

# Port Macquarie Coastal Geotrail

Rocks of the Port Macquarie area tell the story of plate tectonics – how Earth’s crust is formed and how it moves. This geotrail spans the equivalent of up to 6000 km across the Pacific Ocean of today, in just 4 km from Shelly Beach to Rocky Beach! Some rocks are made of microscopic marine organisms, others by volcanoes or underwater gravity currents. Some rocks formed at high pressures and temperatures, over 100 km below Earth’s surface, and were later brought to the surface by faulting.

## Plate tectonics

The theory of plate tectonics is the most important underlying concept in geology. A network of rigid plates extends over Earth’s surface, to depths of about 100 km. The plates move relative to each other, forming and diverging at mid-ocean ridges, converging and, in places, being subducted at ocean trenches.

An oceanic crustal plate is formed at a mid-ocean spreading ridge and consists of mantle rocks in the lithosphere and asthenosphere, overlain by basalt (Stop 1) from underwater volcanoes. As the plate migrates away from the mid-ocean ridge, the basalt collects sediment on top. At first the sediment consists mainly of microscopic marine organisms such as radiolaria, that live near the ocean surface and fall to the seafloor to accumulate when they die (Stop 2). As the oceanic plate approaches a trench it also collects sediments that flow down into the trench from nearby volcanoes (Stop 3). On reaching the trench, the denser ocean crust plate slides (or subducts) under another plate and is carried deeper down into the earth. There it is subjected to increasing pressure and temperature, forming new rocks and minerals such as blueschist and eclogite (Stops 4 and 5).

## The geotrail

To follow the Port Macquarie Coastal Geotrail, you can either travel in the same direction as the oceanic plate was moving, from Shelly Beach and Sea Acres back to Rocky Beach and Town Beach, or you can do it in reverse. You can walk 4 km one way along the geotrail, using the map to guide you. Alternatively you can drive to each stop, as they are all accessible from nearby car parks, or catch the local bus to/from Sea Acres Rainforest Centre.

## Timescale of major geological events in the region

Era	Period	Age*	Geological activity
Cenozoic	Quaternary	Today to 0.01	Modern beaches, estuaries and dunes form
	Neogene to Paleogene	23 and 24	Volcanic events inland
Mesozoic	Cretaceous	72 to 84	Seafloor spreading in the Tasman Sea
	Cretaceous to Triassic	110 to 250	Sediment accumulates in the Surat and Clarence–Moreton basins
Mesozoic to Palaeozoic	Triassic to Permian	237 to 295	Coal and sedimentation in the Sydney–Gunnedah Basin
		254	Inland volcanic activity
Palaeozoic	Triassic to Carboniferous	201 to 359	Inland sedimentation and granites intrude the region
	Permian to Silurian	260 to 425	Marine and inland sedimentation, with volcanic activity
Palaeozoic	Ordovician to Cambrian	460 to 500	Subduction zone forms, with associated marine sedimentation and volcanic activity

\* Millions of years ago.



## Geological map

**REFERENCE**

- Cenozoic**
  - Laterite, and alluvial, swamp, and dune complexes
- (?) Permian–Late Triassic**
  - Sea Acres Dolerite: variably altered dolerite, in places cleaved
  - Tacking Point Gabbro and Town Beach Diorite: gabbro, pyroxenite, diorite, pegmatite
- Devonian**
  - Touchwood Formation: siltstone, sandstone, paraconglomerate, breccia, andesite
- Middle Ordovician–late Carboniferous**
  - Dominant pillow and massive basalt, rare dolerite dykes, but also contains mudstone, sandstone and stratabound metalliferous rocks (Not separately mappable away from coastal exposure.)
  - Dominant chert
  - Undifferentiated rocks: slate, chert, mudstone, sandstone, conglomerate, and minor basalt and stratabound metalliferous rocks
- (?) Early Cambrian**
  - Port Macquarie Serpentinite: Massive, schistose serpentinite, rodingite, serpentinitised peridotite, and orthopyroxenite
  - Port Macquarie Serpentinite: Inferred from drilling
- (?) Neoproterozoic–Middle Ordovician**
  - Rocky Beach Metamorphic Mélange: eclogite, omphacite, blueschist, glaucophane–phengite schist, tremolite marble and rare slate

