The Alpine Fault

Appendix 1
West Coast Regional Council
Natural Hazards Resource Kit
Revised Edition 2012: M Trayes

The Alpine Fault

This work is an Appendix to the West Coast Natural Hazards Resource Kit, 2003. It was revised in February 2012 to include new information about the Alpine Fault since 2003.

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Front page photograph:

The Alpine Fault at Inchbonnie – Hohonus and Taramakau River looking east [L.Homer, GNS]

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The Alpine Fault

Introduction:

Although the Alpine Fault has the potential to cause catastrophic damage on the West Coast, and elsewhere in the South Island, should there be major movement along all or part of its length, there has been no such movement in historical times. On the other hand there have been a number of documented earthquake events causing surface rupture along other fault lines akin or adjacent to the Alpine Fault which give us some measure of what we might be in for when the predicted large event occurs.

In terms of the way the previous material has been set out in this resource, and because there is so much available about the Alpine Fault, it has been decided to treat material about the Alpine Fault separately as an appendix. Projection about what may or may not happen along this Fault Line is the subject of much research currently in New Zealand and new material is coming in all the time.

The object of this appendix is not to collate all such data but to give reader wishing to do research in this area some idea of areas they may like to focus on. “Brainstorming” about this topic for this appendix has brought to mind the following points as a way of “organizing” the vast quantity of material available on this topic and three or four pertinent articles about each key topic are given as examples of material available.

The Reference Section at the end, whilst up to date as of publishing, is not exhaustive and an Internet Search should be made by all students working on this topic for any new information post publication of this work.

Key Topics regarding the Alpine Fault are:

1. **The Work of Pioneering Geologists:** an Historical perspective
2. **Our Knowledge of the Alpine Fault:** due to Technological Innovation
3. **The Structural Geology of the Alpine Fault:** the Scientific picture
4. **Future Earthquake Predictions –** based on all of the above

1. The Work of Pioneering Geologists

"an Historical Perspective"

In any study about the Alpine Fault there is inevitably reference to the past whether it be maps, surveys, texts, reports or theories. And behind all the wealth of material accumulated about the Alpine Fault are the geologists who went out there and found out about it.

An historical account about the Alpine Fault is a worthy study in itself as it goes hand in hand with the development of the theory of modern plate tectonics and all the technological leaps and bounds which made gathering information about the fault line more easy - improved access, aerial photography, modern instrumentation such as ground penetrating radar and interpretative tools such as Carbon 14 Dating.

New Zealand has had some truly great pioneering scientists in past members of the New Geological Survey and in many ways their services to the modern state of New Zealand have been overlooked. For the interested student the centennial history of the ***N.Z. Geological Survey, 1865 -1965*** by Peggy Burton of the NZ Geological Survey Office, published 1965 is a wealth of information about many of these men. The personal anecdotes given bring to life many of their exploits at a time when the West Coast was heavily forested and the only way round was on foot or horseback. Other information is available from biographies and diaries. The following have been chosen as resource examples for this section as they had major input into establishing the existence of the Alpine Fault and how the fault came about.

- Alexander McKay
- Richard Willett
- Harold Wellman
- Richard Walcott

ALEXANDER MCKAY

Resource Example 1a
an excerpt from pp 38-39, Chapter 4, "Waning of Hector's Power,"
N.Z. Geological Survey, 1865 -1965 by Peggy Burton, NZ Geological Survey Office, 1965.

The first three chapters of this history of the geological survey of New Zealand give an outline of the key personnel who undertook the first reconnaissance trips into what was then virtually unknown country. Alexander McKay was a member of the original staff of the Survey Office, which was established in Wellington under the leadership of Dr. James Hector in 1865. McKay made many valuable contributions to the early understanding of West Coast geology, covering much ground on foot and horseback. His diaries and reports give valuable insight into early travel in New Zealand generally and in particular to the heavily bushed West Coast where it was not surprising that the extent of the Alpine Fault remained unrecognized for many years. McKay however picked up signs of it at the northern end where the more open country enabled him to recognize the hallmarks of the Alpine Fault - both uplift and horizontal displacement.

"The Reconnaissance Phase in Retrospect"

"…………….. *(Alexander)* McKay, *(1841 - 1917)* being self taught in geology, had the advantage of no preconceived ideas based on European teaching. His versatility and keen observation gave him insight that in his later years often startled older, university trained colleagues. An astonishing number of McKay's geological reports contain information which has survived later critical examination. His outstanding contributions to New Zealand geology were in the structural field.

Two controversies were of dominant interest and provoked many battles. McKay worked out fresh structural theories in Marlborough which today are accepted as substantially correct. His field work in the Clarence and Awatere Valleys of Marlborough in the 1880's convinced him that the Kaikoura Mountains had originated in comparatively recent (post-Miocene) times. Subsequently he extended this theory, which included mountain building by block-faulting, to the rest of New Zealand, particularly to Otago. Professor C. A. (now Sir Charles) Cotton brought this into prominence in his studies on geomorphology some 20 years later.

McKay's prime discovery, of world importance, was made through his acute observations of earthquake damage. (McKay, 1888.) He investigated a series of earthquakes in Marlborough in 1888 and reported that at the Glenwye sheep station fence lines were broken and laterally displaced by 8 ft and 9 ft. Contemporary theory allowed only for vertical movement along fault lines; here was irrefutable evidence for horizontal shearing traceable for some miles. McKay's original theory was not accepted widely, in fact the significance of transcurrent fault movement was not generally acknowledged until the 1940's.

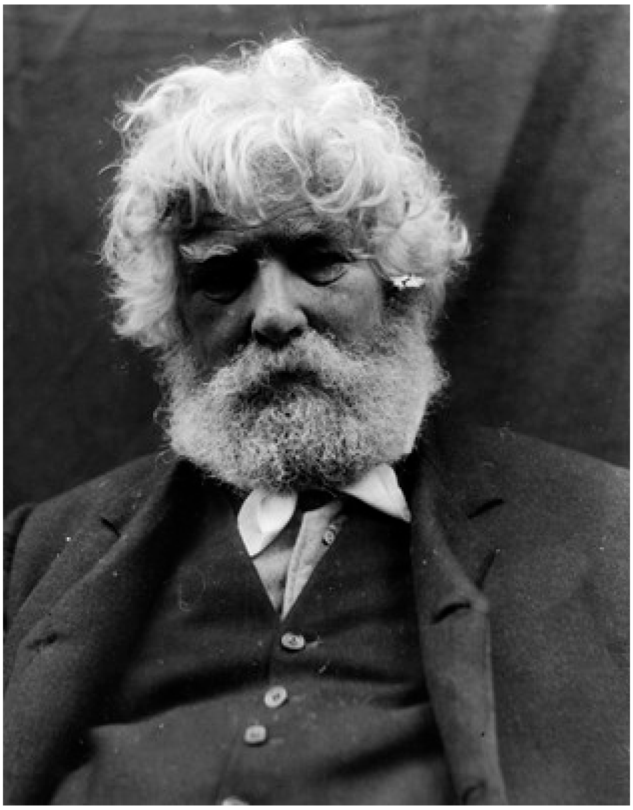
Thus the gains in structural knowledge made during this period were largely due to McKay's perception, particularly in his maturity. Hector's staff had, however, missed the Alpine Fault; also they failed to comprehend structures in complex areas such as the East Coast of the North Island or West Nelson. Their recognition of the simpler structures of the Hokonui syncline and the Wanganui basin was, however, an important advance.

The progress of stratigraphy was hampered by Hector's lack of a paleontologist. In the broad application of theory McKay again made his mark. He was the first to counter Hector's theory that Tertiary sediments occurring in valleys in the Paleozoic rocks (studied mainly in the South Island) were infillings of huge drowned valleys. From his field observations McKay showed that the Tertiary sediments had once formed part of an almost continuous cover over the older rocks, but had been removed by denudation except where protected in valley sites.

Hector's economic surveys had covered much unmapped country. Some of the West Coast work had been so thorough that it was as accurate as much of Bell's 1 mile: 1 inch geological survey. Other mineral investigations were not so exhaustive. One essential role of a geological survey that was fulfilled under Hector was counselling to prevent minor mineral discoveries from using more labour and money than was warranted. The search for coal during Hector's period again owes much to McKay's unbiased judgment. McKay was quick to realise that New Zealand coal might have had a different geological history."

Other references about Alexander McKay include:

- An **Obituary,** Geological Society of NZ website at www.gsnz.org.nz/gssuh2.htm
- A Dictionary of NZ **Biography**, McKay, Alexander 1841 - 1917 at www.dnzb.govt.nz/dnzb/Find
- An **Historical Study,** GSNZ Historical Studies Group, at www.gsnz.org.nzgssuhs.htm
- An **Archival Excerpt** about Hope Fault movements on Geological & Nuclear Sciences website at data.gns.cri./hazardswatch/2003_09_01historyarch.html
- A **short online biography** at www.natlib.govt.nz/collections/online-exhibitions/first-professional-scientists/alexander-mckay



Alexander McKay, ca 1910, Making New Zealand Collection, Alexander Turnbull Library

QUESTION: Why do you think McKay missed recognising the Alpine Fault?

HAROLD WELLMAN

Resource Example 1b

Harold Wellman: an excerpt from GNS Scientist Simon Nathan's 2003 biography of Harold Wellman to be published by the Geological Society of New Zealand. Sections in italics have been taken from Wellman's own diaries and/or reports. Wellman, who died in 1999, is acknowledged as one of N Z's most imminent scientists. He not only realized the extent of the fault but went on to be a major world proponent of plate tectonics.

"7. 4: Discovery of the Alpine Fault"

"In August 1941 Wellman and Willett were sent to investigate a potential mica occurrence in a remote part of South Westland (described in the next section). Wellman was one of the few geologists who had any familiarity with this region from his gold-mining days. Because the geology of this part of the country was poorly known, Henderson told them to record what they could of the geology, and particularly to look out for any interglacial marine benches on the moraines[i].

No detailed topographic maps were available, but Wellman prepared a roll map of their likely route from the 1:250,000 topographic maps, and plotted up existing information. As the trip went on he added geological observations

By 1941 only the north-eastern part of the Southern Alps had been geologically mapped. P.G. Morgan had recognised a large fault at the western edge of the Alps which he called the "Gregory Valley" (after J.W. Gregory who had recognised that the African rift valleys were caused by faulting), and traced it as far south as the Wanganui River. Wellman and Willett were keen to see if it could be traced further south.

Wellman recalled that the staple food they took was lima beans and bacon – his preferred food in the field. Willett's field book[ii] mentions flour, milk powder and macaroni (as well as lima beans). They had duck down sleeping bags, and carried a tent.

They left Wellington on the overnight ferry to Christchurch on 20 August 1941, and then travelled by railcar to Greymouth, where they called in to see Max Gage and others working on the coal survey. The next day they visited the Lands and Survey office in Hokitika, and spent time studying an enormous roll map of South Westland compiled by Charles Douglas, an early explorer in the region. As well as detailed topography, it showed geological observations made by Douglas, which Wellman copied on to their map. Then they started to hitch-hike southwards.

This was when we started to extend the geological mapping into the unknown. We needed a good view, and the best way to do this was by getting a lift on the back of an open truck. The front of the Alps is very spectacular, and it didn't take long for us to realise that Morgan's Gregory Valley could be readily traced southwards.

Dick had done his master's thesis on glaciation, and I wanted to show him some of the glacial features I had seen while gold mining. We went down to Waiho beach. Most of the miners had left, and we had no trouble getting a hut to stay in. The next day we walked along the coast from Waiho Beach to Gillespies Beach, where we stayed with Jock Thomson, my old gold-mining mate. As we looked back to the mountains we took photos, and noted how the moraine hills that slope towards the coast seemed to be faulted off at the front of the Alps.

They got a lift to from the settlement at Fox to Paringa, then the end of a road. To the south a pack track gave access to tiny settlements at Haast and Okuru, and joined up with a track that led over the Haast Pass. They spent four days looking for mica in the Kinnard and Mataketake Ranges (described in the next section), then continued southwards.

Although the mica was not impressive, the geological mapping had gone well. The Gregory Valley was even better in South Westland than in the north. It seemed to be an unusually straight major fault separating granite on the north-west from schist of the Alps to the south-east. We decided that the Gregory Valley was merely the result of the more rapid erosion of the rocks along the fault, which we later decided to call the Alpine Fault.

There was a large exposure on the track at a place called Blue Slip where we were able to get a good look at the work of the Alpine Fault. The schist was broken in pieces some 50mm long, but was we could see from the schist layering they had moved very little. The broken schist looked like the result of explosions, or perhaps we were seeing the heart of old earthquakes.

We walked down to the Haast River, crossed it on a temporary bridge, and went to the Public Works camp to get a meal and somewhere to sleep. When the weather was clear we spread out our roll map on the ground, and saw the relation of the fault to the landscape for the first time. To the north we could see the fault along the front of the Mataketake Range, and to the south we could see that it extended along the range front]. From the map we could see that it was likely to extend up the Jackson River, over the Martyr Saddle, and then southwards to Lake McKerrow at Hokuri Creek. And if that was correct, it was only another twelve kilometres to Milford Sound and the straight coastline of Fiordland.

A decision had to be made – should we return to Wellington, having completed the search for mica, or should we carry on and see if the Alpine Fault could be traced further south. We decided to carry on as we told ourselves that Dr Henderson would be pleased if we had the makings of a good map. Once we had obtained extra stores and posted extra gear back to Wellington we headed south. The Jackson River follows along the Alpine Fault, and the position was exactly as predicted. We could also see that the belt of ultramafic rocks was cut off by the Alpine Fault.

The cattle track led down the Cascade Valley, past the Hermitage Swamp to the coast at Barn Bay. We plodded down the coast. The sandy beaches were easy, but the large boulders were slippery. It took us two days to walk along the coast, and we were almost out of stores when we reached Gunn's Hut at the Hollyford. The hut was open but dusty, so we took some stores and left money to pay for them. From there it was only seven kilometres to Hokuri Creek, the place where we had guessed that the Alpine Fault would cross Lake McKerrow. We got there in the early evening, which was fine and clear, and the fault was exactly as predicted – a ten foot scarp. On the opposite side of the lake was a stream right on the line of the fault and a step in the skyline.

We made camp, feeling pleased with ourselves, as we believed that the difficult part of the trip was over. It was not so. It started to rain in the night, and was teeming by morning. Then we discovered that the track just upstream from the Hokuri had been eroded away, and there was a cliff where the track had previously been. We spent half a day trying to get along the edge of the lake, then decided that the track must be higher up so climbed up and finally found it again. Heavy rain continued, and extreme care had to be taken not to be swept away by little streams that normally would be hardly noticed. Two days later, on 26 September 1940, we arrived bedraggled at the Public Works camp at Marian for workers on the Homer Tunnel. The following day we caught a bus to Gore, then travelled by rail and ferry back to Wellington. We thought that we were pretty intrepid travellers, but later we realised that tramping parties regularly used the coastal route, and even horses had been taken there with some difficulty.

Dr Henderson did not query the length of time Wellman and Willett had been away when they arrived back in the office at the beginning of October 1941, but was keen to see the work written up as quickly as possible before they were out in the field again. October and November were spent writing several reports, including two manuscripts on the geology of South Westland. The first was completed and formally read before the Wellington Branch of the Royal Society on October 9th 1941, and submitted for publication on November 10th 1941[iii] – only about five weeks after returning from fieldwork. Although written rapidly, it remains one of the classics of New Zealand geology. A geological map at a scale of ten miles to the inch summarises the geological data gathered during the trip as well as results from earlier work. The evidence for the Alpine Fault is summarised under five headings:

(a) *The presence of a scarp or a sudden but regular change in summit height*

(b) *Wide crush zones with slips and rapid erosion*

(c) *Subsequent rivers flowing along co-linear courses parallel to the trend of the Alps, connected by low passes*

(d) *Change in rock type and*

(e) *Offsetting in river courses.*

Although the paper is based on reconnaissance mapping and some speculation, the position of the Alpine Fault as recognised today is little changed. Wellman and Willett had expected some resistance to their recognition of a single major fault along the western edge of the Southern Alps, but to their surprise there was almost immediate acceptance within the geological community including leading academics such as Benson and Cotton.

One aspect of their paper was not accepted – or at least, ignored. They showed that there was a consistent displacement of about a mile for many of the rivers that have rock-bound courses, and suggested that this was due to lateral offsetting along the fault. Although the evidence now seems obvious, it was largely ignored at the time because of a widespread reluctance to recognise horizontal movement on faults.

The first paper, containing a description of the Alpine Fault has always overshadowed the second, which deals with glaciation. It gives an account of the widespread moraines which are exposed along the coast, and shows how the coastline was indented by glacial valleys which have subsequently been largely filled by postglacial alluvium. Larry Harrington can remember Wellman correcting the proofs while they were doing fieldwork on D'Urville Island.[iv] Because of wartime restrictions, it was too expensive to publish photographs as half-tones, and Wellman was told by the editor that they would have to be omitted. Instead Wellman persuaded Eileen Hope, a local farmer's daughter, to trace them, and so they were produced in the paper as line drawings."

