A fragment from a distant ocean: a layman's guide to the geological history of Mount Mee

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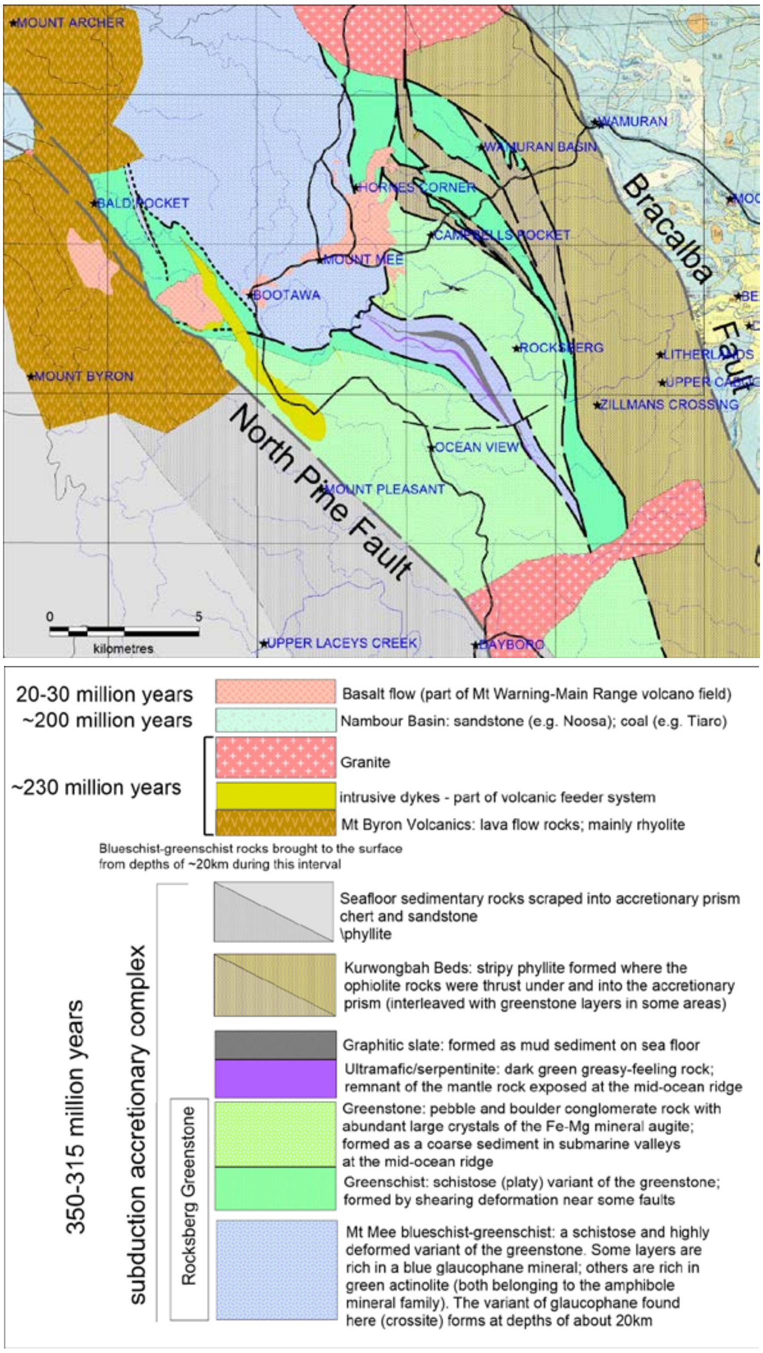
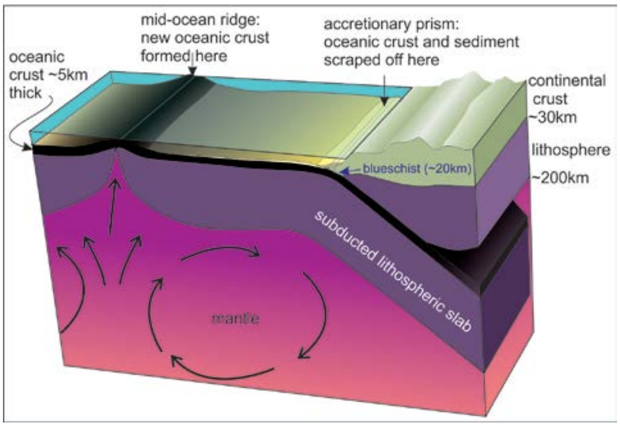
Geologically, Mount Mee is a very special place. Beneath a thin veneer of young basalt lava flows that cover the highest parts of the plateau, the older rocks, exposed in the deep valleys, originated about 340 million years ago at a distant mid-ocean ridge.

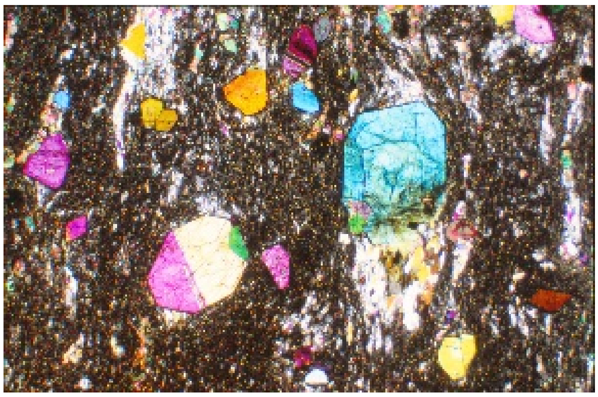


After being transported many 100s of kilometres they sank down beneath the edge of the Gondwana continent to a depth of about 20km. That journey, and their subsequent rise back to the surface, has left a very clear signature in the rocks; easily read by a geologist but also visible to anyone with a little bit of background knowledge. So first some background:



The image above is a cartoon of the process of plate tectonics – **but** this diagram is not to scale. The Earth's surface consists of a mosaic of interlocking semi-rigid lithosphere plates some 200m thick. These plates float on the mantle, a 2900 km thick shell of solid rock that, under great pressure and temperature, has fluid-like properties and is able to flow such that convective cells form.