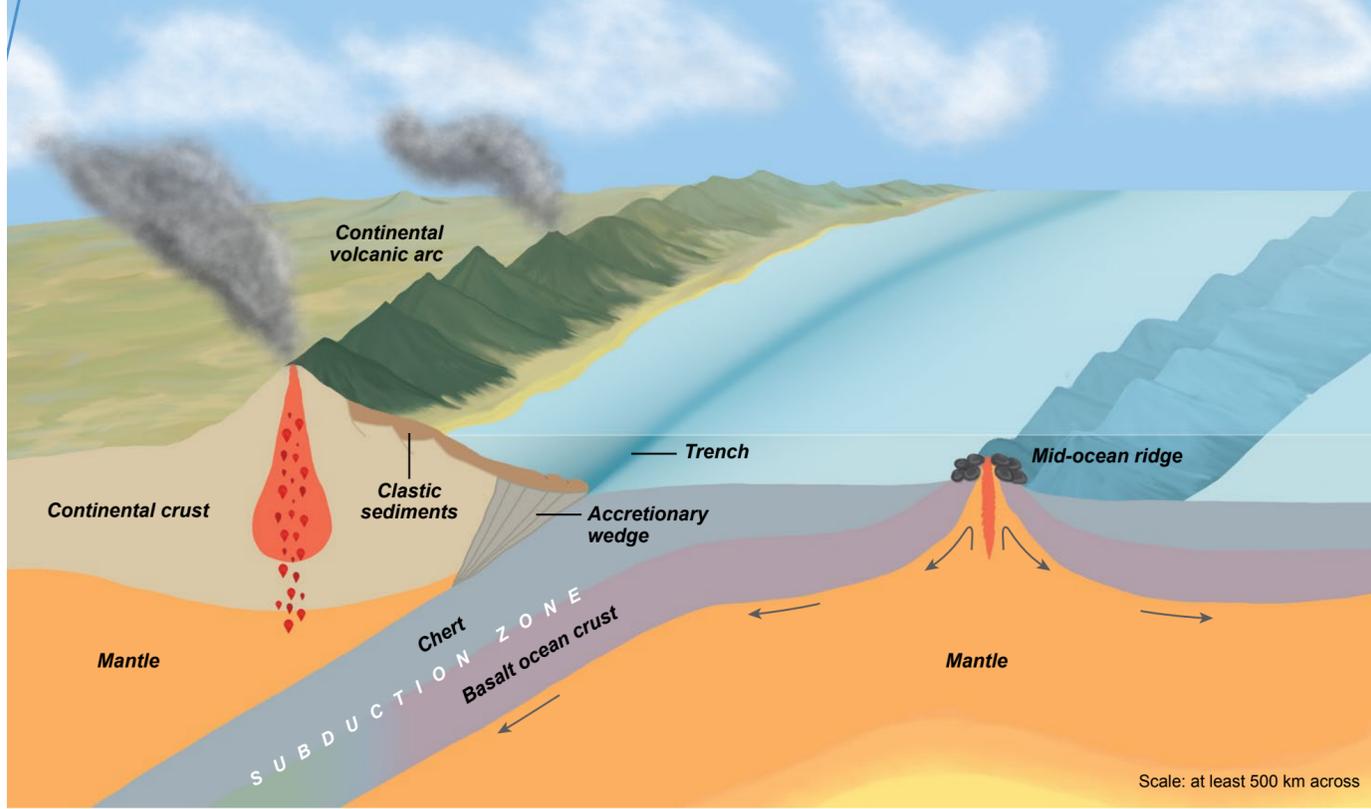
Legend: Road, River, creek, dam, Seawall, Lighthouse

