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TRIASSIC VEGETATION AND GEOGRAPHY OF THE NEW ZEALAND PORTION OF THE GONDWANA SUPERCONTINENT

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Abstract. Middle Triassic (Ladinian) coal measures of the Torlesse Supergroup cropping out in three separate areas of the South Island (Tank Gully, Long Gully, and Benmore Dam) have yielded a variety of impressions of fossil leaves, fructifications, logs, and root traces. Natural associations of these plant fossils are thought to represent several kinds of coastal vegetation: Pachydermophylletum (mangrove), Linguifolietum (swamp woodland), and Dicroidietum odontopteroidium (mesophytic woodland). Judging from associated sedimentary rocks, these narrow coastal plains were dissected by powerful braided streams and hedged in by a fold mountain range of alpine proportions, largely composed of quartzofeldspathic sandstones. The low diversity of the fossil flora and the presence of possible ice-disrupted paleosols and of ferruginized fossil logs with growth rings are indications of a humid, cool temperate paleoclimate. Plant fossils are very rare in Triassic shallow marine rocks of the Murihiku Supergroup, but a considerable amount of material from numerous localities has accumulated in museum collections over the past century. These fossils include plant chaff incorporated in prodeltaic, graded beds of sandstone and siltstone. Large leaves and fructifications from shaly beds rich in marine invertebrates may have settled from flotsam. Fossil plants found are mainly representative of coastal plant associations better known in Triassic rocks elsewhere in New Zealand and Australia. In Early to Middle Triassic (Scythian and Anisian) rocks these include the Dicroidietum zuberi (floodplain forest and coastal heath) and Taeniopteretum lentriculiformis (river and delta levee scrub); and in Middle and Late Triassic (Ladinian to "Rhaetian") rocks, the Pachydermophylletum (mangrove) and Linguifolietum (swamp woodland). Considering the composition of these sedimentary rocks, the coast from which the plants were derived was geologically complex and included active andesitic volcanoes. The fossil plants are very similar to those of the Sydney Basin, New South Wales, and the Torlesse Supergroup, New Zealand, and like these, probably lived in a humid, cool temperate paleoclimate. The close similarity between Triassic fossil plants of New Zealand and other parts of the Gondwana supercontinent is evidence that both the Torlesse and Murihiku supergroups formed in different parts of the southeastern Gondwanian coast. Juxtaposition of the Torlesse and Murihiku supergroups is more likely a result of transcurrent shuffling of continental terranes than of collision of microcontinents or island arcs.

Introduction

Like other lands fringing the Pacific Ocean [Coney et al., 1980], New Zealand appears to have been assembled from a variety of geological elements, some of which may have been transported from far afield. The main geological elements of New Zealand were already assembled by Cretaceous time, when it was juxtaposed against Antarctica [Suggate et al., 1978; Oliver et al., 1979]. Its paleogeography before that time is less clear. New Zealand during the Triassic has been reconstructed as a simple Andean-style continental margin to the Gondwana supercontinent [Fleming, 1970], as an Andean-style Gondwana margin separated by ocean from a large fragment of continental crust [Coombs et al., 1976; Nur and Ben-Avraham, 1977], as a region of intersection of an Aleutian-style volcanic arc and a continental fold mountain range [Mackinnon, 1983], and as a broad tract of ocean including several Marianas-style volcanic island arcs between the Gondwana mainland and a large fragment of continental crust [Howell, 1980; Tozer, 1984]. Such diversity of opinion is not surprising considering the structural complexity of pre-Cretaceous rocks in New Zealand. In this paper, summarizing a decade of my own research [Retallack, 1979, 1980, 1981, 1983a, b, 1984, 1985; Retallack and Ryburn, 1982], I review what is known about Triassic plants and their environment in New Zealand as constraints for understanding its paleogeography and tectonic development.

Two Fossiliferous Sequences

Triassic fossil plants are known from many localities in New Zealand (Figure 1) and in two different sedimentary sequences, the Murihiku and Torlesse supergroups (following nomenclature of Suggate et al. [1978]). These are thick (many kilometers) sequences of such different petrographic character that by most accounts of the tectonic development of New Zealand (such as those