The mantle and the lithosphere below both the continental and oceanic crust are of similar ultramafic composition, They consist of rocks that are rich in magnesium rather than silica (as in the continental crust) and also rich in heavy metals like iron, nickel, and chrome. A narrow band of such ultramafic rock passes through Ocean View. It is a dense greenish black rock (exposed in Gregors Creek) but when it becomes sheared by Earth movements it forms a green greasy rock called serpentinite. The soil formed from this rock is particularly attractive for the growth of grass trees (*Xanthorrhoea*).

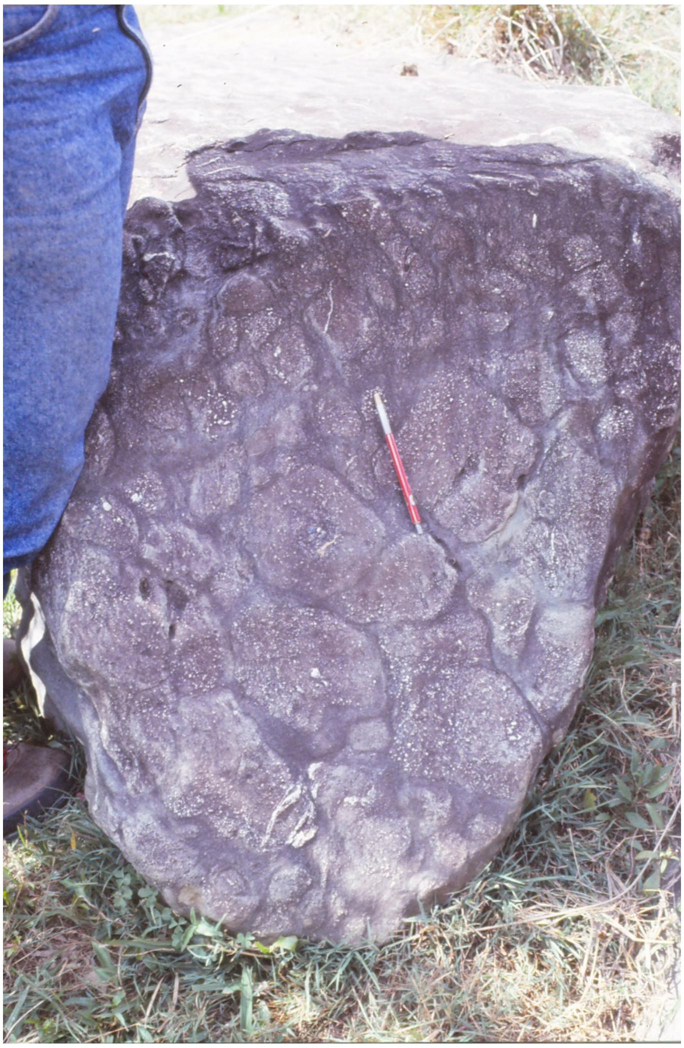


__Above__: Microscope thin section of greenstone from Terrors Creek showing scattered large augite crystals. Although these crystals are quite opaque when picked up, they appear transparent in a rock slice that is only 30 thousands of a millimetre thick. These transparent crystals become highly coloured if viewed in cross-polarized light as shown here.

MID-OCEAN RIDGES – THE SOURCE

The mid-ocean ridges are long fracture zones between plates. In this zone the upwelling mantle heats and melts as it nears the surface. Some of the melt is expelled as basalt lava, or as thin intrusive dykes; the remainder solidifies to form coarse crystal-rich bodies of gabbro rocks. Much of the rock of the Mount Mee plateau is derived from erosion of such gabbro; one of its signatures here is the occurrence of cm-scale crystals of the pyroxene mineral augite. An abundance of this mineral can be found in the soil around the Ocean View area and can be seen in many rock outcrops.

Submarine rift valleys form along the axis of the mid-ocean ridge and rock that is eroded from the walls settles to form layers of sediment along the bottom. The rocks that form the greenstone at Rocksberg and Ocean View are dominated by boulders of augite-rich gabbro enclosed in a pebbly augite-rich sand derived from erosion of the same rock. The boulders are somewhat rounded, indicating some degree of submarine transport and the size of the boulders reflects considerable topographic relief at the point where the erosion was occurring.

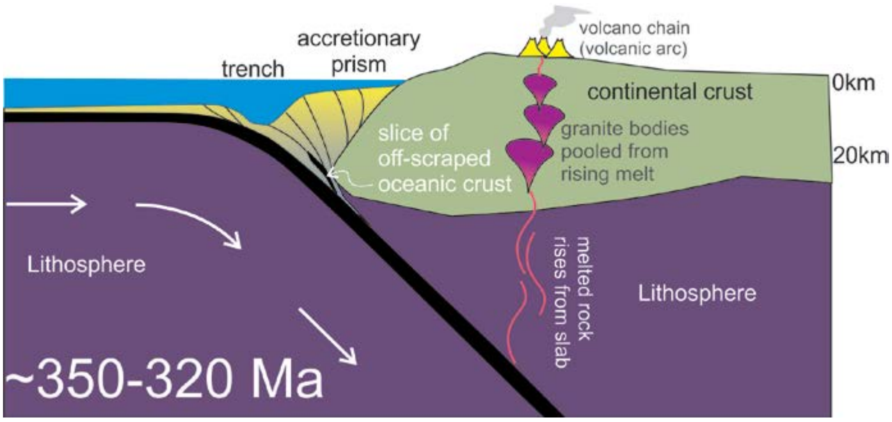


Left: *Boulder-rich layers within pebbly augite sand. The layers are no longer horizontal due to tilting and folding after being scaped into the accretionary prism and brought back to the surface. These deformations also produced the slight flattening of the boulders. (Terrors Creek, Ocean View).*
Above*: Boulder conglomerate of augite-rich gabbro with a sand matrix (Small tributary off Zilman Creek);*
Below*: Sand layer within a pebbly sandstone in which all of the pebbles are partly broken augite crystals (Dayboro-Mt Mee Rd, Ocean View)*

