BRODIE PARK TIME WALK

A brief geological history of the Shoalhaven Region and Beyond

The Shoalhaven region beautifully illustrates how our planet has been shaped by geological processes that can be traced back more than 500 million years.

This Geological Time Walk has been established to provide a graphic record of this geological history. It follows a concrete path through the park, is set in attractive landscaped gardens, and comprises boulders of significant local rocks placed in chronological order and to scale along the path. Each boulder represents a major geological event that affected the local region.

Bronze plaques in each of the garden beds give brief descriptions of each rock. Engraved metal strips are positioned across the path to record the timing of Earth's five major mass extinctions. Signs at the start of each geological period since the Cambrian illustrate the types of animals and plants that lived in the sea and on land at that time, and put local events in the context of the evolution of life on the planet.

The Time Walk was completed in 2015 with funding support from Shoalhaven City Council and is currently one of only 7 known in the World.

THE REGION'S GEOLOGICAL HISTORY

The Earth's crust formed about 4,600 million years ago and the oldest parts of Australia (in Western Australia) are known to be about 4,000 million years old. Eastern Australia is much, much younger, and the oldest known rocks here formed only 510 million years ago. This short walk covers the region's journey since then.

Geologists abbreviate millions of years as Ma and this is used here and on the Walk's signage.

Geologists have divided the last 500 million years (541 Ma to be exact) into a series of geological periods, most of which are bounded by global mass extinctions of animal species or other catastrophic events. During the first period, the Cambrian, which lasted for 56 million years, life in the sea evolved rapidly and the first animals with hard parts were preserved as fossils. This was the "**Cambrian Explosion**" of life, a very significant global evolutionary event.

The story of this region's geological history, as told by the boulders, begins in the middle of the Cambrian period, with the oldest rock at 510 Ma.

Its subsequent history has been strongly influenced by movements of the Earth's tectonic, or crustal plates, which are fragments of the crust that can move slowly and interact with each other in various ways.

Cambrian Period (541–485 Ma)

510 Ma ago this region was the floor of a vast ocean, more than 4 km deep, east of the supercontinent Gondwana (see fig. 1). Submarine volcanoes erupted **basalt** lava as discrete pillow shapes and fine sediment transported from the distant Gondwana landmass slowly formed layers of black organic-rich mud, which became **black shale**. Minute particles of silica carried in suspension by ocean currents formed layers of **chert**.

All of these rocks were deposited in deep water, but, as a result of convergence of an oceanic tectonic plate with the eastern margin of Gondwana ~444 Ma ago, the rocks were deformed and metamorphosed (hardened and recrystallised by heat and pressure). The black shale became **slate**; the chert was recrystallised to **meta-chert** and veined by quartz; and the pillow basalt became **greenstone**.

The 510 Ma age of basalt at Narooma was determined from **conodont microfossils** (worm teeth) in a limestone layer or lens.

The black shiny boulder with a glassy exterior, in the garden bed here, is a **modern day basalt pillow** erupted in more than 4 km of water off the eastern tip of New Guinea. It is included to show what the greenstone was like when erupted onto the sea floor 510 Ma ago.

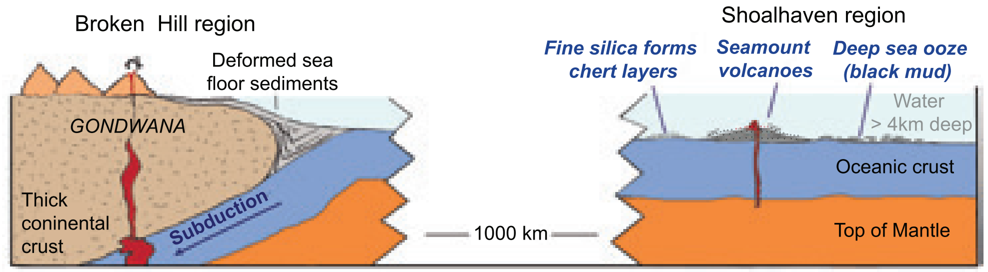

Fig. 1 - Cross-section 510 million years ago. Region is on the deep sea floor with Gondwana, the nearest landmass, more than 1000km to the west (near Broken Hill).