Scale: 0, 0.5, 1 km

(Och et al., 2007)

## Plate tectonics

Schematic diagram showing movement of oceanic crust away from the mid-ocean ridge and down the subduction zone



Scale: at least 500 km across

## Glossary

- Accretionary wedge** is a mass of sediments and rock fragments that accumulates where one of Earth’s plates slides under another, at a subduction zone.
- Asthenosphere** is the upper layer of Earth’s mantle, directly below the lithosphere, at depths of about 80–200 km. This layer is highly viscous and deforms in a ductile manner.
- Blueschist** is a metamorphic rock characterised by a blue, sodium-rich amphibole called glaucophane.
- Clast** is a rock fragment or grain resulting from the breakdown of larger rocks.
- Conodonts** are microfossils known from the Late Cambrian to the Late Triassic. They are hard parts of an extinct group of animals believed to be distantly related to the living hagfish.
- Eclogite** is a metamorphic rock consisting of pyroxene and garnet.
- Metamorphism** is the process by which rocks are physically or chemically transformed by heat, pressure or fluids.
- Phacoid** is an ellipsoidal, doubly tapered, deformed clast, which may have asymmetric shape.
- Serpentinite** is a metamorphic rock composed of one or more serpentine group minerals.
- Turbidite** is a sedimentary deposit of layers of particles that grade upward from coarse to fine sizes and were deposited by turbidity currents in the ocean.
- Turbidity current** is an underwater current of usually rapidly moving, sediment-laden water moving down a slope.
- Volcanic arc** is a curved chain of volcanoes formed in a tectonic plate above a subducting plate. If offshore, it is called a volcanic island arc.

