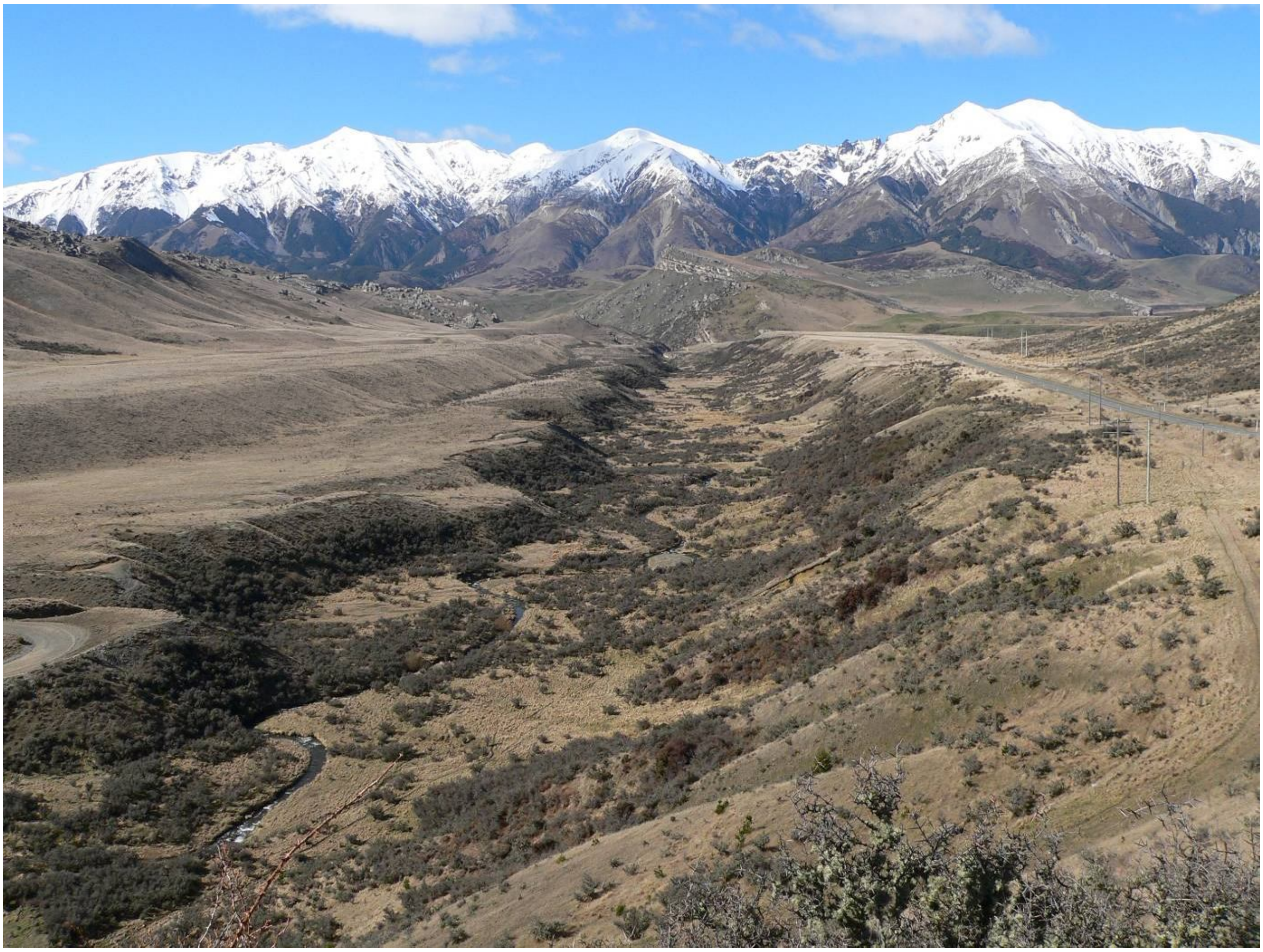
College of Science Outreach

A field guide to the geology of the Castle Hill Basin



By Natalya Reznichenko

Geological Sciences
University of Canterbury

2012

List of sites

Stop 1. Torlesse rocks – the basement of the Southern Alps. The Porters Pass Fault. (30 min)

Stop 2. Limestone - tertiary rocks in the Castle Hill Basin. (1 hour)

Stop 3. Limestone cave and surrounding rock sequences (1.5 hour with lunch during this stop).

Stop 4. Glaciations and geologically recent erosion. Cass Valley and Lake Pearson (Moana Rua) (20 min).

All sites are shown on Fig. 1.

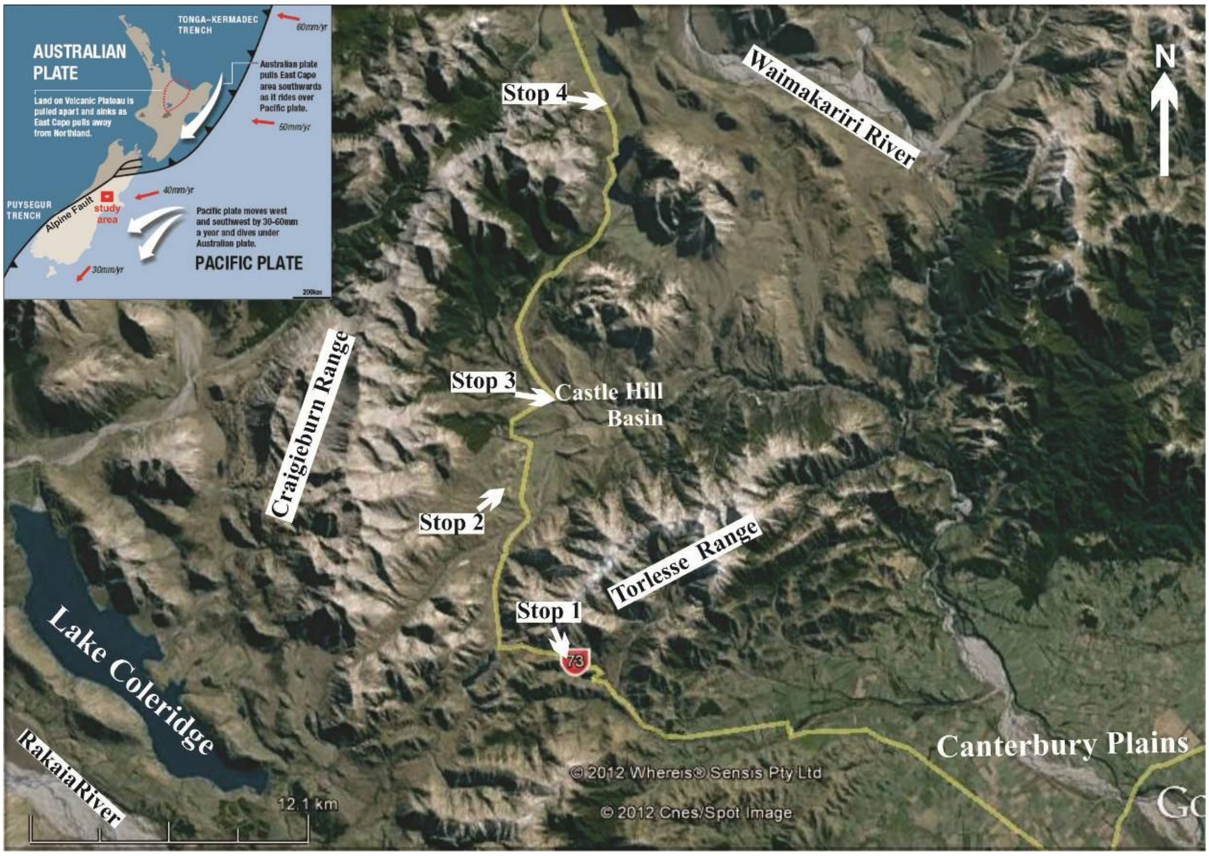
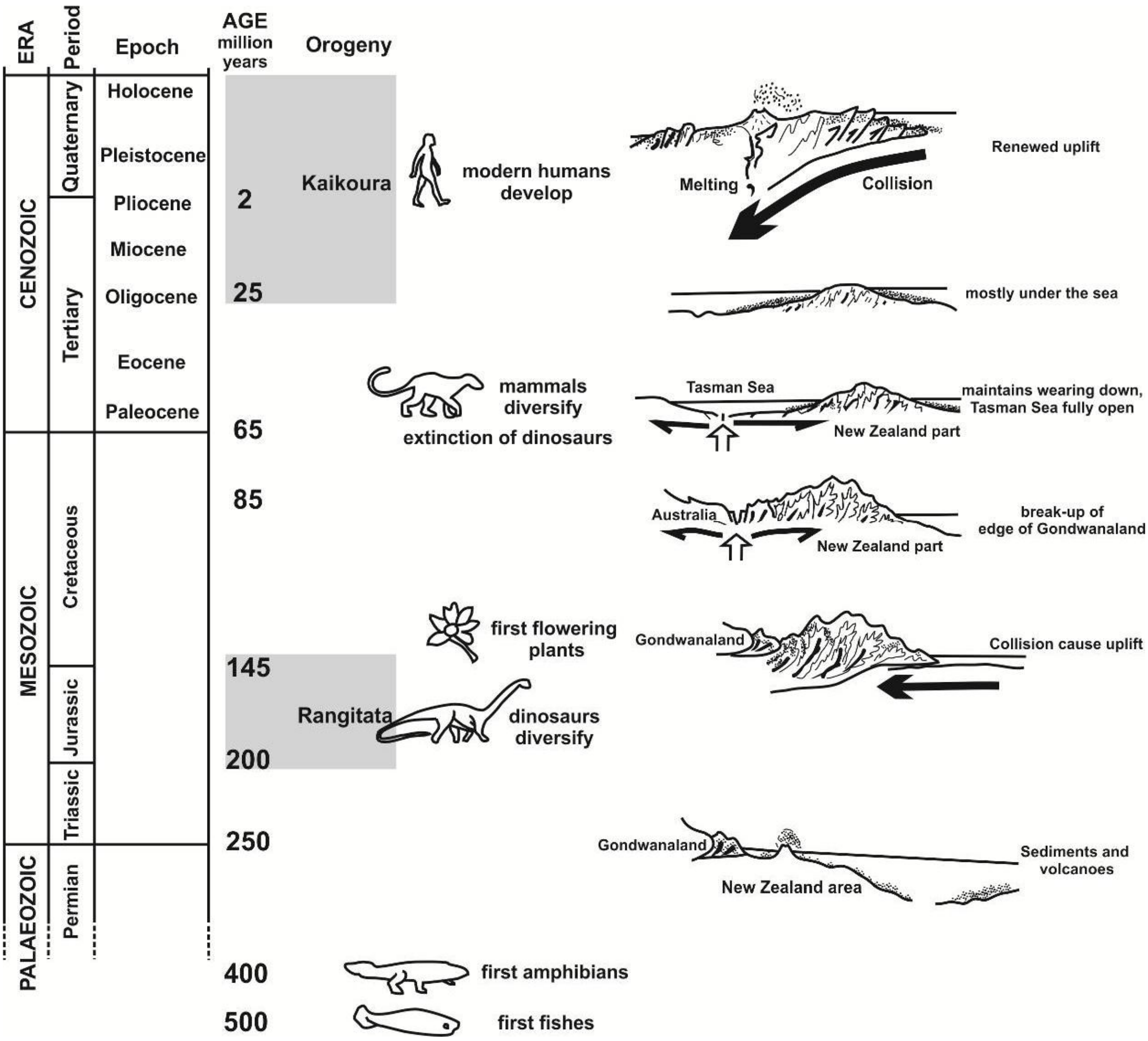


