THE IMPACT OF GLACIATION ON THE PERMIAN MARINE MACRO-FAUNAS FROM EASTERN AUSTRALIA AND EQUIVALENT FAUNAS OF NEW ZEALAND

by J. B. Waterhouse

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THE IMPACT OF GLACIATION ON THE PERMIAN MARINE MACRO-FAUNAS FROM EASTERN AUSTRALIA AND EQUIVALENT FAUNAS OF NEW ZEALAND

Abstract

This article reviews the impact of climatic changes on marine macrofaunas during the Permian Period in east Australia and New Zealand, as assessed from the faunas according to the zonation consolidated in Waterhouse (2026). The Early Permian saw two distinct phases, lasting through much of the Asselian Stage, followed by a warm interval during the Upper Asselian Stage then by a lengthy and relatively stable but cold Sakmarian Stage when faunas expanded but retained their cold-water imprimatur, into early Artinskian time (Aktastinian). A brief warmer episode during the *Azygidium mitis* Zone, followed by a colder *Acanthalosia domina* Zone, and a warm interval followed in the upper Artinskian (Baigendzian), when coal measures were prevalent in east Australia, but not New Zealand. A complex and long-lasting glacial interval developed in the Kungurian Stage which is internationally classed at the top of the Cisuralian Series of Early Permian age, and lasted throughout the Guadalupian Series into the Capitanian Stage, though disrupted episodically by warmer episodes. These climatic conditions developed so strongly in east Australia were reflected world-wide, according to faunas and aspects of sedimentation, particularly in European Russia and in the Arctic faunas of Canada and northeast Russia. The succeeding Lopingian Series was much warmer, although there appears to have been a cool to cold episode near the end of the period during the upper Changsinghian Stage in New Zealand, and reflected to some extent in the Late Permian of the Himalayas in Nepal. It is shown that a number of episodes of limestone deposition in the Permian of Australasia have faunas more indicative of conditions colder than those of clastic units above and below, consistent with the study by Carey & Ahmed (1961), and contrary to the interpretation of Fielding and associates (eg .Fielding et al. (2008a, b) and Frank et al. (2015).

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INTRODUCTION

The Early Permian macrofaunas in eastern Australia commenced with cold-water faunas associated with diamictites and other glacigene sediments, often supporting faunas dominated by the swollen and large shells of the bivalve *Eurydesma,* and associated in two well defined .biozones as recognized by Clarke (1990, 1992) in Tasmania. Both biozones are assigned to the Asselian Stage of the International hierarchy, whereas the overlying late Asselian biozone, best represented in Queensland near Gympie, betokens much warmer waters. This warm phase diminished throughout several overlying biozones classed in the Sakmarian Stage, but its faunas are dominated by cold-water forms, in greater diversity than in the basal Permian zones. A brief warmer episode is represented by the *Azygidium mitis* Zone and followed by a cooler episode represented by the *Acanthalosia domina* Zone in the lower Dresden Limestone of the southeast Bowen Basin, and a little higher in the succession, the *Echinalosia preovalis* Zone marked a cold episode well developed throughout Queensland and New Zealand, but with uncertain presence in Tasmania and New South Wales because faunas from those two regions require more study. This level was followed by a warm interval with coal measures, notably the Greta Coal Measures in New South Wales (Loughnan 1973, 1975), whereas marine conditions persisted in New Zealand with two warm-water macro-faunal biozones of upper Artinskian (Baigenzinian) age.

In both east Australia and New Zealand, the Kungurian to Capitanian Stages were made up of cyclothems, each starting with cold-water carbonates or carbonate-rich sediment with low diversity faunas, followed by more clastic lithologies with higher diversity faunas, but still less diverse than most of those in the Early Permian Sakmarian age, and ending with a sustained cold spell lasting through the *Acanthalosia deari* interval, and *Maxwellosia ovalis*, *Pseudostrophalosia clarkei, Echinalosia* (*Unicusia*) *minima* and *Ingelarella costata* zones, judged to be of Capitanian age, in the Bowen Basin of Queensland.

The uppermost Permian Lopingian Series saw the development of coal measures over the Bowen and Sydney Basins, betokening warm conditions like those of the earlier Greta Coal Measures while extensive shell-derived rather than cold-water carbonates with moderately diverse faunas accumulated seaward, as now preserved near present-day Gympie of southeast Queensland and in New Zealand. An exceptional cold-water zone developed in New Zealand in the very late Permian, before a last very warm interval.

In this study focus is on fossil biota and elaborating a new means of estimating their implications of climate, varying from glacial to very warm, bypassing attempts to resolve such matters through geochemical analyses, but taking account of the nature of the enclosing sediments and their environmental imprimatur. Broader overviews are offered by Shi & Waterhouse (2010), Waterhouse & Shi (2010), and Waterhouse (2021b, 2026). These articles review some of the current approaches, of which many have been centred on rather localized studies, dominated by workers from the northern hemisphere and without the advantage of working in glaciated terranes and on macrofaunas known from the mid-nineteenth century.

RECENT STUDIES ON PERMIAN CLIMATE IN EASTERN AUSTRALIA

Dickins (1985, 1995), Korte et al. (2008). James at al. (2009), Clapham & James (2008) and Frank et al. (2015) have contributed studies on east Australian Permian deposits and faunas. Jones, Frank & Fielding (2006) considered that the presence of apparently ice-rafted boulders in post-Sakmarian east Australia was anomalous. They offered correlations with non-marine sediment and palynomorphs which were not correct, and as well, the understanding of palynomorphs and their parent plants remains highly incomplete. They claimed that paleofloral data suggested equable onshore environments, and that the evidence of scattered clasts in the sediment should be ascribed to upwelling cold abyssal waters, which contributed to the development of ikaite and glendonites. They further claimed relevance to models which suggested that on-shore winds had driven the upwelling. Jones et al. (2006, p. 374) asserted that eastern Australia in mid-Permian was anomalously cold, in comparison with Western Australia. What was anomalous about shrinking glaciation was never explained. And the proposition that Western Australia was at the same paleolatitude (Gorter 2002) may be questioned. Gorter was attached to the oil industry, which by and large in those days rejected theories of continental displacement and interpretations of paleomagnetic records. One of the prime difficulties is that Jones et al. (2006) kept referring to the Sydney and Bowen Basins as being on the coast of east Australia. But were they? Most of the Bowen Basin was separated from the coast by a further basin, the Yarrol Basin, followed to the east (ie. seaward), by sediments of the New England Orogen. Queensland as a whole was fringed by a Highbury – Brook Street volcanic arc. The Bowen Basin did not border the ocean. A great part of its constituent sediment was deposited in shallow water, able to support bottom-dwelling

brachiopods and molluscs, and deep-water turbidites are notably rare: flysch is present especially in the Barfield Formation, yet at intervals was deposited in waters shallow enough to support bottom-dwelling biota such as brachiopods and molluscs. The one area likely to be subjected to upwelling cold-waters was on the seaward side of the volcanic arc, in the Greville and Kin Kin laminites and turbidites which accumulated in Gympie of Queensland and in New Zealand in a trough of Early and early Middle Triassic age. By contrast, the Bowen Basin was not deep. That too allows the rafted ice-ferried blocks that were obviously dropped from the surface melting ice to be exactly what they look like, without any appeal to models relevant to very different conditions. The Jones et al. text summarized text on glendonites and geochemical aspects is of interest, but not compellingly relevant to the argument in question. In detail, the macrofaunas and their implications of temperature and environment provide no support for the upwelling thesis. Jones et al. failed to provide proof that the structure and depth and relationship to wind or nearby sea-currents etc. for the Scottville Member of the north Bowen Basin could have resulted from substantial upwelling. However, Jones et al. do provide confirmation that the blocks were dropped from above, and passed on the information that the blocks were composed of detritus from the more aged rocks exposed in the Lachlan Geosyncline to the west. They referred to Draper (1983) who indicated rafting from local river or beach sources by seasonal ice. Admittedly Draper's study focused on the Denison Trough on the southwest Bowen Basin, but perhaps the observations could have applied more widely. After all, the Scottville Member was deposited not only far from the ocean, but also far from the Denison Trough in the southwest Bowen Basin.

A number of temperature assessments were offered by Korte et al. (2008) with challenging aspects that require verification. The team was largely based in Germany, and so relied on the sole Australian co-author P. J. Jones for stratigraphy and faunal correlation. Peter is a fine paleontologist, but Permian has never been his forte. He relied largely if not entirely on the literature, completely ignored the New Zealand succession which showed that there were large gaps in the macro-faunal record of east Australia, and accepted the severe miscorrelations (and now vanished type material) of Briggs (1998) as well as the flawed SHRIMP age values of Roberts et al. (1996). Thus his correlations show no familiarity with the reality of Permian successions in east Australia, as based on brachiopods and molluscs.

In the same year, Clapham & James (2008) typifies a number of studies on the subject, relying on correlations and timing of glaciations in studies by Fielding et al. (2008a, b), gathering relevant observations from various parts of the world, and building up a limited base of generic and species identifications that are of little consistency, some inaccurate, many out-of-date, many acceptable. For the most part, these authors have never established their credentials through systematic studies of east Australian faunas, as may be testified in the prodigious Treatise series on Invertebrate Paleontology, which comprehensively reviews world-wide faunal studies on brachiopods, and fails to mention any of the aforesaid authors. The most critical failures lie in their use of unreliable paleontology and inaccurate determinations of age, to the extent that their conclusions over the timing and nature of events have to be considerably modified

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The chart showing glacial episodes and the text in Fielding et al. (2008a, Fig. 2) is in disarray for the upper segments, because they stated that they relied on the interpretation proferred by Briggs (1998) that the Freitag to Peawaddy Formations of the southwest Bowen Basin were substantially younger than the Mulbring and Branxton Formations of the Sydney Basin. These Queensland levels were split into two by Fielding et al. (2008a, b), forming so-called “Glaciation 3” and “Glaciation 4”, but the interglacial phase between glacial episodes 3 and 4 was reduced to a sliver of time, supposedly matching *Dulhuntyspora dulhuntyi* APP4.3 palynomorph zone and allegedly the upper Aldebaran Sandstone. Yet Metcalfe et al. (2015), another with limited familiarity of the east Australian Permian geology, accepted the Fielding et al. glaciations. The Fielding et al. correlations were well astray, and their reliance on Briggs (1998) misplaced. Their second interglacial phase included the Greta Coal Measures, which has long been evaluated as a warm

time, and therefore acceptable. They correlated the Greta coals with the Yarrunga Coal Measures, which seems pleasing, but apparently unlikely from mapping (Herbert 1972) and deemed to be unacceptable by palynomorph experts. The Snapper Point Formation was also included, another woeful error. There seems little point in trolling through their table, elaborate, but crammed with miscorrelations. Sedimentation was their forte, not correlation, and it is a pity that authorship did not include, despite their intentions, someone truly competent to unravel what was known of the stratigraphic correlations for rocks and faunas of Permian age, instead of relying on flawed SHRIMP data and the Briggs interpretation. Their care to involve a paleontologist was misplaced. John Roberts had an excellent track record that was limited to Australian faunas of Early Carboniferous rather than Permian age, and their supposed fossil specialist has rarely described any Permian fossil.