Ordovician Period (485 - 444 Ma)

The Shoalhaven region remained deep beneath the sea throughout the Ordovician period and was not yet part of a continent. **Carbon-rich black shale, siliceous chert** layers and pillow basalts, which were being deposited since early in the Cambrian, continued to accumulate slowly. These deep-sea sediments blanketed the south coast region (and further west to Canberra), and, as the ocean crust slowly sank over at least 60 Ma, a thickness of rock strata probably exceeding 30 km gradually built up.

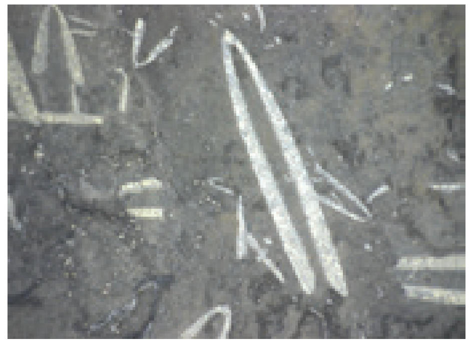

Fig. 2 - Upper Ordovician graptolite in slate

A rich assemblage of planktonic **graptolite fossils** (see Fig. 2) has enabled the age of metamorphosed black shale **(black slate)** exposed in Shoalhaven Gorge to be determined as 460-450 Ma.

By the end of the Ordovician, ~ 444 Ma ago, Gondwana's eastern margin had become a tectonically active convergent plate boundary, buckling, fracturing and metamorphosing the thick pile of sediments that had accumulated on the seafloor.

Silurian Period (444 - 419 Ma)

Further west (in the Canberra region) in shallow seas with prolific marine life, there were major episodes of widespread explosive volcanic activity. However, there is no evidence of any volcanic rocks or sediments in the south coast region, so no Silurian rocks are included in the Time Walk. Any rocks that may have formed during this period must have been subsequently removed by erosion.

Devonian Period (419 - 359 Ma)

Tectonic plate collisions resulted in the building of a significant mountain range in eastern Gondwana that would have rivaled New Zealand's Southern Alps (see Fig. 3). Both igneous and metamorphic rocks formed along the eastern margin of the continent, vast bodies of molten granite were intruded deep in the crust west of Canberra about 415 - 410 Ma ago. Similarly the Bega Batholith, extending from Lake George to the coast south of Bega, had crystallized by ~401 Ma ago. This tectonic activity caused Gondwana to grow progressively in an easterly direction.

In a subsequent tectonic cycle, ~395 Ma ago, the **Moruya Granite**, extending from south of Tuross Heads to Nelligen, was intruded. This was the first large granite body to form near the Shoalhaven region. Another large **granite** body was intruded further east, from South Durras to north of Granite Falls, in a later tectonic cycle.

In the absence of any dating evidence, an estimated age of **~380Ma** was assigned to this intrusion but, recent investigations have shown this to be incorrect with the age of ~380Ma only applying to the granite intrusion further west at Nerriga. Precise radioactive isotope dating of zircon crystals from the granite at Granite Falls has surprisingly yielded a significantly younger age of **~320Ma** for the granite, and this represents the final tectonic activity in the region. The new date means the garden bed should have been positioned further along the Time Walk and placed in the Carboniferous period.

The molten granite magmas, injected into the thick sequence of deformed metamorphosed Cambrian and Ordovician sedimentary rocks that originated on the deep sea floor, baked these "country rocks" forming a halo (or metamorphic aureole) of hard **hornfels** around them *(Moruya Granite garden bed).*

Late in the Devonian, volcanic rock of rhyolite composition was erupted explosively in a belt stretching from the Budawang Range to Eden. The nearest rhyolite outcrop is on Clyde Mountain, but the rock is not included in the Time Walk.

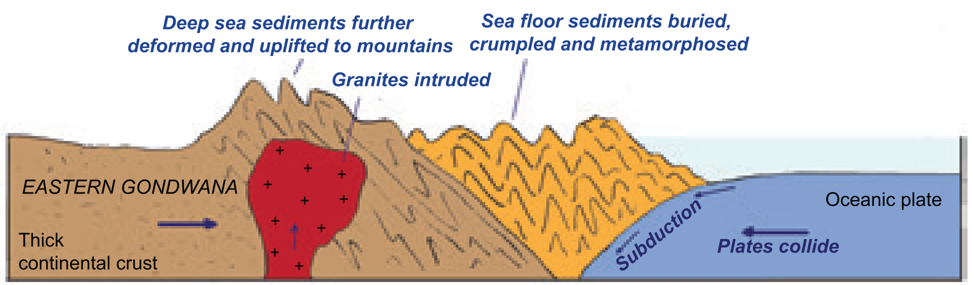

Fig. 3 - Cross-section ~380 million years ago shows tectonically active margin of Gondwana. Sea floor sediments were deformed and metamorphosed, granite was intruded and mountains were uplifted