Figure 1. Location of the Castle Hill Basin and study sites during the field trip.

Geologic timescale



Stop 1. Torlesse rocks – the basement of the Southern Alps.

The Porters Pass Fault.

Torlesse rocks (sandstone and mudstones, greywacke (often with fine layers – laminations) Fig. 2) form the Southern Alps and were deposited at continental shelf and greater water depths during the time that a large southern supercontinent existed (approximately from 510 to 180 million years ago). Rocks that originally made up the continent of Gondwanaland are now found in Australia, Antarctica, South America, Africa, and Madagascar, as well as the Arabian Peninsula and the Indian subcontinent. Erosion of Gondwanaland rocks (now found in western Australia and Antarctica) led to the deposition of vast thicknesses of sediment which in New Zealand are called Torlesse rocks, which make up the bulk of the Torlesse Range (as well as other ranges within the Southern Alps). These rocks are mostly beds of sand, silt or mud, often showing cross-bedding and ripples which when found in coarse sediment such as sand suggest that the environment of deposition included strong bottom currents and frequent storms. Even though the sediments were accumulating in marine conditions, as a result of the dynamic nature of the environment and the rapid accumulation rate, fossils are only rarely found in Torlesse rocks.

Figure 2. Torlesse rocks are sediments (mostly sand- silt- and mudstone) that form the Southern Alps east of the Main Divide.

Torlesse rock deposition was initiated about 300 and ceased 130 million years ago (early Cretaceous times when dinosaurs were still in existence). During this time, collision of the Pacific **tectonic Plate** and the Australia Plate started, resulting in the uplift and folding of those sediments. This event is called the **Rangitata Orogeny** (see glossary). The first **collision** lasted for 50 million years during which some of the sediments were submerged to great depths where high pressures and temperatures resulted in the transformation (**metamorphism**) of those sediments into schist (now found west of the Main Divide and in Otago). There was then a period when sea floor spreading stopped and as a result, accumulation of sediments shifted elsewhere **-** this is why there is a significant time gap in the record from about 200 – 175 million years ago. Then, sea floor spreading began again and sediment accumulation continued for over 100 million years giving rise to vast thicknesses of Torlesse **'greywacke'** which so characterises the alpine landscape of the east coast of Canterbury, Marlborough and east-central North Island. There is evidence that these rocks originated as a result of sediments being deposited in a complex river delta setting, and their composition indicates a different source when compared to those rocks attributed to the first phase of the Rangitata Orogeny.

At the end of the Cretaceous, 'New Zealand' began to separate from the remains of Gondwanaland leading to the formation the proto-Tasman Sea. Between about 85 and 60 million years ago the uplift of Torlesse rock slowed down and intensive **erosion** led to the development of a landscape dominated by low relief and extensive plains. Sediments were deposited in basins within that low-lying landscape, but in the South Island, much of this was removed by erosion so that in places the original basement rock surface is exposed (peneplain). By the Oligocene (25 million years ago) much of the Torlesse rock landmass was submerged by shallow seas into which erosion products from the remaining 'islands' were deposited – these formed into beds of sandstone, siltstone and mudstone. During periods of climatic warming, ocean productivity increased significantly and during such times the remains of many shell and skeleton forming organisms accumulated to form limestones. This is the context for the younger (Tertiary) sediments covering much of the floor of the Castle Hill Basin.

About 25 millions years ago, collision between the Pacific and Australian Plates resulted in the formation of a subduction zone, merging, separation and uplift of continental blocks and mountain building, a process that continued for the next 20 million years (Kaikoura Orogeny). The pressure applied during this collision was simply too much and the crust thickened and cracked in places of higher pressure. These cracks are **faults,** along which the majority of movements occur. When it happens we experience earthquakes. The largest fault goes through the Southern Alps in the west – the **Alpine fault** that spreads through the entire South Island and continues on the bottom of the ocean south from Fjordland.

We can see here one of smaller faults– the **Porters Pass fault**, an active fault for the last 10 thousand years. The fault lies deep down beneath us (up to several km) but at the surface we can trace the fault trough topography. On Figs.3 and 4 we see the fault gouge - the straight line that can be traced. Often it forms a terrace (like a step). Geologists can't always see fault traces like those here on the surface. For example, faults in the Canterbury plains are covered by thick layer of gravels (the rock that are constantly being carried to the bottom of the mountains by erosion of rivers). Thus, for us the most familiar fault under Canterbury has caused the earthquakes and aftershocks for the last 1.5 years. Yet before the first earthquake happened in September 2010 any evidence that this fault existed was covered with a thick layer of gravels.

Five million years ago, the rate of uplift accelerated such that the Southern Alps are now rising faster than most other mountain ranges on Earth. If the Alps are rising at an estimated 10-20 millimetres per year and the uplift has been going on for so long, why are the Alps only kilometres high? In Castle Hill Basin, the answer to that question is all around you – erosion.

