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D.J. Lowe (Editor)

Note: Throughout the text, Ma = millions of years before present, ka = thousands of years before present.

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INTRODUCTION TO NEW ZEALAND

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NEW ZEALAND'S GEOLOGICAL ENVIRONMENT

New Zealand consists of a cluster of islands, the three largest being North, South, and Stewart, in the southwest Pacific Ocean. They have a total land area of about 270 000 km^2 (similar to that of the British Isles or Japan). The islands are the small emergent parts of a much larger submarine continental mass (Fig. 0.1) that was rafted away from Australia and Antarctica by sea-floor spreading in the proto-Tasman Sea between 85 and 60 Ma. Much of this New Zealand subcontinent is a remnant of the former eastern margin of Gondwanaland, the ancient southern supercontinent. The mainland islands form a long, narrow, NE-SW trending archipelago bisected by an active, obliquely converging, boundary between the Australian and Pacific lithospheric plates (Fig. 0.2), which has evolved over the last 25 million years (Kamp 1992). The plate boundary is marked by active seismicity and volcanic arcs, illustrating New Zealand's position as part of the Circum-Pacific Mobile Belt — the so-called "Pacific Ring of Fire". The NE-SW trend of the modern plate boundary cuts across mainly NW-SE oriented structural features inherited from earlier (mid-Cretaceous) rifting events.

In the South Island, continent-continent convergence across the transcurrent Alpine Fault dominates the tectonic scene, with rapid uplift and jagged relief being the result. Numerous peaks exceed 3000 m in elevation. Rates of rock uplift are most rapid in the central portion of the Southern Alps, currently averaging ≈10 mm/year (Kamp & Tippett 1993; Tippett & Kamp 1993). Over the entire period of uplift, mean rock uplift rates range from ≈1-3 mm/yr — the rate of uplift (and denudation) has thus accelerated towards the present day. Fission track dating shows that uplift of the southern end of the Southern Alps began about 8 Ma, the northern end at 5 Ma, and the southeastern margin at 3 Ma (Kamp et al. 1989; Tippett & Kamp 1993). Because of such rapid uplift, the late Cretaceous-early Cenozoic cover rocks have been largely removed and therefore the landforms are developed in indurated basement rocks (Fig. 0.3; see also Williams 1991).

In the North Island, in contrast, the ocean-continent convergence has commonly produced marine sedimentary basins and has inverted them, and so generally late Cretaceous-Cenozoic rock sequences, including volcanic ones, are dominant. The uplift of the crust of northern and central North Island originates from high heat flows, but in southeastern North Island it is driven by tectonic thickening. An active volcanic arc of andesite and dacite volcanoes runs from White Island to Mt Ruapehu (Fig. 0.2; Cole 1990). To the northwest of this arc is a backarc region characterised by a much-faulted basin-and-range topography involving basement rocks and basic and rhyolitic volcanism. Large multivent calderas, the sources of voluminous rhyolite lava and of pyroclastic deposits in the form of thick sheets of ignimbrites and widely dispersed airfall tephras, occur immediately behind the active volcanic arc (Houghton et al. 1994).

Late Cenozoic intraplate and subduction-related volcanism

The North Island, located on the leading edge of the Australian plate, is being underthrust by the Pacific plate at the Hikurangi Trench with the subducting slab dipping to the NW at c. 50°. Since about 5 Ma, a series of NE-trending frontal arc volcanoes has migrated c. 100 km southeastwards across the central North Island, probably because of gradual steepening of the subducted slab, to reach the present-day locus of activity in the Taupo Volcanic Zone (TVZ) about 2 Ma (Fig. 0.2; Kamp 1984; Tatsumi & Tsunakawa 1992).

Two types of volcanism resulting from this tectonic setting are manifest in the North Island, as follows:

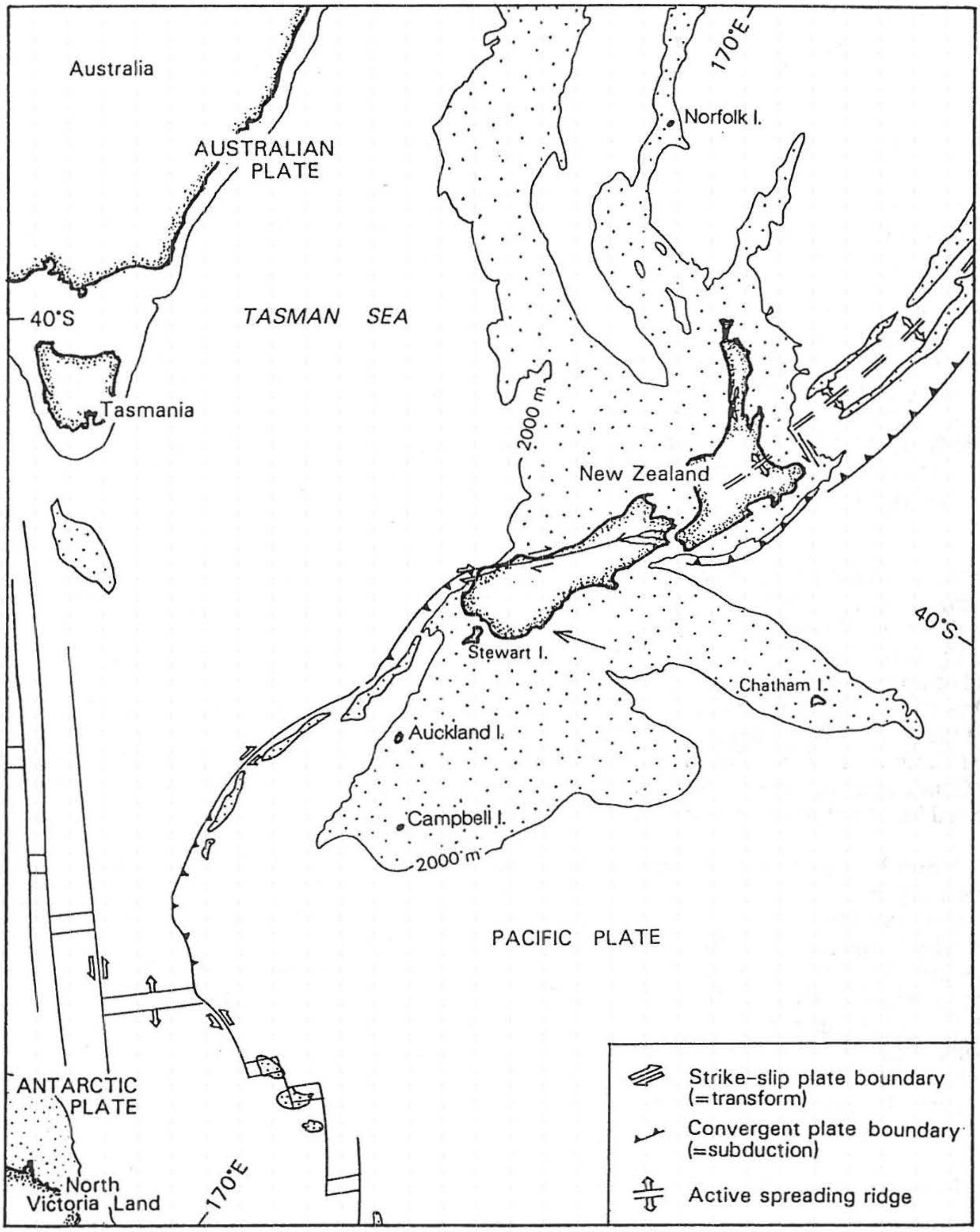

Figure 0.1: Generalised plate tectonic setting of New Zealand and the southwest Pacific. Sparse stipple represents continental sea floor shallower than 2000 m, and defines the New Zealand subcontinent. The active spreading ridge offshore marks the Havre Trough (after Kamp 1986).