Carboniferous Period (359 - 299 Ma)

During the Carboniferous, tectonic activity ceased and the region became part of the stable landmass of the supercontinent of Gondwana. The mountains were exposed to weathering and were worn down over millions of years.

Two ancient fast flowing river systems crossed the region, carving deep wide channels filled with boulders. Swampy lowlands formed between the rivers and these localized basins filled with plant debris from the adjacent forests. Black coal that formed in these swamps was mined briefly (at Rixon's Coal Mine in the Clyde River valley) around 1900, but the deposit was small and the coal was of low quality.

During the Carboniferous, Gondwana had merged with other continents to form Pangaea, and throughout this period, Pangaea drifted south, taking Australia close to the South Pole. Dramatic cooling at the end of the period led to partial coverage by ice, with snow capped peaks and mountain glaciers extending north from Victoria into southern NSW (see Fig. 4).

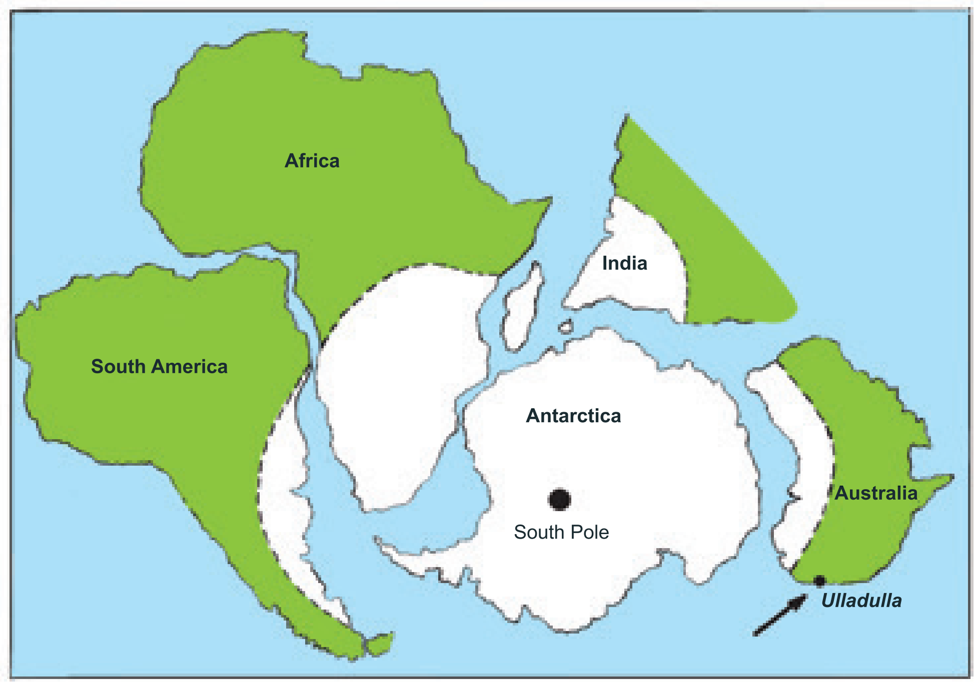

Fig 4 - Reconstruction of Gondwana ~280 million years ago. Shows extent of Australia's Permian ice cap. Ulladulla region was inside the Antarctic Circle, 80°S

Permian Period (299 - 252 Ma)

With Pangaea continuing to drift towards the South Pole, this region lay inside the Antarctic Circle. Stretching of the crust resulted in sagging along Gondwana's coastal margin so that cold seas flooded the coastal region from Newcastle to Durras to form the Sydney Basin.

Despite the cold water, marine life, mostly bottom dwelling, was abundant in these shallow waters. Sediment shed from Gondwana was deposited by ocean currents as horizontal fossil-rich layers. Strong currents deposited sand and pebbles (forming **sandstone** and **conglomerate**), while gentler currents deposited silt and mud (forming **siltstone** and **mudstone**). Build up of these sediments in shallow water continued for >30 Ma, resulting in the sedimentary rock sequence known as the **Shoalhaven Group**, which is >800 m thick (see Fig. 5).

