Chapter 1

The 'Lay of the Land': the geological evolution of the landscape

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> "...the development of cities and new settlements is in so many cases too rushed to pay due regard to natural environment and particularly to geological conditions. It is very often forgotten that the geological history of land is so frequently an important guide to the planning of its future use."
>
> Professor Quido Zaruba, Foreword, in *Cities and Geology* (Legget, 1973, ix).

The landscapes of the Geelong region have been fashioned by geological and geomorphological processes over many hundreds of millions of years, resulting in the topography of today. They comprise both the oldest and youngest rocks in Victoria, spanning a period of more than 600 million years. Yet, despite its unchanging normality when viewed through human eyes, Geelong's terrain is constantly changing through erosion, deposition and tectonic forces. In fact, geologists regard some of the Geelong landscapes as among the most active landscapes in Australia (Gibson and Brown, 2003).

Geomorphologists understand that there is a cause for every shape in the landscape. Landforms such as river valleys, mountains or lakes are not shaped by accident, but reflect some underlying reason why they occur where they do and why they are shaped as they are. Such underlying reasons may be geological boundaries between hard and soft rocks, weaknesses in the rocks created by geological faults and joints, or even the activity of humans using bulldozers or shovels. When we inhabit a landscape, we can avoid many of the hazards - such as landslides, earthquakes, floods and erosion - by recognising these land-forming processes associated with constantly evolving landscapes.

The landscape physiography is also a determining factor in ecology. Plant and animal communities evolve in response to the available water, sun or shade, soil profile and nutrients at any particular place in the landscape. Humans too have chosen to settle in places because of the landforms, soils, rocks, minerals, springs, lakes, rivers, estuaries and coastal embayments. In fact, all of these components played a role in attracting humans to the Geelong region, as reflected in place names like Jillong, the Wathaurong name for the local landforms of Geelong (Pascoe and Krishna-Pillay, 1968-2007), and the place names later used by European settlers, such as Clifton Springs, Limeburners Bay, Waurn Ponds, Lovely Banks and Little River. Hence, the geological evolution could be seen as the basic reason for its initial habitation by Wathaurong (Wadda Warrung) people and eventual evolution to a city.

In the beginning...

Geology, being the science of the Earth's history, is calibrated against the geological timescale (Table 1.1), listed as Epochs, which are subdivisions of Periods, which are in turn subdivisions of Eras (Gradstein et al., 2012). Three basic concepts underpin the Geelong region's geological evolution: 1) the stratigraphy (the succession of rock units from oldest to youngest), 2) the tectonics and structural geology (the movement of the continents and modification of stratigraphy by subsequent tectonic forces to produce features such as faults and folds), and 3) the palaeoclimatic changes (past climates changes responsible for changes in the rates of erosion and deposition and sea level rise and fall).

Forming the ancient basement rock units

The oldest rocks in the Geelong district (and Victoria) are represented by small erosion-resistant outcrops of metagabbro, a generally fine-grained dark green metamorphic rock known as the Ceres Gabbro (Morand, 1995), which occur in the Barrabool Hills and near Dog Rocks (Figure 1.1). In the past the rock was quarried by the Wathaurong people for stone axes which were highly prized and traded throughout South-East Australia (Heritage Council Victoria, 2017). It was briefly quarried for building stone in the late 19th century, since the rock is very hard and holds a good polish, but ultimately proved too expensive to quarry and dress (Mines Department, 1949).

Although the rock unit has not been precisely dated, it is believed to be Neoproterozoic in age, based on its structural setting (Cayley et al., 2002). The outcrops of Ceres Gabbro are thought to represent an ancient block of the Earth's continental crust that underlies central Victoria, Bass Strait and parts of Tasmania. This block of crustal rocks that comprise the regional basement rocks is named the Selwyn Block, in honour of Alfred Selwyn, the founder of the Geological Survey of Victoria (VandenBerg et al., 2000).

