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The Influences of Palaeogeography, Tectonism and Eustasy on Faunal Development in the Jurassic of New Zealand

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RIASSUNTO

Le affinità faunistiche delle successioni a invertebrati marini bentonici nel Giurassico della Nuova Zelanda sono un riflesso dell'apertura e chiusura di corridoi ecologici controllati principalmente dall'interazione di fattori geografici, climatici e oceanografici.

Il progressivo spostamento della Gondwana dalla configurazione polare che occupava durante il Carbonifero ed il Permiano condusse alla scomparsa delle barriere di temperatura e ad una uniformità climatica attraverso tutta la Gondwana orientale. Le caratteristiche faune "maori" del Triassico e del Giurassico inferiore della Nuova Zelanda, a carattere probabilmente freddo o freddo-temperato, cedettero progressivamente il passo alle faune "tetisiane" ad ampio spettro, a carattere subtropicale/caldo-temperato.

movimenti orogenetici diffusi lungo i margini della Tetide facilitarono l'apertura e l'estensione delle vie di migrazione tetisiane. In corrispondenza della Nuova Zelanda la tettonica associata all'orogenesi di Rangitata creò un grande continente ("Proto-Nuova Zelanda"). La presenza di questa estesa massa condientale e la sua espansione verso il Nord ed il Sud offrirono molte nuove possibilità di migrazione egli organismi bentonici.

Sollevamenti e abbassamenti eustatici del livello del mare esercitarono anche una forte influenza sul benthos giurassico della Nuova Zelanda. In certi intervalli le faune mostrano caratteristiche che riflettono le conseguenze ecologiche di fasi di trasgressione marina, cioè: alta diversità delle faune di piattaforma; comparsa di nuovi taxa; K-selezione; spostamento verso la piattaforma di faune non costiere; generale attenuazione del provincialismo; influenze di taxa ad ampia affinità ecologica. In altri intervalli le faune bentoniche mostrano caratteri legati a regressioni marine: bassa diversità, estinzioni, lacune biostratigrafiche, aumento di endemismi. Lo svolgimento di queste fasi trasgressivo-regressive nella sequenza giurassica della Nuova Zelanda ben si correla alle oscillazioni delle curve eustatiche su base mondiale.

Il picco eustativo giurassico del Kimmeridgiano-Titonico, associato ad altri picchi nell'Hettangiano-Sinemuriano, Toarciano, Bajociano e Calloviano, pose le premesse per massicce influenze faunistiche tetisiane, attraverso l'aumento delle vie di migrazione e dell'espansione delle nicchie ecologiche negli ambienti vicini alla costa e di piattaforma.

Le influenze tetisiane legate a queste fasi di innalzamento del livello marino mostravano affinità con le regioni indomalgascia, messicana e quella più meridionale del Sud America, ed inoltre possedevano un forte carattere ad affinità sudeuropea. Alcuni Trigoniacea infine mostrano affinità con l'Asia orientale.

ABSTRACT

The changing affinities of the successions of benthic marine life in the Jurassic of New Zealand are a reflection of the opening and closing of ecological gateways controlled by the interaction of factors relating primarily to geography, climate and oceanography.

The progressive movement of Gondwana away from the pole-centred configuration it occupied during the Carboniferous and Permian led to the disappearance of temperature barriers and an equalising of climate across eastern Gondwana. The distinctive "Maorian" faunas of the New Zealand, Triassic and early Jurassic, of presumed cool or cold-temperate aspect, progressively gave way to wide-ranging "Tethyan" faunas, of sub-tropical/warm-temperate aspect.

Widespread orogenic movements along the Tethyan margins facilitated the opening up and extension of Tethyan migration routes. In the New Zealand region tectonism associated with the Rangitata Orogeny created a large proto-New Zealand continent. The presence of this large landmass, and the associated extensions of land towards both north and south, provided many new opportunities for benthic migration.

Eustatic rises and falls of sea level also exerted a strong influence on the benthic faunas of the New Zealand Jurassic. At intervals faunas display features that reflect the ecological consequences of phases of marine transgression viz: high diversity levels in shelf faunas; appearances of new taxa; presence of K-selected taxa; movement up-shelf of off-shore faunas; overall lessening of provincial differences; influxes of taxa with wide-ranging affinities. At other intervals the benthic faunas show features related to marine regression: low diversity, extinctions, biostratigraphic gaps, increases in endemism. The timing of these transgressive-regressive phases in the New Zealand Jurassic sequence relates well to the highs and lows of sea level curves based on sequences elsewhere in the world

The peaking of Jurassic eustatic sea levels in the Kimmeridgian - Tithonian, with other substantial rises in the Hettangian-Sinemurian, Toarcian, Bajocian and Callovian, helped set the scene for massive influxes of Tethyn faunas, by improving the availability of migration routes and expanding ecological niches in the near-shore and shelf environments. The influxes of Tethyan taxa that occurred at these times of high sea levels had affinities relating to the Indo/Malagasy region, southern South America and Mexico, as well as having a strong overprint of broad southern European affinities. Some Trigoniacea also show East Asian affinities.