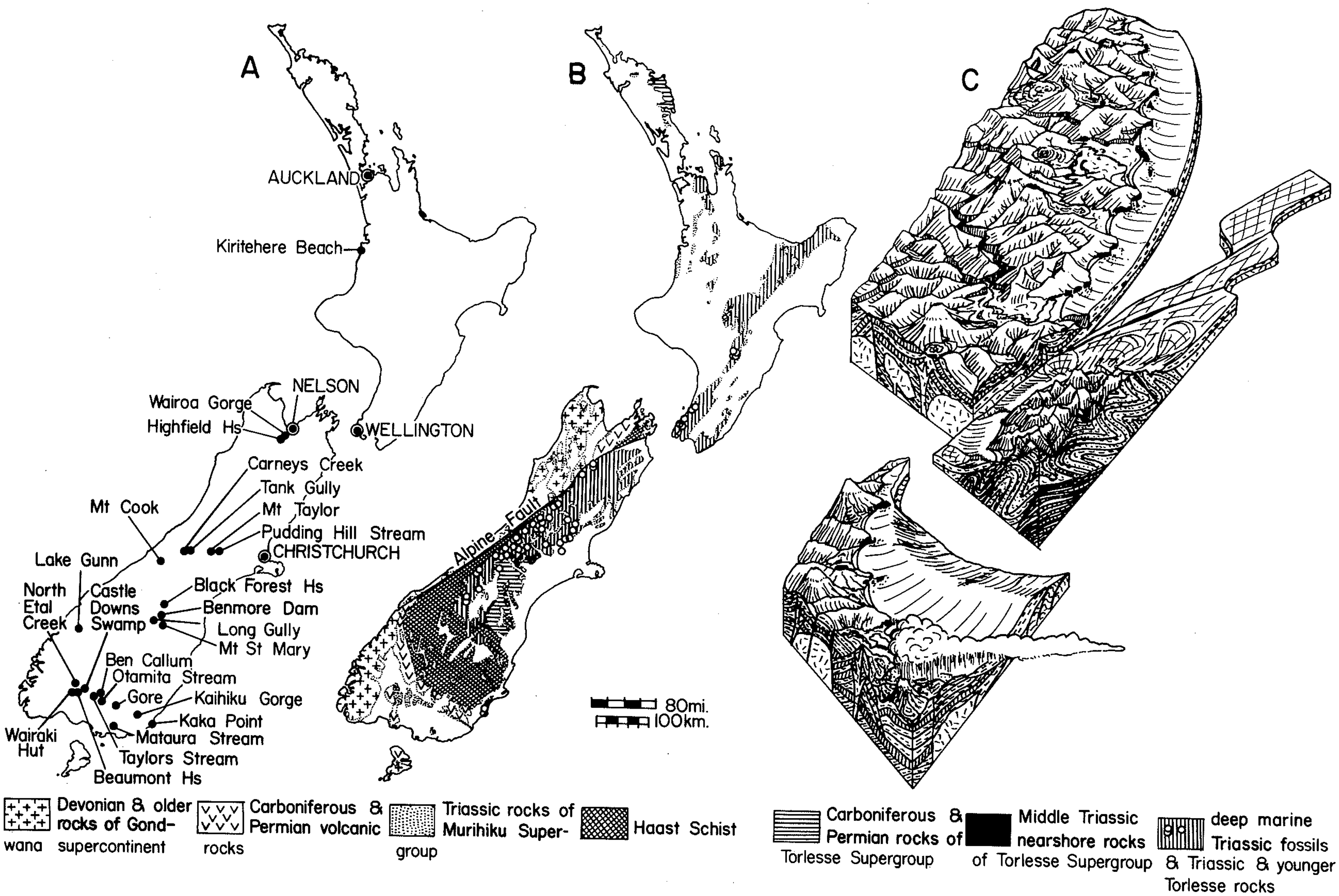

Fig. 1. (a) Triassic fossil localities, (b) geology, and (c) paleogeographic cartoon based on the modern map of New Zealand, distorted by transcurrent displacement along the Alpine Fault and other post-Triassic deformation.

of Coombs et al. [1976], Nur and Ben-Avraham [1977], Howell [1980], and Mackinnon [1983]), they are thought to have formed in different regions and later to have been tectonically juxtaposed.

The Murihiku Supergroup is a volcaniclastic sequence of shallow marine sandstones, siltstones, and shales, gently deformed into a broad synclinal structure. It covers large areas from the east coast of Southland to the foothills of the Southern Alps, from where it has been dislocated northward by post-Triassic movement along the Alpine Fault to the hills south of Nelson and to the coastal ranges southwest of Auckland. Judging from the distribution and composition of pebbles and volcanic ashes within the Murihiku Supergroup, it was derived from a western and southern coast including a variety of sedimentary, metamorphic, and granitic rocks, as well as active andesitic and dacitic volcanoes [Coombs et al., 1976]. This coast probably included Paleozoic rocks now cropping out in Southland, Fiordland, and northeast Nelson provinces. Triassic marine fossils in the Murihiku Supergroup range in age from Early Triassic (Smithian) to latest Triassic [Stevens, 1978; Campbell, 1985] (this is the "Rhaetian" of some authors, perhaps better regarded as latest Norian, according to Tozer [1971]) with most of the intervening Triassic time also represented. Plant fossils in the Murihiku Supergroup are fragmentary and poorly preserved. In some places, "plant chaff" is locally abundant at the base of normally graded sandstone to siltstone beds which appear to be storm deposits. In other places, the intensive collection of shaly, shell beds over the last century has turned up rare, fairly complete plant remains. Presumably these settled from flotsam in deeper areas of the continental shelf, which are unusually fossiliferous because of low rates of sediment accumulation [Retallack, 1985].

In contrast, the Torlesse Supergroup is predominantly quartzofeldspathic sandstone, with few traces of volcanic activity. These sandstones form much of the Southern Alps and hills of the North Island. The flyschlike character of this thick and complexly deformed sequence has been appreciated for many years [Fleming, 1970]. More recently, sedimentological studies have revealed deep oceanic paleoenvironments such as submarine fans [Retallack, 1979; Hicks, 1981; Howell, 1981]. Also consistent with a deep oceanic paleoenvironment are marine fossils known from the Torlesse Supergroup: largely siliceous worm tubes (Terebellina, formerly "Torlessia," and Titahia) and small, epiplanktonic, pteriid bivalves (Daonella, Halobia, and Monotis [Campbell and Warren, 1965; Campbell and Pringle, 1982; Begg et al., 1983]). During my mountaineering excursions in New Zealand, I have found fossils referable to the ichnogenera Cosmoraphe (University of Otago Geology Department specimens U014184 and U014185) and Neonereites (specimens U014182 and U014183) in morainal boulders on the Ball Glacier, presumably derived from the Caroline Face of Mount Cook. Other specimens of Cosmoraphe (Geological Survey of New Zealand specimen GS11471) have been collected from the northern margin of the Ball Glacier (H36/f7525). These meandering feeding burrows are characteristic of deep oceanic sediments and have been seen on the modern ocean floor [Kitchell, 1979].