A lenticular band of black slate up to 200 metres wide that passes between Ocean View-and Rocksberg was a target for gold exploration in the mid-1980s. Such rocks form in quiet, restricted environments, where oxygen levels fall and organic material can accumulate. In a mid-ocean ridge setting the muds and organic material may have been sourced partly from 'black smokers' – sea-floor vents that are common at mid-ocean ridges and attract an abundance of organic life. Such rocks are commonly rich in sulfides and trace metals such as gold. However the exploration failed to turn up anything of economic significance.

The solidified products of mantle melting at the mid-ocean ridge form a thin layer of new oceanic crust some 5 km thick. The new crust is tacked on to the earlier-formed crust, and as it cools it becomes denser and gravity pulls it away from the elevated fracture zone allowing further mantle upwelling to occur. And so the process continues; new crust pushes the older-formed crust away at a rate of 1-10 cms per year. Like a giant conveyor belt the crust formed at the ridge axis can be transported 1000 km in about 20 million years. This might sound like a long time but it is the blink of an eye in geological time. Although we are still a little uncertain as to when our bit of oceanic crust formed in the mid-ocean, we do know that it had reached the edge of the continent by about 315 million years ago. Along the way it had gathered a thin veneer of ocean floor sediment; some derived from the distant continent, some by chemical precipitation in seawater of silica from dissolved organisms.

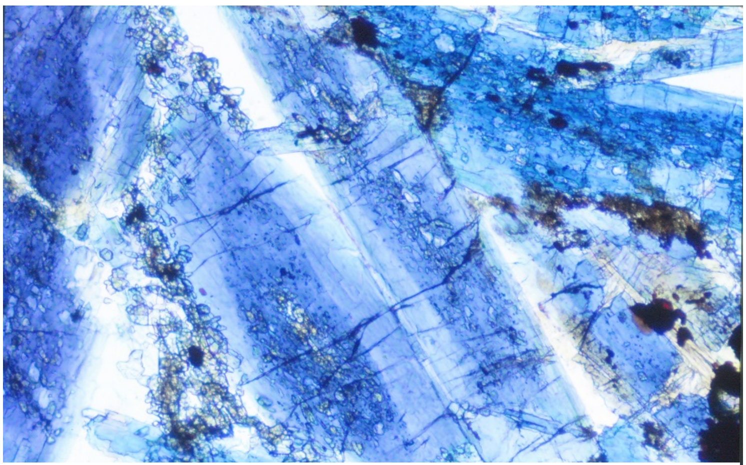
SUBDUCTION – OUR ROCKS REACH THE MARGIN OF GONDWANA



Because they are silica-rich, continental rocks are less dense than oceanic crust or the mantle. Hence, even though continents are 30 km or more in thickness, they remain buoyant, supported by the lithosphere below. The colder and denser oceanic lithosphere sinks beneath the buoyant continental lithosphere as a thick slab. The process is subduction, and the slab will ultimately reach depths greater than 500 km before melting and reincorporation back into the mantle. As it bends and sinks, a deep offshore trench is formed. This trench accumulates a thick pile of sediment derived partly by erosional run-off from the nearby continent, but also by scraping off the veneer of sediment and basaltic seamounts riding on the oceanic plate. Acting much like a bulldozer blade, the continental margin scrapes the advancing pile of trench sedimentary rocks into a thick wedge of sliced-up rock called the 'accretionary prism'.

The accretionary prism that formed at the margin of Gondwana from about 350 to 315 million years ago forms a large part of the rocks exposed along the eastern margin of Australia between Port Macquarie in NSW to Marlborough in Queensland. Most outcrops are from the upper levels of the prism (perhaps from as deep as 10 km) and these rocks can be seen in many of the road cuttings around the city of Brisbane; in the road cuttings of the M1 freeway to the Gold Coast; in the beach rock platforms at Nobby and Currumbin Beach on the Gold Coast; in the roads from Kilcoy into the Conondale Ranges; and in deeply incised valleys and waterfalls along the eastern escarpment of the Great Dividing Range in the New England area. They also make up the hills visible to the west from Ocean View across the deep valley to Mt Pleasant and Lacey's Creek.

What makes Mount Mee different is that part of the oceanic crust itself has become sliced up and inserted deep into the accretionary wedge and transported to depths of about 20km. At such depths both the pressure and the temperature increase. Where the rocks are sheared by faults that slice them up, the rock is not only transformed into a platy schist by the shearing, but the augite minerals in the original rock are replaced by an aggregate of new minerals, and in particular a blue amphibole mineral called crossite (part of the glaucophane family of minerals) and epidote, a yellow-green mineral. (This process of mineral change, driven by changes in pressure and temperature, is called metamorphism). The rocks are called blueschist, and this Mount Mee occurrence is the largest exposure of such rocks in Australia. They



Above: *Microscope thin section of blueschist from Flagstone Creek showing a blueschist rock packed with blue amphibole mineral. Although these look like large crystals, the width of the image is about 8mm so the long laths are only about 5mm long.*

also occur in smaller bodies throughout the Conondale Ranges as far north as Kilkivan. Blueschist is not a particularly attractive rock in outcrop, but in microscope thin section its colour becomes very clear.

