PERMIAN GEOLOGY OF WAIRAKI DOWNS, NEW ZEALAND, AND THE REALIGNMENT OF ITS BIOZONES WITH THE INTERNATIONAL STANDARD

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WATERHOUSE, J. B., 1998:11:30. Permian geology of Wairaki Downs, New Zealand, and the realignment of its biozones with the International Standard. *Proceedings of the Royal Society of Victoria* 110(1/2): 235–245. ISSN 0035-9211.

The Wairaki Downs, south New Zealand, has provided the type species of a number of brachiopod and bivalve genera. A detailed geological map of Wairaki Downs, New Zealand, shows that the Permian succession youngs upwards in stratigraphic order, and that claims of 'broken formations' and 'melange' are not correct. The beds are involved in several low angle thrust slices. These involve Brook Street terrane for several Middle Permian zones in the Letham and Mangarewa Formations, Maitai terrane with Glendale Formation, a Coral Bluff Tectonic Assemblage of Early Permian Takitimu Group and Hilton Limestone Formation with a Late Permian (Changhsingian) zone, and Wairaki Breccia–Conglomerate Formation, possibly at the base of the Murihiku terrane with a very late Permian zone. Various Permian formations are unconformably overlain by Jurassic Elsdun Formation and it is over the Jurassic beds that sliding has mostly occurred. The *Plekonella multicostata* and *Spinomartinia spinosa* zones are newly recognised in the sequence. The zones are summarised and correlated with the International stratotypes.

WAIRAKI Downs lies east of the Takitimu Mountains in western Southland, and contains a significant segment of New Zealand Permian. It is this area which has provided type species for several Gondwana genera, including brachiopods *Lethamia*, *Paucispinauria*, *Wairakiella*, *Aperispirifer*, *Maorielasma*, and bivalves *Striochondria*, *Glabripecten*, *Fletcheripecten* and *Corrugopecten*, as well as the world-wide Carboniferous–Permian brachiopod genus *Echinalosia*. A number of zones have been recognised and correlations proposed (eg. Waterhouse 1982). The essential validity of these zones and their stratigraphic integrity has been challenged with the claim that fossils come from 'melange' or a 'broken formation' (Landis 1987). Further need for reassessment arises from the endorsement by the International Subcommission on Permian Stratigraphy of new world stratotypes for the Permian Period (Jin 1996).

PREVIOUS FIELD STUDIES

(Table 1)

Mutch (1972: text-fig. 28) allocated the Permian of Wairaki Downs to a Takitimu Group followed by Productus Creek Group, and subdivided the latter into Letham, Mangarewa, Elsdun, Hawtel and Wairaki Breccia Formations, with several members also named. The Productus Creek Group was believed to extend from Kungurian (late Early Permian) to topmost Permian, but the succession appeared to be disrupted by several major unconformities, and some formations lacked datable fossils (Waterhouse 1982). Most of the type species for genera came from the Letham and Mangarewa Formations.

Landis (1987) reported Jurassic rocks within the Productus Creek Group, dated from radiometric ages on boulders, and a scattering of palynomorphs and bivalves. The Productus Creek Group was reinterpreted as consisting of a lower Letham–Mangarewa 'broken formation' or melange, followed by massive Glendale limestone, Jurassic 'Barretts Conglomerate', and an easternmost 'Letham Fault Zone', of faulted units involving the Hawtel and Wairaki Breccia. The fault zone underlay Murihiku Terrane of Triassic age. The belt of Jurassic was interpreted as separating two terranes, Brook Street terrane to the west, Murihiku terrane to the east. This, according to Campbell et al. (1995), meant that the Permian faunal succession of Wairaki Downs was suspect.

These critics have not provided any adequate map, other than a sketch, scaled at 2 cm to 1 km, much too small for detailed geology. Even so, the map was remarkably simple (Landis 1987: text-fig. 4). The Landis stratigraphic proposals are yet to be validated, as they were made without adequate definitions or type sections, and only in a field guide, which is discountenanced by the Guide to Stratigraphic Nomenclature (Salvador 1994). Nonetheless, they offered a serious challenge to the former understanding of Wairaki Downs geology.

Mutch 1972	Force 1975	Landis 1987	Present account	
Wairaki Breccia	Wairaki Breccia	Letham Fault Zone	Wairaki Breccia conglomerate	?Murihiku Supergroup
Hilton M	Hilton M		Hilton Limestone F Old Wairaki Hut F	Coral Bluff Tectonic Assemblage
Hawtel F	Hawtel F	Barretts conglomerate	Elsdun F	Jurassic
Glendale M	Glendale M	Glendale F	Glendale F	Maitai Supergroup
Elsdun F	Elsdun F		Elsdun F	Jurassic
Mangarewa F	Mangarewa F	Mangarewa broken F	Mangarewa F	Wairaki Downs Group
Letham F			Letham F	
Takitimu Group	Takitimu Group	Caravan F	Caravan F	
			Elbow Creek F	Takitimu Group
		Elbow F	Old Wairaki Hut F	(continues down)

Table 1. Summary of stratigraphic names applied to Permian and Jurassic in Wairaki Downs. F=Formation; M=Member.