An enduring problem with the deep oceanic interpretation of the Torlesse Supergroup has been its Triassic fossil land plants and shallow marine shellfish. These fossils are now known to be of late Middle Triassic age (Ladinian, or Kaihikuan in the local biostratigraphic scheme) and have been found in a chain of localities through the Southern Alps from Pudding Hill Stream [Campbell and Pringle, 1982], to Mount Taylor [Oliver, 1979; Oliver et al., 1982], Carneys Creek [Campbell and Warren, 1965], Tank Gully [Retallack, 1979], Black Forest homestead [Force and Force, 1978], Benmore Dam [Retallack, 1983a], Long Gully [Retallack and Ryburn, 1982] and Mount St. Mary [Campbell and Warren, 1965]. These shallow marine and terrestrial fossils were not all transported into a deep ocean basin. Trace fossils, by their nature, are untransported. I have found dark, organic, stuffed burrows referable to the shallow marine ichnogenera Scalarituba and Planolites in the One O'Clock Formation in Long Gully, near Otematata (University of Otago specimens U014215 to U014228 from locality H40/f1). Dwelling burrows, Macanopsis erewhonensis [Retallack, 1980], from the Nowhere Formation in Tank Gully, are also of a kind characteristic of shallow water. Fossil roots in their place of growth have been found associated with fossil plants at Tank Gully, Long Gully, and near Benmore Dam [Retallack, 1979, 1983a; Retallack and Ryburn, 1982] where deposits of swamps, rivers, lagoons, tidal flats, beaches and shallow seafloors have been recognized. This landmass was not merely the emergent part of a subduction complex, nor a continental fragment, like present oceanic plateaus. The grain size, sorting, and sedimentary structures of conglomerates in Tank Gully and near Benmore Dam [Retallack, 1979, 1983a] are most like those of low-sinuosity braided streams and draining fold mountain ranges of alpine proportions, like the present streams draining into the Alaskan Gulf Coast. All that remains of this mountain range are foothills and ranges enclosed by the chain of localities from Mount Taylor to Mount St. Mary (Figure 1), east of which mainly Permian and Carboniferous marine fossils have been found [Campbell and Warren, 1965; Hitching, 1979]. The terrestrial and shallow marine localities appear to be remains of a Middle Triassic coastline dividing these mountains of older rocks from Late Triassic and Jurassic deep oceanic rocks farther west and north. No Early Triassic fossils have yet been recognized within the Torlesse Supergroup. This was presumably a time of mountain building. No plant fossils and few shallow marine ones of Late Triassic age are known either. It is likely that at this time the shoreline had moved beyond the present outcrop of the Torlesse Supergroup.

It has proven so difficult to reconcile in a single coherent tectonic scheme such distinct sequences as the Murihiku and Torlesse supergroups that there is now a strong suspicion that they were somehow independent of one another during

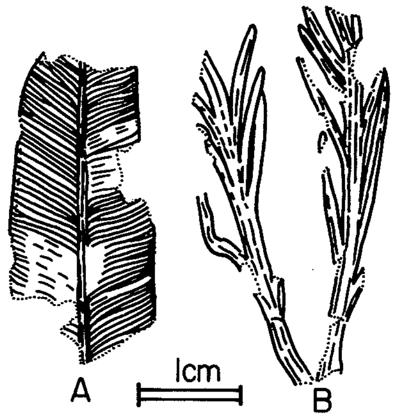

Fig. 2. New records of Triassic plant species from Tank Gully Coal Measures in Tank Gully (locality J35/f8569), recently discovered in collections of the British Museum (Natural History), London. (a) Taeniopteris lentriculiformis (Etheridge) Walkom (specimen v15696). (b) Dicroidium elongatum var. elongatum (Carruthers) Archangelsky (v15704). Scale indicated by bar.

Triassic time. This is compatible with geological evidence, since they are separated by major faults and by strongly deformed and metamorphosed rocks, such as the Haast Schist. The question remains, however, of how independent they were. For some guidance on this matter we may turn to Triassic fossil plants of each sequence for similarities between species, past vegetation types, and paleoclimatic indicators.

A Checklist of Fossil Plant Species

Triassic plants of New Zealand are mostly impression fossils. The metamorphic grade of the enclosing rocks (zeolite grade in the Murihiku and prehnite-pumpellyite in the Torlesse Supergroup) was too great for preservation of plant cuticles. Those few ferruginous and calcareous petrifications found are also poor in quality. Despite these obstacles to detailed study, many new fructifications have been discovered, and knowledge of comparable Triassic floras is such that most of the common plants are now reasonably well understood. During the course of my studies [Retallack, 1979, 1981, 1983b, 1985], numerous nomenclatural changes have arisen from general paleobotanical advances (especially by Playford et al. [1982] and Anderson and Anderson [1983]), and the locality numbers of the New Zealand Fossil Record File were changed during conversion to a metric (1:50,000) map base. In addition, I discovered two species of fossil plants new to New Zealand in collections of the British Museum (Natural History), London (Figure 2). These collections are suspected of being mixed, including some Jurassic plants in a similar matrix [Retallack, 1979], so only those slabs containing other distinctive Triassic fossils were studied. Each of these developments has been considered in preparing this checklist as a summary of my present understanding of the Triassic flora of New Zealand.

In order to facilitate Gondwana-wide comparisons of the flora, the following letters (in parentheses) have been used to indicate the occurrence of the same species or comparable species in the fossil flora of the Esk and Bryden formations of Queensland (E: Rigby [1977]), of the Ipswich Coal Measures of Queensland (I: Jones and de Jersey [1947]), of the Basin Creek Formation of New South Wales (B: Flint and Gould [1975] and Retallack [1977]), of the Gunnee Beds of New South Wales (G: Bourke et al. [1977]), of the Wallingarah Formation of New South Wales (W: Holmes [1982]), of the Molteno Formation of South Africa (M: Anderson and Anderson [1983]), of the Lashly Formation of the Transantarctic Mountains (T: Townrow [1967] and personal observations of collections of the New Zealand Geological Survey and Victoria University of Wellington), of Livingston Island in the Antarctic Peninsula (L: Lacey and Lucas [1981]), and from the Las Cabras (C) and Cacheuta and Potrerillos formations (P) of the Cacheuta Basin of Argentina [Jain and Delevoryas, 1967].

Shonabellia verrucosa Retallack: from Benmore Dam (H39/f9759), Torlesse.

Selaginella sp.: from near Gore (F45/f9693), Murihiku.