(1) Mainly basaltic, intraplate volcanism in the backarc region. Effectively confined to western and northern North Island in seven volcanic fields (Fig.0.2), this volcanism may be caused by the upwelling of asthenospheric materials from deeper parts of the mantle (Fig. 0.4). There is a progressive younging in age of the fields from the Alexandra Volcanics (2.74-1.60 Ma), to Ngatutura (1.83-1.54 Ma), to South Auckland (1.56-0.51 Ma), and to Auckland (0.14 Ma to 600 years) (Briggs et al. 1989; Kermode 1992). However, the Northland fields (numbered 5-7 in Fig. 0.2) show a wide range of ages from c. 10 Ma to c. 1.2 ka.

(2) Mainly andesitic and rhyolitic, subduction-related volcanism along the frontal arc and in the backarc region (collectively referred to as the Central Volcanic Region). Since c. 2 Ma, this volcanism relates chiefly to activity in the TVZ, a relatively narrow (<≈50 km) volcanotectonic depression comprising a young backarc basin — the Taupo-Rotorua Depression — formed within thin continental crust in an area of active extension (rifting) and very high heat flow (700-800 mW/m^2), and the adjacent frontal arc (Cole 1990; Tatsumi & Tsunakawa 1992). The arc extends about 250 km NE-SW from the active volcanoes of White Island in the Bay of Plenty to those of Tongariro Volcanic Centre south of Lake Taupo (Fig. 0.5) (cf. Wilson 1993). It is primarily andesite-dacite in composition, making up about 3% (volumetrically ≈800 km^3) of the TVZ deposits. Very rare basalts (proportionally <1%; ≈2 km^3) also occur in the region (Gamble et al. 1990). The Taupo-Rotorua Depression in the TVZ is evidently the southern extension of active oceanic back-arc rifting along the Havre Trough offshore (Fig. 0.1; Wright et al. 1990), and is currently widening at the rate of 18 ± 5 mm/yr (Darby & Williams 1991). A possible mechanism for this rifting is the injection of asthenospheric materials into the mantle wedge which, together with the subducted slab, is being pushed trenchwards (Fig. 0.4; Tatsumi & Tsunakawa 1992).

A second (part) subduction-related volcanic chain in the backarc region is that of the mainly basaltic Alexandra Volcanics and the andesitic Taranaki volcanoes (aged c. 1.8 Ma to A.D. 1755) in western North Island. These volcanoes are described in Briggs & McDonough (1990), Neall (1979), and Neall et al. (1986).

Taupo Volcanic Zone

The central part of the TVZ, which is comparable in size and longevity to the Yellowstone volcanic area in the United States (Wilson et al. 1984; Houghton et al. 1994), has erupted huge quantities (≈10 000 to 16 000 km^3) of rhyolitic lavas and pyroclastic deposits, including both welded and non-welded ignimbrites, of ≈2 km or more thickness (Wilson et al. 1984; Stern 1987). These silicic materials make up c. 97% of the TVZ deposits, and drillholes reveal that they are underlain in places by andesite lavas locally >1 km thick (Browne et al. 1992). The deposits have been erupted mainly from eight multivent centres marked by large calderas (Fig. 0.5), the earliest known eruptives originating from Mangakino caldera at least 1.6 Ma (Pringle et al. 1992; Soengkono et al. 1992; Briggs et al. 1993). The Taupo volcano is an 'inverse' volcano, so called because it is concave with the flanks sloping gently inwards towards the vent locations (Walker 1984), rather than forming the steep convex cones characteristic of andesite stratovolcanoes (e.g. Mt Taranaki) or rhyolite domes (e.g. Mt Tarawera). This inverted form arises largely because eruptions from rhyolitic volcanoes of this sort are typically so powerful that accumulation of erupted material near the vent is insufficient to counteract subsidence due to caldera collapse because of magma withdrawal and regional tectonic extension, and because later effusion of steep-sided domes is comparatively minor (Wilson 1993). The Mangakino and Kapenga calderas are probably extinct, Rotorua and Maroa may be feebly active, and Taupo and Okataina are very active, the latest eruptions occurring c. 1850 years ago (Taupo) and in A.D. 1886 (Tarawera), respectively. The Whakamaru caldera is probably extinct but intense faulting in the area may be partly due to resurgence (Wilson et al. 1986). Reporoa Caldera, previously described as a fault-angle depression, has recently been recognised as the eighth major rhyolitic centre in TVZ (Nairn et al. in press). It is the source of the Kaingaroa Ignimbrites (0.24 Ma).

The known history of eruptions from these calderas is summarised by Wilson et al. (1984, 1986), Wilson (1986, 1993), Briggs et al. (1993), Houghton et al. (1994), and Nairn et al. (in press). Such eruptions include one of the largest late Quaternary eruptions known, that of the Whakamaru-group ignimbrites and an associated airfall component, the Rangitawa Tephra, from Whakamaru caldera c. 0.35 Ma, producing >≈1200 km^3 of pyroclastic material (Froggatt et al. 1986; Kohn et al. 1992).