A revised interpretation of Wairaki Downs

My own work on Wairaki Downs has been proceeding for several decades. The prime need lies in adequate mapping, so far not provided by any previous publication, and this has been conducted from a base of a greatly enlarged aerial photograph (1:6800). For all its distortion, it provides a far better base than was available from the 1:63 360 map used by Mutch (1972) and Force (1975) or the 1:50 000 map and small-scale aerial photos used by others. The resurveyed area map used by Landis is yet to be published. My map is reduced and greatly simplified for reproduction in this article (Fig. 1).

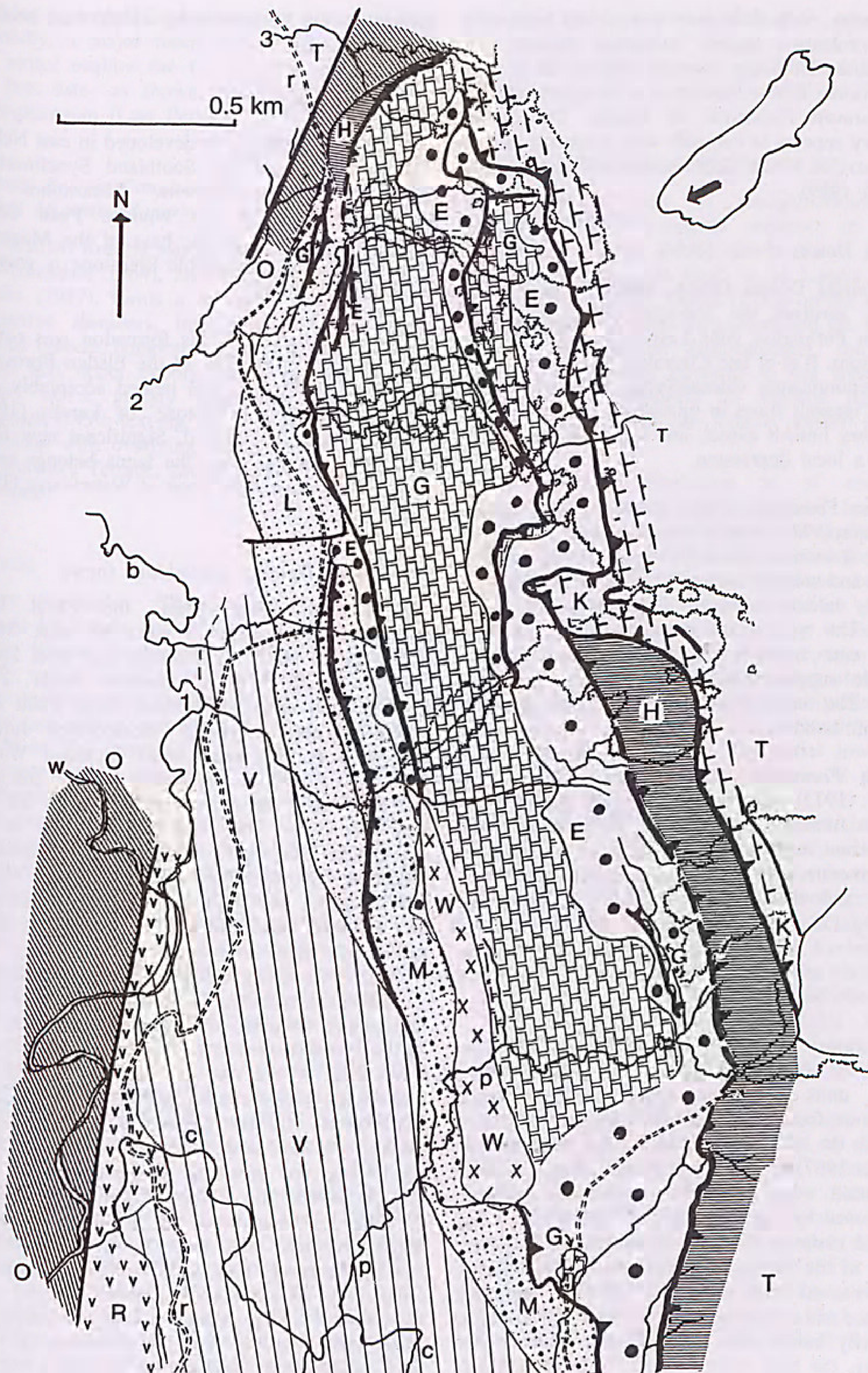
SUMMARY OF THE STRATIGRAPHIC SEQUENCE

Upper Takitimu Group

Old Wairaki Hut Formation (new). Named from the old Wairaki Hut that used to lie beside the Wairaki River, the formation includes the lower part of the Elbow Formation of Houghton (1981), and lower part of an undefined Caravan Formation of Landis (1987). The type section extends along the Wairaki River below the junction with Elbow Creek to the top of the underlying MacLean Peaks Formation, approximately as indicated by Houghton (1981), and beds are approximately 660 m thick. The Old Wairaki Hut Formation is characterised by volcaniclastic sediment derived from andesitic to basalt rocks, and contains black shales and prominent red argillites, with conglomerate and basalt flows. Beds like those typical of the formation are also found to the east within the Coral Bluff Tectonic Assemblage, regarded as part of the Productus Creek Group by previous authors.

Elbow Creek Formation (new). Named from Elbow Creek, with type section along the lower reaches of Elbow Creek at and above its junction with the Wairaki River, the formation is typified by well bedded, mostly well sorted, fine and coarse

Fig. 1. Permian and Mesozoic geology, much simplified, for Wairaki Downs, southern New Zealand. General area 167°57′E,45°47′S—shown in New Zealand Topographical Map 1:50 000 NZMS 260 Sheet D 44 (1986). Inset at top right shows South Island, New Zealand, with arrow pointing to Wairaki Downs. Formations: E, Elsdun (Jurassic); G, Glendale (late Wuchiapingian); H, Coral Bluff Tectonic Assemblage, with Hilton (early Changhsingian) and ?Old Wairaki Hut (late Cisuralian); K, Wairaki Breccia-Conglomerate (late Changhsingian); L, Letham (Kungurian); M, Mangarewa (Guadalupian); O, Old Wairaki Hut (late Cisuralian); R, Elbow Creek (early Kungurian); V, Caravan (early Kungurian); W, Weetwood (?Cretaceous). Geographic features: b, Letham Burn; c, Elbow Creek; p, Productus Creek; r, track from Beaumont Station to (now destroyed) Barrett's Hut; w, Wairaki River, 1–3 major east tributaries of Letham Burn. Map base prepared from Aerial photograph no. 5215 (1978)—position of tracks has since changed a little.