Other references regarding Harold Wellman include:

- An **Obituary,** written by Simon Nathan for the Geological Society of New Zealand after Harold Wellman died April 30th 1999 [www/gsnz.org.nz/gsprnf5.htm]
- A 1999 BBC **Television Documentary** (30 minutes), entitled "A Man Who Moved the Mountains." Available from BBC
- A **Dictionary of NZ Biography** entry, "Wellman, Harold, 1909 - 1999" at www.dnzb.govt.nz/dnzb
- Geological & Nuclear Sciences **website entry**, " What we do: The Active Earth" at www.gns.cri.nz/what/earthact/crustal/

Harold Wellman surveying in the field, 1940. Photograph courtesy of Simon Nathan, New Zealand Institute of Geological & Nuclear Sciences

QUESTION: Where can you see Wellman' s theodolite and other survey gear today?

RICHARD WILLETT

Resource Example 1c
Richard Willett: an excerpt from the start of Chapter 9 (of the history of the) ***N.Z. Geological Survey 1865 - 1965*** by Peggy Burton, published 1965. Richard (Dick) Willett accompanied Harold Wellman on the historic 1941 trip (see Resource Example 1c) along the southern part of the Alpine Fault, proving himself an able field geologist. In 1956 he became Director of the N.Z. Geological Survey and during the next ten years under his directorship there were many advances in mapping and an accelerated accumulation of geological knowledge about New Zealand in general and the Alpine Fault in particular. Willett was very supportive of Wellman as the latter began to promote his initially quite controversial theory about Plate Tectonics and its relation to New Zealand's Alpine Fault during the 1950 - '60's.

"Developments under Willett"

"The rapid re-organization of the Geological Survey following the appointment of the present director, Willett, in 1956 was assisted by several favourable factors. The country's economy was buoyant since the shadow of war in the early 1950's had cleared and the outcome of the Korean and other military crises had proved such could be localised. The new Labour Government was willing to finance further special geological surveys for economic minerals and radical new scheme for areal survey. The professional staff the Survey now numbered 32: the new Director, together with his contemporaries, formed the senior staff with some 20 years experience. The post-World-War II intake of young geologists provided the other major group of field men, who by then had useful 7-10 year's service: added to these were small specialist sections.

Although his geological interests had been channelled into the Coal Survey and other economic projects, Willett had earlier made some difficult field expeditions. His survey of the length of the Southern Alps with Wellman was climaxed in 1941 with a 200 mile-long exploration along the Alpine Fault, accomplished much as in Hector's day. The results were the first real confirmation of the extent of the Alpine Fault and the formed the basis for Wellman's later theories."

………… Chapter 9 then continues on to list Willett's administrative experience starting in 1942 as head of the NZ Geological Survey's District Office in Invercargill through to his taking on the Directorship at the Wellington Office in 1956. Much of the time between these appointments was spent overseas in key roles and during this period Willett wrote a series of papers on the mineral resources of the British Commonwealth. Finally Chapter 9 lists the many advances Willett instigated post 1956, including a much needed shift of the Geological Survey's Wellington Office to improved and larger quarters (a great benefit in particular to the rapidly accumulating library), a new geological mapping programme, new methods of cartography (map making), regular publication of work done by the Survey's geologists, prospecting guides for those searching for minerals and much improved techniques for fieldwork. Some of these technological improvements will be referred to in the next section of this Appendix.

Other relevant references about Richard Willett include:

- An **Obituary,** Geological Society of NZ website at www.gsnz.org.nz/gssuh2.htm

QUESTION: Despite being colleagues on the 1941 trip down the West Coast, Willett and Wellman were quite different. What are some of those differences?

RICHARD WALCOTT

Resource Example 1d
Richard Walcott: an example of the influence of Wellman on other geologists taken from the **internet** at www.agu.org/inside/awards/walcott.html)

"Walcott Receives 1999 Whitten Medal"

"Richard I. Walcott was awarded the 1999 Charles A. Whitten Medal at the AGU Fall Meeting Honours Ceremony, which was held on December 15, 1999, in San Francisco, California. The medal recognizes outstanding achievement in research on the form and dynamics of the Earth and planets.

Citation (by Dan P. McKenzie, University of Cambridge, England)

In the 19th century, geodesy - the measurement of the shape of the Earth - became the first part of the Earth sciences where rapid progress became possible through accurate measurement. The group who first exploited this technique on a large scale was the Indian Survey, based at Dehra Dun. Its measurements in India led to the idea of isostasy, but the group's influence was much greater: the people it trained went all over the world making accurate geodetic measurements and thinking about the results. For a long period the survey's research dominated the development of geodynamics and is now slowly doing so again. One of the people who has brought about this recent change is Dick Walcott, and it is partly for this reason that he is the recipient of the 1999 Charles A. Whitten Medal.

Dick's early research for his Ph.D. concerned the geology of the Red Hill complex in New Zealand, an ophiolite complex cut by the Alpine Fault. The origin and emplacement of such complexes have long puzzled petrologists, and his work was carried out shortly after the association of such structures with oceanic crust had been recognized. However, field studies of ophiolites are notoriously difficult, and Dick left this field when he moved to British Columbia, Canada, as a postdoctorate in 1966. A year later, he moved to the Dominion Observatory in Ottawa, where he stayed for 8 years until he returned to New Zealand in 1975.

I first met Dick at this time, when I visited the observatory. He was working on one of the classical geophysical problems of interest since the 19th century: lithospheric flexure. Dick had realized that this subject was central to understanding how plates could move. What particularly interested him was the gravity signature of flexure, and he used this to estimate the elastic thicknesses of continental and oceanic plates. His early estimates of flexural rigidity, made in the space domain, have been confirmed by studies using the much larger data sets now available and spectral techniques in the frequency domain as well as space domain modelling. These studies have confirmed the accuracy of Dick's early estimates, which showed how thin the elastic layer is that is responsible for the rigid motion of the plates.

In 1975 Dick returned to New Zealand and again changed the direction of his research, this time to one that every geodesist would recognize as geodesy! The plate boundary between the Australian and Pacific plates crosses New Zealand, and the relative motion of these plates is responsible for the seismic activity and quaternary deformation that is such a striking feature of the country. When Dick returned, he started a major project to understand how this deformation was related to the motion of the plates on either side.

There are a number of reasons why New Zealand is a good place to carry out such a study. It is one of the relatively few places where continental tectonics occurs between plates whose velocity is known from oceanic spreading rates. In addition, 19th century geodesists, trained in India by the survey, had surveyed the islands with extraordinary care and accuracy. But perhaps the most important reason is that there was a small group of outstanding Earth scientists and geodesists in the Wellington area of New Zealand, all of whom Dick knew well. So he did not have the problem faced by most geologists and geophysicists in other parts of the world who wished to use geodetic measurements for tectonic purposes---namely, convincing the geodesists that the movements are real and not the result of surveying errors. What Dick and his colleagues found was that the deformation was distributed over a wide region as it crossed New Zealand and also that it involved rotations as well as translations. In a beautiful use of yet another field of geophysics, he then used paleomagnetic measurements to demonstrate the existence of these rotations. He is now exploiting the new space-based geodetic techniques, and especially the Global Positioning System, to examine the deformation in more detail.

Dick's research involves geodesy in its widest sense. He is one of a very small band of people who has brought the subject back to its rightful place at the centre of geophysics. It is fitting that his great contribution to our understanding of tectonics should be honoured by the Charles A. Whitten Medal."

Response (by Richard Walcott)

"The award of the Charles A. Whitten Medal has a particular pleasure for me, as I enjoyed meeting Charles at several AGU meetings. He took a serious interest in the research activities of the time, particularly those involving survey data with which he was familiar, and he was invariably helpful and supportive. I thank the AGU for the award and this opportunity to acknowledge debts to several people.

Earlier this year, Harold Wellman died in Wellington. He was the most eminent geologist of this century in New Zealand and, by far, the dominating personality in the Geology Department at Victoria University where I studied. He was noted for a number of major contributions; the stratigraphy of the New Zealand Cretaceous and the discovery of the Alpine fault as a major continental strike-slip fault are examples. But to my mind, his most important characteristic was his quantitative approach to geological deformation, which probably came about through his earlier training as a surveyor. To Harold, description was not explanation - an uncommon geological view of the time - and my interest in the measurement of Earth deformation by whatever means was something acquired from him. In 1967 I obtained my first job with the Gravity Division of Energy Mines Resources Canada in its systematic gravity mapping of the country, and an inevitable problem of interpretation of gravity was the nature of the compensation for topographic loads.

It was the very different behaviour of the Earth in northern Alberta compared to the Basin and Range Province that focused attention on the problem of flexure. Surfaces underlying the flat-topped Caribou Mountains in Alberta showed no deflection because of their very substantial load, yet if the Earth behaved the same way as Crittenden had described for Pleistocene Lake Bonneville, we would expect to see a downward flexure of several kilometres. Because this was not so, the lithosphere had to support the load and spread the compensation and thus be many times stiffer under the Interior Plains of Canada. From that conclusion it was natural to proceed to estimating the stiffness of the lithosphere in other examples of surface loading.

I returned to New Zealand in 1975 and joined Hugh Bibby in extending his earlier work on measurement of shear strains from re-observations of old surveying networks. Repeated triangulation estimates of deformation resulting from earthquakes were common in New Zealand and elsewhere, but with the instruments then available, only changes in angles could be determined with accuracy so that the displacement vector of any particular trig point could not be obtained. However, as F.C. Frank showed, the shear-strain components of the deformation of any triangle could be unambiguously measured. Hugh had showed that repeated triangulations could indeed give sensible shear-strain estimates in an area of rapid tectonic deformation and, importantly, that the triangulations need not be of highest geodetic standard; old surveys, although not of great accuracy in themselves, could provide excellent estimates of the deformation because of the long period between repeated surveys. It was clear that abundant information already existed in national archives to obtain extensive coverage and thus map the rate and direction of relative displacements during the intervening period. With mapped shear strains it was possible to estimate the kinematics of the deformation. Thus it was shown that the current rate of deformation across the Pacific-Australian plate boundary through New Zealand had the same sense, rate, and direction as that predicted by the Euler vector describing relative plate motion on a geological timescale."

Richard I. Walcott, Victoria University of Wellington, New Zealand

Other references about Richard Walcott include:

- An **Entry** from the School of Earth Sciences, Victoria University, Wellington about Walcott & Plate Tectonics at www.vuw.ac.nz/home/prospectuses/ses
- **A Royal Society of New Zealand Fellowship Entry** on George Grindley includes notes on Richard Walcott: at ww.rsnz.govt.nz/directory/yearbooks/2001/fellows.php
- An **Article**, "Life to Order" including notes on Walcott's work at www.stalbans.org.nz/Teaching/RobYule/Creation/life_ord.htm

QUESTION: What technology do GNS use today to measure the ground deformation caused by tectonic plate movements?

2. Recording Knowledge about the Alpine Fault

"Due to Technological Innovation"

Technological innovation over the last 150 years has markedly improved the modern geologist's ability to:

a. Achieve easy access

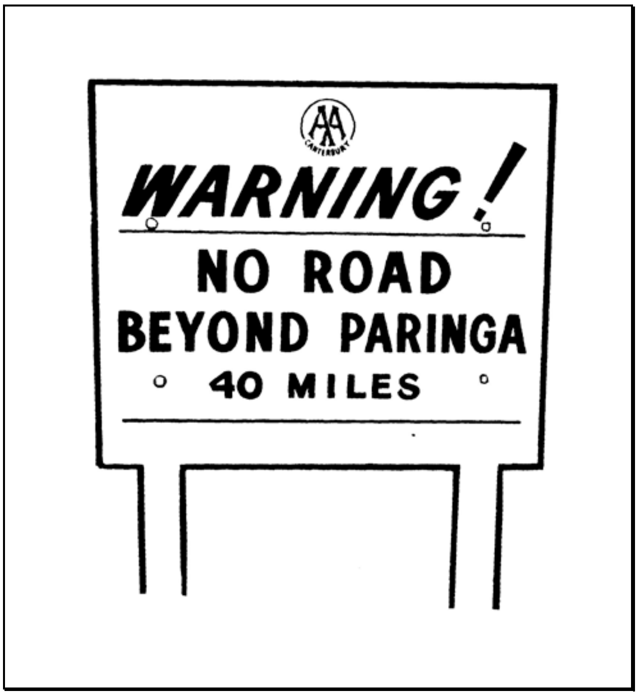
b. Produce geological maps

c. Make field recordings

d. Interpret field recordings

Some of the outcomes for geologists due to these improvements are:

- More field time and less travel time
- Being able to log more field data at a faster rate
- An escalating accumulation of knowledge
- A greater understanding of natural hazard risks



AA road sign in John Pascoe's 1966 book, *"The Haast is in South Westland."* The book outlines the long story of building the road link between Otago and Westland over the Haast Pass. This was finally achieved, with the completion of the Paringa section, in November 1965.

2a: Easy Access

These days when one can just hop into a modern car and drive from Greymouth to Queenstown it is hard to remember that it is only in the last fifty years that one has been able to do this. In fact it was back on November 6th 1965 when Sir Keith Holyoake, then Prime Minister of New Zealand, finally cut the ribbon to open the road link over the Haast Pass to South Westland. And even then it rained so hard the road was shut again within hours due to slips. Making roads on the West Coast has never been easy.

These days the Paringa Cattle Track is a walking track for trampers, managed by the Department of Conservation, but for many years before and after World War II it was the only foot link between Paringa where the road south from Hokitika ended, and Haast. The need for a road was well understood but the slow progress made in the 1930's became no progress during and after World War II until finally some action began again in the 1950's. Finally Makarora and Haast were joined in 1960 and the northern link five years later.

Nineteenth century early explorer - prospector - geologists such as Julius von Haast, James Hector, William Docherty and Alexander McKay would have walked or ridden horses along rough bush tracks from one settlement to another in between making foot forays into the wilds to search for minerals. Then motorcars came onto the scene and by the 1920's motoring was relatively common in central Westland. However the road south finished at Weheka (Fox Glacier) for many years with only a pack track over the Haast to connect to Wanaka. For a geologist working anywhere along the length of the Alpine Fault finding fault traces was difficult enough, but to "connect" them into one coherent story in the heavily bushed rough country was well nigh impossible. It wasn't until Wellman and Willett made their epic trip in 1941 that full realisation began to dawn.

The loneliness of residents of the far south was alleviated in many ways by the air and radio services which came to South Westland in the 1930's. While flying mail and stores south from Hokitika to the bush strips of South Westland pilots would have seen the line of the Alpine Fault, especially in the Jackson River area but as they were offering a service rather than doing exploration, most pilots would have flown the safer router route along the coastline, away from both the mountains where it rains most heavily and where the fault lies.

Once the road was made it became possible to access points along the southern part of the fault much more readily because the road south more or less follows the line of the fault (the fault line is in fact a great deal straighter than the road!). In the 1960’s Mt Cook Airlines began flying their ski-plane scenic flights over Westland National Park making it possible to see the extent of the Alpine Fault and photograph it from the air. By the 1970-80's helicopters began to come into widespread use in the area for first deer culling then deer recovery giving geologists yet another choice for access.

Today young geologists from the Otago University Geology School have it made in terms of access, although there will always be a need for foot travel given the West Coast’s rough country. With easier access there is now more time for field work, to take samples, recordings and photographs. We could be critical of the fact that the early geologists missed making the links which would have shown them the existence of the Alpine Fault but in reality they did a good job given the access they had for so many years.

Resource Examples about 2a: Easy Access

These **excerpts** are taken from ***Stories of the Fox - Paringa - Haast Road,*** a collection put together for the 30th Anniversary of the road opening in 1995.

"Through the Haast in the Early '30's" by Pamela Bourne

"Twenty miles Waiho, Fred awaited me with horses. Here the bridges ended, the road became a track and the forest untamed. At the Cook River begins the Back of Beyond…. Through this country few people travel. There are perhaps a dozen families in all it's length. Every three weeks Charlie and his pack horses penetrate to the Haast River with the mail and stores, but if the rivers are up he does not come…..

Once over the Cook River we were in the land of horsemen and farmers' oilskins. One of these was rolled round the small bundle strapped to the saddle bow in which were all my possessions…. We had to first to cross the Cook river at a point there the riverbed was over quarter of a mile wide we reached the main stream. The constant and sudden floods are always changing the fords, the rivers are swift and treacherous, though seldom deep, and the bottoms are boulder-strewn. My mare was smaller than Fred's gelding, so he tried the ford first, and then, clutching my bridle, urged the mare to follow. She did not like the icy water, which piled up on one side and swirled dizzily round her chest…. At last we were over…………"

"The Overland Bulldozer" by Paul Beachamp Legg

"It was back in the 50's that I heard this story. Unfortunately I have forgotten the names of the people and many of the exciting details, but hopefully visitors to the celebrations will add to the story and correct my errors. I would like more details. This was an epic drive that deserves to be recorded.

Some heroes, whose names elude me, drove a bulldozer from Paringa to Haast before the the road was made. In all likelihood the drivers pushed their way via the cattle track, difficult enough for cattle, but almost impossible for a bulldozer which had to pass over steep razorback country as it made it's own track through the thick bush.