<u>Summary questions for Stop 1:</u>

What can geologists say about these rocks?
They are layers of sandstone and mudstone that formed as a result of sediments being deposited on the bottom of the ocean as sedimentary rocks; fossils are very rare, but ripples and cross-bedding indicate that bottom currents at times were quite strong. The sand and mud was laid down as horizontal layers, but crustal collision and uplift associated with plate tectonics have distorted the beds such that many are now discontinuous and lying almost vertically.

What can geologists say about the surrounding mountains?
They are composed mostly of sedimentary rocks that have been uplifted and folded during times of orogeny. The fractured and faulted nature of these rocks and the weather patterns have led to a high erosion rate.

What can geologists say about faults?
The fact that the mountains are still rising is clear evidence that the faults are active. Earthquakes, when they happen, are associated with a fault, however in some circumstances, movement on that fault may not be expressed (show) on the surface.).

Exercise 1 – Find the line of the fault during stop 1, trace the fault line on the image and compare it with what you see.

Figure 3. Oblique photograph of the Porters Pass fault looking eastwards towards the Canterbury Plains and Christchurch. White arrows show position of fault scarp, block arrows show lateral movement.

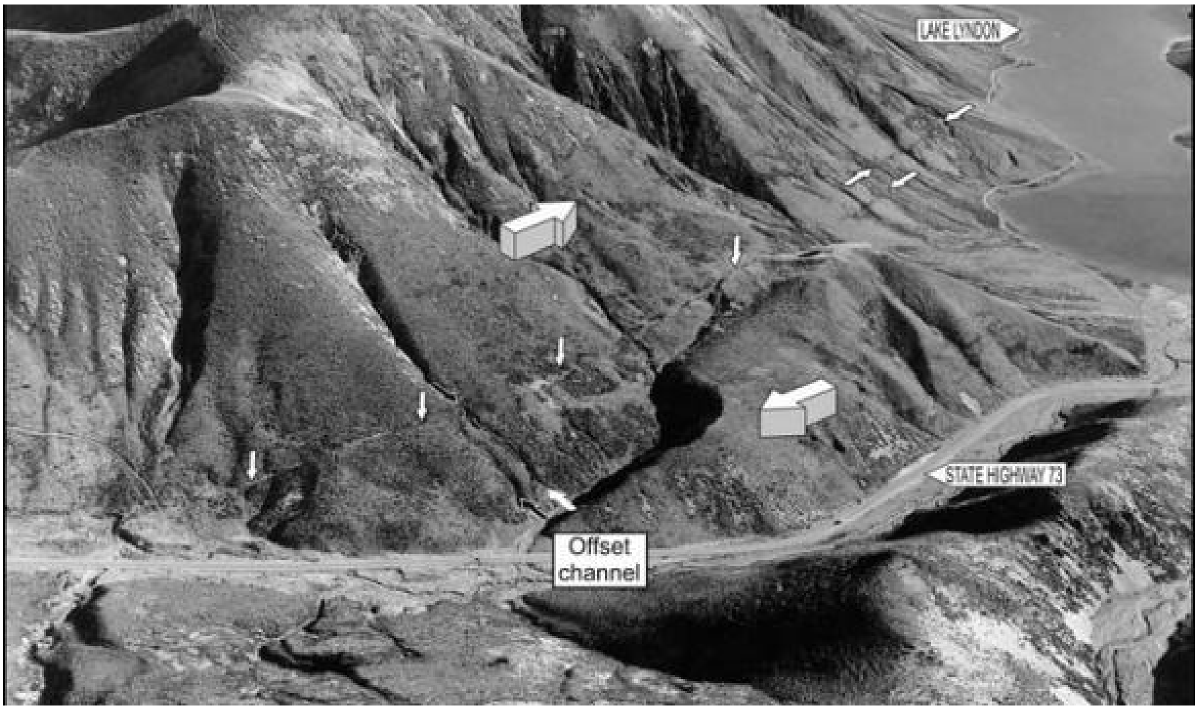


Figure 4. Oblique aerial photograph of Porters Pass fault between Porters Pass and Lake Lyndon facing south. White arrows show position of Porters Pass fault scarp, block arrows show lateral movement.

Exercise 1. Trace with a pencil the Porters Pass Fault. (Indicated by white line)

Stop 2. Limestones – tertiary rocks in the Castle Hill Basin are a remnant of more extensive deposits.

We have now entered the geographically well-defined basin, an area of special cultural, spiritual and historical significance to Ngai Tahu who named it **Kura Tāwhiti** (literally meaning "the treasure from a distant land", referring to the kumara that was once cultivated in this region). Europeans call this basin the **Castle Hill Basin** from the castle-like landforms distributed over much of the basin (Fig. 5).

Figure 5. The castle-like forms in the limestone deposit at the Castle Hill Basin.

The basin is enclosed by the mountains of the Craigieburn and Torlesse ranges (Torlesse rocks) that formed during the Kaikoura Orogeny (over the last 23 million years and continuing). However, Torlesse rocks are not the only sediments in the basin, because on the lower parts, limestone escarpments and outcrops dominate the view. Before the Kaikoura Orogeny, during Oligocene times (about 30 million years ago) the majority of the Torlesse rocks were submerged by a large, shallow inland sea inhabited by a large variety of organisms, many of which constructed shells or skeletons from calcium carbonate. Because so many of those organisms were filter feeders, we know that very little in the way of fine-material eroded off the surrounding topographic highs and entered that inland sea (see stratigraphic column and thin section micrographs).

Limestone is a sedimentary rock that consists of the skeletal, shell or body remains of organisms that lived in the water column or on the seafloor (Fig. 7). To construct their homes, these organisms remove carbon dioxide from the sea-water (it originated as atmospheric CO_2) and also use calcium dissolved in the sea water that originated as a product of erosion. The shallow, warm water sea water provided ideal conditions for growth and the thick limestone beds indicate the existence of an abundant and diverse life assemblage over millions of years.

