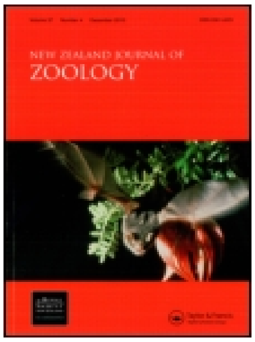

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New Zealand tectonostratigraphic terranes and panbiogeography

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Abstract Tectonostratigraphic terranes of New Zealand, grouped for purposes of the present discussion into six groups, are briefly reviewed as to their role in the biogeographic evolution of the present day biota of New Zealand. Of all the terranes so far recognised, only the Torlesse (Rakaia) terrane is thought to have originated outside the New Zealand region; of the various models proposed to explain its origin and emplacement, only that by McKinnon (1983) would allow it to have acted as a "raft" that could have transported a biota en masse. The former existence of a "lost continent" (Pacifica), suggested as a possible source for Torlesse sediments, is regarded as improbable. The long time (at least 140 Ma, and probably 190 Ma) since terrane accretion, and the extreme degree of geological (and geographical) complexity and change that New Zealand has undergone since accretion, make it most improbable that the present day distribution of plants and animals among the terranes reflects the original distribution of their ancestors.

Keywords accretion; panbiogeography; biotic transport; Pacifica; terranes; Torlesse

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INTRODUCTION

Tectonostratigraphic terranes (terranes for short) are a useful concept in analysing the tectonic history of orogenic regions of the earth (Jones et al. 1983). The concept is being applied in New Zealand (discussed below) and the New Zealand region is now viewed by tectonostratigraphers as an amalgam of at least nine distinct terranes. The recognition of tectonically composite regions such as New Zealand, western North America, and western South America has been seen by some biogeographers as a key to the explanation of disjunct plant and animal distributions (Melville 1981; Nur & Ben-Avraham 1981). In North America, Hendrickson (1986) concluded that the congruence of phylogenetic and terrane area cladograms for salamanders (bolitoglossines) indicates that present day distribution of salamanders can be explained by isolation on, and transport by, mobile terranes. Panbiogeographers (e.g., Craw 1985; Craw & Weston 1984; Craw & Page 1988) see the recognition of these composite regions as consistent with predictions derived from Croizat's panbiogeographic analysis of global plant and animal distributions (see Craw & Weston 1984 for references to the several papers by Croizat 1952–1982). Terranes are seen as potential "rafts" or "vehicles" for bringing together elements of the shallow marine and terrestrial biota from distant regions, thus creating disjunct distributions. The distribution of composite regions around the pacific margin is seen by panbiogeographers as consistent with Croizat's view that the ocean basins are centres of plant and animal ancestral distributions ("baselines"), rather than barriers separating discrete biogeographic regions.

It is therefore of some interest to examine the New Zealand terranes and what is known of their origin and transport history. They have already been discussed in relation to the distribution of the native frog, *Leiopelma*, by Craw (1985), of micropterygid moths by Gibbs (1983), and of trichopteran insects by Henderson (1985). Could the New Zealand terranes have acted as "rafts" or "vehicles" for transportation of the biota—oceanic "railway terranes" as it were—and if so when did they arrive and where have they come from? The emphasis here, as in most of Croizat's writings, is on terrestrial and shallow marine organisms.

This paper aims briefly to summarise those aspects of the terrane concept and its application in New Zealand that are of relevance to biogeography, particularly panbiogeography. It does not attempt to fully review the subject and those wishing to examine the geological basis for many of the generalisations made here should consult the references cited. Recent reviews of New Zealand terranes are given by Bishop et al. (1985) and Spörli & Ballance (1985).

Because the tectonostratigraphic terrane concept is relatively new and still evolving, there is some diversity in its use among different workers. A good recent summary of the nature of terranes is given by Schermer et al. (1984).

What are tectonostratigraphic terranes?

Tectonostratigraphic terranes are defined as fault-bounded geological entities of regional extent, each characterised by a geological history that is different from the histories of contiguous terranes (Jones et al. 1983). Linear belts of rocks characterised by having a distinctive geological history have long been known to geologists, particularly those mapping in orogenic zones around the Pacific rim. Such rocks have variously been called belts, tracts, troughs, elements (of geosynclines), tectonosedimentary belts, and tectonostratigraphic terranes; the bounding faults have been called thrusts, transcurrent faults, lineaments, and axes. The present day juxtaposition of such belts poses the problem of how they could have evolved with different geological histories while lying so close together, and a variety of (generally unsatisfactory) models have been proposed to achieve this.

With the arrival of plate tectonic theory (in 1968) a more "mobilist" view of the continents and oceans became acceptable and, during the 1970s and 1980s, the existence of mobile microplates, especially in convergent and transform plate boundary settings such as the Mediterranean region (Berckhemer & Hsü 1982) and New Zealand (Wellman 1981) was recognised. At the same time, regional studies in North America indicated that the western part of the continent is made up of a collage of over 100 terranes and that at least some of these, such as that named Wrangellia, contained faunal and paleomagnetic evidence suggesting that they may have originated some considerable distance away (e.g., hundreds or thousands of kilometres; Jones et al. 1982). Thus, the notion of terrane mobility or allochthoneity (a term meaning transport of rock masses a long way from their place of origin) arose and is now widely held as being an essential part of the terrane concept.

> Because terrane mobility is seemingly a proven fact, it is now more reasonable to assume allochthoneity among terranes than lithofacies linkage between contrasting rock assemblages (Howell & Jones 1984: 6).

Having said that, it must also be pointed out that whereas many (probably most) geologists working in the field are happy to accept some degree of allochthoneity among terranes, it is certainly a mistake to assume that large scale (trans-oceanic) movements are generally accepted for most terranes. In New Zealand (see below) trans-oceanic scale displacements are improbable for most terranes.

