New Zealand's ALPINE FAULT

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Why is the Alpine Fault important?

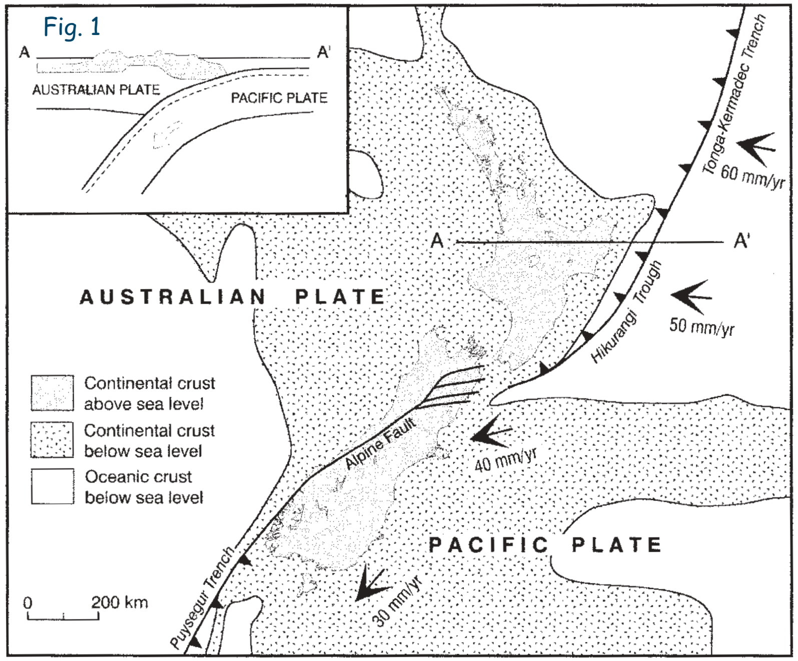
The outermost layer of the Earth is broken into a series of tectonic plates that are about 100 km thick. These plates are in constant motion above a softer layer. New plate material is created at oceanic ridges where hot magma reaches the surface. It cools, splits along the ridge, and each part moves away – driven by the conveyor belt-like motion of the underlying layer. Plates are recycled at deep-sea trenches where they subduct under buoyant continental rock.

New Zealand straddles a complicated boundary between two enormous tectonic plates – the Australian and the Pacific plates (figure 1). It involves two offshore subduction zones that are linked by the Alpine Fault.

New Zealand's northeast plate boundary is the Hikurangi Trough. It runs parallel to the coast northeast from Marlborough and marks where the Pacific Plate subducts under the North Island, which sits on the Australian Plate. Southwest of Milford Sound, subduction occurs the opposite way. Oceanic crust on the Australian Plate subducts under Fiordland, which is on the Pacific Plate. The Alpine Fault Zone connects the Hikurangi Trough and the Puysegur Trench.

New Zealand's Alpine Fault

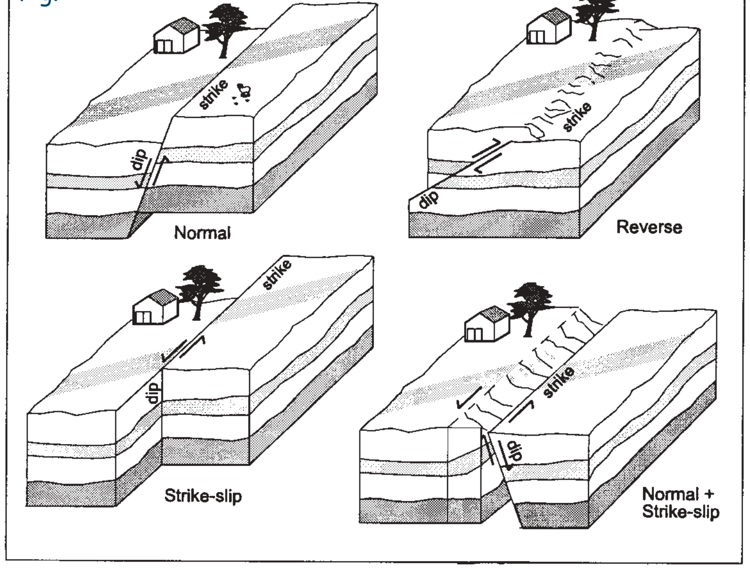
About 25 million years ago, Otago's Red Mountain and Nelson's Dun Mountain were close neighbours. Since then, earthquake movements along the Alpine Fault have separated them by nearly 500 kilometres. These movements have been caused by the collision between the Australian and Pacific tectonic plates. Continuing tectonic movement and future earthquakes along the Alpine Fault are a certainty.