Towards the end of the Permian, the Sydney Basin became closed off to the sea, and detritus from forests of Glossopteris trees filled vast swampy marshes, which stretched across the Illawarra and further west to the Burragorang Valley. These deposits, known as the Illawarra Coal Measures, rival those of the Bowen Basin in Queensland as Australia's biggest black coal resource.

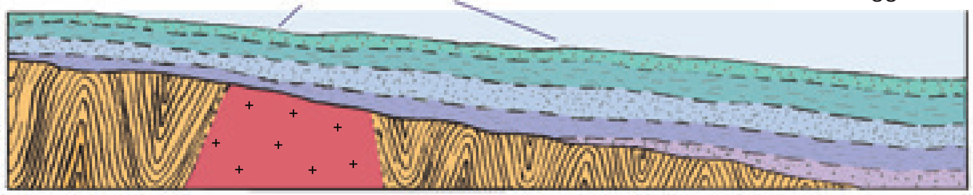

Fig. 5 - Geologic cross-section ~265 million years ago following 30 million years of deposition of fossiliferous sediments. Eroded Cambro-Ordovician folded metamorphic rocks and Devonian granite are overlain by >800m of horizontal Permian sedimentary rock strata.

Triassic Period (252 - 201 Ma)

Sediments ceased to accumulate in the southern Sydney Basin and the entire basin remained closed to the sea. Further north a massive river system deposited sand over an area from north of Newcastle to the Illawarra, forming the impressively thick fresh-water strata of the Hawkesbury Sandstone which form spectacular cliffs bordering Sydney Harbour.

During this period, as Gondwana drifted north, three circular molten intrusions were injected into the crust in the region (see Fig. 6). Because they are geographically and geochemically related, it is likely that their magmas emanated from a 'hotspot ' deep in the Earths mantle beneath the crust, which was active for at least 6 million years.

At 247 Ma ago, it appears that the hotspot lay beneath today's Jervis Bay region, and rising magma formed a circular **gabbro** pluton ~10 km across. As Gondwana drifted north at ~2 cm/yr, it is believed that the hotspot became active again 245 Ma ago, under Milton, to form a laccolith (a mushroom-shaped intrusion), also about 10 km across, and two horizontal sills of **monzonite**. By 241Ma, Gondwana had drifted further north again and the hotspot produced another circular **gabbro** pluton, ~10 km across,in the Bawley Point–Kioloa region.

The ascending magma that formed each of these shallow intrusions was prevented from reaching the surface (to form volcanoes) by thick massive sandstone strata.

Further evidence in support of this "hotspot origin" theory is provided by a parallel situation with intrusions of similar composition and size forming part of a hotspot chain in the New England region of North America.

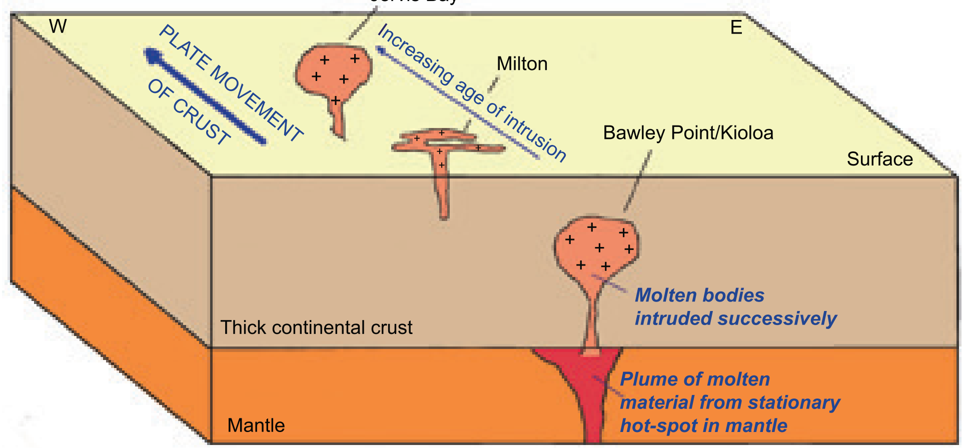

Fig. 6 - Block diagram to show "Hot spot" model for the origin of the Jervis Bay Gabbro, Milton Monzonite and Termeil Gabbro intrusions from 247 to 241 million years ago.