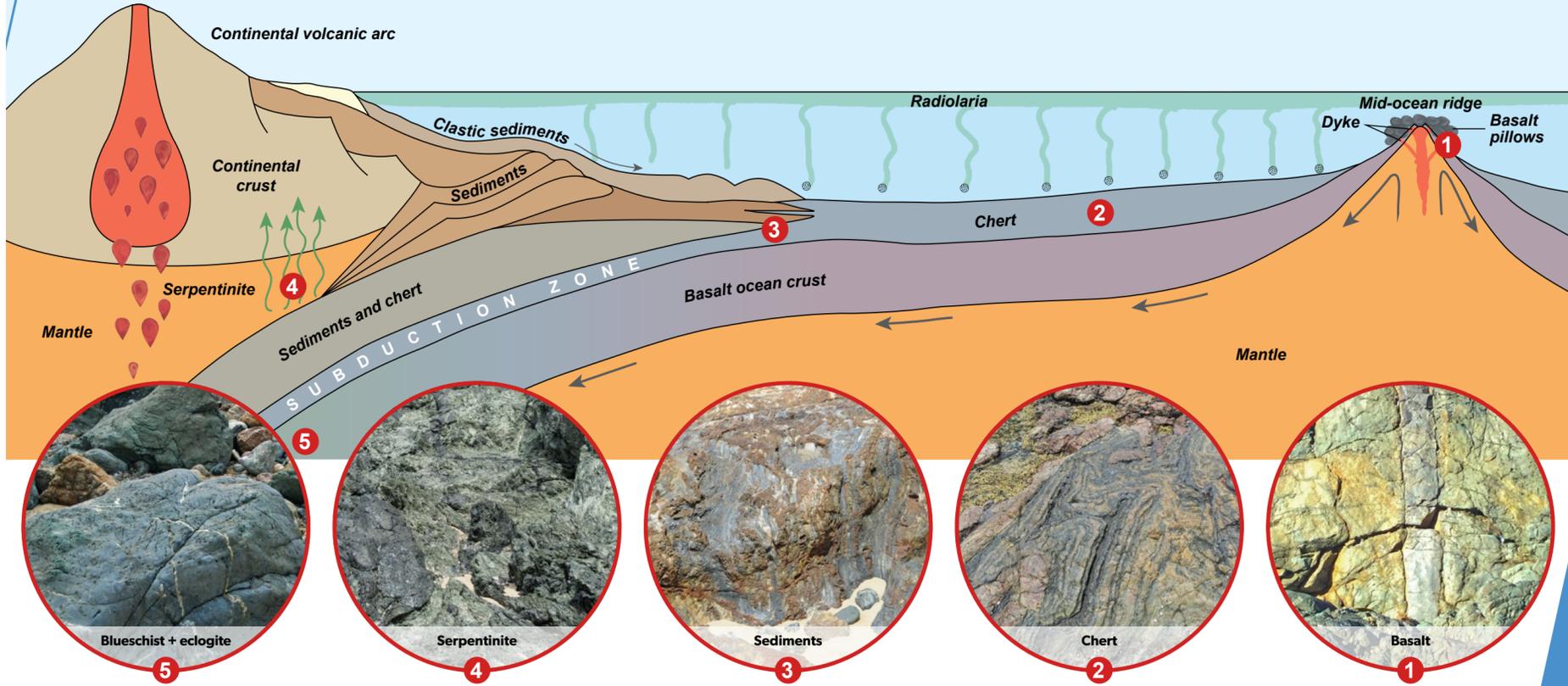
## Reference

Och DJ, Leitch EC & Caprarelli G, 2007. Geological units of the Port Macquarie–Tacking Point tract, north-eastern Port Macquarie Block, Mid North Coast of NSW. *Quarterly Notes of the Geological Survey of New South Wales* 126.

**CAUTION**  
TAKE CARE WHEN EXPLORING COASTAL AREAS. WILDLIFE, WEATHER, SURF CONDITIONS AND UNSTABLE GROUND CAN POSE RISKS.

## Geotrail stops

Section through one interpretation of the Ordovician subduction zone, looking northwards across several hundred metres



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Cover photo: Port Macquarie coast.

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### 1 Volcanoes under the sea

At southern Shelly Beach, you can see rocks formed at the start of their plate tectonic journey across the ocean. Ocean crust is mostly formed from a dark, fine-grained volcanic rock called basalt. This type of rock forms in mostly underwater (or submarine) volcanoes in places like the mid-ocean ridge. On southern Shelly Beach the basalt flowed out of submarine volcanoes as molten lava that cooled in the shape of pillows. Sometime after the first cooling episode, new molten basalt was injected into the ocean floor crust as long, thin fingers called dykes. In some locations, basalt first cooled slowly deep in the earth forming big shiny feldspar crystals, before later flowing out onto the seafloor and forming the smaller surrounding dark crystals.



Basalt pillows (two outlined) on southern Shelly Beach.



A thin basalt dyke (outlined in red) that injected into older pillow basalts.



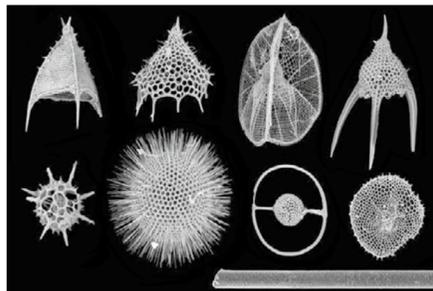
This dyke (centre) squeezed through older, colder basalt. As it cooled, the edge cooled faster than the middle. This 'chilled margin' has a finer grain size and a darker colour than the middle.



Large shiny feldspar crystals in fine-grained basalt at Shelly Beach.

### 2 Death on the seafloor

In the middle of Shelly Beach, rocks called chert formed part way along their plate tectonic journey. After the ocean crust basalt (Stop 1) was formed, it travelled away from the mid-ocean ridge and began to collect sediment on top. This sediment mainly formed from tiny marine organisms such as radiolarians that lived near the surface of the ocean. After death, their skeletons rained down on the sea floor. They collected in layers above the basalt. These layers formed from variations in the type and amount of marine skeletons and the amount of external sediment added. When thick layers of sediment built up, pressure and chemical changes converted the fossil skeletons into the rock we call chert. As the chert was transported towards the trench, it commonly slumped and slid, forming sinuous folds. Fossils known as conodonts (jaw structures of oceanic eel-like animals) can be used to date the chert, which at Port Macquarie is around 460 million years old.



