AUSTRALIA - HALF A BILLION YEARS AGO
Castlemaine's rocks were formed about 480 million years ago when the Australian mainland formed part of the Gondwana supercontinent. At that time the east coast of the mainland was approximately along a line where Broken Hill, Mildura and Portland are today, and just to the east was the seafloor of the ancient Pacific Ocean. This ocean floor was gradually filled with thousands of sediment layers called 'turbidites'. The layers we see in Lyttleton St are some of these ancient sedimentary layers that were once horizontal on the seafloor.

WHERE DID THE SEDIMENT COME FROM?
Rivers constantly eroded the continental mountains along eastern Gondwana and carried sand, silt and clay to the coastline where the sediment accumulated in relatively shallow waters of the continental shelf. These loosely formed deposits were soon to become turbidites.

WHAT IS A TURBIDITE?
Turbidites are a type of sediment deposited by fast-moving sea-floor currents called turbidity currents. A turbidity current is a turbulent mixture of water, sand, silt and clay. The process often starts along the continental shelf where accumulated sediment becomes unstable, either because of its own weight, or more commonly triggered by earthquakes. The sediment can violently surge down into deeper water with speeds exceeding 60 km/hour. Modern turbidity currents have been known to break submarine cables.

Figure 1
Graded sandstone bed

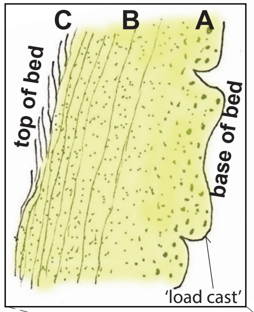
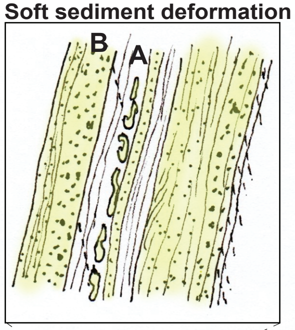


Figure 2
Soft sediment deformation



THE ENERGY STATE OF TURBIDITES
The sedimentary layers (or beds) reveal a lot of information about the varying energy states of the ancient turbidity currents. The currents gradually lost energy as they travelled farther from their source and this is reflected in the thickness and the detailed form of the sandstone and mudstone beds. As the current slowed down it could no longer support the sand grains, which settled on the seafloor to form a sandstone layer. The silt and clay grains remained in suspension a little longer but they too eventually settled to form mudstone layers. This basic sorting into different grain sizes is the main reason for the alternating layers of sandstone and mudstone. But the varying energy state of the currents had other more subtle effects, such as the gradation of sand size within individual sandy layers.

Graded Bedding - Figure 1
So-called 'Graded Beds' show a subtle gradation from coarse to fine sand. The larger sand grains were deposited first during the initial high-energy stages of the current. As the turbidity current slowed down the finer grains were deposited on top of the coarser sand and the graded bed was completed. Figure 1 shows the detail of a layer at the west side of the Lyttleton St outcrop (Figure 3). Here there is a subtle reduction in sand grain size from the base, or bottom of the bed (A), to the top (C) i.e. from right to left. This change is accompanied by the gradual appearance of laminations, which are parallel to bedding (B). Laminations form when the turbidity current continues to lose energy.

By the time the top of the bed was deposited the current was so gentle that small ripples started to form on the seafloor - like mini sand dunes ('C' in Figure 1).

The base of a graded bed is often very sharp because the sand was quickly dumped on top of the muddy underlying layer. The base of this bed also has an irregular profile, known as 'load casts'. Load casts formed when the initial heavy sand sank into the soft underlying muddy seafloor.

Soft-sediment deformation - Figure 2
Occasionally there is evidence that a layer on the sea-floor was 'reworked' by water currents. In this example (Figure 2) an originally continuous layer at 'A' was deformed into balls of silt and sand by a later water current. The contorted shapes of the layer show that it was still plastic at the time so we can assume it happened soon after the layer was originally deposited, but before the next layers (B) covered it over.