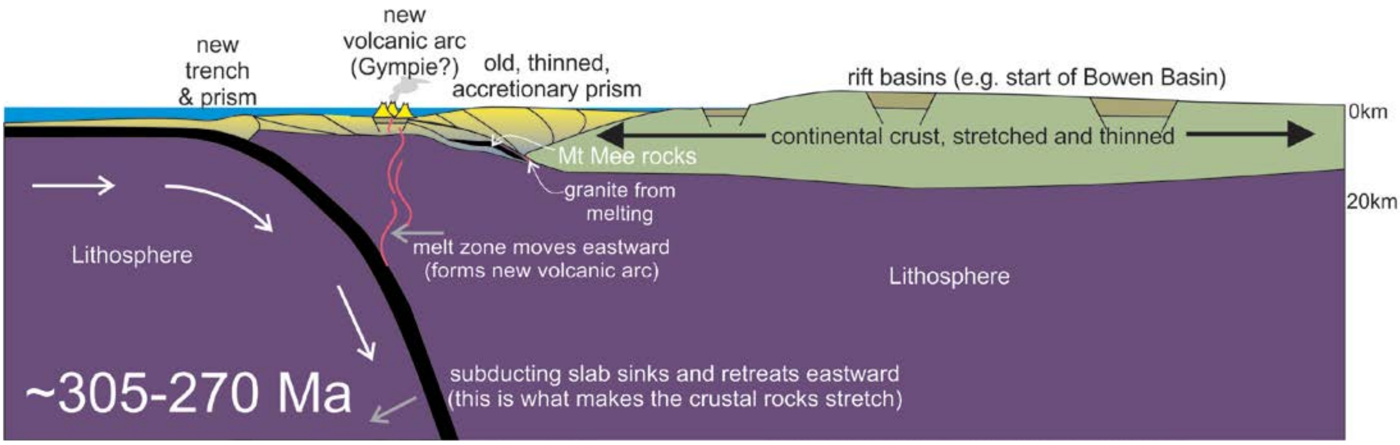
Blueschist is particularly important to geologists; they are a particular signature of subduction, where the rocks are transported quickly enough to great pressure such that the temperatures remain somewhat cooler because of the relatively colder subducting slab. At Mount Mee the pressures recorded by the mineral changes indicate that the pressure was around 6000 times atmospheric pressure and the temperature was about 375°C. The pressure corresponds to a depth of about 20 km. This is not particularly deep for many blueschist terranes around the world, where pressures corresponding to depths in excess of 40 km are commonly recorded. Blueschist rocks that have once been to depths of up to 60km are now exposed at the surface in New Caledonia.

The Kurwongbah Beds, a belt of rock that stretches from Delaneys Creek, past Wamuran, to Petrie, contains rocks that were shaped by the processes that scraped off our slice of oceanic plate rock. These rocks are hard slaty rocks with stripy bands on the surfaces of the rocks. Both the platy nature of the rock and the stripes are a result of the smearing of the rock as the oceanic rock was slid into place against them. The lines mark the direction of movement, although they have since been buckled and distorted. The eastern flank of the Mount Mee plateau (through Campbells Pocket and Ocean View) is crossed by several narrow belts of these same rocks.

Above: *Striped platy rocks of the Kurwongbah beds at Jackson Historic Park, on Basin Road near Wamuran.*

In most outcrops of the Kurwongbah beds the platy layers are wrinkled and contorted. These folds reflect the next part of the story, which is how such deep rocks made it back to the surface over the next 80 million years or so.

STRETCHING AND THINNING THE CONTINENT –THE ROCKS START THE TRIP BACK TO THE SURFACE



At about 300 million years ago, shortly after the Mount Mee rocks had been deeply subducted and transformed into blueschist, the ocean plate slab started to steepen and roll back to the east. This rollback process has the effect of dragging the edge of the continent with it – thus stretching and thinning it. The deeply buried Mt Mee rocks are dragged back toward the surface along fault fractures that arch upward. The pressure decreases as the rocks are drawn up, and this decompression, if it is fast enough, causes some of the rock to melt and pool as granite bodies. The temperature rise in the Mount Mee rocks was not enough to cause the local rocks to melt, but along the ridges of the Conondale Range around Gallangowan are large granitic bodies that formed this way from rocks at even deeper depths.

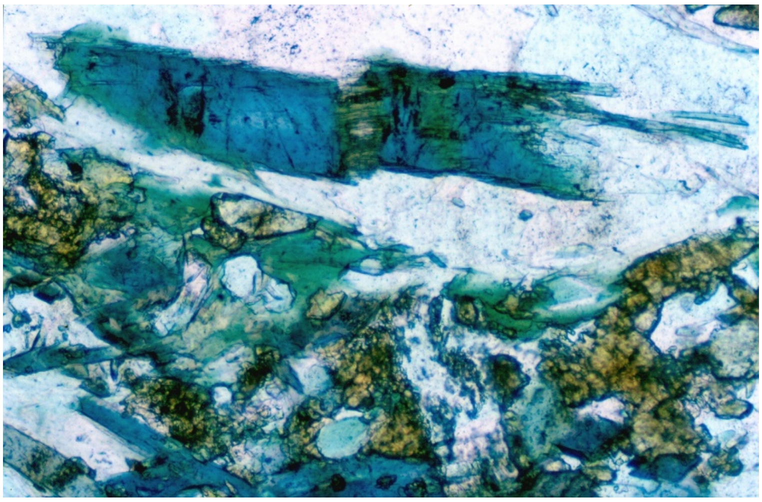
The stretching and thinning causes the rock layers to shear and flatten and to develop a platy fissility (called a *foliation*). This foliation that was originally almost horizontal, but has now been arched by the next crustal movement such that it is only still horizontal near the top of the Mount Mee plateau (near Culvert Creek), but inclines to the east around Campbell's Pocket and the eastern slopes of Ocean View, and inclines to the west in the Mount Mee State Forest.