I believe the drive took them six weeks. At times they almost ran out of food and supplies and by the time they arrived the bulldozer's motor was in a very sorry state. Some near vertical climbs had kept the oil from the rear cylinder, which I understand was useless. Can anyone add to this story for me?"

"Air Ambulance Rescue from the Haast Road by Richard Waugh

"The air service as an integral part of South Westland life from the 1930's until the completion of the Haast Highway in the 1960's. Legendary pilot Bert Mercer founded his independent airline Air Travel (NZ) Ltd. in December 1934 at Hokitika…...

…..Over the year two veteran de Havilland aircraft types maintained the service - the single engine DH 83 Fox Moth and the twin engine DH89 Dominie. These wooden and canvas covered aircraft proved to be very hardy and reliable and, along with their pilots, were highly respected by the people of South Westland.

Over the years virtually all road construction workers flew on the air service at one time or another and most of the food, drink and mail supplies were also flown in. Another particular benefit was the air ambulance service which the aircraft provided. If there was an accident it was comforting for people in South Westland to know that Westland Hospital was only a matter of an hour away. Over the years many residents and road construction workers were flown out on emergency air ambulance flights…….."

2b: Geology Map Production

Geological maps have come along ways from the first years of the European settlement in New Zealand and the beginnings of the NZ Geological Survey Office in 1865. The early geologists were also explorers and surveyors exploring unknown frontiers. They sketched, surveyed and prospected as they went.

One of the earliest of these to come to the West Coast was Julius von Haast who made a foray over what is now known as the Haast Pass to the West Coast as Provincial Geologist for the Canterbury Provincial Government in 1863. His reports about payable gold helped to stimulate the first gold rushes in 1864 and Haast produced one of the very first geological maps of New Zealand following a second trip to South Westland in 1868. Appendix B of the ***"New Zealand Geological Survey, 1865 - 1965"*** states of Haast's Four Miles to One Inch Geological Map—1868"

"The original map is held at Canterbury Museum; the first 4-mile map to be completed in New Zealand. It covered all Canterbury and Westland, showing all the geological information collected during Haast's term as Geologist to the Canterbury Provincial Council. Referred to in the Journal of Proceedings, Canterbury Provincial Council, Session **XXX,** 1868, is the "Report of Dr J. Haast on the Completion of the Topographical and Geological Survey of the Province of Canterbury". In a letter dated 30th November 1868, also printed in Haast's Report, three sheets of geological sections were presented to the Council. Haast wrote*: 'May I suggest that a copy of my Geological Map as well as of these sections are prepared and hung up in the Canterbury Museum, as the Provincial Government does not intend to have them published, so that at least the public or those interested in becoming acquainted with the geological structure of the Province can consult them.' "*

Geological detail was shown by a key of 27 divisions; gold workings were marked; volcanic rock outcrops were reasonably accurate, and "in the Pleistocene probably better divisions were shown than those in this century until the recent work for the 4-mile series". (D. R. Gregg, pers. comm.). This map formed the basis for the 1879 publication, "The Geology of Canterbury and Westland". In this, however, detail was much reduced for the smaller scale map; only 13 colour divisions being shown to give geological information."

Under the directorship of James Hector the fledgling New Zealand Geological Survey also produced an early map. Finished in his first year of office, 1865, this colour map was a large scale one at 1:2,000,000 but it showed the general geological boundaries with reasonable accuracy. However Hector and his small staff soon found the lack of cadastral maps to base their work on a real impediment to the completion of a progressive programme of geological mapping over the next twenty years. In fact the early geologists had to survey and then map the topography of the countryside as well as noting geological details which proved slow work at times.

However once the New Zealand wide first series of one inch to the mile topographical maps got under way in 1884 they formed the basis of all geological mapping until 1939. Further progress in mapping from 1884 was then more a measure of the numbers of staff available and the cost of producing them and this varied as the Directors changed and funding was more or less available.

Space is too small here for a comprehensive account of all the work which has gone into forming the quality geological maps we have today in New Zealand but one major breakthrough is worthy of note and that was the advent of aerial photography. From pages 74-75 of ***New Zealand Geological Survey, 1865 - 1965*** comes the following:

"Aerial Mapping"

"The initial use of air photographs, for soil and geological information in addition to topographic detail, was made during the depression, when Dr Marsden was approached by a delegation of Hawkes Bay men for expert advice on land utilization. Economic difficulties of the district had been intensified by alteration of the water-table level by the 1931 earthquake. Dr Marsden made a personal visit to Hastings and, realising the urgency of a fairly extensive soil survey basic to the problems, saw P. van Asch, who had a small plane at the local aero-club. A half-joking suggestion, *'Can't you put a hole in the bottom of the plane and stick a camera through?'* was taken up by van Asch. *(continued…………)*

> He cut a hole in the fuselage, fixed a camera, and with much ingenious improvisation a shutter-timer and other modifications. Air-photo coverage of the Heretaunga Plains was then flown (133 sq. miles at a cost of only £70). From this first cheap job van Asch refined his methods and gradually built up his aerial mapping business. Among many early jobs for the Geological Survey was flying for the Glenorchy survey towards the end of the 1930's. Dr Marsden informed him that there were "a few hills" when arranging a contract price, but failed to explain that some of these were over 8,000 ft. During the war much air photography was carried out by the RNZAF, and the organisation of systematic air-photo coverage of the country was passed over to Lands and Survey Department."

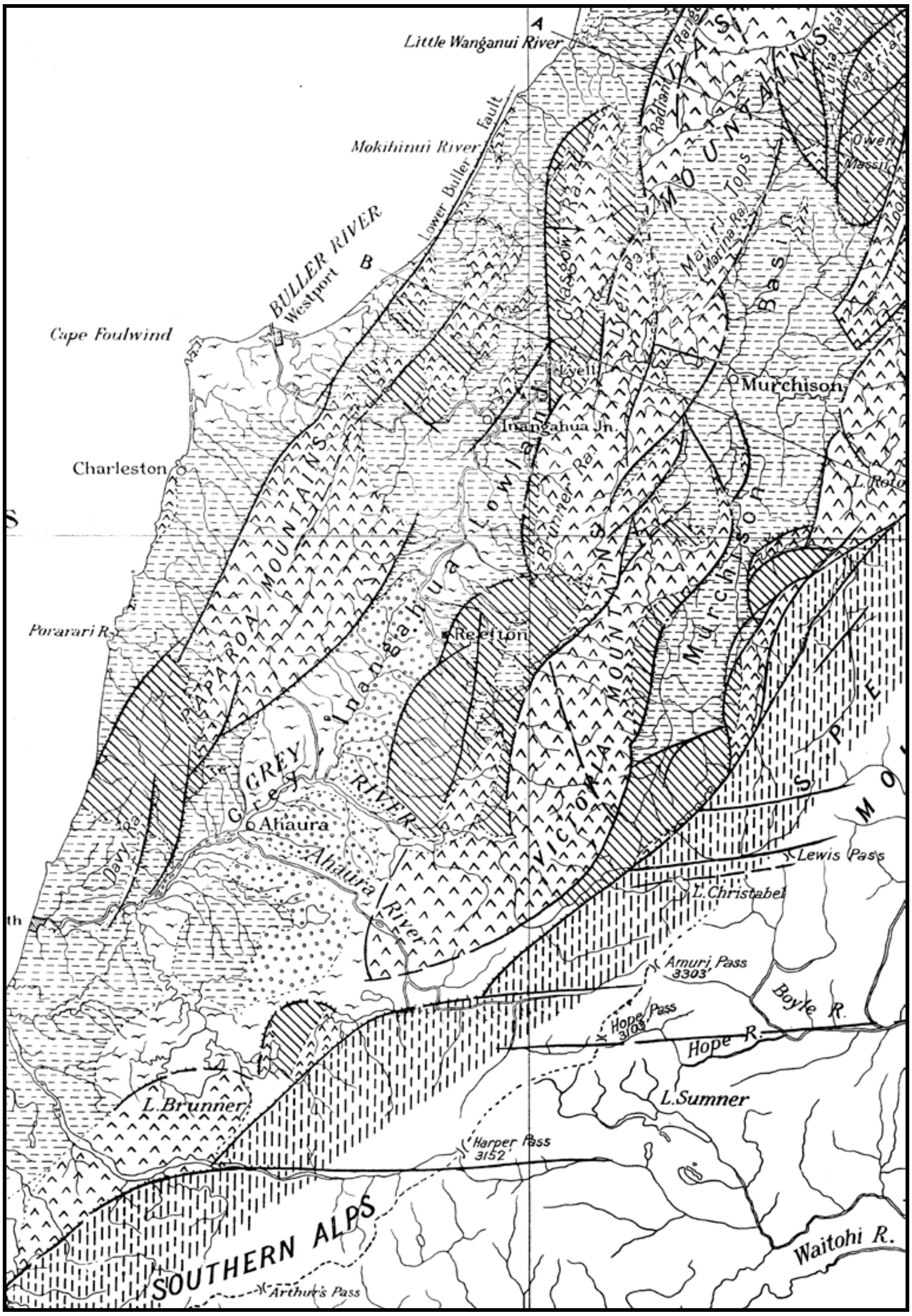
As far as the Alpine Fault goes there does not seem to have been any early systematic aerial photography done which showed up the extent of the fault trace, at least not until after 1937, when a map (shown on the next page) was put together as part of a report on the 1929 Murchison Earthquake by the NZ Geological Survey under Director Henderson. But some radical changes have definitely taken place between 1937 and 1973 when satellite photography proved that the Alpine Fault was visible from space.

Resource Example 2b.2 is seen on many geography classroom walls today as a poster, an example of how far we have come from Haast's day technologically. And since the 1990's the development of the Global Positioning System (GPS) has enabled us to utilize satellites to help fix our location accurately on almost any point of the globe. A real boon for geologists wanting to pinpoint mineral locations or changes in strata. As we enter the 21st century many maps today are electronic with modern computer software allowing us to work in three dimensions - a far cry from pencils, paper, compass and theodolite.

Resource Examples about 2b: Geological Map Production

MAP 1. Part of Plate I, without the Key, from ***The West Nelson Earthquakes of 1929*** by J. Henderson, DSIR, 1937. Fault lines shown in black. Scale 1 inch:10 miles. Note the difference between the fault lines on this map and the clear line of the Alpine Fault on the satellite photo to follow.

"A Map of West Nelson Showing Geology and Principal Faults"

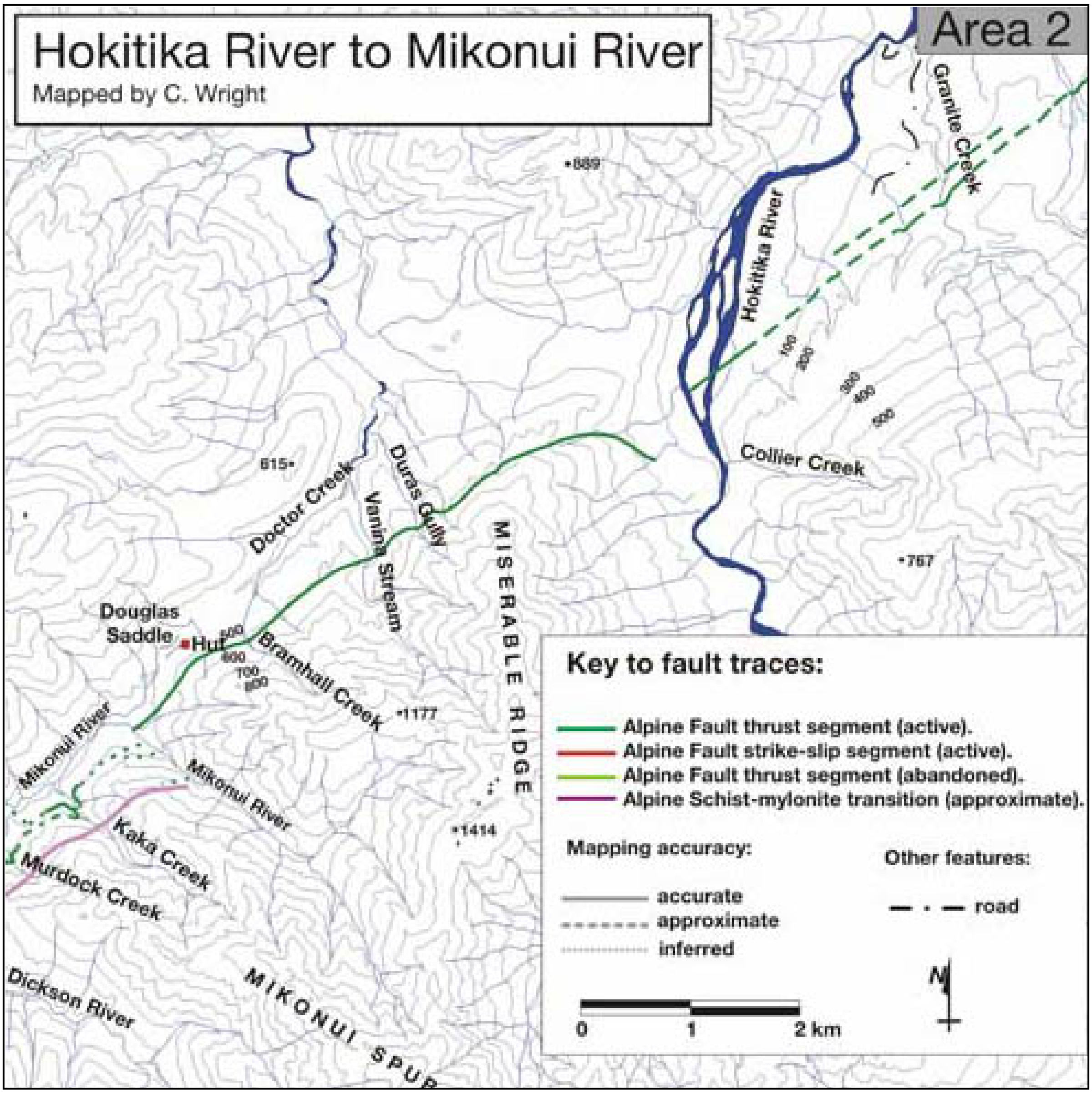


This map was made before Wellman and Willet's historic 1941 trip
and before aerial mapping was utilised for geological mapping.

MAP 2. ALPINE FAULT *Photo: DSIR*
Pel 104 Brands 1.2.4.POS ENH Landsat 1503-12421
December 8, 1973

An early view of the Alpine Fault from space which was made into a poster. Standing back from this picture, the line of the Alpine Fault is very apparent particularly in the poster format. .

MAP 3. Hokitika River to Mikonui River, Alpine Fault Map by C Wright. This is Map 2. of a set of 20 map series covering the Alpine Fault from the Styx River to the Arawata River. They have been developed from work done by University of Otago Geology students and staff. Reference: **www.otago.ac.nz/geology/research/structural_geology/alpinefault/index.html**



This area behind Hokitika is popular with hunters and trampers with tracks into the back country via Doctors Creek and Hokitika Rivers. On which of the 20 maps does the Alpine Fault criss-cross State Highway 6?

2c: Field Recording:

Traditional Methods: geologists today still spend much time using well proven field techniques including:

- **Making observations:** e.g. to sketch, photograph, take notes
- **Excavating material:** e.g. by digging, trenching, removing vegetation and/or soil layers to enable better observation OR take samples
- **Taking field measurements:** e.g. with compass, inclinometer, theodolite, tape measure
- **Taking samples:** e.g. from the surface by hand (small), by digging mechanically (larger) and by drilling with hand auger or mechanical drill for core samples to establish the presence of a desired natural resource (coal, gas petroleum etc)

Modern Methods: in addition, going into the 21st century there are some other tools of immense value to the modern geologist. These evolved rapidly in the last quarter of the 20th century with the advent of the microchip and modern computers. They include:

- **Digital photography**
- **Electronic data logging**
- **Ground positioning survey** (GPS)
- **Ground penetrating radar** (GPR)
- **Satellite imaging**
- **Cosmogenic analysis** (surface exposure dating)
- **LiDAR** (light detection and ranging)

Combined Techniques Make the Breakthrough:
The breakthroughs which have enabled much more accurate predictions to be made about future movement on the Alpine Fault have come with the combination of both older and newer techniques across scientific disciplines.

These techniques include the traditional method of trenching plus three new ones. The new ones are all based on the fact that severe earthquakes in heavily forested terrain such as we have on the West Coast, cause massive landslides, which in turn markedly alter the terrain downstream and wipe out large areas of existing vegetation which then give rise to new forests with trees all of the same age.

1. Trenching & Digging of Pits: These are dug across at key points across the Alpine Fault rupture and sample material containing organic matter (e.g. wood) is then removed from both the older sheared material (mylonite) and younger post earthquake sediments for Carbon 14 Dating in a laboratory.

2. Observation of Terraces & Landslides: Vegetation on river terraces, old slips and creek fans can be observed and photographed from the air (for ongoing observation) to help build up a picture of past massive landslides due to Alpine Fault movement. Changes in vegetation colour with discernible boundaries can denote different age vegetation. Downstream of these massive landslides existing forests would have been destroyed, fully or in part, by such things as uplift or subsidence of river terraces, rivers changing course, aggradation of gravels, liquefaction and floods. Whichever, once things settled down, new vegetation would have grown, establishing obvious stands of same age vegetation.