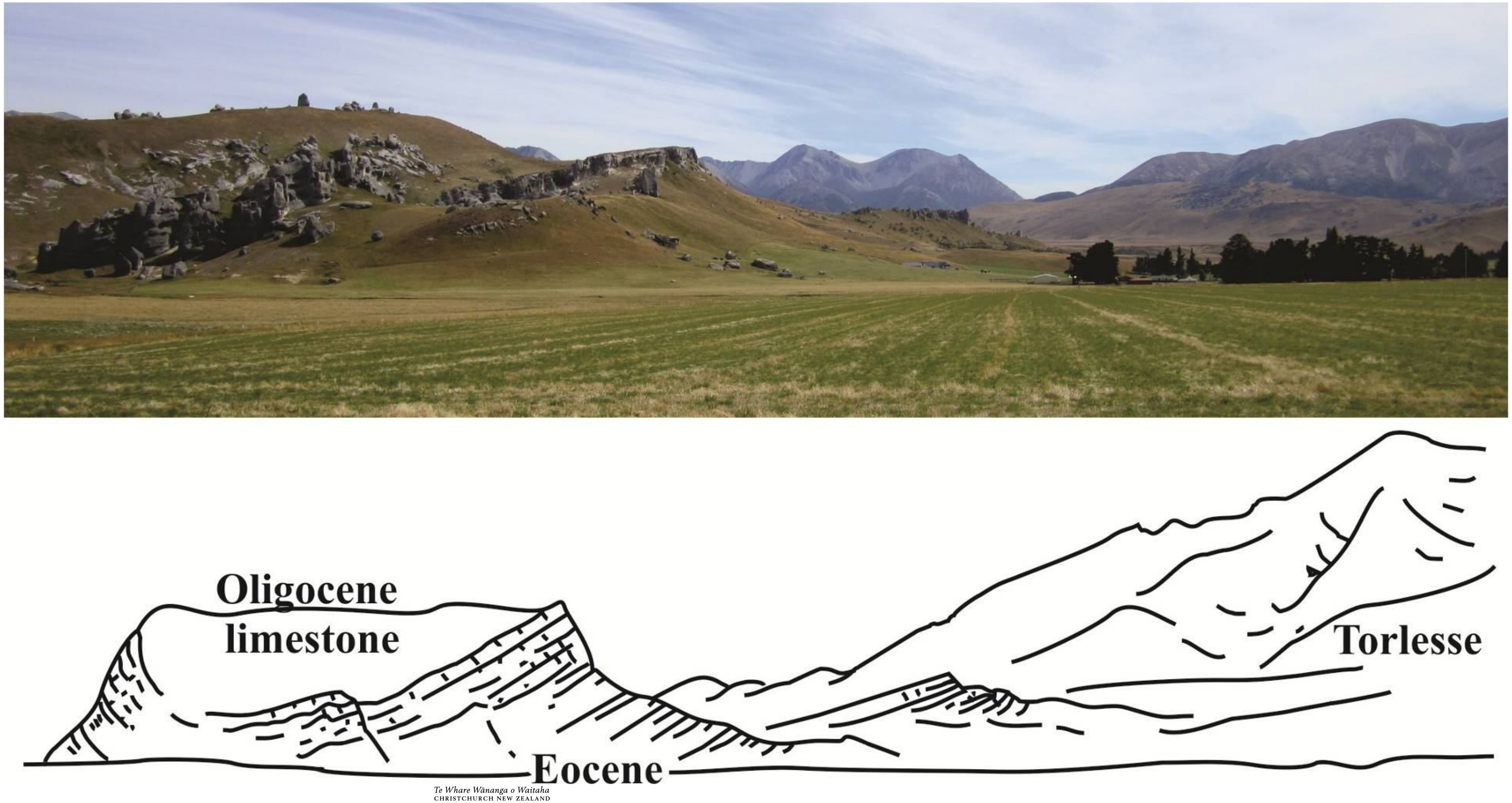


Figure 6. Limestone (foreground) and greywacke (distant centre and right) at Castle Hill Basin.

During the Kaikoura Orogeny, a total of about 20 kilometres of uplift of the Southern Alps took place but as soon as the sediments were exposed they were weathered and eroded. As a result, once extensive younger sediments deposited on top of Torlesse basement rock are now preserved in only a few localities (of which the Castle Hill Basin is a good example, Fig. 6).

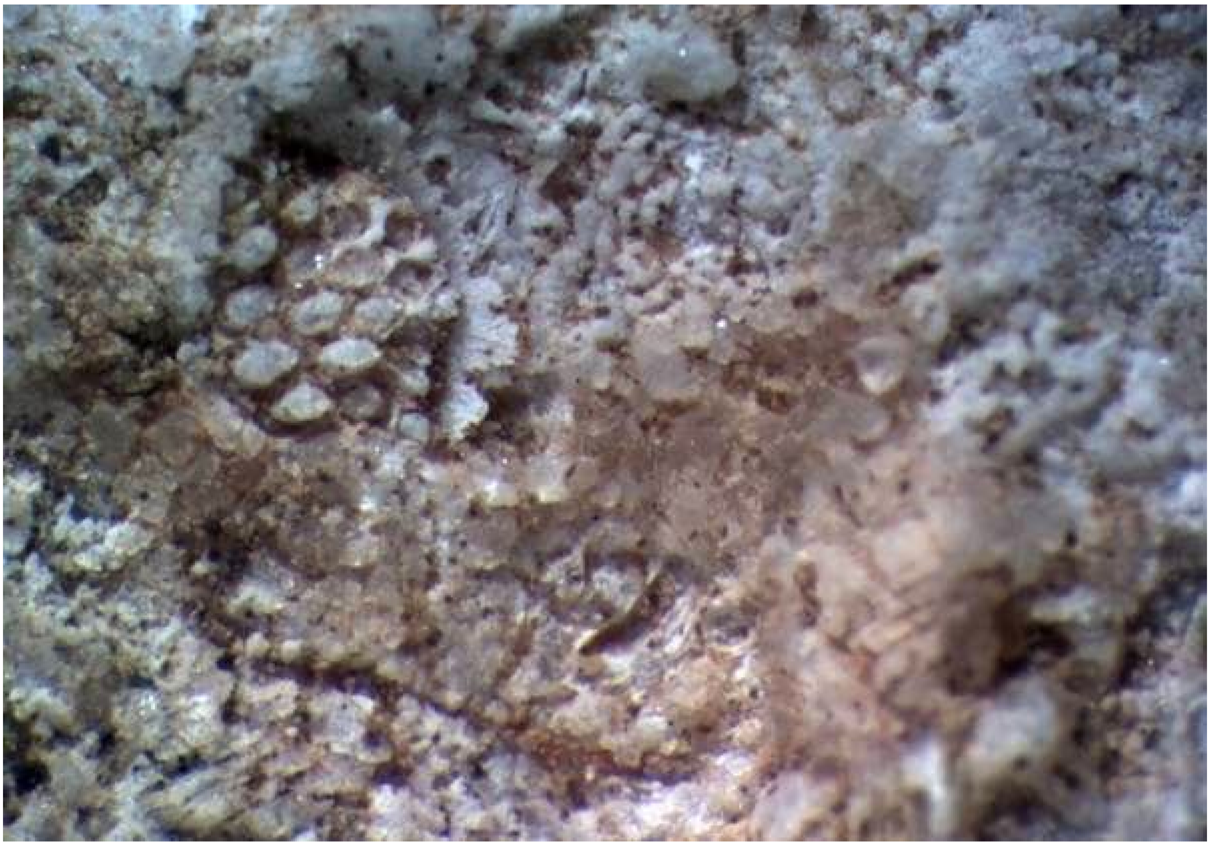


Figure 7. Limestone from the Castle Hill Basin under the microscope.

Because limestone is a carbonate rock its formation plays a very important role in Earth's **carbon cycle**. Figure 8 illustrates how volcanoes vent carbon dioxide (**CO_2)** into the atmosphere, where CO_2 is combined with rain water to form carbonic acid which in turn then corrodes/and dissolves many of the minerals which make up and bind the rocks that form our landscape. The products of that erosion including carbon, calcium, iron and silica are transported by rivers to the ocean where those elements are then available for use in metabolic processes and as building blocks for shells, skeletons and tissue. In environments where limestone is accumulating, the remains of the organisms that have died are mostly composed of calcite (calcium carbonate = calcium, carbon and oxygen) and these sea-floor accumulations in effect lock up huge quantities of carbon dioxide. Later, some of these carbon-rich sediments (limestone) are pushed beneath the continents as a result of plate tectonics, while others are uplifted and incorporated into developing landscape. Limestone and similar rocks melt at relatively low temperatures. As a result, they contribute to the formation of much of the magma occurring at depth below the surface of the Earth. When this magma is erupted by volcanoes, the carbon is returned to the atmosphere as CO_2 and the recycling process begins again. Limestones also play an important part in the carbon cycle: in effect these deposits on land also act as a repository for carbon dioxide, but as a result of being exposed to slightly acidic rainfall, portions of that carbon are released by erosion and transported back to the oceans. Currently only about 30% of man-made carbon dioxide being added to the atmosphere is absorbed by the oceans. This why when humans burn fossil carbon fuels (coal and oil) they disturb the balance of the carbon cycle by pumping extra carbon into the atmosphere, resulting in global climate change.

Limestone is a very valuable resource for humans. It is light and is easy to cut, but at the same time is it quite solid. From the earliest times, it has been used as a building material, and nowadays is an essential ingredient of cement (used to make concrete) and in the construction of industrial water filters. Almost 500 years ago the Egyptians built the Pyramids using this stone, and many buildings in New Zealand are made almost entirely of the finest New Zealand limestone, or have elements and ornaments made from it. Powdered limestone is used extensively as soil fertiliser (because grass growth increases when to soil acidity is reduced), in glass making, paints and refrigerants. Other types of limestone are used in papermaking, plasters, cosmetics, ceramics etc (Fig. 9).