In summary, the faunas of Kungurian and Guadalupian age strongly suggest that the so-called third glacial phase of east Australia was much colder than the so-called second phase of Fielding and colleagues, except for the very top *Echinalosia preovalis* Zone of the western Bowen Basin and New Zealand. Much of the second (Sakmarian-Artinskian) phase was in fact was a time of conditions a little warmer than those of Asselian and Kungurian to Guadalupian time, from faunal and indeed sedimentary evidence and comparatively stable. The extended and weakly fluctuating Kungurian and Guadalupian glacial phase coincides with the introduction of a number of genera related to those of east Australia into the Guadalupian of the paleotropical Glass Mountains in west Texas, as described in the series by Cooper & Grant (eg. 1975, 1976), and noted in Waterhouse (2016, p. 237, Fig. 305) in drawing attention to a striking example of a trigonotretoid genus from the China Tank and Appel Ranch Members of Wordian and Capitanian age, allied to cold-water relatives in the younger Maitland, Shoalhaven and Back Creek faunas of the Sydney and Bowen Basins, Australia, and Mangarewa Formation of New Zealand.

Two of the authors had combined in James et al. (2009) to offer an even more challenging version of Permian stratigraphy and correlations, stemming from the articles by Fielding et al. (2008a, b). In their Fig. 2, the Berriedale Limestone deemed to be of upper but not late Sakmarian age was miscorrelated with the slightly older Elvinia and Dresden beds of the southeast Bowen Basin, and the ”Curra/Gigoomgan” Limestone was matched with the Malbina-Wandrawandian Snapper Point beds of the south Sydney Basin, although the faunas of the latter clearly indicate a

much younger age, as reinforced by stratigraphic matches with New Zealand rocks. The Fairyland Sandstone is shown as 10m thick – or less, certainly from measured sections, but the formation is over 60m thick elsewhere, and includes three members, so it should be treated as a full formation (see Briggs 1979; Waterhouse 1986). Their Fig. 3 offers an intriguing cross-section across part of the Bowen Basin, with no horizontal or vertical scale, ascribing the Oxtrack Formation and "Buffel Group" both to limestones (the Buffel includes much clastic material) accumulated at the crest of horsts, deposited above synrift and pre-rift unnamed volcanics, with rift-fill unnamed sandstone and Cattle Creek and Tiverton diamictite helping to occupy the intervening grabens. (There is no way that the bulk of the Tiverton Formation is diamictite). Some visiting geologists from overseas have contributed enormously to Australian geology, such as Etheridge Snr and Jnr: whereas many others over recent years have certainly offered challenging contributions, with all the hall-marks of unfamiliarity with the rocks of east Australia, let alone their relative age.

As in their companion studies of James et al. (2009), their proferred correlations were well astray, James et al. (2009, Fig. 2) calling the South Curra and Gigoomgan limestones of Gympie Wordian to late Artinskian, and the Elvinia and Dresden beds of the southeast Bowen Basin were assigned to Kungurian late Artinskian, instead of Sakmarian. But there is no consistency: the Berriedale Limestone of Tasmania was better matched with late Artinskian (in my view it should be lower Artinskian, though it should not to be forgotten that international correlations are still in a state of flux. More important at present are the intercorrelations within Queensland and east Australia, and it is these that are almost ridiculously fanciful (James et al. 2009, Fig. 2). For instance the so-called "Curra-Gigoomgan Lst". of Gympie (meaning South Curra) is correlated with the Wandrawandian Siltstone and upper Snapper Point Formation of the south Sydney Basin, and Malbina Formation and most of the Deep Bay Formation of Tasmania. In fact, the Gympie units are much younger. The Elvinia and Dresden so-called members are matched with the lower Curra/Gigoomgan Limestones and the Snapper Point and the Berriedale Limestone of Tasmania – both "members" are significantly older. Moreover these units are divisible into members, and so should be called formations, and the so-called Buffel Group should be acknowledged as a group rather than formation.

James et al. (2009) also ignored the Carey-Ahmed study. Moreover they claimed that the east side of the Bowen Basin represented the southeastern margin of Gondwana, as if there had

been no bordering volcanic arc and trough nor even Yarrol Basin and New England Orogen for Queensland, nor plate tectonic disruption further south. As in their companion studies, their proferred correlations were well astray, James et al. (2009, Fig. 2) calling the South Curra and Gigoomgan limestones of Gympie Wordian to late Artinskian, and the Elvinia and Dresden beds of the southeast Bowen Basin were assigned to Kungurian late Artinskian, instead of Sakmarian. But there is no consistency: the Berriedale Limestone of Tasmania was better matched with late Artinskian (in my view it should be lower Artinskian, though it should not to be forgotten that international correlations are still in a state of flux. More important at present are the intercorrelations within Queensland and east Australia, and it is these that are almost ridiculously fanciful (James et al. 2009, Fig. 2). For instance the so-called “Curra-Gigoomgan Lst”. of Gympie (meaning South Curra) is correlated with the Wandrawandian Siltstone and upper Snapper Point Formation of the south Sydney Basin, and Malbina Formation and most of the Deep Bay Formation of Tasmania. In fact, the Gympie units are much younger. The Elvinia and Dresden so-called members are matched with the lower Curra/Gigoomgan Limestones and the Snapper Point and the Berriedale Limestone of Tasmania – both “members” are significantly older. Moreover these units are divisible into members, and so should be called formations, and the so-called Buffel Group should be acknowledged as a group rather than formation.

On the other hand, valuable data was added on the detailed construct of various limestones, without realizing that some carbonates had only cold-water biota (ie Oxtrack [in which they appear to have grouped beds of a different and somewhat older Roses Pride Formation with very different fossils] and Scottville and Mantuan Member, both largely ignored, whereas others (Elvinia, Berriedale) had warmer-water much more diverse faunas, whilst the upper Dresden Limestone has a fauna colder-water than the lower limestone in the same unit. They quoted with approval the claim that the Barfield Formation was of Capitanian age, apparently sceptical of foraminiferal studies that favoured an earlier age. but giving no evidience, and claimed there was only or mainly flysch deposition, with no overlying carbonates (ignoring the Mantuan and Scottville Members). It should be remembered that C. R. Fielding was one of the authors: yet for all the papers he contributed while employed at the University of Queensland, it would seem that he gained a remarkably distorted understanding of Permian stratigraphy, as far as correlation and distribution are concerned. There is much of interest in their study but the misinterpretation of the

Oxtrack beds and the imposition of the glacial episodes and miscorrelations proposed by Fielding et al. (2008a, b) should encourage more meticulous analysis with closer attention to prevailing temperature conditions and closer attention to the complexities of sedimentation and correlation that prevailed in eastern Australia during the Permian Period.

This study embraces a wider range of fauna and more detailed correlations, as summarized in Waterhouse (2026), to show a complex series of climatic changes, and a gradual impoverishment of faunas from north to south, as also recognized by James et al. (2009). The values indicated for each biozone are founded on the data summarized in Waterhouse (2021a, 2026). Moreover the climate-induced changes were mirrored simultaneously in other parts of the world. The complexity is considerable, stemming from the use of a substantially greater amount of information, based partly on sedimentology from one more than familiar with glacial conditions in modern glaciated mountain chains such as the Himalayas, European Alps, Rocky Mountains and Southern Alps of New Zealand, and some familiarity with continental glaciation in Canada and seen at the fringe of modern mountain chains, combined with detailed and sequential assessments of the Permian macro-faunas of east Australia and New Zealand, involving a recent moderately comprehensive summary of all described taxa amongst Brachiopoda and their known distributions (Waterhouse 2023a, b; 2024a-f). That alone supersedes the restricted faunal overview and underlines some of the limitations found in short articles. Individual specimens and entire faunas convey a great deal of information of environmental conditions at the time when they lived, and have indeed been subject to climate-controlled world distribution studies relevant to paleolatitudes, not only in Waterhouse & Bonham-Carter (1975) but more intimate and detailed studies, though not published. By contrast, geochemical studies that aim to evaluate the age of rocks, and more rarely the temperature in which shell was formed, are largely data-poor, except in Frank et al. (2015) and Shi et al. (2022), as discussed shortly, with few values achieved, based on a very few samples achieved from a single station and then averaged out. Overall, these provide information for a few stations collected sparsely from a stratigraphic unit, even though the unit may be thick and be found over tens and even hundreds of square kilometres. Rarely if ever are attempts made to trace variations on geochemical values along strike, or compare samples at closely spaced intervals within a metre or less. The excessively few data points are linked by a smoothly and symmetrically undulating line to indicate changing temperatures (cf. Shi et al. 2022, Fig. 14). Why the poverty of data? Why the

absence of any data that can be statistically supported? The answer is two-fold. First the expense – even though the procedures are largely automated, and should be replicatable. There is simply not enough money available to conduct statistically acceptable measurements. Secondly, the conviction in at least some quarters centred on geochemical and physical aspects that a single measurement will apply to the entire unit. That has not been established in general for most sedimentary units. It is convenient of course, but may not always be true. Rocks of a stratigraphic unit were not deposited or cooled solely in obedience to a single all-pervasive and enduring physical law. Instead, there was a range of conditions and a range of physical controls, and these may vary during the development of a single stratigraphic unit. It is well known that geochemical and physical parameters may be modified by complex biological laws, often at variance with physical laws and indeed able to overcome and even exploit certain physical and chemical constraints. Furthermore, data related to cooling temperatures has not been gained from observations and measurements on living rock, but from laboratory-controlled conditions, with huge assumptions necessary because of extremely constrained scale and time, far different from those conditions prevailing in nature. That is where the environmental parameters have to be assessed for climatic influence on substrate and biological presence/absence. The very history of age-dating, with its constant and justifiable refrain of change and improvement, recalls the history of biological nomenclature: there may well prove to be further change and improvement. The latest is always the best – until the next update. In short, the current view is not necessarily going to be regarded as correct for all time. In biological studies, there is – or should be – awareness of more to be done and the recognition that the conclusions are incomplete, especially in attempts to quantify boundaries.

Frank et al. (2015, pp. 179-181, Table 2) offered a substantial number of age-values for parts of east Australian Permian, but provided no explanation in their text of exact location or even footage from the base of the formation concerned and limited location data. Their ages were premised on ages conjectured by Briggs (1998) and calculated in part from estimated rates of sedimentation rather than direct geochemical data. Significantly, δ-13C_{org} negative excursion and 18 O organic values were attributed to the samples, numerous compared with other values achieved in other articles, and though poorly documented as to source, of great interest, with considerable variation was displayed, as discussed by Frank et al. (2015).