KEY WORDS

Jurassic; Palaeogeography, Tectonism; Eustasy; Pangaea; Gondwana; Indo-Pacific; Tethyan; New Zealand; South America; Antarctica; Indonesia; New Caledonia; Papua New Guinea.

INTRODUCTION

The history of the Tethyan seaway, and the manifold influences it has had on faunas, floras, sedimentation, climate and environment, has been a topic of continuing interest since the pioneering studies of Neumayr (1885) and Suess (1893).

This interest in the Tethys and its diverse aspects has received major stimulii over the last two decades through publication of a number of symposia on Tethyan themes (e.g. Adams & Ager 1967; Aubouin et al. 1980; Piccoli & McKenzie et al. 1982-83; Fourcade et al. 1985; Nakazawa & Dickins 1985; McKenzie 1987), as well as comprehensive studies by individuals (e.g. Celal Sengor 1985, 1987). Tethyan geology and palaeontology is also the topic of several IGCP projects (e.g. Branch 1987). In the light of these new studies, and the refinements flowing from them, it is timely to review the New Zealand data on Tethyan relationships and to set them in a global context.

The importance of Tethyan influences in the Mesozoic of the SW Pacific was first highlighted by Marwick (1929, 1952, 1953) and Fleming (1962, 1967, 1970, 1975, 1979). Tethyan as well as trans-Pacific immigration was also documented by Arkell (1953, 1956). All these studies were set in the context of the then prevailing methodological climate of continental stability, and the observed faunal relationships were interpreted as being the result of migrations around the edges of the existing continents.

Acceptance of crustal mobility (continental drift and its successor plate tectonics) opened the way for a reassessment of the faunal data, and for recognition that the Tethyan radiations were a reflection of and an integral part of the changing palaeogeographic relationships of Pangaea. A number of studies of such relationships from a New Zealand perspective have been made, using the powerful new tool of plate tectonics (eg. Stevens 1967, 1971, 1974, 1977, 1980a, b; 1985a; Stevens & Fleming 1978; Stevens & Speden 1978), However, the last few years have seen the advent of a number of refinements and the availability of new data:

(I) A more tightly constrained palaeogeographic reconstruction for Gondwana has become available (eg Lawver & Scotese 1987; Grunow, Dalziel & Kent 1987; Grunow, Kent & Dalziel 1987). However, the influence (if any) on such a reconstruction of factors such as earth expansion, of either moderate (eg Owen 1983a) or substantial major proportions (eg Shields 1983; but see Hallam 1984), and the part played in palaeobiogeography by the rafting of exotic terranes (eg Howell *et al.* 1984; Hallam 1986) remain largely unresolved. Both factors have the potential of having a major influence on Tethyan and in particular New Zealand palaeobiogeography. For example, acceptance of even a moderate amount of earth expansion would substantially close the Pacific and Tethyan gaps in most of the commonly accepted palaeogeographic reconstructions (e.g. Smith, Hurley & Briden 1981), and would considerably shorten biotic dispersal routes (Fig. 1). Acceptance of the proposition that many circum-Pacific continents are largely collages of exotic terranes would call into question the geometric relationships of many elements of "conventional" palaeogeographic reconstructions such as that published by Lawver & Scotese (1987).

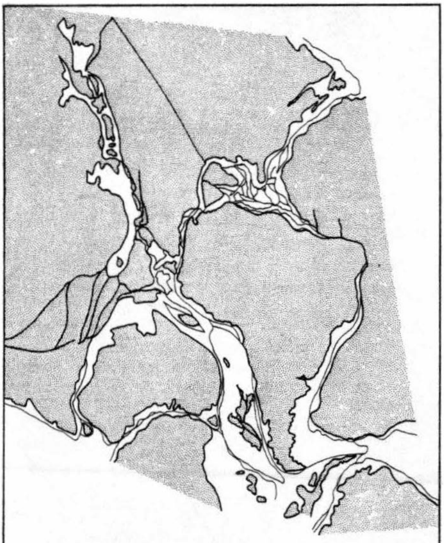

Figure 1 - A reconstruction modified from Shields (1983, fig. 1) of the circum-Pacific region, with the Pacific Ocean completely closed, leaving the landmasses separated by complexes of narrow seaways, basins and troughs. Although this reconstruction represents an extreme situation, it nonetheless demonstrates that an alternative view is possible of the distributional patterns illustrated in Figs 7-18 (see also Poole 1987).