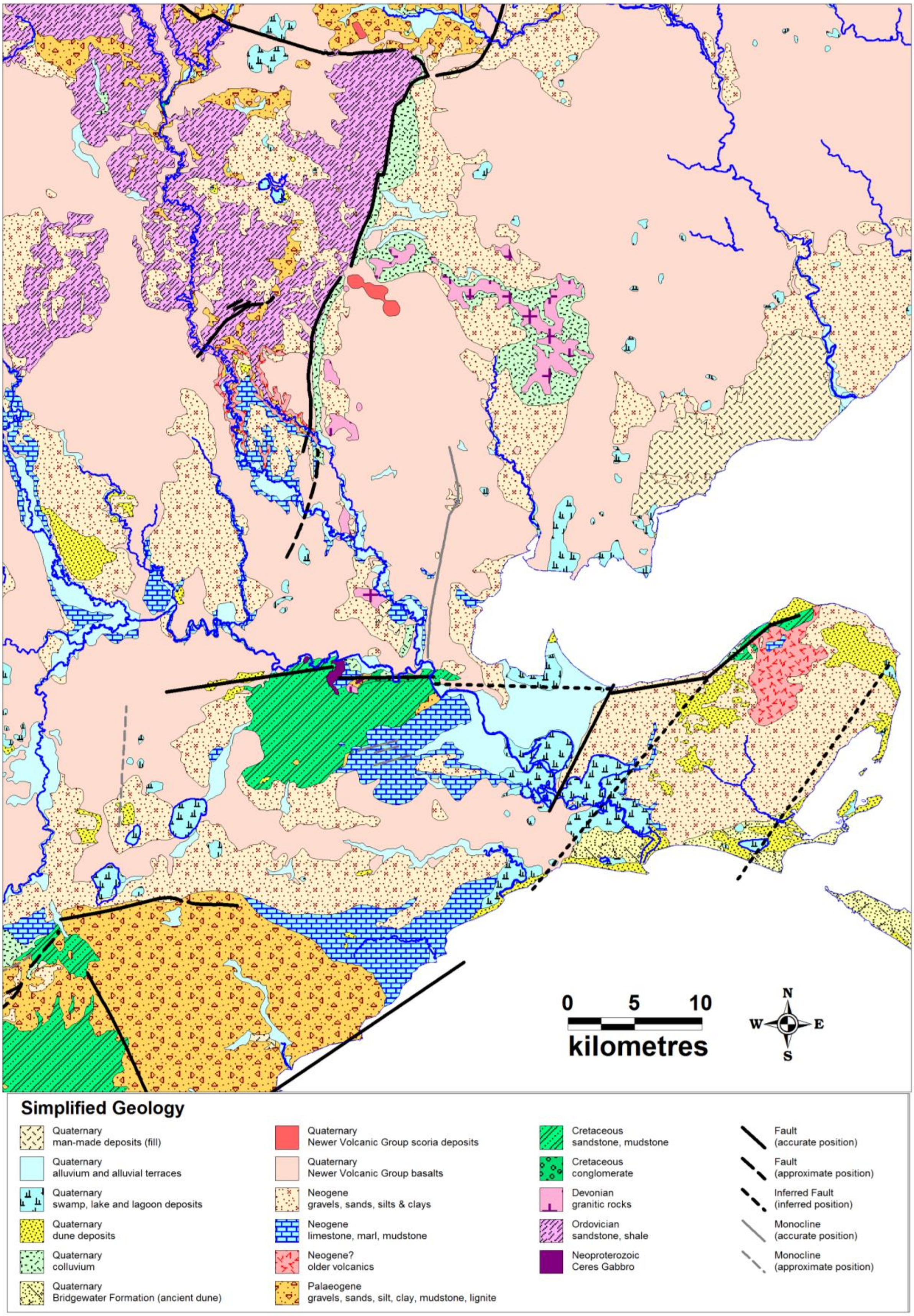

Figure 1.1: Simplified geology of the Geelong region. (modified from: GSV, 2010).

Table 1.1 The portion of the geological timescale represented in Geelong landscapes.

Era	Period	Epoch	Numerical age of epoch (millions of years ago)
Cainozoic	Quaternary	Holocene	0 - 0.01
		Pleistocene	0.01 - 3
	Neogene	Pliocene	3 - 5
		Miocene	5 - 23
	Palaeogene	Oligocene	23 - 34
		Eocene	34 - 56
		Palaeocene	56 - 66
Mesozoic	Cretaceous	Early Cretaceous	101 - 145
Palaeozoic	Devonian	Late Devonian	359 - 419
	Ordovician		444 - 485
Neoproterozoic			541 - 1,000

At the time of the Selwyn Block formation, this corner of Australia looked very different to today, as it was a crustal fragment coalescing with other fragments of the Earth's crust to form the supercontinent of Gondwana. Throughout most of the Palaeozoic Era eastern Australia formed part of the coastline of Gondwana, including the late Palaeozoic when Gondwana had collided with other continental crust to form the supercontinent termed Pangea. In the mid-Mesozoic Era, Pangea separated again into the supercontinents of Gondwana and Laurasia. Throughout the late Mesozoic and early Cainozoic eras, Gondwana slowly fragmented into smaller continents, including the continent of Australia.