Indeterminate equisetalean stem: from near Beaumont homestead (D45/f7500), Murihiku.

Neocalamites carrerei (Zeiller) Halle: from Tank Gully (J35/f8569), Torlesse; also C, I, M, P.

N. sp. cf. carrerei (Zeiller) Halle: from near Gore (F45/f9560), Murihiku.

Neocalamostachys sp.: from near Gore (F45/f9606), Murihiku; also M.

Asterotheca hilariensis Menendez: near Beaumont homestead (D45/f7500), Murihiku.

Cladophlebis australis (Morris) Halle: from near Benmore Dam (H39/f9757), Torlesse; also B, E, I, M, P.

C. carnei Holmes and Ash: from near Gore (F45/f9693), Kaihiku Gorge (G46/f9499), and Beaumont homestead (D45/f7500 and f7509), Murihiku.

C. indica (Oldham and Morris) Sahni and Rao: from Tank Gully (J35/f8569) and Benmore Dam (H39/f2, f9050, f9664, f9665, f9756, and f9760), Torlesse; also M.

C. sp. cf. C. takezakii Oishi: from Long Gully (H40/f7754), Torlesse.

C. sp. indet.: from near Ben Callum (E45/f9026 and f9027), Murihiku.

Lobifolia dejerseyi Retallack: from Tank Gully (J35/f8569); also B, E, G, M, P.

L. sp. indet.: from near Gore (F45/f9693), Murihiku.

Sphenopteris sp. cf. Todites maoricus Retallack: from Tank Gully (J35/f8569 and f8573), Torlesse; and near Gore (G45/f8552), Ben Callum (E45/f9026 and f9027), and Mataura Island (F47/f6551), Murihiku; also M.

S. sp. indet.: from near Gore (F45/f9606), Murihiku.

Todites maoricus Retallack: from Long Gully (H40/f7754) and near Benmore Dam (H39/f9050 and f9664), Torlesse.

Ginkgophytopsis cuneata (Carruthers) Retallack: from near Benmore Dam (H39/f9050), Torlesse; also M.

G. lacerata (Arber) Retallack: from Tank Gully (J35/f8569 and f8572), Long Gully (H40/f7631), and near Benmore Dam (H39/f9050, f9756, f9757, f9760, and f9664), Torlesse; and from near Lake Gunn (D41/f7513), Highfield homestead (N28/f7498), and Taylors Stream (E45/f9494), Murihiku; also M.

G. tasmanica (Walkom) Retallack: from near Benmore Dam (H39/f9756), Torlesse; also M.

G. sp. indet.: from near Gore (F45/f9650 and f9693) and Highfield homestead (N28/f7958), Murihiku.

Dicroidium crassum (Menendez) Petriella (= "var. remotum" and "var. argenteum" of Retallack [1977]; and "forma crassinervis" and "trilobita" of Anderson and Anderson [1983]): from Tank Gully (J35/f8569 and f8573), Torlesse; also B, C, I, M, P, W.

D. dubium var. dubium (Feistmantel) Gothan (= "D. eskense" and "D. zuberi var. sahnii" in part of Retallack and "subsp. dubium" of Anderson and Anderson): from Tank Gully (J35/f8569 and f8573), Torlesse; also B, C, E, G, I, L, M, W.

D. dubium var. tasmaniensis (Anderson and Anderson) Retallack: from Tank Gully (J35/f8569), Torlesse; and near Kaka Point (H46/f8661), Murihiku; also E, G, I, M, P, W.

D. elongatum var. elongatum (Carruthers) Archangelsky (discussed by Retallack [1985]): from Tank Gully (J35/f8569), Torlesse; also E, I, L, M, P, W.

D. odontopteroides var. lancifolium (Morris) Gothan (= "D. lancifolium" of Retallack and "forma odontopteroides" in part of Anderson and Anderson): from Tank Gully (J35/f8569), Torlesse; also B, E, G, I, M, P.

D. odontopteroides var. odontopteroides (Morris) Gothan: from Tank Gully (J35/f8569 and f8573), Torlesse; also E, I, M, P.

D. odontopteroides var. moltenense Retallack (= "Johnstonia dutoitii" of Retallack [1979] and "subsp. orbiculoides" of Anderson and Anderson): from Tank Gully (J35/f8569) and near Benmore Dam (H39/f9050), Torlesse; also B, E, G, I, M, P, W.

D. stelznerianum var. stelznerianum (Geinitz) Frenguelli (discussed by Retallack [1985]): from Tank Gully (J35/f8569), Torlesse; and near Castle Downs Swamp (E44/f8833), Murihiku; also C, G, I, M, P.

D. zuberi var. feistmantelii (Johnston) Retallack: from Wairaki Hut (D44/f205), Murihiku.

D. zuberi var. papillatum (Townrow) Retallack: from Tank Gully (J35/f8569), Torlesse; also B, C, E, I, M, P.

D. spp. indet.: from near Gore (F45/f9525, f9595, f9560, f9606 and f9693), Kaihiku Gorge (G46/f9499), Ben Callum (E45/f9015, f9026, and f9027), and Mataura Island (F47/f6551), Murihiku.

Pilophorosperma sp. cf. P. costulatum Thomas: from Tank Gully (J35/f8569); also B, G, I, M, W.

P. sp. cf. P. geminatum Thomas: from near Benmore Dam (H39/f9050), Torlesse, and near Ben Callum (E45/f9026), Murihiku; also M.

Pteruchus johnstonii (Feistmantel) Townrow: from Tank Gully (J35/f8569), Torlesse; also B, G, I, M, W.

P. dubius Thomas: from Benmore Dam (H39/f9050), Torlesse; also B, I, M.

Umkomasia geminata (Shirley) Playford et al. [1982] (= "Pilophorosperma sp. A" of Retallack [1979, 1983b]): from Tank Gully (J35/f8569) and near Benmore Dam (H39/f9756), Torlesse; also I, W.