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volcarenites, with little mudstone or red beds, and minor volcanic layers, including basalt and ankaramite. Thickness exceeds 200 m. It is part of the former Elbow Formation of Houghton (1981) and Caravan Formation of Landis. The lower boundary appears to coincide with a recently active fault, next to which beds contain a Triassic fossil (Aslund 1989).

Wairaki Downs Group (new)

The Wairaki Downs Group, named from Wairaki Downs, involves the restricted, here formalised Caravan Formation, plus Letham and Mangarewa Formations. It is of late Cisuralian and Guadalupian age, predominantly volcaniclastic, with little in the way of igneous flows or intrusions. Each formation is of very limited extent, and the group represents fill of a local depression.

Caravan Formation. This formation was named by Landis (1987) from a stream he called 'Caravan Creek'. It involves some 500 m of coarse volcanic rudites and arenites formed as channel-fill deposits, possibly laharic in origin (Waterhouse & Flood 1981). The type section is just south of the last major east tributary of Letham Burn, with a valuable supplementary section along Productus Creek. The name is used pending full ratification by Prof. Landis.

Letham Formation. The Letham Formation of Mutch (1972) maps out as a valid unit, not a 'broken formation' or melange. Three major units are present, each made up of basal volcaniclastic conglomerate, followed by volcaniclastic sandstones and then shales, and impure carbonate, totalling 128 m thick in the type section. Sediment was derived from the south overall, judged from thickness and nature of the units. There are numerous fossil localities.

Mangarewa Formation. The Mangarewa Formation of Mutch (1972) is a valid unit, with four major units including minor limestones and numerous fossil localities. The units total 108 m thick in the type section. Claims that it is melange (Landis 1987) or indistinguishable from the Letham Formation were not based on detailed mapping, as allowed by Landis, and careful mapping shows that the claim is mistaken. A substantial low-angle thrust in the lower beds, not previously detected, has removed beds and zones. Judged from the presence and coarsening of clastic units, distribution of shelly bands, and incoming of carbonate and argillite, the beds were derived from the north, in contrast to the Letham beds, which were sourced from the south.