NEW ZEALAND TERRANES

South Island

Ten late Paleozoic to Mesozoic terranes are currently recognised in the South Island (Bishop et al. 1985; Landis & Blake 1987) and are grouped, for the purposes of this discussion, as follows (Fig. 1).

1. Tuhua terrane (mid Paleozoic to early Mesozoic), formed by the amalgamation (probably in Devonian time) of the early Paleozoic Buller and Takaka terranes (Cooper 1989). During mid Paleozoic to Cretaceous time, the Tuhua terrane was part of the Pacific segment of Gondwana.
2. Caples, Dun Mountain/Maitai, Brook Street, Murihiku, and Drumduan terranes (Permian to Jurassic); all are formed largely of volcanics or volcanic-derived sediments and together are inferred to represent a composite arc-trench system developed along the oceanward side of the Gondwanaland margin and separated from it by a marginal sea (MacKinnon 1983). Landis & Blake (1987) point out that the system was complex and involved arcs now removed by tectonic or subaerial erosion. The arc-trench (volcanogenic) terranes are separated from Tuhua terrane by the Median Tectonic Line (or zone).
3. Torlesse terrane (= older Torlesse or Rakaia Terrane; Permian to Jurassic) areally is the most extensive terrane of onshore New Zealand and is interpreted as representing an accretionary prism developed along a trench-transform system. Its contact with the Caples terrane to the west has been subsequently obscured by development of the Haast Schist zone.

Several small patches of limestone-bearing strata are scattered through Torlesse rocks and generally appear to be stratigraphically and structurally distinct from the Torlesse proper. At Waitaki Valley (Akatarewa terrane), Permian fusulinid Foraminifera have Tethyan affinity, in contrast with other South Island Permian faunas. At Kakahu (Kakahu terrane), Carboniferous conodonts are present. These two, possibly along with several other small patches, are inferred to be allochthonous with respect to surrounding Torlesse rocks and to have amalgamated with the Torlesse before its suturing to the volcanogenic terranes to the west.

4. Younger Torlesse (= Pahau terrane; Late Jurassic to early Cretaceous). Northeast of the Esk Head Melange, rocks mapped as Torlesse generally resemble the older Torlesse rocks to the southwest, but differ in containing a much larger percentage of sediments derived from an older sedimentary and meta-sedimentary source, most probably the older Torlesse and Haast Schist itself (MacKinnon 1983; Bishop et al. 1985). The younger Torlesse rocks, like their older equivalents, represent an accretionary prism thought to have developed against the oceanward side of the uplifted and partially metamorphosed older Torlesse (MacKinnon 1983), from which they are separated by the Esk Head Melange.

North Island

A preliminary tectonostratigraphic analysis of the North Island by Spörli & Ballance (1985) recognises six terranes. The pre-Cenozoic terranes are shown in Fig. 1 and related to their South Island equivalents. There are some differences between the two islands, in a few of the terranes (Spörli & Ballance 1985), but they do not concern us here.

1. No equivalents of Tuhua terrane outcrop onshore, but Tuhua rocks have been intersected in petroleum exploration wells off-shore in the Taranaku Basin and Western Platform.

2b. Murihiku, Dun Mountain, and Waipapa terrane (includes Hunua and Morrinsville facies). The Waipapa terrane may not be the equivalent of any South Island terrane.

3. Torlesse terrane, equivalent to the South Island Torlesse.

4b. Mata River terrane, equivalent to the younger Torlesse (Pahau) terrane. The boundaries between terranes are defined less well than in the South Island, especially that between Torlesse and Mata River terranes. The main New Zealand Cenozoic terranes (Spörli & Balance 1985) are shown in Fig. 2.

5(a, b). Northland/East Coast allochthon disrupted terrane includes late Cretaceous to Oligocene strata that have clear stratigraphic and faunal links with the autochthon and are thought to have originated at no great distance to the NE of the present New Zealand region (Brook et al. 1987; Spörli 1987). It was emplaced by thrusting or gravity sliding during late Oligocene/early Miocene time.

6a. Tangihua, and 6b Matakaoa terranes, comprise mainly mafic volcanics and plutonics. The Tangihua rocks are thought to represent the upper part of an ophiolite sequence (Brothers & Delaloye 1982) and the Matakaoas appear to be, at least in part (Pirajno 1979), of oceanic origin. Both sequences were tectonically emplaced berfore the late Miocene.

The two Cenozoic terranes thus tectonically overlie older rocks and in this respect differ from the pre-Cenozoic terranes. Fig. 2 also shows the main currently active tectonic zones of the North Island, including the currently accumulating accretionary prism adjacent to and overlying the site of present day subduction—the Hikurangi Trough.

The relative order of accretion of terranes, so far as it can be determined, is shown in Fig. 3.

Terrane transport—how far, where from?

Of all pre-Cenozoic New Zealand terranes, only the Torlesse (together with its amalgamated Kakahu and Akatarewa components) is thought to have originated outside the New Zealand segment of the SW Pacific region. The Tuhua terrane (region 1, Fig. 1) was clearly part of Gondwana in late Paleozoic – Cretaceous time, and those of region 2 (a+b) are thought to represent an arc-trench system separated from the Gondwana margin by a marginal sea. Terranes of region 4 (a+b) are linked stratigraphically or by provenance (that is, sediment in one terrane is derived from source rocks in another) with older terranes and by this reasoning could not have originated far away.