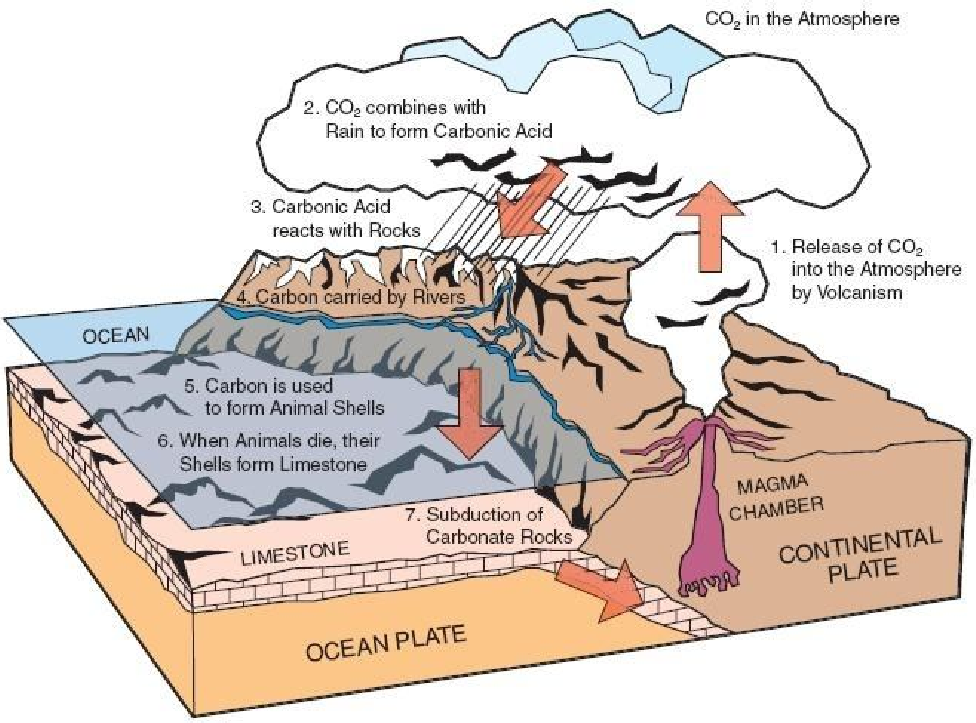


Figure 8. Limestone deposits play an important role in the carbon cycle of the planet by storing the carbon. After a period of storage measured in millions of years, the chemical components of the original limestone are recycled by volcanic activity.

Figure 9. Limestone have been used in building construction from Ancient Egyptian till the present day: 1 - the Great Pyramids of Giza; 2 – Oamaru buildings; powdered limestone being used as: 3 –a soil fertiliser and 4 - as a plaster (“gib”).

Why do the limestones in Castle Hill Basin look like the ruins of an old castle? The answer lies within the carbon cycle. Limestone is composed of calcium carbonate which is a highly reactive compound. All it takes is for a reaction involving the combination of atmospheric carbon dioxide and rainwater - the result is solution of carbonic acid which despite being very weak, is still acid enough to slowly and progressively dissolve limestone,

$$H_2O + CO_2 = \mathbf{H_2CO_3}$$

When rain-water arrives on the surface of a limestone surface it reacts with the calcium carbonate and forms calcium bicarbonate which is very soluble in rainwater. Carbonic acid penetrates pores, spaces around sand grains and crystals, and cracks, which over time are enlarged and opened by dissolution. Eventually what remains of the limestone is a variety of shapes and imaginary figures, all reflecting variations in the original rock and the subsequent history of uplift and erosion.

(Demonstration of the reaction when a small amount of 10% hydrochloric acid is placed on a piece of limestone – “fizz test”).

Summary questions for Stop 2:

What types of rocks can geologists see here?
Torlesse rocks (sand- and mud stones) which surround the limestones.

What are the main differences between these rocks?
Both are sedimentary rocks, but greywacke is composed of sands, silts and mud that are mostly quartz; limestone on the other hand is made up of the remains of organisms – most of which are composed of calcite. Torlesse rocks are more than hundreds of millions of years older than the limestone.

What environments did those sediments accumulate in and when did that accumulation take place?
Greywacke sediment was deposited between 500 to 130 million years ago on the sea floor of a deep ocean. These were then uplifted by the Rangitata and Kaikoura Orogenies to form the Southern Alps (Stop 1). The limestone was deposited on the bottom of shallow, warm inland seas that existed about 30 million years ago, with only small amounts of sand and silts being eroded off the land Then, the limestone and the Torlesse rocks lying beneath, were uplifted during Kaikoura Orogeny with the majority of those sediments being eroded away (both uplift and erosion continue today).

Are there other places along the Southern Alps where geologists have discovered similar limestone deposits?
Yes, limestone is preserved in association with folded Torlesse rocks in small inland basins and coastal areas where rocks still being uplifted: Kaikoura, Oamaru, Timaru; Fjordland; northern West Coast - Punakaiki.

Why are the limestones in Castle Hill Basin formed into such characteristic shapes?
The limestone is composed mostly of calcite and this mineral is highly reactive. As rain water absorbs atmospheric CO_2 it becomes weakly acidic and that fluid has the ability to corrode and dissolve exposed surfaces on and within the rocks.

Stop 3. Cave formation from limestone erosion. Geological structure, rock stratigraphy and forces of the erosion.

Stop 3.1. The exit from the cave. Karst.

The cave formed as a result of erosion by the stream is one of the most outstanding natural features in the Canterbury region and an excellent example of the erosion in limestone. This distinctive topography associated with a limestone landscape that has been largely shaped by the dissolving action of water is called **karst**. Enriched with carbon dioxide, water naturally exploits any cracks or rock crevices in the rock. Openings in that rock increase in size and as a result, an underground drainage system begins to develop, allowing more water to pass, further accelerating the formation of karst. Over thousands of years this geological process results in unusual surface and subsurface features ranging from sinkholes, disappearing streams and springs to complex underground drainage systems and caves (Fig. 10).

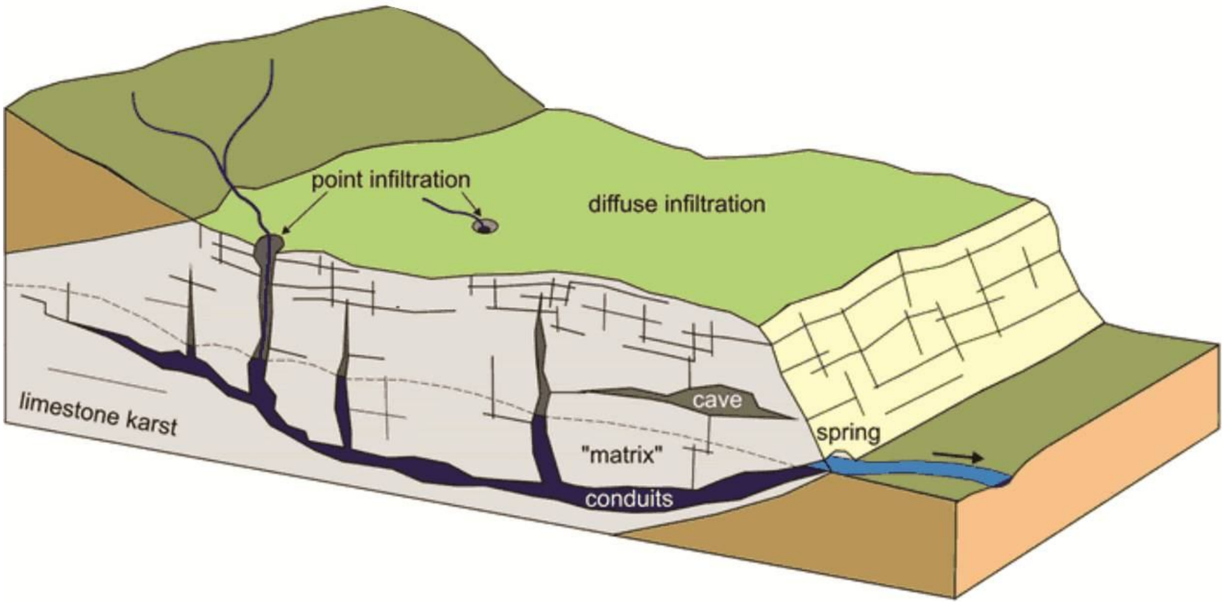


Figure 10. The illustration of the karst development by the stream through the limestone.

The cave in the Castle Hill Basin is occupied by **Cave Stream**, that meanders from the north into the Broken River immediately after it exits from the cave. The cave follows a sinuous path, a pitch black route of 362 metres ending in a 3-metre waterfall that cascades into a deep pool. The abandoned channel is left as a dry valley near the upstream end of the cave (Fig. 11).