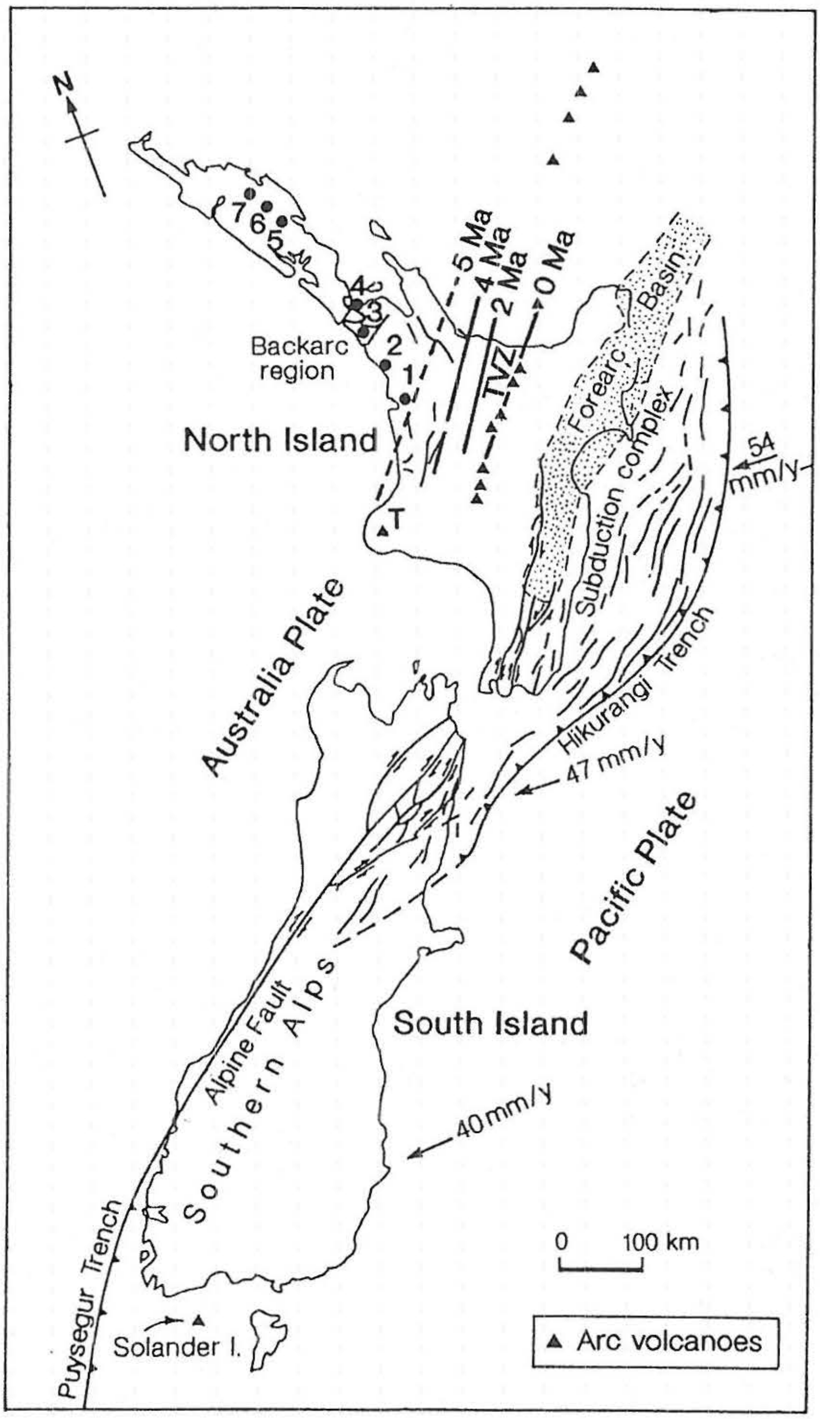

Figure 0.2: The present tectonic character of the obliquely convergent modern Australia-Pacific plate boundary through New Zealand (after Kamp 1992), and the trenchward migration of the arc volcanoes during the last 5 Ma (after Tatsumi & Tsunakawa 1992). TVZ = Taupo Volcanic Zone. Intraplate basalt volcanic fields are: 1, Alexandra (co-existing intraplate and subduction-related eruptives; Briggs & McDonough 1990); 2, Ngatutura; 3, South Auckland; 4, Auckland; 5, Whangarei; 6, Puhipuhi; 7, Kaikohe-Bay of Islands. T = Mt Taranaki.

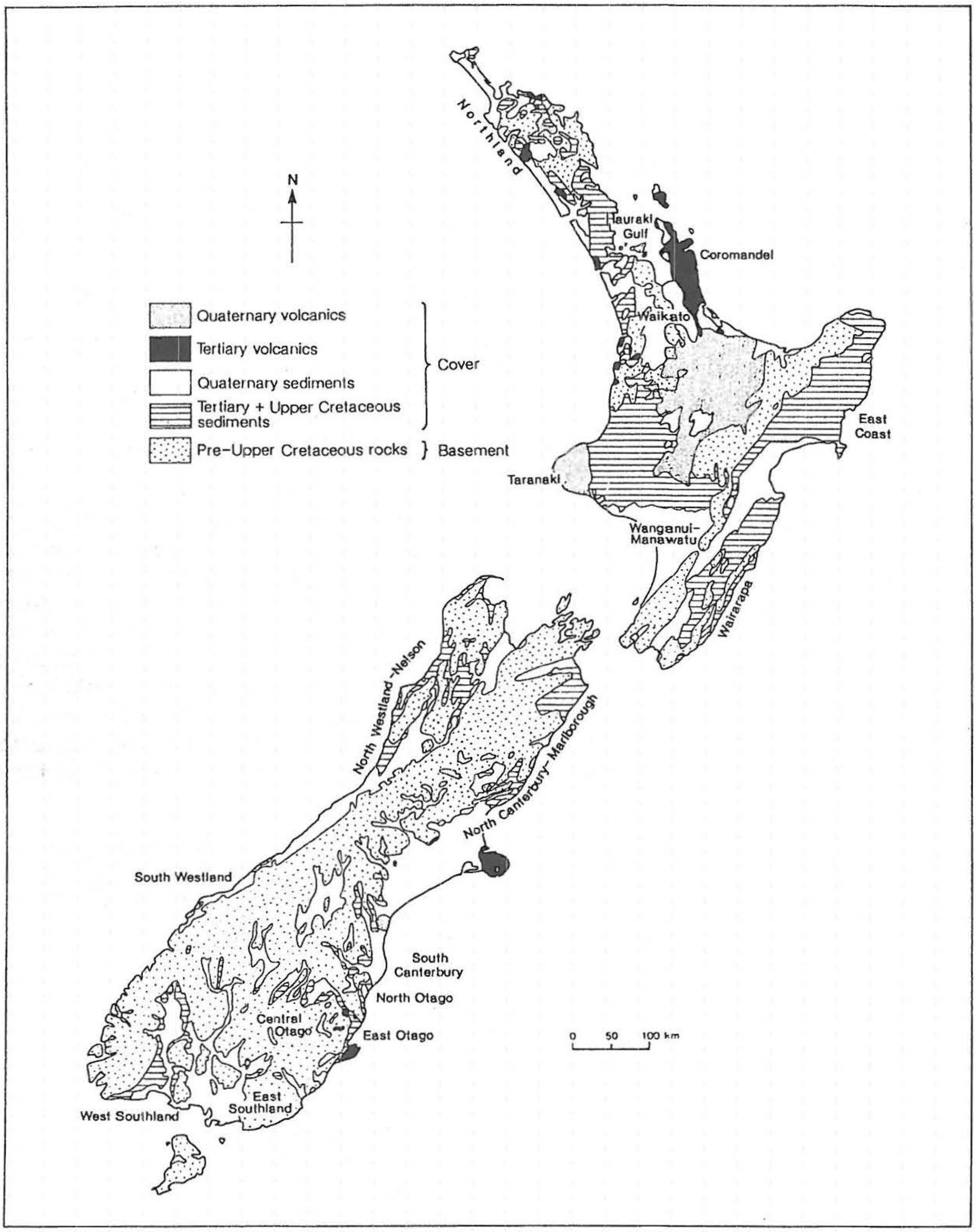

Figure 0.3: Generalised geological map of New Zealand (from Kamp 1992). Quaternary, 2-0 Ma; Tertiary, 65-2 Ma; Upper Cretaceous, 100-65 Ma; Pre-Upper Cretaceous, pre-100 Ma.