The Northland/East Coast allochthon (terrane 5a,b) is inferred to have been derived from the NE

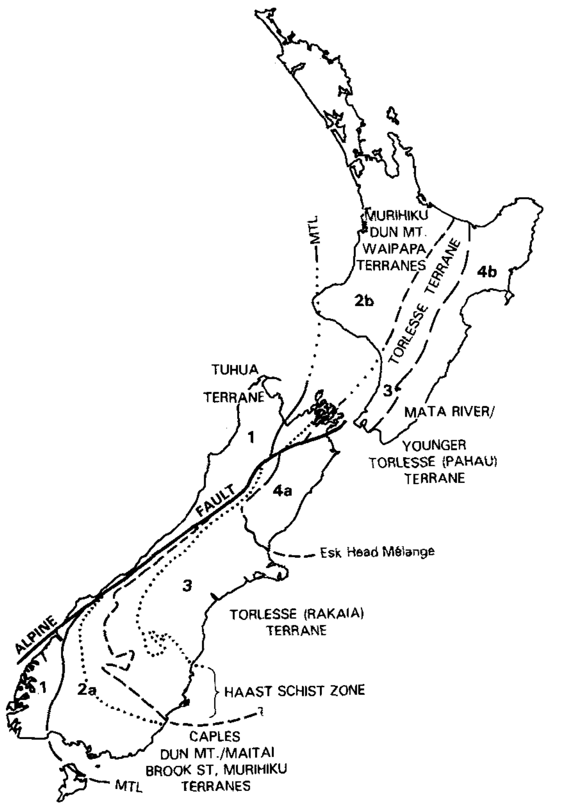

Fig. 1 Principal pre-Late Cretaceous terranes of New Zealand. The late Paleozoic Tuhua Terrane (1) is formed by amalgamation of the two early Paleozoic terranes (Takaka and Buller). The five late Paleozoic-early Mesozoic volcanogenic terranes: Caples, Dun Mountain/ Maitai, Brook Street, Murihiku, and Drumduan are grouped (2a) and shown in the same zone as the Murihiku, Dun Mountain, and Waipapa terranes of the North Island (2b). Younger Torlesse terrane (4a) is regarded as equivalent to Mata River terrane (4b). Position of the 2a/3 boundary is approximate, being obscured by the later Haast Schist zone (Haast Schist and Aspiring terranes). The Alpine Fault splits into numerous branches (not shown) in the North Island. (Data from Bishop et al. 1985; Spörli & Ballance 1985.)

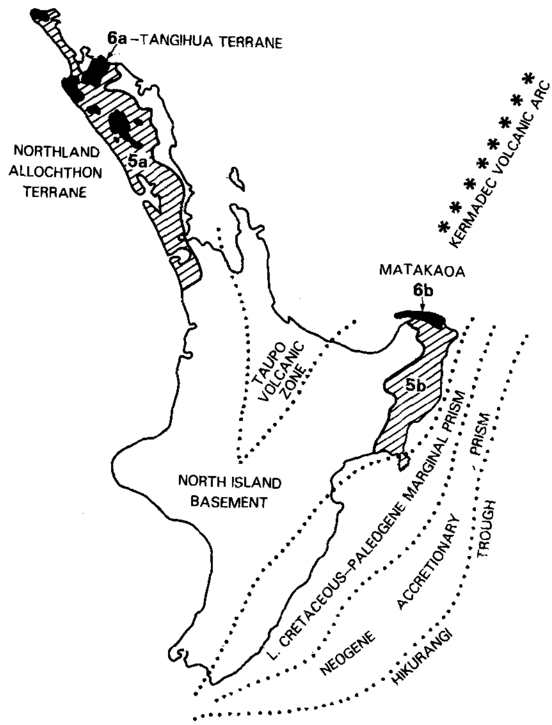

Fig. 2 Principal post-Cretaceous terranes of New Zealand. The Northland allochthon/East Coast allochthon (5a,b) and the Tangihua/Matakaoa (6a,b) terranes are recognised as being significantly distinctive or allochthonous with respect to adjacent rocks. The late Cretaceous–Paleogene marginal sedimentary prism (not a discrete terrane) onlaps and lies outboard of the pre-Cretaceous Mata River terrane and is also present in Northland; it was imbricated by faulting in the late Neogene. Also shown are the major currently active tectonic elements—the Taupo volcanic zone, the Neogene accretionary prism (currently forming), and the Hikurangi Trough—site of present day subduction. (After Spörli & Ballance 1985.)

New Zealand region continental margin (Brook et al. 1987) by obduction associated with a west-dipping subduction system, or alternatively by complex collision with the southern end of the Three Kings – Loyalty Ridge System (Spörli 1987). Either way, it originated at no great distance to the northeast. On the other hand, the Tangihua/Matakaoa terranes (or terrane?) are most probably of oceanic origin and may have come some considerable distance. There is no evidence of shallow marine or terrestrial deposits associated with them, however; the nature of their volcanic rocks, associated sediments, and the contained (mainly foraminiferal) faunas suggest that they represent ocean floor and submarine volcanics. It therefore appears extremely unlikely that they could have carried a shallow marine or terrestrial biota from their place of origin.

For the panbiogeographer, the Torlesse terrane is that of most interest, and its origin is therefore discussed in more detail below.

Origin of Torlesse terrane

Torlesse terrane rocks are composed almost entirely of quartzofeldspathic greywacke and mudstone, derived from a mountainous source region of silicic

