Mesozoic tectonics, North Island, New Zealand

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ABSTRACT

The Kawhia synclinorium along the western margin of North Island, New Zealand, is a relatively simple open structure with a subvertical to steeply east-dipping axial surface and contains a Triassic-Jurassic shelf or arc-trench gap sequence. It is bounded to the east by a narrow zone of serpentinite and ultramafic rock corresponding to the magnetic Junction anomaly.

In the Waipapa and Torlesse terranes east of the Junction anomaly, three deformation phases can be recognized: (1) formation of mélange and imbrication of strata, with fold axes trending across the now-dominant basement grain and fold vergence predominantly toward the south; (2) strongly asymmetric folding and imbrication and further mélange formation on horizontal axes parallel to the present structural grain; folds verge to the east, and beds in the axial ranges have rotated to vertical and overturned attitudes; and (3) open folding on steeply plunging axes. Phases 1 and 2 are part of the Early Cretaceous Rangitata orogeny or predate it. There is no evidence yet for the age of phase 3 structures.

It is hypothesized that the rocks of the Waipapa and Torlesse terranes were imbricated and accreted in a suture zone east of the Junction anomaly. Phase 1 structures were formed oblique to the trend of the New Zealand geosyncline because of a strike-slip component of movement transmitted to the sedimentary column only before and during early décollement. Age patterns in the Torlesse and Waipapa terranes indicate that simultaneously with accretion the clastic apron prograded from south to north.

INTRODUCTION

The New Zealand geosyncline belongs to a belt of Mesozoic clastic sediments deposited along the margin of the Antarctic-Australian part of Gondwanaland. This margin has had a long history of plate convergence (Craddock, 1975). Major tectonic-stratigraphic subdivisions of pre-Tertiary rocks are shown in Figure 1, A. In general, the pattern for North Island is analogous to that described from the South Island, for example, by Landis and Bishop (1972) and Coombs and others (1976). A western foreland ("western province" of Coombs and others, 1976) is rimmed on the Pacific side by a belt of clastic and volcanic rocks (Murihiku and Maitai terranes) in which fossils are relatively common. The

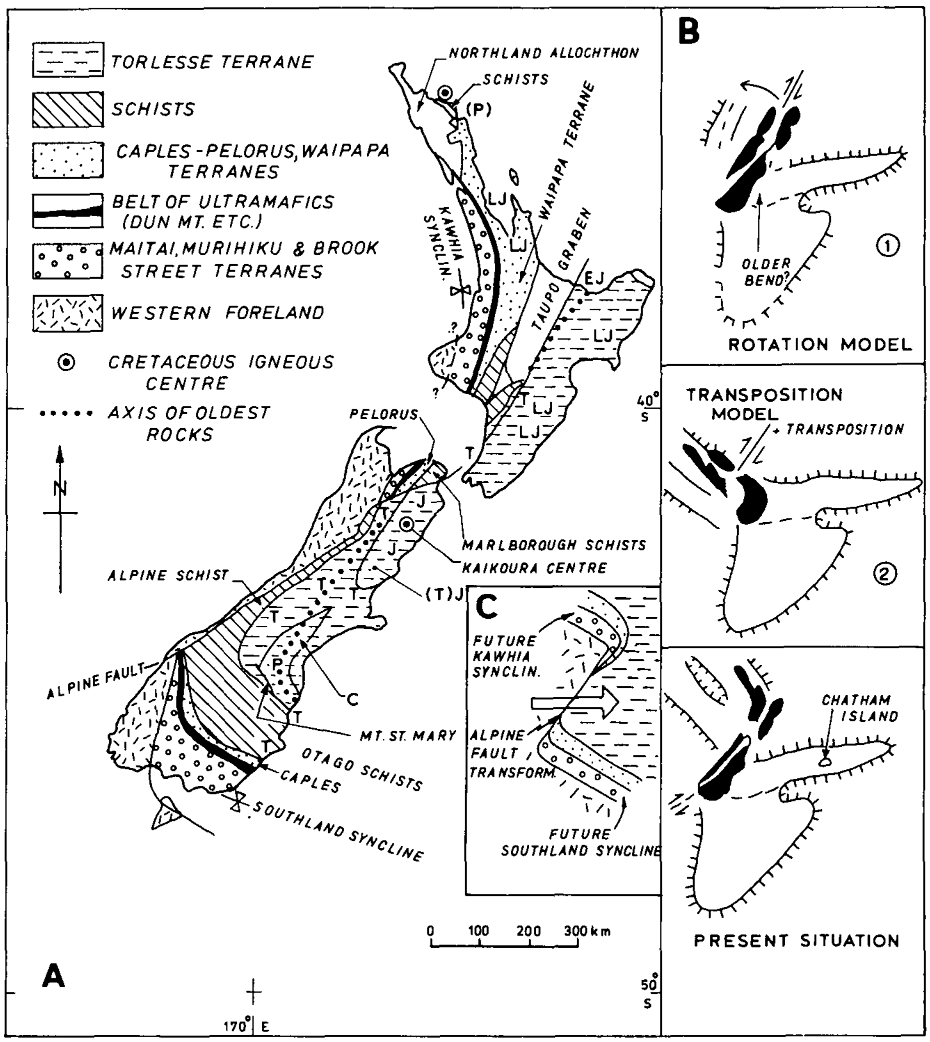

Figure 1. A. Tectonic-stratigraphic subdivision of New Zealand, compiled after Landis and Bishop (1972), Speden (1975), and Coombs and others (1976). Letters without parentheses = ages of terrigenous clastic rocks in Torlesse and Waipapa terranes. Letters in parentheses = ages of oceanic basement on which clastics were deposited. C = Carboniferous (possibly also a basement age?), P = Permian, T = Triassic, J = Jurassic, EJ = Early Jurassic, LJ = Late Jurassic. B. Models for movement on Alpine fault. C. Transform fault model, modified after Schofield (1960). Patterns for terranes same as those in A. White arrow shows direct access of westerly derived continental clastics to Torlesse deposition area. Not to scale.

Geological Society of America Bulletin, v. 89, p. 415–425, 5 figs., March 1978, Doc. no. 80309.

volcanic rocks (Brook Street terrane) represent an island arc. The Maitai terrane of the South Island has not been recognized in North Island. Immediately to the east of the Murihiku terrane lies a narrow belt of ultramafic rocks. On its Pacific side lies the Waipapa terrane, which, while probably considerably younger, is nevertheless in a tectonic position analogous to that of the Caples and Pelorus terranes of South Island. In all the pre-Cretaceous rocks east of the ultramafics, fossils are much more rare than in the Murihiku terrane. Schists to the south of the Waipapa terrane are a continuation of the Otago, Alpine, and Marlborough schists in South Island. The eastern part of North Island is underlain by the Torlesse terrane. The predominance of quartzofeldspathic clastic assemblages in part derived from silicic plutonic sources in the Torlesse has often been contrasted with the abundance of lithic volcanic detritus in the Caples, Pelorus, Waipapa, and Murihiku terranes.