(II) More faunal information has become available in key geographic areas (eg Antarctica: Willey 1972, 1973; Thomson 1983a,b; Mutterlose 1986; Crame 1986, 1987. Indonesia: Stato *et al.* 1978; Westermann *et al.* 1978; Challinor & Skwarko 1982).

(III) Refinements have been made in dating and correlation of the Jurassic (eg Harland *et al.* 1982; Westermann 1984a; Snelling 1985; Haq *et al.* 1987; Bayer 1987). However, subdivision and correlation of the late Jurassic still remains the subject of debate (eg Westermann 1984a). The uncertainity in overseas correlations has served to emphasise the continuing need for an independent New Zealand time scale (e.g. Thomson 1916; Hornibrook 1965, 1971) and the New Zealand data presented in this paper have been plotted with reference to this scale.

(IV) New eustatic information has become available. Publication of a revised version of the Vail/Exxon eustatic curves (Haq *et al.* 1987) has been accompanied by a continuation of the debate about the applications of such curves (eg Miall, 1986; Poag & Ward 1987; Hallam in press). However, full and informed debate has been hampered by the difficulty, and often the impossibility, of directly checking the raw data used as the basis for the curves. In the instance of the Jurassic curve, for example, it is suspected (but not known with any accuracy) that the data have largely been derived from the North Sea and because of local tectonism, may have limited application elsewhere (Miall, 1986; Hallam in press).

INFLUENCES ON NEW ZEALAND JURASSIC MARINE FAUNAS

The marine faunas of the New Zealand Jurassic, like all natural biotic systems, have been influenced by the interplay of a complex mix of palaeoenvironmental factors. Although not necessarily an all-inclusive list, the major factors may be grouped as follows: (a) palaeogeography, (b) climate, (c) tectonism, (d) sea level changes.

As the first three factors have been discussed in previous publications (e.g. Fleming 1967, 1975; Stevens & Fleming 1978; Stevens 1980a) they are not treated in detail in this paper. Instead, because of the availability of new and refined data relating to sea level changes discussion in this publication is primarily focused on eustasy and its influences on faunal development in the New Zealand region.

(a) PALAEOGEOGRAPHY

In the Jurassic the Greater New Zealand landmass formed by the Rangitata Orogeny (see below) was an integral part of eastern Gondwana. Routes around the margins of Gondwana were available to facilitate faunal interchange (Stevens 1980a, 1985a).

(b) CLIMATE

Progressive rotation of Gondwana throughout late

Paleozoic and early Mesozoic times had rotated eastern Gondwana into mid-latitudes in Jurassic times (Grunow, Kent & Dalziel 1987). Climatic differences had therefore been largely smoothed out and climate was reasonably uniform over large areas of eastern Gondwana. (Stevens 1980a, 1985a).

(c) TECTONISM

The Jurassic period spanned the onset of the Rangitata Orogeny. Although some orogenic movements occurred in the middle Jurassic, and these have been interpreted as precursory to the main Rangitata Orogeny (eg Fleming 1967, p. 420; 1970, p. 148), there is a difference of opinion as to their importance (eg Suggate *et al.* 1978, p. 319; Spörli 1987, p. 121). Nonetheless, it is generally agreed that the main Rangitata orogenic movements commenced in the late Jurassic and extended into the early Cretaceous (Bradshaw *et al.* 1981; Spörli 1987; Norris & Craw 1987). As a result of these movements a large landmass was created in the New Zealand region - a Greater New Zealand - half the size of the modern Australian continent. Creation of this Greater New Zealand landmass provided fresh opportunities for the migration of shelf faunas around its shoreline. Also, it is probable that orogenic movements occurring in areas to the north (New Caledonia, Papua New Guinea and Indonesia: Paris 1981; Skwarko *et al.* 1983; Audley-Charles, 1978) and to the south (Antarctica, South America; Thomson 1983; Riccardi 1983), with timings comparable to those occurring in New Zealand, had the overall effect of extending migrational links in these directions, so facilitating the wide dispersal of shelf marine faunas ("Tethyan" faunas) in a broad arc extending around the periphery of eastern Gondwana (see Fleming 1967,1975; Stevens 1980a, 1985a).