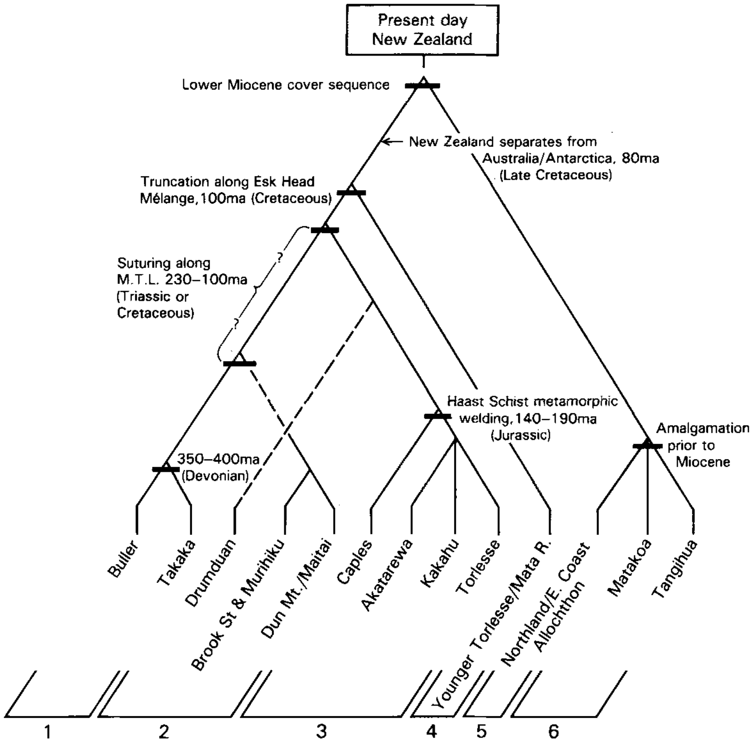

Fig. 3 Branching diagram to show degree of relationship among terranes based on geological history. Because the terranes are coalescing, rather than diverging, with time; branch points represent suturing events, oldest events at the bottom and youngest events at the top. Any pair of terranes share a common history beyond their time of suturing, i.e., above the junction of their branches in the diagram. Note the alternative configurations resulting from uncertainty about time of suturing along the Median Tectonic Line (MTL). Terranes are grouped into the six regions shown in Fig. 1, 2 at bottom.

plutonic and volcanic rocks (ensialic arc). The literature describing and discussing the nature and origin of Torlesse rocks and their relationship (and contrast) with rock belts to the west and south is considerable (see references in MacKinnon 1983). However, the first to recognise the probable allochthonous nature of the Torlesse were Blake et al. (1974), who envisaged it as being derived from an active continental margin and transported away from its place of accumulation (to its present site adjacent to the volcanogenic terranes) by sea floor spreading. The Marie Byrd Land-Jones Mountains region of West Antarctica was suggested as a possible source area, consistent with the earlier, similar suggestion by Bradshaw & Andrews (1973).

The Torlesse sediments accumulated in trench, slope, or borderland basins (Coombs et al. 1976) as submarine fan deposits, but deposition was accompanied by deformation, and internal stratigraphy is commonly incoherent. Most recent workers (e.g., Spörli 1978; Bradshaw et al. 1981; Howell 1981; MacKinnon 1983; Bishop et al. 1985; Korsch & Wellman 1988) regard Torlesse terrane as representing an accretionary prism or imbricate wedge built up by convergent plate movement along a subduction zone. The plate convergence that generated the Torlesse accretionary prism may have been that which also gave rise to the arc-trench system further to the west, represented by the volcanogenic terranes.

However, although the Torlesse and volcanogenic terranes (regions 2 and 3 in Fig. 1) have distinctly different provenances and accumulation histories, opinions about the distinctness of their fossil biota are less clear. An overall similarity in marine shelly faunas (Campbell 1985) and terrestrial plants (Retallack 1984, 1987) is apparent, and Retallack (1987) interprets the paleolatitude and paleoclimatic conditions of the two terranes as being compatable with a model in which they formed in different parts of the southeastern Gondwana coast in Triassic time. On the other hand, Grant-Mackie (1985) stressed the difference in total faunal content of the two regions (regions 2 and 3), listing several taxa endemic to one or the other, and contrasting a "Maorian Province" (region 2) with "Tethyan affinities" (region 3). However, H. J. Campbell (pers. comm. 1988) points out that much of the distinctive Torlesse (region 3) fauna is found in a sedimentary facies (clean bioclastic limestone) that is largely lacking in region 2, and apparent faunal differences may, in part, reflect facies differences. There is also the possibility that some of the fossiliferous limestones, many of which are