COVER PHOTO: view southwestwards along the Alpine Fault towards Milford Sound (far distance) with tussock slopes of the Gorge Plateau on the left (east). In the foreground, the Alpine Fault trace steps right with a sag-pond developed in the stepover region between the two fault stands. DR ALLAN COOPER

The Alpine Fault is the onshore plate boundary. The Marlborough Fault System (the Awatere, Hope, and Clarence faults) transfers tectonic movement from the Hikurangi Trough to the Alpine Fault by strike-slip faulting. This involves blocks of rock rupturing and being displaced with one side of the fault offset from the other in a horizontal direction (figure 2).

Fig. 2



When fault surfaces become locked together, rather than slide smoothly, conditions for earthquakes develop. Tectonic movement does not stop simply because bits of stressed plate are jammed. Pressure mounts and eventually the tectonic forces exceed the strength of the rocks and the friction that holds them together. The rock ruptures and generates an earthquake.

Throughout Westland, the tectonic motion is at 18° to the Alpine Fault, so the two plates collide obliquely and the fault currently combines horizontal and vertical displacements. The effect is that the West Coast and Nelson are moving northeast relative to the rest of the South Island, and the rocks east of the fault (the Southern Alps) are uplifted relative to those on the west.

Geological faults are classified by their direction of displacement. In normal faults, rock above the fault plane slips down the dip of the plane because of extension forces. In reverse faults, rock above the fault plane is forced up the dip by compression. Strike-slip faulting involves horizontal displacement. Most faults combine some vertical and horizontal displacements.

Extent of displacement

Horizontal offset

In 1949 Harold Wellman, late Professor of Geology at Victoria University, shocked the scientific world by suggesting that rocks in Otago and Nelson could be matched up. He claimed they had once been a single unit that was split by the Alpine Fault and then displaced horizontally by some 480 km. The speed of the Pacific Plate relative to the Australian Plate along this fault has most recently averaged 37 mm/year. The rates have clearly changed with time, and in 10 million years, Milford Sound and Christchurch will be opposite each other.

The Dun Mountain Ophiolite Belt outcrops northwest of the Alpine Fault in east Nelson and southeast of the fault in west Otago. These ancient seabed rocks (more than 250 million years old) have been uplifted, and separated by movements along the Alpine Fault. The Wairau Fault (1), the northern extension of the Alpine Fault, is less active than the Marlborough Fault System – the Awatere, Clarence and Hope faults, (2–4) respectively.

Streams with right-angled corners, lines of "sag" ponds, offset glacial deposits, and series of lined-up notches in hills indicate fault traces and sites of past earthquakes.

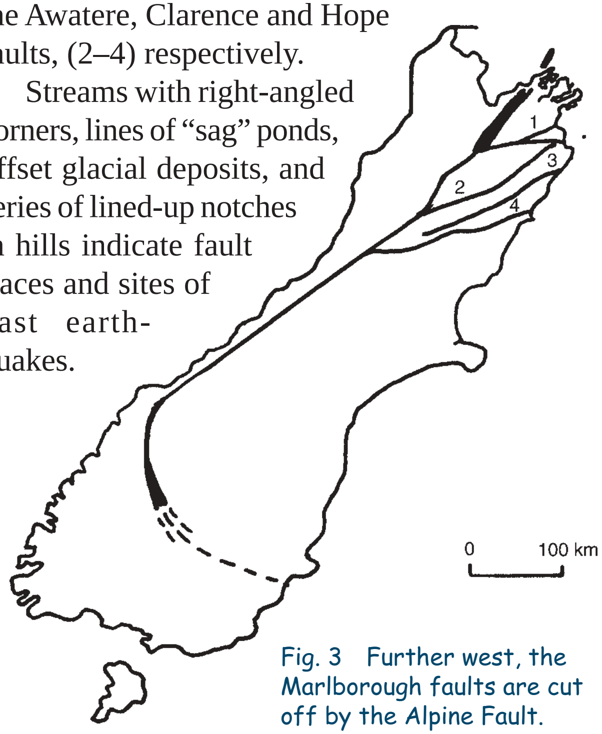


Fig. 3 Further west, the Marlborough faults are cut off by the Alpine Fault.