At the end of Jurassic and during earliest Cretaceous time, New Zealand was affected by the Rangitata orogeny, which is represented by the metamorphic climax in the Otago schists (Landis and Bishop, 1972), intrusion of granites in the western foreland, and lack of Neocomian sedimentary rock in New Zealand. Beginning with Aptian time, a new sequence of fossiliferous clastic material was deposited on parts of the deformed belt, and at least two centers of mafic igneous activity came into existence (Fig. 1). The transgression and volcanicity coincided with the initiation of the separation of New Zealand from Gondwanaland.

The presence of the Alpine fault complicates any reconstruction of pre-Tertiary geology in New Zealand. Although the present consensus seems to be that major dextral displacement occurred in Tertiary time (Molnar and others, 1975; Ballance, 1976), the possibility still exists that the fault was already active in Mesozoic time (Suggate, 1972). Some of the internal structures of the Mesozoic rocks, to be described below, also may indicate a persistent strike-slip component of deformation. Nevertheless, I have simplified the reconstruction by assuming no significant pre-Tertiary offsets in New Zealand.

Two main types of pre–Alpine fault configurations have been proposed (Fig. 1, B): (1) rotation of subordinate tectonic trends back to the now-dominant northeast trend (Griffiths, 1974; Ballance, 1976); movement on the Alpine fault is thus inferred to have caused the currently northwest-trending segments to rotate in a counterclockwise sense; and (2) reconstruction back to the now-subordinate northwesterly and east-west trends (Austin, 1975; Molnar and others, 1975). The currently northeast-trending structures of New Zealand are thus inferred to reflect pervasive transposition and/or clockwise rotation along the trace of the Alpine fault. Since the internal structures of the northeast-trending segment provide little evidence for great transposition in this direction, the first type of reconstruction has been used here to establish the outcrop pattern at the end of the Rangitata orogeny.

The term "mélange" will be used here in the broadest sense, to denote indurated packets of pervasively disrupted rocks, mainly graywackes, but with a well-developed argillite matrix, and commonly, but not necessarily, including lenses of spilite, chert, and limestone. This usage is similar to that of Bradshaw (1973). No genetic meaning is attached to the term "mélange," since it is not possible, in my opinion, to distinguish mélanges from olistostromes by the internal structures or the shape of the body of disrupted rock. The distinction can be difficult even if the general stratigraphic and tectonic framework is quite well known. Furthermore, it is conceptually wrong in many cases to draw a sharp dividing line between tectonic and nontectonic structures.

KAWHIA SYNCLINORIUM

Lithology

The Kawhia synclinorium is bounded on the east by a structural line marked by ultramafic rocks and coinciding more or less with a facies junction (Kear, 1971; Speden, 1975; Fig. 2). To the west of the synclinorium are "foreland" rocks similar to those exposed in Nelson on South Island (Wodzicki, 1974).

Richly fossiliferous sedimentary rocks belonging to the Murihiku terrane range from Karnian (Oretian) to Tithonian (Puaroan) in age and have a total thickness of about 10 km. They consist mainly of mudstones, tephra, sandstones, and conglomerates. Conglomerate clasts include andesite, quartzite, graywacke, granophyre, and other granitic rocks. Clasts of metamorphic origin are especially concentrated in the Toarcian (Ururoan) conglomerates (Macdonald, 1954; Laird, 1967). The youngest beds are fresh-water deposits. Other nonmarine intercalations occur throughout the Jurassic rocks (Kear, 1960) but are most common in the Toarcian rocks. No Permian strata are exposed in the synclinorium, but Wellman (1959) inferred "upper Paleozoic with lava and serpentine" under Kawhia Harbour. Coombs and others (1976) came to the conclusion that the Murihiku terrane was deposited in the arc-trench gap of the subduction zone marked by the belt of ultramafic rocks.

Structure

Slumping has been described from several localities (Grant-Mackie and Lowry, 1964; Laird, 1967; Smith, 1971). Generally the movements are inferred to have taken place at the very top of the sedimentary column, shortly after deposition of the beds. However, more detailed work is necessary to determine whether some of the sliding could not have occurred somewhat later and somewhat deeper within the stack of sediments. Movement directions are to the east and southeast, except in the Jurassic rocks of the Port Waikato area (Fig. 2), where the slump folds verge to the northwest (Purser, 1961; Smith, 1971).

Folding of the Kawhia synclinorium must predate Eocene strata that overlie a sharp, and in places very smooth, erosion surface carved on the Mesozoic rocks. It is possible that the erosion surface already existed in Cretaceous time. Dips on the limbs of major folds vary from 20° to 40° but are as steep as vertical on the east limb of the synclinorium, indicating a vergence to the west, which probably is the counterpart of a southward vergence in the Southland syncline (Fleming, 1970). There is as yet no satisfactory explanation for these vergences toward the western "foreland."

The facts that the outcrop trends of the limbs of the synclinorium are parallel over long distances and that the same Upper Jurassic sequence forms the core along the entire length of exposure (140 km) indicate that the main fold axis must be horizontal. In contrast to this, the axes of the second-order folds of the synclinorium consistently plunge 10° to 20° to the north (Kear, 1960; Smith, 1971; Martin, 1975). It is not yet clear what the tectonic significance of this discrepancy is. The simplest explanation would be that the northward plunge is counteracted by cross faults with downthrows to the south. Very few faults of this type have been mapped.