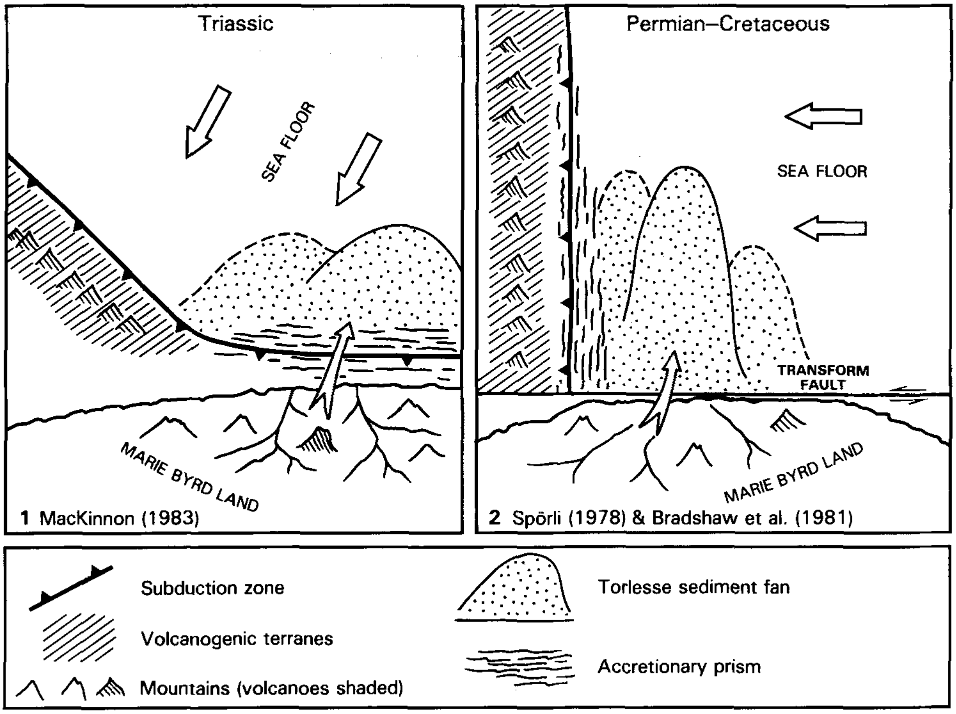

Fig. 4 Contrasting models for origin and emplacement of Torlesse terrane. (1), Accretionary prism built up against the Antarctic (Gondwanaland) margin from sediments supplied from Gondwanaland during Permian and Triassic time. Later, during the Jurassic, transform, or oblique transform faulting displaces the prism and brings it into collision with the volcanogenic terranes. (2), Accretionary prism is built up continuously during deposition of Torlesse sediments on the sea floor, throughout Permian to Jurassic time. Note that in both models the site of subduction migrates towards the ocean during Triassic to Jurassic time.

demonstrably, or inferred to be, allochthonous, may be exotic and not represent the same faunal province as in situ faunas. Further, H. J. Campbell and others (unpubl. data) have found fossil taxa present in both regions that previously were thought to be confined to one, thus diminishing the apparent difference. Clearly, further work is required before the question can be fully resolved. However, the faunal distinctness is likely to be less pronounced than Grant-Mackie thought, and taken together with Retallack's data, and the substantial shared fauna, it can be tentatively concluded that the two regions were unlikely to have lain in distinctly different faunal provinces (implying allochthoneity on a "transoceanic" scale) in Triassic and Jurassic time.

The probable site of Torlesse deposition is regarded by MacKinnon as the Western Province–West Antarctic segment of Gondwana. However, it should be pointed out that this site, and the proposed source area of West Antarctica, have yet to be adequately justified by geological and geophysical evidence.

Within the constraints of this general picture two alternative models for the Torlesse have been proposed (Fig. 4). MacKinnon suggests that deposition and accretion took place along a convergent plate boundary adjacent to the source region; the accretionary prism was subsequently (in latest Triassic or Early Jurassic time) moved by transform or oblique transform ("transpression") faulting away from its source region to its present position against Caples terrane. In the second model (Spörli 1978; Bradshaw et al. 1981), the Torlesse sediments were continuously transported away on a moving ("conveyor belt") plate while deposition was going on, and they were accreted as an imbricate stack or wedge at their present site against the volcanogenic terranes (a similar, "in situ" accretion model is proposed by Korsch & Wellman 1988).

Torlesse as a raft for the biota

For biogeographers considering the Torlesse to be a raft for transporting elements of the biota from one region of the earth to another, the difference between the above two models is vital. The following points are relevant:

1. In the first model the Torlesse is moved as a whole, as a built-up accretionary prism. It is reasonable to assume that it had achieved a considerable, possibly continental, thickness and that parts of it could have protruded above sea level, thus enabling a terrestrial biota to have been carried. Shallow marine or terrestrial deposits of middle Triassic age are preserved in several small outliers, summarised by MacKinnon (1983), consistent with such a possibility.
2. In the second model, transport took place while Torlesse sediments lay as sheets (detached fan or apron segments) on the ocean floor and it is extremely unlikely that any but deep marine elements of the biota could have been transported.
3. Transport of Torlesse sediments (Spörli) or rocks (Mackinnon) took place before (or simultaneously with) collision with Caples rocks and before formation of the Haast Schist during Triassic or Jurassic time, i.e., prior at least to 145 Ma and probably to 199 Ma. Potassium-argon studies of schist indicate that uplift and cooling of at least part of the pile took place at least 199 Ma ago (Adams et al. 1985).
4. In both models the accretionary prism represented by the Late Jurassic to Cretaceous rocks of the younger Torlesse/Mata River terrane was built up against the older Torlesse and no great amount of transport was involved, so it is unlikely to have acted as a raft for the biota.
5. The small exotic fragments with fossiliferous limestone (Kakahu and Akatarewa Terranes), are likely to have originated a considerable distance away from the New Zealand region (Spörli and Gregory 1980). Very little is known of their origin, or of their transport, which must, however, have pre-dated the Late Triassic or Jurassic (199–145 Ma). Spörli (1978) envisages them as sedimentary cappings to submarine intraplate volcanoes (guyots) that were largely sheared off and accreted to the upper plate at the site of subduction and accumulation of the Torlesse accretionary prism. They could, by this model, have transported marine organisms for a considerable distance, but there is no evidence of the emergent land necessary for transporting a terrestrial biota.

Pacifica – lost continent or lost cause?

An eastern source for the Torlesse sediments was suggested by Bradshaw & Andrews (1973) and Andrews et al. (1976), reviving an earlier idea of Kingma (1971) for younger sediments. Their evidence was mainly a westward decrease in conglomerate abundance and clast size, and the presence of shallow marine sedimentary facies in the east but not in the west. The evidence was used by Kamp (1980; see also Howell 1981: 114) in his proposal that the Torlesse sediments were derived from the long-conjectured "lost continent" of Pacifica which purportedly lay to the east of the site of Torlesse deposition. This continent then underwent "fragmentation in the Triassic and inclusion within the circum-Pacific Cordillera" (Kamp 1980: 659). Pacifica has been suggested as the source of other extensive exotic terranes now found at various localities around the Pacific (Nur & Ben Avraham 1981, 1982). Such a continent would have been of substantial size and would obviously have important implications for biogeography (Melville 1981) and would be consistent with Croizat's findings (Craw 1982a: 310, fig. 1; 1982b: 107).