3. Determining Forest Ages: The location and taking of samples from logs which have been "trashed" due to past earthquakes, enable scientists to pinpoint the approximate age at which the event occurred by using the Carbon 14 Dating method. Such logs can be found either standing in river beds (with the bottom sections well hemmed in by good depth of river gravels), or poking out of river banks after rivers have cut new courses across the toes of an old fans or river terraces.

4. Dendrochronolgy *(Tree Ring Chronology):* By drilling live trees scientists can determine the age of same age forest stands. Thin drill cores can be taken from select trees, without killing them, for growth ring analysis later at a laboratory. This method works well on West Coast's podocarp species, e.g. rimu, totara, kahikatea, because they are very long lived. The same technique can also be used on trees which have lived through earthquakes because such trauma slows growth right down so that the rings during this period are very close together.

Resource Examples about 2c: Field Recordings

All three examples describe a mixture of field recording techniques.

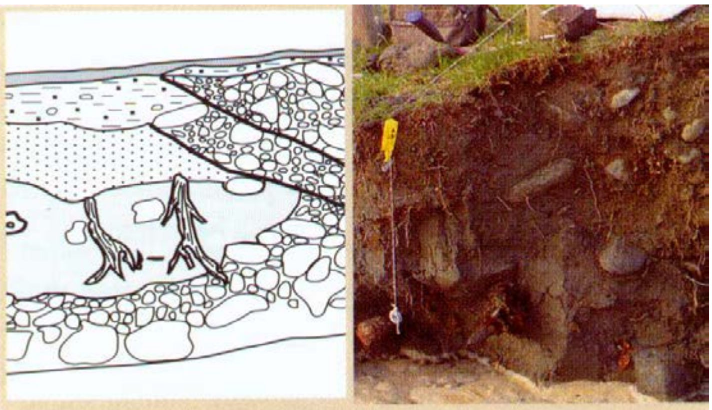
1. The first example is the Abstract from Mark Yetton's PhD Thesis published by the University of Canterbury Geological Sciences Department, 1998. Note that the breakthrough in dating Alpine Fault movements has come from inter-disciplinary co-operation between geologists and plant scientists.

"LIGHT SHED ON ALPINE FAULT'S PAST - AND FUTURE"

"Recently completed geological investigations along a section of the Alpine Fault in north Westland have yielded significant new information about New Zealand's largest active fault. Collaboration between scientists from different disciplines has revealed the timing of several large prehistoric earthquake ruptures of the fault, as well as the recurrence time between such earthquakes and probability estimates for the next rupture.

The Alpine Fault extends over 650 kilometres from Milford Sound to Blenheim, with the most active part of the fault being the central and north section forming the western boundary of the Southern Alps from Haast to north of Inchbonnie. The project by PhD student Mark Yetton of the Natural Hazards Research Centre, Department of Geological Sciences, examines the earthquake hazard of the fault between the Hokitika River and Springs Junction.

To evaluate the probability of a future earthquake, the history of past earthquakes must first be established. This has been done by a combination of four methods.



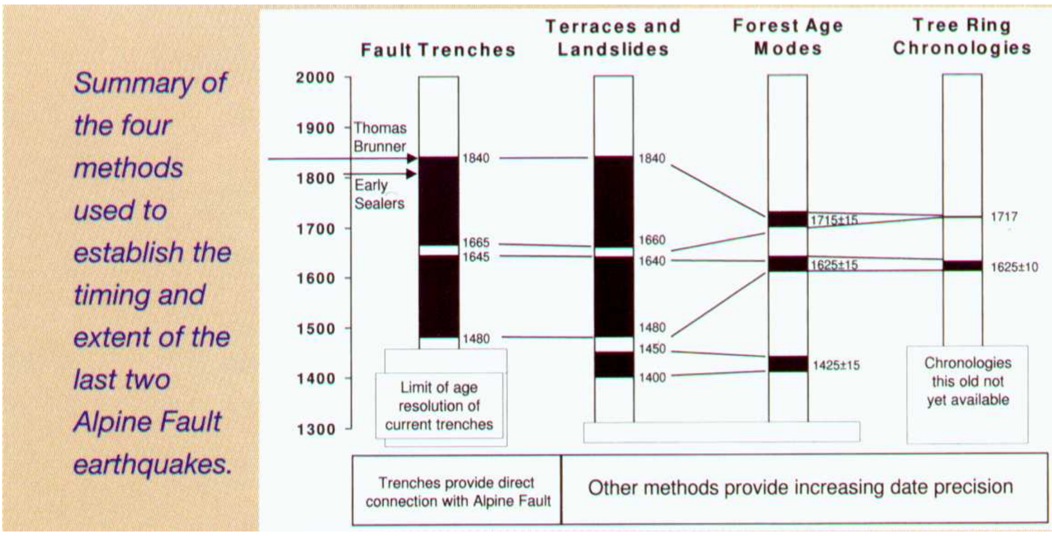
A detail of the trench exposure with a diagram of the faulted sediments, showing snapped trees in growth positions.

The first and most direct method is the excavation of trenches and pits across the most recent area of fault rupture. By defining and dating older sheared strata, and overlying younger post earthquake sediments, the timing of past fault ruptures and associated earthquakes can be estimated. Dating requires the presence of organic material to allow the use of 14C radiocarbon methods, and fortunately organic material is relatively common in the forested areas of Westland. The resolution possible with radiocarbon dating is limited, but the timing of the last earthquakes can be bracketed within broad date bands, normally spanning several decades.

The other three methods applied are made possible because previous earthquakes in rugged forested terrain in New Zealand and overseas have demonstrated the profound effects of earthquakes on slopes, rivers and forests in the epicentral area. Earthquakes commonly trigger landslides on sloping ground; cause liquefaction, subsidence, and river aggradation (building up of the flood plain by sediment deposition) in alluvial areas; and shake trees until some are broken or fall.

The time of occurrence of some landslides can be established by radiocarbon dating of buried logs. In addition, new forest tends to re-establish simultaneously in clear areas created by the earthquake damage, leaving a potential record for the timing of the earthquake in the age structure of the forest. Many trees are able to survive the earthquake but still suffer root damage, broken branches and tilting. This damage is often recorded in their growth rings, which potentially provide a very accurate way to estimate the timing and extent of earthquake disturbance.

With the assistance of Andrew Wells, a doctoral student from the Plant Science Department at Lincoln University, all four of these methods have been applied in this Alpine Fault study. The combined methods have produced a much more refined and consistent record, which indicates two recent earthquakes on the Alpine Fault in the last 500 years. The results achieved also highlight the tremendous value to be gained from such collaborative links between different science disciplines in order to tackle complex issues."



"The most recent event appears to have taken place in 1717 AD, and the surface fault rupture extended in length from Milford Sound to the Haupiri River, a distance of at least 375 kilometres. Approximately 100 years earlier, at around 1620 AD, another earthquake occurred in the north section of the fault and extended at least as far south as the Paringa River. Prior to this, another earthquake at around 1450 AD is suggested by the data but has not yet been recognised in trenches.

The implied pattern of earthquake recurrence is not regular but averages around 200 years and varies from 100 years to at least 280 years, which is the elapsed time since the last earthquake. Future earthquake probability estimates can be made using the record of Alpine Fault earthquake recurrence and a combined analysis of earthquake timing on similar plate boundary faults around the world.

Other faults also exhibit a wide range in recurrence behaviour, but for the Alpine Fault the probability estimates of the next earthquake are consistently high, with a probability of 65 ± 15% over the next 50 years increasing to 85 ± 10% over the next 100 years.

Based on the rupture length, we estimate both of the most recent earthquakes were around magnitude 8, and reconstructions can be made of the most likely pattern of earthquake shaking intensity. Those earthquakes which also rupture the more northern portion of the fault, like the one around 1620 AD, have generally more impact on the main population centres.

The next Alpine Fault earthquake is likely to produce very strong shaking in locations close to the Southern Alps. In particular locations such as Arthurs Pass, Otira, Mount Cook and Franz Josef will be seriously affected. Hokitika and Greymouth will also be strongly shaken. Predicted intensities are generally less on the east coast, but in virtually all central South Island locations the next Alpine fault earthquake will be stronger than any other earthquake experienced there in the last 100 years.

Direct effects of the next earthquake will include landslides and liquefaction. It is likely some large rock and debris avalanches will be triggered in the Southern Alps, where the landslides will be most severe, and temporary landslide dams are likely to be created. Landslides will also be triggered in sloping ground in Greymouth and the east coast foothills. They are unlikely to be serious as far away as the Port Hills of Christchurch; however, the greater density of housing in this area may still result in significant property damage. Liquefaction in Christchurch is likely to cause more damage than landslides, because the city is known to have susceptible soils, and it is well within the likely range of liquefaction. Liquefaction will also be widespread in Westland.

One of the most profound long-term impacts will be to the river regimes in river catchments draining the Southern Alps. Increased sediment load from landslide material entering the rivers will result in aggradation of the river bed and channel shifting, particularly in the upper catchment. This has potential implications for river control, bridging and transportation routes, and hydroelectric generation.

This research project by Mark Yetton was funded by Earthquake Commission, University of Canterbury, and a number of South Island Regional and Territorial Authorities including the West Coast Regional Council.

2. The second example is about Global Positioning Survey, a technique which enables scientists to monitor small movements on the Alpine Fault.

About GPS: This information is from the course outline for Waikato University's Professional Development Course in Mapping and GIS, Laboratory Two.

" ……………. 3. An introduction to GPS

Global Positioning Survey is the name given to a technology designed to provide accurate locational references anywhere in the field. There are well-established needs for people to have knowledge about their location on the Earth's surface; these include marine navigation and survey mapping. Geography field trips have also seen the benefits.

The concept of GPS came from the celestial navigation principles that have been used for thousands of years where sailors located themselves with reference to the position of visible, distant (but constant) reference points like stars. GPS satellites are surrogate stars. The earliest technological developments in GPS were radio based and these included the LORAN and DECCA systems for coastal navigation. The first navigation system to use satellites was called SAT-NAV. This system was dependent on a number of low altitude satellites with a very limited coverage leading to infrequent sightings.

The US Department of Defense provided a public service in the late 1980s, using a system that had 24 satellites orbiting the Earth at very high altitudes. (See Figures 3 to 7 in the accompanying Powerpoint file). The system was costly ($12 billion) but effective because it provided coverage for 24 hours a day. Even at coarse resolution (without differential correction) the accuracy of these devices is expected to be within 10 metres, and with differential correction or real-time correction we can expect to make measurements down to centimetre accuracy.

4. GPS operational principles

The first principle is that of triangulation; we establish our position with reference to four known points (satellites) at different angles and bearings. The satellites are in known orbits at heights of 11,000 miles. The second principle is establishing distance from these points using the travel time of radio waves. These waves travel at the speed of light, 186,000 miles per second. If a satellites was immediately overhead, it would take only 6/100s of a second for the signal to reach us. The third principle is that of synchronous timing using very accurate atomic clocks on the satellites. These clocks cost $100,000 each. Most terrestrial receivers measure with reasonable but not nano-second accuracy; (0.0000000001) of a second. Because the Garmin 12 receiver used in this laboratory has a reasonably cheap clock, we use a fourth satellite to increase accuracy.

When we know the distance of our receiver from one space vehicle, we can picture ourselves as located somewhere on an imaginary sphere. When we establish our distance from a second satellite, our position is then defined as being somewhere on the circle that marks the intersection between the two spheres. The third satellite will increase the specification of the reference to two point on this circle, and our receiver will be able to establish which of these two points is "real" (ie on the surface of the Earth; see Figure 7). The locational reference figure will be reported in one of the major grid reference systems.

When it comes to the use of GPS for locating features in mapping environments, if you spend a few minutes at a site you can expect the GPS to 'settle down' and give you a reading within 10m of the real location in each direction. The height estimation is more problematic, and 20m is as close as we expect from the Garmin 12." ………………………

***Application of GPS*:**

From GNS website at http://gns.cri.nz/Home/Our-Science/Natural-Hazards/Earth-Revealed/Plate-motion-and-deformation/Measuring-deformation/Continuous-GPS

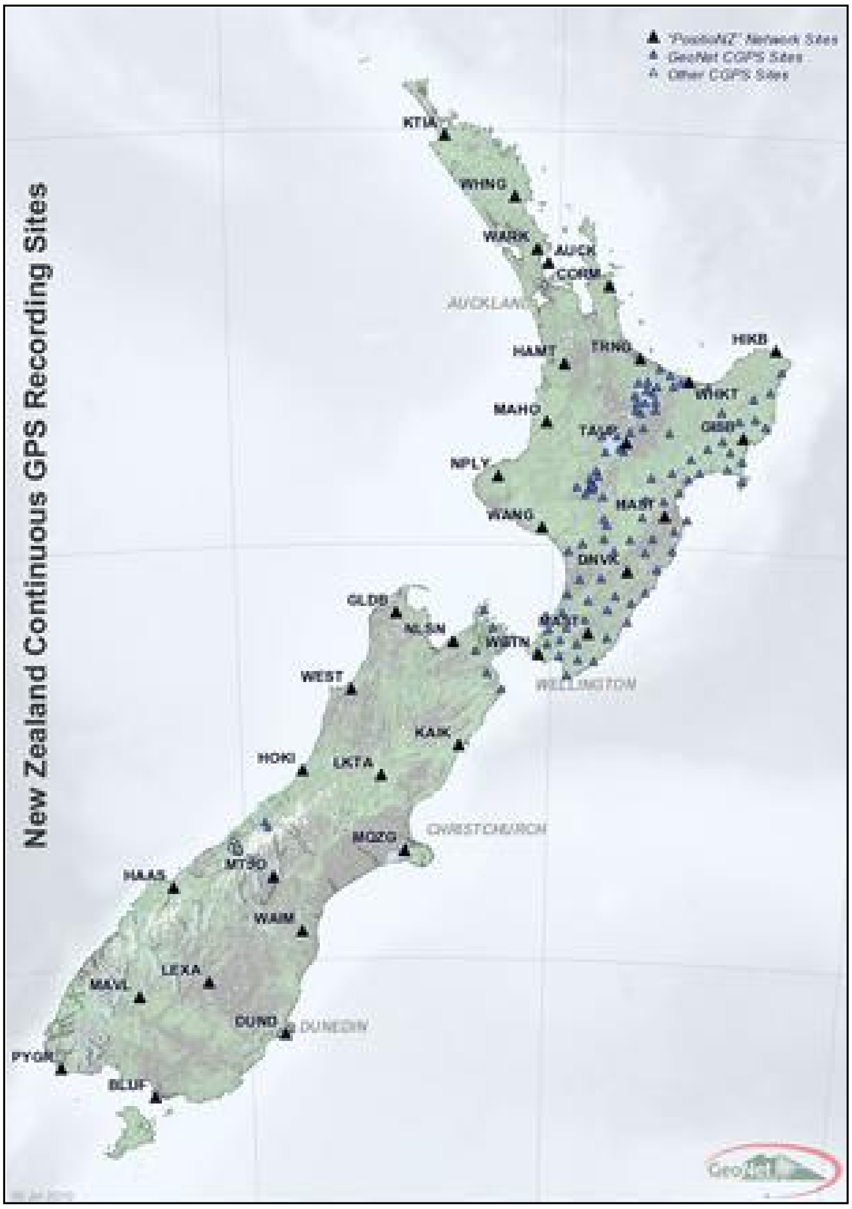
"Continuous GPS"

"To be able to monitor deformation continuously, or in near real-time, continuous GPS observations are needed.

Occasional GPS measurements only give a snapshot of the deformation at the time of each new set of measurements. For example, if a GPS survey is made through the Marlborough region every three years, we can only get a new picture of the deformation every three years.

GPS instruments are installed at permanent sites to measure the movement of these sites continuously. We are also able to process the data almost in real time so that we can have a continuous, nearly real-time measurement of motion at these sites.

The figure shows the continuous GPS stations currently operating in New Zealand. Stations were installed by GNS Science and LINZ over the past decade, under the GeoNet project. Data can be viewed on the GeoNet and LINZ sites."



3. **The third example is about LiDAR**, a technique most useful for modern research on the Alpine Fault. LDAR information is readily available on the Internet, e.g. in Wikipedia.

"LIDAR (Light Detection And Ranging, also LADAR) is an optical remote sensing technology that can measure the distance to, or other properties of a target by illuminationg the target with light, often using pulses from a laser. LIDAR technology has application in geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, remote sensing and atmospheric physics, as well as in airborne laser swatch mapping (ALSM), laser altimetry and LIDAR contour mapping. […………]."