A later, still undated phase of deformation on steeply plunging axes can be de-

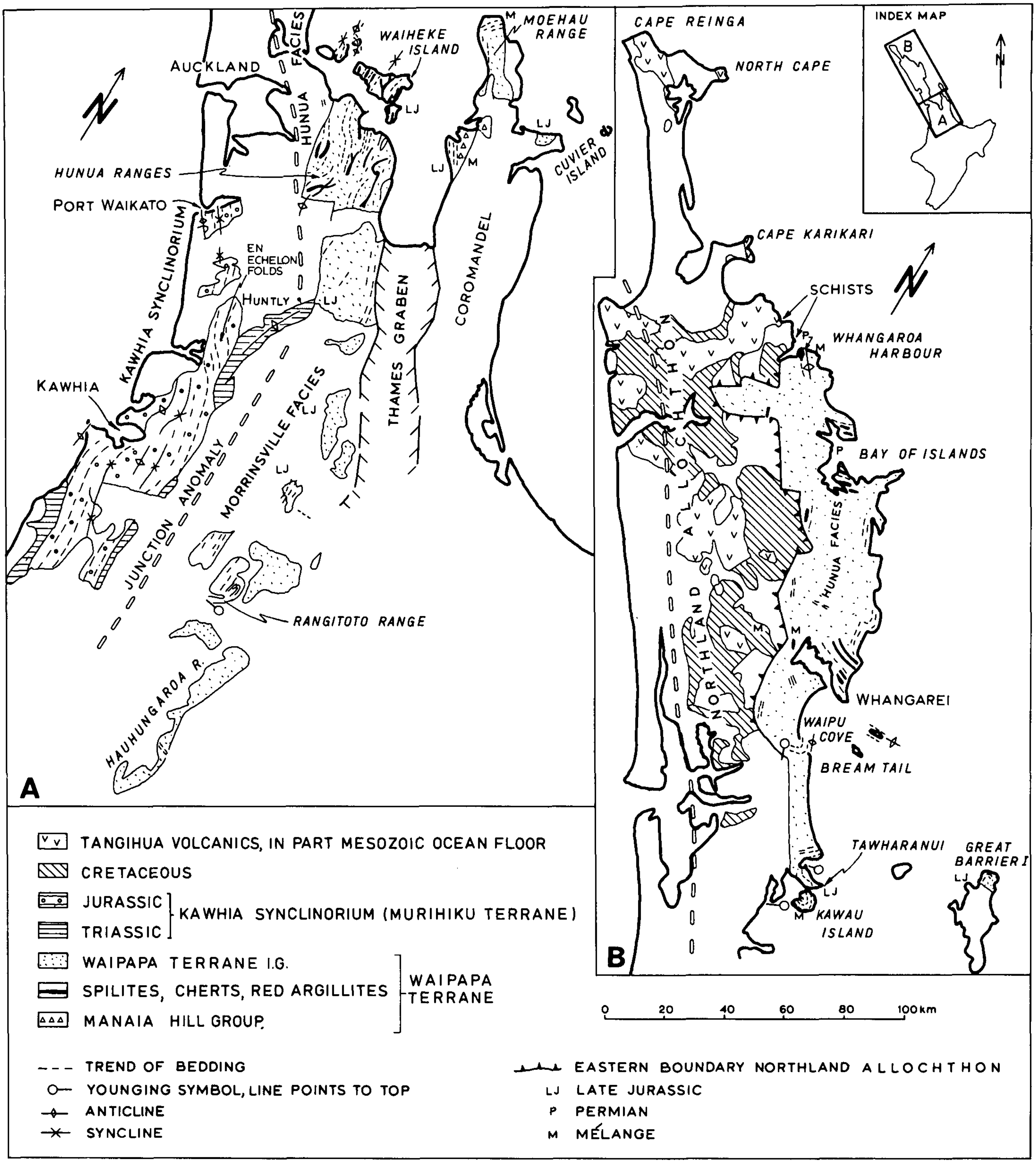

Figure 2. Geology of pre-Tertiary rocks of Auckland-Northland peninsula. Compiled after Barron (1957), Black (1967), Elliott (1966), Finlow-Bates (1970), Hay (1967, 1975), Kear (1960, 1971), Le Couteur (1967), Maehl (1970), Mayer (1968), Schofield (1967, 1974), Sekula (1972), Skinner (1962, 1972), Small (1969), Spörli (unpub.), Tarvydas (1966), and A. Wood (1976, personal commun.).

duced from dextral swings in strike of beds and axial surfaces north of Kawhia Harbour and in the Hakarimata anticline near Huntly (Fig. 2). Small folds west of the Hakarimata anticline deviate in the opposite sense from the general structural trend. However, since they seem to form an en echelon array, they may also be due to a regime of dextral shear.

The gradual swing in tectonic trends within the Kawhia synclinorium from north-northeast in the south to north-northwest in the north is part of the transition from the general structural trends in central North Island to those in the Auckland-Northland peninsula. There is so far no structural or other evidence that allows this bending to be dated. On the basis of the volcanic history of North Island, Ballance (1976) has proposed that Northland began rotating away from the eastern part of North Island in late Oligocene to early Miocene time.

It is generally inferred that the Kawhia synclinorium and the Southland syncline were once continuous and have been subsequently displaced by dextral movement along the Alpine fault (Fleming, 1970). However, Schofield (1960) has postulated that they represent two distinct basins connected by an intermediate area of deposition along the already existing Alpine fault (Fig. 1, C). In such an array the Alpine fault could have played the role of a trench-trench transform fault. The concept developed by Schofield (1960) could perhaps be taken one step further to include the possibility that the two basins were at certain times separated by an area where granitic-plutonic continental-type crust was immediately adjacent to the Torlesse depositional domain. The granitic-plutonic detrital material destined for the Torlesse could then easily bypass the volcanic-rich source areas of the Murihiku and Waipapa terranes (Fig. 1, C). The configuration of such a fault could have been inherited from older transform or transcurrent faults that intersected the margins of Gondwanaland.

ULTRAMAFIC BELT

Scattered lenses of ultramafic rocks and serpentinites, in part sheared and elevated by Cenozoic movement (O'Brien and Rodgers, 1973) are derived from a buried belt that is the source of the Junction magnetic anomaly (Wellman, 1959; Hatherton and Sibson, 1970). The facies junction between the Murihikua and Waipapa terranes coincides over long distances with the Junction anomaly (Fig. 2). The belt of ultramafic rocks can be correlated with a similar belt in South Island which is believed to represent the major suture zone of a Mesozoic subduction regime (Coombs and others, 1976). In North Island there is no evidence in the sedimentary rocks of the adjacent Murihiku and Waipapa terranes that the zone was tectonically active during Triassic or Jurassic time.

WAIPAPA TERRANE AND CRETACEOUS ROCKS, AUCKLAND-NORTHLAND

Lithology

Kear (1971) has subdivided the Waipapa terrane into the proximal Morrinville facies and the more distal Hunua facies. The Morrinsville facies includes the Manaia Hill Group (Skinner, 1972; Fig. 2). Most of the clastic rocks in the Waipapa terrane may be Late Jurassic (Spörli and Grant-Mackie, 1976; Speden, 1976).

In the Morrinsville facies, which may have been in contact with the depositional system of the Murihiku terrane to the west, boulders with Triassic fossils indicate recycling of Triassic graywacke-type rocks during Late Jurassic time (Speden, 1976). Coarse boulders of silicic plutonic rock in the Jurassic sedimentary strata of Great Barrier Island (Bartrum, 1921; Fig. 2) indicate that the Morrinsville facies had another source to the east.

Skinner (1972) has subdivided the Manaia Hill Group of the Coromandel Peninsula into an older Moehau Formation, which has a lithic-volcanic detrital suite derived from calc-alkalic volcanic and plutonic rocks, and a younger Tokatea Hill Formation, which has a feldspathic detrital suite, derived from a calc-alkalic plutonic terrane. Possibly, the progressive change in detrital material indicates an erosional unroofing of a calc-alkalic pluton. Perhaps the eastern source was a volcanic arc with a plutonic core and with deformed Triassic sediments.

In the Rangitoto Range (Fig. 2), Finlow-Bates (1970) has distinguished three lithofacies: I, interbedded thick sandstone and thin argillite beds; a detrital suite dominated by lithic fragments derived from mafic volcanic rocks; similarities to clastic rocks in the Kawhia synclinorium; II, interbedded thick sandstone beds and thin-banded argillites; detrital suite almost entirely silicic to intermediate volcanic rocks; and III, a flysch-type sequence; detrital suite derived from silicic to intermediate volcanic rocks.