Fallout from this eruption probably reached S America, 10 000 km E of New Zealand, and beyond (Froggatt et al. 1986). Another enormous eruption was that of Kawakawa Tephra from Taupo volcano c. 22.6 ka, producing ≈500 km^3 of fall deposits, ≈300 km^3 of ignimbrite, and ≈500 km^3 of intra-caldera fill (Wilson 1993).

Tephrostratigraphy

Pyroclastic fall deposits associated with the central TVZ caldera eruptions are widespread in the North Island, with some forming important stratigraphic markers extending to the South Island and in deep sea cores both west and east of New Zealand (e.g. Nelson et al. 1985b; Barnes & Shane 1992; Pillans & Wright 1992). Apart from a few exceptions, the earliest tephra deposits ('tephra' is a widely-used collective term for all the unconsolidated, primary pyroclastic products of an eruption; Froggatt & Lowe 1990) at distal localities peripheral to TVZ have generally not been well dated. However, recent work using improved fission track dating techniques and the K-Ar and $^{40}Ar/^{39}Ar$ methods, together with paleomagnetism and new stratigraphic work, is making great advances (e.g. Shane 1991; Berryman 1992; Kohn et al. 1992; Pringle et al. 1992; Soengkono et al. 1992; Alloway et al. 1993). In the Waikato region, there are two groups of old, strongly weathered tephra sequences: the Kauroa Ashes (erupted from c. 2.3 to ?1 Ma; Briggs et al. 1989), and the Hamilton Ashes (erupted from c. 0.35 Ma to 0.1 Ma; Selby & Lowe 1992). Both groups have uncertain sources — the Kauroa beds possibly represent very early eruptions from TVZ (?Mangakino caldera), and the Hamilton beds may relate to the eruptions from the Taupo, Whakamaru, or Maroa centres.

Pyroclastic eruptives from TVZ over the past c. 50 ka are much better documented and their chronology (by radiocarbon dating) and distribution are generally well established (Froggatt & Lowe 1990; Lowe 1990; Lowe & Hogg 1992; Wilson 1993). In this time there have been ≈50 or more pyroclastic eruptions from the Taupo and Okataina calderas alone, a mean rate of one every ≈1000 years. Many eruptions produced volumes of deposits >>1 km^3 (cf. the 1980 eruption of Mt St Helens produced ≈1 km^3 of pyroclastic material). The three largest, volumetrically, were the Rotoiti (240 km^3), Kawakawa (800 km^3), and Taupo (90 km^3) eruptive episodes, with the total volume of rhyolitic material erupted from TVZ in the past c. 50 ka conservatively estimated at ≈800 km^3 of airfall tephra, 540 km^3 of ignimbrite, and 550 km^3 of extrusive lava, together equivalent to more than 700 km^3 of magma (Froggatt & Lowe 1990; Wilson 1993). Correlation techniques using discriminant function analysis have been successfully applied to late Quaternary tephras by Stokes & Lowe (1988) and Stokes et al. (1992).

Numerous andesitic tephras have been erupted from the Tongariro Volcanic Centre in late Quaternary times (e.g. Topping 1973; Cole et al. 1986; Lowe 1988; Donoghue et al. 1991, in press), and from Taranaki/Egmont Volcanic Centre (e.g. Neall 1972, 1979; Alloway 1989; Alloway et al. 1992a).

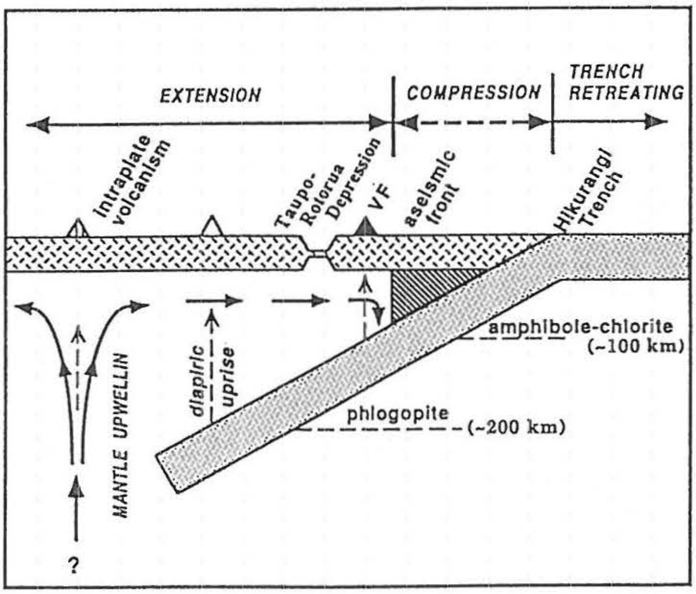

Figure 0.4: Model for the origin of backarc rifting and pattern of stress in North Island as related to intraplate and subduction-related volcanism (from Tatsumi & Tsunakawa 1992). VF = volcanic front (TVZ); hatching = forearc mantle wedge.

