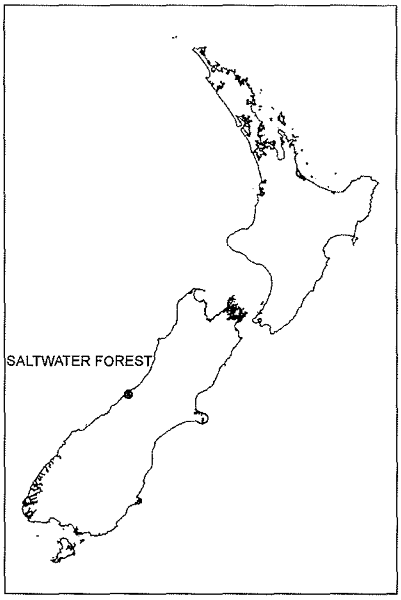
Stories from a forest soil

Peter Almond

Early in the European colonisation of New Zealand, settlers were attracted to the colony by promises of a land abounding in fertile soils. A similar subterfuge was used to encourage the wave of settlers pushing west in the 1860s in the United States, only then with the mantra 'The rain follows the plough' ringing in their ears. The misrepresentation of the fertility of New Zealand's soils was based on what has become known as the biometric fallacy – that tall forest, as greeted early explorers to New Zealand, indicates fertile soils.

This fallacy is no better exemplified than in the beech and podocarp forests on the glacial landforms of Westland. The tall, dense forest belies soils impoverished by leaching by annual rainfalls measured in metres, over tens of thousands of years. The large biomass is supported by the forest's frugal use and efficient scavenging of nutrients, along with slow growth rates. This article examines an example of such soil from Saltwater Forest in Westland, from the perspective of both the processes that it results from, and the rich history of environmental change over tens of thousands of years that it records.



Perch-gley Podzol

In the parlance of the New Zealand Soil Classification the soil is known as a Perch-gley Podzol. The Perch-gley part of the name acknowledges the effects of near permanent saturation of the upper part of the profile due to the low permeability of the subsoil and the significant annual rainfall. Podzol is of Russian origin and refers to the ash-grey colour of the subsoil that results from stripping of colour-giving oxides of iron. This stripping is promoted by organically charged solutions that have filtered through the forest litter on the soil surface. The dissolved iron re-precipitates in the lower part of the soil to form pans that contribute to the poor drainage of the soil.

Soil formation

The general history and mode of formation of these soils are well known from studies of soils on sequences of land surfaces that increase in age. This approach to deciphering the evolution of soils is necessary because of the slowness of change. The moraines of the Franz Josef Glacier form such a sequence. Across the moraines, soil profiles show a trend of increasing complexity and decreasing fertility as they increase in age from near the present glacier terminus westwards to the coast.

Initially undifferentiated glacial debris – the parent material – changes within years to profiles with an organic-rich surface, the A horizon, over glacial debris. These soils evolve over centuries to have deep litter horizons over the A horizons. These overly subsoils – the B horizons – stained yellow-brown by iron oxides formed by chemical weathering of the parent material. After thousands or tens of thousands of years a Podzol with ash-grey subsoil and a cemented iron pan beneath has formed. Many other chronosequences have been studied in Westland and all show a similar progression, with only the rate of change altering in proportion to annual rainfall.

Along with evolution of the soil profile morphology are very important changes in soil nutrient content. The most significant of these are probably the changes in the amount and chemical forms of phosphorus. Phosphorus is an essential nutrient for metabolic processes including energy transfer from photosynthesis and cell division. The amounts of phosphorus in the soil decline over time. Significantly, what remains changes from the chemical forms inherited from the parent material that are readily soluble and available to plants, to organic and inorganic forms that are chemically inert.