(d) EUSTASY

Although details of the Exxon/Vail eustatic curves have been the subject of considerable discussion, notably by Hallam (in press), nonetheless a consensus has emerged about the general trend of sea levels throughout the Jurassic: important sea level rises occur in the late Hettangian, early Sinemurian, Toarcian, Bajocian, Callovian and Kimmeridgian-early Tithonian. Regardless of the exact details of the sea level curve, it is apparent from the data presented in the following section of this paper that the New Zealand Jurassic marine faunas have been exposed to the effects of global cycles of regression and transgression.

The biological effects of transgressions and regressions have been reviewed by a number of authors (eg Jablonski 1980; Hallam 1975, 1977, 1978, 1987). However, it is of particular relevance in the New Zealand context to note that transgressive-regressive effects can operate on various scales, ranging from local to global. At one extreme, local tectonic activity may produce regional cycles of falling and rising sea level. At the other extreme, eustatic effects can be distinguished that are of such magnitude that they are largely independent of local tectonism. In between these two extremes are various combinations of circumstances that locally may impose complexities and considerably modify the global eustatic patterns: largely nullifying or accentuating the effects of rises and falls in global sea levels.

The possibility of local tectonic movements imposing modification on global eustatic patterns is of great relevance to the New Zealand situation in the Jurassic, when like today (e.g. Walcott 1987) the areas of sedimentary deposition were at or very close to an active continental margin (Kamp 1980, 1986; Spörli 1987; Korsch & Wellman 1988). Nonetheless, judging from the close correlation between New Zealand faunal data and global eustatic curves, the role of tectonism appears to have been mainly restricted to a pulse of uplift in the middle Jurassic (Fleming 1967, 1970) and the onset of the main movements of the Rangitata Orogeny in the latest Jurassic (Suggate *et al.* 1978, pp. 318-333).

Regardless of whether the transgression originates from local (tectonic) or global (eustatic) causes, a phase of actively rising sea level will have the following biological consequences (modified from Fortey 1984; see also Brenchley, 1984):

1. In cratonic areas widespread flooding will produce vast epicontinental seas. The great expansion of environmental niches in such seas will induce high speciation rates.

2. In areas of continental shelf, a transgressive phase will tend to lift off-shelf Faunas and bring in open oceanic faunas onto the shelf. Simultaneously, there will be a landward advance of shelf biofacies so that inner shelf faunas give way to those of the outer shelf, and if transgression is very rapid, there may be extinctions of some inner shelf faunas, as they will be unable to adapt sufficiently quickly to the rising sea level.

3. Because off-shelf and open ocean faunas are more independent of continental shorelines, times of transgression may *appear* as times of a lessening of provincial faunal distinctions.

4. As the rising sea level progressively immerses offshore "highs", there will be a marked reduction in the

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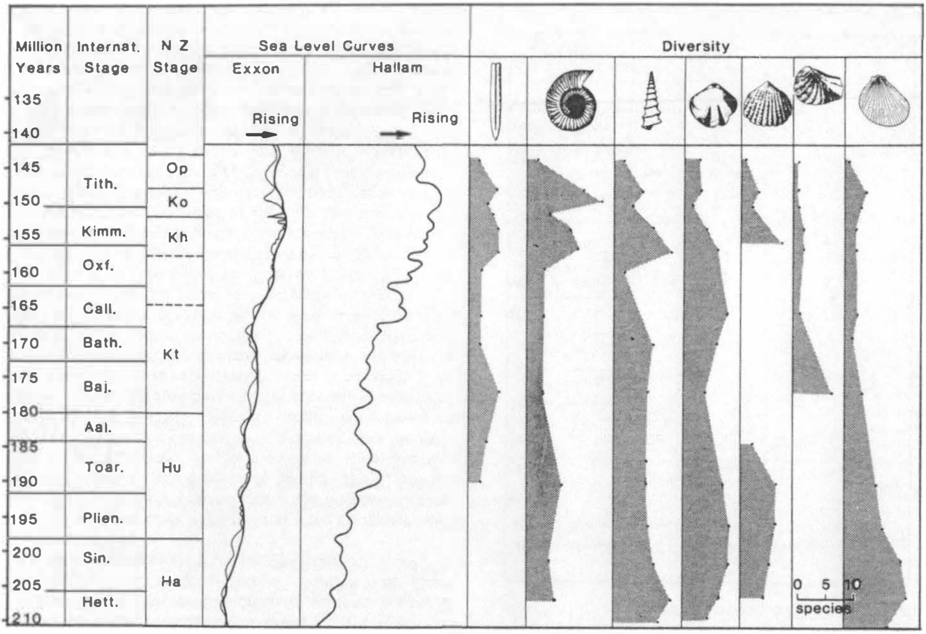
Figures 2 - 5 - Diagrams illustrating faunal diversity (Fig. 2), numbers of taxa making their first appearance (Fig. 3) and last appearances (Fig. 4) in the New Zealand Jurassic column, and faunal turnover (Fig. 5). The graphs are based on the following taxonomic revisions: Fleming (1987, Trigoniacea), Braithwaite (1984, Limidae), Stevens (1965, Belemnitida), Challinor (1968, 1970, 1974, 1977a, b, 1979a, b, 1980, Belemnitida), Stevens (in prep. Ammonoidea), Mac Farlan (1985, Rhynchonellacea) and on palaeontological records held on file at NZ Geological Survey. Reading from left to right, the individual columns present data from: (1) Belemnitida, (2) Ammonoidea, (3) Gastropoda, (4) Brachiopoda: Rhynchonellacea, (5) Brachiopoda: Inarticulata, Spiriferacea, Terebratulacea (6) Bivalvia: Trigoniacea (7) Bivalvia: Limidae. The plotting of the data in the graphs is in terms of the New Zealand Jurassic stage sequence (see Stevens 1980c), the symbols for which are shown in the column headed "N.Z. Stage" (Op = Puaroan; Ko = Ohauan; Kh = Heterian; Kt = Temaikan; Hu = Ururoan; Ha = Aratauran).

