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Quaternary environmental change in New Zealand and its effects on the soil pattern

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Abbreviations: NZ = New Zealand; NI, SI = North, South Island; LG = Last Glaciation; Ma, ka = millions, thousands of radiometric years ago

Introduction

NZ is an exceptional place for studying environmental change and soil evolution during the Quaternary: (1) it lies in a climatically sensitive, oceanic location spanning 17 degrees of the mid-latitudes; (2) its active plate boundary setting has produced high mountains lying athwart the prevailing westerlies, active volcanism, and a dynamic landscape; and (3) it has an exceptionally short prehistory (*c.* 700 years). Consequently, there is a striking diversity of topography – the landscape is characterized by strong relief and youthfulness – and lithology, markedly variable climatic regimes, and a unique, relict 'Gondwana' flora. In this paper, we firstly describe environmental change in NZ during the Quaternary and then examine examples of the effects of such change, chiefly during and since the LG, on the soil pattern in NZ.

Quaternary Environmental Change in New Zealand

Environmental change in NZ was reviewed by Newnham et al. (1999) (Table 1). Late Cenozoic glaciation commenced *c.* 2.6–2.4 Ma. The record of glacial deposits is fragmentary and poorly dated except for the most recent events. However, climatic interpretations of cores from marine sediments near NZ, together with those of long sequences of interbedded marine and terrestrial sediments (e.g. Wanganui Basin), indicate broad synchrony with continental Northern Hemisphere glacial-interglacial events. The LG, from *c.* 100–10 ka, was characterized by at least five glacial advances (stadials) and three warmer intervals (interstadials). Forest occupied much of NZ during the interstadials but was restricted during the stadials when shrubland and grassland communities predominated. During the Last Glacial Maximum, *c.* 25–15 ka, a glacier complex extended ~700 km along the Southern Alps with snowlines lowered by ~600–800 m and sea levels lowered by ~120 m. In contrast, glaciation in NI was minor: cirques and small valley glaciers developed in the Tararua Range in southern NI and small ice caps formed on central NI stratovolcanoes. At this time forest was sparse, if present at all, in many regions except for Northland. Grassland or open herbfield vegetation was dominant over much of SI, and shrubland cover important in coastal areas and much of NI. Temperatures were lowered by ~4–5º C on average and these decreases, together with other factors including fire, drought, frost, outbreaks of freezing air masses and increased windiness, were responsible for the widespread loss of forest. In Northland, however, forest persisted (generally kauri and hard beech dominated during interstadials and stadials, respectively). Periglacial activity and severe fluvial and wind erosion occurred in SI (with some permafrost) and in much of NI except Northland, and thick alluvial sequences, some volcanogenic, accumulated beyond the glaciated areas of both main islands. Loess deposits, generally lacking carbonates and dating to *c.* 0.8 Ma or earlier, occur in SI ('glacial' loess), southern NI ('mountain' loess), and as subsurface deposits interbedded with tephra deposits in central NI ('tephric' loess). Loess accumulation rates typically were fastest during cool/cold intervals and slowest during mild/warm intervals (slow deposition of loess and aerosolic dust continues today).

Table 1. Topics covered in a review of NZ Quaternary environmental change (Newnham et al. 1999).

Geochronology	Glaciation/periglaciation	Loess deposits	Tree-ring studies
Tectonics	Sea-level change	Paleosols	Cave/speleothem records
Volcanism	Stratigraphy	Vegetation history	Faunas; NZ prehistory

The retreat of SI glaciers from *c.* 15 ka was accompanied by a rapid wave of reafforestation in the NI from *c.* 14.5 ka in the Waikato region and progressively later at more southerly sites. The speed of reafforestation, and other evidence, suggest that forest species must have survived the glacial in refugia throughout the country. Most of NZ was forested by *c.* 10 ka. Isotopic, pollen and palaeolimnological data indicate that conditions *c.* 10–7 ka were warmer, wetter and drought-free, but since *c.* 7 ka they have become cooler, frostier and droughtier.

Tectonic and volcanic processes have had major influences. These processes originate because NZ bisects an obliquely convergent plate boundary (marked by the Alpine Fault in SI). Some parts of NZ are subsiding, notably the coastal regions of Bay of Plenty, Marlborough Sounds and central Canterbury (these stay above sea level as a result of high sedimentation rates) but the rest is rising. In the SI, rates of uplift have been especially fast during the Quaternary and increase markedly towards the Alpine Fault. The mean long-term rate of rock uplift and erosional denudation is ~2.5 mm a^{-1}. Quaternary volcanism in NI is of three main types: (1) intraplate, forming basaltic volcanic fields; (2) subduction-related, forming andesitic stratovolcanoes; and (3) crustal-derived and explosive, forming rhyolitic calderas (some with lava domes), ignimbrite sheets, and widespread tephra-fall deposits. The Taupo Volcanic Zone, active since *c.* 2 Ma, has produced >10 000 km^3 of magma, and the central part has erupted rhyolite at the (very fast) mean rate of ~0.28 m^3 s^{-1} since *c.* 0.35 Ma. Consequently, large areas of central and western NI have been modified drastically by the emplacement of voluminous rhyolitic ignimbrites and by rhyolitic and andesitic tephra fallout. Multiple tephra-fall deposits have successively mantled antecedent landsurfaces forming buried paleosols (up to *c.* 2 Ma in age) in many places.