The next oldest rocks represented in the Geelong district are those of the Ordovician Period when the region lay within ocean basins off the edge of Gondwana. These rocks were formed by the deposition of sediment in a deep marine trough that extended north-south across central Victoria (Fergusson and VandenBerg, 2003). The sediment source was the ancient highlands of South Australia and western Victoria, known as the Delamarian Highlands. Much of the sediment was deposited by turbidity currents caused by subsea landslides and are termed turbidite deposits. Turbidites are recognised by the cyclic sedimentation of coarse-grained to fine-grained sediments as the gravel, sand, silt and clay settle through the water column, as well as scours and ripples preserved in the strata. The rocks are dated through the abundant fossils of graptolites - organisms that had colonised the Earth's seas at the time and whose various species represent distinct time zones. From these fossils geologists deduce that Victoria was closer to the equator, experiencing a tropical to sub-tropical climate (Webb, 1991).

A subsequent series of continental collisions deformed and compressed the turbidite sediments (several kilometres thick) to form sedimentary rocks, firmly attaching the rocks to the continental crust. These tectonic events, or orogenies, folded and faulted the strata into high mountain ranges that were eroded over the following 400 million years to expose the rocks that we see in the Brisbane Ranges and in the Moorabool and Leigh valleys today. Typically, they comprise interbedded sequences of quartz-rich grey sandstone and mudstone with minor conglomerate and black shale. In the near surface they are weathered into pale, bleached mudstones, siltstones and sandstones that are usually orange, yellow, white and red colours.

Figure 1-2 Folded Ordovician sandstone near Meredith

During the orogenic mountain building events, the sedimentary rocks were infused with hot mineralised groundwater that percolated into the cracks and openings of the deformed rocks to form quartz veins, some of which contained gold. The gold was exploited during the mid 19th century by gold miners around Steiglitz and Morrisons when Geelong became a major gateway to the gold fields of Ballarat.

Further tectonic activity during the Late Devonian injected the Ordovician sedimentary rocks with magma that seeped upwards from blocks of crust that were being subducted into the Earth's mantle (VandenBerg et al., 2000). The magma cooled deep below the surface to form granite rock now exposed in the You Yangs and at Dog Rocks. The granite has been dated as 365 ± 2 million years old and it is thought that two to five kilometres of overlying rock has been eroded away to expose the granite at today's surface. Much of the erosion of these basement rocks probably occurred during the Permian Period (250 - 300 million years ago) when southern Australia resided in the Antarctic Circle and was subjected to glacial erosion. Being a harder crystalline igneous rock, the granite is more erosion resistant than the surrounding rocks, and rise to 319 metres elevation at Flinders Peak (You Yangs). The granite has been used for local building construction.

A foundation for the present landscapes

Towards the end of the Mesozoic Era, the basement rocks had been eroded to a more planar surface. Much of Gondwana had fragmented and by the Early Cretaceous, the separation of Australia and Antarctica, the last remaining continents to split, had started (Duddy, 2003). The separation formed a rift valley around 600 kilometres long and 100 kilometres wide along the southern margin of Australia. Volcanic eruptions commenced with the rifting and lasted for about 20 million years, providing a source for the sediment deposited in the rift valley by wide braided river systems. Around three kilometres of sediment was subsequently lithified into layers of sandstone and mudstone rocks, with some thin seams of black coal. Located within the Antarctic Circle at the time, fossils confirm that the sediment was deposited in valleys inhabited by diverse plants and animals, including small dinosaurs.

As the rifting continued and Australia drifted further northwards, the associated tectonic forces caused parts of the Early Cretaceous rocks to gently fold, fault and uplift. The uplifted blocks now form the Otway Ranges, Barrabool Hills and part of the Bellarine Peninsula. The rocks, known as the Otway Group, are relatively poor in quartz but rich in feldspar and fragments of volcanic rocks, making the dark grey-green sandstone and mudstone prone to weathering to brownish-yellow clays. It was widely used as a building stone in the 19th century and many grand buildings in Geelong and Melbourne have been constructed with 'Barrabool Sandstone' (King and Weston, 1997).

By the mid Palaeogene Period of the Cainozoic Era, Australia had completely separated from Antarctica and continued its drift northwards. Initially, the rate was less than a centimetre per year, but increased to around five to six centimetres per year from about 40 million years ago (Webb, 1991). The geological separation from Gondwana changed the course of the region's landscape evolution ultimately shaping the geomorphic features of today.

Shaping the landscape...

As the Australian continent separated from Antarctica, the ancient Mesozoic surface in the north of the region was gently uplifted to create the beginnings of the Great Dividing Range. The uplift renewed erosion of the land and created broad valleys of scree, outwash and braided river deposits between meridional ridges of Palaeozoic bedrock. The general form of this topography has persisted from the early Palaeogene Period, establishing the proto-valleys of the Moorabool and Leigh rivers (Holdgate et al., 2006). The remnants of the Palaeogene fluvial sediments form a quartz-pebble conglomerate, often cemented with iron or silica. They are observed in the northern part of the region (Figure 1-1) as isolated deposits overlying Palaeozoic rocks and broad tablelands fringing the overlying basalt.