Jurassic Period (201- 145 Ma)

Although deposition of freshwater sediments continued in other parts of the Sydney Basin further north, there is no evidence of this in the south coast region. Nor is there evidence of any igneous activity in the region during this period. Because the south coast region remained above sea level during the Jurassic, the terrain was slowly eroded throughout the period.

Cretaceous Period (145 - 66 Ma)

By 100 Ma ago, an approximately north-south rift or fracture developed in east Gondwana, extending from central Queensland to Antarctica. Magma was injected along this rift, known as the "Tasman line of Fire", forming a chain of explosive volcanoes. Mt Dromedary (or Gulaga), south of Narooma, is an eroded remnant of one such volcano.

The stress field that produced this deep rift resulted in geometric fracturing of fine-grained sedimentary rock strata to form a **tessellated pavement**.

Following the rifting phase, at 84 Ma ago, a big chunk of Gondwana, "**Zealandia**", began to drift away from Australia–Antarctica, to open up the Tasman Sea. This continued throughout the Cretaceous (see Fig. 7).

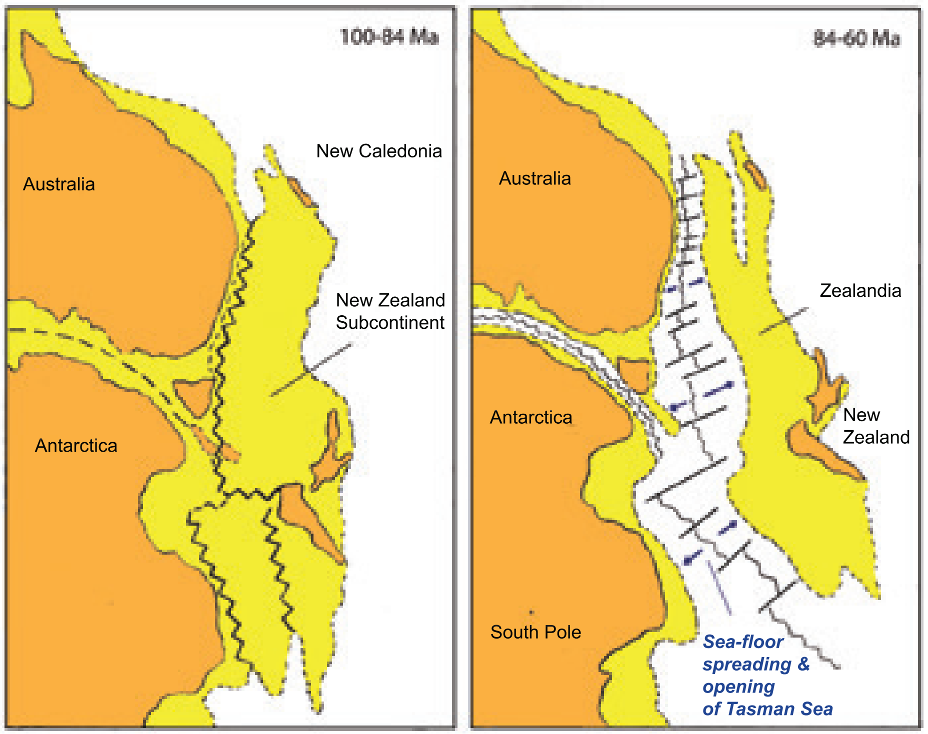

Fig. 7 - Maps show 2 stages in break-up of East Gondwana. Rifting began 100 million years ago. Then sea floor spreading resulted in the opening up of the Tasman Sea and formation of "Zealandia" subcontinent by 60 million years ago.

Palaeogene Period (66 - 23 Ma)

By 60 Ma ago, the continental drifting that had opened up the Tasman Sea ceased, and a rebound effect resulted in extensive uplift along the old edge of the continent, forming Australia's eastern highlands, which stretch from far north Queensland down into Antarctica (see Fig. 8). Subsequent erosion along the eastern edge of these highlands has produced the spectacular "Great Escarpment" we see to-day.