A vegetation succession mirrors the changes in soil fertility. Initially, light-loving, nitrogen-fixing pioneers dominate, such as broom *Carmichaelia,* tree daisy *Olearia,* and tutu *Coriaria*, which thrive in the relatively phosphorus rich, young soils. These are eventually out-competed by taller shrubs and trees including totara *Podocarpus hallii*, kamahi *Weinmannia racemosa* and rata *Metrosideros umbellata*, as soil organic matter and nitrogen levels increase. As continued leaching strips the soils of phosphorus and other nutrients, low fertility-tolerant podocarps such as rimu *Dacrydium cupressinum* and miro *Prumnopitys ferruginea* gain dominance. From this stage onwards soil carbon and nitrogen levels decline. At the extremes of low fertility even these species struggle and a stunted forest of rimu and silver pine *Manaoa colensoi* or heath vegetation prevails.

Our soil in Saltwater Forest fits well in to this general scheme of soil evolution, showing the features typical of Podzols and supporting a dense stand of terrace rimu forest. Reality, however, is always more complicated than simple models can capture. The soil profile has a suite of features reflecting the interaction of the kinds of soil processes described with changing climate and vegetation, and very slow sediment accumulation. These complexities are manifested in the interesting layering of the soil profile and subtle features of its makeup.

Slow formation

The most important divergence of the history of this soil from the soil evolution story described above is that it has formed in slowly and episodically accumulating wind-blown silt known as loess. Loess is usually blown from river beds, particularly those formed by glacial meltwater rivers which carry high concentrations of glacial rock flour. The significance of this kind of parent material is two-fold.

First, loess accumulates very slowly – something like 30 years is needed for a millimetre to accumulate. Consequently, as the soil grows upward as loess accumulates, the material is simultaneously chemically weathered and stripped of most nutrients. This contrasts with the top-down way in which most soils form. Glacial debris or river gravel is usually deposited so fast that soil does not have a chance to form, and it is only after those processes stop does soil form downward into the parent material.

This takes place in a manner similar to rusting of a piece of steel, or mould growing on a piece of fruit. Below the surface the steel or the fruit is still fresh, likewise the subsoil of a soil formed in a 'top-down' manner still has nutrients, even if the top is intensely leached. In contrast, the subsoil of a loess soil formed in the high rainfall climate of Westland is almost completely devoid of nutrients. Some of the most nutrient poor ecosystems in Westland are those formed on deep loess soils.

Recording information

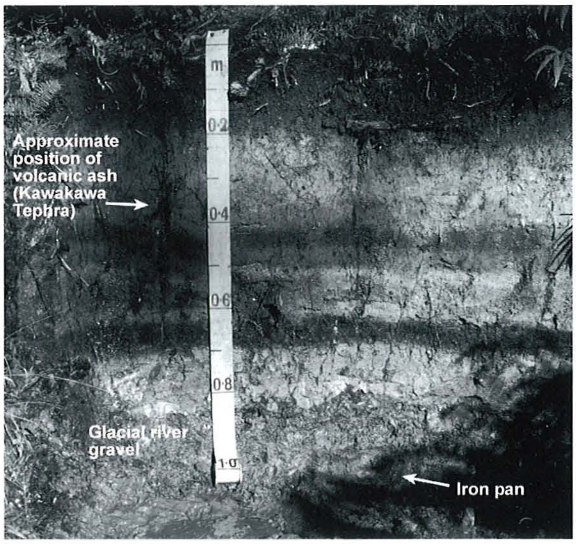
The second significant feature of soils formed in loess is that as they accumulate they act like a tape recorder, storing information about the environment. What can we learn from this soil in Saltwater Forest? The most striking features of the soil are the dark layers amongst the grey loess. These dark layers are buried former topsoils that formed during breaks or slow-downs of loess accumulation. Periods of fast loess accumulation correspond to times when there are large floodplains formed by glacial meltwater rivers.

So this layering of peaty topsoils and grey loess is a proxy record of climate change. Grey loess equates to cold glacial climates when glaciers advanced and extensive, unstable floodplains formed. Peaty topsoils correspond to warm interglacial times. Having a record of past climate is interesting but it becomes valuable when we can put a timeline to it. Fortunately, the peaty organic layers are amenable to radiocarbon dating.