Contemporaneously, in the southern part of the region known as the Torquay basin, mostly non-marine sediments were accumulating to form the mudstones, sandstones and brown coal beds of the Eastern View Group rocks (Holdgate and Gallagher, 2003). The brown coal units were exploited from the mid 20th to early 21st century for electricity generation at Anglesea, powering the aluminium smelter in Geelong.

As the rate of sea-floor spreading increased, a wide seaway formed between Australia and Antarctica, contributing to a major change in global climate and large turnovers in marine and terrestrial biota. The formation of large ice sheets on the Antarctic continent and changes in oceanic currents created a massive drop in global temperatures in the early Oligocene (Williams et al., 1993). In the north of the Geelong region, the onset of cool, drier conditions reduced streamflows, resulting in smaller streams following the broad valleys of the ancient Moorabool and Leigh rivers. Dendritic drainage patterns developed and the streams gradually incised the deposits of coarser gravels deposited in the earlier, higher energy environments, to expose the highly weathered bedrock. By the late Oligocene these valleys, incised into weathered Palaeozoic rocks, had been well developed (Taylor et al., 1996).

The end of the Palaeogene Period is marked by a major influx of the sea, or marine transgression, which significantly changed the sediment deposition regimes throughout the entire region. As the sea levels rose and the coast crept into the river valleys, the erosive capacity of the streams reduced and alluvial sediment began to fill the valleys of the dissected northern highlands. In the south, the deposition of terrestrial sediment gave way to marine sediment, mostly biological carbonates initially deposited shallow seas, but by the early Neogene Period, deep water conditions had formed (Holdgate and Gallagher, 2003). The subsequent lithification of these sediments has formed the marls and limestones now visible in the coastal cliffs at Jan Juc and Torquay.

By the mid to late Miocene Epoch the depositional environment had changed to intermediate depths as the sea began to retreat and limestone was deposited in the southern part of the region. The Fyansford Formation limestone has been extensively quarried from the mid-19th century for cement manufacture, building stone and agricultural lime. In the quarries near Batesford, abundant fossils of shells, bryozoans, echinoids, foraminifera and shark's teeth in the Batesford Limestone indicate that this was formed as a fringing reef around Dog Rocks, which was an island in the ancient sea (Gourley and Gallagher, 2004).

Meanwhile, sporadic volcanic eruptions continued. The Older Volcanics are basalts and fragmental rocks (pyroclastics) that were erupted across the region either in the late Palaeogene or the Neogene. The basalt landscapes of Mount Bellarine represent the largest outcrop in the region, with smaller outcrops at Maude. The stone is quarried for crushed rock supplies (Olshina and Jiricek, 1999).

Forming the structural elements

A change in the direction of regional tectonic stress occurred during the Miocene as the Australian Plate collided with the Pacific Plate (Edwards et al., 1996). The previous north-south tensional forces were replaced by compressional forces along a northwest - southeast axis, reactivating some old geological faults and creating new ones. These faults shape the current day landscape elements such as the direction of the coastlines and bays, which are oriented more or less perpendicular to the axis of compression.

The Otway Ranges began uplifting between two reverse faults: the westerly dipping Torquay Fault (which shapes the present day coast from Barwon Heads to Cape Otway) and the easterly dipping Bambra Fault to the west (Sandiford, 2003). The uplift renewed erosion, creating deeply incised and steep river valleys. The forces in the Earth’s crust also raised the Brisbane Ranges west of the Rowsley Fault, the Barrabool Hills along the Barrabool Fault, and raised the Bellarine block, while the Moolap block has subsided.

Uplift of the Bellarine block occurs along three structures, the Curlewis Monocline in the north, the Bellarine Fault in the east and an inferred fault in the west. The effect is that the Bellarine block is tilted to the south, with the greatest uplift along the Curlewis Monocline. Hence, areas around the Bellarine coastline include steep cliffs as well as coastal terraces.