Skeletons of modern radiolarians. Human hair on bottom for scale. Radiolarians from 460 million years ago look very similar, and when compressed they form chert. Image source: Sarah Kachovich, University of Queensland.



The basalt/chert boundary at Stop 2, shown by a red dashed line with chert above, is where the top of the ocean plate was located 460 million years ago.



Folded chert at Shelly Beach, showing zig-zag folds formed by slumping on the seafloor.



Conodont fossil from chert at Port Macquarie used to date the rocks as around 460 million years old (from Och et al., 2007). Each conodont is around half a millimetre long.

### 3 Sediments move from land to sea

On the northern side of Nobby Head, we are mid-way along the geotrail. The ocean plate was also mid-way along its tectonic journey, nearing a subduction zone and a chain of volcanoes. Here, sediments were eroded from the volcanoes and deposited nearby in the ocean. The sediments were transported by gravity-driven (or turbidity) currents downslope into a trench, where they accumulated with the marine cherts in deposits called turbidites.

Trenches lie next to chains of volcanoes either in oceanic or continental areas and are the deepest parts of the ocean. After leaving the trench area, the ocean plate and the sediments riding on it descended into the subduction zone, where they experienced increased heat and particularly pressure. There they underwent slumping, sliding, folding and faulting. To see the sediments, walk 80 m down the path to the headland at the southern end of Nobby Beach.



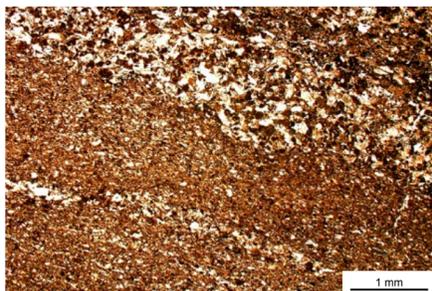
On the northern side of Nobby Head is a mix of turbidite sediments and chert. The grey rock has alternating coarse- and fine-grained sedimentary layers; the chert is mostly brown. During subduction, both rock types were strongly deformed and mixed together.



Strongly folded chert (brown) and mudstone (grey) are exposed on the rock platform. These deposits consist of skeletons of tiny marine creatures (chert) and sediments eroded from the land nearby (mudstone). The layers were folded during subduction.



Bands of mudstone (dark) and siltstone (light) formed from gravity flows that transported fine-grained sediments down slope from land into deep water. Each siltstone to mudstone layer is one flow event.



Microscope photo of turbidite layers. The pale, coarse-grained layers are silts and sands and the browner colours are mud, all composed of volcanic rock fragments.

### 4 Down the subduction zone

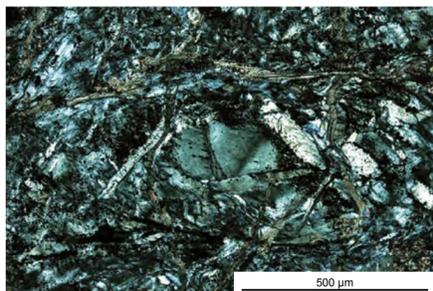
The rocks at Flynn's Beach descended into the earth down a subduction zone and affected the mantle rocks around them. The original mantle material surrounding the basalt was transformed into a rock called serpentinite, which has a soft greasy feel and is commonly bright green. This colour is due to the original dark mantle minerals transforming into greenish minerals such as lizardite and antigorite as a result of heat and water produced during subduction. Serpentinite was formed at depths of 1-60 km, where pressures are low but temperatures are relatively high (350-600°C). Due to stress in the earth, or shearing, the serpentinite has a strongly aligned texture called cleavage. It also contains unshredded, large dark fragments of the transformed mantle, making it look like green fruit cake on cliff faces. Serpentinite is exposed at the southern headland of Flynn's Beach.