Shi et al. (2022) presented a considerable number of age-values, based on U-Pb assessments of zircons. They deprecated aspects of their study (p. 15), noting that all were “with relatively large uncertainties when compared to high precision high-precision U-Pb CA-TIMS ages”. The age of the Wasp Head Formation was lowered a little, into upper Asselian, closer to the age evaluation based on fossils as in Waterhouse (2021a). They also cautioned (p. 17) against the Metcalfe et al. (2015) claim of a post-Kungurian age for the Pebbley Beach Formation of the south Sydney Basin. Their discussion on the age of this formation contains only indirect evidence, considered to favour an Artinskian age, but treating the unit as a whole, with no consideration of the possibility that the formation could have spanned several stages, nor recognition that the Shi et al., 2020 study which established a likely Kungurian age for the upper beds, even though Shi was supposed to be senior author in that article. In that study, Sangmin Lee and J. B. Waterhouse had argued from both correlation with other east Australian macrofaunas, and solar chronologic evidence for a basal Kungurian age for the youngest beds and faunas of the Pebbley Beach Formation. A Kungurian age was also deemed likely for the overlying Snapper Point Formation. U-Pb evidence provided for the Wandrawandian Formation was consistent with a Kungurian to early Roadian age. Shi et al. (2022) indicated a possibly preferable Wordian age for the Mulbring Siltstone, but noted a late Wordian age for the Bumbo latite near the base (Belicha et al. 2017), and allowed that Laurie et al. (2016) had assigned an early Capitanian age and pointed to a Capitanian age being favoured by strontium isotopes of 264.8 + 0.6 Ma claimed by Garbelli et al. (2019). On the other hand, Metcalfe et al. (2015) assigned a CA-TIMS age of 263.51 + 31 Ma from an ash bed near the top of the correlative Broughton Formation in the north Sydney Basin. The discussion by Shi et al. (2022) certainly brings out discrepancies between differing modes of age-value analyses and arguably establishes that ages are still in a state of some uncertainty, if not a state of flux. It may be asked if attention to solar chronology and more attention to more meticulous geochemical procedures, as well as closer elucidation of stratigraphic and biotic evidence would lead eventually to more consistent outcomes? The cautious and flexible – at times almost sceptical approach towards some modern assumptions over the scientific superiority of geochemistry over biological analysis in Shi et al. (2022) has much to commend. Metcalfe et al. (2015) has been the first in Australia to explain the need for current radiometric techniques, and bring a check to the erratic application of the local (Australian, followed by some New Zealand) SHRIMP node of

analysis, but even some of the Metcalfe dates were speedily changed in Laurie et al. (2016) and Smith et al (2017), each for different examples in different directions.

There is a further discrepancy, in the interpretations offered for the sequential development of carbonates in Frank et al. (2015), with substantial stratigraphic input from C. R. Fielding. Their interpretation followed the more or less standard view of deglaciation leading to massive input of clastics, followed by carbonates developing from comminuted shell material above the clastics under ameliorating temperatures. But the species content in some of the clastic beds shows greater diversity than the species found in the carbonates. Examples include the Brae clastics below the Oxtrack carbonates, and the following Barfield clastics above the Oxtrack carbonates. The Scottville Member, comprised mostly of carbonates with scattered erratic boulders is another example, found between clastics of the underlying lower Blenheim Formation (*Echinalosia maxwelli* Zone) and younger Blenheim beds (with the *Echinalosia* (*Unicusia*) *minima* Zone. The pattern was not immutable: in older rocks, the fauna is basically more diverse in the lower Dresden Limestone than in the underlying Fairyland Formation, but less so in the Roses Pride beds than in the underlying Elvinia Formation. In several of these instances, the restricted nature of the fossils in the carbonates suggests colder temperatures, rather than rising temperatures, and for the Scottville Member this is reinforced by the introduction of rafted blocks of sediment, dropped from above by melting ice. In short, the real pattern is closer to the interpretation by Carey & Ahmed (1961), an article ignored by Frank et al. (2015). put the next part

Solar chronology involves the output of heat by the sun as inferred from earth-based evidence for climate change, and in this case, in particular evidence provided by glaciation, and by the impact of cooling or warming temperatures on fossil biota. The distribution of fossil biota varies over the globe according to geographic position and relationship to the poles and equator, which reflects on climate and influence of the sun, involving temperature control. The assumption is that temperatures controlled by heat from the sun will be world-wide and essentially simultaneous, such as we are witnessing today, while the earth is in the throes of climate change. Opponents cling to their preference for atmospheric carbon fluctuations, but this would require an uninterrupted build-up lasting many years, whereas the fluctuating temperatures in the actual record convey more rapid changes, as if responding to changes in solar energy.

There has to be a caveat. Local climate change can also occur. For example several glaciations represent by till and other sediments in the vicinity of the Mt Cook National Park of New Zealand are not mirrored in the Alps of Europe: they appear to have been local. I suggest that the glaciations could have been strongly influenced by local tectonics. Glaciation during the Pleistocene in the Mt Cook Park commenced over tectonically uplifted peaks at the head of glaciers named Tasman, Murchison, Classen and Whymper (Waterhouse 2016). Later, peaks to the south and bordering the Tasman Glacier, including Mts Lendenfeld, Tasman, Aoraki-Mt Cook as far south as Mt Sefton were lifted and raised above the initial and seminal centre of glaciation, and the increased cold due to increased altitude supplied considerable volumes of ice to the lower Tasman Glacier, and the Hooker and Mueller Glaciers, which spilled with their eroded sediment on the plains to east, providing evidence for glaciation not matched in Europe, where there had been no synchronous tectonic activity.

A further complication to our understanding of the causes of glaciation arises from the modern evidence that atmospheric carbon has been responsible for glaciation. **T**o some students, the great loss of life at the end of the Permian period coincided with high atmospheric carbon, which owed its presence to high volcanic activity. The two events were separated by a lengthy time interval lasting millions of years: hardly in agreement with what we are seeing today. To these pundits, the volcanic activity was responsible for the much later rise in high atmospheric carbon, and so was responsible for the climatic catastrophe. The great time gap between volcanicity and extinction should give pause. At one phase in the development of fossil studies, there were even claims that the volcanicity saw major extinctions: this theory is now set aside, and even claims promulgated for major extinctions at the end of the various Middle and/or Late Permian stages have to be viewed as more reflective of limitations knowledge of Permian biota world-wide. Given what is happening now over the globe, it is clear that global warming is increasingly responsible or the rise in atmospheric carbon, due to release of methane thanks to warming of Arctic swamps and ocean floor sediment, and the enormous increase of forest fires. Man’s activities may have triggered the start of the problem, but now nature is reinforcing the original cause under the impact of feed-back loops. The climate record with its sequence of changes does not support a gradual increase in warmth towards the end of the Permian Period. Instead it shows a series of alternating shifts, as though caused by some external force of nature, such as the sun. The solar chart that summarizes

temperature shifts during the Late Permian (Fig. 1, p. 19) shows that cold interventions due to declining solar radiation were disrupting any climate trend reflecting warmer weather due to supposed high atmospheric carbon. The relatively short life of each climatic episode may possibly discourage any view that atmospheric carbon rebuilt itself from time to time, especially as there seems to have been no geologic event that was reseeding a renewal of atmospheric carbon.

The correlation scheme adopted in the present article with its sudden changes is much more accurate than some of the others in recent years, with more attention to detailed stratigraphy and to macro-fossil content, more accurate that the recent effort by Briggs (1998) which purported to zone and correlate the Permian of east Australia, and made numerous errors over correlation as well as morphological misrepresentations, as discussed in Waterhouse (2026), even though his scheme came to be adopted by other geologists working in east Australia. For example, the study by Frank, Shultis & Fielding (2015) contains useful observations on carbonate sedimentation (though ignoring the Carey & Ahmed 1961 contribution), but correlation was erratic, through relying on the Fielding et al. interpretation of glaciation, with their acceptance of the Briggs version of correlation. The large bivalve *Eurydesma* was even reported as being in the lower Oxtrack beds, following Hill & Woods (1964), Hill et al. (1972) and Runnegar (1979), who were unaware that their Oxtrack involved two different stratigraphic units, a restricted Oxtrack, and an underlying somewhat older Roses Pride Formation (Waterhouse 1986). There is emphatically no *Eurydesma* in the Oxtrack beds, writing as one who spent a long time collecting from the type Oxtrack Formation.

The chart showing glacial episodes and the text in Fielding et al. (2008a, Fig. 2) is in disarray for the upper segments, because they stated that they relied on the interpretation proferred by Briggs (1998) that the Freitag to Peawaddy Formations of the southwest Bowen Basin were substantially younger than the Mulbring and Branxton Formations of the Sydney Basin. These Queensland levels were split into two by Fielding et al. (2008a, b), forming so-called “Glaciation 3” and “Glaciation 4”, but the interglacial phase between glacial episodes 3 and 4 was reduced to a sliver of time, supposedly matching *Dulhuntyspora dulhuntyi* APP4.3 palynomorph zone and allegedly the upper Aldebaran Sandstone. Yet Metcalfe et al. (2015), another with limited familiarity of the east Australian Permian geology, accepted the Fielding et al. glaciations. The Fielding et al. correlations were well astray, and their reliance on Briggs (1998) misplaced. Their second interglacial phase included the Greta Coal Measures, which has long been evaluated as a warm

time, and therefore acceptable. They correlated the Greta coals with the Yarrunga Coal Measures, which seems pleasing, but apparently unlikely from mapping (Herbert 1972) and deemed to be unacceptable by palynomorph experts. The Snapper Point Formation was also included, another woeful error. There seems little point in trolling through their table, elaborate, but crammed with miscorrelations. Sedimentation was their forte, not correlation, and it is a pity that authorship did not include, despite their intentions, someone truly competent to unravel what was known of the stratigraphic correlations for rocks and faunas of Permian age, instead of relying on flawed SHRIMP data and the Briggs interpretation. Their care to involve a paleontologist was misplaced. John Roberts had an excellent track record that was limited to Australian faunas of Early Carboniferous rather than Permian age, and their supposed fossil specialist has rarely described any Permian fossil.

In summary, the faunas of Kungurian and Guadalupian age strongly suggest that the so-called third glacial phase of east Australia was much colder than the so-called second phase of Fielding and colleagues, except for the very top *Echinalosia preovalis* Zone of the western Bowen Basin and New Zealand. Much of the second (Sakmarian-Artinskian) phase was in fact was a time of conditions a little warmer than those of Asselian and Kungurian to Guadalupian time, from faunal and indeed sedimentary evidence and comparatively stable. The extended and weakly fluctuating Kungurian and Guadalupian glacial phase coincides with the introduction of a number of genera related to those of east Australia into the Guadalupian of the paleotropical Glass Mountains in west Texas, as described in the series by Cooper & Grant (eg. 1975, 1976), and noted in Waterhouse (2016, p. 237, Fig. 305) in drawing attention to a striking example of a trigonotretoid genus from the China Tank and Appel Ranch Members of Wordian and Capitanian age, allied to cold-water relatives in the younger Maitland, Shoalhaven and Back Creek faunas of the Sydney and Bowen Basins, Australia, and Mangarewa Formation of New Zealand.