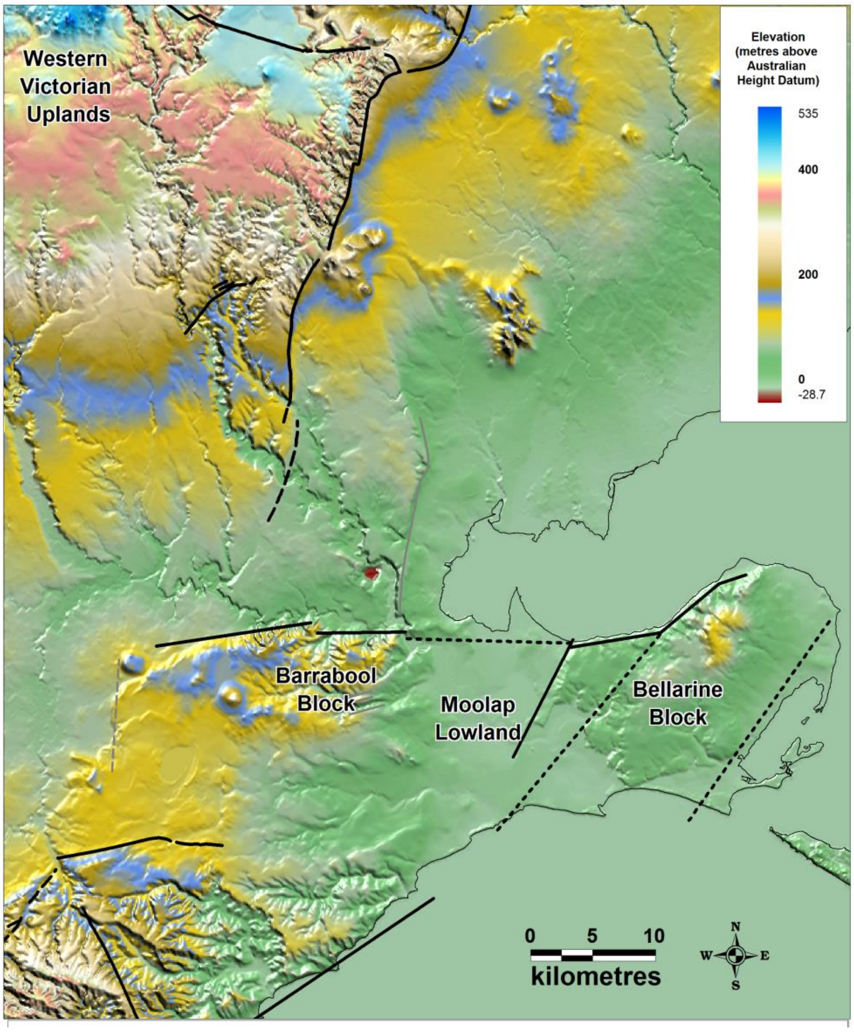

Figure 1-3 Structural elements of the Geelong region

Laying a veneer of sand and volcanic rocks

During the Pliocene a marine transgression commenced in the south-east and shallow seas eventually covered most the region (Wallace et al., 2005). In the valleys of the northern highlands, sands and gravels were locally deposited in response to the changes in stream base level. As the sea retreated to the south-west towards the end of the Pliocene, a widespread thin veneer of coastal sand was left behind. Known as the Moorabool Viaduct Formation, it is a thin (generally no more than a few metres thick) unit of sand and sandstone cemented with iron oxide which is widespread across south-western Victoria. Isolated deposits of Neogene sands, often cemented with iron (ferricrete) or silica (silcrete) also occur in the north of the region.

Volcanic eruptions commenced around the same time as the marine transgression (Price et al., 2003). Initially sporadic, the volcanism increased to its greatest activity by around two million years ago. The volcanic activity is associated with up to 150 metres of uplift in the northern part of the region, which has preserved the shoreline deposits of the Pliocene seas near Elaine from being covered by the volcanic lavas (Carey and Hughes, 2002). Elsewhere the erupted lavas flowed into the valleys, filling all of the drainage systems of the pre-volcanic landscapes, displacing the water flows to the edges of the lava flows. Disruption to the drainage systems forced the drainage divide of the Moorabool and Leigh rivers further north to its present position and formed large lakes on the plains to the west.

The Newer Volcanics basalts are the most widespread geological unit in the Geelong region (Figure 1.1). The final eruption points form prominent scoria cones, or composite scoria/lava cones, such as The Anakies (Rosengren, 1994). In the south, the Mount Duneed basalt flow encroaches upon the Lake Connewarre Complex and is a critical component in the development of the Lower Barwon wetlands and estuary (Rosengren, 1973). North of Corio Bay, the widespread cover of basalt has buried the ancient Neogene landscapes, including the ancient drainage systems of the Moorabool and Barwon rivers (Evans, 2006). On the western side of Corio Bay and across the Moolap Sunklands the former channel of the Barwon River was filled with lava from the volcanic eruptions, directing the course of the present day Barwon River.