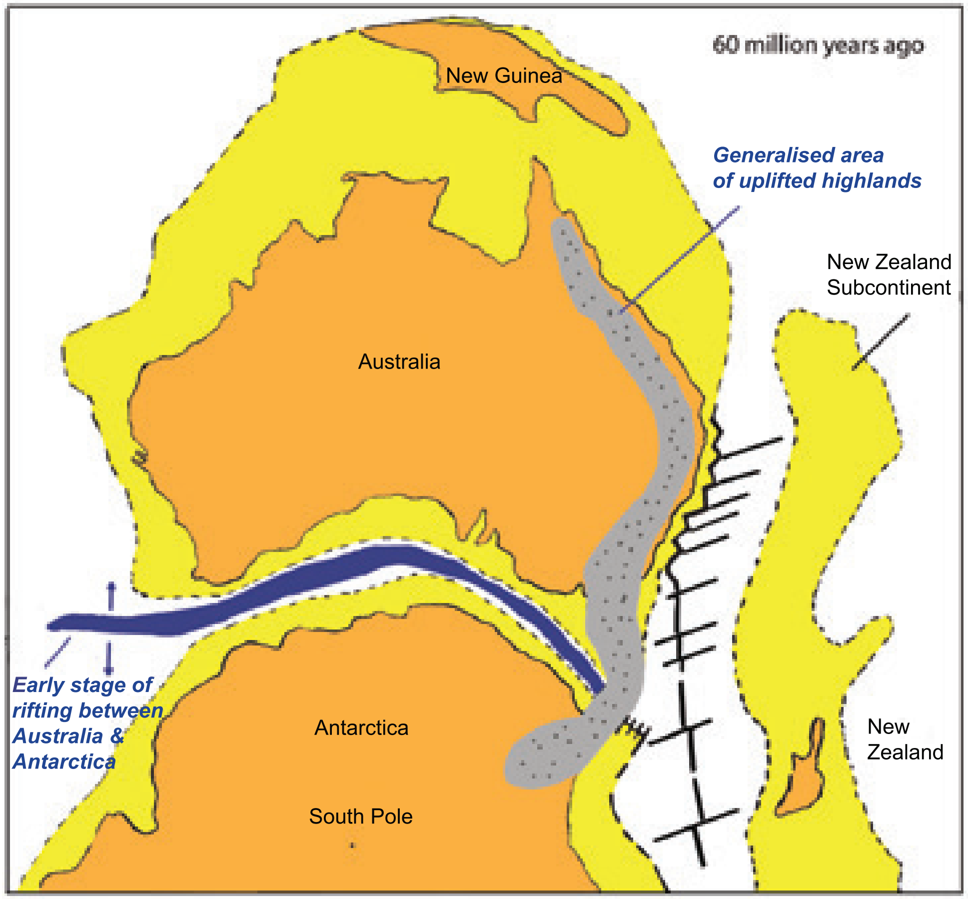

Fig. 8 - When E-W drifting ceased 60 million years ago, a rebound affect is believed responsible for uplift of Australia's eastern highlands (>1000m in this region).

By 55 Ma ago, another rift was developing in what remained of Gondwana, between Australia and Antarctica. By 34 Ma ago, separation was complete and the Southern Ocean was formed (See Fig. 9).

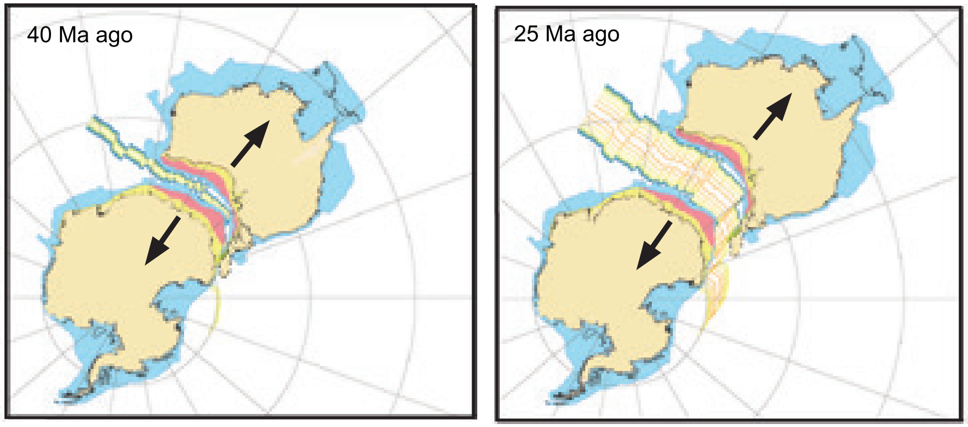

Fig. 9 - Antarctica-Australia split 40Ma and 25Ma. Australia's faster drift north caused stretching, thinning and fracturing of crust in eastern Australia. Basalt magma intruded forming numerous small dykes and sills.