Radio carbon dating

This dating technique relies on the decay of a naturally occurring radioactive form of carbon (C). At the time of a plant or animal's death the ratio of ^{14}C, the radioactive isotope, to ^{12}C, the common stable isotope, is fixed at a known level. After death and cessation of photosynthesis for a plant, or eating of plant-derived material for an animal, the amount of ^{12}C stays the same but ^{14}C decays away. The ratio of these two isotopes can thereby be used to determine the age of death of the plant or animal, so long as the rate of decay of ^{14}C is known.

Radiocarbon dating places the prominent peaty horizon between 65 and 70 cm depth at about 37,000 years before present.



Another key timeline in the soil has been established by a volcanic ash. At about 35 cm depth, invisible to the naked eye but obvious under a microscope, are angular, contorted fragments of volcanic glass typical of the eruptions of the central North Island. We know from the chemistry of these glass grains that they belong to a large eruption from Lake Taupo that happened about 27,000 years ago.

This volcanic ash, known as Kawakawa Tephra, is the only ash known to have made it to the South Island in the last 300,000 years. Therefore, from the layering of loess and buried peaty topsoils, we know that in the period between about 37,000 and 27,000 years before present there were two cold climate periods with intervening times of warmth. The grey loess between 20 cm depth and the Kawakawa Tephra is indicative of the coldest period in the last ice age, known as the Last Glacial Maximum, between 25,000 and 18,000 years before present. The upper 20 cm of the soil is the present organic-rich topsoil formed beneath the modern podocarp forest.

Pollen records

What other information does this soil profile contain about the environment during these fluctuations of climate over the last 37,000 years? The very wet nature of these Perch-gley Podzols is fortuitous in this regard. Pollen produced by the vegetation of the past as it responded to the changing climate is well preserved in the saturated, oxygen-deprived subsoil. Pollen is very resilient material and it can be extracted from soil by using extremely corrosive acids that dissolve up mineral and other organic material to leave the pollen visible for microscopic analysis. Pollen analysis reveals startling aspects of vegetation history over the last 37,000 years.

About 37,000 years ago, when the dark peaty topsoil between 65 and 75 cm depth was forming at the soil surface, the site was an open, infertile bog, dominated by wire rush *Empodisma,* and the fern *Gleichenia,* with minor stands of silver pine and bog pine *Halocarpus bidwillii.* From this time to the time of Kawakawa Tephra, the vegetation changed relatively subtly from this community, with shrubs being more dominant in warmer periods and grasses becoming more abundant in the colder times.

After Kawakawa Tephra, a major change in the pollen rain occurred. At this time, corresponding to the Last Glacial Maximum, fossil pollen indicates a grassland, typical of present day alpine regions above about 1000 metres elevation, at a site that is today only 60 metres above sea level. At the time, global sea level was about 130 metres lower than present day as a result of ocean water being transferred into large northern hemisphere ice sheets. However the site would have still been less than 200 metres above sea level. It is this kind of information that allows scientists studying ancient climate to gauge the magnitude of past climate change.

A pollen assemblage consistent with the forest seen at the site today occurs within the soil's A horizon. Radio carbon dates suggest recolonisation by forest took place about 11,500 years ago. This lends an interesting perspective to the antiquity of New Zealand's lowland forest. A common perception is that New Zealand's forests have persisted from the farthest reaches of time, only to be largely destroyed with the arrival of humans in New Zealand from about 700 years ago. The truth is that over the last million years when the Earth experienced numerous glacial cycles of about 100,000 years, forests like we see today in the present interglacial may have shared the landscape as a junior partner to the grasslands and shrublands of long glacial periods.

In a time of changing climate, histories of past climate change like that recorded in the soil in Saltwater Forest take on new significance. Similarly, understanding the pattern and properties of soils and the processes responsible for them is important if forests are to be conserved and well managed. In a future article we will take a wider view of the soils of Saltwater Forest and examine how the soil pattern influences forest dynamics, structure and composition.

Peter Almond is a soil scientist at Lincoln University who, after graduating from Massey University in the mid 1980s, started studying soils on the West Coast as part of surveys run by NZ Forest Service and DSIR Soil Bureau.