WHAT CAUSED THE FOLDING?
Thousands of sedimentary layers were deposited on the seafloor for about 35 million years - but at 445 million years ago something new happened. The gradual movement of tectonic plates began to squeeze and fold the horizontal layers. This happened because the Pacific tectonic plate started moving westwards towards Gondwana's eastern margin. A huge part of the seafloor was caught in this vice-like grip - an area several hundred kilometres wide, perhaps thousands long and at least 5km thick. The sedimentary beds were not yet hard rock, but still relatively plastic and were squeezed and folded to form the countless anticlines and synclines we see across eastern Australia.

The seafloor was deformed so much that the ocean drained away as the crumpled rocks rose up to form the land we now call eastern Australia.

YOUNGING DIRECTION
Geologists use graded bedding to determine the up-side of sandstone beds. The so-called 'younging direction' is very useful tool to help unravel the folding pattern. The bed in Figure 1 is younging west, that is, the left or west side of the bed is slightly younger than the right or east side - perhaps by only a day or so.

Sedimentary beds always 'young' away from anticlines but 'young' towards synclines (Figure 3). The younging direction in the very centre of an anticline or syncline is up, just like on the original seafloor.

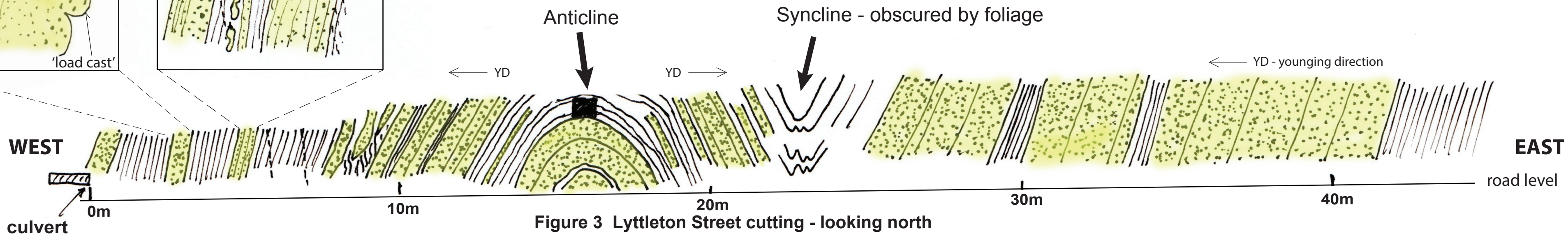
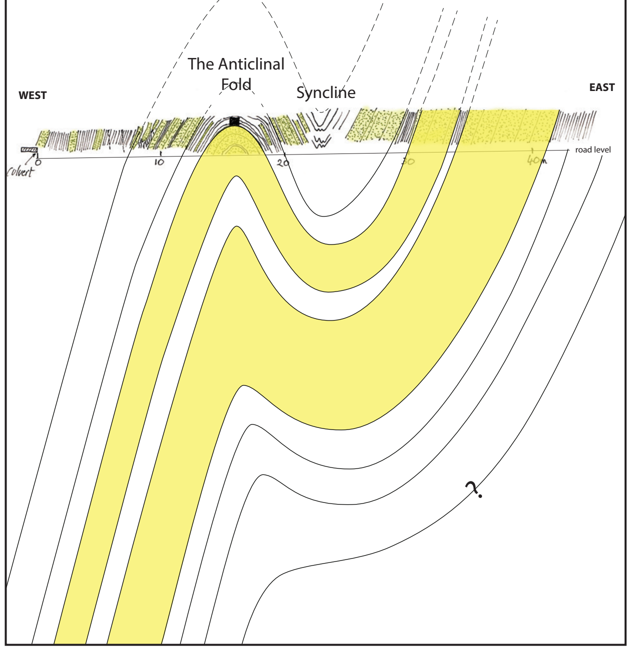


Figure 3 Lyttleton Street cutting - looking north

Figure 4



WHAT LIES BENEATH THE ANTICLINAL FOLD?

If we were able to excavate down a few tens of metres we may see that the sandstone beds that form the Anticlinal Fold appear again about 12 m to the east because they are refolded about the Syncline. We would also see that other layers, further below, are folded in the same way.

The Anticlinal Fold, and its sister Syncline, could be traced deep below Lyttleton Street for perhaps hundreds of metres. The depth to which a fold will continue depends partly on its half-wavelength, that is, the distance between adjacent anticline and syncline crests. Folds with half-wavelengths of hundreds of metres can be traced to great depths - we know this from drillholes and shafts at Castlemaine and Bendigo which have traced anticlines and synclines downwards for nearly 2km. Folds with short wavelengths, like the Anticlinal Fold, tend to be less persistent with depth and often merge with adjacent folds, as inferred in Figure 4.