In the clastic rocks of the Hunua facies, the detrital suite indicates erosion of a silicic plutonic and silicic to intermediate volcanic source area (Mayer, 1969). In contrast to the Morrinsville facies, the Hunua facies also contains lenses of spilite, chert, and volcanic argillite. These are confined to comparatively thin zones. On Motutapu Island near Auckland (Mayer, 1969), on Kawau Island (A. Wood, 1976, personal commun.), and on Tawharanui (Spörli, unpub.) they occur preferentially together with the more distal facies of sediments. Also typical is the association of this suite with zones of mélange or mélange-like structure. On Tawharanui, for example, variolitic pillow lavas are separated from "graywackes" below by an intensively sheared mélange and are in sedimentary contact above with a thick sequence of chert.

Cherts of the Hunua facies commonly contain abundant radiolaria. Near the contacts with the spilites there are concentrations of manganese oxides. Manganese appears to be more common in the Hunua facies than in the Torlesse of the axial ranges.

Percentages of K_2O in the spilites range from 0.2 to 2.8 and those of TiO_2 from 1 to 1.7 (Elliott, 1966; A. Wood, personal commun.). Especially on Kawau Island, the K_2O content is much lower than that recorded from the axial ranges. It is not yet possible to deduce the tectonic environment of extrusion of these volcanics from the available major- and trace-element analyses. The high TiO_2 contents would be compatible with an intraplate source.

Limestones are confined to the northern end of the Auckland-Northland peninsula and have yielded Permian faunas indicating shallow-water conditions (Hornibrook, 1951). At Whangaroa Harbour (Fig. 2), the limestone lenses lie within and are restricted to a pile of spilitic lavas. There is no indication that the surrounding "graywackes" are also of Permian age. It is very likely that the limestone-bearing volcanic rocks are stratigraphically overlain by cherts and volcanic argillites, which in turn grade upward into the "graywackes." The "graywackes" may therefore be considerably younger than the volcanic rocks. It may be a reasonable hypothesis that the spilites, limestones, and cherts were once part of an oceanic feature (guyot?) that protruded into shallow-water regions but subsided before being buried by the clastic material.

Structure

Structural trends in the Waipapa terrane (Fig. 2) are much less regular and in many areas the beds are less steeply dipping than in the Torlesse of the axial ranges. The lower dip angles may indicate that the Waipapa terrane is underlain by a schist complex. Structures would have been rotated toward horizontal from originally steeper attitudes by isostatic uplift of the tectonically overthickened sequence upon relief of compression at the end of the Rangitata orogeny. Absence of such rotation would then be due to absence of schists below the Torlesse terrane of North Island. The contrast between the relatively flat-lying structure in the Otago schists and steep dips in the Torlesse of South Island could be explained in a similar way.

The earliest deformation of the Waipapa terrane appears to have produced mélange-like structures. Mélange zones on Kawau Island and on Tawharanui attain thicknesses of several hundred or even thousands of metres. Thinner mélange zones are intercalated between more coherent sequences in the Hunua Ranges and are very closely related to bands of volcanic rocks and cherts (Schofield, 1974; Spörli, 1975). Thin zones of "mylonite" described from Waiheke Island near Auckland (Halcrow, 1956), Waipu Cove (Tarvydas, 1966) are probably mélanges or are similar to the slide breccias of Bradshaw (1972). Reported "boudinage" and "schistosity" (Elliott, 1966; Barron, 1957) are in many cases due to mélange-like deformation. Fold axes of this deformation are still poorly known. On Kawau Island, axes are disposed in arcs oblique to the general structural trend (A. Wood, 1976, personal commun.) The east-trending B-corrugations of Tawharanui (Brothers, 1956) may also be related to this system.

In the Moehau area (Fig. 2), early fold axes are either parallel or oblique to the regional trend, and the disrupted material appears to have locally moved from north to south (Skinner, 1961).

It is not yet known how much of the mélange deformation is due to compressive tectonics and how much to gravity sliding. Also not known is the relationship to soft-sediment deformation such as clastic dikes on the Chicken Islands east of Whangarei (Small, 1969) and sand injections subparallel to cleavage on Tawharanui (Spörli, unpub. data).

The next phase of deformation consists of relatively open folds with subhorizontal axes, often trending northwest and with a predominant vergence to the east. Exceptions are the Hunua Ranges (Schofield, 1974) and the Rangitoto Range (Finlow-Bates, 1970), where symmetrical U-shaped folds with vertical axial surfaces have been described.

During the third deformation, the pre-existing structures were rotated on subvertical axes, so that open folds of variable but often considerable plunge were the result. Both dextral and sinistral asymmetric folds are present (Fig. 2). North of Whangarei (Fig. 2, B), a broad zone of sinistral swings in trend extends as far north as the Bay of Islands. These steeply plunging folds can be correlated with similar folds in the Kawhia synclinorium and in the axial ranges.

It is certain that the first two deformations predate deposition of Eocene sediments on a well-defined erosion surface (Thompson, 1961). They probably date back to the Rangitata orogeny. However, it is not yet possible to give age brackets for deformation on the steeply plunging folds. There appear to be no steeply plunging folds within the Cretaceous rocks of the Cape Karikari–North Cape area. Instead, two directions of subhorizontal folds are present (Hay, 1975): an older, northwest-trending set, probably active until Late Cretaceous time, and a younger, Tertiary east-west trend, possibly in some way related to emplacement of the Northland allochthon.

Very little is known about the schistose Cretaceous rocks between Whangaroa Harbour and Cape Karikari. The parent lithologies appear to have been mainly mafic igneous rocks (Le Couteur, 1967). Schists brought up as xenoliths in Tertiary and Pleistocene volcanic rocks in Whangarei and Auckland (Searle, 1959) may belong to a similar tectonic unit. Three hypotheses have been advanced to account for these rocks: (1) that they are regional metamorphic schists within the Waipapa terrane (formerly continuous with the Kaimanawa schists?); (2) that they are post–Lower Cretaceous regional metamorphic schists, affecting Cretaceous or even Tertiary mafic volcanic rocks; and (3) that the schists are due to contact metamorphism by Cretaceous(?) intrusions. For hypothesis 1, the Cretaceous age of the schistose rocks south of Cape Karikari would have to be questioned. Hypothesis 2 was put forward by Searle (1959) for the schist xenoliths of Auckland and would account for the age of the schists south of Cape Karikari. It could be argued that the schistosity records the intial obduction of the Tangihua ophiolite block that was emplaced in the Northland allochthon at the end of Oligocene time (Brothers, 1974). Contact metamorphism was proposed by Le Couteur (1967) but was rejected by Searle (1959) for the Auckland schists.

Structures of the Cretaceous rocks in the Northland allochthon are too little known to allow recognition of Mesozoic deformation. They are therefore not considered further here.