Current processes shaping the landscapes

The youngest geological units are sediments that have been deposited in the last three million years, including stream alluvium, hillslope colluvium, swamp and lagoon deposits, coastal and inland dunes, and man-made fill. These relatively thin deposits of the Quaternary Period include sands, silts, clays and limestone, as well as anthropogenic rubble and rubbish.

Much of the sedimentation in the Quaternary was influenced by sea-level changes in response to global climate changes. Approximately 125,000 years ago the sea levels were around seven and a half metres higher than present, and the Bellarine Block was an island in a shallow sea (Marsden, 1988). As the sea levels dropped in response to the onset of the last ice-age, a high coastal barrier dune developed along the coast of Southern Australia. The remnants of this barrier now form the headland at the mouth of the Barwon River, known as The Bluff (Figure 1-4). It comprises limestone of the Bridgewater Formation, deposited as wind-blown lime sand that formed coastal dunes before the last glaciation, and has since been cemented.

Figure 1-4 The Bluff, Barwon Heads - an ancient large dune formed during the last ice age

Sea levels continued to recede, dropping to at least 150 metres below present levels by about 20,000 years ago (Holdgate et al., 2001). During this time the climate was arid and cold, with evidence of frequent high wind events. The Geelong region was situated well inland, with the shoreline west and south of Tasmania. It was during this time that the first humans arrived in the region, possibly up to 40,000 years ago, and migrated across the land to Tasmania (Mulvaney and Kamminga, 1999). As the ice-age ended, sea levels rose at varied rates, peaking at two and a half metres per century (or 25 millimetres per year). By 6000 years ago the sea levels were approximately two metres higher than present and covered a considerable portion of the Moolap Sunkland. The sea levels then fell to their present level around 3000 years ago. A sand blockage to the entrance of Port Phillip Bay is believed responsible for Port Phillip Bay (and Corio Bay) to have nearly completely dried between 2800 and 1000 years ago and is recorded in Aboriginal stories (Holdgate et al., 2011). In the past century the sea levels are believed to have risen slightly.

Hence, the majority of the sediments and landforms of the coastal and low-lying areas around Corio Bay and the Bellarine Peninsula have very recent origins. Swan Bay is a shallow open lagoon fringed by salt marshes and seagrass beds of high environmental value, the eastern side of which has been greatly modified since European settlement including the growth of the spit in the north eastern section known as Edwards Point (Bird, 1993). Salt Lake occupies an ancient embayment between St Leonards and Indented Heads which is now isolated as salt marsh terrain bordered by a barrier of shelly sand. Lake Victoria and Point Lonsdale occupy a low-lying coastal plain area between the Buckley Park Foreshore Reserve and the uplifted block of the Bellarine High. This area of distinctive terrain includes thick shell beds which are remnants of the abundant marine life in the warm inlets and lagoons of the Holocene maximum sea levels, 6000 to 3000 years before present (Gill, 1948). These shell beds have been extensively mined since the first European settlement of the area, greatly modifying the landscape by drainage, landscaping and engineering works.

Similarly, across the Lower Barwon wetlands and estuary, the recent geological evolution is recorded in the landforms, such as the broad barrier spit at Ocean Grove that has been shaped by the waves refracting around The Bluff. The spit has trapped sediment carried by the Barwon River flows and the tides to form broad wetlands colonised by mangrove, salt marsh and seagrass plants (Rosengren, 2009). A delta comprised of silt islands has formed in Lake Connewarre where the tidal channel enters, and has grown in area over the past 150 years. Lake Connewarre is estimated to be half as deep as it was in the mid 1800s.

Erosion too continues, especially in areas along the coast such as Clifton Springs and Point Lonsdale (Bird, 1993). Uplift continues through the earthquakes recorded in the past century or more, indicating that the north-east trending faults (i.e. perpendicular to the current axis of compression) are still active. A preliminary assessment of the seismic risk for the City of Greater Geelong (Miner and Dahlhaus, 2000) indicated that at least eight faults in the area can be considered active. These include the Rowsley Fault, the Lovely Banks Monocline, and the inferred fault from Point Henry to Lake Connewarre (Figure 1.1). The Bellarine Fault has recorded earthquakes to Richter magnitude 3.5.

Looking to the future...

Geology and geomorphology have long been recognised as critical in the development of civilisation, providing access to water, the raw materials for tools and buildings, and the strategic landforms for defence and trade. It is an underlying reason why cities and towns are founded where they are, and why they are abandoned when the geological resources are exhausted. But it was not until the environmental revolution of the 1960s that these subjects were recognised as critical in landscape and urban planning. The seminal publication '*Design with Nature*' (McHarg, 1969), recognised that landscapes were dynamic and therefore designing with nature (as opposed to designing against nature) avoided many of the pitfalls that had beset cities over the centuries of civilisation.