A SIMPLE METHOD OF CALIBRATING THE INFLUENCE OF TEMPERATURE FROM FOSSILS

As shown in Waterhouse (2021b, p. 273) a basic faunal range of fossil Brachiopoda is displayed at most stations in east Australia, involving members of Streptorhynchinae, Rugosochonetidae, Echinalosiidae, Paucispinauriidae, Plekonellinae, Cleiothyridininae, Ingelarellidae, Notospiriferidae, Pustuloplicidae, Trigonotretidae, Georginakingiidae, Pennospiriferidae,

Permasyrinxinae, Dielasmidae, Gillediidae with the addition of Pseudodielasmidae (see Waterhouse 2024f) in sixteen family groups that are widely pervasive and often dominant in Permian faunas of east Australia. They are grouped in this study under the heading EAD, standing for East Australian Dominants. There is a degree of arbitrariness in their section, with some admittedly approaching the category of being Australia-wide, but these do not affect overall scores and affinities.

Stations and biozones that display genera restricted to this narrow range of family groups classed as EAD are considered to have signified cool to cold-water, well adapted to living in high paleolatitudes typical of the east Australian Permian. Stress on subfamilies and families recognizes that genera and generic strands were evolving locally in east Australia. The mere number of genera does not suffice on its own to signal climate, given the likelihood of other ecological parameters, and evaluation is best reinforced by having a number of collections from various lithologies. Size of shell can be misleading. Although some have assumed that the larger the shell, the warmer the climate, this was denied by Carey & Ahmed (1961), who pointed out the size reflected availability of CaCO3, and that glacial conditions could improve the availability of shell material. Clarke & Farmer (1982) attacked the Carey-Rao thesis, but it seems to me that the reply by Rao (1983) disposes of their argument. Field observations make this clear. The Permian shells found in the tropical realm of Texas or Thailand are small and thin – and very numerous. The shells found associated with the glacial sediments of east Australia are often large and thick.

The recognition of an EAD group of genera marks the first approximation to the distinction of an east Australasian number of associated genera developed under very cold conditions. It is preliminary and robust, but there are complications. A small subset of genera are associated which appear only in a few of the faunas, such as the brachythyrid *Pustuloplica,* or rare punctate spiriferinids such as *Lamnaespira* They so far appear to confined to the northern limits of glaciation, principally in Queensland and New Zealand. For this article they are regarded as subEAD. A distinct group may be suggested for genera with Australian rather than east Australian genera, involving large productiform genera such as *Taeniothaerus, Lipanteris, Neilotreta, Spiriferella* and allies, with others. These genera appear to have commenced or retained a presence in Western Australia, but spread now and then into east Australasia. They could be designated A (for Australasia) group. And other genera displayed a more ubiquitous distribution. But for this article, the EAD group is

retained, to mark an initial and robust group typifying east Australian cold-water faunas, found in faunas of limited diversity and often associated with tillite or other glacigene sediments.

Calibration values

Brachiopod assemblages which have solely components of EAD affinities are judged to be indicative of glacial conditions. They yield an A/B ratio of 0. Ratios of 0.1 or 0.2 are judged to be close to glacial conditions. At the other extreme, if only non-EAD components are present, they are considered to indicate warm conditions. Because there are a range of faunas, only a few have high numerical values, and many faunas show an assortment of associations, with warm-water brachiopods mixing with cool water ones, and ratios of often close to 0.4 up, and a few with low complete digits.

APPLICATION OF THE EAD DOMINANT COMPONENT IN EAST AUSTRALIAN MACRO-FAUNAS OF PERMIAN AGE

In tables and figures accompanying this text, the number of family groups counted as East Australian Dominants (EAD) summarized as “A” is divided into the number of genera present that do not fall within the EAD category (= “B”), and therefore indicate exceptional conditions, involving invasion by genera normally found at lower paleolatitudes, permitted and encouraged to do so through, it is inferred, a climatic change to warmer conditions. That assumption provides a first approximation to conditions prevailing during the accumulation of a particular zone. An overall chart (Fig. 1, p. 20) is constructed from the values estimated for the type sections of each macrofaunal biozone, and a further diagram is constructed to suggest the shifting Highbury and Brook Street volcanic arc tend to yield higher diversity again, reflective of its offshore position and probably greater accessibility to faunas migrating from further afield, though shifted in time under continental displacement or ocean growth.

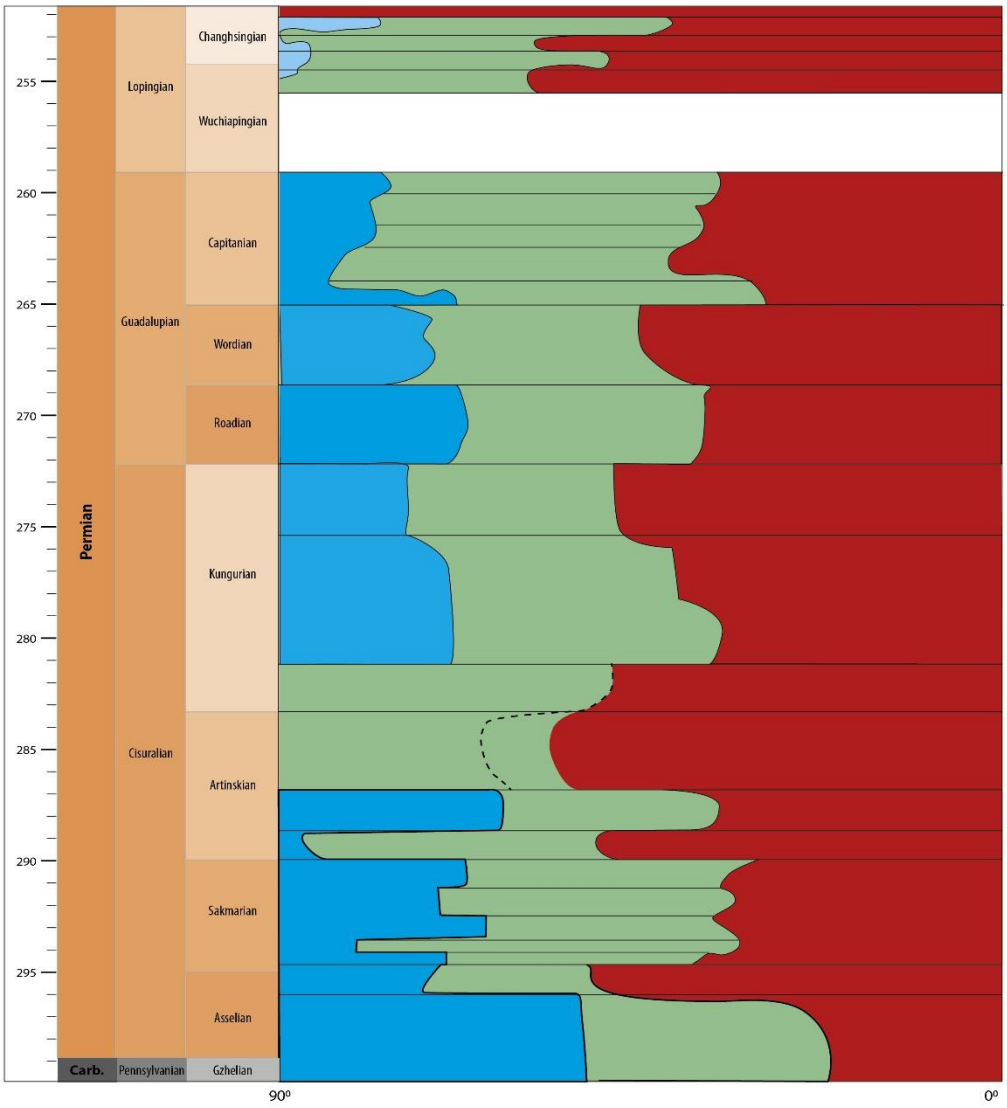


Fig. 1. Impressionistic reconstruction of shifts in marine faunal distributions of tropical, temperate and glacial climatic attributes based principally on evidence for macro-faunal changes throughout the southern hemisphere for the Permian Period, blue equivalent to conditions of severe cold, the red to tropical and subtropical conditions, with intervening paleotemperate (green) realm. The time scale follows more or less the International scheme. The blank part of column, called Wuchiapingian, was a time when marine faunas were few and coal measures prevailed in east Australia, and when marine sediments overwhelmed the New Zealand record, leaving few shelly fossils. Adjusted from Waterhouse (1977) and Waterhouse & Bonham-Carter (1975).

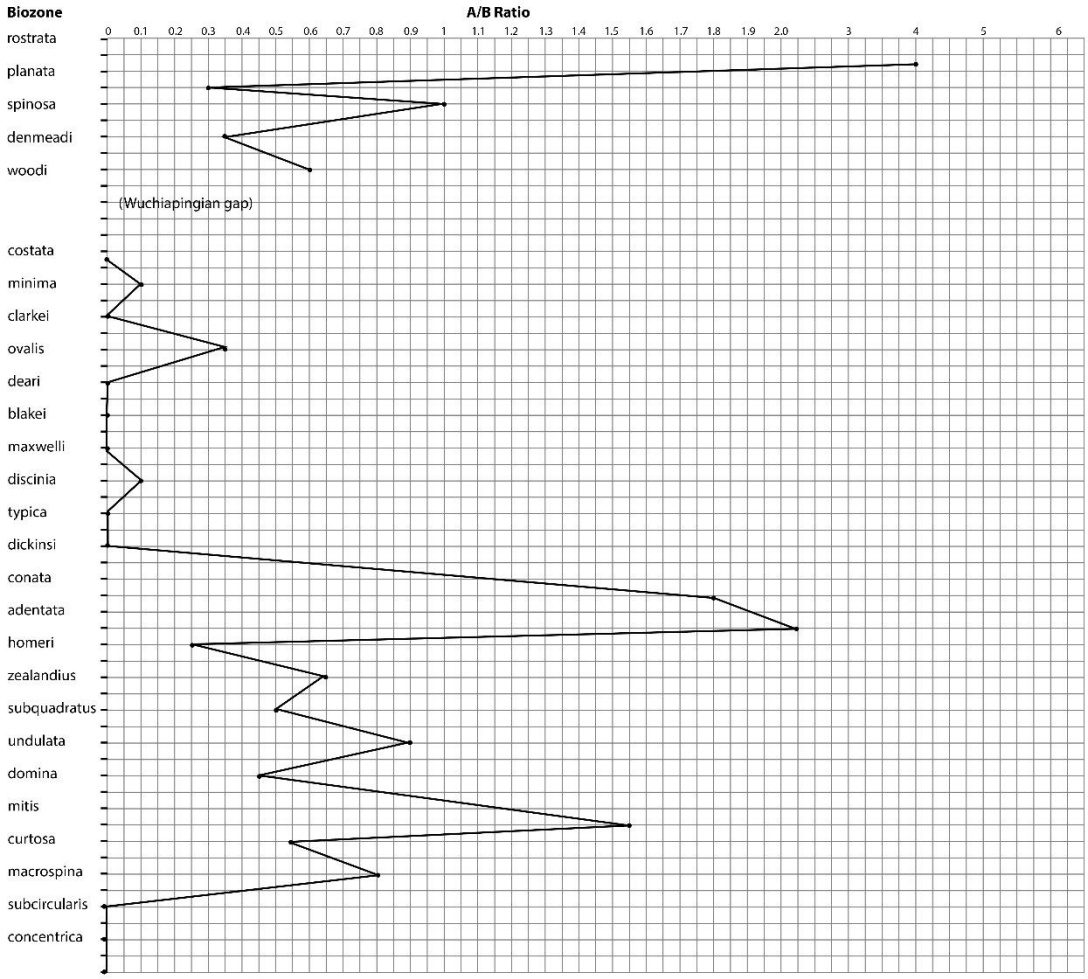


Fig. 2. Line graph plotting the changes in A/B ratios through the successive biozones of the marine Permian of east Australia and New Zealand. The lowest score lies to the left, and progressive increases in the A/B ratio to the right are assumed to indicate increasingly warm temperatures. Biozones are listed in the left-hand column.