Images for Fig. 9 were supplied by Lloyd White, Gordon Lister and G Gibson.

As a direct result of this drifting, from 55 Ma to 30 Ma basaltic magma from the mantle forced its way through fractures in the thinning Gondwana crust, flooding onto the surface as extensive lava flows at Tuross, Cooma and Sassafras on the southern highlands. In this region, ~30 Ma ago, several vertical basalt or dolerite dykes (mostly aligned E–W) were intruded, and horizontal sills 10 m thick were intruded between sandstone beds at Bannister Head and Bendalong Point (see Fig. 10).

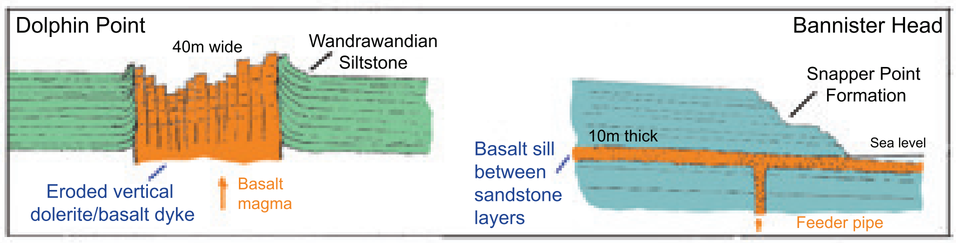

Fig. 10 - Basalt intrusions at Dolphin Point and Bannister Head.

Neogene Period (23 - 2.6 Ma)

As a consequence of the formation of the Southern Ocean, with its circum-polar current, Australia became increasingly arid. Rainforest that had spread across much of southern Australia disappeared and grasslands developed.

Although Australia's climate was drying, during sustained wet periods in this region, two different types of weathering products developed over the landscape. Deep leaching of sandy soils formed shallow deposits of **silcrete** ~15 Ma ago. Then, ~3–4 Ma ago, leaching and precipitation of iron formed a hard **ferricrete** cap on the silcrete on coastal headlands.

Another striking feature of this period was the fluctuation of sea levels, as evidenced by a **shelly limestone** bed found on the continental shelf 30km east of Ulladulla. This bed now lies ~300 m below current sea level but ~5 Ma ago, the animals (fossilized in the limestone) were burrowing in sand in shallow water very close to shore.

At the start of the Neogene, Earth's climate warmed, but by the end of the period it had cooled below current levels. This signaled the start of Earth's most recent major Ice Age.

Quaternary Period (2.6 Ma–present)

The Quaternary Ice Age mainly affected the northern hemisphere, but the alternating glacial and interglacial phases produced major fluctuations in sea levels around the world as ice formed and thawed again. By the end of the last glacial phase, ~20,000 years ago, sea level had dropped 140 m below its present level. During the subsequent warmer interglacial phase, which we are now in, sea level has risen steadily. Coastal river valleys in this region have been drowned to form spectacular features such as Jervis Bay, Ulladulla Harbour and Batemans Bay.

The first Aboriginals arrived in this region ~40,000 years ago. Captain Cook sighted Aboriginals on local beaches in 1770 and the first European settler, Rev Thomas Kendall, arrived here and began cutting cedar in 1828.

Erosion of the horizontal Sydney basin rock sequence has produced Ulladulla's unique hinterland landscape (See Fig. 11).

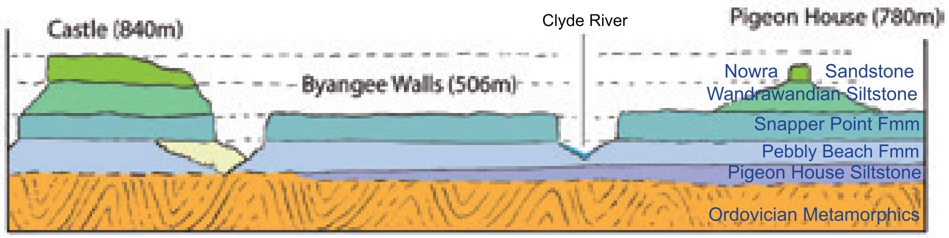

Fig. 11 - Today's spectacular landscape that forms Ulladulla's hinterland is the result of 60 million years of erosion by Clyde and Shoalhaven rivers of alternating hard and soft horizontal Permian strata.