The Aboriginal inhabitants of the Geelong region recognised that their landscapes were dynamic, changing with the seasons and millennia (McNiven, 1998, Holdgate et al., 2011) and adapted their lifestyle to account for that. European settlers also recognised the dynamic processes, but responded with engineering, such as constructing the breakwater in the Barwon River only a few years after settlement, to control tidal inflows. In hindsight, few (if any) of the engineered changes heeded the landscape dynamics. Many man-made structures have since been destroyed by nature, or have irreversibly altered natural processes, or created a costly legacy of environmental degradation and maintenance.

Looking to the future, the Geelong region faces many challenges from: 1) exponential population growth and urbanisation, 2) a changing climate and the consequent acceleration of sea level rise and erosion, and 3) accelerated demand for geological resources such as water and construction materials. In the face of such challenges, it is critical that future developments are designed with nature, taking into account the dynamic processes of landscape evolution, if they are to succeed.

References

BIRD, E. C. F. 1993. *The Coast of Victoria. The shaping of scenery,* Parkville, Melbourne University Press.

CAREY, S. P. & HUGHES, M. J. 2002. Regolith of the West Victorian Uplands, Victoria, Australia. *In:* PHILLIPS, G. N. & ELY, K. S. (eds.) *Victoria Undercover, Benalla 2002: Collaborative Geoscience in Northern Victoria. Conference Proceedings and Field Guide.* Benalla, Victoria: CSIRO Publishing.

CAYLEY, R. A., TAYLOR, D. H., VANDENBERG, A. H. M. & MOORE, D. H. 2002. Proterozoic - Early Palaeozoic rocks and the Tyennan Orogeny in central Victoria: The Selwyn Block and its tectonic implications. *Australian Journal of Earth Sciences,* 49**,** 225-254.

DUDDY, I. R. 2003. Mesozoic. *In:* BIRCH, W. D. (ed.) *Geology of Victoria.* Geological Society of Victoria.

EDWARDS, J., LEONARD, J. G., PETTIFER, G. R. & MCDONALD, P. A. 1996. Colac 1:250 000 map Geological report. *Geological Survey Report.* Melbourne: Department of Natural Resources and Environment.

EVANS, T. J. 2006. *Geology and Groundwater Flow Systems in the West Moorabool River Catchment and their Relation to River Salinity.* M.Sc.(Hydrogeol), University of Technology Sydney.

FERGUSSON, C. L. & VANDENBERG, A. H. M. 2003. Ordovician. *In:* BIRCH, W. D. (ed.) *Geology of Victoria.* Melbourne: Geological Society of Australia (Victoria Division).

GIBSON, G. & BROWN, A. 2003. Earthquakes. *In:* BIRCH, W. D. (ed.) *Geology of Victoria.* Melbourne: Geological Society of Australia Inc. (Victoria Division).

GILL, E. D. 1948. Geology of the Point Lonsdale - Queenscliff Area, Victoria. *Victorian Naturalist,* 65**,** 38-46.

GOURLEY, T. L. & GALLAGHER, S. J. 2004. Foraminiferal biofacies of the Miocene warm to cool climatic transition in the Port Phillip Basin, southeastern Australia. . *Journal of Foraminiferal Research,* 34**,** 294-307.

GRADSTEIN, F. M., OGG, J. G., SCHMITZ, M. D. & OGG, G. M. (eds.) 2012. *The Geologic Time Scale 2012,* Boston: Elsevier.

GSV 2010. Victoria - Databases and Seamless Geology DVD. Melbourne, Victoria: GeoScience Victoria, Department of Primary Industries.

HERITAGE COUNCIL VICTORIA. 2017. *Victorian Heritage Database: Greenstones Axe Quarry* [Online]. Melbourne: Heritage Council Victoria. Available: http://vhd.heritagecouncil.vic.gov.au/places/21767 [Accessed 9/1/2017].

HOLDGATE, G. R. & GALLAGHER, S. J. 2003. Tertiary. *In:* BIRCH, W. D. (ed.) *Geology of Victoria.* Melbourne: Geological Society of Australia (Victoria Division).

HOLDGATE, G. R., GEURIN, B., WALLACE, M. W. & GALLAGHER, S. J. 2001. Marine geology of Port Phillip. *Australian Journal of Earth Sciences,* 48 439-455.

HOLDGATE, G. R., WAGSTAFF, B. & GALLAGHER, S. J. 2011. Did Port Phillip Bay nearly dry up between ~2800 and 1000 cal. yr BP? Bay floor channelling evidence, seismic and core dating. *Australian Journal of Earth Sciences,* 58**,** 157-175.