The species are genera itemized in the following text are each summarized and illustrated in the series of Earthwise authored by Waterhouse (2023a, b; 2024a-f) and are available as PDF's from the New Zealand Geoscience Society website at https://gsnz.org.nz/publications-and-webstore/product/171.

CISURALIAN SERIES (EARLY PERMIAN)

ASSELIAN STAGE

Strophalosiella concentrica biozone

Faunas of the *Strophalosiella concentrica* biozone are totally and exclusively made up of five EAD genera, at least amongst the documented components (Clarke 1990, 1992; Waterhouse 2021a, p. 194), and there are no non-EAD genera. Together with the overlying zone, the faunas belong to Glacial 1 of the east Australian Permian (Fielding et al. 2008a). The A/B ratio is zero.

Strophalosiella concentrica	**0**	**5**	**0**
Crassispinosella subcircularis	**0**	**5**	**0**
Bandoproductus macrospina	**5 or 6**	**5 or 6 1**	**8**
Echinalosia curtosa	**2**	**12**	**0.16**
Azygidium mitis	**5**	**9**	**.55**
Acanthalosia domina	**2**	**8**	**0.4**
Magniplicatina undulata	**6**	**9**	**0.66**
Taeniothaerus subquadratus	**3**	**12**	**.25**
Notostrophia zealandicus	**7**	**9**	**0.7**
Notostrophia homeri	**1?**	**6**	**0 or .16**
Martiniid *adentata*	**3-4**	**0**	**0**
Capillaria conata			

Fig. 3. Summary of EAD affinity scores for Early Permian of east Australia and New Zealand.

Crassispinosella subcircularis biozone

A similarly limited range of genera is found in the overlying macrofaunal zone (Clarke 1990, 1992; Waterhouse 2021, p.196). All five genera belong to the EAD group, and therefore indicate an evolutionary but no climatic change from the underlying zone. An uppermost is distinguished by the presence of *Unicostatina crassa* (Clarke). The same species is also found in the Cranky Corner

Macrofaunal zone	Type section	Other formations or faunas
Capillaria conata	McLean Peaks & Heartbreak F, NZ	?lower Aldebaran (swBB); equivalent Greta M (nSB)
Martiniid *adentata*	Chimney Peaks F. NZ	?Wall Ss (nBB)
Echinalosia preovalis	Upper Tiverton F. nBB	Sirius Shale, up. Cattle Ck beds (swBB); Roses Pride F (seBB), ?mid-Pebbley Beach F (sSB), *Notostrophia homeri* fauna of Brunel F, (NZ).
Notostrophia zealandicus	Upper Brunel F NZ	?barren marine sediments elsewhere
Taeniothaerus subquadratus	Berriedale L (Tas),	high Tiverton F, nBB, Riverstone Ss (swBB), Lakes Cr beds, (Q), upper Elvinia F (swBB), Gondor F (NZ)
Magniplicatina undulata	middle Tiverton nBB	Elvinia F with Boughyward Mbr (seBB),
Acanthalosia domina Subzone	upper Dresden L seBB	Basal Elvinia F (seBB), Not known elsewhere but included with underlying *mitis* fauna in *Bookeria pollex* Zone of mid-Tiverton F (nBB)
Azygidium mitis subzone	lower Dresden, seBB	Not known elsewhere. Probably equivalent of *Bookeria pollex* of mid Tiverton F (nBB)
Echinalosia curtosa	Fairyland F, seBB	?basal Tiverton F (nBB)
Bandoproductus macrospina	Upper Rammutt F; Gympie	Burnett F (YB), Rutherford F (nSB), Silver Spur beds (Q)
Crassispinosella subcircularis	lower Bundella F Tas	Darlington L. (Tas) Mid Wasp Head F (sSB), mid-Rammutt F (G), Lizzie Volcanics (Q)
Strophalosiella concentrica	Quamby F, Tas	Woody Isl. F, Tasmanites Shale, up. Wyndyard tillite, Tas.,Lower Wasp Head F. (sSB), Lochinvar F. (nSB), Burnett F., Youlambie Con. (YB)

Fig. 4. Early Permian brachiopod zones recognized in east Australia and central New Zealand, with temperature indications from faunas, coded blue very cold to glacial; green ameliorating temperatures, and red, relatively warm temperatures. Bracketed letters indicate geographic location as follows: G Gympie, southeast Queensland, (Q) Queensland, (nBB) north Bowen Basin, (seBB) southeast Bowen Basin, (swBB) southwest Bowen Basin, Queensland, sQ south Queensland, (Y) Yarrol Basin, Queensland. (NZ) Takitimu Range, New Zealand. (nSB) north Sydney Basin, (sSB) south Sydney Basin. (Tas) Tasmania those rather poorly known faunas of the southwest Bowen Basin. And the Gympie-New Zealand Highbury and Brook Street volcanic arc tend to yield higher diversity again, reflective of its off-shore position and probably greater accessibility to faunas migrating from further afield, though shifted in time under continental displacement or ocean growth. The *Notostrophia homeri* Zone of New Zealand shares critical species with the *Echinalosia preovalis* Zone of the Bowen Basin of Queensland.

Distribution of Early Permian glacial faunas in east Australia

Briggs (1998, p. 28) reported that *Eurydesma burnettensis* Waterhouse, 1987 initially described from Maxwell's upper division of his Burnett Formation in the Yarrol block of Queensland was also to be found in the Tasmanites band (Dun 1913, Runnegar 1970b, pl. 15, fig. 4, 9; Clarke 1992, Fig. 20G), near the base of the Quamby beds in the *concentrica* Zone, and Briggs also identified the species in the basal Lochinvar Formation in what as called the Gosforth Shale of Browne & Dun (1924) and in the Cranky Corner outlier in the basal "Seaham Formation." These valuable insights do need confirmation, but help tie the Tasmanian zones into the broader picture.

***Bandoproductus macrospina* biozone**

The *Bandoproductus macrospina* biozone is based on the macrofauna from the upper Rammutt Formation of the Gympie area in southeast Queensland (Waterhouse 2015a, pp. 44-73; 2021a, p. 200). In New South Wales the zone is developed in the lower Rutherford Formation of the north Sydney Basin. Species include *Bandoproductus macrospina* Waterhouse, and as shown in Fig. 1, there is a sharp rise in non-EAD genera and members of family groups that are exceptional for east Australian Permian faunas.

SAKMARIAN STAGE

East Australian faunas were far more diverse than those of the Early and Middle Asselian Stage, building on the enrichment that started in the late Asselian *Bandoproductus macrospina* Zone, but it would appear that temperatures remained low, because for much of the stage, few non-EAD genera appeared, whereas the stable though low temperatures lowed a build-up of EAD genera. The succession of zones is selected from the southeast Bowen Basin as summarized in Waterhouse (1987b), and then transferred first to the north Bowen Basin for the *Taeniothaerus subquadratus* Zone, and then to southern New Zealand Takitimu Mountains for the concluding four zones (Waterhouse 1982, 2001).

***Echinalosia curtosa* Zone**

The *Echinalosia curtosa* Zone is best known in the Fairyland Formation of the southeast Bowen Basin of Queensland, and typified by *Echinalosia curtosa*, accompanied by a substantial fauna *Eurydesma truncatum* Waterhouse, and other forms, summarized in Waterhouse (1987b, p. 201, Table 6; Waterhouse 2021a, p. 206). Fewer but similar species are also found in the lower

Tiverton beds of the north Bowen Basin, and in the lower Farley Formation of the north Sydney Basin, and most genera are EAD Dominants. The A/B ratio at 0.3 shows a fall from the *Bandoproductus* level, with three non-EAD genera, involving *Lipanteris,*and *Linoproductus* paired with *Costatumulus*

***Azygidium mitis* Zone**

The Dresden Limestone has two distinct faunas. The lower fauna is assigned to the *Azygidium mitis* Zone, as tabulated in Waterhouse (1987b, p. 202) and further discussed in 2021b, p. 208). The species *mitis* (Hill), referred to a distinct genus *Azygidium* by Waterhouse (1986). Briggs (1998) declared that *mitis* belonged to *Anemonaria* Cooper & Grant, 1969, but he failed to observe that *Anemonaria* was characterized by strut spines, completely absent from *mitis*, and he further erred on his conjectured possible presence of a zygidium in *mitis* (Waterhouse 2023a, p. 66). *Azygidium* is clearly exceptional for east Australian Permian. The A/B ratio is higher than even that for the *Bandoproductus macrospina* zone, even though a number of the genera and family groups are allied to those of preceeding and following faunas. The species *mitis* is not only outstanding for the fauna, but is represented by numerous specimens in the fauna.

***Acanthalosia domina* Zone**

The upper Dresden Limestone (Waterhouse 1987b, p. 204; 2021b p. 208) is occupied by a different fauna with more strongly cold-water fauna, even though the limestone looks similar, and clearly would repay closer and expert inspection. *Azygidium* is replaced by an EAD member *Acanthalosia*, which is numerous and crowds out other species. Other EAD genera include *Notostrophia, Terrakea*, an anidanthid, *Permasyrinx, Ingelarella, Trigonotreta* and

***Magniplicatina undulata* Zone**

Above the Dresden Formation in the southeast Bowen Basin (Holcome & Jell 1983, Waterhouse 1983, 1986b, 2021, p. 209) has a comparatively large number of genera. including *Magniplicatina, Notostrophia, Terrakea*, an anidanthid*, Permasyrinx, Ingelarella, Trigonotreta*and *Pustulospirifer,* and to bring the A/B ratio to 0.4. There are as many non EAD taxa, though fewer in number of specimens, including an overtoniid and *Taeniothaerus*. *Eurydesma* shells are present.

Taeniothaerus subquadratus Zone

The *Taeniothaerus subquadratus* Zone is well represented by the Berriedale Limestone of Tasmania and is also found in the high Tiverton Formation of the north Bowen Basin, upper Elvinia beds of the southeast Bowen Basin, Riverstone Sandstone of the southwest Bowen Basin, Lakes Creek beds near Rockhampton, Queensland (Waterhouse 2021a), and Gondor Formation of southern New Zealand (Waterhouse et al. 1983). The large-shelled aulostegoid brachiopods (see Waterhouse 2024a) are characteristic and they indicate ties with Western Australia rather than tropical faunas. The large and completely monographed fauna from the higher Tiverton Formation may be taken as typical, as summarized in Waterhouse (2015, Table 11, p. 25), and is further discussed in Waterhouse (2021, pp. 213ff).