***Right**: Flattened grains and boulders in the rock produce an almost horizontal laminar foliation in this road cutting at Terrors Creek on the Mount Mee-Dayboro Rd.*

Where the rock is layered, these layers have become crumpled (*folded*) and squashed into the same horizontal plane of flattening. These folds are particularly prominent in some of the tributaries off Culvert Creek running up to Hausmann Rd. They are also very prominent in the highly laminated rocks of the Kurwongbah Beds in the Campbells pocket area.

***Right**: Contorted layers in Kurwongbah beds, cause the layers to be flattened into a near-horizontal plane. Antibidawa Creek on the Campbells Pocket Rd, just below the bridge.*

In the Mount Mee rocks the heating and pressure loss caused by the bringing the rocks closer to the surface was enough to raise the temperature of the rocks to over 400°C at a pressure that caused the blue amphibole to be transformed into a green amphibole mineral called actinolite. So, many of the blueschist rocks are transformed back into a greenish rock called greenschist. The process can be seen easily in microscope thin sections where green minerals start to replace blue minerals. In the image shown here you can see the large original long grain of blue amphibole stretched until it breaks, then the new mineral that forms in the fractures are fibres of green actinolite. This change back to a greenschist in much of the rock body makes it difficult to find remnants of the blueschist.

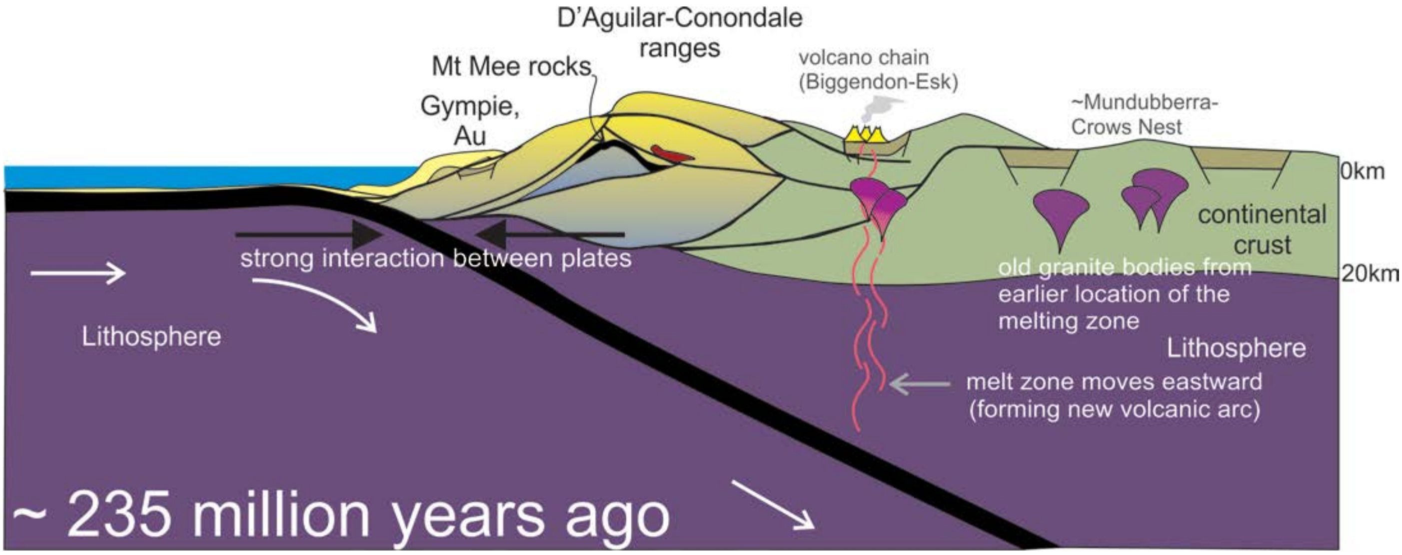


***Above**: Laths of blue amphibole stretched and broken, with the gap filled up with fibres of green actinolite. The yellowish grains are the mineral epidote, which produces yellowish streaks on many of the rocks that contained blue amphibole.*

Other minerals, such as garnet, formed in some rocks. (Garnet is found in some of the rock bands within the Mount Mee State Forest). Because the different chemical reactions involved in forming these new minerals are well known, we can determine the temperature and pressures of the reactions, and thus the depth at which it occurred. Using data from the entire D'Aguilar and Conondale Ranges we know that by the end of this process the rocks were above 400°C but were at a depth of around 13-15km. By this stage the very deeply buried rocks under Mount Mee had been dragged up and placed against the much shallower rocks that are typical of the accretionary prism around Brisbane and Beenleigh.

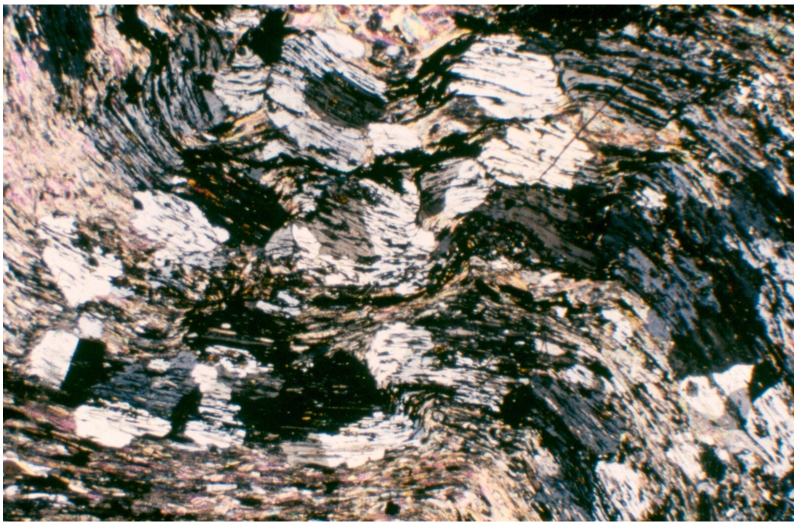
But we are still about 13km below the surface and it takes another event to get us the rest of the way.