HOLDGATE, G. R., WALLACE, M. W., GALLAGHER, S. J., WITTEN, R. B., STATS, B. & WAGSTAFF, B. E. 2006. Cenozoic fault control on 'deep lead' palaeoriver systems, Central Highlands, Victoria. *Australian Journal of Earth Sciences,* 53**,** 445-468.

KING, R. L. & WESTON, K. S. 1997. Dimension stone in Victoria. Melbourne: Geological Survey of Victoria, Department of Natural Resources & Environment.

LEGGET, R. F. 1973. *Cities and Geology,* McGraw-Hill Inc.

MARSDEN, M. A. H. 1988. Bellarine Peninsula. *In:* CLARK, I., COOK, B. & COCHRANE, G. C. (eds.) *Victorian Geology Excursion Guide.*: Australian Academy of Science and Geological Society of Australia (Victorian Division).

MCHARG, I. L. 1969. *Design with Nature,* Garden City, New York, Published for the American Museum of Natural History by the Natural History Press.

MCNIVEN, I. J. 1998. Aboriginal settlement of the saline lake and volcanic landscapes of Corangamite Basin, western Victoria. *The Artefact,* 21 63-94.

MINER, A. S. & DAHLHAUS, P. G. 2000. Preliminary study of seismic risk for the City of Greater Geelong. *P.J. Yttrup & Associates Pty Ltd consulting report.* for the City of Greater Geelong.

MINES DEPARTMENT 1949. Victorian Building Stones. Melbourne: Victorian Mines Department.

MORAND, V. J. 1995. The Barrabool Hills Metagabbro: a curious piece of the Cambrian jig-saw puzzle in Victoria. *Geological Society of Australia Abstracts,* 40**,** 111-112.

MULVANEY, D. J. & KAMMINGA, J. 1999. *Prehistory of Australia,* St. Leonards, Allen & Unwin Pty Ltd.

OLSHINA, A. & JIRICEK, F. 1999. Geelong Supply Area - Extractive Industry Interest Areas. Melbourne: Department of Natural Resources and Environment.

PASCOE, B. & KRISHNA-PILLAY, S. H. 1968-2007. *Wathawoorroong dictionary,* Geelong Vic, Wathaurong Aboriginal Co-op.

PRICE, R. C., NICHOLLS, I. A. & GRAY, C. M. 2003. Cainozoic igneous activity. *In:* BIRCH, W. D. (ed.) *Geology of Victoria.* Geological Society of Australia (Victoria Division).

ROSENGREN, N. J. 1973. Lake Connewarre and the Barwon Estuary. *Victorias Resources,* Sept - Nov**,** 19-22.

ROSENGREN, N. J. 1994. *Eruption points of the Newer Volcanics Province of Victoria - an inventory and evaluation of scientific significance,* National Trust of Australia (Victoria) and the Geological Society of Australia (Victorian Division).

ROSENGREN, N. J. 2009. Murtnaghurt Lagoon, Bellarine Peninsula & related landforms: Nature, origin & geoscience significance. *LaTrobe University & Environmental GeoSurveys Pty Ltd report prepared for Save Barwon Heads Alliance.*

SANDIFORD, M. 2003. Geomorphic constraints on the late neogene tectonics of the Otway Range, Victoria. *Australian Journal of Earth Sciences,* 50 69-80.

TAYLOR, D. H., WHITEHEAD, M. L., OLSHINA, A. & LEONARD, J. G. 1996. Ballarat 1:100 000 map geological report. *Geological Survey of Victoria Report.* Melbourne: Energy and Minerals Victoria.

VANDENBERG, A. H. M., WILLMAN, C. E., MAHER, S., SIMONS, B. A., CAYLEY, R. A., TAYLOR, D. H., MORAND, V. J., MOORE, D. H. & RADOJKOVIC, A. 2000. *The Tasman Fold Belt System in Victoria,* East Melbourne, Geological Survey of Victoria.

WALLACE, M. W., DICKINSON, J. A., MOORE, D. H. & SANDIFORD, M. 2005. Late Neogene strandlines of southern Victoria: a unique record of eustasy and tectonics in southeast Australia. *Australian Journal of Earth Sciences,* 52**,** 279-297.

WEBB, J. A. 1991. Geological History of Victoria. *In:* COCHRANE, G. W., QUICK, G. W. & SPENCER-JONES, D. (eds.) *Introducing Victorian Geology.* Melbourne: Geological Society of Australia (Victorian Division).

WILLIAMS, M. A. J., DUNKERLEY, D. L., DE DECKKER, P., KERSHAW, A. P. & STOKES, T. J. 1993. *Quaternary Environments*, London, Edwards Arnold.