U. sp. cf. U. macleanii Thomas: from near Gore (F45/f9560), Murihiku; also M, W.

cf. Antevsia sp.: from near Mataura Island (F47/f6551), Murihiku.

Lepidopteris madagascariensis Carpentier: from near Benmore Dam (H39/f9050 and f9664), Torlesse; also B, E, P.

Pachydermophyllum dubium (Burges) Retallack: from Long Gully (H39/f3) and near Benmore Dam (H39/f9050 and f9665), Torlesse; also I, M.

P. praecordillerae (Frenguelli) Retallack: from Long Gully (H40/f3, f7754, and f7755) and near Benmore Dam (H39/f2, f9664, f9665, f9756, and f9760), Torlesse; and near Kaihiku Gorge (G46/f9499), Ben Callum (E46/f7015 and E45/f9017), and North Etal Creek (D44/f9482), Murihiku; also M, P.

P. sp. indet.: from near Benmore Dam (H39/f9050, f9665, and f9756), Torlesse; also M, P.

Peltaspermum sp. indet.: from Long Gully (H40/f7754) and near Benmore Dam (H39/f9756), Torlesse.

Townrovia petasata (Townrow) Retallack: from Long Gully (H40/f7754), Torlesse.

Carpolithus mackayi Arber: from Tank Gully (J35/f8569, f8570, and f8573), Long Gully (H40/f3 and f7754), and near Benmore Dam (H39/f9050), Torlesse, and Wairoa Gorge (N28/f7499), Murihiku.

Linguifolium arctum Menendez: from Tank Gully (J35/f8569, f8571, and f8572), Long Gully (H40/f3, f7751, f7754, and f7755), and near Benmore Dam (H39/f2, f9050 and f9756), Torlesse, and Wairoa Gorge (N28/f7499) and near Highfield homestead (N28/f7498), Murihiku.

L. lilleanum Arber: from Tank Gully (J35/f8569, f8570, and f8573), Long Gully (H40/f7751, f7752, f7754, and f7755), and near Benmore Dam (H39/f9050, f9665, and f9760), Torlesse, and Otamita Stream (F45/f8897) and near Highfield homestead (N28/ f7958), Murihiku; also I.

L. steinmannii (Solms-Laubach) Frenguelli: from Tank Gully (J35/f8552, f8569, f8570, f8573, and f8574), Long Gully (H40/f3, f7751, f7753, and f7754), and near Benmore Dam (H39/f9050 and f9760), Torlesse, and near Highfield homestead (N28/f7498 and f7958), Murihiku; also I, W.

L. tenison-woodsii (Etheridge) Retallack: from Tank Gully (J35/f8569, f8571, f8572, and f8574), Long Gully (H40/f3, f7631, f7751, f7752, and f7753), and near Benmore Dam (H39/f2, f9050, f9756, f9757, f9758, f9664, and f9665), Torlesse, and North Etal Creek (D44/f9482), Murihiku; also I, L, M.

L. spp. indet.: from Wairoa Gorge (N28/f7499), Murihiku.

Indeterminate pollen organ: from Long Gully (H40/f3), Torlesse.

Karkenia fecunda Retallack: from Long Gully (H40/f3), Torlesse, and North Etal Creek (D44/f9482), Murihiku.

Sphenobaiera robusta (Arber) Florin: from Tank

Gully (J35/f8569) and Long Gully (H40/f3 and f7754), Torlesse.

Taeniopteris carruthersii Tenison Woods: from Kaihiku Gorge (G46/f9753), Murihiku; also B, E, I, M.

T. lentriculiformis (Etheridge) Walkom: from Tank Gully (J35/f8569), Torlesse, and near Gore (F45/f9606, f9635, and f9693) and Mataura Island (F47/f6552 and f7572), Murihiku; also E, I, M, W.

T. sp. cf. T. nilssonioides Zeiller: from Long Gully (H40/f7551) and near Benmore Dam (H39/f9758), Torlesse, and near Ben Callum (E45/f9026), Murihiku; also B, C, E, I, M, W.

T. sp indet.: from Wairoa Gorge (N28/f7499), Murihiku.

Heidiphyllum elongatum (Morris) Retallack: from Tank Gully (J35/f8569, f8571, f8572, f8573, and f8574), Long Gully (H40/f7631, f7751, f7752, f7753, f7754, and f7755), Torlesse, and near Gore (F45/f9560) and Wairoa Gorge (N28/f7499), Murihiku; also B, E, M, P, W.

Indeterminate needle-leaf conifer foliage: from near Gore (F45/9606 and f9693), Murihiku.

Indeterminate small (pollen?) cone: from Long Gully (H40/f7754), Torlesse.

Telemachus lignosus Retallack: from Long Gully (H40/f7754), Torlesse.

Voltziopsis sp.: from near Ben Callum (E45/f9026), Murihiku.

Yabeiella sp. indet.: from near Kiretehere Beach (R16/f8510), Murihiku; also I, M, P.

Desmiophyllum sp. cf. D. indicum Sahni: from Tank Gully (J35/f8569), Torlesse, and near Gore (F45/f9560), Murihiku.

D. sp. indet.: from Tank Gully (J35/f8569) and Long Gully (H40/f7754), Torlesse; also C, P.

Indeterminate large logs: from Tank Gully (J35/f8569) and Long Gully (H40/f7751), Torlesse.

Indeterminate rhizomes with bundled adventitious roots: from Tank Gully (J35/f8569) and Long Gully (H40/f7751), Torlesse.

Indeterminate roots with helically arranged rootlets: from Long Gully (H40/f7754), Torlesse.

Some 54 identifiable taxa of Triassic fossil plants are here recognized from New Zealand. If the duplication of names for various parts of plants is considered, this represents about 29 species in the especially well known Middle Triassic (Ladinian) floras, four additional species from Early Triassic (Anisian), and two from Late Triassic (Carnian to "Rhaetian") floras. Compared to other Gondwanian nonmarine fossil floras, the New Zealand flora has very few unique species and no unique genera. It is clearly a Gondwanian flora, quite distinct from Triassic floras of North America [Ash, 1980] or Eurasia [Vakhrameev et al., 1978].