Displaced streams just north of the Haast River have been offset at rates that average 25 mm/year over the last 4000 years (about the same rate as your finger nails grow).

Vertical offset

The Southern Alps are the effect of tectonic uplift resulting from compression due to the angle of the collision between the Australian and Pa-

Plate 1 Dun Mountain ophiolites outcrop in Otago and Southland for about 180 km. The most dramatic exposures of this uplifted ancient sea floor are Red Mountain and Bald Mountain in west Otago. View from the Australian Plate looking over the Alpine Fault (lower left to mid right), which blunts the lower slopes of Red Hill Range. REPRINTED WITH PERMISSION OF IGNS

cific plates. Geoscientists estimate that there has been 20–25 km of uplift across this segment of plate boundary. At no time, however, could mountaineers have had a 20-km-high view, because rates of uplift are nearly equalled by those of erosion. Erosion takes the tops off the Southern Alps almost as fast as they are created (plate 1), mainly because they are in the path of a prevailing westerly wind and exceptionally high rainfall.

Total uplift is estimated from the condition and type of rocks and minerals currently exposed at the surface. Some contain minerals that experiments show could only have formed at minimum pressures equivalent to those 30–35 km below the earth's surface. Probably 20–25 km of this uplift is related to movements (and their accompanying earthquakes) on the Alpine Fault.

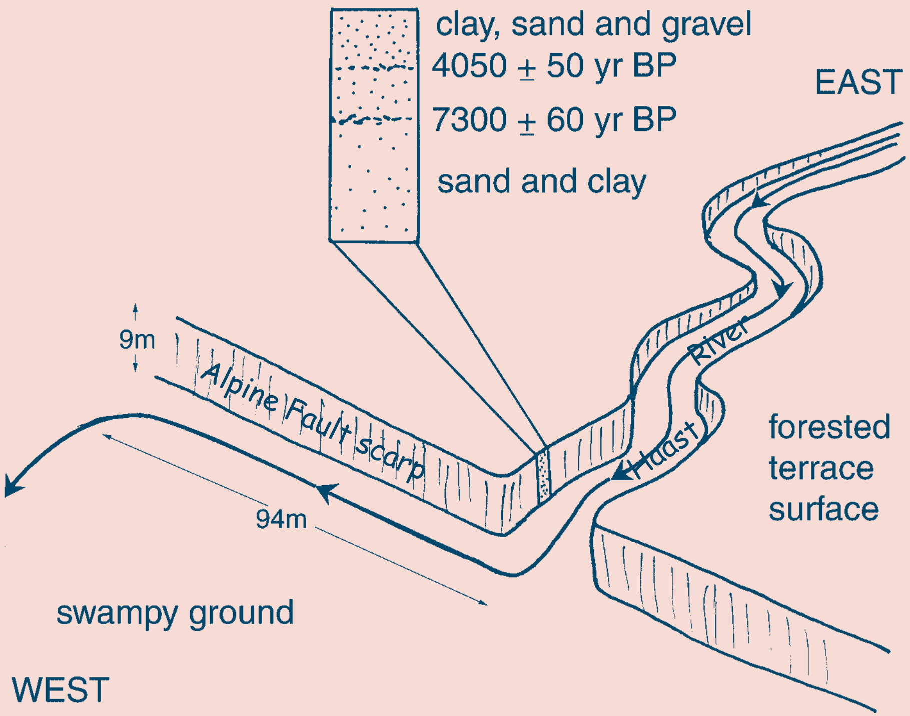
Timing of fault movements

Recent small earthquakes and the offset of streams and glacial moraine ridges tell us that the Alpine Fault is indeed active. But just when the fault developed, when is last moved and, more to the point, when it will next move, are hotly debated.

Case study

On the north bank of the Haast River, a terrace marking the old riverbed level has been raised up to 9 metres by movement on the Alpine Fault. A stream that has cut through the terrace is horizontally displaced by 94 metres where it crosses the fault. Sediments from the old riverbed are exposed in its banks, and include ancient wood and plant material that that can be dated.