The Bradshaw & Andrews data are, however, compatible with an axial feeding of the geosyncline (or trench) from a source to the southeast (e.g., Bradshaw et al. 1981), and they suggest that Marie Byrd Land might be such a source. This leaves scope for a model such as that proposed by Spörli above and requires no "lost continent". Kamp's other main reason for Pacifica was that alternative paleogeographic and paleotectonic models would not work; however, MacKinnon and Spörli have both suggested feasible models. There thus is no compell-ing New Zealand evidence for Pacifica.

The Pacifica concept has gained little support among tectonocists elsewhere. Whereas most tectonocists and tectonostratigraphers appear to accept the allochthonous nature of terranes in the Circum-Pacific Cordillera and a considerable distance of transport (from a low latitudinal belt to high latitude) is implied for some terranes (such as Wrangellia), there is "little evidence to support the idea that any of these diverse fragments had a common origin. More likely they began as numerous arcs, sea mounts, and continental fragments similar to those present in the southwest Pacific and Indonesian regions today" (Schermer et al 1984: 120). Further (and admittedly less convincingly), all present day continents have a core of ancient (> 1 billion years old) Precambrian metamorphic and igneous rock, the "crystalline basement". The break-up of a continent of substantial size implies the dispersal of thick (30–50 km) blocks of such ancient basement. Terranes of this type are lacking in North America and to a large extent in South America (Batten & Schweikert 1981; Tedford 1983).

Geophysical features interpreted as evidence for a former Pacifica continent include positive anomalies in the geoid (the figure of the earth considered as a mean sea-level surface extended continuously through the continents). Pal (1983) suggests that geoid highs, one of which lies in the mid to north Pacific, are residual features related to centres of continent dispersal and to hot thermal plumes in the lower mantle. However, Pal requires the presence of the former supercontinent in order to develop his model and does not therefore provide independent evidence for it.

A major problem with Pacifica, as envisaged by Nur & Ben-Avraham (1981, 1982) and Kamp (1980), is that the presence of a large continental mass adjacent to New Zealand conflicts with the evidence for long-lived ensimatic arc activity from Permian to Triassic and Jurassic in the volcanogenic terranes (region 2; Coombs et al. 1976), and makes it almost impossible to derive the exotic Akatarewa and related terranes from Tethyan regions.

In summary then, the notion of Pacifica as envisaged by Nur & Ben-Avraham does not stand up to critical analysis and must be regarded, on geological grounds at least, as dubious.

New Zealand's separation from Australia/Antarctica

New Zealand's separation from Australia/Antarctica has been well dated by seafloor spreading, and commenced in the Late Cretaceous (85 Ma). Its separation from the remnants of Gondwana therefore happened at least 60 (and probably more than 115) Ma after the time of accretion of the Torlesse terrane to proto-New Zealand.

The early part of this period (200 Ma–100 Ma) was occupied by the Rangitata Orogeny, a period of major tectonism associated with the accretion of the Torlesse and Younger Torlesse/Mata River terrane sequences. During this period, extensive uplift (Adams et al. (1985) estimate long-term uplift rate of 0.23 mm/year; total uplift was of tens of km), formation of mountains and basins, rapid erosion, and frequent changes in the position of topographic highs, lows, and the coastline, would have taken place. At this time the biota would have been forced to migrate considerable distances as shorelines changed and as mountains rose and were eroded away. In the Tuhua terrane during the later part of the orogeny (Suggate in Suggate et al. 1978; Laird 1981; Mattinson et al. 1986; Tulloch & Kimbrough 1987) crustal extension, uplift, erosion, and basin formation took place.

New Zealand's geological history from the Middle Cretaceous (100 Ma) to present day is also one of changing coastlines, formation of mountain ranges, depression of mountain ranges, and eversion of sedimentary depressions by fault block rotation, and (especially during Miocene – Recent time) large scale horizontal rotation and distortion by distributed shear and transcurrent faulting. The details of the tectonic history of the country during this period are still somewhat controversial and a review of them is beyond the scope of this discussion. Readers are referred to the following papers and references contained therein (Suggate et al. 1978; Fleming 1979; Ballance et al. 1982; Kamp 1986; Nathan et al. 1986; Walcott 1987; Korsch & Wellman 1988). The Korsch & Wellman model for the displacement