Acknowledgements

The concept of a harbourside Time Walk was first put to Council in April 2010 by Fossil Walk founder, Phil Smart. Development on the project started in Oct 2013 with **Gondwana Coast Fossil Walk** volunteer, Mike Jefferis as project manager, and a hard working team of **Gondwana Coast Fossil Walk** volunteers has spent several thousand hours turning the concept into a reality. Special thanks go to local contractor, Rob Wheatley, as all of his skills were tested in recovering the boulders from tricky sites and to precisely position them in the Park.

Retired Geoscience Australia(GA) geologists have played a major role. The wording on signs, and the text of this brochure, has been written by geologist, Phil Smart. Former GA geoscience editor, Ian Hodgson and geologists, Dr Ian Lavering, and Stewart Needham edited the manuscript. Text figures in this brochure were produced by Warwick Willmott from sketches by Phil Smart. The images on the geological period signs were the work of Dr Alex Ritchie of the Age of Fishes Museum.

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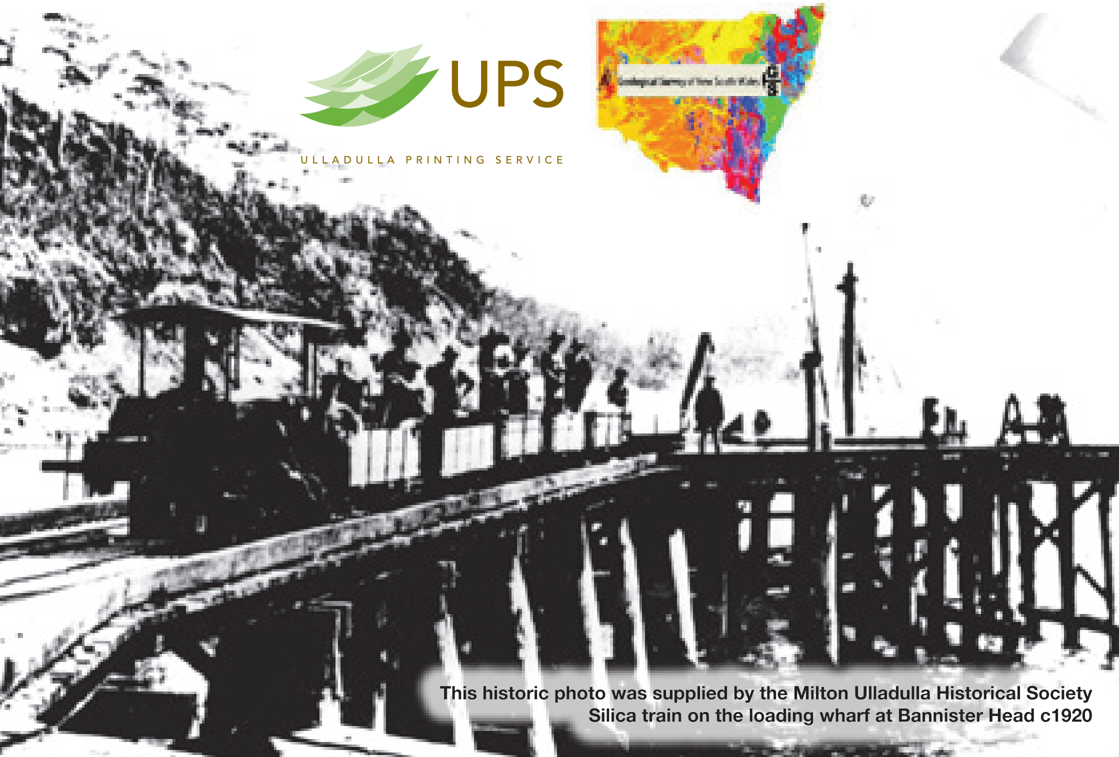

This historic photo was supplied by the Milton Ulladulla Historical Society
Silica train on the loading wharf at Bannister Head c1920