Radiocarbon dates on this organic material gives a maximum age for the terrace of about 4000 years. So, in the geological short-term, 94 metres of horizontal and 9 metres of vertical movement give average rates of 23.5 mm/year and 2.25 mm/year, respectively.



The uplifted terrace on the north bank of the Haast River is a 9-m-high section of sand and gravel deposited in the river's floodplain. Movement of the Alpine Fault has offset the terrace, and a stream that cut into the terrace, by 9 metres vertically and 94 metres laterally in the past 4000 years.

Plate 2 Rocks at the top of Mt Cook were probably below sea level not much more than a million years ago. Erosion can occur in dramatic events — this 1991 avalanche removed nearly 20 metres from the top of Mt Cook and carried 14 million cubic metres of rock and ice at an average speed of 300 kph. Present-day uplift and erosion rates are 8–10 mm/year. While 10 mm/year may not sound impressive, it equates with 10 km in a million years. REPRINTED WITH PERMISSION OF IGNS

Consequences of Alpine Fault uplift

- The Alps have been growing 8–10 mm/year for at least 5 million years and are still only a little over 3 km high, so erosion is clearly taking its toll. This vast amount of eroded sediment down West Coast rivers causes major problems with roads and communications across the Alps during floods. Earthquakes may trigger landslides that dam streams and rivers creating emergencies because unstable dams can abruptly collapse and cause catastrophic flooding.
- Deep rocks east of the fault are pushed up faster than they cool down. Hot rocks interact with near-surface water (mainly from rain) that permeates through cracks and fractures. Heated waters then rise buoyantly forming hot springs, such as those in the Copeland Valley, at Maruia Springs, and by the Wanganui River, where their therapeutic benefits can be enjoyed.
- When heated waters circulate through the uplifted rock, they may leach out elements and carry them upward in solution. As the temperature decreases, they are precipitated as mineral veins. Some veins contain gold or tungsten, and when the veins erode, the valuable minerals turn up in rivers and along beaches. Both have been prospected by generations of West Coasters.

Mechanism and frequency of fault movements

Not all of the stress caused by the collision of the plates can be released by very small slow movement (fault creep) of the Alpine Fault. South of Haast there is evidence such as displacement of streams by 7–8 m horizontal and 1–2 m vertically that suggest a single earthquake rupture. Such movements are typical of fault movements that produce earthquakes of magnitude 7.4 to 8.0. Earthquakes that release this much energy cause major damage to buildings and bridges.

Skylab view of the South Island. The Alpine Fault between Makawhio Point to Greymouth looks like a straight line from outer space. The sharp western boundary of the snow-covered Southern Alps is defined by the Alpine Fault.

The last Alpine Fault displacements

No major earthquakes have been recorded in the Southern Alps during the 150 years of European settlement. There is also no reference to major earth tremors associated with an earthquake on the Alpine Fault recorded in Maori oral history. Scientists have agreed on dates for the last four large earthquakes on the Alpine Fault based on research by many geologists in the past five years. This included cutting trenches across offset landforms, radiocarbon dating, tree-ring analysis, the study of lichens and contemporary earthquakes, statistical analyses, and highly accurate measurements of deformation using global positioning satellites.

The last four ruptures along the fault occurred at intervals of 100–300 years. The last happened around 1717. It appears to have involved a rupture nearly 400 km long in the southern two-thirds of the fault and generated an earthquake about magnitude 8. About 100 years earlier another earthquake in the central and northern section of the fault produced a similar sized earthquake. Before this, there were equally large earthquakes in about 1450 and about 1100.

The Earthquake Commission — New Zealand's insurance against an unstable future

Compared with people in many other earthquake-prone countries, New Zealanders are fortunate. When the inevitable occurs and the Alpine or any other fault ruptures, New Zealanders can rest assured that in all but the most cataclysmic of events, damage will be completely covered by the Earthquake Commission.

The Earthquake and War Damage Commission, as it was originally, was established in 1944. In June 1942 Wellington and Wairarapa suffered greatly in an earthquake. Hundreds of buildings collapsed or were extensively damaged. The majority of people did not have adequate insurance – many had none and, because it happened in the middle of the Second World War, there were limited resources for reconstruction. In badly hit Wairarapa, two years after the earthquake, little rubble had even been cleared away.