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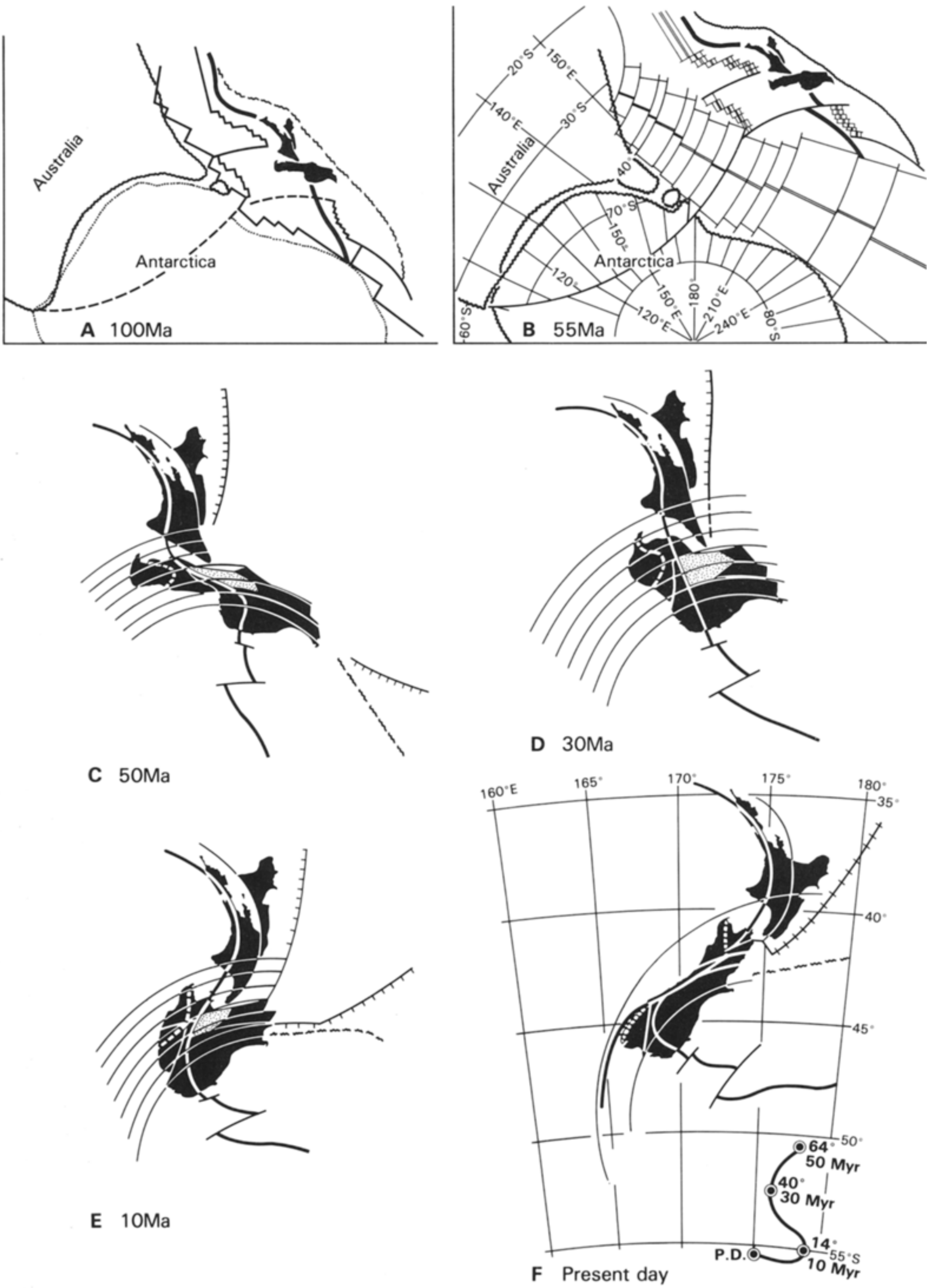
Fig. 5 The Korsch & Wellman model for the displacement history and reconstruction of the New Zealand region, from mid Cretaceous (100 Ma) to present day. The model achieves restoration of the pre-Tertiary structures and terranes (e.g., Dun Mountain—shown as a heavy line through New Zealand—and associated terranes, the Stokes Magnetic Anomaly, the Torlesse terrane, and Haast Schist) and, at the same time, the rotation required to align sea floor spreading anomalies of the Tasman Sea and seafloor SW of Campbell Plateau. A and B (mid Cretaceous and Eocene), show the failed rift, represented by the Bounty Trough and New Caledonia Trough, and the opening of the Tasman Sea. C–F (respectively Eocene, Oligocene, Late Miocene, and present day), drawn at a larger scale, show the rotation of eastern South Island with respect to northern North Island, the changing shape of the shear zone (parallel arcs), and inferred displacement of eastern North Island.

The successive positions of the India/Pacific pole of rotation are shown (F); the stippled part of New Zealand is land that has been obducted and eroded, the dashed white line approximates to the Buller/Takaka terane boundary. Convergence across the Kermadec Trench is indicated by convergence of the two lines with ticks (shown in C and E).

The model should be compared and contrasted with those of Walcott (1984) & Kamp (1986). (From Korsch & Wellman 1988, slightly modified.)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60°S
B 55Ma
C 50Ma
D 30Ma
E 10Ma
160°E
165°
170°
175°
180°
35°
40°
45°
50°
64°
50 Myr
40°
30 Myr
14°
55°S
10 Myr
P.D.
F Present day

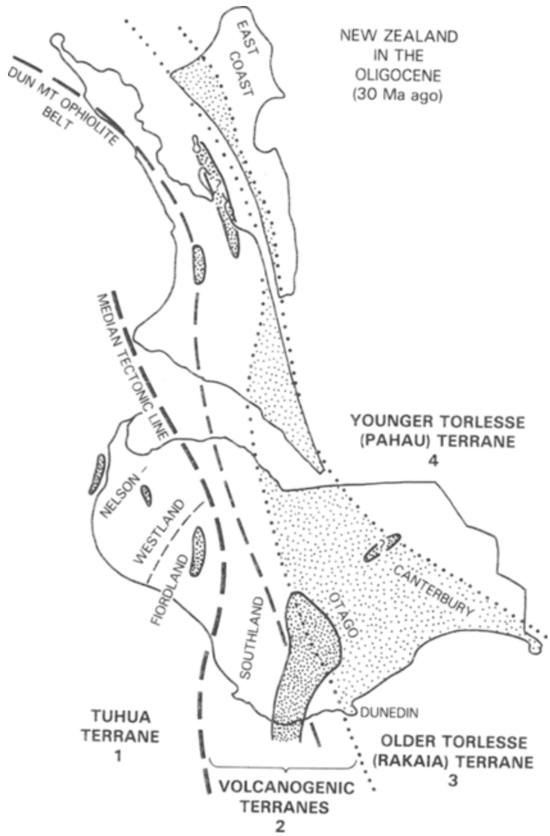

Fig. 6 Shoreline data from Stevens & Suggate (in Suggate et al. 1978, fig. 11.22), modified slightly in light of recent New Zealand Geological Survey work, plotted on 30 Ma (mid Oligocene) reconstruction of Wellman & Korsch (see Fig. 5). Although the shorelines lack precision of definition, it can be seen how the emergent areas (dark stipple) are confined to a few islands, implying a severe contraction of the space available for terrestrial plants and animals. Torlesse (Rakaia) terrane—light stipple.

history and torsion of the New Zealand region during the last 100 Ma is shown in Fig. 5.