The New Zealand stages have been correlated with the "international" stages and with an absolute time scale but such correlations are tentative (see Stevens 1978; Stevens & Speden 1978; Hudson *et al.* 1987).

The relationship of the international stages to the absolute time scale is based on Westermann (1984a), with modifications from Bayer (1987).

The sea level curves plotted in the middle part of each diagram are based on Haq *et al.* (1987) for the "Exxon" curve and Hallam (in press) for the "Hallam" curve.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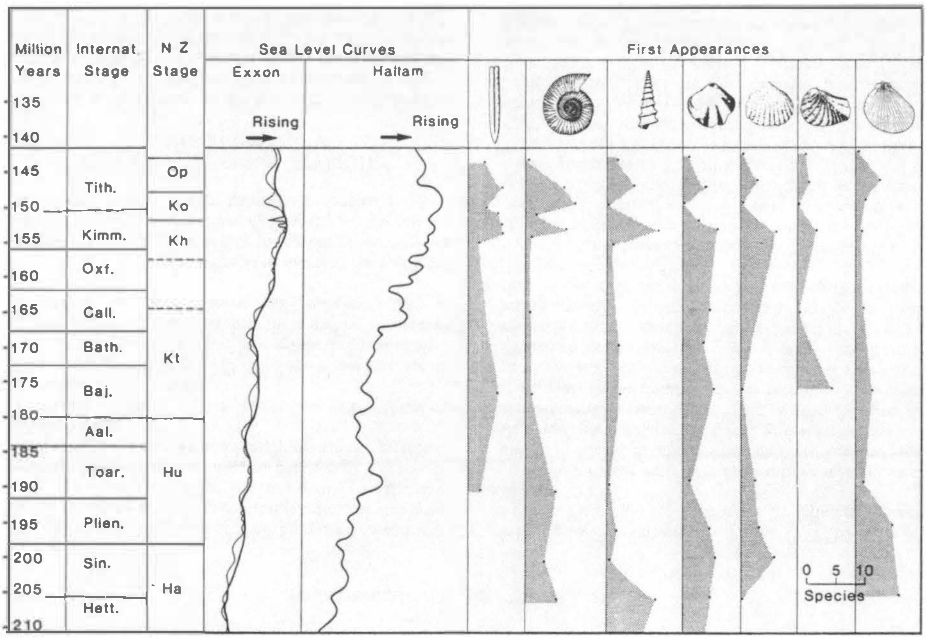
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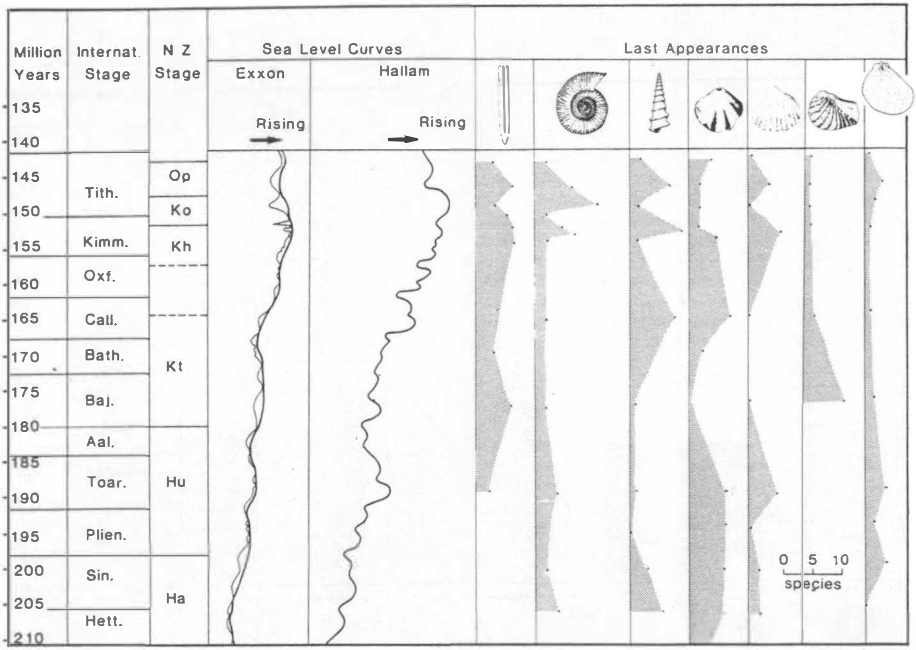
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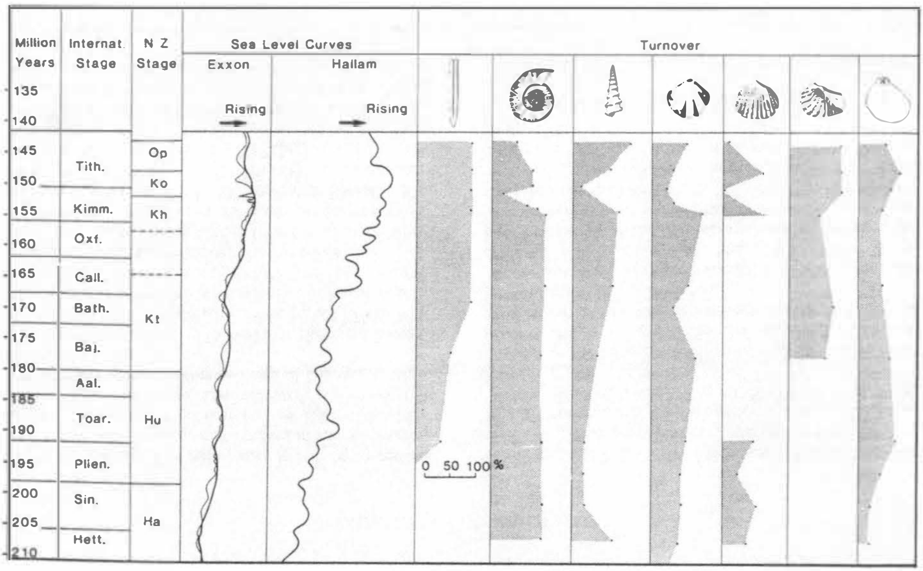
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possibilities for dispersal of shelf faunas via island hopping. But along active continental margins (as was probably the situation of New Zealand in the Jurassic; e.g. Kamp 1980, 1986), the on-going creation of volcanic island arcs may overtake and largely negate the effects of transgression.