Notostrophia zealandicus Zone

Unlike several of the preceding zones, the *Notostrophia zealandicus* Zone is of very limited extent, being found only in the upper Brunel Formation of southern New Zealand (Waterhouse 1982a, p. 78; 2021, p. 216), and the zone is separated as marking a warm episode in the climatic regime that developed in New Zealand. But no trace has yet been found in east Australia, and so may have been ephemeral, though the Permian of that region is still far from having been adequately studied.

***Echinalosia preovalis - Ingelarella plica* Zone** of east Australia**, = *Notostrophia homeri* Zone of New Zealand**

This zone (Waterhouse 1983) overlaps with the *Notostrophia homeri* **Zone** of New Zealand (Waterhouse 2021, p. 218).

The brachiopods in the Takitimu Group of New Zealand are typical EAD constituents, and point to links with Western Australia. It thus has cold-water and west Australian links. An exemplar for the *Echinalosia preovalis- Ingelarella plica* Zone is provided by the macrofauna at the top of the Tiverton Formation in the north Bowen Basin, and similar macrofauna is developed in the Sirius Shale and upper Cattle Creek Shale in the southwest Bowen Basin, and Roses Pride Formation in the southeast Bowen Basin, where *Eurydesma* is also prominent.

Martiniid *adentata* Zone

This zone is limited to the Chimney Peaks Formation of the Takitimu Range in New Zealand and the brachiopod genera are only four in number and limited to the martiniid, aulostegid, *Psilocamara* and *Spinomartinia*, not EAD genera. So that the A/B ratio is very high, to suggest a strong warming event.

Capillaria conata Zone

The *Capillaria conata* Zone (Waterhouse 1982, pp. 83, 84) is also limited to New Zealand, found in the McLean Peaks and Heartbreak Formations of New Zealand, and the fauna again points to warm conditions, with four or five genera involving an aulostegid, *Taeniothaerus, Martinia, Attenuocurvus* and *Grebneffia* (but see Waterhouse 2026, p.136) marking taxa exceptional for the region, and only three of more east Australian affiliations, *Capillaria, Aperispirifer and Notospirifer,* resulting in an A/B ratio as high as 1.3 or 1.6. There is no marine equivalent in east Australia.

The fauna is regarded as being of lower Artinskian, ie Aktastinian age. (top)

THE MIDDLE PERMIAN GUADALUPIAN SERIES AND KUNGURIAN STAGE

Sharp cold changes to faunal make-ups occurred throughout the Middle Permian Series. Depauperate and cold-water Kungurian faunas in east Australia were preceeded in Queensland especially by barren ?freshwater sediments or non-deposition, whereas in the north Sydney Basin correlative beds (Elderslie Formation, Branxton Subgroup) are preceeded by the Greta Coal Measures, which Loughnan (1973, 1975) has shown, contain subtropical soils. This is consistent with the situation in New Zealand, where marine faunas of the *Capillaria conata* Zone in the upper Takitimu Group deemed correlative with the Greta Coal Measures because they occupy the same stratigraphic position between the *Echinalosia preovalis* and equivalent *Glendella dickinsi* Zones and provide evidence for warm conditions.

Glendella dickinsi, Wyndhamia typica and *Echinalosia discinia* Zones

Overall, the Kungurian as well as overlying Roadian to Capitanian Stages, or more precisely for east Australia, given the provisionality over the putative correlations, the *Glendella dickinsi* to *Ingelarella costata* Zones, are judged to represent cool to cold conditions, with some warmer episodes, and several episodes displaying sharply colder conditions. The zones form several

cyclofauns, made up of cold low diversity EAD-dominated faunas followed by higher diversity faunas. Apart from the Filippovian level of the early Kungurian Stage, conditions for biota appear to have been more favourable for marine life than in the earliest Permian, as represented by the *Strophalosiaria concentrica* and *Crassispinosella subcircularis* Zones of Tasmania and Sydney Basin (Waterhouse 2021a), but for the most part were not as favourable as for faunas that accumulated in Sakmarian time, when faunal diversity was distinctly higher for Brachiopoda and Mollusca. One striking difference between the Asselian to Kungurian and the post-Kungurian Roadian to Capitanian is the absence of the bivalve *Eurydesma*, whereas many brachiopods persisted, though with less evolutionary innovation than during Sakmarian times, especially amongst Spiriferida and Terebratulida. But Strophalosioidea and to lesser degree Productidina continued to diversify, especially at a specific and subgeneric level rather than generic category.

The earliest faunas in this bracket, believed to include or be correlative with the *Glendella dickinsi* fauna from the Glendoo marine incursion in the north Bowen Basin, display a few brachiopods all belonging to the EAD family group categories, four from the Glendoo Member, five from the upper Pebbley Beach beds in the south Sydney Basin, and three from the Caravan Formation of New Zealand (Waterhouse 2021a, p. 225; 2026, p. 21). There are no other brachiopod genera: all belong to the group predominant in east Australia. The same pattern is evident in most of the overlying faunas, grouped as the *Wyndhamia typica* Zone (Waterhouse 2026, p. 28), with four EAD groups in the Elderslie Formation of the north Sydney Basin and Freitag Formation of the southwest Bowen Basin, and as many as eight EAD groups from the Snapper Point Formation (south Sydney Basin), none of the faunas with any representatives from beyond east Australia (Waterhouse 2021a, p. 228, 2026, p. 28). The correlative middle Letham fauna of New Zealand is an exception, indicating a position more in keeping with its situation as part of the Brook Street volcanic arc offshore from east Australia, with not only five EAD groups, but *Spiriferella*, member of a family well represented in more temperate climates, such as Western Australia and much of the Arctic. (Waterhouse 2021, p. 229). A third zone based on *Echinalosia discinia* is found in the Letham Formation of New Zealand Brae Formation of the southeast Bowen Basin of Queensland, with further faunas .

	non EAD	EAD	A/B
Glendella dickinsi	0	4	0
Wyndhamia typica	0Snapper Pt	9	0
Echinalosia discinia	7	6	1.1
Echinalosia maxwelli	0	7	0
P*seudostrophalosia blakei*	0	8	0
Acanthalosia deari	0	9	0
Nothalosina glabra	3	13	0.23
clarkei		6	0.16
minima	1	10	0.1
costata e Aust.	2	8	4
costata NZ	0	11	0

See Fig. 4, p. 23

Fig. 5. A and B ratio scores for the Middle Permian zones of east Australia and New Zealand.

Echinalosia maxwelli Zone

The zone is represented in New Zealand, in dark calcareous mudstones of the Letham Burn Member (Waterhouse 1982, Fig. 8; 2026, p. 44), with seven EAD which overlie the upper Letham Formation that faunally matches the Brae Formation in Queensland. The New Zealand faunas contain no genera indicative of non-EAD ie. paleotemperate values.

The age of the zone has been severely misinterpreted by Briggs (1998) and in Shi et al. (2022), as discussed in Waterhouse (2026, pp. 26-27). It is decidedly younger than the Caravan beds.

Pseudostrophalosia blakei Zone

For Wordian faunas, the overlying *Pseudostrophalosia blakei* Zone involves a complex of faunas, distinguished even in the Bowen Basin by some faunas with *Ingelarella* and others with *Johndearia* and *Tumulosulcus* (Waterhouse 2026, p. 44). The dispersed nature of the faunas suggests unfavourable conditions for preservation, perhaps reflecting an increased supply of fine clastic sedimentation, under ameliorating conditions and melting of ice. In the Moonlight Sandstone of the north Bowen Basin (Watehouse & Jell 1983, Tables 7, 8, pp. 242, 243), there

are genera in seven of the common east Australian dominant family groups. The fauna requires further clarification, but contains no members that could be classed as non-EAD.

***Acanthalosia deari* Interval, *Maxwellosia ovalis* Polyzone**

. In the southeast Bowen Basin, the basal Flat Top Formation (Waterhouse 1987b, Table 17, p. 222, 2026, p. 53) contains a fauna dominated by short-lived *Acanthalosia deari* The following *Maxwellosia ovalis* polyzone zone was complex, and appears to indicate a proliferation of short-lived little dispersed variants, subspecies, species and genera amongst Productida and especially Strophalosiidina, as shown in Waterhouse (2026, p. 55ff), probably under the influence of highly changeable but mostly cool to cold climate, and what appears to have been rapid evolutionary change by life now adapted to such conditions. In the beds of the Flat Top Formation above the *Acanthalosia deari* interval, species developed a complex of communities, including faunas that were moderately diversified, to indicate persistent conditions that, although probably no better cool to cold than cool, were stable enough to encourage a flourishing of genera and species well adapted to such conditions (Waterhouse 1987b, Table 18, p. 221). Many bivalves and gastropods are present, so that the fauna is more diverse than that of the underlying zone, but with few genera from far afield, being indicative of local proliferation under stable cool conditions.

From Tasmania, the Malbina E fauna of Clarke (1987) has six EAD, including with *Georginakingia* as well as *Sulciplica* and *Oviformia.* Similar faunas developed at Wairaki Downs in New Zealand. Unit 6 of the Mangarewa Formation with *Ingelarella dissimilis* contains members of only east Australian predominants, together with rare *Lethamia*. Mangarewa unit 7 of New Zealand is only marginally different from the underlying unit, and includes seven EAD brachiopod groups, including *Terrakea solida*, also found in the Mantuan Member and as in the Bowen Basin. A rare additional A-wide genus also found in east Australia, such as *Neochonetes*, Numerous molluscs, especially amongst bivalves, are mostly shared with east Australia. There was an active volcanic chain nearby over which ice could have developed, but that postulation lacks proof, because then-emergent volcanoes have since been eroded away.

***Pseudostrophalosia clarkei* Zone**

Towards the top of the Guadalupian Series, the *Pseudostrophalosia clarkei* Zone marked another sharp stratigraphic and faunal change in the northern Bowen Basin, where the Scottville Member

(former Big Strophalosia Band) includes many large dropped pebbles as well as large clasts (Reid 1929). Towards the top of the Guadalupian Series, the *Pseudostrophalosia clarkei*

Macrofaunal zone	Standard area	Correlative faunas
Ingelarella costata	Mangarewa 8 (WD)	Upper Blenheim, lower Black Alley Shale (n BB) South Marulan NSW) NSW bore (nSB) Flowers F (N)
Johndearia pelicanensis Subzone *Echinalosia* (*Unicusia*) *minima*, *Terrakea elongata planidisca* *Ps. furcalina* Subzone	Upper Blenheim, (nBB)	
Pseudostrophalosia clarkei, - *Terrakea elongata elongata*	Scottville Mbr (nBB)	
Maxwellosia ovalis or *M. ovalis wassi* or *Nothalosiina glabra*		Mantuan Mbr (swBB) lower middle Flat Top F (seBB)., lower Blenheim F (nBB), Mulbring F (nSB). Berry , Broughton F (sSB)
Acanthalosia deari interval	Flat Top (seBB)	
Pseudostrophalosia blakei *Pseudostrophalosia blakei ingelarensis*	Moonlight F (nBB), Peawaddy, (sw BB)	Catherine F lower Ingelara Ss (swBB) Barfield (seBB), ?Muree, ?Belford (nSB) , ?Nowra (sSB), Mangarewa 5 (WD)
Echinalosia maxwelli	Letham Burn Mbr (WD)	Oxtrack F (seBB), Wollong Mbr?, upper Wandrawandian (sSB)
Lethamia hillae – L. ligurritus ---------- *Echinalosia discinia*	top Letham F (WD) Upper Letham F (WD)	Upper Brae F (seBB) Brae F (seBB) u. Wandrawandian (sSB)
Wyndhamia typica	Elderslie F (nSB),	Freitag F (swBB) Snapper Point F (sSB), Middle Letham F (WD)
Wyndhamia yalwalensis interval *Glendella dickinsi Notospirifer gentilis*	*Acanthalosia mcclungi*	Lower Snapper Point F (SB) Upper Pebbley Beach F (sSB), Glendoo Mbr (nBB), Caravan F, lower Letham F (WD)
Upper *Attenuocurvus altilis* beds		---------- Elbow Creek F (WD)

Fig. 6. Climatic attributes of faunal zones from most Midde Permian in east Australia and New Zealand. The *Attenuatella altilis* fauna appears to be a remnant of the warm-water *Capillaria conata* fauna.

