Core 28 - Slee

General description of the soil

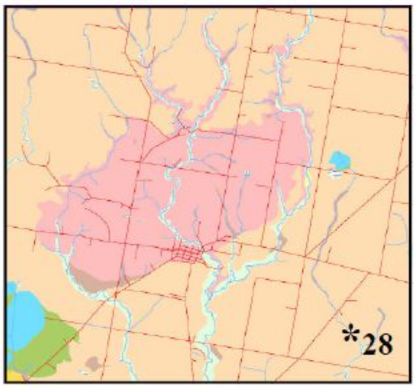
Greyish brown , loam topsoil over a profile of dark grey clays. Extreme dryness prevented full core extraction. Saline plant species present.

Distribution:	Creek flats and flood plains
Typical land use:	Grazing or cropping in dry years
Common variants:	Clay content, depth to carbonates and salinity levels
Other names	Mundy Gully Black Clays, black Vertosol

Environment and location of the example profile

Landform:	Saline creek flats
Parent material or substrate:	Alluvial
Drainage class:	Poor
Surface condition:	Cracked but hard
Site disturbance:	None
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map



Site photo

Soil morphology

Horizon	Depth (m)	Colour	Mottles	Texture	Structure			Consistence	Course fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.13	Dark greyish brown	-	Loam	Strong	Blocky	20-50mm	Very firm (dry)	-	<2% medium FeMg concretions	Clear
B2	0.13-0.44	Dark grey	-	Light medium clay	Strong	Blocky	10-20mm	Firm (dry)	-	-	Abrupt
B3	0.44-0.65	Dark grey	-	Medium clay	Weak	Polyhedral	5-10mm	Very weak (mod. Moist)	-	2-10% Very coarse calcareous nodules	-

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	$CaCO_3$ test
A1	0.0-0.13	5.5	-
B2	0.13-0.44	7	-
B3	0.44-0.65	9	High

Core 29 - Slee

General description of the soil

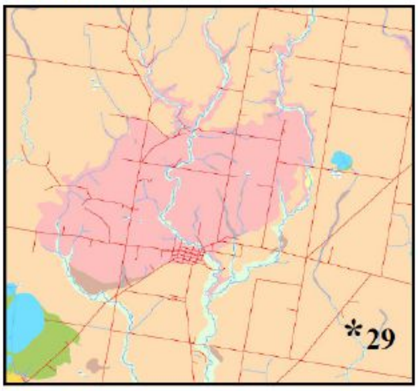
Light clay upper profile leading into clay loam, sandy before basalt rock prevent the extraction of a full core. A friable, well drained red soil found on banks above creek flats.

Distribution:	Red banks found only slopes where creeks have cut their channels
Typical land use:	Cropping or grazing
Common variants:	Depth to carbonates, amount of basalt rocks found on surface
Other names	Nowra Red Clays, brown Ferrosol

Environment and location of the example profile

Landform:	Moderate slope
Parent material or substrate:	Basalt
Drainage class:	Excellent
Surface condition:	Friable
Site disturbance:	Grazed by sheep
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map



Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure			Consistence	Course fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.21	Dark brown	-	Light clay	Strong	Polyhe-dral	2-5mm	Strong (dry)	-	Floating chunks of basalt between 2 and 5cm big found between 0.18m and 0.6m	Clear
B2	0.21-0.54	Dusky red	-	Light clay	Strong	Angular blocky	2-5mm	Very firm (dry)	-		Abrupt
B3	0.54-0.60	Dark brown	-	Clay loam, sandy	Strong	Angular blocky	2-5mm	Very firm (dry)	-		

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test
A1	0.0-0.21	6	-
B2	0.21-0.54	6.5	-
B3	0.54-0.60	7	-

Core 30 - Slee

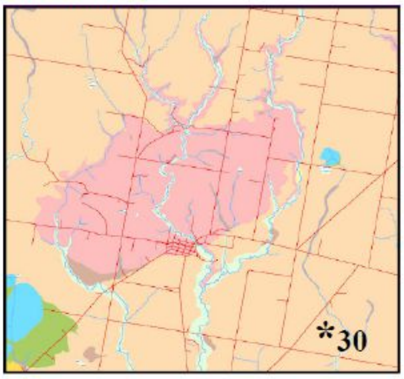
General description of the soil
Moderate to weakly structured clay profile with clay content increasing with depth. Carbonates found at depth which showed moderate effervescence to hydrogen chloride. Typical soil of the basalt plains.