During a regressive phase the following biological effects are likely to occur:

1. Stratigraphic gaps will develop in cratonic areas.
2. In shelf areas there will be a seaward retreat of shelf biofacies, and in some extremes there will be widespread deposition of supra-or infra-tidal sediments, poor in fossils.
3. Falling sea levels will tend to increase the incidence of island faunas, by increasing the extent of surrounding productive shelf, and by bringing formerly submerged volcanic islands into shallow sub-littoral depths.

CHANGES IN FAUNAL DIVERSITY AND TURNOVER

To obtain a measure of the extent of faunal radiation and extinction in response to environmental change in the Jurassic of New Zealand, diversity and turnover analyses have been undertaken in a number of invertebrate groups (Figs 2-5). These analyses have been based only on those groups for which modern taxonomy is available. The New Zealand faunas are notably less diverse numerically (Fig. 2) than those of Europe, for example (cf. Hallam 1987). This lowered diversity is probably a result of New Zealand's marginal-Tethyan situation in the Jurassic, equivalent to modern temperate climes (Stevens 1971, 1980a, 1985b).

The analyses have been plotted with a primary relationship to the New Zealand time scale. Because of correlation uncertainties (Stevens & Speden 1978), linkage with "International" stages is tentative. The diversity graphs consist of plots of the numbers of taxa for each stratigraphic interval. Separate plots have also been provided for the numbers of first and last appearances of taxa occurring in each stratigraphic interval (Figs 3, 4).

A turnover rate for the taxa involved in the analyses has been derived by averaging the number of first and last appearances, dividing by the total number of taxa, and expressing the result as a percentage (Fig. 5).