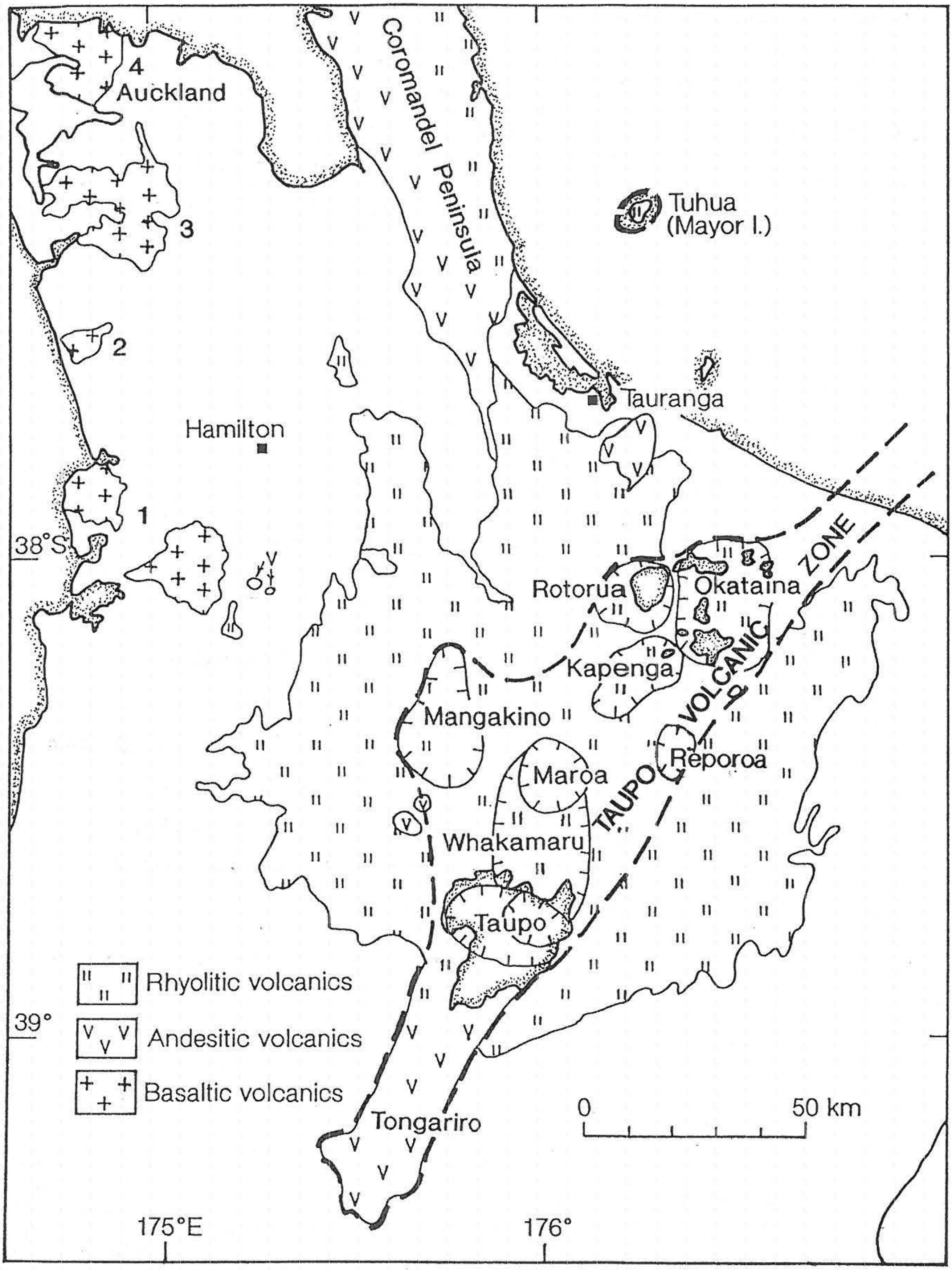

Figure 0.5: Generalised distribution of basaltic, andesitic, and rhyolitic volcanics (including welded ignimbrites) in central North Island, and the locations of eight multivent calderas and Tongariro Volcanic Centre in the Taupo Volcanic Zone (after Briggs et al. 1993 and Nairn et al. in press). The TVZ forms the eastern part of the geologically and geophysically distinct wedge-shaped Central Volcanic Region. The Tuhua volcano of Mayor Island is a peralkaline caldera complex most recently active in the Holocene (Houghton et al. 1992). The Coromandel Peninsula lies in the Coromandel Volcanic Zone, an area of active volcanism in Miocene-Pleistocene times (Skinner 1986). Intraplate basalt fields (numbered) are as in Fig. 0.2.

Quaternary events and deposits

The stratigraphy of the New Zealand Quaternary has recently been reviewed by Pillans (1992), who prepared a generalised map of Quaternary deposits (Fig. 0.6). Time-stratigraphic subdivsions of New Zealand Quaternary strata, based on marine biostratigraphy and climatostratigraphy, has resulted in a series of locally defined stages and substages (Table 0.1). The Plio/Pleistocene boundary as defined at Vrica, Italy, and dated at c. 1.63 Ma, lies near the top of the Nukumaruan Stage in New Zealand. The first faunal evidence of cooling in New Zealand Plio/Pleistocene sequences occurs much earlier, at the base of the Nukumaruan Stage c. 2.4 Ma, with the appearance in central New Zealand of the subantarctic taxa *Chlamys delicatula* and *Jacquinotia edwardsii.*

TABLE 0.1. New Zealand Quaternary stages and substages with boundaries as defined in Wanganui Basin (from Pillans 1992, p. 407.)

Epoch	Series	Stage	Substage	Boundary position
				Present day
PLEIST		Haweran		
				Top Putiki Shellbed
	WANGANUI	Castle-cliffian	Putikian	
				FAD *Pecten*
			Okehuan	
				Base Butlers Shell Conglomerate
PLIOCENE		Nukumaruan	Marahauan	
				Base Ohingaiti Sand
			Hautawan	
				Base Hautawa Shellbed
		Mangapanian		
				Base Mangapani Shellbed
		Waipipian		

New Zealand's maritime mid-latitude location has made it particularly sensitive to the climatic fluctuations and associated glaciations and sea level changes of the Quaternary Period. Glaciations have had their greatest influence in the South Island where the tectonic uplift produced elevated areas for snow accumulation and the relief and structural features necessary for alpine ice caps and major valley glacier systems to develop. Analysis of cores from DSDP Site 594 southeast of New Zealand (Fig. 0.6) has shown that the South Island glaciations were in phase with those of the Northern Hemisphere (Nelson et al. 1985a; see also Nelson et al. 1993). During the maximum of the last glacial (c. 23-13 ka), an almost continuous glacier complex stretched nearly 700 km along the Southern Alps with snowlines lowered around 800 m below those of the present (Porter 1975). Sea levels were lowered by about 120 m (Pillans et al. 1992).