Zone marked another sharp stratigraphic and faunal change in the northern Bowen Basin, where the Scottville Member (former Big Strophalosia Band) includes many large dropped pebbles as well as large clasts (Reid 1929). Postulations that the blocks were deposited by upwelling deep sea waters (Jones et al. 2006) seem most unlikely. The faunal diversity is comparatively low, and as a whole, the Scottville fauna was dominated by *Pseudostrophalosia clarkei*, Although Fielding et al. (2008a, Fig. 3; 2008b, Fig. 3) portrayed an ice-sheet limited largely to New South Wales and well south of the northern Bowen Basin, it would appear from the Scottville rocks and faunas that ice either extended far into Queensland, or developed an independent accumulation.

Echinalosia (*Unicusia*) *minima* Zone

Cool to cold climatic conditions persisted into the *Echinalosia* (*Unicusia) minima* Zone of the north Bowen Basin (Waterhouse 2022, p. 125ff; 2026p. 63) with ten EA**D** *Isbellina, Echinalosia (Unicusia), Pseudostrophalosia, Cleiothyridina, Geothomasia, Glendonia, Aperispirifer, Permasyrinx, Sulcicosta, Fletcherithrys* and *Marinurnula***.** and a less usual brachiopod genus in *Cleiothyridina*, as in the underlying *Pseudostrophalosia clarkei* Zone which does make rare appearances throughout the succession, but is provisionally counted as -EAD. leading to a low A/B ratio of 0. A possibility is that the genus became adapted to east Australian conditions during the Middle Permian. An array of bivalves is present.

Ingelarella costata Zone

In the upper Mangarewa Formation of Wairaki Downs, New Zealand, the brachiopods and molluscs of the *Ingelarella costata* Zone have been fully described, including an exceptional *Spiriferellina lacunosa*, and syringothyrid specimens, that need clarification as well as a preponderance of Mollusca, so that the climatic implications are close to those of the Bowen Basin in Queensland (Waterhouse 2026, p. 69). though the syringothyrid interpretation is open to question.

THE UPPER PERMIAN LOPINGIAN SERIES

WUCHIAPINGIAN STAGE

Martiniopsis woodi Zone and *Mytilidesmatella woodi* Zone

Although the Lopingian record for marine faunas in Queensland and New Zealand is incomplete, especially for the Wuchiapingian Stage, available evidence points to predominantly warm climate, with a cool incursion in the late Changhsingian Stage. The bulk of Wuchiapingian marine sediment,

best represented in New Zealand by the Maitai limestones, have a scattering of brachiopods that appeared in warm and cold-water faunas such as *Capillonia*, temperate brachiopods such as *Spiriferella*, and large atomodesmid bivalves, including *Mytilidesmatella woodi* and *M. sivelli* (Waterhouse 2002). The limestones are made up largely of prisms derived from Atomodesmidae, suggesting an abundance of calcium carbonate available for biotic capture and not developed from cold, but from warm conditions, Atomodesmidae being well developed in the warm temperate to subtropical Tethyan faunas of Timor. Most of these rocks in New Zealand remain unassigned to zones.

Only a pair of correlative macro-faunal zones are formally recognized for part of the column, the *Mytilidesmatella woodi* Zone and correlative *Martiniopsis woodi* Zone (Waterhouse 1982, Table 22, p. 96, 2026, p. 91)

CHANGSINGIAN

Echinalosia denmeadi -Tigillumia parallela Zone

The faunas of the overlying *Capillaria denmeadi - Tigillumia parallela* Zone are decidedly cooler in their attributes when compared with the *Martiniopsis woodi* Zone, but are diverse with an abundance of east Australian genera and a few related to genera from further afield, such as *Neilotreta,* found in Western Australia. Some eleven EAD genera and four non-EAD Genera are present in the Kildonan Member of New Zealand (Waterhouse 1976 etc, 2026, p. 92 etc)

***Spinomartinia spinosa and Trabeculatia trabeculum* Zones**

The trend towards markedly higher basic temperatures is evident in New Zealand (Waterhouse 1982, Table 25, p. 102 etc, 2026, p. 78), with only five groups belonging to the east Australian preponderant family groups, 5) and more groups found of non-EAD affinities, including several genera less usually found in east Australia - New Zealand, to pushes the ratio to 018. Even the Gympie values, found mainly in carbonates, are high. **(**5 6 0.8). Landis (1980) had treated the zone as being of unspecified Triassic age, setting aside the fossil evidence and relying on what he claimed was external similarity to Triassic sediments, not particularized in any way, but although championed by H. J. Campbell, with no further evidence, the claim has never been verified.

***Marginalosia planata* Zone**

There followed a sharp drop in diversity and therefore in temperature. The faunas of the *Marginalosia planata* Zone in east Nelson of New Zealand (Waterhouse 2026, p. 81 ff) are low in

Macrofaunal zone	Number of non-EAD genera A	Number of EAD groups B	Ratio A/B
rostrata	6	1	6
planata	2	8	0.25
spinosa	6	6	1.0
denmeadi	4-6	11-12	0.3-0.5
woodi	4	8	0.5

Fig. 7. Changes in brachiopod diversity for the Lopingian Series. Prime values from New Zealand.

diversity, although sharing *Marginalosia* with Changhsingian faunas of the Himalayas (Waterhouse 1978; Waterhouse & Chen 2007), and possibly high paleolatitude faunas of northeast Russia (Abramova & Grigorieva 1988, Klets 2005). The easterly band of Pig Valley Formation (Waterhouse 2002, p. 136) contains limestone olistostromes, to suggest a rapid fall in sea-level, as figured in Waterhouse (1964, Fig. 38, 39), and a boulder bed 20m thick. 3 6 0.5. H. J. Campbell (2019, 2026) has continued a sustained attack on the nature of the *planata* Zone, without any sustaining evidence. Campbell, Owens & Landis claimed that the limestones were all olistrostomal, ignoring the fact that the type sequence was solid limestone (Waterhouse 1982), and they asserted that Permian fossils were intermixed with Triassic fossils. A further study was promised showing the intermixed fossil localities and fossils. That promise was broken. It has never appeared. May be in the field I have overlooked the Triassic fossils. But I found Triassic fossils in a separate and younger Shaggery Formation (Waterhouse 2002, p.) and yet to find any reason for trusting the Campbell et al. reports that run counter to actual occurrences, figures and any other verifiable data. The prominent locality exposed by the Wairoa River and reported as containing mixed Permian and Triassic fossils by Owen was found to expose only Triassic ammonoids.

Zone	Type section	Occurrence elsewhere
Wairakiella rostrata	*Wairakiella rostrata*	
Marginalosia planata	Pig Valley Limestones (N)	
Spinomartinia spinosa	Trig DD (NO)	upper South Curra, Gigoomgan (G) Glendale (WD), Pine Bush (K), Little Ben Ss (N, E),
Capillaria denmeadi -Tigillumia parallela	Kildonan Mbr (NO), Basal South Curra L,	Gigoomgan L (G) South Curra L. Tramway Mbr (N, E) Pine Bush (K), Glendale (WD)
Megadesmus ponderosum interval		
Martiniopsis woodi Mytilidesmatella woodi	Earnvale Mbr (NO)	Waimahaka L (K) Otaria L. (N))

Fig. 8. Climatic affinities of the Late Permian zones from east Australa and New Zealand. The *Megadesmus ponderosum* interval has no brachiopods and is judged tentatively to be of intermediate climatic affinities, with two normally cold-water bivalve genera (*Megadesmus* and *Pachymyonia*), and a warm-water form.

***Wairakiella rostrata* Zone**

The topmost *Wairakiella rostrata* Zone Waterhouse 1982, Table 28, p. 106; 2026, p. 85), with extensive collections by H. J. Campbell yet to be properly examined, appears likely to be a warm-water fauna, containing as it does the distinctive genus *Wairakiella* also found in a warm-water fauna of the *Martiniopsis woodi* Zone, and *Martiniopsis patella*, member of a genus rare in east Australasia and more common in the warm-water diverse faunas of the Salt Range of Pakistan. The gastropod *Peruvispira* is unusual in its elaborate morphology. There is one EAD member, ?*Pseudodielasma*, originally referred to *Labaia,* and H. J. Campbell (2019, 2026) has treated the Wairaki Breccia as being of " Induan" age, equivalent to Griesbachian of Tozer (1976) which is recognized internationally, Campbell did this on the mistaken assurance of the Triassic age of C. A. Landis for the Little Ben Sandstone, but even apart from the absurd lack of evidence for a Triassic age, there is no warrant, not ever has been evidence for regarding the Wairaki Breccia as being

overlain by Little Ben Sandstone. The Wairaki Breccia lies above, not below, beds with *Marginlosia planata* *(Waterhouse 2002, p. 20), but that has been ignored by Campbell.

COEVAL INTERNATIONAL CHANGES TO CLIMATE

Kungurian Stage and Guadalupian Series

World-wide, a sharp change in macrofaunas occurred at the Filippovian level of the lower Kungurian Stage, as shown by Stepanov (1973). In east Australia this matched the faunally depauperate levels such as the *Glendella dickinsi* Zone of the Bowen Basin, and the upper Pebbley Beach Formation of the south Sydney Basin, with radiometric support for age provided by A. Nutman (*in* Shi et al. 2020, Shi et al. 2022), not to mention the well-dated Kungurian ammonoid *Aricoceras* (Leonova 1998). A series of faunal oscillations characterized the former world stratotypes of Russia, involving the upper Kungurian, Ufimian and Kazanian levels, recorded by faunas much less diverse than those of the early and middle Cisuralian Series in Russia, with sparse if any conodonts, no fusulines, and rare ammonoids (Licharew 1966). In Arctic Canada, drop-stones appeared in the succession, and the Arctic faunas strongly indicate that conditions were cooler than those which had prevailed during Sakmarian and much of Artinskian time (Waterhouse 2018, 2020). Of course, this is not to discount geographic shifts under plate tectonics and continental displacement, yet another complicating factor in the changing regimes of climate. East Australian genera such as *Echinalosia, Wyndhamia* and *Terrakea* or closely allied, perhaps derived forms, were introduced into the Arctic, testimony to fresh faunal interchange with east Australia (Waterhouse 1967, 1969), and the Arctic faunas are correlated through conodonts with the world standard stratotypes. Even the world stratotype sequences of paleotropical Texas shared generic and family links with east Australia, notably amongst *Terrakea*, *Magniplicatina* and Trigonotretoidea, to strongly suggest the invasion of some Australian cold-water fauna. The ratio depends part on how *Nakimusiiella* is assessed: it may be counted as EAD, or not so the EAD forms number four or five, and the non-EAD forms as cold-water genera, indicative of a world-wide cooling that was most marked in east Australia. During Early Permian times, when glaciation prevailed over much of Gondwana, faunas flourished in the paleotropics, as if life had been squeezed into the warmest of climatic belts, and there was little input from Gondwana. But through time, cold-water marine life had adapted to cold conditions, flourished in the ensuing Sakmarian time, and penetrated shallow-water paleotropical faunas during the Guadalupian Series, notably in the Glass Mountains of Texas.