Nevertheless, confining attention to the well-known Middle Triassic (Ladinian) flora of New Zealand, few of its 44 identifiable taxa are shared with the various Gondwanian floras chosen for comparison: Livingston Island (9%), Esk and Bryden formations (30%), Ipswich Coal Measures (52%), Basin Creek Formation (30%), Gunnee Beds (20%), Wallingarah Formation (20%), Molteno Formation (66%), Lashly Formation (34%), Las Cabras Formation (18%), and Cacheuta and Potrerillos formations (30%). There are three possible explanations for these low percentages. Foremost among these is the less intensive and prolonged collection of Triassic floras of New Zealand, Antarctica, and inland New South Wales, compared to those of, for example, the Ipswich Coal Measures [Jones and de Jersey, 1947] and Molteno Formation [Anderson and Anderson, 1983]. Other reasons for these differences between Gondwanian floras, such as local paleoecological variation in fossil plant assemblages and paleoclimatic control of plant diversity, are discussed in the following sections.

Fossil Plant Associations

A good deal of the distinctive nature of New Zealand Triassic plant associations stems from their proximity to coastal sediments and fossils, which are known in very few other parts of Gondwana. This is strikingly seen in the distribution of Middle Triassic plant associations (Figure 3), as established from the study of fossil plant assemblages found in place of growth or closely associated with fossil soils, rather than mixed within lake or stream deposits [Retallack, 1977].

Traveling progressively inland from the coast during Middle Triassic time, the following kinds of vegetation would have been encountered. Along estuaries and other coasts protected from waves was a low-diversity, scrubby mangrove vegetation of Pachydermophyllum (Pachydermophylletum of Retallack [1977]). Within freshwater coastal lowlands around lagoons were swamp woodlands dominated by trees of Linguifolium, with shrubby ferns (Cladophlebis) and progymnosperms (Ginkgophytopsis). Inland of these low-diversity woodlands (Linguifolietum of Retallack [1977]) were diverse mesophytic, swamp woodlands of ferns, horsetails, seed ferns, karkeniaceans, and cycadophytes (Dicroidietum odontopteroidum of Retallack [1977]), and low-diversity levee scrub of voltzialean conifers (Heidiphylletum, formerly "Phoenicopsetum" of Retallack [1977]). Farther inland were xerophytic woodlands on well-drained soils (Sphenobaieretum: a better term for the "Dicroidietum odontopteroidium xylopterosum" of Retallack [1977], considering personal observations of fossil soils and Holmes' [1982] recent work on the fossil flora of its reference locality) and broadleaf scrub of lowland soils (Dicroidietum coriacei, a better term for the "Johnstonietum" of Retallack [1977], considering recent taxonomic revisions of Anderson and Anderson [1983]).

The Torlesse Supergroup has an excellent fossil record of coastal assemblages, such as the Pachydermophylletum (at H39/f2 near Benmore Dam and H40/f3 and f7755 in Long Gully) and Linguifolietum (at J35/f8570, f8572, and f8574 in Tank Gully; H40/f7751, f7752, f7753, and f7754 in Long Gully; and H39/f9760 near Benmore Dam). The Dicroidietum odontopteroidium has been found in Tank Gully (at J35/f8573) and may also be present at a locality now under the waters of Benmore Dam (H39/f9050). Heidiphyllum elongatum is locally common in New Zealand, but there is no locality where it forms a distinctive association. Nor is there evidence of

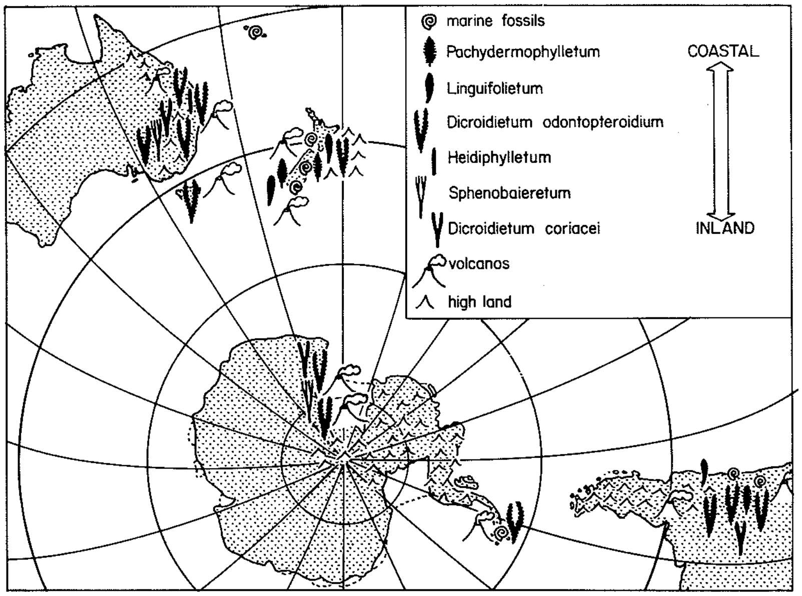

Fig. 3. Distribution of Middle Triassic marine fossils and fossil plant associations on the modern map of the south Pacific region.

other, more inland associations in New Zealand. Chile is the only other place in Gondwana where Middle and Late Triassic fossil plants and marine fossils are preserved in close proximity, and not surprisingly there is a clear example of the Linguifolietum there [Steinmann, 1921]. The Dicroidietum odontopteroidium of New Zealand is most similar to coastal plain floras of the same age from the Esk, Bryden, and Basin Creek formations of eastern Australia, and less similar to more inland floras such as those of the Gunnee Beds and Wallingarah Formation of New South Wales, the Lashly Formation of Antarctica, and the Las Cabras Formation of Argentina. When only paleoecologically similar fossil plant assemblages are considered, the Triassic floras of New Zealand are impressively similar to those of the Gondwana supercontinent.