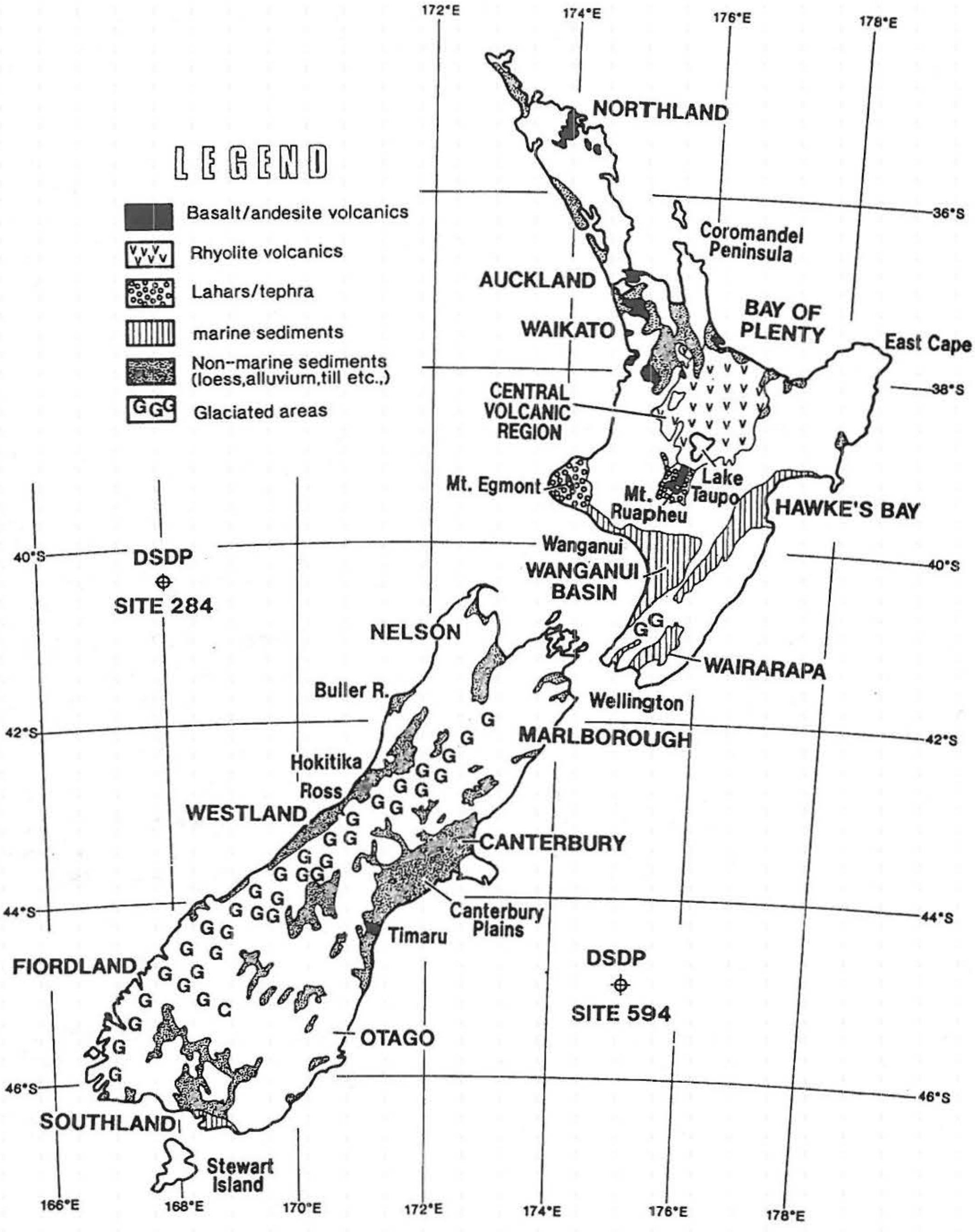

Figure 0.6: Generalised distribution of Quaternary deposits in New Zealand (from Pillans 1992, p. 406).

The estimated drop in annual temperature (ignoring regional variations and assuming similar precipitation levels to those of today) is 4.5 to 5.0°C (McGlone 1988). Cold temperatures, high winds, severe frosts, and droughty conditions were prevalent (Alloway et al. 1992b; Nelson et al. 1993; Pillans et al. 1993).

During the periods of glacial advance and retreat, erosion debris of glacial drift, outwash gravels, and loess was deposited in large quantities in inland basins and on both coastlines, with loess deposits especially abundant on the eastern side of the South Island (e.g. see papers in Eden & Furkert 1988; Pillans 1992).

By comparison with the South Island, glaciation in the North Island was minor with cirques and small valley glaciers occurring in the Tararua Range, and a small ice field on the volcanoes in central North Island. Periglacial activity, including severe fluvial and wind erosion at times, occurred in much of the North Island with the notable exception of the Northland peninsula. Loess sheets were deposited in the southern half of the North Island (Milne & Smalley 1979; Eden & Furkert 1988; see Post-Conference Tour Guide). Dating of these sequences has been mainly by radiocarbon, tephrochronology, and, most recently, thermoluminescence analysis (e.g. Berger at al. 1992). In parts of central North Island, at elevations >400 m, tephric loess was deposited between airfall tephra units during the colder periods (Kennedy 1988, in press).

The dominantly hilly and often mountainous nature of much of New Zealand (around 50% is classed as steep, 20% moderately hilly, and 30% rolling or flat), coupled with a generally high rainfall and the widespread occurrence of highly jointed basement rocks and soft sedimentary rocks that are very susceptible to erosion, has produced generally very fast rates of denudation, especially through landsliding, either as deep rock and debris slides or as shallow, regolith slides. Denudation rates in the Southern Alps range from ≈2.5 mm/yr to ≈0.5 mm/yr with increasing distance from the Alpine Fault across the Alps to the east (Kamp & Tippett 1993). The landsliding is evidently an episodic process controlled chiefly by the frequency of earthquakes and high magnitude climatic events such as rainstorms (Williams 1991; Crozier et al. 1992). In the last millennium human activities, especially deforestation, both by Polynesian and European settlers, have tended to increase rates of erosion (McGlone 1989; McSaveney & Whitehouse 1989).

Thus active tectonism, volcanism, generally abundant rainfall, and high rates of erosion in New Zealand have resulted in a dynamic, sharp textured, and youthful landscape with great landform variety. Almost all of the present landscape has developed within the past two million years, indeed much of it in the second half of the Pleistocene or in the Holocene (Pillans et al. 1992).

SOILS

The soil pattern associated with the New Zealand landscape is complex, partly because of the many different kinds of parent materials, and partly because of the varied conditions under which they have been transformed into soils (Soil Bureau Staff 1968; Molloy 1988). All the orders of *Soil Taxonomy* (Soil Survey Staff 1992) are represented in New Zealand, but Mollisols and (especially) Vertisols are very rare (Hewitt 1992).

Northern North Island, which largely escaped the effects of the glacial periods (Newnham et al. 1993), is warm and humid, and many soils are old, deeply weathered, and clayey, forming mainly Ultisols and some Oxisols (Fig. 0.7). Spodosols, commonly associated with forest species that produce an acid litter (e.g. kauri, rimu), are also represented. Elsewhere in New Zealand the soils are almost all relatively young because of the effects of tectonism, land instability, and the Pleistocene glaciations (especially influential in the South Island). In central and western North Island large areas of soils (and buried paleosols) are developed on the sequences of airfall tephra deposits, forming mainly Udands and Vitrands dominated by short-range order clays. Parts of southern North Island, and eastern South Island, often experience seasonal moisture deficiencies (ustic moisture regimes) and the soils typically are Alfisols or Inceptisols. The very dry inland basins of the South Island (Central Otago) contain Aridisols, whilst in the very high rainfall areas of western South Island, Spodosols, often Aquods, predominate (Fig. 0.7).