Maitai Supergroup

The Maitai Supergroup is developed in east Nelson and both limbs of the Southland Synclinorium, including Wairaki Downs. Limestones are particularly thick in the Wooded Peak Group (Waterhouse 1987b) at the base of the Maitai in east Nelson, and comparable limestone is younger in Wairaki Downs.

Glendale Formation. This formation was originally treated as a member of the Elsdun Formation by Mutch (1972), but was treated acceptably as a separate 'Glendale Limestone' by Landis (1987), and this usage is followed. Significant new fossil finds by the writer show the fauna belongs to the *Plekonella multicostata* Zone of Waterhouse (1973, 1982).

Coral Bluff Tectonic Assemblage (new)

Named from Coral Bluff, the Coral Bluff assemblage is applied to parts of what Mutch (1972) called Hawtel Formation, and what Landis (1987) variously called Letham Shear Zone, Letham Fault Zone and Letham Ridge Fault Zone (Table 1). Mutch (1972) incorporated Jurassic in his formation, and Landis included Wairaki Breccia-Conglomerate, as well as Jurassic and some Glendale beds. These are excluded from the new unit. There are three component parts to the assemblage. Red argillites and coarse volcaniclastic sandstone look indistinguishable from Old Wairaki Hut Formation. As well, these beds form burrowed and meagrely fossiliferous substrate for overlying carbonates and coral-bryozoan bioherms. The carbonates including bioherms are discriminated as the Hilton Limestone Formation, upgraded from the Hilton Member of Mutch (1972). The type section is transferred to Coral Bluff, from the track to the top of the first (westernmost) bluff. The assemblage contains what appears to be bands of Old Wairaki Hut and Hilton Limestone, probably replicated at least three times within the assemblage by folding and thrusting. Campbell (1990: text-fig. 7) showed the Hilton Limestone as a string of aligned discrete lenses at the top of a merged Hawtel–Jurassic unit, but this is disproved by detailed mapping. Two further significant changes from the Mutch–Force–Campbell model may be noted. Firstly, Landis (1987) correctly, if tentatively, proposed that the limestones of Coral Bluff might be the same as Mutch's Hilton Member,

marking a major improvement to understanding. Secondly, a major fossil find at Coral Bluff by the writer enables the formation to be dated for the first date—as shown subsequently, it is early Changhsingian (Late Permian).

Wairaki Breccia-Conglomerate, ?basal Murihiku Supergroup

The Wairaki Breccia was proposed by Mutch (1972, in Waterhouse 1964), and although discounted by Landis (1987), forms a mappable unit with three distinctive members, involving red- and green-flecked breccia, conglomerate of fine well rounded clasts, and upper pebbly coarse arenites. It was shown as a grossly over-simplified unit by Campbell (1990: text-fig. 7). The formation appears to belong with overlying Triassic beds as part of the Murihiku Terrane, and its beds are not strongly deformed.

Jurassic

Elsdun Formation. The Jurassic that was discovered by Landis and colleagues is here referred to the Elsdun Formation, modified from Mutch (1972), and restricted to Jurassic clastic beds. These vary considerably in thickness because of tectonic elision and sliding, and appear to reach a thickness of 300 m. The emended type section is shifted to the upper middle reaches of Elbow Creek, with supplementary section in the upper south branch of the second last major tributary of Letham Burn. Although the Stratigraphic Guide recommends the choice of new names where interpretations are changed, names are at a premium, and here the Elsdun is applied. Landis (1987) applied the name Barretts Conglomerate, but this name has already been in use as a Permian stage name since Waterhouse (1969), and it would be folly to apply a Permian name to Jurassic beds, for that would undo what Landis has achieved in unravelling the confusion in Mutch (1972) and Force (1975). The distribution of the Jurassic Elsdun shown by Landis (1987) must be substantially emended, as it occurs in several thrust slices and flakes, not as one mass.

Weetwood Formation. This formation is an igneous intrusion along a thrust between Mangarewa and Glendale Formations, and likely to be of late Jurassic or Cretaceous age. Its author is A. R. Mutch (in Waterhouse 1969), although Force (1975) wished to claim authorship for herself. When A. R. Mutch and I discovered the formation (*c.* 1958), I argued that it was an intrusion, although I quoted Mutch's later view that it might be a tuff. Landis mistakenly wrote that I had argued it was part of the Permian succession.