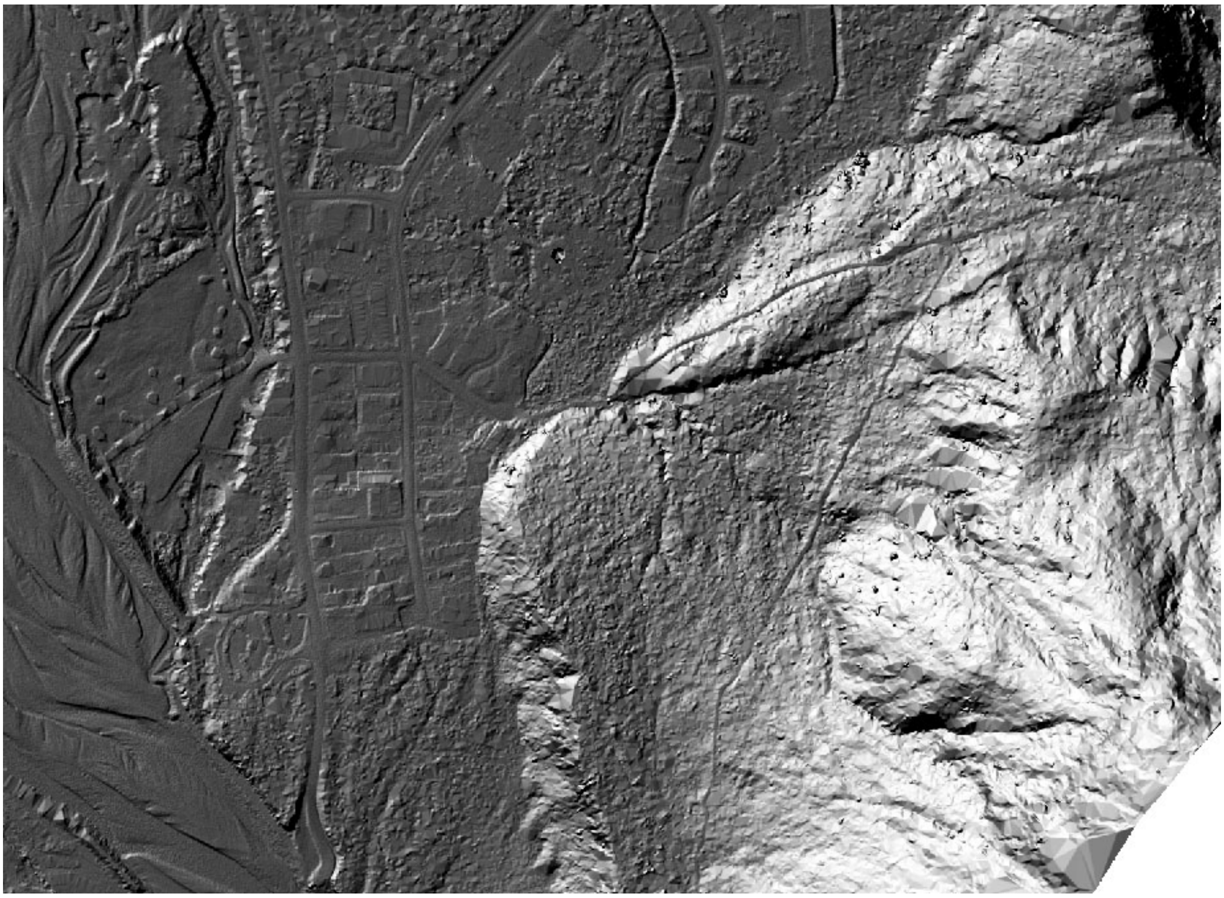
Applications:
"In geophysics and tectonics, a combination of aircraft-based LIDAR and GPS have evolved into an important tool for detecting fault and measuring uplift. The output of the two technologies can produce extremely accurate elevation models for terrain that can even measure ground elevation through trees. […….]

The combined technologies of GPS and LiDAR were used very recently (2011) by GNS Science to provide a detailed map of just where the Alpine Fault has previously ruptured in the greater Franz Josef Area. The fault goes through the town so knowing where it is liable to rupture in the future is extremely important for both development and people safety.

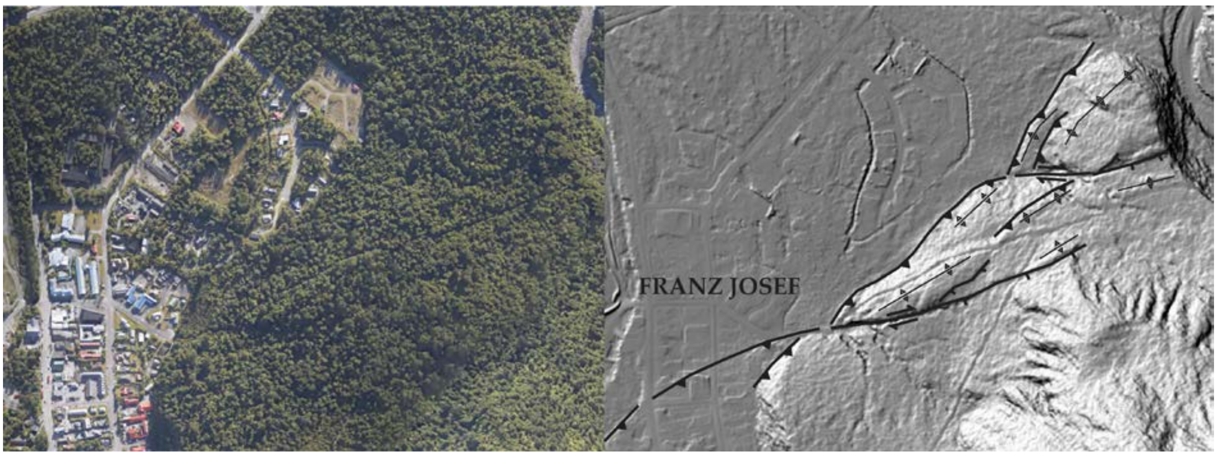
See LiDAR maps developed for Franz Josef over the page.

A. 'Unfiltered' LiDAR Map of Franz Josef area, GNS 2010.

This is a 'first cut' map made from raw data obtained from the aerial runs over the location. It shows the terrain minus vegetation but still including man-made things like roads as well as natural topographic features like fault scarps, rivers and terraces.



***B. Same area as A interpreted by a scientist** trained in identifying earthquake fault scarps.*



2d: Interpretation of Field Data

This section outlines two key methods, with examples of their application, which have enabled scientists to date when movement might have occurred along the Alpine Fault. While it was observed early on (pre-1900) that horizontal displacement had taken place and that deformation and shearing had occurred, actual dating of the times of movement has had to wait for relatively modern technology.

The counting of growth rings in trees (dendrology) and Carbon 14 dating are both well established tools for scientists here in New Zealand. Dating using isotopes of other elements such as Potassium, Oxygen and Uranium and a technique which uses the optical luminescence of rock particles such as quartz sand are also used. However the biggest advance in this area may well come from Cosmogenic Isotope analysis which is just gaining ground now here in New Zealand. The Marsden Fund's No.11, April 2000 newsletter at **www.rsnz.govt.nz/funding/marsden_fund/news11/index.php** states that:

"Kiwi scientists are harnessing homegrown technology to improve a technique that helps track the changing landscape due to erosion, glaciation and **the movement of tectonic plates.**

The method relies on measuring the trace amounts of beryllium and other isotopes produced in the surface of rocks by cosmic rays hitting the Earth. The amount of isotope in a rock can be used to infer how long the rock has been exposed, in the geologically important range from 10 thousand to half a million years ago.

Beryllium isotopes, for example, are generated in minerals like quartz in rock surfaces. This occurs through the interaction of cosmic rays, mainly neutrons, with atoms of oxygen and silicon…………. "

1. Dendrochronology

To measure growth rings in a living tree a sample must be taken from that tree. To do this a hollow-cored manual drill with a long drill-bit and a handle that looks much like a wheel-brace is used. This technique requires a strong person.

The drill is put up against the selected tree (preferably one clear of low branches) at a set distance above the ground (usually about 1.4 - 1.5m). Then the handle is turned, driving the bit into the tree. After this the drill bit is carefully removed along with a long core of wood. On a good day a field team can take around 30 cores.

Back at a laboratory lab the long thin samples are then dried, sanded flat and the rings counted. This is generally done under a low-power microscope, although for fast-grown trees where the rings are far apart it can be done with the bare eye.

With small to medium sized trees, it is possible to drill to the centre. If this can't be done because the distance to the centre is longer than the drill bit, one can only assume that the growth rate is the same for the distant past as the recent (which may not be true). With a regular tree the centre can be calculated from measuring the diameter but sometimes the centre of the tree rings is offset from the physical middle of the tree which can skew the data. However by selecting trees for coring carefully, and doing enough of them, a good estimate can still be made of the age of trees and their growth rate at various times. In good years the growth rings are further apart but after drought or earthquake disturbance growth can be minimal, with the rings then much closer together.

Resource Example for 1.

This resource example shows how the analysis of tree ring growth has been used for an ongoing (as of 2002) study at Whataroa, South Westland by a team of interdisciplinary researchers from the Institute of Geological & Nuclear Sciences (GNS) and Lincoln University. The material has been taken from a report called ***"The Next Great West Coast Earthquake"*** by Mauri McSaveney, GNS scientist. A full copy of this report can be found in Section 4 of this Appendix (Earthquake Prediction) or/and in *Tephra Magazine*, Volume 19, June 2002 pp 36-41.

(An excerpt from)

"The Next Great West Coast Earthquake"

“The study at Whataroa tests the idea that recent changes in the landscape have been dominated by the effects of Alpine fault rupture (the last there estimated to have occurred in 1717 AD). By combining geomorphic mapping, stratigraphy, and dating of soils, terraces and fans with inform-ation on the age of areas of forest obtained by tree-ring counting**,** the study team has evaluated the nature and timing of recent periods of build-up of alluvium on the Whataroa lowland plain.

HOW OLD IS THAT TREE?

Much of the forest within the Southern Alps area and to the west of the Alpine fault is dominated by long-lived trees (commonly living more than 700 years) that tend not to tolerate shade well. These trees become established on land surfaces disturbed by landslides or floods, or in areas where the major forest canopy has collapsed. Forested areas that have been affected by major disturbance typically contain an approximately even-aged stand of trees (a cohort) because they all became established at about the same time in disturbed openings. By determining the age of the oldest trees in a cohort, by coring and counting of growth rings, the date of the disturbance that formed the opening can be estimated.

Tree ages on the Whataroa lowland alluvial-fan surfaces were collected from 14 stands of trees. In all 267 trees on the fan were cored. The upper reaches of the Whataroa alluvial fan near the mountain front are largely covered by relatively young trees, most of which became established after the Alpine fault earthquake of 1717 AD. In contrast, the lower reaches of the fan closer to the coast are dominated by older trees that were established before 1717 AD and the reach also includes a group established around 1625 AD……………..."

Taking a tree core as per the photo gallery by Henri Grissino- Mayer at http://web.utk.edu

The tree is a Caribbean Pine on the Island of Abaco in the Bahamas, Central America

2. Carbon Dating

The following excerpts from **radiocarbon WEB-info www.c14dating.com / “The Method”** explain both how Carbon Dating works and about some of the background behind the development of the technique. The website material has been collated by Thomas Higham and also quotes from *Radiocarbon Dating: An archaeological Perspective* written by Taylor in 1987.

By Higham:

"Radiocarbon dating has been one of the most significant discoveries in 20th century science. Renfrew (1973) called it 'the radiocarbon revolution' in describing its impact upon the human sciences. Oakley (1979) suggested its development meant an almost complete re-writing of the evolution and cultural emergence of the human species. […………] The radiocarbon dating method was developed by a team of scientists led by the late Professor Willard F. Libby of the University of Chicago in immediate post-WW2 years. Libby later received the Nobel Prize in Chemistry in 1960: "for his method to use Carbon-14 for age determinations in archaeology, geology, geophysics, and other branches of science." According to one of the scientists who nominated Libby as a candidate for this honour; ‘Seldom has a single discovery in chemistry had such an impact on the thinking of so many fields of human endeavour. Seldom has a single discovery generated such wide public interest.’

By Taylor:

Today, there are over 130 radiocarbon dating laboratories around the world producing radiocarbon assays for the scientific community. The C14 technique has been and continues to be applied and used in many, many different fields including hydrology, atmospheric science, oceanography, geology, palaeoclimatology, archaeology and biomedicine.

The 14C Method

There are three principal isotopes of carbon which occur naturally - C12, C13 (both stable) and C14 (unstable or radioactive). These isotopes are present in the following amounts C12 - 98.89%, C13 - 1.11% and C14 - 0.00000000010%. Thus, one carbon 14 atom exists in nature for every 1,000,000,000,000 C12 atoms in living material. The radiocarbon method is based on the rate of decay of the radioactive or unstable carbon isotope 14 (14C), which is formed in the upper atmosphere through the effect of cosmic ray neutrons upon nitrogen 14. The reaction is:

14N + n => 14C + p

(Where n is a neutron and p is a proton)

The 14C formed is rapidly oxidised to 14CO2 and enters the earth's plant and animal lifeways through photo-synthesis and the food chain. The rapidity of the dispersal of 14C into the atmosphere has been demonstrated by measurements of radioactive carbon produced from thermonuclear bomb testing. 14C also enters the Earth's oceans in an atmospheric exchange and as dissolved carbonate (the entire 14C inventory is termed the carbon exchange reservoir (Aitken, 1990)). Plants and animals which utilise carbon in biological foodchains take up C14 during their lifetimes. They exist in equilibrium with the C14 concentration of the atmosphere, that is, the numbers of C14 atoms and non-radioactive carbon atoms stays approximately the same over time. As soon as a plant or animal dies, they cease the metabolic function of carbon uptake; there is no replenishment of radioactive carbon, only decay.

Libby, Anderson and Arnold (1949) first discovered that this decay occurs at a constant rate. They found that after 5568 years, half the C14 in the original sample will have decayed and after another 5568 years, half of that remaining material will have decayed, and so on (see figure 1 below). The half-life (t 1/2) is the name given to this value which Libby measured at 568±30 years. This became known as the Libby half-life.

After 10 half-lives, there is a very small amount of radioactive carbon present in a sample. At about 50 - 60 000 years, then, the limit of the technique is reached (beyond this time, other radiometric techniques must be used for dating). By measuring the C14 concentration or residual radioactivity of a sample whose age is not known, it is possible to obtain the count rate or number of decay events per gram of Carbon. By comparing this with modern levels of activity (1890 wood corrected for decay to 1950 AD) and using the measured half-life it becomes possible to calculate a date for the death of the sample. As 14C decays it emits a weak beta particle (b), or electron, which possesses an average energy of 160keV. The decay can be shown:

14C => 14N + b

Thus, the 14C decays back to 14N. There is a quantitative relationship between the decay of 14C and the production of a beta particle. The decay is constant but spontaneous. That is, the probability of decay for an atom of 14C in a discrete sample is constant, thereby requiring the application of statistical methods for the analysis of counting data.

It follows from this that any material which is composed of carbon may be dated. Herein lies the true advantage of the radiocarbon method, it is able to be uniformly applied throughout the world. The following is a list of just some of the carbonaceous natural materials that have been often radiocarbon dated in the years since the inception of the method.

charcoal wood twigs seeds peat leather shells mud soil pollen
ice cores iron meteorites tufa water corals antlers horn

Later measurements of the Libby half-life indicated the figure was ca. 3% too low and a more accurate half-life was 5730±40 years. This is known as the Cambridge half-life. (To convert a "Libby" age to an age using the Cambridge half-life, one must multiply by 1.03). The major developments in the radiocarbon method up to the present day involve improvements in measurement techniques and research into the dating of different materials. Briefly, the initial solid carbon method developed by Libby and his collaborators was replaced with the Gas counting method in the 1950's. Liquid scintillation counting, utilising benzene, acetylene, ethanol, methanol etc, was developed at about the same time.

Today the vast majority of radiocarbon laboratories utilise these two methods of radiocarbon dating. Of major recent interest is the development of the Accelerator Mass Spectrometry (AMS) method of direct C14 isotope counting. In 1977, the first AMS measurements were conducted by teams at Rochester/Toronto and the General Ionex Corporation and soon after at the Universities of Simon Fraser and McMaster (Gove, 1994). The crucial advantage of the AMS method is that milligram sized samples only are required for dating. Of great public interest has been the AMS dating of carbonacous material from prehistoric rock art sites, the Shroud of Turin and the Dead Sea Scrolls in the last few years. The radiocarbon dating method remains arguably the most dependable and widely applied dating technique for the late Pleistocene and Holocene periods." (i.e. the most recent geological periods) …………..”

Resource Example for 2.

This **abstract** can be found Royal Society of NZ website, **www.rsnz.govt.nz** under the New Zealand Journal of Geology & Geophysics 1998, Volume 41: 475-483

“Progress in understanding the paleoseismicity of the central and northern Alpine Fault, Westland, New Zealand”

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Abstract

“Radiocarbon dates from trenching of the Alpine Fault trace at Crane Creek, between the Haupiri and Ahaura Rivers, demonstrate the last earthquake rupture at this location occurred between AD 1480 and 1645, with associated local river aggradation and terrace formation. A second trench 6 km farther north at Ahaura gives the same radiocarbon age for the last event.