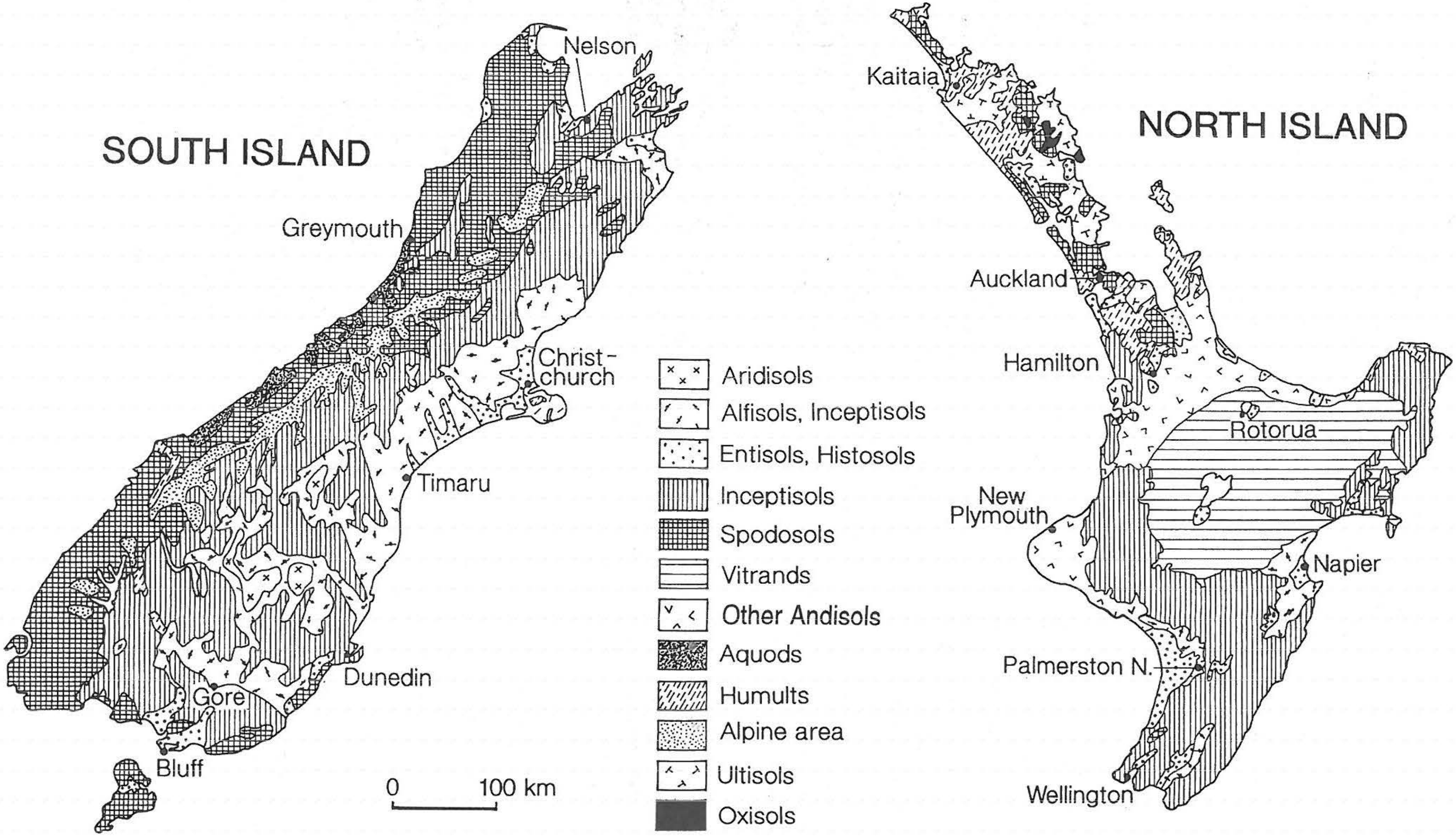

Figure 0.7: Generalised soil map of New Zealand (after Soil Bureau Staff 1968 and Hewitt 1992).

Paleosols

Paleosols, or soils of an environment or landscape of the past, have been differentiated into buried paleosls and relict paleosols (including exhumed paleosols) in New Zealand (Gibbs 1971, 1980). There are numerous paleosols buried under tephra, loess, colluvium, and alluvium deposits of Quaternary age; surface (paleo)soils with relict characteristics are less common.

A review of paleosols in New Zealand was published by Campbell (1986); other New Zealand work of note includes papers by Goh (1972), Birrell & Pullar (1973), Leamy et al. (1973), Runge et al. (1974), Tonkin et al. (1974), Leamy (1975), Kirkman (1976), Birrell et al. (1977), Limmer & Wilson (1980), Stevens & Vucetich (1985), Lowe (1986), Hodder et al. (1990), Lowe & Percival (1993), and Kimber et al. (in press).

CLIMATE

New Zealand lies within the zone of mid-latitude westerly winds extending from 70^{o} to 30^{o}S. These strong, consistent winds are moisture laden after their passage over the surrounding ocean, but moderated in temperature. The main climatic features of the country result from interaction of this air flow with the substantial barrier of the northeast-trending mountain chains (Tomlinson 1975). Because few areas are more than 100 km from the coast, oceanic influence is dominant and the climate is generally moist, windy, and with low annual cloudiness. Most of New Zealand can be classified as warm or cool temperate (McGlone 1988). Annual mean temperatures vary from about 15^{o}C in northern North Island to about 9^{o}C in southern South Island, with summer temperatures relatively cool and winter conditions generally mild. Westerly winds predominate for most of the year although there may be considerable modification by local topography. In many North Island areas, southwesterly flows predominate. In the past few years, mean monthly temperatures have been about 0.5^{o}C lower than normal, and winds generally more southerly, because of the influence of the El Nino phenomenon (ocean surface temperature anomalies of the equatorial Pacific) and fine ash fallout from the Pinatubo eruption in the Phillipines in mid-1991.

Rainfall is highly variable and strongly related to the topography, ranging from more than 7000 mm in the central Southern Alps to 350 mm in inland Central Otago east of the main mountain ranges. The average for the whole country is probably >2000 mm but for much it lies between 600 and 1600 mm. Day-to-day weather variation is high and is controlled by a progression of eastward-moving anticyclones and depressions, with associated cold and warm fronts, at approximately 5 tò 10 day intervals (Tomlinson 1975). Persistent weather patterns are rare. Sunshine levels are relatively high with much of the country receiving >2000 hours per year.

FLORA AND FAUNA

Fossil remains show that New Zealand has long been forested, and recognisable ancestors of some present-day trees such as rimu (*Dacrydium cupressinum*), kahikatea (*Dacrycarpus dacrydioides*), totara (*Podocarpus totara*), matai (*Prumnopitys taxifolia*), miro (*Prumnopitys ferruginea*), and kauri (*Agathis australis*) extend back 250 Ma (Bishop 1992). At that time, New Zealand was part of Gondwanaland. Ancestors of various ancient or 'archaic' animals — the tuatara, native frogs, and giant land snails — lived in New Zealand as far back as 150 Ma. The ancestors of the moas and kiwis, southern beeches (*Nothofagus*), and rewarewa (*Knightia*) were also present when New Zealand first began to separate from Antarctica and Australia c. 85 Ma. When this happened many previously dominant plants and animals became extinct. Dinosaurs and other giant reptiles, many marine invertebrates, and some of the fern-like plants and gymnosperms, were lost as climates changed and new life forms evolved. For the plants and animals left 'aboard' New Zealand when it drifted away from Gondwanaland, the islands became both a paradise and a prison (Bishop 1992). Only a trickle of new plants and animals has subsequently arrived from across the sea. Thus New Zealand's early separation and long isolation have provided opportunities for the evolution of peculiar endemic plants and animals. Since then the country's turbulent geological development, involving tectonism, volcanism, and climate change, has further influenced evolution and extinction in New Zealand (McGlone 1985).

The impact of humans or other exotic invaders (especially mammals) has occurred only very recently, being restricted to the last 1000 years or so (Caughley 1989). However, the forests have changed significantly in this relatively short time. About 75% of the land was covered in forest in pre-Polynesian times but this was reduced to about 55% by the time European settlement began about 150 years ago. This reduction in forest cover is attributed largely to Polynesian firings (McGlone 1983, 1989). Since European arrival, forest cover has been further reduced to about 25%, with practically all lowland areas being cleared for agriculture.