BUILDING MOUNTAINS: DEFORMING THE CONTINENT



Some 40 million years after the subducting oceanic slab had moved to the east, away from the continental plate, it started to return with a vengeance. From about 270 million years ago, and for the next 30 million years, the force of the two plates interacting began to crumple the edge of the continent; a mountain-building process called *orogeny*. Rocks buckled, and were sliced and stacked on top of one another, producing a fold mountain belt similar to the mountains of Papua-New Guinea. As the subducting oceanic plate now lies well below the continent the zone of melting produces a new arc of volcanoes and granite bodies well inland, in a belt running near Mundubbera and Monto.

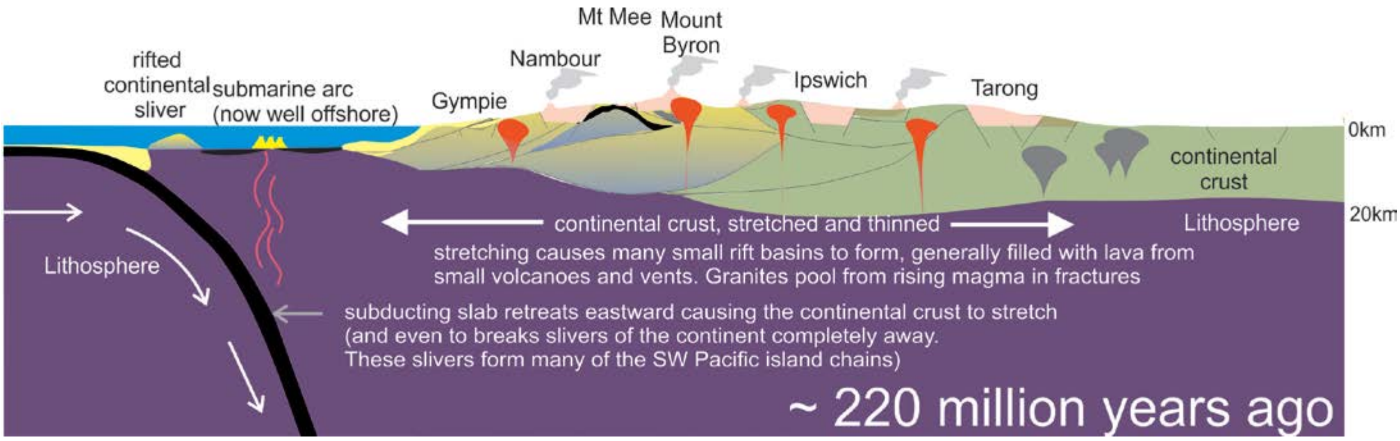
Across Mount Mee the horizontal foliation that formed during the stretching of the crust was buckled to form a broad arch across the plateau (recognised now by the variation in inclination of the foliation described a few pages back). Layers were also buckled at a small scale and there are many examples of this throughout the area. In the early stages of this buckling the rocks were still hot enough for yet another set of chemical transformations. Large clots of a clear white mineral called albite formed profusely in the old blueschist rocks as the buckles formed. These clots, which are commonly 1-4 mm across, give many rocks a salt-and-pepper appearance.



***Above**: Buckles (folds) formed in black slate in Antibidawa Creek.*
***Left:** Microscope view of clusters of albite clots about 1 mmm across growing over small buckle folds in a schist in Mount Mee State Forest. Albite is a clear transparent mineral when viewed under a microscope; in this view polarized light has been used to colour the grains various shades of grey and white.*

The initial arching of the rocks upward across Mount Mee occurred at about 260 million years ago, as that is when the mica in our rocks finally cooled below 350°C[1]. This corresponds to a depth of about 9-10 km below the surface. We don't know exactly how much closer to the surface our blueschist rocks rose in that early stage, but they hadn't yet made it to the surface. It was 25 million years later that the final major pulse of deformation of the edge of the continent really caused a major mountain range to form. At this stage the mountain range would have been several thousand metres high and it would have been at this time that our rocks were brought up to be very close to the surface. We know that because of what happens next.

STRETCHING THE CONTINENT AGAIN: WE SAY GOODBYE TO THE OCEANIC PLATE



The 30 million year period of mountain building ended when once again the oceanic plate rolls back to the east, this time for good. As we saw previously, this retreat of the subducting slab stretches and thins the continental crust. The mountains that had been formed eroded rapidly and new rift basins form. At the very margin of the continent, rifts may completely separate small ribbon-like strips of the continent and these float away as new oceanic crust forms behind them. These fragments eventually become some of the ribbon-like island chains that form our SW Pacific neighbours (although some may have rifted away in the previous stretching interval. These ribbons of continental crust include parts of New Zealand, New Caledonia, Vanuatu, and Fiji.

As the slab retreated, the zone of melted rock rising from the slab also moved east, eventually forming submarine volcanic chains. Locally the rising melt zone left behind many granite bodies such as the Neurum Granite, between Delaneys Creek and Woodford, and the Dayboro Granite, to the northeast of Dayboro. Volcanoes were active and over the next 20 million years the rifts filled with lava, sediment, and lush swamps that eventually formed coal. Mount Byron is a product of this volcanic activity, and the Mount Byron Volcanics lie directly on an erosion surface formed on our old blueschist rocks. Thus, by about 230 million years ago, the age of these volcanics, our blueschist rocks had completed their 20 km trip back to the surface.