In terms of the criteria proposed by Fortey (1984) for recognition of the biological effects of transgression and regression, and summarised in the preceding section, the faunal analyses presented in Figs 2-5 indicate that the New Zealand Jurassic sequence has been responsive to the environmental effects of rising and falling sea levels.

Biological changes in the New Zealand Jurassic that may, in terms of Fortey's criteria, be related to rising sea levels include: high diversity, increases in speciation rates; influxes of off-shelf and open oceanic faunas (e.g. Phylloceratinae and Lytocerarinae: Tanabe 1983; Stevens 1985b); occurrence of K-selected taxa (eg Stevens 1985b); influxes of taxa with wide-ranging affinities (e.g. Cosmopolitan, Tethyan, Indo-Pacific etc; see following section).

Biological changes that may be related to falling sea levels include: low diversity, extinctions, biostratigraphic gaps and/or general paucity of shelf biofacies (associated with sedimentological evidence for regression; see Kear in Suggate, Stevens and Te Punga 1978, pp. 228-240; Kear & Fleming 1976); increases in endemism (Grant-Mackie 1985).

While tectonic activity may also have influenced the observed biological changes in the New Zealand Jurassic, the degree of correlation with global eustatic sea level movements, especially in the late Jurassic, indicates that in general eustasy dominated over tectonism. The effects of tectonism appear to be confined to local uplift in the Temaikan, followed by the onset of regional uplift in the upper Puaroan, resulting in termination of marine sedimentation, and interpreted as signalling the beginning of the main movements of the Rangitata Orogeny (Suggate, *et al.* 1978, pp. 318-320).

Comparable correlations between biotic patterns and environmental changes related to eustatic sea levels have been documented from the Jurassic of France (Gabilly *et al.* 1985), the Umbro-Marchean Apennines of central Italy (Mariotti *et al.* 1979; Farinacci *et al.* 1981) and the Trentino region of northern Italy (Sarti 1985, 1986).

A notable and consistent feature of the analyses presented in Figs 2-5 is the occurrence of a twin 'peak' in the late Jurassic of the New Zealand succession. The first peak occurs in the middle Heterian Stage, in beds equivalent to the Captain King's Shellbed, Ohineruru Formation and Waikutakuta Siltstone of the Kawhia Harbour succession (Fleming & Kear 1960) and the second peak in the lower Puaroan Stage, in beds equivalent to the Puti Siltstone at Kawhia Harbour. The two peaks are separated by a very marked trough, in the lower and mid-

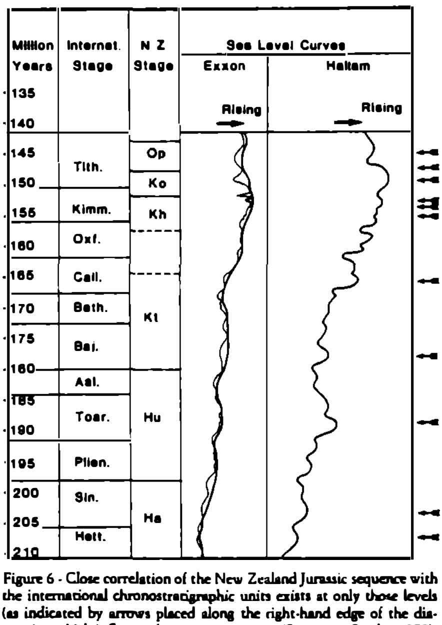


Figure 6 - Close correlation of the New Zealand Jurassic sequence with the international chronostratigraphic units exists at only those levels (as indicated by arrows placed along the right-hand edge of the diagram) at which influxes of overseas taxa occur (Stevens & Speden 1978). As shown in this diagram, these influxes (depicted by the arrows) show a positive correlation with global transgressive highs, as documented by Haq *et al.* (1987) and Hallam (in press).

dle Ohauan Stage. The twin peaks appear to correspond with major global transgressive pulses in the Kimmeridgian and Tithonian, as documented by Haq *et al.* (1987) and by Hallam (in press), and indicate a positive correlation between transgression and faunal change, as noted above.

If correlation of the twin peaks of the New Zealand late Jurassic with the global eustatic pulses of the Kimmeridgian and Tithonian is sustained, this linkage can be used (as noted by Hoedemaeker 1987) to provide an independent connexion between the New Zealand and International stages in the Upper Jurassic - a topic which has been the subject of differences of opinion (Enay 1972a, b, 1973; Stevens 1978; Stevens & Speden 1978; Verma & Westermann 1973; Jeletzky in Westermann 1984b, p. 188, 189; Helby *et al.* 1988) (Fig. 6). The linkages based on eustasy may be interpreted as supporting correlation of the middle Heterian with the Kimmeridgian and the lower Puaroan with the lower Tithonian stage (both stages used in the central and southern European sense; eg Sarti 1985, 1986; Michelsen, 1987, p. 5). Other peaks of faunal change occur lower in the New Zealand Jurassic column, but they are generally less marked than those in the late Jurassic (Fig. 6). Nonetheless, as in the late Jurassic, there appears to be a correlation between changes in the New Zealand faunal succession and transgressive highs in the Callovian, Bajocian, Toarcian, Sinemurian and Hettangian as documented by Haq *et al.* (1987) and Hallam (in press).