An inevitable result of deforestation on this scale, together with the introduction of carnivorous and herbivorous mammals such as rats, stoats, pigs, deer, and possums, has been the extinction of unique native plants and animals, particulary from the lowland forests, through competition, predation, and disease (Towns & Atkinson 1991). A large proportion of the extinctions can be attributed directly to the loss of habitat or to the reduction of forested areas to patches too small to provide adequate resources for survival of populations. Nearly 25% of all the endangered species of birds listed from around the world are from New Zealand, and over 300 of the flowering plants and ferns (10-15% of the total) are currently at risk (Hackwell 1983). Those offshore islands free of introduced pests have assumed special significance as 'safe havens' to transfer native animals whose existence is threatened elsewhere. Such transference to offshore islands, together with programmes of pest eradication on them, now form the mainstay of New Zealand's threatened species management (Towns & Atkinson 1991; Bishop 1992).

Flora

The flora of New Zealand is not rich as the total number of higher plants — slightly more than 2000 — is small compared with other countries of similar size and latitude. However, c. 85% of species and c. 10% of genera are found nowhere else, including one endemic genus of fern and 38 endemic genera of flowering plants. Twenty-four of these 39 endemic genera are represented by a single species (Hackwell 1983). The early naturalist Sir Joseph Banks, visiting New Zealand in 1769 with Captain Cook, remarked that "The entire novelty of what we found recompensed us as natural historians for the want of variety". About 80% of New Zealand's higher plant genera are found also in Australia, but the most distinctive and widespread Australian genera, *Eucalyptus*, *Acacia*, and *Banksia*, do not occur in New Zealand (McGlone 1988).

New Zealand forests are of two major types, dominated either by (1) conifers (podocarps, 'cedar', kauri) and broadleaf 'hardwood' (e.g. tawa, taraire, rata, kamahi, rewarewa) trees, or (2) by one or more of the four southern beeches. Conifer-broadleaved forests are very diverse, occurring throughout the country under all climates but are best developed on warm, fertile, lowland sites. Beeches tend to occupy sites climatically less favourable for plant growth than those dominated by conifer-broadleaved forests, hence are concentrated in cooler, southern regions, and in uplands rather than lowlands (McGlone 1988). The largest tree, kauri (*Agathis australis*), occurs only in warmer regions north of latitude 38°S; it rarely exceeds heights of more than 30 m but has massive, cylindrical boles normally up to 3 m in diameter but some may be as large as 7 m.

As a whole, New Zealand forests are quite different from those of the Northern Hemisphere and other temperate regions, resembling tropical rain forest in many ways: they are moist, dense, and evergreen with many multi-storied vegetation layers, and both the forest floor and trees are often covered in mosses and ferns, with the trees also carrying vines and other plants on trunks and upper branches. Other characteristics include a dearth of deciduous species or annuals; trees frequently have differing juvenile and adult forms; many shrubs and juvenile trees have divaricating forms with widely-angled branches and a tangled growth habit; flowers are usually inconspicuous and lack bright colours; many plants produce colourful, bird-dispersed, small fleshy fruits; and an unusually high proportion (c. 12%) of native species have male and female flowers on separate plants (Hackwell 1983). Finally, New Zealand forests differ from all others in that they have developed in the absence of herbivorous mammals, and hence they more closely resemble the ancient forests of Gondwanaland than those of any other southern continent. New Zealand also has the world's largest buttercup (*Ranunculus lyallii*), the smallest member of the pine family (*Lepidothamus laxifolius*), the largest tree fern (*Cyathea medullaris*), tree-sized daises (*Olearia, Senecio*), mosses 0.3 m high (*Dawsonia superba*), and numerous cushion plants including the huge 'vegetable sheep' of the South Island mountains (*Haastia, Raoulia*).

Fauna

Like the flora, the fauna of New Zealand is a curious mixture of 'archaic' animals of Gondwanaland lineage and later arrivals from more recent times, mostly from Australia. Only a few examples are described here. Among the birds, there has been an evolutionary trend towards increasing size, loss of flight, and dark plumage. Kiwis (*Apteryx*), together with the now extinct moas (*Dinornis*), are endemic representative of the ratites, which also include the emu, cassowary, rhea, and the ostrich. Until recently, both kiwis and moas were thought to have become flightless on Gondwanaland, but new work has suggested that kiwis are of more recent origin than moas, their lineage dating back only 40 million years. If so, how the kiwi's ancestors reached New Zealand, well isolated from Gondwanaland by then, is a puzzle (Bishop 1992). Kiwis, of which four species are known (more probably exist), are unusual amongst living ratites because of their small size and adaptation to life on the forest floor. They are nocturnal and feed on small insects and other invertebrates. Their long beak has nostrils at the tip and cat-like sensory hairs at the base. Moas were herbivores of different sizes, the largest being over 2 m tall and weighing c. 200 kg, and the various species may have browsed in different habitats (see Caughley 1989).

One of New Zealand's rarest flightless birds is the bright green kakapo or New Zealand ground parrot (*Strigops habroptilus*), the world's largest parrot. It has evolved a solitary, nocturnal existence and sometimes climbs trees to get its food. Other flightless herbivorous birds include the rare takahe (*Porphyrio mantelli*), formerly widespread but now restricted to parts of Fiordland, and the weka (*Gallirallus australis*), an opportunist feeding on a variety of animal and vegetable matter (Bishop 1992).

The tuatara (*Spenodon punctatus*) is the sole remaining species from a family of reptiles (Sphenodontida) with a lineage going back more than 225 million years and little changed from its ancient predecessors. It resembles a lizard and a crest of fexible spines along the back, the shape of the skull and jaw, and the enlarged pineal gland suggestive of a 'third eye' are among its special features.

Another distinctive animal, the 'velvet worm' or peripatus (*Peripatoides novaezelandiae*), occupies what appears to be a half-way position in the evolutionary scale between worms and insects. It has the soft, flexible, unjointed body of a worm yet clawed feet and air-conducting tracheae of an insect (Bishop 1992).

The ancestors of New Zealand's three native frog species (*Leiopelma*) probably date back to Gondwanaland times. They are considered to be the most primitive of all living frogs. They lack vocal sacs hence are non-croaking, have tail-wagging muscles but no tail, and have fish-like vertebrae. Lacking fully webbed feet for swimming, they deposit eggs in moist ground or seepages rather than in water. The young of Hamilton's frog (*L. hamiltoni*) are hatched as virtually tailed froglets which then crawl onto the moist back of the adult male to complete development (Bishop 1992).

Perhaps the most 'deadly' archaic animals of the forest floor are the giant snails (*Powelliphanta*) that grow up to 10 cm in diameter. These members of the ancient Gondwanaland snail family, Rhytididae, are voracious carnivores and hunt earthworms, slugs, and smaller snails which are consumed with the hundreds of tiny dagger-like teeth covering their radula, or tongue (Bishop 1992).

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