It was clear to the Government that something needed to be done to assist recovery from future disasters. A premium was collected from all holders of fire insurance policies to set up the Earthquake and War Damage Commission. It was to administer the funds and pay for damage caused by war and earthquakes. Landslip, tsunami, volcanic eruption and hydrothermal activity cover was added later.

Fortunately New Zealand's rash of serious disasters during the previous 100 years abated, allowing funds to accumulate.

In 1993, the Government passed the Earthquake Commission Act. Changes from the original legislation included the withdrawal of war damage cover, the exclusion of non-residential property and a name change to Earthquake Commission (EQC).

EQC's financial nest-egg along with the measures people take in their homes ensure that we are well prepared to recover from the natural disasters that are part of life in New Zealand. EQC also encourages and funds research in matters relevant to natural disaster damage and it informs people about what they can do to prevent damage caused by disasters.

People in other disaster-prone areas of the world are not so lucky. In Japan and California few people can afford earthquake cover because it is so expensive and the excesses are so high. At the time of the Kobe earthquake, in 1995, only 3% of the damaged houses were covered by insurance.

Protecting your property

There are things you can do to prevent or minimise property damage from natural disasters. The measures listed below may prevent objects turning into potentially lethal projectiles and protect irreplaceable ornaments and pictures from damage.

- Fit child-proof latches to cupboard doors to stop objects flying out.
- Use Velcro under the TV, video and stereo to hold them in place.
- Use Blu Tack or plastic putty under ornaments.
- Screw or wire tall furniture to wall framing.
- Hang pictures on closed hooks.
- Check slopes, banks and walls for cracks, distortion, erosion etc.
- Ensure your home is secured to piles with bolts or nail plates.
- Bolt free-standing fireplaces into or through the floor.
- Use metal bands or wires to strap the chimney to the house.
- Replace inflexible metal pipes and fittings with flexible ones.
- Strap and wire hot water cylinders and header tanks so they don't topple.
- Check tiles are well attached to the roof with screws or nails.

EQC
EARTHQUAKE COMMISSION

The next one, when and how big?

Accurate prediction is not possible with current knowledge, but the likely timing and magnitude can be gauged by what has gone before. The principles that "the past is the key to the future", and "the present is the key to the past" underlie much earthquake and fault-rupture research.

Let's assume that the average horizontal displacement along the Alpine Fault is 30 mm/year, and that every earth-quaking rupture displaces rock 8 metres horizontally. The time it would take to accumulate the 8 metres of strain released in a typical quake is 267 years, and 267 after the last quake gives us 1984!

Consequently, if the Alpine Fault behaves as it has in the past and our assumptions are valid, a major earthquake, possibly magnitude 8, is well overdue.

Stand by, and be prepared

Scientists do not want to alarm people, but they have a responsibility to keep communities and authorities informed about the latest research. This allows time to make plans for the impact of a large earthquake. The next Alpine Fault earthquake will be stronger than any jolt in the South Island for 100 years. Ground shaking will be severe in the West Coast, especially for places such as Franz Josef where the fault runs through the main street! Christchurch, Nelson, and Dunedin will also suffer damaging ground shaking.

Not only will ground ruptures cut road, rail, and communications along the West Coast and trans-alpine links to the east, but slips and landslides will dam rivers and block roads. Liquefaction, where some soils behave like liquid because of the shaking ground, can be expected, causing railway embankments and power poles to sink, tilt, or topple. Landslides may have a profound long-term impact because their huge sediment loads could choke drainage systems causing floods. This has implications for river control, bridges, and hydro-electricity generation. Some roads, bridges, and services may not be fully restored for months, or even years.

The Alpine Fault must never be underestimated in terms of its impact on New Zealand society. It is one of the planet's major structural features, and is potentially the South Island's most destructive natural hazard.

Evidence for the 1717 Alpine Fault earthquake

Just north of Milford Sound, beech trees on the Alpine Fault have been broken off 10–15 metres above ground – presumably by violent shaking during an earthquake. In the same general area, floods of gravel eroded from fault-zone rocks fill hollows burying the vegetation of the earlier forest floor. These features, together with massive landslides, resulted from the same quake.

The quake's date is calculated through radiocarbon dating of buried organic material, the size of unbroken beeches that grew after the earthquake, and tree ring analyses (dendrochronology). At Okuru River, and several hundred kilometres north from Paringa to Springs Junction, major and widespread forest disturbance is evident. Its destruction has been accurately dated to 1717.

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