THE AGE OF THE ROCKS

The age of Castlemaine's sandstone and mudstone beds has been dated to the Ordovician period (485 - 444 million years ago) using fossils called Graptolites.

Graptolites were free-floating pelagic animals that lived in the oceans of the world from the Cambrian to the Devonian periods. Their pelagic character, and their rapid evolution, make them ideal fossils for comparing the age of rocks in different continents because each new species was able to rapidly colonize all the oceans of the world. This means that geologists can be confident that a particular species found in Australia will be the same age as those found in North America or Europe.

Fossils give us the relative age of rocks but how do we assign an absolute age in years? In some parts of the world fossil-bearing strata occur with rocks that can be dated using radiometric methods, such as U-Pb dating. In this way it is possible to infer an absolute age in years for particular species. Geologists have been able to build a complicated timescale for the earth that uses both relative fossil ages and absolute radiometric ages. The fossil in Figure 5 was found just south of Castlemaine and is about 469 million years old.

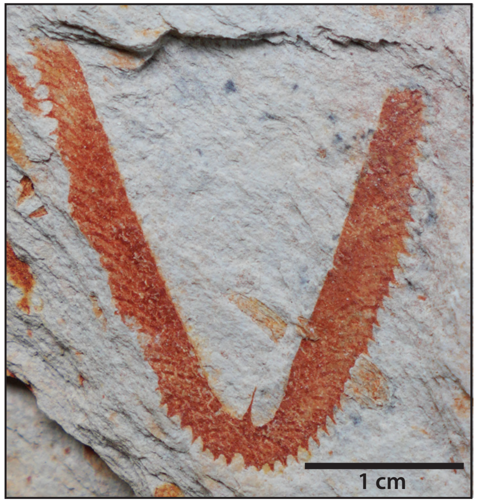


Figure 5 Fossil graptolite
Isograptus victoriae maximus

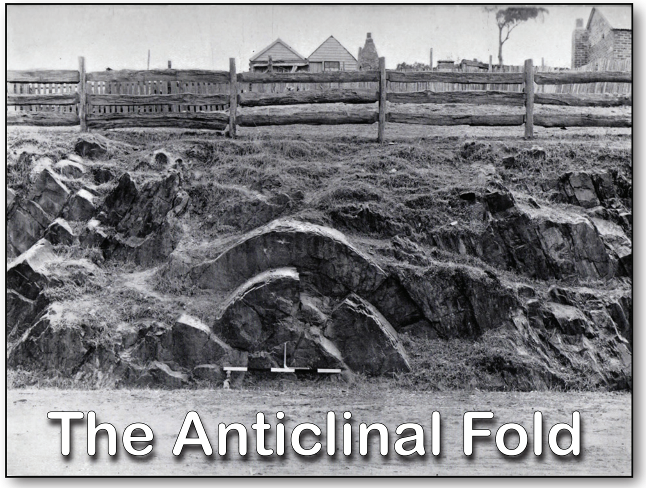


Photo: Geological Survey of Victoria c1902

The **Anticlinal Fold** is a natural geological feature that gives us a rare glimpse of the extraordinary forces that folded ancient rocks across eastern Australia.

Located in Lyttleton St, just east of Urquhart St, the Anticlinal Fold was uncovered by road building in 1874.

Anticlines are very common in the earth's crust and are formed when layers of rock are squeezed. If the squeezing persists, the layers start to buckle to form a series of corrugations that geologists call 'folds'. It's a bit like the folds that form when two sides of a tablecloth are pushed together across a smooth table. The A-shaped folds are called anticlines and the V-shaped folds are called synclines.

The Lyttleton St anticline was formed 445 million years ago when horizontal layers of sandstone and mudstone were squeezed by massive horizontal forces, from the west and east. It is just one of many folds that have affected the bedrock of the Castlemaine area. Most are hidden from view but gold mining and detailed geological mapping have revealed many hundreds in this area and across Victoria.

The Lyttleton St rocks also reveal much more about the ancient oceanic environment that once existed here.

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