Figure 11. The aerial view of Cave Stream and Broken River. Cave Stream flows into Broken River after passing through a 362 m long cave (indicated by red dots). Yellow dotted line indicates the abandoned Cave Stream channel.

Stop 3.2. The abandoned Cave Stream channel. Structural geology and stratigraphy.

Tectonic events such as mountain building lead to compression and crustal deformation that often results in the formation of folds in rock sequences. Folds may vary in size from microscopic to mountain-sized, and the simplest are **anticlines** and **synclines**. Thus, an anticline is convex folding of rock sequences such that the oldest beds are found in the core, whereas in a syncline, it is the younger layers that occur in the centre of the structure (Fig. 12).

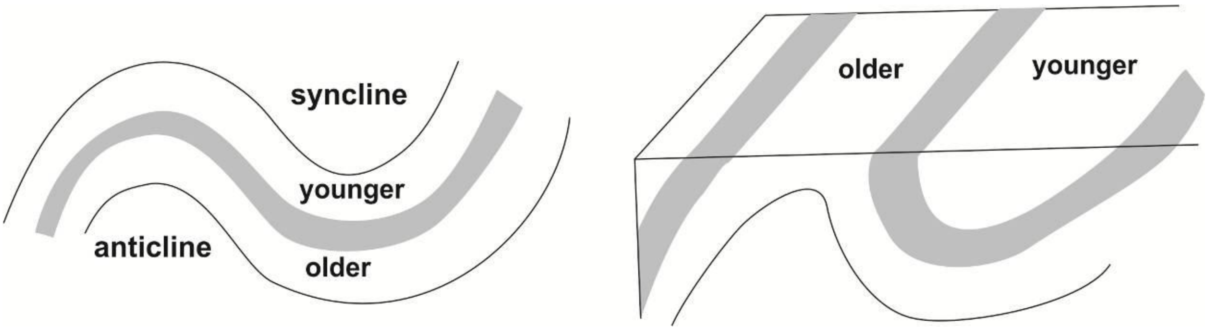


Figure 12. Folding in rocks.

Limestones in Castle Hill basin form an anticline. The younger limestone is tilted away from the core of older exposed limestone and even older layers of greensand beneath (Fig. 13). In general, the entire Castle Hill Basin is large scale syncline with older, surrounding rocks of Mesozoic greywacke being tilted towards the core of younger Oligocene (limestone) deposits. The older Mesozoic rocks of the Torlesse and Craigieburn Ranges have been uplifted during the last 35 million years (by fault movement and deformation). In most places, the younger deposits that covered much of the older greywacke have been completely removed by erosion. Only in areas of significant folding, such as Castle Hill Basin, are the younger rocks preserved, with their tilted orientation providing clear evidence of the deformation that occurred during uplift.

The description of rock structure, their deformation and orientation is part of a science known as **structural geology**. On the other hand, the description of the rock layers and sequences (stratification) from youngest through to the oldest and their age relationships is known as **rock stratigraphy**.

In the old Cave Stream valley, it is possible to view the limestone rocks in sequence (stratigraphy), with the younger limestone on top and getting increasingly older downwards to the abandoned channel. The stream over tens of thousands of years, cut through the limestone on the top of the anticline and then progressively corroded/eroded the older rocks making up the core. The older layers of the limestone are different from the younger layers because they contain greensand and volcanic material released during underwater eruptions. Volcanic eruptions, as now, were a recurrent feature during the development of the South Island landscape. As a result, when the limestone-forming sediments were being deposited on the sea-floor (Oligocene, see geological timescale) fine material from the ash showers would also be incorporated into the limestone sediment (settling and often being mixed with that sediment during periods of eruption, but missing from the limestone when the volcanoes were inactive) (Fig. 14).

Figure 13. Cave Stream channel cut through the anticline formed by the limestones and exposed the stratigraphy. Using the stratigraphy column (on the left) indicate on the picture the corresponding rock layers.

From the stratigraphic column (Fig. 13) it can be seen that below the limestone are layers of **greensand** and **coal measures**. The name "greensand" indicates the presence of grains containing the green mineral **glauconite**. Glauconite is an iron potassium mineral with a characteristic green colour with very high resistance to weathering. Such grains are known to form on the sea-floor at water depths of between 100-500 metres at times when sediment accumulation rates were slow and input of erosion products from the land were low. It is thought that the New Zealand landmass was low-lying when the greensand was deposited in nearby seas. (Late Oligocene time, see geological timescale). The layer of greensand under the limestone will be seen at Stop 3.3.

Coal measures is the name for the sediment sequence that represents the remains of **fluvio-deltaic** sediment (river sediment accumulating in shallow embayments in lakes and marginal marine environments e.g. estuaries) and consists mainly of sediment rocks (claystones, siltstones, sandstones) with the beds of coal in between. The **coal** forms from dead plant matter which is under pressure and temperature, to form **lignite**. This involves biological and geological processes that take place over a long period of time. Coal has been, and remains, of crucial importance for human development because it is still the most commonly used fossil fuel and is also an important source of chemicals. These coal measures in Castle Hill basin are older than the limestones, being deposited sometime during Palaeocene and Eocene times (see geological timescale).

Stop 3.3. View of the stratigraphy as a result of the erosion by the Broken River.

The cave stream exposure and stratigraphy of the rocks in this area are described earlier in this text (Fig. 13). **(Discussion about stratigraphy and observation of how Cave stream come out from the cave and coalescence with Broken River).**

The exposed slopes of the older rocks were developed as a result of the **erosion** by the Broken River. Erosion is the process by which materials (sediment, soil, rock and other particles) are removed from the surface by water or wind actions, transported and finally deposited elsewhere. During the last few thousands of years the river was cutting through the older rocks from the top towards the bottom with subsequent exposure of the older layers of rocks (Fig. 13).

What other erosional agent could you see in a valley?? (Preparation for next stop). Debris flows, landslides, terraces upstream of the cave inlet were formed many thousands of years ago by a glacial-fed river.

<u>Summary questions for Stop 3:</u>

What the main processes responsible for the cave formation?
The cave was formed as a result of the dissolving action of water in the limestone deposit, called karst. The Cave Stream found its way through the limestone cavities and after hundreds of years developed a channel in the deposit.

What do structural geologists say about the relationship of the rocks exposed in Cave Stream? Cave Stream cut through the anticline during the last few thousands of years. This anticline (with older rocks at the bottom – core and younger at the top) has been formed before Quaternary during the Kaikoura Orogeny, when the modern Southern Alps was formed.

What is stratigraphy of rocks and how does that story help us interpret the Broken River landscape?

Stratigraphy is the description of the rock layers and sequences and their age relationships.

The Broken River eroded through limestones - the younger rock deposited at the shallow areas, than glauconic limestones – limestones with some volcanic and greensand, greensand layer indicates on the presence of glauconite (iron potassium mineral) that form on the sea-floor at water depths of between 100-500 metres, coal measures is the river sediment accumulating in estuaries, consists mainly of sediment rocks with the beds of coal in between.

Exercise 3 – Stratigraphy exposed by the Broken River. On figure 13 indicate the exposed stratigraphic rock layers by using the stratigraphy column at the left.