Another product of the volcanism at this time is the narrow belt of white rock exposed along the Mount Mee-Dayboro Road (near the Pitstop Cafe). This is a rock called granophyre (a type of fine grained granite) and it intrudes through the old blueschist rocks as a narrow sheet (called a dyke). It was a feeder dyke for the old volcanoes that formed the rocks at Mount Byron. There are many smaller examples of such dykes throughout the Mount Mee area.

But this is not the end of the geological story for Mount Mee. There are still more than 200 million years left.

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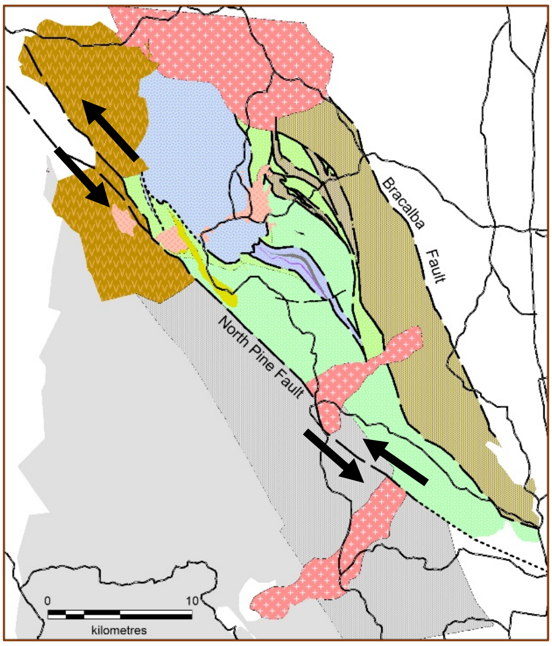
[1] [The procedure to measure the age of cooling depends on measuring the isotopic decay of potassium to argon, which is a gas. If the mineral being dated (a mica) is too hot, the argon escapes. So the geological clock for that mineral only starts ticking once it gets below its particular 'blocking' temperature, which in the case of our type of mica was 350°C.]

THE FINAL SHAPING OF MOUNT MEE: VOLCANOES AND EARTHQUAKES

Over the next 100 million years much of eastern Australia cooled and subsided to form the vast Great Artesian Basin. Dinosaurs evolved, flourished, and disappeared. Periodically, interactions at the distant plate boundaries caused minor changes, particularly intervals of minor rifting during which volcanoes formed. Swamps formed in these rifts produced the conditions for new coal measures (such as at Tiaro and at Maryborough). The Bracalba fault, which passes through Wamuran, is the margin to one of these basins (locally called the Nambour Basin). A few granites bodies intruded as magma into the crust, and some made it close to the surface (such as at Granite Bay in Noosa National Park).

Mount Mee itself may have gone up and down a little during this time as some of these mild events affected the local crust, but very little of it affected this area. During this time the Australian continent, afloat on its own large plate, was drifting northwards. At around 20-30 million years ago the landscape began to change as a volcanoes began to develop as the continent drifted over a deep source of abnormally hot rock (called a mantle plume[2]). Vast fields of basalt (and sometimes a light coloured lava rock called rhyolite) flowed over the land and built up shield volcanoes such as Mt Warning. The thin veneer of basalt that forms the very topmost layer of rock at Mount Mee is a remnant of these basalt flows. Similar flows occur at Maleny (and many other places in southeast Queensland). Basalt breaks down to form a very rich soil, and many of the pockets of rainforest that occur throughout the region occur on this soil type.

The Glasshouse Mountains form at this time at around 25-27 million years ago. The rocks are volcanic rhyolite and trachyte (the differences are very subtle). The lavas that produce this type of rock are very viscous, and do not flow readily. Hence they commonly freeze within the vents of the volcanoes, plugging them and causing very explosive eruptions that producing an enormous amount of dust and ash. Being easily eroded, nothing now remains of the ash deposits that lay around these central vents.



The final event that shaped the landform of the Mount Mee plateau produced the very deep valley to the southeast formed by Laceys Creek and its tributary along the Mount Brisbane Rd. This valley is formed by erosion of the North Pine Fault, a major Earth fracture. The effect of this fault can be seen on the geological map, where it cuts and displaces two prominent rock bodies. The Dayboro Granite (trending northeast from Dayboro) has been displaced about 9 kilometres from its other half, the Mount Samson Granite. The fault also cuts and offsets the Mount Byron Volcanics by the same amount.

Until 2014 the only age constraint that we had on this fault was that it was younger than about 230 million years (the age of the Mount Byron Volcanics). But workers from The University of Queensland recently found that this fault was part of a swarm of such structures in southeast Queensland that cut and offset the basalt bodies. Thus the fault formed less than 20 million years ago and is one of the youngest features at Mount Mee. They surmise that the entire continental coast was twisted north-westward by movements occurring at the plate boundaries. The North Pine Fault would not have moved 9 km in one go. It would have taken more than a thousand earthquakes, each moving the blocks a few metres at a time, probably occurring intermittently over a period of 10000 to 50000 years. Living at Mount Mee during that time would be similar to living in other active fault areas, such as San Francisco, Tokyo, or the Anatolia area of Turkey.