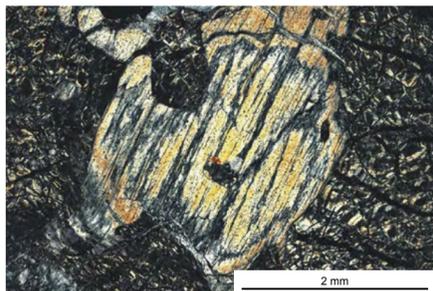
Serpentinite outcrop at the southern end of Flynn's Beach, showing the green serpentine minerals and the darker, massive blocks of serpentinite called phacoids.



Shearing during fault movement led to the serpentinite forming cleavage - a curved alignment of crystals traced out by the dashed red lines.



Under a microscope, blade-like crystals of antigorite can be seen cutting older crystals of another serpentine mineral, lizardite. These minerals help tell us the temperatures and pressures at which the rock formed.



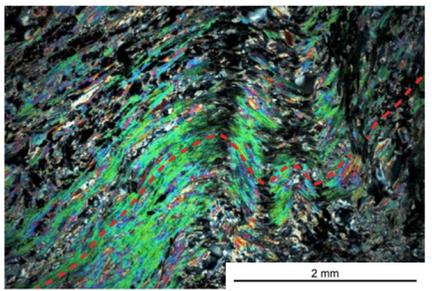
This microscope view shows a big fibrous crystal of the serpentine mineral lizardite. However it has retained the shape of its original source mineral (orthopyroxene), enabling us to identify its origin in the mantle. Source: David Och.

### 5 Rare rocks from deep Earth

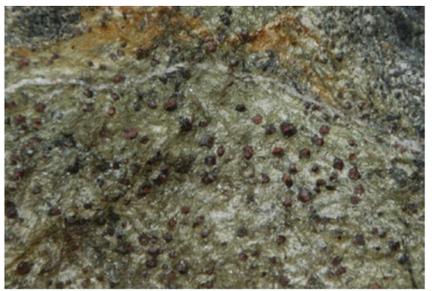
Look down on Rocky Beach from the cliff-top. The rocks on the beach represent the end of the plate tectonic journey. Around 460-490 million years ago, after travelling thousands of kilometres across the ocean, these rocks were dragged down (or subducted) as part of a crustal plate to depths around 104 km below the surface, and to temperatures around 570°C. We know subduction happened at Rocky Beach due to the special rocks and minerals found here. They only occur deep in subduction zones and include blueschist and eclogite. They are very rare to find on Earth's surface today. Blueschist is a deep blue colour and has beautiful minerals such as phengite, which has been folded during the subduction event. Eclogite is an emerald green rock composed of attractive minerals such as omphacite and lawsonite.



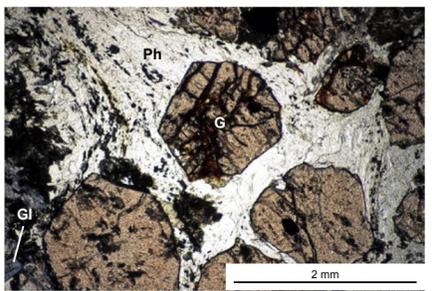
A boulder on Rocky Beach that contains blueschist (blue) mixed with eclogite (green). The blueschist contains small folds.



Blueschist seen under a microscope, showing colourful phengite minerals. The crystals were folded during subduction, as shown by the red dashed lines.



The red crystals in this green eclogite are a few millimetres across. They are garnets, and only form in high temperature and pressure situations, such as 104 km below the surface and at 570°C.



Eclogite seen under a microscope, showing high pressure and high temperature minerals such as brown garnet (G), silver phengite (Ph) and grey glaucophane (Gl). Source: David Och.