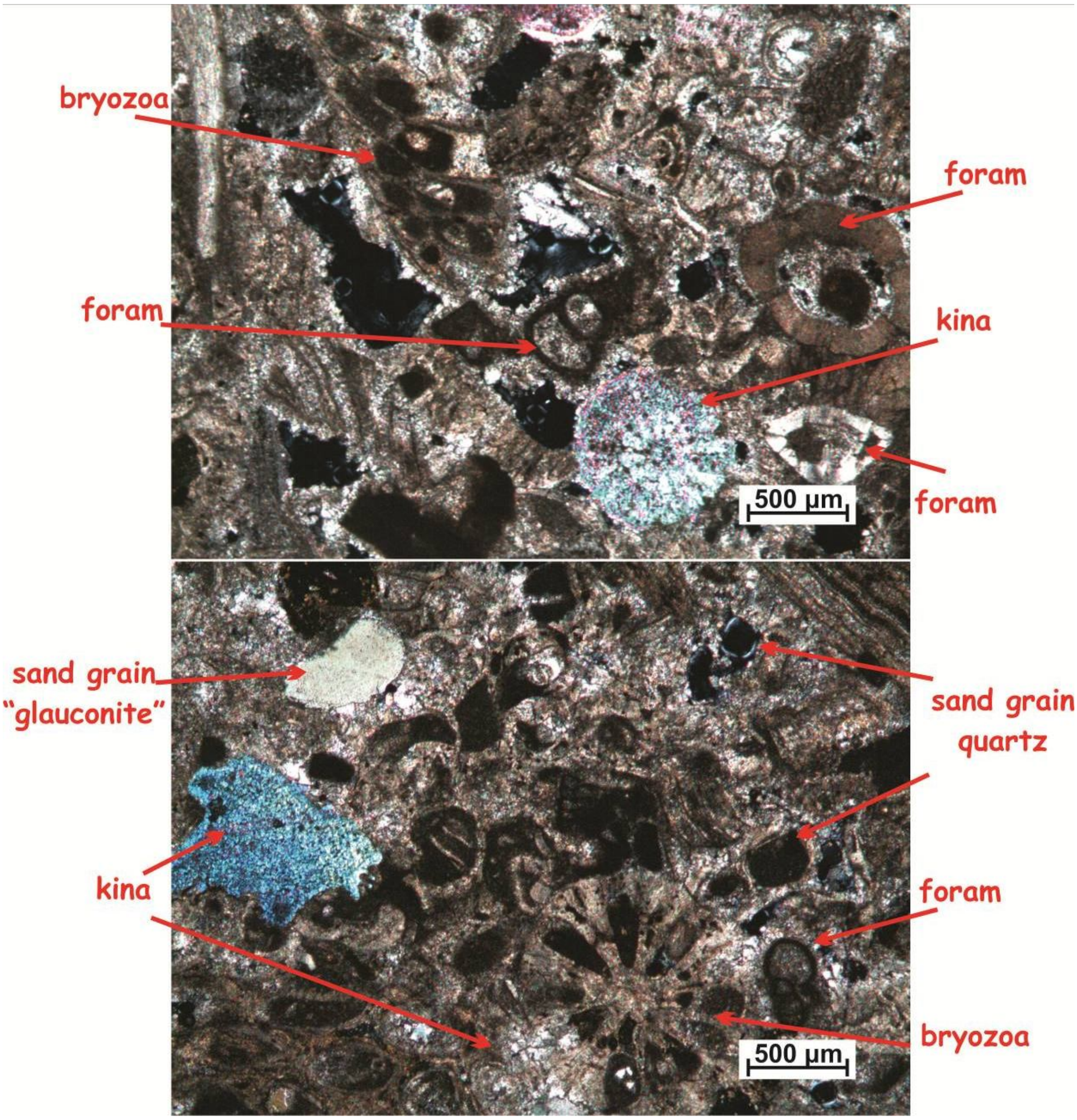


Figure 14. The thin section of the limestones from the Castle Hill Basin under the microscope. On top – the clean limestone (see stratigraphic column on Fig. 13) composed mostly of organisms remnants such as bryozoa, foram or kina. At the bottom – the lower layers of the limestones, co-called glauconitic limestone, with presence of the glauconite and quartz grains.

Extension Exercise 4 – Prepare a poster about the organisms found in the limestone (bryozoa, foram or kina,) and their lifestyle.

Stop 4. Glaciations and Postglacial erosion (15 min). Cass Valley and Lake Pearson.

Because of their high relief and high precipitation, the Southern Alps were glaciated a number of times during last 2 millions years (Quaternary, see geological table). The continued existence of **glaciers** in some valleys nearer the Main Divide is an evidence of the ongoing glaciation. The glaciers occur in mountain ranges that are higher than the **snowline** where after the melting season, snow remains preserved at the tops. As a result, after several years this snow is compacted into ice by pressure and then, under the influence of gravity, flows into the valleys. Climatic cooling results in increased thickness and length of the glaciers, such that in some instances they flow down valley towards the seashore e.g. Franz and Fox Glaciers), In contrast, during periods when the climate is warmer more ice melts than is being formed and the glaciers retreat back towards their source in the mountains. During the advance, glaciers erode surrounding rocks and move the sediment within their valleys. The maximum extent of ice is usually marked by **moraines** – ridges of the sediment that has been pushed at the front of the ice during it advance. During the retreat, large volumes of melted water carried sediment down the valley and filled depressions, levelling valley floors and often extending flood plains well beyond the mountains (**outwash plain**). Glacial lakes often formed in depressions created by very large chunks of ice that were left by the glacier and subsequently slowly melted (Fig. 15).

Both Castle Hill Basin and Cass Valley have been covered by glacier ice on a number of occasions. During the coldest period, this ice filled the entire valley reaching the hill tops (marked by smoothed tops and **trimlines**). The Long Hill was polished by the ice flow. The ice came from the Waimakariri and Rakaia Valleys and coalesced in the Castle Hill Basin area. Lakes were left when the ice started to melt and retreat about 20 thousand years ago. Small hummocky hills are the remnant of the **terminal moraine** left by the glacier when it reached its maximum position down the valley.

Since the ice left the valley, uplift and weather-induced intensive erosion re-shaped the valley's sides and filled depressions with often thick accumulations of sediment (larger boulders, gravel, sand and silt). In the valley, there are numerous examples of **slope degradation** (**debris flows** forming **debris fans**, rivers carrying sediment from the valley and depositing it as **alluvial fans**, and occasionally large masses of hill slopes or tops have fallen as **landslides**) (Fig. 16). Three debris fans and one alluvial fan have impacted on Lake Pearson, filling much of it with sediment making it smaller and shallower through time. The topography debris and alluvial fans are different: alluvial fans have smooth surfaces because they are formed slowly by a migrating stream channel, whereas debris fans have a rough irregular topography formed as a result of the rapid movement of debris from the source under the influence of gravity (these deposits often include large boulders).