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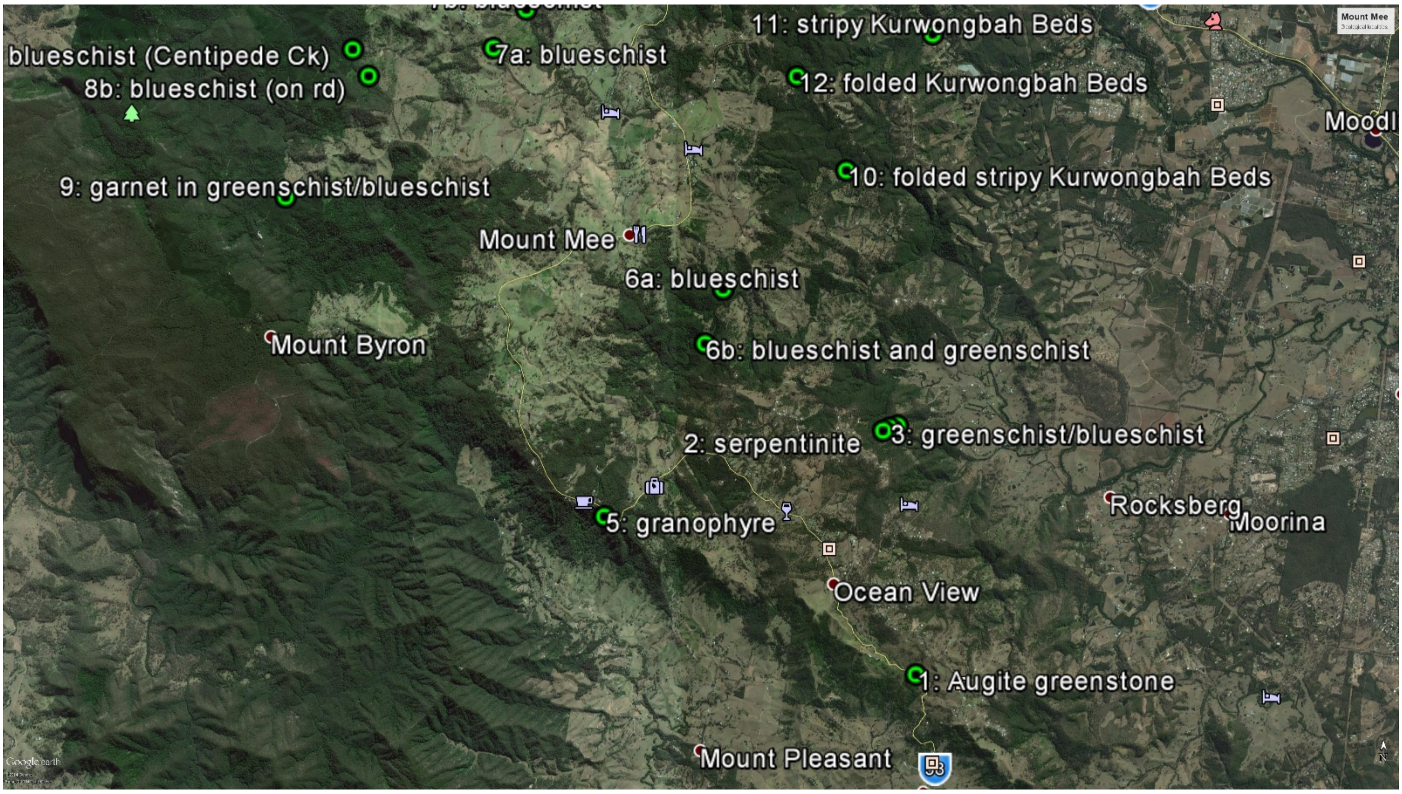
[2] Mantle plumes are columns of abnormally hot rock convecting upwards from very deep within the Earth's mantle, perhaps from as deep as 1500 km. As the surface plate drifts over the stationary column, new volcanoes form as the old ones drift away. The result is a line of volcanoes that get younger in one direction. The Hawaiian Islands are a very good example of this process.

WHERE TO SEE THE ROCKS



The map above is a Google Earth image with locations marked where you can find some of the rocks described here.

Where possible I have tried to pick localities that have public access. Although there is an abundance of blueschist at Mount Mee, most of its outcrops are on private land and permission needs to be sought. In particular the localities in Flagstone and Deep Creek (labelled 6a & b) and the localities in Culvert Creek and its small southern tributary (labelled 7a & b) are on private land. The outcrops in Mt Mee State Forest (8a & b; 9) may need Forestry or State Park permission for access.

Localities 2 & 3 (in Eliza Creek) and localities 12 can be accessed via small Conservation Parks. Locality 11 is in the creek at the Jackson Historical Park on Basin Rd.

Locality 1 in Terrors Creek is one of the best exposed outcrops of the augite-rich greenstone at Mount Mee. It is accessed directly from the Mt Mee-Dayboro Rd. This is a busy road and the creek area has a small waterfall drop: care needs to be taken with both. Be particularly careful of the Terrors Creek outcrop in the wet. Best to leave it for a dry day. There is a parking pull-out on the eastern side of the main road just uphill from the bridge.

ACKNOWLEDGEMENT TO THE PEOPLE OF MOUNT MEE

I have written this account as a tribute to the people of Mount Mee. I have many connections to the area and it is close to my heart. My brother-in-law lived here with his family more than 60 years ago; he once showed me the old power poles on Hausmann Rd that he had helped build out of twisted tree trunks to finally get power to their house. In the late 1980s and early 1990s I mapped the geology of Mount Mee as part of a University of Queensland research project into the geology of the D'Aguilar Ranges as a whole. I have revisited Mount Mee many times over the years since then showing international visitors our own version of blueschist; that most distinctive of all metamorphic rocks.

In November, 2015 I will be again showing a group of Australian and international visitors over the area as part of a geological conference to be held at Caloundra. During the past few months, in preparation for that trip, I have been revisiting many of the rock outcrops and connecting with local landowners. As with my previous work I have been overwhelmed by the hospitality shown by local residents, their willingness to let me traipse over their land, and in the interest shown in what I am doing. This guide is my thanks to the entire community.

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