SUMMARY OF STRUCTURE

The simplistic view of straightforward east dipping, eastward younging sequence in Mutch (1972) and Force (1975) is modified by the insertion of a Jurassic band, as in Landis (1987) and Campbell (1990). Landis (1987) further showed the Mangarewa–Letham Formation and the Hilton–Wairaki beds to be fault-bounded, the latter portrayed as moving upwards to the west. This model is not supported by detailed mapping. Major changes from the Landis model involve these facets:

1. The Caravan Formation is of restricted distribution within a large channel less than 10 km long, and is followed subconformably and partly grades laterally northward into Letham Formation. Faulted boundaries between the two are minor. Fossil localities are in stratigraphic order, and there is no melange.
2. The Mangarewa Formation is separate from Letham, and is more restricted than shown by Landis (1987). It is not demonstrably disrupted by oblique NNE faults. Fossil localities are in stratigraphic order. A substantial low-angle thrust, missed by previous workers, is present within the lower formation.
3. The Glendale is somewhat as shown in early maps, but additional strips of Glendale Formation to the east and west have been overlooked by Landis and colleagues, and generally confused with Mangarewa Formation and with Elsdun ('Barretts') Formation.
4. The so-called Letham Shear Zone of Landis (1987) is now reduced to Coral Bluff Tectonic Assemblage and involves Takitimu Group rocks, not realised hitherto. The Coral Bluff Assemblage has moved eastwards, not westwards.
5. The Elsdun Formation, of Jurassic age, is not restricted to one band, as shown by Landis (1987) and Campbell (1990). It forms four strips, from west to east—E1 channelled unconformably into Mangarewa Formation; E2 thrust-bound within Glendale Formation; E3, the only band recognised by Landis (1987), lying unconformably on Glendale Limestone; and E4, lying unconformably, but mostly faulted against Glendale, and overthrust by Coral Bluff Tectonic Assemblage.

The predominant structural feature of the Wairaki Downs geology is the presence of several low-angle thrusts, not previously recognised (Fig. 1). These are shown clearly on the accompanying map. Thin sheets of fossiliferous rock have moved over the thrusts without substantially changing the stratigraphic order, except at the north end of the area, where Coral Bluff Tectonic Assemblage has been placed 'below' the older Glendale Formation. The speculative alarms raised by Campbell et al. (1995) on stratigraphic order and faunal succession, and the allegation that the Letham–Mangarewa are possibly melange (Landis 1987) prove unfounded. A summary of the major tectonic terranes, represented by sheet-like thrust-blocks, is as follows from west to east, within the mapped area.

1. Volcanics and clastics of the Brook Street Terrane, made up of Takitimu and Wairaki Downs Groups, containing one major thrust, and overlain unconformably by Jurassic Elsdun conglomerate. Possibly in situ.
2. Glendale Limestone, derived from Maitai Terrane, thrust over Elsdun conglomerate, containing at least one thrust pod of Elsdun conglomerate, and overlain unconformably by Elsdun Formation. This packet is overthrust by a second packet of Glendale and Elsdun rock.
3. The Coral Bluff Tectonic Assemblage is thrust eastwards over Elsdun–Glendale, and is also thrust or downfaulted to the north partly against Letham Formation at Coral Bluff. It appears to have been derived from the west, because more than half of the rocks are upper Takitimu Group, overlain disconformably by Late Permian carbonate with bioherms (Hilton Limestone Formation). This assemblage is made up of several thin tectonic slices or flakes.
5. The Wairaki Breccia-Conglomerate to the east is believed to lie in thrust contact with the Coral Bluff Tectonic Assemblage, and may have formed a flake at the sole of the overlying Murihiku Terrane. The Murihiku Terrane has been emplaced from an entirely separate basin, distinguished by having a component of Proterozoic crust, and emplaced either by strike-slip faulting (Paull et al. 1996) or by thrusting (Waterhouse 1993). Aslund (1989) suggested derivation from the east.

BIOSTRATIGRAPHIC SUCCESSION OF BIOZONES

A number of faunas and biozones are recognised for the Wairaki Downs succession. These are updated, but not substantially altered from Waterhouse (1982) except where indicated, and include a number of additional species and genera.

Attenuatella (or *Biconvexiella*) beds

This brachiopod is found in the Elbow Creek Formation as part of a zone previously ascribed to Baigendzinian—Artinskian—but now Kungurian if the boundary of that stage is to be lowered by incorporating at least upper Saranin beds of Russia (Jin 1996).

Megousia solita and *Spiriferella supplanta* faunas

These are small faunas, the first from the Caravan Formation, the other from beds near the base of the Letham Formation (Briggs & Campbell 1993; Waterhouse 1982).

Echinalosia discinia Zone

Well developed and containing a number of additional species shared with east Australia, this zone is found in the middle and topmost units of the Letham Formation. It was partly described as a *Lethamia ligurritus* fauna by Waterhouse (1982: 92).

Echinalosia maxwelli Zone

Most species of this zone have been described. The zone occurs in the basal unit of the Mangarewa Formation. It was wrongly shown as occurring below the *Spiriferella supplanta* fauna by Mutch (1972), and on this basis Briggs (1991) incorrectly reversed the order of *discinia* and *maxwelli*, to severely compromise his zonations and correlations, both for New Zealand and eastern Australia. Zonal distribution has been affected by the Mangarewa thrust fault.