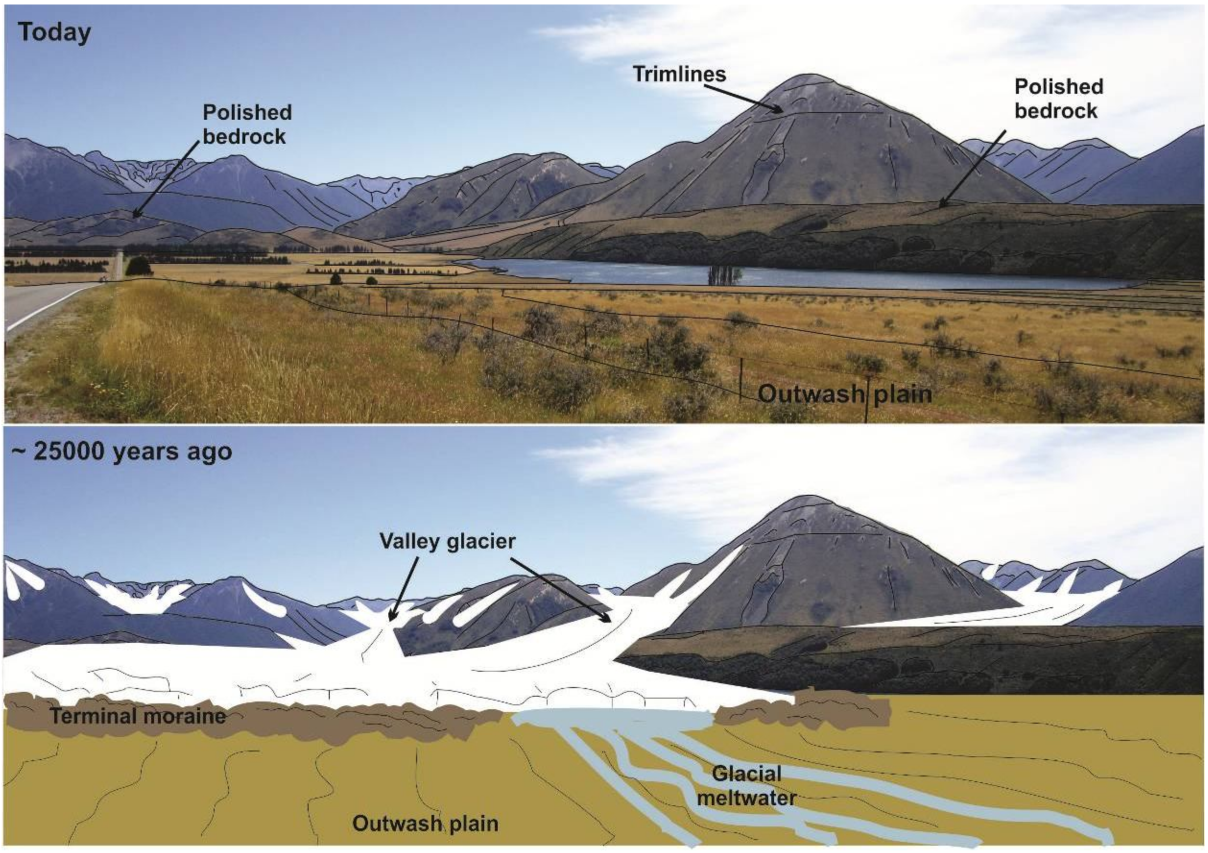


Figure 15. Above: Cass Valley view with main postglacial features: outwash plain, polished and scoured bedrock, trimlines and lakes. Below- reconstruction of the valley view about 25 thousands years ago (last glacier stand in this valley).

Figure 16. Examples of the slope degradation processes: at the left - debris flow fan descending into Lake Pearson; at the right – steep debris flow in the Castle Hill Basin.

<u>Summary questions for Stop 4:</u>

What are the main erosional processes operating in the valley?
The glacial erosion (erosion of the rock and transportation of the material) and postglacial erosion (slope degradation – debris flows, river sediment transportation, landslides).

What are glaciations and when did these occur in Southern Alps?
Glaciation occurred in cold periods when glaciers grew from the Main Divide down into the valley. In the Southern Alps during the last 2 million years glaciers advanced and retreated several times. Currently glaciers are retreating since their maximum position during the last 20 thousand years.

Describe the evidence for the presence of glaciers in Cass Valley?
Polished slopes, trimlines, glacial lakes, moraines, outwash plains and terraces.

What post-glacial processes are currently impacting on the Cass Valley landscape? Slope degradation and river erosion, human impact.

Exercise 5 - The ultimate fate of the materials being eroded off the Alps. Suggest the students compile a photographic essay that portrays evidence of the erosion for the Torlesse rocks and the younger sediments (limestones). Compare and contrast responses of these to the agents of erosion.

Glossary

Alluvial fan is a cone-shaped deposit made by stream where it runs out into a level plain or meets a slower stream.

Anticline is a fold that is convex upward with older rocks towards the centre of curvature.

Clast is the fragments of pre-existing rocks or minerals that make up a sedimentary rock. The degree of sorting of clasts indicates the depositional environment. Thus, in water larger clasts (sand) are generally settled faster, while the mud (fine, light-weight) would be transported far off shore. Therefore, a well sorted (clasts of approximately the same size), coarse sandstone indicates deposition in a reasonably high energy environment (near-shore) probably close to the source of the sand. Conversely, a mudstone generally indicates deep water deposition (low energy environment, far off shore).

Coal is a black or brownish-black sedimentary rock derived from dead plant matter, which was altered under pressure and temperature. Coal is commonly used as a source of energy and one of the largest worldwide sources of carbon dioxide releases by humans.

Coal measure is the name for the sediment sequence that represents the remains of estuaries and consists mainly of sedimentary rocks (claystones, siltstones, sandstones) with the beds of coal in between.

Continental collision occurs when two tectonic plates are moving towards each other. It is a variation on the fundamental process of subduction, where the subduction zone is destroyed, mountains produced, and two continents join together. It is a prolonged event and may take several tens of millions of years before the faulting and folding caused by collision stop.

Continental shelf is a gently sloping, shallowly submerged, marginal zone of the continent extending offshore.

Debris fan is fan-shaped deposit of soil, sand, gravel and boulders derived from the debris flows at the point where the flow velocity is reduced to form deposit.

Debris flow is a movement of the debris of different kinds(size range from clay to boulders) downslope.

Erosion is the process by which materials (sediment, soil, rock and other particles) are removed from the surface by water or wind actions, transported and finally deposited elsewhere.

Estuary is a partly enclosed coastal body of water with one or more rivers or streams flowing into it.

Fault is a fracture along which there has been displacement of the sides relative to one another parallel to the fracture. Large faults within the Earth's crust result from the action of tectonic forces. Energy release associated with rapid movement on active faults is the cause of most earthquakes.

Fluvio-deltaic describes river estuaries.

Glaciation is a period when glaciers covered large areas of the land. Glaciations occurred several times during the last 2 million years, lasted for thousands of years and were characterised by colder temperatures and glacier advances.

Glacier is a mass of ice that originated from the compacting of the snow by pressure over years, which travels because of its weight.

Glauconite is a green mineral (potassium iron silicate) that commonly occurs in sedimentary rocks of marine origin.

Greensand is a quartz sandstone rich in glauconite grains.

Greywacke is hard variety of sandstone. Because it has been subjected to significant amounts of tectonic movement over a long period of time, greywacke is commonly extremely deformed, fractured, and veined. It comprises a large percentage of the basement rock of New Zealand.

Karst is the process of erosion within the limestone by the dissolving action of water. Karst features are sink-holes, caverns and caves.

Landslide is a slope degradation process, when a large mass of slope (soil and rocks) slides or falls downward.

Limestone is a sedimentary deposit and consists mostly of calcium carbonate derived from skeletal, shell or body remains of organisms that lived in the water column or on the seafloor in a shallow and warm-water sea.

Lignite is brown-type coal that is geologically younger than higher-grade coals.

Metamorphic rock is a rock of any origin that has been modified by heat, pressure or deformation (see Metamorphism).

Metamorphism is the alteration of pre-existing rocks in the solid state due to changes in temperature and pressure. Under increasing temperature and/or pressure existing minerals become unstable and break down to form new minerals.

Moraine (terminal moraine) is the sediment that has been derived, modified and transported by a glacier. The terminal moraine is usually the debris that was pushed at the front of the glacial ice and marks the maximum position that ice reached at the particular time period.

Orogeny is the process of forming mountains, particularly by folding and thrusting.

Rock stratigraphy - the description of the rock layers and sequences (stratification) from youngest through to the oldest and their age relationships.

Sandstone is a sedimentary rock formed from cemented sand-sized clasts. The cement that binds the clasts can vary from clay minerals to calcite, silica or iron oxides. Sandstone can be divided according to *clast size* - fine (0.06-0.2mm), medium (0.2-0.6mm), coarse (0.6-2mm). Clasts dominantly are quartz and feldspar (orthoclase, plagioclase) and varying minor amounts of other minerals.

Schist is medium grade metamorphic rock, formed by the metamorphosis of mudstone/ shale, or some types of igneous rock, that have been subjected to higher temperatures and pressures. Due to the more extreme formation conditions, schist often shows complex folding patterns. There are many varieties of schist and they are named for the dominant mineral comprising the rock, for example, mica schist, green schist (green because of high chlorite content) or garnet schist.

Sedimentary rocks are the product of the erosion of existing rocks. Eroded material accumulates as sediment, either in the sea or on land, and is then buried, compacted and cemented to produce sedimentary rock (a process known as diagenesis).

Slope degradation is the erosion of the mountains slope, sides or walls, which lead to their collapse and removal by erosional agents such as water, wind or ice.

Structural Geology - a part of science that describes rock structure, their deformation and orientation.

Subduction zone is the zone where one tectonic plate moves under another tectonic plate, sinking into the Earth's mantle, as the plates converge.

Syncline is a fold of rock that is convex downward, with younger layers closer to the centre of the structure.

Tectonic Plates are massive, irregularly shaped slabs of solid rock and are pieces of the Earth's crust. They are generally composed of both continental and oceanic lithosphere. Plate size can vary greatly, from a few hundred to thousands of kilometres across; the Pacific and Antarctic Plates are among the largest. New Zealand formed on the collision zone of the Australian and Pacific Plates.

Trimline is a clear line on the side of a valley formed by a glacier. The line marks the most recent highest extent of the glacier.

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