Fossil plants from the Murihiku Supergroup are so fragmentary and have been transported so far that fossil plant associations cannot be identified with confidence. Nevertheless, fossil plants identified are all those most prominent in plant associations recognized elsewhere in coastal regions of Gondwana. Pachydermophyllum, the main element of the Pachydermophylletum, has been found in Middle Triassic localities of the Murihiku Supergroup, and Carpolithus mackayi, Linguifolium, and Ginkgophytopsis, common elements of the Linguifolietum, have been found in Middle and Late Triassic localities. Other Middle and Late Triassic fossil plants of the Murihiku Supergroup, such as Dicroidium stelznerianum var. stelznerianum, Taeniopteris sp., and Yabeiella sp., are common elements of the Dicroidietum odontopteroidium association in eastern Australia and South Africa. Earlier Triassic fossil plants in the Murihiku Supergroup are also consistent with fossil plant associations of comparable age in eastern Australia. The Dicroidietum zuberi was a coastal heath and woodland there [Retallack, 1977], and includes the following species represented by more than one specimen in the Murihiku Supergroup: Dicroidium zuberi var. feistmantelii and Cladophlebis carnei. In eastern Australia also, the Taeniopteretum lentriculiformis formed a scrub of sandy river and deltaic levees, and the Voltziopsetum formed conifer forests on well-drained soils developed on volcaniclastic sandstone and claystone [Retallack, 1977]. Only a single cone unit of Voltziopsis and some foliage fragments possibly belonging to that genus were found in the Murihiku Supergroup. There are, however, several localities (F47/f6572 and f6552 near Mataura Island and F45/f9635 and f9693 near Gore) of early Middle Triassic age (Anisian) where Taeniopteris lentriculiformis is the most common fossil, as in the mainland Australian association named after it [Retallack, 1985]. For the Murihiku Supergroup also, comparisons based on dominant plants of natural associations point to a free connection with vegetation of the Gondwana supercontinent.

Paleoclimate

An additional consideration for the geological history of the Torlesse and Murihiku supergroups is their Triassic paleoclimate. Differences between these two parts of New Zealand were especially striking during late Paleozoic times. Volcaniclastic sediments underlying the Murihiku Supergroup contain shallow marine faunas very similar to cool temperate and glacial faunas of southeastern Australia [Suggate et al., 1978]. In contrast, Permian limestones interbedded with cherts and volcanics customarily included within the Torlesse Supergroup contain fusuline foraminifera, thought to have lived within the photic zone of shallow tropical seas [Retallack, 1983b]. Do these striking differences extend also to the Triassic rocks?

There is a good deal of evidence from the Torlesse Supergroup that this part of New Zealand during Middle Triassic time (Ladinian) enjoyed a humid, seasonal, cool temperate climate. It was not too frigid for the growth of trees, whose trunks attained diameters of up to 27 cm [Retallack, 1980]. A cool climate may be a part of the reason why this flora is so low in diversity and includes smaller leaves and more compact fructifications than fossil floras of comparable age farther north in Gondwana, such as those of the Esk, Bryden, and Basin Creek formations of eastern Australia. The shallow marine fauna of the Torlesse Supergroup is also much lower in diversity than, for example, that of tropical reefs of Ladinian age in northern Italy [Fürsich and Wendt, 1977]. Fossil soils in the Torlesse Supergroup are all weakly developed, as is usual in temperate to frigid climates, and one especially peaty and waterlogged fossil soil shows evidence of frost heave [Retallack, 1983a]. Associated conglomeratic stream deposits are very similar to those now forming outwash of glaciated high-latitude mountains, such as the Chugach Mountains of Alaska [Retallack, 1979, 1983a]. Seasons, including a very cold, probably snowy, and perhaps perpetually dark winter, are recorded by strongly develpped growth rings in fossil wood [Retallack, 1980] and in marine shellfish [Retallack, 1979]. There are also sequences of claystone beds several centimeters thick containing contorted leaf fossils and separated by thin leaf coals of Linguifolium. As noted by Steinmann [1921] for similar beds in Chile, these could represent autumn leaf fall and spring thaw deposits. Finally, a rainy climate is indicated by the abundance of pteridophytes, such as horsetails and ferns, as well as plants tentatively referred to as progymnosperms. In addition, fossil soils found are all noncalcareous, and those few reddish fossil soils present are also nonclayey; this is an indication of podzolization [Retallack, 1979; Retallack and Ryburn, 1982]. Other indications of a humid climate are the presence of coals and sedimentary structures produced by streams of great power [Retallack, 1979, 1983a].

Evidence is less secure for paleoclimate during accumulation of the Murihiku Supergroup, but there is no reason to believe that it was different from that of the Torlesse Supergroup. The flora and fauna of both sequences share many species and are comparably low in diversity. Earlier Triassic (Anisian and Scythian) fossil plants of the Murihiku Supergroup are identical to those of the Sydney Basin in eastern Australia, where fossil soils and plants are evidence of a humid, seasonally cool temperate climate [Retallack, 1977]. Middle and Late Triassic plants of the Murihiku Supergroup are similar to those of the Torlesse Supergroup and presumably lived under similar climatic conditions.

Conclusions

The best preserved and most abundant Triassic fossil plants in New Zealand are from the Torlesse Supergroup. These quartzofeldspathic sandstones which form most of the spectacular mountain scenery of New Zealand were not entirely deposited in deep oceanic environments. During the late Middle Triassic (Ladinian), an alpine fold range of older Torlesse sediments was cannibalized by powerful streams which built a narrow coastal plain. Middle to Late Triassic rocks of the Torlesse Supergroup contain a great variety of fossils, from remains of terrestrial vegetation to shallow marine algae, shellfish, and trace fossils, to worm tubes of deep submarine fans and meandrine grazing traces of deep ocean floors (Figure 4). Compared to the uniformly shallow marine volcaniclastic Murihiku Supergroup, Torlesse rocks formed in a greater variety of paleoenvironments and had a much more complex history than hitherto recognized. Thus, it is unlikely that the Torlesse Supergroup was simply a trench deposit offshore from the Andean-style volcanic arc which produced the Murihiku Supergroup (as advocated by Fleming [1970]). Nor is the Torlesse Supergroup likely to have been the emergent part of a subduction complex associated with an Andean-style continental margin. The Torlesse Supergroup contains almost no volcaniclastic material of Triassic age, and its Middle Triassic fluvial conglomerates appear to be derived from a hinterland of much greater relief than a subduction complex.