Magniplicatina magniplica lens

Mangarewa unit 2 contains a fauna with possible *Wyndhamia blakei*, *Magniplicatina magniplica* and *Terrakea exmoorensis* not found elsewhere in the succession. The unit apparently has been reduced by the thrust fault in the lower Mangarewa Formation.

Echinalosia ovalis Zone

This is a richly fossiliferous zone well developed in the third and fourth Mangarewa units, with a number of additional species. *Paucispinauria solida*

(Etheridge & Dun) occurs in this zone, together with a new widespread species of *Aperispirifer*.

Terrakea elongata Zone

The *Terrakea elongata* Zone is extensively fossiliferous in the topmost Mangarewa unit, and is also represented by the fauna of the Flowers Formation in west Nelson. *T. elongata* (Etheridge & Dun) is a name change from *T. brachythaera* (Morris). The former name is secure, the latter still open to revision, but seems to involve a smaller species with finer ear spines and more vaulted visceral disc.

Plekonella multicostata Zone

This zone is recognised for the first time in Wairaki Downs from new collections and revised earlier collections in the lower Glendale Formation. *Terrakea verecunda* from the top of the formation belongs to the same zone (Waterhouse 1982). The zone is well represented by fossiliferous outcrops in the upper Arthurton Group of south Otago, within the Maitai terrane.

Spinomartinia spinosa Zone

A large new collection from the Hilton Limestone Formation in its type area of Coral Bluff contains species of the *spinosa* Zone. This is well represented 16 km south of Coral Bluff at Wether Hill Station, and further afield in the regional synclinorium at Mataura Island, and in the upper Arthurton Group near Clinton. The zone is found in both Maitai and Brook Street terranes.

Wairakiella rostrata Zone

This zone is found in the Wairaki Breccia-Conglomerate Formation, as summarised by Waterhouse (1982: 105) and Campbell (1990).

The *Martiniopsis woodi* and *Marginalosia planata* biozones found elsewhere in New Zealand are missing from the Wairaki Downs sequence.

INTERNATIONAL CORRELATIONS AND THE WORLD STANDARD

The world standard as adopted by the Subcommission on Permian Stratigraphy (Jin 1996; Jin & Menning 1996; Spinosa 1996) may be tentatively applied to New Zealand, with relevance to Australia, which shares a number of the biozones. The strength of the new scheme is that it is now based on fully marine sequences that constitute the best known sequences in the world. The subcommission has placed principal stress on conodonts, which are too rare in New Zealand and Australia to offer any realistic prospect of direct correlation with the world stratotypes. But the first draft of the international scheme was drawn up on the basis of brachiopods (Waterhouse 1983b), which are abundant throughout the Australian and New Zealand Permian. Event stratigraphy and biostratigraphy also offer prospects for correlation (Waterhouse 1976a), including climatic change through a shared common trend in faunas towards cold or warm affinities. The following account briefly summarises correlation based on the new Permian classification and evaluation of substantial new faunas from Wairaki Downs, now under study.

CORRELATIONS FOR WAIRAKI DOWNS

(Table 2)

Upper Cisuralian Series

Kungurian Stage. Briggs & Campbell (1993) indicated correlation of the *Megousia solita* faunule with Elderslie beds in the Sydney Basin, and it may be regarded as approximately Kungurian. An Elderslie ammonoid *Aricoceras meridionalis* (Teichert & Fletcher) was regarded as post-Sarginian by Leonova & Bogoslovskaya (1990),

Series	International stage	New Zealand Zone
Lopingian	Changhsingian	*rostrata*
		planata
		spinosa
	Wuchiapingian	*multispinosa*
		woodi
Guadalupian	Capitanian	*elongata*
		ovalis
	Wordian	*=blakei*? f
		maxwelli
	Roadian	*discinia*
Upper Cisuralian	Kungurian	*supplanta* f
		Terrakea f
		Biconvexiella f
	Artinskian	*Echinalosia* sp.
		Wyndhamia sp.
		plica

Table 2. Correlations of New Zealand Permian brachiopod zones with International Standard for Permian stages. f indicates one fauna only.

pointing to Kungurian. The overlying *Spiriferella supplanta* fauna in Wairaki Downs is slightly younger, perhaps upper Kungurian (Nevolin or Irenian), with several brachiopod species demonstrating ties to the *Tomiopsis undulosus* Zone of east Australia.