Soil Pattern

The modern soil pattern in NZ is complex and a wide range of soils is evident (Table 2). Some have globally distinctive features (Hewitt 1997). In elevated, 'glacierized' parts of the SI, the direct action of ice destroyed pre-existing soils and parent materials or buried them with moraine. In periglacial zones, both in the SI and in higher parts of central and southern NI, the pre-glacial soils were removed by solifluction, sheet, and wind erosion, exposing bedrock in places. Severe frost action produced vast screes and other debris, much of which was eventually chanelled and debouched from valleys as fluvioglacial outwash. Wind erosion led to the deposition of coarse loess in inland valleys. At lower elevations in both islands, fluvioglacial outwash was deposited, especially during the late-glacial retreat phase, and loess was deposited extensively in SI and southern NI forming soils characterised by 'upbuilding' and 'topdown' processes according to relative rates of accumulation and soil formation. Regions least effected by the LG include Northland and northwest SI, and here many soils on residual weathered regolith show pre-glacial 'relict' features originating largely from 'topdown' pedogenesis.

Since *c.* 15 ka, parent materials and soils have been affected by climatic amelioration and other controls. Periglacial activity essentially petered out in most places, and the accumulation of alluvium and loess diminished. Gullying began on slopes with solifluction debris or loess cover (rainfall increased). Rising sea levels inundated harbours, forced rivers to form deltas, and helped form extensive dune fields. Peat bogs were formed as water tables rose. Landsliding, ongoing today and usually the consequence of earthquakes or frequent rainstorms, exhumed soils, regolith or underlying rocks in the axial ranges or high country of both islands. Such denudation was complemented by rapid sedimentation in lowlands and offshore. During and since the LG, eruptions of ignimbrites (e.g. Oruanui event *c.* 23 ka) modified the central NI landscape directly and produced voluminous loose materials for fluvial and aeolian reworking. Tephra-fall deposits, however, provide the main soil-forming materials in central and western NI, either as relatively thick deposits near source, where pre-exisiting soils are buried and isolated, or more typically as multisequal deposits at distal sites where soil formation is characterized by a complex interplay of 'upbuilding' and 'topdown' processes. The *c.* 200 AD Taupo eruption deserves special mention because it generated, in a few hours, a 'single' soil parent material covering an area ≥30 000 km^2 (~25% of NI) on which extensive vitric Andisols (and Spodosols) are formed.

Table 2. Abundances (percentage land area)[1] of soil orders in NZ using Soil Taxonomy.

Inceptisols	47.4	Alfisols	9.9	Mollisols	1.2	Oxisols	0.2
Spodosols	13.1	Entisols	7.4	Histosols	0.9	Vertisols	0.1
Andisols	12.9	Ultisols	4.2	Aridisols	0.9	Gelisols	0[2]

[1] After Hewitt (1998, p. 9-14) and 1: 1 000 000 maps published by Landcare Research in 1995. Non-soils ≅ 2%.
[2] Gelisols (on frost-churned materials underlain by permafrost) occur in NZ's Ross Dependency, Antarctica.

Conclusions

In general, much of the soil pattern in NZ relates strongly to the climatic and associated effects of the LG or its aftermath, especially in destroying antecedent soils or producing new parent materials. The SI was influenced by the direct action of ice and the deposition of extensive fluvioglacial alluvium, solifluction debris, colluvium and extensive loess deposits, which provide the parent materials for many soils. In southern NI, loess (etc) is prevalent, but continuing volcanic eruptions have generated new parent materials in the form of tephra deposits in much of central and western NI. Soil 'upbuilding' is thus an important process in both islands. In northern NI, relatively unaffected by the LG, older 'residual' soils predominate. In both islands, axial ranges and hill country are typically (not everywhere) unstable. Apart from northern NI and some other areas with stable land surfaces, most soils in NZ are young (many <15 ka). The effects of topographic, vegetational and climatic factors, quite distinctive at 'land region' scale (10–100 km; Hewitt 1997), are overprinting these soil-parent material patterns.

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