TORLESSE TERRANE AND CRETACEOUS ROCKS, EASTERN NORTH ISLAND

In eastern North Island, Mesozoic rocks are exposed in the axial ranges, in the Raukumara Peninsula, and in the highly deformed belt along the east coast north of Cape Palliser (Fig. 3). They can be divided into underlying Torlesse terrane and overlying Cretaceous rocks. A little-known zone of schistose rocks extends along the western margin of the axial ranges as far north as the Kaimanawa Ranges (Grindley, 1960; Cope and Reed, 1967; Spörli and Barter, 1973) and can be considered to be the continuation of the Marlborough schists of South Island (Vitaliano, 1968; Fig. 1).

It is probably justifiable to infer from the distribution of the few fossil localities known in the Torlesse terrane (Speden, 1975) that there is a zone of predominantly Triassic clastic rocks to the southeast of the schist belt. This zone extends at least as far north as the Ruahine Range (Figs. 1 and 3, A). Farther north, the oldest exposed rocks are Early Jurassic in age but are flanked to the northwest and southeast by Upper Jurassic Torlesse terrane, which also occupies most of the area southeast of the zone with Triassic ages. However, some of the easternmost Torlesse rocks may be Lower Cretaceous (Van den Heuvel, 1960; Speden, 1976).

Clastic assemblages of the Triassic "graywackes" of Wellington (Webby, 1959a) and of the Torlesse terrane in the Kaimanawas (Spörli and Barter, 1973) are typically silicic plutonic and therefore comparable to the detrital suite of the Triassic Torlesse of South Island. The Jurassic sequences in the eastern parts, however, appear to have a higher content of volcanic rock fragments (Manion, 1974; Spörli and Bell, 1976; see also Dickinson, 1971).

Volcanic sequences in the Torlesse terrane consist of amygdaloidal or massive red and green spilite, in part with variolitic pil-

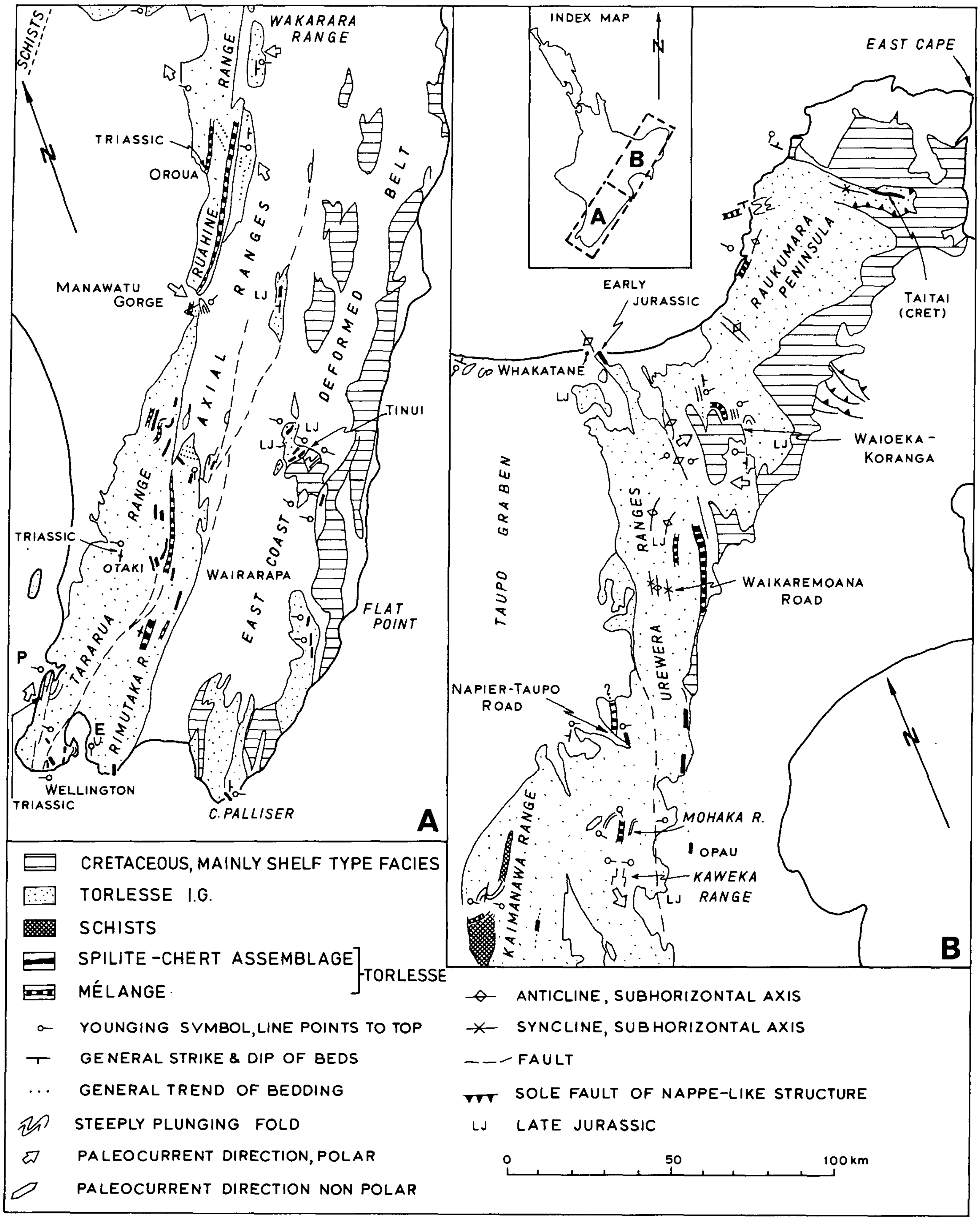

Figure 3. Geology of pre-Tertiary rocks of eastern and southern North Island. Compiled after Challis (1960), T. Crippen (1976, personal commun.), Feary (1974), Grant-Taylor and Waterhouse (1963), Grant-Taylor and others (1974), Grindley (1960), Healy and others (1964), Hill (1975), K. Hoolihan (1976, personal commun.), Isaac (1972), Johnston (1975), Kingma (1958, 1965), Lensen (1958), Lauder (1962), Lillie (1953), Manion (1974), Moore (1974), Moore (1957), Neef (1974), Paltridge (1958), Speden (1976), Spörli and Barter (1973), Spörli and Bell (1976), Spörli (unpub.), Reed (1957a, 1957b), Webby (1959a, 1959b), and Zutelija (1974). P = Porirua, E = Eastbourne.

lows, and sheared equivalents (Wellman, 1949; Reed, 1957b; Spörli and Bell, 1976). Dolerites typically contain titaniferous augite. K_2O percentages in the spilites range from 1.7 to 3 and percentages of TiO_2 from 1.6 to 3.6 (Reed, 1957b; Challis, 1960). No definite feeder dikes are known for these igneous rocks. Camptonite dikes at Cape Palliser (Challis, 1960) may belong to the post-Torlesse phase of igneous activity centered on the Kaikoura Ranges of South Island (Fig. 1; Grapes, 1975).