Guadalupian Series

Roadian Stage. The overlying *Echinalosia discinia* Zone of New Zealand is close to the preceding faunas, and is putatively matched with the Roadian Stage, a unit currently based on only one faunal zone. The *discinia* Zone is well represented in the Brae Formation of southeast Bowen Basin (Waterhouse 1987a), and apparently in the Belford Formation of the north Sydney Basin, judged from *E. discinia* (see Briggs 1991) and *Tomiopsis subplicatus* (Waterhouse)=*belfordensis* (McClung).

Wordian Stage. Three major macrofaunal assemblages are developed in the Wordian of the Glass Mountains, Texas, from members named China Tank, Willis Ranch and Appel Ranch (Cooper & Grant 1972). In the Bowen Basin, Queensland, and New Zealand there are three allied and successive biozones that can be tentatively matched with the three in the Glass Mountains, and also with the comparable three in Russian Platform and Urals—upper Ufimian, Kalinovian and Sosnovian. The three successive Queensland and New Zealand faunas are the *Echinalosia maxwelli*, *Wyndhamia blakei* and *Echinalosia ovalis* zones (Parfrey 1988; Waterhouse 1987a; Waterhouse & Jell 1983). The *blakei* Zone is poorly represented in New Zealand, by the *magniplica* lens. The Ingelara Formation with *blakei* (*~ingelarensis*) has yielded a foraminiferal assemblage identical to *Pseudonodosaria borealis* Zone of the Russian Kazanian (Palmieri et al. 1994). The shell banks rich in *Echinalosia maxwelli* may provide some support for a fall in sea-level, emphasised as marked for the Ufimian Stage in Russia (Jin & Menning 1996).

Capitanian Stage. On the basis of conodont studies, there are suggestions that the uppermost Wordian zone should be transferred to Capitanian (Dr M. Menning, pers. comm.), and that is approximately when the Illawarra Reversal ended. The Illawarra Reversal is found in the uppermost Maokou of China, lower Tatarian of Russia (Jin & Menning 1996), and in the north Sydney Basin, either in the Wittingham or Tomago Coal Measures or perhaps as low as Mulbring Formation. This means that the *Echinalosia ovalis* Zone becomes Capitanian. Above the *ovalis* Zone, the overlying *Terrakea elongata* Zone of New Zealand, and in east Australia, correlative *Wyndhamia clarkei*, *M. pelicanensis* and *Martiniopsis havilensis* faunas (Dear 1972) of the north Bowen Basin, and possibly Kulnurra marine tongue in the Tomago Coal Measures of the Sydney Basin (Dickins 1989) are here referred to Capitanian.

Lopingian Series

Wuchiapingian Stage. It has been a long campaign to achieve recognition of the high value of the Chinese Permian (Zhao 1966; Waterhouse 1966: 86, 1969), and the choice of China for world stratotype marks an outstanding advance. There are very rich and diverse faunas there, but full understanding is yet to be achieved. For the early Late Permian, fusuline, brachiopod and possibly ammonoid studies indicate that there are substantial faunas involved in Midian, Laibinian and Djulfian divisions amongst fusulines (Leven 1993) and Punjabian–Djulfian amongst brachiopods (Waterhouse 1976a), to use old names. There are no clear links between New Zealand and palaeotropical China or southeast Asia, but there are more apparent ties between New Zealand and Western Australia, Timor, Salt Range and Himalayas. In the classic Salt Range Permian the Wargal Formation, containing diverse faunas in the Kalabagh Member at the top is overlain by the Chhidru Formation. Faunally the Chhidru was subdivided by Waagen (1891) into the major Kufri (=Ghund Ghat) Member with characteristic brachiopods, the Ganjaroh Member with Waagen's 'bivalve fauna' and topmost white sands (Khisor Member) with sparse brachiopods (Waterhouse 1983b). Wuchiapingian conodonts are found in Wargal, Kalabagh and lower–middle Chhidru, and Changhsingian conodonts in the uppermost Chhidru, or 'white sand' Khisor Member (Wardlaw 1997). Grant (1970) could not distinguish the three faunal levels, but was dismissive of the upper brachiopods, and seems to have overlooked the Waagen work on the bivalves. Grant's conclusions must be set aside. Grant & Cooper (1973: fig. 4) even assigned the Zewan 'Series' of Kashmir, which has *Cyclolobus* and a number of Chhidru species, and Illawarra Reversal to the Roadian–Artinskian. Instead, the Waagen analysis is substantially buttressed from faunas in the Himalaya, especially Nepal, where Kufri-equivalent faunas of the widespread *Lamnimargus himalayensis* Zone are followed locally by the 'bivalve fauna' (Popa Member of Dolpo, *Pyramus silicius* Zone) and substantial Khisor faunas in the Pija Formation (*Krotovia arcuata* Zone) of Dolpo and Manang (Waterhouse 1978, 1983a).