An enlarged record of radiocarbon ages for aggradation terraces and landslides in central and north Westland has a group of dates which are a reasonable match to the date range from the trenching. While this is compatible with regional aggradation and landsliding associated with an Alpine Fault earthquake during this period, this type of data cannot be used to demonstrate the dates were synchronous or co-seismic.

However, historical earthquakes have shown that, in steep forested terrain, an earthquake causes extensive forest mortality, with a corresponding synchronous period of regeneration. Recent information of forest age in Westland indicates two such periods in the last 600 yr, and the most recent of these reflects the earthquake rupture recorded in the trenches. This implies the earthquake occurred at the young end of the trench date range at c. AD 1600-1650.”

Keywords: *Alpine Fault; central and northern Westland; paleoseismology; trenching; neotectonics; radiocarbon; forest disturbance*

Combustion system for preparation of CO2 from organic carbon materials. See website at :www.c14dating.co,/lsc.html

3. Structural Geology of the Alpine Fault

"About the effects of tectonic plate movement"

Tectonic plate movement along the Alpine Fault has had a number of major effects on the South Island's landscape. These include:

a. Displacement

b. Uplift

c. Metamorphism

d. Shearing

The effects listed are included in one form or another over the six resource examples set out below. For more information students should check out the Reference Section of this Appendix which lists a number of good texts and websites. Research is continuing in this area all the time and yearly new reports from scientists add to the bigger picture about both the general mechanics of plate tectonics and what is happening at the interface of the Australasian and Pacific Plates in New Zealand's South Island.

As this is a more scientific section with terminology which may be unfamiliar to the student, a glossary of words and terms generally related to Alpine Fault movement has been made available. For other explanations students are referred to texts in the reference or a Dictionary of Geology.

Resource Example 3a)

Definitions from *New Penguin Dictionary of Geology*, Philip Kearey, 1996 Edition

A Glossary of Terms

structural geology	the branch of Earth Sciences dealing with rock *structures* formed by *deformation*
structure	any geological feature than can be defined geometrically
deformation	a geological process in which the application of *force* causes a change in geometry, such as the production of a *fold, fault* or *fabric*, often associated with *metamorphic* reactions
force	that which produces motion in a body: mass times *acceleration*
fold	a curved or angular shape of originally planar geological surface
fault	a discontinuity surface across which there has been a *shear displacement*
fabric	the pervasive features of a rock
shear	deformation in which the angular relationship between material lines in a body change, i.e. a rotational *stress* or *strain*
stress	the *force* per unit area acting on the surface of a solid plus the equal and opposite reaction of the material
strain	a change in shape or internal arrangement of rock caused by *tectonic* activity
displacement	the relative distance moved across a line or plane
shear fault	a *fault* on which *displacement* has been produced by *shear*
shear direction	the direction in which *displacement* takes place during *shear*
shear band	a narrow band of localized *strain* developed in deforming, *anisoptropic, foliated* rocks, e.g. *mylonite, phyllonite*, in which the *deformation* folds the existing *metamorphic* foliation
tectonic	1. descriptive of a *structure* produced by *deformation* 2. relating to a major Earth *structure* and its formation
foliation	a repeated or penetrative planar feature in a rock which be defined by fabric, compositional layering or pervasive fracture. Most commonly used for metamorphic fabrics, e.g. *cleavage, schistosity, gneissosity*
schistosity	A *foliation* produced by deformity in which tabular minerals, coarse enough to be visible to the naked eye, have a *preferred orientation*

Resource Example 3b)

Figure 4.11 from page 26 of "*New Zealand Adrift*" by Graeme Stevens, 1980.

This shows how rocks now located in the Dun Mountain area near Nelson, have been displaced some 480 kilometre from their former position near the present Red Hills of far South Westland. The displacement has happened in stages over many earthquakes, going back some 140 million years ago (although some scientists would argue for the nearer date of only 9 million years ago). Whichever full recognition for just how big a part the Alpine Fault has played in shaping New Zealand only came about with Wellman's findings in the 1940's and 50's. Early geological reports do not even describe the Alpine Fault as we know it.

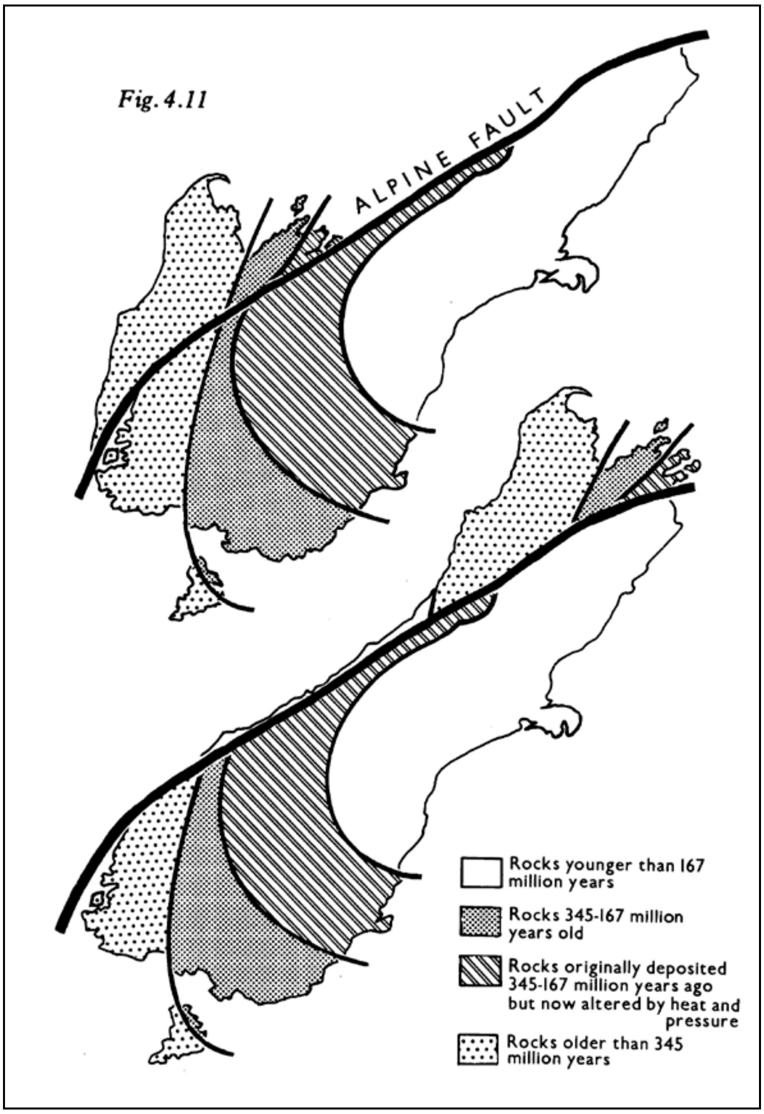

Fig 4.11 shows diagrammatically a 480 km displacement along the Alpine Fault. The last movement in 1717 is estimated to have caused an 8metre sideways displacement. How many times does 8m go into 480 kms. Just 6000 (earthquakes that is) - give or take a few.

Resource Example 3c)

A professional presentation to other geologists and lay people.

"DYNAMIC LANDSCAPES: THE FALL AND RISE OF A SMALL CONTINENT"

Inaugural Professorial Lecture delivered by Professor Richard Norris MA DPhil FRSNZ at the Castle Lecture Theatre, University of Otago, Wednesday October 13th, 1999.

"Wild and dramatic landscapes are New Zealand's premier tourist attraction. Whether sailing on Milford Sound, skiing at Coronet Peak or trekking up the Franz Josef Glacier, the rugged landscape of southern New Zealand forms the basis of the country's tourist industry and provides the major marketing focus.

One of the first tourists to visit New Zealand remarked on sighting the South Island that it was 'A great land uplifted high'. Abel Tasman's comment showed considerable insight. He could have merely said "A mountainous land" or "A land of great height" or some other purely descriptive phrase which avoided any reference as to why the land was mountainous. Perhaps being a Dutchman and coming from a country where any land more than a few metres above sea-level is a major feature, made him think intuitively that the snowy peaks of the Southern Alps had not always been at their present height but had been uplifted from more humble elevations at some time in the past.

Whether or not such implications were intentional, we can now confirm that Tasman was on the right track. Recent geological research, however, shows that not only is the South Island a land uplifted high, but that it is a land still actively being uplifted. The Earth's crust is being twisted, compressed and distorted as mountains are pushed up and collapse. The rates may be slow but they are inexorable. It is a sobering thought that the Southern Alps are higher now than when Tasman saw them and the western coastline has shifted some 8 metres further northeast. Since his visit, some 30 cubic kilometres of crust has been raised above sea-level and a similar amount eroded and washed down the rivers. The dynamic landscape and the geological processes responsible ultimately control the nature and evolution of the whole environment.

In this lecture I wish to explore how the recent geological evolution of New Zealand is responsible for the natural environment in which we live and for many of the processes which affect our interactions with it. Geology affects us in a variety of ways no matter where on Earth we live. Sometimes these influences may be indirect and not immediately apparent, for instance why a few countries appear to have a monopoly on the world's oil supplies. However, nowhere perhaps are the effects more dramatic than in New Zealand, where active volcanoes and frequent earthquakes remind us that dynamic landscapes carry with them an element of risk. Less obvious are the effects on climate, on drainage systems, on soils and sedimentation, on flora and fauna. Mountains may be uplifting but they are also falling down almost as fast. Deep-seated geological materials are being raised to the surface to be eroded and redistributed within the environment. Active Earth processes and the materials from which the Earth is formed are a fundamental influence on the flora and fauna which inhabit it and together constitute the natural environment.

New Zealand was born on the margin of the great southern continent of Gondwana. Gondwana was made up of Australia, Antarctica, South America, South Africa and India and occupied the southern hemisphere for over 200 million years until it began to break up some 120 million years (Ma) ago. The Tethys Ocean separated it from the northern supercontinent of Laurasia.

The eastern coastline, formed by Australia and Antarctica, faced towards the great ocean of Panthalassa, the precursor of today's Pacific Ocean. It was an active continental margin, like the Pacific margins of today. It grew oceanward by the accretion of materials such as thick sedimentary deposits, volcanic arcs and slices of ocean floor. These additions were generally dismembered, deformed and metamorphosed as they were piled up against the continent by the westward underflow of the ocean floor. Around 100 Ma, this westward underflow ceased and instead, the area was pulled apart as Australia, Antarctica and New Zealand began to go their different ways. By 85 Ma, the tensional forces had caused a large piece of the continental margin to split away, with new sea-floor being generated in the widening gap of the Tasman Sea and southern ocean. The New Zealand mini-continent had begun its independent existence and its long and continuing drift out into the Pacific.
The New Zealand continental plateau covers approximately 3 million square kms, about ten times the present land area of the two islands. Most of it today is under water. The stretching of the crust that preceded the split

from Gondwana meant that most of the mini-continent is substantially thinner than normal continental crust. As the newly independent New Zealand left the shores of Gondwana behind and moved off into the Pacific, its thinned crust cooled down and slowly sank beneath the waves. Only where areas of thicker crust remained, such as central Otago, did low lying islands project above sea-level. Elsewhere the sea extended across the mini-continent and deposited marine sediments such as the mudstones and limestones around Dunedin and Oamaru or the limestones of Waikato.

This early history may seem rather remote from the environment of today and to have little relevance. In fact, it is critical to much of the character of present day New Zealand. The rock units from which New Zealand is built were largely emplaced by this time. Most of New Zealand's deposits of minerals and coal had already formed. A thin layer of poorly consolidated marine clay was deposited over much of the country during this period. These clay layers overlying resistant basement rocks, such as the Abbotsford Mudstone near Dunedin, create easily eroded and unstable hillsides when uplifted above sea-level. Many of the geological fault lines and other zones of weakness in the crust were initiated during the stretching of the continental fragment, only to be reactivated again in later times. New Zealand's unique flora and fauna owes its character largely to this break from Gondwana and its subsequent history. Nevertheless, this early phase is essentially about the fall of a small continent. Had New Zealand remained as a series of low wind-swept islands in the South Pacific, similar to the Chatham Islands of today, it is doubtful whether its attraction as a tourist destination would have been notable. Fortunately for the tourist industry, events beginning around 45 Ma ago would lead to the rise of part of the continent from beneath the sea and eventually to "a great land uplifted high".

Sea-floor spreading in the Tasman Sea ceased around 55 Ma. Australia then parted company with Antarctica and followed New Zealand northwards, leaving behind a rapidly expanding southern ocean. Because Australia was travelling northwards faster than New Zealand, a plate boundary between them developed around 45 Ma. This boundary ran through western New Zealand and linked up with island chains in the western Pacific. The mini-continent was splitting in two. At first the plate boundary was a zone of slow oblique extension, with the Australian plate moving northwards and away from New Zealand. Small ocean basins such as the Emerald Basin formed south of Fiordland. Over time the motion became more of a NE-SW shear and around 25 Ma ago, the Alpine Fault developed through South Island as a discrete shear zone. Areas close to the fault were deformed and uplifted and the sea began to retreat. The rate of shear increased towards the present and, particularly over the last 7 Ma, developed a component of convergence. During this time, the tempo of deformation increased as the two halves of the mini-continent were driven together. The Pacific plate was thickened and uplifted to form the Southern Alps and the dynamic landscape of today was established."

Resource Example 3d)

Online results of annual **field trips** undertaken by Otago University Geology students (and staff) regarding the Alpine Fault. The examples below are part of their "Virtual Trips" shown online
www.otago.ac.nz/geology/features/aftrip/thrust.htm

1. Thrust Section at Gaunt Creek *(part text only)*

The Alpine Fault in the central region forms dipping sections with oblique thrust characteristics connected by sections with mainly dextral strike-slip, resulting in a "zigzag" outcrop pattern. In this view looking south across Gaunt Creek, the Alpine Fault is seen emplacing mylonite over Holocene gravels. The light-coloured material is the basal cataclasites (crushed mylonite), here some 40 m thick. The fault dips c.35° SE near the base of the outcrop although it flattens to the west as it reaches the original ground surface.

2. Alpine Fault mylonites, Harold Creek

The convergence across the Alpine Fault has resulted in the uplift and exhumation of an extensive mylonite zone, formed at depths of 20-25 km. The zone outcrops immediately east of the fault and is up to 1 km wide. A zone of cataclasite and gouge up to 50 m thick bounds the mylonites to the west, and ultramylonite and mylonite grade eastwards into protomylonite and eventually into amphibolite facies Alpine Schist which forms the western flanks of the Southern Alps.

Quartzo-feldspathic mylonite with winged porphyroclast of feldspar indicating dextral movement. *(camera lens cap to show size)*

Broken up mylonite intruded by pseudo-tachylyte or friction melt, the result of momentary high temperatures developed during coseismic frictional sliding

Resource Example 3e)

Online information: outline of student project parameters for **Alpine Fault research** by University staff as per **http://pcwww.liv.ac.uk/earth/web/Prior.html**

"Kinematics of the Alpine Fault zone, New Zealand: material pathways during exhumation"

Supervisors: Dr D Prior, Dr J Wheeler, Prof N Kusznir
& Prof R Norris (University of Otago, New Zealand)

"Understanding the mechanisms of creep deformation in the Earth and the conditions under which creep occurs is crucial to the understanding of geodynamics. The Alpine Fault zone of New Zealand is an excellent place to examine rocks that have deformed by creep because we can place independent constraints on the conditions of natural deformation and the way these conditions have changed with time. This is because the Alpine Fault is a section of the Australian-Pacific plate boundary. The Cainozoic plate boundary history is well constrained in the New Zealand region, geodetic data constrain the present day surface deformation and geomorphological data constrain uplift rates. Metamorphic rocks are carried to the surface and deformed in the Alpine Fault zone, east of the plate boundary, to form the Alpine Fault mylonites. This project aims to use field data and kinematic modelling to constrain the kinematic pathways by which mylonite samples may have reached the surface and the potential strain, strain rate and temperature histories that they have experienced. The final stage of the project will use the predicted pathways to model the kinetics of rock deformation and associated metamorphic changes in the Alpine Fault mylonites.

1. **Field Data.** The distribution of strain east of the Alpine Fault is required to build realistic kinematic models. Strain close to the boundary must be high, but obtaining reliable strain data is difficult as the area is covered in rain forest and strain markers are lacking. Recent work (Norris & Cooper, in press) has shown that the distributions and dimensions of distinctive pegmatite suites can place good constraints on the shear strain as a function of distance from the Alpine Fault. Other distinctive and traceable rock units have been identified (Prior, 1988). The student will make detailed lithological logs of mylonite sequences in creeks (stream sections) that sample the zone to the east of the Alpine Fault.

These data will be used to develop a much more complete picture of strain distribution in the fault zone. In addition, variations in kinematics of mylonitic deformation provide a constraint for kinematic modelling. The kinematics of mylonite deformation is often difficult to assess as there is no lineation: probably due to the high strain. The student will collect large mylonite samples with 50 to 100m spacing in the creek transects. Slicing these samples will enable the kinematic indicators to be visualised in 3D and the mylonite kinematics to be determined.