Spilite, chert, red and green argillite, and limestone form only a very minor part of the volume of the Torlesse terrane. As in the Waipapa terrane, these rock types tend to occur together and are often concentrated in mélange zones that include distal-facies clastic sedimentary rock (Spörli and Bell, 1976). They seem to be especially common in the Tararua and the Rimutaka Ranges (Fig. 3) and decrease in number toward the north along the axial ranges. An increase in supply of clastic material and/or a change in tectonic style in that direction may be indicated.

Abundance of red argillite, chert, and volcanic rock seems to be characteristic of the probably youngest Torlesse sequences, which have been mapped as Mokoiwi Formation in the Raukumara Peninsula (Grindley, 1960; Speden, 1976) and Waewaepa Formation on the east coast (Johnston, 1975). Distal-facies clastic sedimentary rocks are typical, as are lenses of massive sandstone (Taitai sandstone, Taipo Formation), which have been interpreted as channel deposits by Speden (1976). Structure of the Mokoiwi-type rocks is often mélange-like, which could indicate that the assemblage is in part tectonic rather than purely stratigraphical. Possible older equivalents have been found in the Ruahine Range (Spörli and Bell, 1976).

Cretaceous sedimentary rocks ranging from Aptian to Maestrichtian are restricted to the deformed belt along the east coast, the northern tip of the axial ranges, and the Raukumara Peninsula (Fig. 3) and unconformably overlie the Torlesse terrane. It is not known whether these deposits ever lapped onto the main part of the axial ranges, because of the strong peneplaning in Tertiary time. Fleming (1970) inferred that the ranges were emergent during Cretaceous time. Where present, the Cretaceous unconformity provides a convenient upper boundary for the Torlesse terrane.

Structure

Trends. Main strike trends are consistently north-northeast to northeast, except at the northern end of the Torlesse outcrop, where there is a swing into a north or even northwest direction (Fig. 3). On Raukumara Peninsula, older(?) northeast trends of folds interfere with younger west-northwest trends, probably of Tertiary origin (K. Hollihan, 1976, personal commun.).

In the axial ranges as far north as the Napier-Taupo Road and in the deformed belt along the east coast, younging directions based on sedimentary criteria dominantly point to the northwest, whereas the age zones based on fossils become younger toward the southeast. These two conflicting facts can be reconciled if the Torlesse terrane is assumed to be imbricated, so that older strata rest on younger. Such imbrication has been proposed for the Wellington area (Grant-Taylor and others, 1974) and is well documented from the Ruahine Range (Spörli and Bell, 1976) and from parts of South Island (Bradshaw, 1972). It appears that the number of eastward-younging sequences increases toward the north, which could indicate that the intensity of imbrication decreases in that direction.

Dips of Torlesse strata are uniformly steep in the axial ranges and in the east coast deformed belt. Beds overturned toward the west are known from a number of localities (Grant-Taylor and others, 1974; Webby, 1959b; Van den Heuvel, 1960; Spörli and Bell, 1976). This overturning may be related to the westward vergence of the Kawhia synclinorium. Relationship to unconformities in the east coast deformed belt (Johnston, 1975; and Fig. 4, c), in Raukumara Peninsula (Speden, 1973), and in the Urewera Ranges (Grindley, 1960) indicate that Torlesse strata were

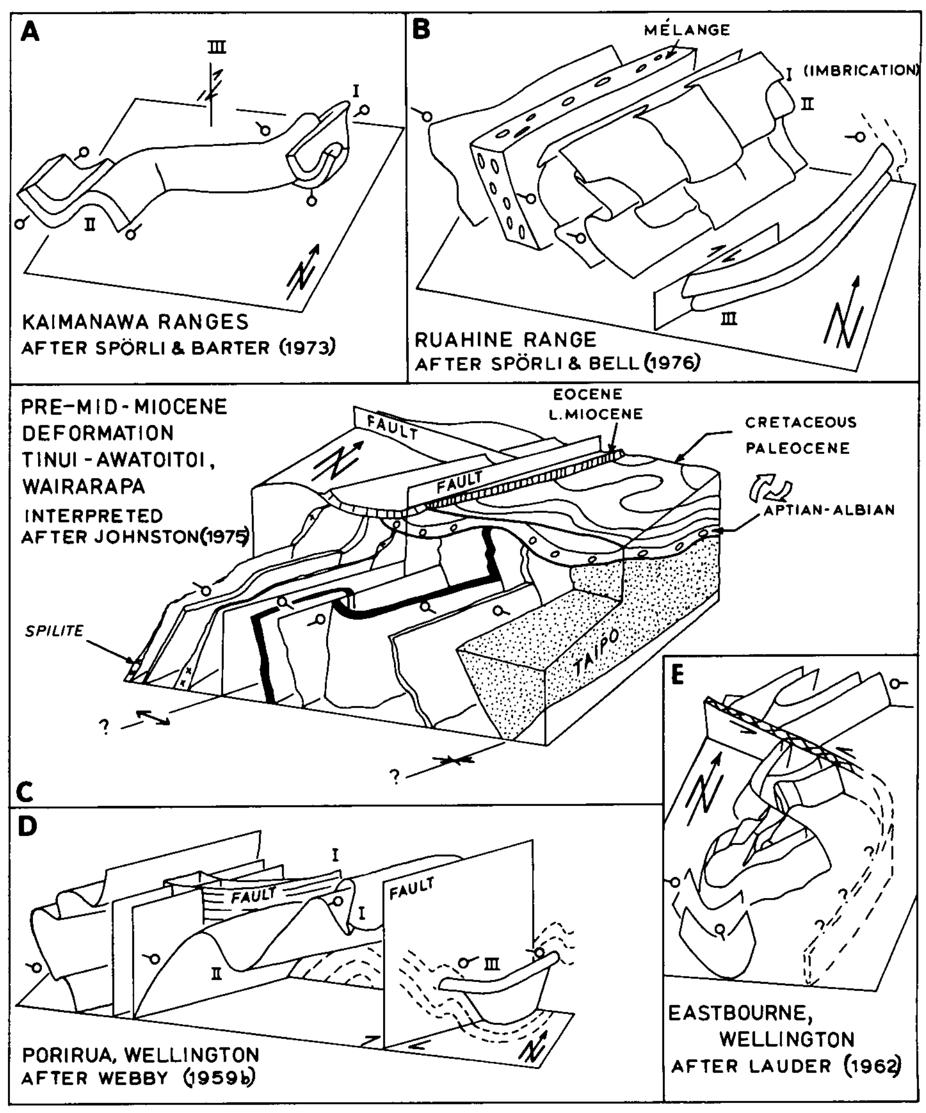

Figure 4. Schematic structural block diagrams of key areas. Not to scale. See Figure 3 for locations. Younging shown with circle and line symbol; line points to top of beds. Roman numerals show sequence of deformations. In C, unit shown in black to indicate structure; no special lithology intended. In E, fault with braid pattern may be tilted, originally normal, "indurated fault zone."

already in subvertical position at the end of the Rangitata orogeny (Aptian).