During the mid Oligocene (30 Ma) marine transgression, most of the area occupied by present day New Zealand was below sea-level (Fig. 6); terrestrial organisms derived from pre-Oligocene New Zealand ancestors must have got to their present locations by migration from one of the several small, emergent islands ("refugia"?). This implies migration on a scale at least as great as that of the terranes themselves (Henderson 1985; Worthy 1987).

Geological versus ecological time scales

If we accept MacKinnon's view for origin of the Torlesse (in my view the less likely of the two alternatives discussed above), then it could conceivably have transported a shallow marine or terrestrial biota. This finding is consistent with the panbiogeographic proposition that some elements of the New Zealand biota may owe their presence here to transport on exotic terranes (Craw 1982a, 1985; Gibbs 1983); however, the postulated Gondwana origin of Torlesse rocks was not predicted by panbiogeographic analysis. There are also some severe implications concerning constraint on migration, that I wish to examine now, deriving from the long time lapse since terrane accretion.

Firstly, the panbiogeographic (and, for that matter, the vicariance biogeographic) method depends on the assumption that inferences about the ancestral distribution of plants and animals can be made from the present distribution of their descendents. When applied to accreted New Zealand terranes, we are talking about very restricted areas. For example, Craw (1985: 3) sees it as significant that "virtually all distribution records" of the native frog *Leiopelma* lie on suspect terranes (note, however, the revised and updated distribution records of Worthy 1987); the apparent paucity of distribution records on the old "Gondwana" province, west of the Median Tectonic Line, was regarded by Craw as evidence against a Gondwana origin for *Leiopelma*. The implication here is that most *Leiopelma* populations today inhabit the terrane that transported them. I ignore, for this discussion, the probable Gondwana origin of Torlesse terrane, and Worthy's (1987) conclusion that distribution of *Leiopelma* in Tuhua terrane was wider than formerly thought.

If we take the minimum length of time since suturing (or accretion) of Torlesse rocks to "old New Zealand" as 140 Ma we can calculate the number of generations for any surviving lineage, for average reproductive cycles of, say, 1 year, 10 years, and 50 years (Table 1). Plants with an average interval separating generations of 50 years would go through 2 800 000 generations; if the reproductive cycle is shorter or the geological interval since suturing longer, the number of generations is correspondingly increased. If the offspring of each new generation migrated only 1 m away from its parents, the possible migration distance, since the Jurassic, is 2 800 km (Table 2), a distance many times the greatest possible dimension across the Torlesse terrane (even when extended offshore).

Put another way, to imply that the ancestors of a modern species have been confined (or largely confined) to one terrane or terranes, measuring, say, 1000 km × 100 km, since the Jurassic is to imply that the maximum average migration distance between generations (given an average reproductive cycle of 50 years) is less than 357 mm along the length of the terrane and less than 36 mm (a short hop for *Leiopelma*) across it. These distances are reduced when shorter reproductive cycles or longer geological periods are used.

The figures are not claimed to accurately reflect reproductive cycles for any particular group of the biota, nor is it thought likely that migration would occur by progressive steps in one direction. They do show, however, the extreme degree of "fixism" with which biotic distribution must be viewed if present day distribution is taken to reflect original distribution among terranes.

A second implication concerns the similarity (taxonomic affinity), sufficiently marked to allow vicariance to be recognised, in organisms that represent phylogenetic lineages that have been separated for at least 140 Ma. This applies to groups that are thought to have arrived by terrane, even if the present distribution of those groups is not congruent with terranes, for example micropterygid moths (Gibbs 1983) and Trichoptera (caddisflies; Henderson 1985). Either the groups have evolved little, or evolution in the disjunct populations has shown remarkable parallelism. Panbiogeographers appear to acknowledge and accept the second

Table 1 Geological versus ecological time scales. Number of generations, since suturing of terrane, with reproductive cycles of 1, 10, and 50 years.

REPRODUCTIVE CYCLE (Ecological time)	TIME SINCE SUTURING (Geological time)		
	140Ma	180Ma	240Ma
1 yr	140 million	180 million	240 million
10 yrs	14 million	18 million	24 million
50 yrs	2.8 million	3.6 million	4.8 million

Number of generations

Table 2 Maximum migration and average migration rate in relation to terrane dimensions, assuming that suturing occured 140 Ma (see text for explanation).

	Max. migration assuming	Max. average migration distance in a terrane 1000km × 100km	
	1m per gen.	Along terrane	Across terrane
1 yr	140,000 km	7mm/gen.	0.7mm/gen.
10 yrs	14,000 km	71mm/gen.	7mm/gen.
50 yrs	2,800 km	357mm/gen.	36mm/gen.

alternative; "panbiogeography predicts a general model of differential form-making by "orthogenetic" evolutionary trends in space and time" (Grehan & Henderson in press).

CONCLUSIONS

1. If the MacKinnon model (of Torlesse origin) is correct, then the Torlesse (Rakaia) terrane could conceivably have transported a terrestrial biota from outside the New Zealand region. Whereas this is consistent with predictions by panbiogeographers, the probable Gondwana origin of Torlesse is not. In the continuous transport/accretion model of Spörli & Bradshaw (in my view the more likely alternative), the Torlesse terrane was most unlikely to have transported a terrestrial biota.
2. The concept of a "lost continent" of Pacifica adjacent to New Zealand, although consistent with panbiogeographic analysis, is dubious on geological grounds.
3. The long period of time (at least 140 Ma and probably 190 Ma) since Torlesse (Rakaia) docking, and the repeated changes in land surface elevation, climatic zones, and coastlines in that time, make it highly improbable that the present day distribution of living organisms on that terrane reflects the original distribution of their ancestors.
4. Any inter-regional (transoceanic) vicariance that is attributable to terrane transport has survived at least 140 million years of separation of the vicariant groups.

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