Distribution:	Found extensively across plains of newer basalt
Typical land use:	Cropping or grazing
Common variants:	Depth to carbonates
Other names	Lismore Grey Clays, brown Sodosol

Environment and location of the example profile

Landform:	Flat
Parent material or substrate:	Basalt
Drainage class:	Moderate to poor
Surface condition:	Friable
Site disturbance:	Cultivated and formed into raised beds
Native vegetation:	None present (originally Plains Grasslands EVC 132)

Location map



Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure Grade	Structure Shape	Structure Size	Consistence	Course fragments	Segregations	Boundary
A1	0.0-0.15	Greyish brown	-	Clay loam	Moderate	Blocky	20-50mm	Firm (dry)	-	<2% medium FeMg concretions	Clear
B21	0.15-0.48	Dark grey	-	Light medium clay	Weak	Blocky	10-20mm	Very firm (dry)	-	<2% medium FeMg concretions	Gradual
B22	0.48-0.75	Dark greyish brown	-	Medium heavy clay	Weak	Blocky	10-20mm	Very firm (Mod. moist)	-	<2% medium FeMg concretions	Gradual
B3	0.75-0.96	Olive grey	<2% fine faint orange	Medium heavy clay	Moderate	Blocky	10-20mm	Firm (dry)	-	<2% medium FeMg concretions	-

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test
A1	0.0-0.15	5.5	-
B21	0.15-0.48	6.5	-
B22	0.48-0.75	7	-
B3	0.75-0.96	8.5	Moderate

Core 31 - Gala

General description of the soil

Clay loam sandy profile with large with large very firm peds scattered through a finer matrix. Compaction of the topsoil had occurred. An abrupt change to a higher clay content lower B horizon.

Distribution:	Lower slopes of the granite sands
Typical land use:	Grazing, some cropping
Common variants:	Depth to clays, amount of buckshot present
Other names	Granitic Sandy Loams, brown Sodosol

Environment and location of the example profile

Landform:	Lower slope of gentle undulation
Parent material or substrate:	Granite
Drainage class:	Moderate
Surface condition:	Compacted
Site disturbance:	None
Native vegetation:	None present (originally Plains Grassy Woodlands 55)

Location map

Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure			Consis-tence	Course frag-ments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.13	Dark greyish brown	-	Clay loam sandy	Moder-ate	Blocky	10-20mm	Weak (dry)	-	<2 % medium FeMg nodules	Clear
B21	0.13-0.34	Brown	-	Clay loam sandy	Weak	Platy	20-50mm in < 2mm matrix	Weak (dry)	-	20-50% coarse FeMg nodules	Clear
B22	0.34-0.51	Brown	-	Sandy clay loam	Weak	Blocky	5-10mm	Firm (dry)	-	>50% coarse FeMg nodules	Abrupt
B3	0.51-0.59	Yellowish brown	<2% fine faint red	Light clay	Moder-ate	Polyhe-dral	10-20mm	Very firm (dry)	-	2-10% % medium FeMg nodules	-

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	$CaCO_3$ test
A1	0.0-0.13	4	-
B21	0.13-0.34	5	-
B22	0.34-0.51	5.5	-
B3	0.51-0.59	6.5	-

Core 32 - Gala

General description of the soil

A loam topsoil showing signs of compaction over a clayey sand lower A horizon with high levels of buckshot. A sharp transition into medium clay subsoil which may impede drainage of the site

Distribution:	Lower slopes and drainage lines through the granite sands
Typical land use:	Grazing, some cropping
Common variants:	Amount of buckshot material and depth to heavier clays
Other names	Granitic Sandy Loams, brown Sodosol

Environment and location of the example profile

Landform:	Saline lower slopes, near drainage line
Parent material or substrate:	Granite sands
Drainage class:	Poor to moderate
Surface condition:	Compaction to 0.30m
Site disturbance:	None
Native vegetation:	None present (originally Plains Grassy Woodlands EVC 55)

Location map

Site photo

Soil morphology

Hori-zon	Depth (m)	Colour	Mottles	Texture	Structure			Consis-tence	Course fragments	Segregations	Boundary
					Grade	Shape	Size				
A1	0.0-0.30	Dark brown	<2% fine faint orange	Loam	Weak	Platy	50-100mm	Very weak	-	10-20% coarse FeMg nodules	Gradual
A21	0.30-0.46	Dark brown	-	Clayey sand	Apedal	Loose mass of individual particles, no peds, found around buckshot		-	-	>50% coarse FeMg nodules	Abrupt
A22	0.46-0.58	Brown	-	Clayey sand	Apedal			-	-	>50% coarse FeMg nodules	Sharp
B2	0.58-0.93	Dark yellowish brown	10-20% fine faint red and grey	Medium clay	Moder-ate	Blocky	20-50mm	Firm	-	-	-

Soil chemical and physical properties

Horizon	Depth (m)	pH (w)	CaCO3 test
A1	0.0-0.30	4.5	-
A21	0.30-0.46	5.5	-
A22	0.46-0.58	6.5	-
B2	0.58-0.93	8	-

Bushfire between Mt Elephant and Timboon’ Eugene Von Guerard 1859