Soft-sediment Deformation. Evidence for soft-sediment deformation is abundant in the Kaimanawa Range (Spörli and Barter, 1973), where large, irregular masses of mobilized sand intrude into well-bedded fine-grained sediments. Clastic dikes cut across early isoclinial folds. Clastic dikes in the Ruahine Range are located along early normal and reverse faults (Spörli and Bell, 1976).

Mélange. Mélange zones as much as several kilometres thick are present in the Ruahine Range (Grant-Mackie, 1971; Spörli and Bell, 1976), in the Kaimanawa Ranges (Spörli and Barter, 1973), on the Waikaremoana Road (Fig. 3), and on Raukumara Peninsula (Hill, 1975; K. Hoolihan, 1976, personal commun.). "Autoclastic breccias" and "pseudotillites" recorded from the Tararua and Rimutaka Ranges and the Wellington area (Reed, 1957a, 1957b; Lensen, 1958; Neef, 1974) may in part be such mélanges. The "indurated fault zones" in the Wellington graywackes (Grant-Taylor and others, 1974) are probably related to this group of structures.

Early Steeply Plunging Folds. Commonly highly asymmetric folds, plunging at moderate to very steep angles, or being refolded by horizontal northeast-trending folds, have been recognized at Porirua (Webby, 1959b; Fig. 4, D), at Eastbourne (Lauder, 1962; Fig. 4, E), Tinui (Johnston, 1975; Fig. 4, C), Manawatu Gorge (Zutelija, 1974), Ruahine Range (Spörli and Bell, 1976; Fig. 4, B), Kaweka Range (T. Crippen, 1976, personal commun.), and in the Kaimanawa Ranges (Spörli and Barter, 1973; Fig. 4, A). Soft-sediment deformation and "indurated fault zones" are associated with these structures at Porirua, Eastbourne, in the Ruahine and Kaimanawa Ranges. In the southern part of the axial ranges and in the Kaweka Range, the folds face south. Toward the north, northward-facing folds become more common. Southfacing folds oblique to the regional trend have also been described from the Marlborough schists (Vitaliano, 1968), North Canterbury (Bradshaw, 1972), and the Mount Cook area (Spörli and others, 1974). Structural geometry indicates that much transport parallel to bedding was involved in this deformation, together with changes from compressional to extensional tectonics and vice versa. Formation of nappelike units probably was quite common.

Subhorizontal Folds. This group includes both relatively tight asymmetric folds (Fig. 4, A, B, D) and more open folds and smooth warps, which are responsible for the overturning of some westward-younging sequences. The asymmetric folds verge uniformly to the east (or upward in overturned sequences; see, for example, Fig. 4, B) and appear to become tighter toward the east. North of the Napier-Taupo road (Fig. 3), the subhorizontal folds apparently become dominant (Grindley, 1960; Manion, 1974; Feary, 1974), so that a much simpler structure of the Torlesse terrane results, indicating a fundamental change in tectonic regime.

Late Steeply Plunging Folds. These structures are similar to those described from the other areas, but dextral vergences seem to predominate (Fig. 3). Close association with active faults indicates that these folds were, at least in part, formed during Cenozoic time.

DISCUSSION

Significance of Spilites

The structural geometry of Torlesse and Waipapa igneous rocks, the association with distal- and abyssal-facies sedimentary rocks, and the lack of feeder dikes in the "graywackes" indicate that most of the spilites were formed in an oceanic environment and that they are part of the basement on which the clastic rocks were deposited (Spörli, 1975), although extrusion concurrent with sedimentation cannot be ruled out everywhere (Challis, 1960; A. Wood, 1976, personal commun.).

The high titanium contents and reconnaissance trace-element determinations on specimens from Tawharanui, Whakatane, and the Kaimanawa and Ruahine Ranges (Spörli, unpub. data) indicate that the original rocks may have been intraplate volcanics, possibly alkali basalts. Derivation from piles of oceanic intraplate volcanics would explain features such as the locally high percentages of amygdules (Coombs and others, 1976) and the association with shallow-water limestone on one hand and radiolarian chert on the other. As protruding, relatively incompetent masses, the volcanic piles (guyots?), together with the sediments deposited over and around them, would have been selectively sheared off and accreted to the upper plate during low-angle décollement in the Mesozoic subduction system along the Antarctic-Australian margin while the more competent ophiolitic oceanic crust was carried down with the lower plate. Such low-angle décollement is typical of subduction systems in which large volumes of clastic sediments are accreted (Karig and Sharman, 1975). These examples show that zones of intensive deformation along convergent margins need not necessarily be marked by high-pressure–low-temperature metamorphism.

If the model proposed above is correct, the fossils closely associated with volcanic rocks should in most cases give significantly older ages than those in the immediately adjacent "graywackes." An example of such an age relationship exists in the northern part of South Island (Triassic volcanic rocks versus Jurassic "graywackes"; Bradshaw, 1972) and may also be present at Whangaroa in North Island (Fig. 2), where Permian fossils are restricted to limestones in a volcanic pile and the adjacent clastics are yet undated but may be of Jurassic age (Spörli, 1975).

Model for Sedimentation

"Cannibalistic" reworking of detrital material, evidence for uplift and erosion concurrent with sedimentation, and soft-sediment deformation indicate that the clastic sedimentation in the Waipapa and Torlesse terranes took place on an active Pacific-type margin. The clastic apron probably spread out onto a moving ocean floor carrying cones built up by intraplate volcanism and covered with deep-sea sediments.

Very little is yet known about the configuration of the apron. The most simple pattern would be that of a long, straight "geosyncline" with progradation of sediments to the east (Fleming, 1970; Griffith, 1974). To account for an age pattern in South Island inconsistent with simple progradation, Landis and Bishop (1972) proposed that extensional basins have intermittently trapped sediment well behind the prograding slope. Austin (1975) reconstructed the New Zealand geosyncline as a spenochasm within the continental border of Gondwanaland, to obtain a two-sided basin. Bradshaw and Andrews (1973), Blake and others (1974), and Coombs and others (1976) have proposed that the Torlesse terrane was derived from the east whereas the Caples terrane is only the offshore facies of the Murihiku sediments in South Island. Juxtaposition of Torlesse and Murihiku-Caples is due to subduction of several thousands of kilometres of oceanic crust between them during Jurassic time and collision in Cretaceous time, climaxing in the Rangitata orogeny.

It is difficult to visualize how the Torlesse clastics could achieve this collision without any trace of their continental source area in the east being preserved. Torlesse sedimentation areas must have had access to such sources at least until late Jurassic time. During early Cretaceous collision, this continental crust must have avoided being sutured to the New Zealand western foreland by some unknown process and then was removed (back to Antarctica?) by strike-slip movement involving several thousand kilometres.