Lopingian Series

Overall and across the globe, Lopingian faunas indicated high diversity and warm times as far as shallow-water faunas were concerned: obviously deeper water faunas were of cooler disposition. The *Capillaria denmeadi - Tigillumia parallela* Zone in the South Curra Limestone of Gympie and allied beds in New Zealand appear to have been correlative with the Popa Sandstone of northwest Dolpo in west Nepal with its meagre *Pyramus silicius* Zone fauna of Waterhouse (1978) and Zewan D of Kashmir and Ganjaroh Member of the upper Chiddru Formation, Here a Changhsingian age is preferred. In the very late Permian, the *Marginalosia planata* Zone was dominated by genus *Marginalosia,* a genus particularly characteristic of Changhsingian faunas in Nepal (Waterhouse 1978, Waterhouse & Chen 2007) and reported from northeast Siberia (Abramov & Grigorieva 1988), and is deemed to indicate cool and approaching cold-water conditions. The genus is also found in the Pig Valley limestones of New Zealand. The latest known Permian fauna in east Australasia, represented by the *Wairakiella rostrata* Zone in New Zealand, is indicative of warm waters, just as found in the high Changhsingian of Nepal (Waterhouse & Chen in prep.) and late stratotype Changhsingian of China (Xu & Grant 1995).

It does appear that although faunal distributions were complex, under the ever-changing climatic regime which prevailed during the Permian Period, imposed over a longer term and much slower regime of continental displacement and active tectonic change, the sequence of climatic changes so exceptionally displayed in the east Australian stratigraphic and faunal record were mirrored over the globe at large. Certain climatic events, such as the episodes of significant warming during the late Asselian, Baigendzinian and much of the Lopingian, cooling in the early and middle Asselian and much of the Guadalupian, and equable to warm temperatures prevalent in the late Artinskian, and a brief cool episode in the Changhsingian Stage, provide potential anchor points for correlation. In my opinion, these correlations outweigh currently favoured radiometric values posited for some of the stratigraphic levels. Today, climatic change is certainly worldwide and simultaneous but complicated, and so it was during the Permian Period.

CORRELATION POTENTIAL IN DIVERSITY SHIFTS

Comparisons between Sequences in New Zealand and Himalaya

Krassilov (1974, 1975) has long championed the correlation potential in climatic shifts as recorded by flora, and he showed how climatic shifts also were a major driving force in evolution. An example of correlation potential along such lines may be offered from stratigraphic and faunal successions of Late Permian age in New Zealand and Nepal, where there are closely studied successions, though it is beyond the scope of this report to provide a comparable analysis for the Nepal-Himalayan region, given the need for extensive assessments of faunal affinities for that region. General similarities may be suggested. In New Zealand, as already outlined, the *Capillaria denmeadi - Tigillumia parallela* Zone of Changhsingian age bears a moderately diverse fauna with low A/B ratio of 0.6, to suggest a moderately temperate cool episode, allowing for the position of the volcanic arc seaward of mainland Australia, followed by high diversity faunas which are widespread and well-sampled for the *Spinomartina spinosa* Zone. The ratios for these two zones as represented in southeast Queensland are of the same order, though given their more restricted distribution and less favorable preservation in Queensland, it is not surprizing that the ratios are lower than in the New Zealand segment of the volcanic arc, represented by the Brook Street Volcanics. For the younger levels, sampling in New Zealand shows a considerable decline from the *Spinomartinia spinosa* Zone into the *Marginalosia planata* Zone, where the ratio suggests moderately cool rather than cold conditions. It is followed by the *Wairakiella rostrata* Zone, with faunas incompletely described and with a presently known high ratio of 6, indicating warm conditions.

In Nepal, the Popa Sandstone has a meagre fauna, influenced by substrate, and referred to the *Schizodus pinguis* Zone, the nominate species suggested to replace the identical but less widespread *Pyramus silicius* Zone found in northeast and central north Nepal. This zone incorporates the Ganjaroh Member of the Salt Range, Pakistan, and Member D, Zewan Formation of Kashmir (Waagen 1891, Waterhouse 1978, 2004, 2010: Waterhouse & Chen 2006, p. 65). The conodonts from the Ganjaroh Member have been dated as latest Wuchiapingian or basal Changhsingian by Wardlaw & Mei (1999) and Shen, Mei & Wang (2003). The conodont study was handicapped by the lack of familiarity with

New Zealand	Northwest Nepal	North central Nepal
Wairaki Breccia		Marsyangdi F.
Pig Valley F Kyobra M.	?Kuwa M.	?Ngawal M., upper Galte M.,
	Luri M., Nisal M.	Galte M., Kyobra M.
Trig DD M.	Pija M.	Pija M.
Kildonan M.	Popa M.	Popa M.

Fig. 9. Changhsingian correlations between New Zealand and Nepal. M. = Member, F. = Formation.

outcrop and macro-faunal content, and contingent on collections rather than field experience, and so less reliable than the interpretation summarized in Waagen (1891), which was further checked by a field party of J. M. Dickins, N. D. Newell and me some seventy years later. The faunal level is deemed to match the moderately diverse *Capillaria denmeadi - Tigillumia parallela* Zone, to suggest a time of temperate conditions, when various genera were also introduced into east Australasia. Given this correlation, it is clear that the faunal level is better represented at Gympie and in New Zealand than in the Himalayan region, reflecting sedimentary conditions, which in the Salt Range were drawing to a close, and in parts of the Himalayas, were just being invaded by seas in the very Late Permian, continuing into Triassic times. (A model promulgated by some American-based writers which claims that widespread transgression only occurred in Early Triassic time is incorrect for various parts of the world, including the Himalaya and northern Canada).

The diverse *Spinomartinia spinosa* Zone that follows the *Capillaria denmeadi - Tigillumia parallela* Zone in New Zealand and Gympie of southeast Queensland can be matched with the Pija Member and *Lazarevonia arcuata* Zone of Nepal, characterized by a more restricted lithology, yet nonetheless supporting a diversity of genera (Waterhouse 1978, 1983). The Pija beds include various genera typical of the Himalayan region but also saw an influx of Changhsingian chonetids found also in the paleotropical faunas of China, and spiriferinidin genera.

The overlying *Marginalosia planata* Zone in the Pig Valley Formation of New Zealand is dominated by EAD genera, yet includes a few unusual genera, and so is not overwhelmingly indicative of completely cold conditions, although it could be postulated on the other hand that the

temperature tolerance of genera was increasing. The zone was apparently correlative with the *Biplatyconcha grandis* Zone of Nepal, widely represented in a diversity of lithologies in the Nisal, Nambdo and Luri Members of northwest Nepal (Waterhouse 1978) and much of the Galte and Puchenpra Members of north-central Nepal, as well as ties with the lower Qubuerga Formation in south Tibet (Waterhouse & Chen 2007, p. 66). The faunas in Nepal are diverse but nonetheless have implications of a cool temperate climate, with Himalayan species (notably amongst Spiriferellidae) preponderant, and southerly (ie. Australasian) links suggested by such genera as *Echinalosia, Marginalosia, Taeniothaerus, Anidanthus* and *Hoskingia*,

The Kuwa Member of west Nepal has few brachiopods, but is correlated with Ngawal, upper Galte and Kyobra Members in central Nepal, and deemed to belong to the upper part of the *Biplatyconcha grandis* Zone, a diverse and complex zone with several well-defined faunal communities.

At the top of the sequence, the warm-water *Wairakiella rostrata* Zone in the Wairaki Breccia of Wairaki Downs and possibly near Mossburn in Southland, New Zealand, would appear to be correlative with the *Retimarginifera xizangensis* Zone with its diversified faunas in the Marsyangdi Formation at the top of the Permian succession in north central Nepal (Waterhouse & Chen, in prep.). This zone includes several genera found also in the paleotropical waters of south China, notably *Spinomarginifera.* But Marsyangdi layers also contain such mid-latitude genera as *Spiriferella* (Waterhouse 2004), to suggest that there were several short-lived alternating warm-water (*Spinomarginifera, Callispirina*) and cooler water episodes with *Spiriferella* and other Spiriferellinae (Waterhouse 2010, Table 2, p. 281; Waterhouse & Chen in prep.). In Nepal the sedimentary and fossil sequences are much better exposed thanks to the high altitudes and lack of any vegetative cover,in contrast to the Wairaki Breccia in New Zealand.

SUMMARY

To summarize, the imprint of climate on fossil brachiopods and molluscs distributed throughout the marine Permian of eastern Australia, including the volcanic arc that is now preserved in the Gympie region of Queensland and New Zealand, provides a record of temperature changes, both through diversity changes, and the affinities of individual species and genera with allied taxa from other parts of the globe. They demonstrate a succession of glacial advances and retreats, that may be

grouped within a major cold interval, Asselian and a short-lived late Sakmarian interval during the *Echinalosia preovalis* Zone. Cold times and less diversified faunas prevailed during the Kungurian Stage and Guadalupian Series. Severely depauperate faunas characterized as the *Glendella dickinsi* Zone, followed by the *Wyndhamia typica* Zone in the Snapper Point, early Wandrawandrian Formation, Freitag Formation, Grange Mudstone of Tasmania and middle Letham Formation of New Zealand, of Irenian (younger Kungurian) age. The overlying zones of the Guadalupian Series saw a succession of short-lived cold episodes separated by cooler episodes, dominated faunally by east Australian genera and species well adapted to the cold, which was probably not as severe as the Early Permian glacial times, but under conditions rarely as favorable as those which prevailed through most of the Sakmarian Stage and much of the Artinskian, especially Baigendzinian time.

The Late Permian Lopingian Series, known for marine faunas at Gympie, Queensland, as well as New Zealand and New Caledonia, appears to have been predominantly warm, with faunas allied to those of Western Australia and south Asia. But a very Late Permian fauna in the *Marginalosia planata* Zone witnessed a return to cool if not cold conditions, before the last warm interval of latest Permian age, recorded in the *Wairakiella rostrata* Zone.

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