2. **Kinematic Modelling.** The student will use their own geological data together with the existing geological, geophysical and geodetic data sets as boundary conditions for 3D kinematic models of the Alpine Fault zone. The student will explore end member models in which i) the whole zone deforms simultaneously with heterogeneous strain-rates and ii) the shear zone narrows and shear strain-rates increase with time, as well as iii) employing hybrid and more complex models. The models will be used to synthesise the exhumation pathways and the kinematic and thermal histories of samples at different distances from the fault. It is crucial to see whether the models make testable predictions and to see how sensitive the synthesised exhumation pathways might be to the model parameters.

3. **Kinetic Modelling.** The student will undertake kinetic modelling of diffusion processes to assess how the pathways might influence final rock microstructures, mineral assemblages and major element/ isotope ratios so that we can assess what such data can tell us about the conditions and processes during deformation at depth.

The student will complete up to 2 field seasons in New Zealand, including some time at Otago University. The student will receive extensive training in field analysis of metamorphic tectonites, kinematic analysis of samples, kinematic modeling and kinetic modeling. The student will also participate in the Departmental and University Postgraduate training programme."

Other publications by supervisor(s) relevant to research area

- **Norris, R.J.** & Cooper, A.F. *In Press*. Very high strains recorded in mylonites along the Alpine Fault, New Zealand: implications for the deep structure of plate boundaries.

- **Prior, D.J.** 1988, 'Deformation processes in the Alpine Fault Mylonites, South Island, New Zealand'.

For more information contact:

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Department of Earth Sciences, University of Liverpool,
4 Brownlow Street, Liverpool, L69 3GP, U.K.
Website: **www.liv.ac.uk/earth**

Resource Example 3f)

Two example of **abstracts** or summaries on research about the Alpine Fault found in the New Zealand Journal of Geology Geophysics listings on the Royal Society of NZ website at **www.rsnz.govt.nz/publish/nzjgg**

SAMPLE A [from 1994 listings]

"Late Quaternary evolution of the Alpine Fault Zone at Paringa, South Westland, New Zealand"

GUY D. H. SIMPSON
ALAN F. COOPER
RICHARD J. NORRIS
Department of Geology
University of Otago
P.O. Box 56
Dunedin, New Zealand

Abstract

"Recent mapping of the Alpine Fault trace in the Paringa region has revealed the existence of an extensive Haast Schist-derived thrust nappe resting on Western Province basement rock and moraine. Erosion of the nappe by the Paringa River and its tributaries, however, has resulted in eastward propagation of the active fault zone, forming southeast-dipping thrust faults linked by swarms of steeply dipping strike-slip faults.

Late Quaternary sediments of the Paringa Formation have been intensely deformed along a newly developed zone of shortening and uplift on the northeast side of Paringa River. Marine, fluviatile, lacustrine, and terrestrial sediments record progressive uplift east of the Alpine Fault. The occurrence of lake deposits rhythmically interbedded with forest horizons may have resulted from damming of the Paringa River behind the zone of rapid uplift.

The uplift rate for this region over the last 16 ka has been calculated at 13.7 +/- 1 mm/yr. After removing the effects of tilting due to localised uplift, a regional uplift rate of 7-8 +/- 1 mm/yr can be obtained. Estimated average uplift rates for the intervals between 16 ka and the present, and between 11 ka and the present are statistically indistinguishable.

Keywords: Alpine Fault; neotectonics; Paringa Formation; 14C dates; uplift rate

SAMPLE B [from 1995 listings]

"The Main Divide Fault Zone and its role in formation of the Southern Alps, New Zealand"

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Abstract

The Main Divide Fault Zone of the Southern Alps is a major fault system extending for a minimum of 60 km immediately below and east of the Main Divide. Regionally it strikes parallel to the Alpine Fault, but in detail is segmented with N-NNE-striking oblique-reverse faults dipping 40-60deg. northwest, linked by steeper NE-E-striking, oblique strike-slip structures. Dextral steps in the Main Divide follow segmentation of the adjacent faults, with major saddles above the NE-E fault segments. The hangingwall rocks are relatively homoclinal, dipping c. 40deg. WNW, and composed of pumpellyite-actinolite facies greywackes and semi-schists with bedding transposed by anastomosing faults. The footwall rocks are less deformed, mostly non-schistose prehnite-pumpellyite facies greywackes and argillites, striking generally northeast (dip 50-85deg. northwest), but are folded by large kilometre-scale, steeply plunging folds. Thermochronological data indicate significant vertical offset during the late Cenozoic. The Main Divide Fault Zone is a backthrust off the Alpine Fault plate boundary, and is fundamental to the uplift and strain within the Southern Alps.

Keywords: tectonics; uplift; faulting; transpression; Torlesse Terrane; Alpine Schist; Alpine Fault; Main Divide Fault Zone; New Zealand; Southern Alps

NOTE: *For some of the more technical terms in these abstracts refer to the Glossary of Terms in this section or/and to a Dictionary of Geology*

4. Future Earthquake Predictions along the Alpine Fault

"based on combined historical, technological and scientific knowledge'

The information combined from all research about the Alpine Fault has enabled New Zealand scientists to make some fairly definite predictions about what might happen in the future in the light of what they have determined of the past. The acquisition of such information escalated over the last 25 years of the 20th century hand in hand with technological innovation and this looks set to continue into the new millennium with the application of the recently developed Surface Exposure Dating technique which uses cosmogenic isotope analysis.

The bulk of this information has been put together by geologists and their kith and kin - geomorphologists, geophysicists, paleontologists - but the real breakthrough has come with the addition of the cross discipline work from the field of plant science and the investigation of same age forest stands.

Scientists have been making predictions about the next movement on the Alpine Fault for many years, but as we move into the 21st century these predictions have become more authoritive, more assertive. With recent research to back their assertions, scientists are issuing predictions with far more surety than in the past. This can be seen from studies of news articles since the 1970's.

West Coasters, or South Islanders, for that matter do not rest easy when the subject of movement on the Alpine Fault is broached with all current predictions being for a level of trauma - a Force 8 earthquake - never previously recorded. However rather than being wilfully ignorant, most residents are surprisingly aware and just get on with their lives taking what steps they can to be prepared. Local agencies responsible for Civil Defence also get on with planning as charged because there are always lesser events for which their planning and skills are needed and doing nothing because a Force 8 event would overwhelm the West Coast is simply not an option.

Resource material in this section includes :

a. A Summary of Known Information

b. Newspaper Predictions over the Years

c. The Latest from our own Scientists

d. A Qualified Prediction

Resource Example 4a

GNS **News Release** of September 10th 1998, giving a summary of known information about the Alpine Fault. Also available online at **www.gns.cri.nz/news/release/alpf.html**

"A CLEARER PICTURE OF THE ALPINE FAULT'S EARTHQUAKE HISTORY"

"Scientists have reached agreement on the dates for the last four large earthquakes on the Alpine Fault, which runs from Milford Sound up the spine of the South Island to Blenheim, 650km to the north.

For several years there has been debate about how many earthquakes have occurred on parts of the fault over the past 1000 years, and when they occurred.

Agreement on the dates and sizes of the historical earthquakes came at a two-day workshop on the Alpine Fault in Wellington at which 20 scientists reviewed all the latest research.

Workshop organiser Kelvin Berryman, a geologist with the Institute of Geological & Nuclear Sciences Limited, said the workshop had consolidated research done by many groups during the past five years. The workshop marked the first time that all the main players in the research had gathered to discuss their results.

'Our aim was to synthesise the available research to see if we could reach a consensus on when the last major ruptures occurred. The improved confidence we now have will form the basis of evaluating the future hazard of this fault,' Dr Berryman said.

Dr Berryman said that the best estimate was that there was a high likelihood of an earthquake on the Alpine Fault within a few decades. It would cause severe ground-shaking in many parts of the South Island.

To evaluate the probability of a future earthquake on a major fault, scientists need to establish the dates and size of past earthquakes. In the case of the Alpine Fault, this had been done by a combination of fault trenching, radiocarbon dating, tree-ring analysis, the study of lichens and contemporary earthquakes, statistical analysis, and highly accurate measurements of the deformation at the Earth's surface using global positioning satellite technology.

Results of all these studies have confirmed that the previous four ruptures along the fault occurred at intervals of 100 to at least 300 years. The last happened about 1717AD.

It appears to have involved a rupture of nearly 400km of the southern two thirds of the fault and generated an earthquake of about magnitude 8. About 100 years earlier, at around 1620AD, another earthquake occurred in the central and northern section of the fault. It produced a similar sized earthquake.

Prior to this there were earthquakes at about 1450AD and about 1100AD. Their magnitudes were also about 8.

The most active part of the fault is the central section between Milford and Inchbonnie. Further north the fault becomes progressively less active as movement is transferred onto the numerous faults in Marlborough.

Dr Berryman said when the next rupture occurred on the Alpine Fault ground-shaking intensities were expected to be less on the South Island's east coast, but throughout most of the South Island the next earthquake on this fault would be stronger than any jolt experienced there in the past 100 years.

Direct effects will include landslides and liquefaction - where some soils behave like liquid during the earthquake causing structures to sink, tilt or topple. Landslides would be most severe in and around the Southern Alps. Some roads, bridges and services may not be fully restored for months, or even years.

Dr Berryman said one of the more profound long term impacts would be landslides that caused major changes to rivers that drain the Southern Alps. This had implications for river control, bridges, and hydro-electricity generation.

Scientists did not want to be "doomsayers", but it was important to keep communities and local and national authorities informed about the latest research. This would allow time to prepare for such an event.

Regional and national planners could initiate a number of actions that would help to reduce the impact of a large earthquake. Dr Berryman said because New Zealand was such a geologically active country, life was all about accommodating potential natural hazards.

He added that because the Richter scale was logarithmic, each step up represented 30 times more energy released during an earthquake. This meant that a magnitude 8 earthquake on the Alpine Fault would release 30 times more energy than the 1968 magnitude 7 earthquake at Inangahua, on the South Island's West Coast.

Seismologists regarded the past 30 to 40 years as a period of quiescence in New Zealand as there had been no big on-land earthquakes. This was not unusual as large earthquakes sometimes came in "clusters" lasting 10 to 20 years. Clusters were sometimes followed by a period of quiescence.

The "busiest" period since European settlement was between 1929 and 1934 when there were at least five large on-land earthquakes in New Zealand.

Scientists and engineers are continuing to work with regional councils and local communities to help develop strategies to cope with earthquakes, landslides, volcanic eruptions, and tsunamis.”

Resource Example 4b

Selection of NZ **newspaper predictions** over the last quarter of the 20thC.

i) Sunday News, 6/10/1985, article by Warren Grant

"Quake doc denies shock"

"A GEOLOGIST who has forecast a potentially tragic earthquake for parts of the South Island denied a DSIR press release on his findings was scare-mongering. But Kelvin Berryman, 32, leader of the DSIR Geological Survey's earth deformation section admitted he was 'not particularly happy' at some of the emotive descriptions used in the release this week.

It forecast 'catastrophic results'" if an established alpine fault running from Blenheim and down the South Island's West Coast to Fiordland moved. And while admitting "very real damage and loss of life" could occur in several reasonably remote areas, Mr Berryman said the release changed the emphasis a bit.

"We have been working on the alpine fault for the last year or two, and our investigations have suggested the hazard is greater than previously considered,' he said. I have tried as a scientist to point out to the public from an informative point of view what would happen when the earthquake occurs. 'We don't even know when - it could be in a hundred years time, next week, or even tomorrow.'

'But I'm not particularly happy at what has come across. It has changed the emphasis a bit. Mine was public education rather than catastrophic warning.' 'From a scientific point of view, overstating the case can have quite a negative effect.' 'I'm rather unhappy at the fine line between taking things seriously and panicking.'

'A considered, orderly approach to it is much more desirable.'

Mr Berryman said there would be a severe earthquake if the alpine front moved, but most damage would be confined to the less densely populated parts of the South Island's West Coast.

'There will be severe damage to buildings and bridges, and communications systems there, but it will be felt on the coast stronger than anywhere else. 'Loss of life was also a possibility,' he said.

Centres like Blenheim, Nelson, Christchurch and even Timaru will feel its effect, but that will probably be confined to losses of chimneys and contents thrown around in shops. 'The losses there will be more economic.'

Mr Berryman said department geologists had been investigating the alpine fault with increased effort. He said the DSIR had decided to release findings after wide-spread publicity surrounding the tragic earthquake in Mexico, where loss of life is still expected to run into the thousands.

'The story's been written for two or three months and it was opportune time to release it,' Mr Berryman said.' The department decided to tag on to the television pictures of the Mexican 'quake because people are now very aware at the damage they can cause.'

Meanwhile Greymouth Borough Council Civil Defence Controller Norm Schultze told Sunday News he doubted Mr Berryman's comment would have much effect on residents in the district. 'To be honest - and most Coasters are - we know we live on a fault line, and we also know we have to learn to cope with earthquakes,' he said.

'But if these groups are concerned, then information should be sent through the proper channels. It's not very nice reading about stuff like this in the newspapers.'

'But if a major earthquake hits us, we can handle it. Since the last earthquake in 1968 our civil defence has become much more efficient.' 'Here in Greymouth, we don't have the high rise buildings they have in other centres. It's a different situation. One thing you mustn't cause is panic. We live with the prospect of earthquakes here, and if a big one hits us, as it probably will sooner or later, we'll cope.'

ii) Christchurch Press, 14/7/1987

“Big 'quake "overdue"

A big earthquake in the South Island's Alpine Fault which would seriously damage Christchurch can be expected within the next century - or sooner, says a Canterbury University geography lecturer.

Dr David Bell told a combined Civil Defence-West Coast United Council seminar last weekend that the South Island was overdue for an earthquake about magnitude eight on the Richter Scale.

There would be lloss of life, serious damage of buildings both modern and old, and disruption to essential services, he said.

Christchurch could expect to receive a shake of about nine on the Mercalli Scale. 'Damage would be considerable. Buildings would be collapsed and thrown out of plumb and conspicuous cracks in the ground would appear,' he said.

The Alpine Fault had earthquakes of that size about once every 500 years. The last one was estimvated to have occurred about 550 years ago.

That meant an earthquake of up eight on the Richter Scale could be triggered at any time.

'On that basis,' he said, 'Christchurch and Greymouth were in as much danger from earthquakes as Wellington was.'

He added that the city's emergency services and Civil Defence were 'prepared as reasonably as they could be.'

However discussions were continuing constantly between Civil Defence and local authorities to improve preparations for a big earthquake.

iii) Greymouth Evening Star, 13/11 2001

"Huge quake impact predicted"

"'The next major earthquake on the Alpine Fault will shake so much rock off the Southern Alps that parts of the West Coast will be buried in metres of gravel, sand and silt, scientists say.

A recent study suggests this effect could be even greater than scientists had anticipated, two scientists told a public meeting at the Whataroa Hall last night.

Kelvin Berryman, of the Institute of Geological and Nuclear Sciences in Wellington, and Peter Almond, of Lincoln University, told the meeting that many West Coast rivers would become choked by huge amounts of rock and debris after the next big quake on the Alpine Fault.

The debris would eventually be transported to the lowlands, burying them in metres of gravel, sand and silt. The scientists have radiocarbon dated trees and buried soils, and studied the layering of buried gravels to test their hypothesis of huge gravel outwashes after big quakes. They found that after the 1717 quake, the Whataroa floodplain was overwhelmed by as much as 5m of gravel. The outwash of the gravel after the 1630 quake appeared to be even larger.

'The findings of our study suggest the floodplains of the Westland will be significantly impacted following the next Alpine Fault earthquake, with potentially major economic impact,' the scientists said.

Dr Berryman said one of the aims of the talk was to provide a forum for discussion and outline the research they would be doing this summer.

The Alpine Fault has ruptured three times in the past 600 years - in 1717, 1630 and 1460. Each rupture produced an earthquake of about magnitude 8. Strain and stress currently accumulating on the fault like a rubber band being stretched. Eventually the rocks would fail and an earthquake would result, Dr Berryman said.

After a magnitude 8 earthquake, large aftershocks could last for weeks or even months accentuating the build-up of gravel and debris in rivers."

Resource Example 4c

Full text of a **scientific report** [also referred to in Section 2 of this Appendix]. Missing are the map and photographs which can be seen in *Tephra Magazine*, June 2002, a CDEM publication.

The next Great

"West Coast Earthquake"

by Mauri McSaveney, GNS

"A great earthquake is one whose magnitude is 8.0 or greater. New Zealand's last great earthquake was the great Wairarapa earthquake of 1855, which had an estimated magnitude of 8.2. Few New Zealand faults are capable of releasing the energy required for such a large magnitude event. Obviously, the North Island Wairarapa fault was one of them, but we do not expect it to give a repeat performance in the current millennium. Another strong candidate for generating earthquakes greater then magnitude 8 in the North Island is a much less obvious fault, one that has no surface expression on land. This is the fault marking the boundary between the Australian plate and the downgoing Pacific plate as it slides under the east coast of the North Island. Scientists are attempting to decipher a record of the timing of its earthquake activity, but that story is as yet too incomplete to be told. Recent research on the South Island's Alpine fault has shown that it too is capable of generating great earthquakes because sometimes it slips more than 8 metres along its full length of 450 kilometres.