Triassic fossil plants and paleoclimates of both the Murihiku and Torlesse supergroups are similar to each other and to those of nearby coastal regions of the Gondwana supercontinent. These similarities are much greater than would have been expected if these were parts of isolated mid-Pacific island arcs or continental fragments (as espoused by Nur and Ben-Avraham [1977], Howell [1980], and Tozer [1984]). If this were the case, more endemic Cathaysian or Euramerican fossil plants would have been found, and there would have been indications of warmer paleoclimates. This latter condition appears to have been the case for Permian rocks of the Torlesse Supergroup, but by Triassic times both sequences were attached to Gondwana and at high latitudes.

The evidence of fossil plants and their paleoenvironments presented here is compatible with the view that the Torlesse and Murihiku supergroups formed in different parts of a geologically heterogeneous Gondwanian coast. Like the present west coast of the Americas, this included fold mountain ranges, perhaps elevated in the course of transcurrent motion of continental fragments [Coney et al., 1980], as well as andesitic volcanic chains formed in areas of subducted oceanic crust. A case has been made [Mackinnon, 1983] that New Zealand during the Triassic was similar to the part of Alaska adjoining the Aleutian Islands. However, there is no evidence of a Triassic seaway landward of the Murihiku volcanic arc and considerable evidence that this arc was geologically more complex than the modern Aleutians; it may

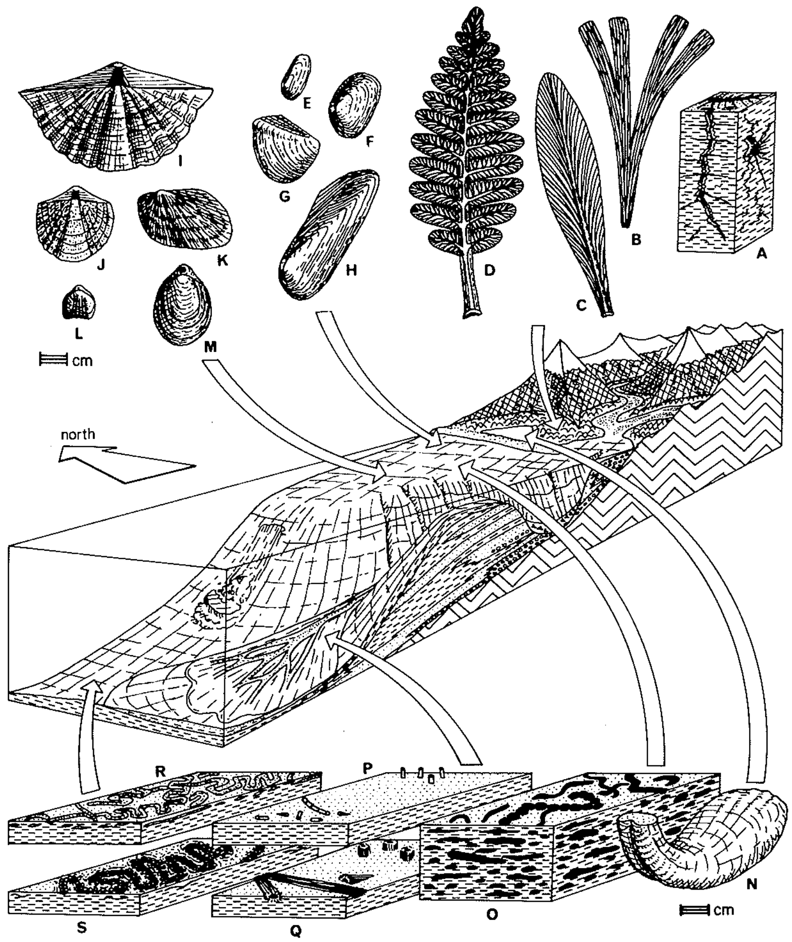

Fig. 4. Paleoenvironments of the Torlesse Supergroup during Middle Triassic time (Ladinian) showing characteristic fossil biota of each environment. (A) fossil root traces. (B) Ginkgophytopsis lacerata. (C) Linguifolium steinmannii. (D) Pachydermophyllum praecordillerae. (E) Paleoneilo sp. (F) Balantioselena gairi. (G) Praegonia coombsi. (H) Bakevellioides sp. (I) Alipunctifera kaihikuana. (J) Mentzeliopsis spinosa. (K) Daonella apteryx. (L) Rhynchonella zealandica. (M) Dielasma zealandica. (N) Macanopsis erewhonensis. (O) Planolites sp. (parallel sided) and Scalarituba sp. (beaded). (P) Terebellina mackayi. (Q) Titahia corrugata. (R) Cosmoraphe sp. (S) Neonereites sp. Scales for fossils indicated by bars.

have included Triassic volcanic rocks on the Gondwana supercontinent now in the Transantarctic Mountains, Tasmania, eastern New South Wales, and Queensland [Retallack, 1984]. It could be that the Torlesse Supergroup was juxtaposed against the Murihiku Supergroup in a similar fashion to the northward movement of the Salinian Block along the San Andreas Fault of California. Each of these modern analogies is instructive in principle, but none is comparable in detail with the situation in New Zealand. The detailed Triassic paleogeography of New Zealand remains to be worked out from continued field studies of the Pacific margin of Gondwana, of which New Zealand was an important part.

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