Deformation Model

As an alternative to the collision model, I propose a working hypothesis involving either continuous or discontinuous accretion throughout Mesozoic time (Fig. 5). It avoids the necessity of a continental block to the east while preserving the sedimentary differences between the Caples Pelorus and Waipapa terranes on one hand and the Torlesse terrane on the other hand. The first two deformations recognized in the Torlesse and the Waipapa terranes (south-facing cross folds and subhorizontal east-verging folds) are inferred to be diachronous.

Some important features of the model are the following.

1. The present pattern of ages and facies is compressed, due to imbrication (Fig. 5, distance d_1 versus distance d_2). Original thicknesses of the sediments may therefore have been much less than is apparent from their present tectonic juxtaposition.

2. If the configuration of New Zealand at the end of the Rangitata orogeny is reconstructed (Figs. 5, 1), age patterns in the Waipapa and Torlesse terranes delineate a central strip of oldest sediment, in which ages become progressively younger toward the north. This central strip may originally have been the central strip of a clastic apron prograding from south to north. Large submarine fan systems in a similar tectonic situation are known from the Aleutian abyssal plain (Stewart, 1976) and the Bengal fan–Andaman island arc system (Curray and Moore 1974). Similarities also exist with the situation along the Barbados Ridge (Westbrook and others, 1975).

3. The clastic apron was superposed on and interacted with a zone of convergence located to the west of the Torlesse terrane. Along the suture zone, sediments were imbricated and in part uplifted to provide elevated sites for the formation of shallow-water basins (for example, mid-Triassic, South Island; Mt. St. Mary, Figs. 1 and 5, b; Force, 1974). Eroded material was transported back to the fan system beyond the imbrication zone. The question is still open whether this zone temporarily assumed the character of a volcanic island arc, as might be indicated by the influx of coarse calc-alkalic plutonic and volcaniclastic material in the eastern Waipapa terrane. With the imbrication zone lying to the east, it is possible that the depositional area of the Waipapa terrane (and the Caples and Pelorus terranes?) may at least temporarily have been a back-arc extensional basin.

4. The imbrication zone migrated into the area of North Island between Late Triassic and Late Jurassic time (Fig. 5, c). This event may be marked by the Oxfordian-Kimmeridgian fossil gap in the New Zealand paleontological record.

5. The imbrication zone may have been continuously or discontinuously active during Triassic and Jurassic time. The western suture zone, today marked by the Junction magnetic anomaly (Fig. 1, A, and 5) may have been mostly inactive during this time.

6. The early oblique folds may have been controlled by cross-fault patterns similar to those on the shelf area off California (Moore, 1969) or may have formed en echelon patterns due to a strike-slip component transmitted to the sediments only during early décollement (Fig. 5, b, model 1). As a third possibility, the oblique folds may have

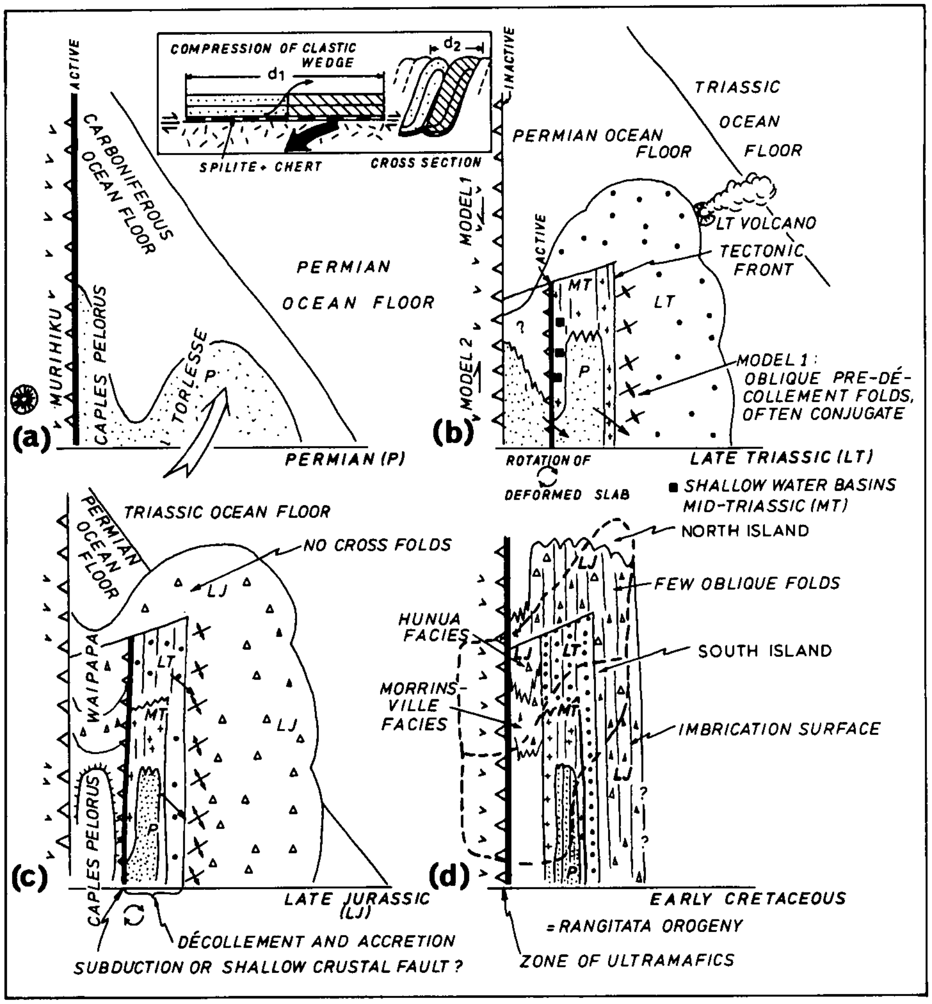

Figure 5. Working hypothesis for sedimentation and tectonics in New Zealand geosyncline. Not to scale. Possible primary bends in geosyncline (site of Otago schist arc?) omitted for simplicity. Inset shows geometry of imbrication and of compression of age and facies patterns. Outline of New Zealand before major movement on Alpine fault shown in part d. Main supply of sediment from south and from reworking of accretion ridges. Orientation of age zones on ocean floor arbitrarily chosen. Cross, dot, and triangle patterns on sedimentary aprons depict age and not type of sediment. Intraplate volcano in b illustrates possible mechanism for interfingering of volcanics and clastic sediments. Solid-head arrows on accretion belt show relative rotational movement of upper plate.

been caused by rotation of the accretion zone (Fig. 5, b, c, model 2) in a mechanism similar to that occurring along the strike-slip–controlled Venezuelan borderland (Silver and others, 1975).

ACKNOWLEDGMENTS

I thank T. Wilson, M. Isaac, and N. Rutherford for performing chemical analyses, and A. Wood, K. Hoolihan, and T. Crippen for providing unpublished data. Research was supported by grants from the Research Committee, University of Auckland.

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MANUSCRIPT RECEIVED BY THE SOCIETY SEPTEMBER 15, 1976
REVISED MANUSCRIPT RECEIVED MAY 19, 1977
MANUSCRIPT ACCEPTED JUNE 10, 1977