Great earthquakes are of interest because of the huge areas affected by severe ground shaking. Even though these earthquakes may occur in regions distant from major population centres, their effects are likely to be felt nationally as well as regionally. One morning, somewhere on the planet, people are going to awake to the news that there has been a devastating great earthquake in New Zealand. As likely as not, this great earthquake will be on the Alpine fault. The earthquake will have its greatest effects on the west coast of the South Island, and in the Southern Alps, but these will not be the only areas affected. Some recent research suggests that the great West Coast earthquake may not be as imminent as we thought a few years ago. Other research results indicate that many of the effects of this earthquake are not going to appear in the minutes of violent ground shaking. For some communities, serious problems are going to develop over months and may persist for decades, as rivers erode the deposits of many earthquake-triggered landslides and spread the massive quantities of gravel and silt over the coastal lowland farm communities downstream.

WHEN? - THE BIG QUESTION

Murphy's Law would have the next great West Coast earthquake on a dark and stormy night, and given the Coast's notorious rainy climate, there is a 50% chance that Murphy will be at least half right. But earthquakes show no preference for time of day, weather or season. A most informative piece of new research on the Alpine Fault by Russ Van Dissen and David Rhoades of the Institute of Geological & Nuclear Sciences adds now new data, but changes how we interpret what data we have, and any new data added in the future.

The alpine fault has been generating earthquakes for more than a million years in its role as the boundary between the pacific and Australian tectonic plates through the South Island. These plates are inexorably moving relative to each other at some 36 millimetres a year, but their boundary at the fault is somehow locked, preventing slip. The strain is being stored esastically, much as in winding a spring, until the next rupture, when the accumulatd elastic strain energy will be released in a groundshattering earthquake. The last rupture, over a length of about 450 kilometres, had about 8 metrues of lateral and 3 metres of vertical displacement, and occurred in about 1717 AD. The next big question now is how well "wound" is the Alpine fault "spring" for the next rupture. Direct measurements of the relative plate motions over the past few years suggest that the "spring" currently is wound for a displacement of about 7.7 metres and the expected displacement is increasing by about 27 mm each year. Just how much more elastic strain energy has to accumulate before the fault can be expected to rupture is *The Big Question.*

We can only attempt to answer it in terms of probability such as what has been the most frequently occurring interval between past ruptures, or what has bee the average time between ruptures. From either of these we can subtract the 285 years or so since the last rupture. It turns out that these give very different answers for an estimate of the time of the next great earthquake, and so we have to be very careful about how we interpret the answer.

The cumulative effect of the repeated fault movements is plain to see, but determining the frequency and magnitude of individual earthquakes is more difficult and evidence is not easily found in the rainforest of Westland. One technique for determining the history of faulting is to dig trenches across the fault. Scientists examine the way in which various layers of sediment have been offset by faulting, and obtain radiocarbon dates of organic material in the layers to tell when he offsets occurred. Evidence for the time of occurrence and displacement of the last four ruptures has been found the northeastern end of the fault, and for the last three, at the southwestern end. These most recent ruptures however, are but a very small sample of the thousands of ruptures that have occurred along the fault, so we must cautious in interpreting information about the entire population of earthquakes from these most recent ruptures.

Studies of ruptures of plate boundary faults elsewhere in the world show that, for a given fault, the amounts of fault slip during earthquakes and the intervals between earthquakes are closely related, but they are often very variable. It takes time for plate-tectonic motion to accumulate enough strain energy to cause a fault to rupture, but many factors determine just how much strain energy must build up. A series of ruptures along a given fault may have different amounts of slip and different intervals between them. Relatively short intervals (and small slips) are relatively rare; longer intervals and slips occur more frequently, but very long intervals and slips are also rare. Some of these intervals can be very long indeed, and when the fault gives way, huge amounts of slip, and a correspondingly massive earthquake, may occur.

I can illustrate the effect using three dated ruptures of the southwestern portion of the Alpine fault in 1717, 1450±100, and 1150±50 AD, which constitute a very small sample of the thousands of Alpine fault ruptures in the last few million years. The total slip at Haast from these three events is 25 metres, and so we can infer how long the plate-tectonic crustal "spring" had been "winding up" before the event of c.l 150 AD. From these data, we can calculate that the fault last ruptured 285 years ago, that the previous rupture was about 267 years before that, and another about 300 years earlier. The average slip in the three ruptures was 8.33 metres, and so at 27 millimetres per year, the average interval between the last four ruptures has been about 309 years. At face value, the most probable time to the next rupture would thus appear to be a very short 24 years (allowing for uncertainties, Russ van Dissen and David Rhoades extended this to about 35 years). They also determined the likelihood of a rupture in the southwest in the next 20 years to be about 12%, and for the northeast where rupture appears to be more frequent, about 15%.

Scientists are also interested in the longer-term average time to rupture and the average amount of slip. Studies of faults such as the North Anatolian fault in Turkey, which has a very long historical record of earthquakes, suggest that the interval between quakes can vary considerably. While 309 years and 8.33 metres are the modal rupture interval and slip for the recent movements along the Alpine fault at Haast, the average interval for all possible earthquakes along the Alpine fault could be as much as 430 years, with a slip of 11.5 metres. So, ignoring uncertainties, after 285 years, we still may be well over 100 years short of the average interval between ruptures.

These new views of past Alpine fault earthquakes do not alter when the next Alpine fault earthquake will occur, but they do alter our expectation of how long we might have to wait, and what it is that we might be waiting for.

WHAT ARE WE WAITING FOR?

The next great West Coast earthquake will probably produce at least a minute or so of violent destructive shaking within tens of kilometres of the rupture, and potentially damaging amplification of long-period rolling motion in susceptible ground and tall buildings for a hundred or more kilometres. These, however, are just the immediate effects. An interdisciplinary team of researchers from the Institute of Geological & Nuclear Sciences and Lincoln University is looking at how landscape evolution in South Westland has been affected by past Alpine fault earthquakes. Because the effects of more recent earthquakes tend to obliterate evidence of earlier ones, the story is limited to the last few events. We now know that these earthquakes reflect the recent pattern of more frequent earthquakes, and were thus probably less severe than the average.

The study has concentrated on the behaviour of the Whataroa River drainage basin. The most recent rupture of the Alpine Fault to affect the Whataroa area involved a roughly 400km-long segment rupturing in 1717 AD, with prior earthquakes in about 1620 AD, and 1460 AD. The magnitude of these earthquakes would have ranged from

7.3 to 8.3, and the Southern Alps east of the fault would have experienced ground accelerations greater than 0.4 g, ie the mountains would have been tossed upward at four-tenths the acceleration due to gravity. Such motion would have triggered numerous landslides for up to 50 kilometres from the fault. Fed by annual rainfalls in the mountains of more than ten metres, rivers draining the western Southern Alps would have swept the large volumes of sediment brought down in these large earthquakes down to the West Coast lowlands.

The study at Whataroa tests the idea that recent changes in the landscape have been dominated by the effects of Alpine fault rupture. By combining geomorphic mapping, stratigraphy, and dating of soils, terraces and fans with information on the age of areas of forest obtained by tree-ring counting, the study team has evaluated the nature and timing of recent periods of build-up of alluvium on the Whataroa lowland plain.

HOW OLD IS THAT TREE?

Much of the forest within the Southern Alps and to the west of the Alpine fault is dominated by long-lived trees (commonly living more than 700 years) that tend not to tolerate shade well. These trees become established on land surfaces disturbed by landslides or floods, or in areas where the major forest canopy has collapsed. Forested areas that have been affected by major disturbance typically contain an approximately even-aged stand of trees (a cohort) because they all became established at about the same time in disturbed openings. By determining the age of the oldest trees in a cohort, by coring and counting of growth rings, the date of the disturbance that formed the opening can be estimated. Tree ages on the Whataroa lowland alluvial-fan surfaces were collected from 14 stands of trees. In all 267 trees on the fan were cored.

The upper reaches of the Whataroa alluvial fan near the mountain front are largely covered by relatively young trees, most of which became established after the Alpine fault earthquake of 1717 AD. In contrast, the lower reaches of the fan closer to the coast are dominated by older trees that were established before 1717 AD and the reach also includes a group established around 1625 AD.

The earthquakes of 1717 and c.1620 AD appear to differ in their local impact. On the Whataroa and nearby Ohinemaka alluvial fans, the earthquake of c.l 620 AD appears to have caused a massive aggradation of river sediment, creating new surfaces for trees to colonise over much of the existing fan surface. This aggradation also appears to have had a major impact on the lower reaches of the Wanganui floodplain. In contrast, the aggradation following the 1717 AD earthquake was less extensive on the Whataroa lowland, where it was mostly confined to the upper reaches of the fan.

HOW OLD IS THAT GRAVEL?

Erosion of the banks of the Whataroa River has exposed layers illustrating some of the earlier history of gravel deposition in the valley. Downstream of the Alpine fault, which cuts across the catchment at the steep front of the range, the present-day river bed is incised 5 to 10 metres into an older Whataroa fan surface. The river is also actively cutting into the toes of other alluvial fans from small rangefront valleys. The various fan deposits and their relationships to one another have been mapped, together with the present and buried soils of the various former river levels. The ages of the former surfaces have been determined from radiocarbon ages of material incorporated into the fan deposits or from remnants of former forests overwhelmed by fan or terrace aggradation, and from the ages of trees on various terrace levels. The work shows a succession of rapid accumulations of coarse-to-fine angular schist gravels, separated by young, but recognizable soil horizons. Within the soil horizons are rooted stumps of trees killed by the rapid influx of gravel. The information is interpreted to represent infrequent pulses of river aggradation, with intervening the many buried forest remnants and wood, indicate a limited fan-building episode around 1717 AD, a more extensive episode after 1620 AD, and perhaps an episode around 1400 AD.

WHAT HAVE WE LEARNED?

The data from the Whataroa River valley suggests that the 1717 AD rupture of the Alpine fault was followed by a period in which the river aggraded from 5 to 8 metres in the main valley. Sediment from this aggradation crossed the line of the Alpine fault, obliterating all trace of the fault across the valley floor. The aggrading gravels spread out and thinned across the upper part of the Whataroa alluvial fan, where most of the Whataroa farming community is now sited. In most of the smaller valleys along the rangefront, however, a major episode of aggradation does not seem to have followed 1717 AD, except in a few local drainages.

The event around 1620 AD by comparison caused much more extensive changes, with major fan building from the rangefront and in the Whataroa plain. New forests sprang up in the lower coastal reaches, implying extensive aggradation in the upper reaches as well. A prior event around 1400-1460 AD is also identified from the ages of trees and, more tentatively, in the dating of trees buried in the range front fan deposits. This difference in local impact of aggradation episodes triggered by the Alpine fault rupture could reflect differences in magnitude of the earthquakes. A smaller earthquake could cause fewer and smaller landslides in upland catchments and consequently less aggradation, and thus less new forest growth.

However, the amount of aggradation could also be determined by the amount of loose material available in upland catchments. This could depend on the time since the last major episode of earthquake-triggered erosion.

Given the roughly 100 year interval between the C.I 620 AD and 1717 AD earthquakes, and the c.160 years between the c.1460 and c.1620 AD events, more sediment may have been available at the time of the c.1620 AD earthquake, leading to a more extensive aggradation across the floodplains.

The researchers infer that Alpine fault earthquakes have played a major role in landscape evolution in the Whataroa River catchment (and perhaps more generally in most of the Westland valleys), but only because rainfall has always been sufficient to transport the loose debris out of the mountains onto the lowland alluvial plains. Prior large aggradation episodes have had intervals between events of 100 to 160 years, but the elapsed time since the last event is 285 years. More material may potentially be still sitting in the headwaters of streams in the Southern Alps at present than before the two most recent aggradation episodes. A future aggradation episode might therefore be larger than the last two episodes.

To complicate the issue, the Fox River fan, south of Whataroa at Fox Glacier, has had *no* major fan aggrading episodes through the last three ruptures of the Alpine fault!

WHERE NEXT?

Researchers plan to refine the ages of forests destroyed by aggradation through radiocarbon dating of in situ tree stumps at Whataroa. Episodes of aggradation and erosion of the rangefront fans will also be looked at more closely, to see whether the 1717 AD event did cause more aggradation at other locations. Older deposits and buried soils indicate a potential to date other fan-building episodes going back at least a thousand years.

In upstream parts of the catchment the researchers will try to determine the volume of material available for release in the next large earthquake, as well as identifying how much erosion occurs between earthquakes. The occurrence of the nearby Mt. Adam rock avalanche in October 1999 indicates that some slopes in the alpine valleys along the mountain front are close to failure.”

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The Whataroa River bank from which logs were taken for carbon dating
[photo M Trayes, 2008]

Resource Example 4d

Abstract of the 1998 report by Mark Yetton, Andrew Wells and Nick J Traylen regarding their major work on the *"Probability and Consequences of the Next Alpine Fault Earthquake."* This report is a major reference for anyone seriously interested in the Alpine Fault (see also References).

"Probability and Consequences of the Next Alpine Fault Earthquake"

by Mark D Yetton, Andrew Wells and Nick J Traylen

"We have carried out paleoseismic investigation of the central and northern sections of the Alpine Fault. Trenching of the fault at five locations between Hokitika and the Ahaura River indicates the last rupture south of the Haupiri River occurred after 1660 AD and probably between 1700 and 1750 AD. An earlier event in the central section at around 1600 AD is the most recent event at the more northern locations. An updated record of landslide and aggradation terrace ages is consistent with two earthquakes in the last 500 years but does nto significantly refine the date estimates.

Analysis of forest age in Westland from the Paringa River to Springs Junctions reveals two periods of synchronous regional forest disturbance and re-establishment at 1625 ± 15 AD and 1715 ± 15 AD which we infer was the result of the two most recent earthquakes. Analysis of tree rings in trees which have survived these earthquakes allows estimates of event timing to be narrowed to 1620 ± 10 AD for the penultimate event. The most recent event occurred in 1717 AD and appears to have been a synchronous rupture from Milford Sound to the Haupiri River, a distance of approximately 375 kilometres.

The paleoseismic history can be used in conjunction with typical recurrence data from other plate boundary faults to predict the probability of the next earthquake using the method of Nishenko & Buland (1987). This indicates a probability over the next 50 years of 65 ± 15 % increasing to 85 ± 10% over the next 100 years.

Based on the previous events the next rupture is likely to produce an earthquake of magnitude 8 ± 0.25 with an epicentral area displaced slightly east of the fault trace. Very strong shaking will occur close to the epicentral area and for most locations the next Alpine Fault earthquake will be larger than any previous earthquake in the last 100 years. Landslides and liquefaction are likely to cause the greatest immediate impact but longer term the increased sediment loads will cause strong aggradation in major rivers with increased channel avulsion and flooding."

Resource Example 4e

As more information about past events come to light revised evaluations (using statistical and modelling methods) of the probability of the next Alpine Fault earthquake have been made since Yetton's work in 1998. This one comes from ***Mapping and fault rupture avoidance zonation for the Alpine Fault in the West Coast region***, R Langridge & W Ries, 2010, Introduction p.3-4.

………. "The Alpine Fault has not ruptured during the modern period of New Zealand history, i.e. since the beginning of European colonisation in AD 1840, and for some time the low level of seismicity along the fault was taken by some as an indication that the fault was inactive. However, paleoseismic studies of the Alpine Fault have revealed that large to great earthquakes (M 7.8-8) have occurred on the fault several times during the last millennium (Adams 1979; Berryman et al. 1992; Sutherland et al., 2007). Consensus at present points towards a large earthquake rupture at c. AD 1717, with other large rupture events having occurred at c. AD 1615 (±5 yr), c. AD 1430 (±15 yr) and AD 1230 (±50 yr) (Yetton 2000; Rhoades and Van Dissen, 2003; Wells and Goff, 2007; Wells et al. 1999, 2001). The average recurrence interval for rupture events along the Central segment of the fault, i.e. between Milford Sound and Hokitika, using average values for displacement of c. 9 m and a slip rate of 27 mm/yr is c. 333 years."

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Mapping and fault rupture avoidance zonation for the Alpine Fault in the West Coast region: R Langridge, GNS, 2010.

Alpine Fault Websites

www.gns.cri.nz/news/release/alpf.html This is an up to date media release the Alpine Fault: it summarises and draws together previous research on the Fault and gives information about likelihood of future earthquakes.

www.gsnz.org.nz NZ Geological Society website. Lists basic Alpine Fault information, publications by members, obituaries (Wellman), links to other agencies

www.earth.uq.edu.au Source of some academic papers published about Alpine Fault research

www.scecdc.scec.org/eqabc.html
US site with definitions basic terminology needed for understanding work about earthquakes and Faults

www.otago.ac.nz/geology/features/aftrip/introduc.htm "Virtual Field Trip." Excellent site for senior secondary students. Many links and references to combined groups research.

www.rsnz.govt.publish/ Source of many of academic papers published about Alpine Fault research. Very good search facility for specific topics. Lists school resources.

www.otago.ac.nz/geology/news/dfdp/index.html This site lists updates and news from the Alpine Fault Deep Drilling Project at Gaunt Creek, Waitangi-Taona River, South Westland.