The best faunas at these levels in New Zealand occur in Arthurton Group of south Otago, with

three zones in sequence, named after *Martiniopsis woodi*, *Plekonella multicostata* and *Spinomartinia spinosa* zones. Only the latter two mentioned are present at Wairaki Downs. Cawood (1987) claimed these zones were redeposited and of no value, within beds mapped as the Greville Formation. Like Ongley (1937) he interpreted the sequence as a simple southward younging succession, and did not mention numerous younging directions and fold axes demonstrated for the area by Bishop (1965), Wood (1956) and Waterhouse (1976b).

The *Martiniopsis woodi* Zone shares strong specific affinities with the lower to middle Chhidru or Kufri fauna of the Salt Range, and like that fauna shows warm-water attributes. That strongly implies that Kalabagh and Wargal faunal levels of early Wuchiapingian age (Jin 1996) are not represented in New Zealand. There are also ties between the *woodi* Zone of New Zealand and the Amarassian fauna of Timor, and the *Waagenoconcha imperfecta* Zone of the Cherrabun Member in the Canning Basin of Western Australia (Archbold 1993). The ammonoid *Cyclolobus* is found in these Cherrabun and Amarassi levels, and also in the Kufri fauna of the Salt Range.

The overlying *Plekonella multicostata* Zone is matched with upper Wuchiapingian Stage, from superposition and overall cold-water affinities, apparently correlative with reputed tillite of the Gijigin horizon in Kolyma–Omolon of northeast Siberia. The New Zealand fauna is matched with the *Pyramus silicius* Zone of Nepal and Waagen's bivalve fauna in the Ganjaroh Member of the Salt Range.

Changhsingian Stage. Three conodont zones typify the Changhsingian of China (Kozur 1997), and Shen & He (1994) and Shen et al. (1995) have discussed a succession of three substantial brachiopod faunas. There are three major possibly matching brachiopod zones in both the Himalayas and New Zealand. The Khisor Member or white sand unit which contains Changhsingian conodonts as well as brachiopods in the Salt Range is matched faunally with the much richer *Krotovia arcuata* Zone of the Pija Member, found in west and central Nepal (Waterhouse 1983a), and containing lower Changhsingian and some late Wuchiapingian brachiopod links. This level appears to be represented in New Zealand (and New Caledonia and possibly southeast Queensland) by the *Spinomartinia spinosa* Zone, with moderately rich faunas. One bivalve common in the *spinosa* Zone is *Trabeculatia*, found in the Late Permian Hivach and Delenjin faunas of Siberia (Astafieva 1993), above the Gijigin horizon. The distinctive Changhsingian Strophalosiid *Marginalosia* is found in the uppermost *spinosa* Zone, and in the Hivach Formation. *Trabeculatia* is widespread in sandstone widely mapped—possibly mismapped—as Little Ben Sandstone, above *Maitaia trechmanni* in the Tramway Formation. The Little Ben Sandstone in its type section has yielded low C_{13} ratios indicative of basal Triassic (Gangetian *Otoceras* level) according to Campbell (1996). That certainly seems a direct challenge to the present scheme. It may be theoretically possible to have Permian-type faunas surviving into lower Triassic, because it has been argued that southerly faunas survived the Permian–Triassic life crisis (Waterhouse 1997). But there are possibilities also of miscorrelation. The middle of the type Greville Subgroup has a massive sandstone called the Washley Formation at D'Urville Island (Waterhouse 1987b), and possibly this is the same as type Little Ben Sandstone. More fundamentally, it has been demonstrated by Foster et al. (1997) that carbon isotope ratios are strongly affected by the nature and presence of plant material, a matter apparently not yet evaluated for the Little Ben samples.

The middle Changhsingian of Nepal is represented by the *Marginalosia kalikotei* Zone with three subzones. An allied species of *Marginalosia* characterises the *planata* Zone of the Pig Valley limestone lenses in the lower Te Mokai Group of east Nelson, and further Changhsingian links are shown by distinctive species of *Spiriferella* and *Peruvispira.* The limestones have slid downslope from the Brook Street Terrane to the west (as shown at Wairaki Downs) to be mixed with an array of Scythian ammonoids and even Anisian gastropod *Mellarium mutchi* (Waterhouse 1993).

The *Wairakiella rostrata* Zone of the Wairaki Breccia-Conglomerate Formation beds in Wairaki Downs is late Changhsingian, and matched with the faunas as yet undescribed from the Marsyangdi Formation at the top of the Permian in Manang, central Nepal (Waterhouse & Shi 1991). This formation is late Changhsingian (Meishanian), and is overlain directly by *Otoceras woodwardi* Zone of the basal Gangetian Stage of Early Triassic age (Waterhouse 1994).

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