It is not clear whether the decline in the magnitude of faunal change in the early and middle Jurassic (compared with that of the late Jurassic) is a reflection of the lesser magnitude of such transgressive peaks, compared with those of the late Jurassic, or is due to a lack of data, or whether the effects of global eustasy have been diminished by local tectonism associated with the Rangitata Orogeny.

TETHYAN INFLUENCES

The transgressive peaks in the Tithonian, Kimmeridg-

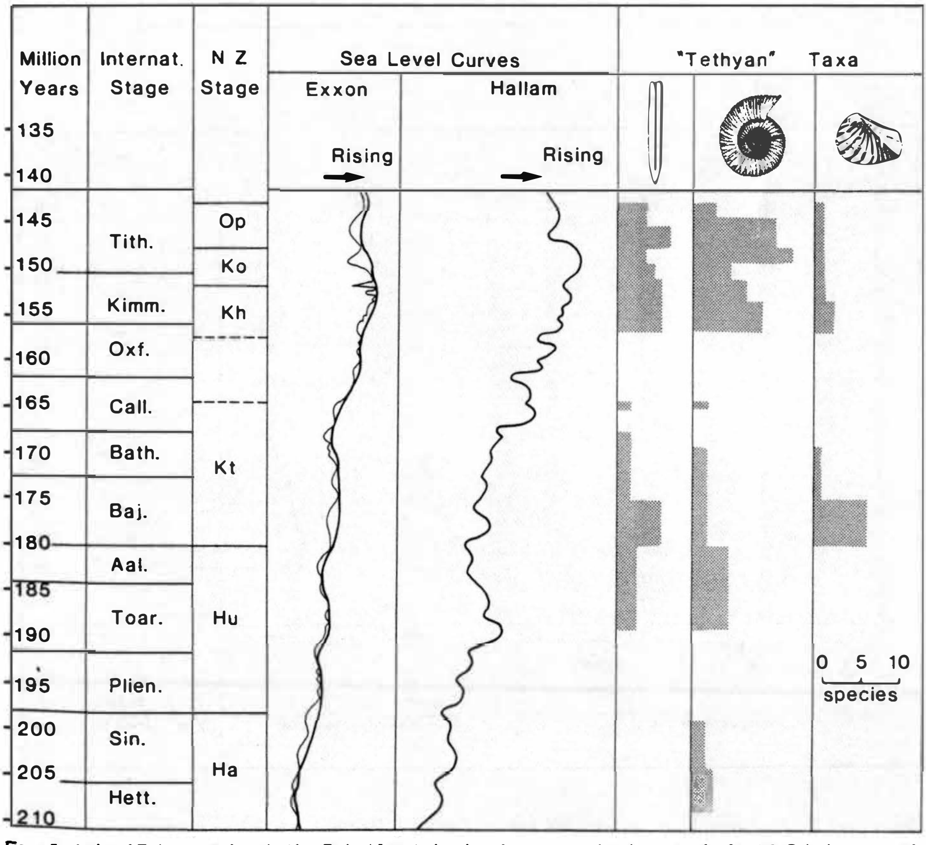


Figure 7 - A plot of Tethyan arrivals in the New Zealand Jurassic, based on the sources cited in the caption for Figs 2-5. Only those taxa with clearly defined Tethyan affinities (in the sense of Fleming 1975; Stevens 1980) have been included.

ian, Callovian, Bajocian, Toarcian, early Sinemurian and late Hettangians coincide with major influxes of overseas immigrants, notably from the Tethyan region (Fig. 7), and it is suggested that these immigration waves are primarily related to transgressions in the manner proposed by Fortey (1984), and summarised earlier in this paper.

The affinities of immigrant taxa that came to New Zealand in middle and late Jurassic times are illustrated for some representative examples in Figs 8-18. A summary of the range of these affinities is provided in Fig. 19, from which it may be seen that much of the faunal immigration was via routes around the margins of the Tethys. However, notable exceptions are the East Asian affinities shown by some Trigoniacea (Fleming 1964, 1987), presumably related to immigration across the width of the Tethys (cf. Celal Sengor & Hsu 1984).

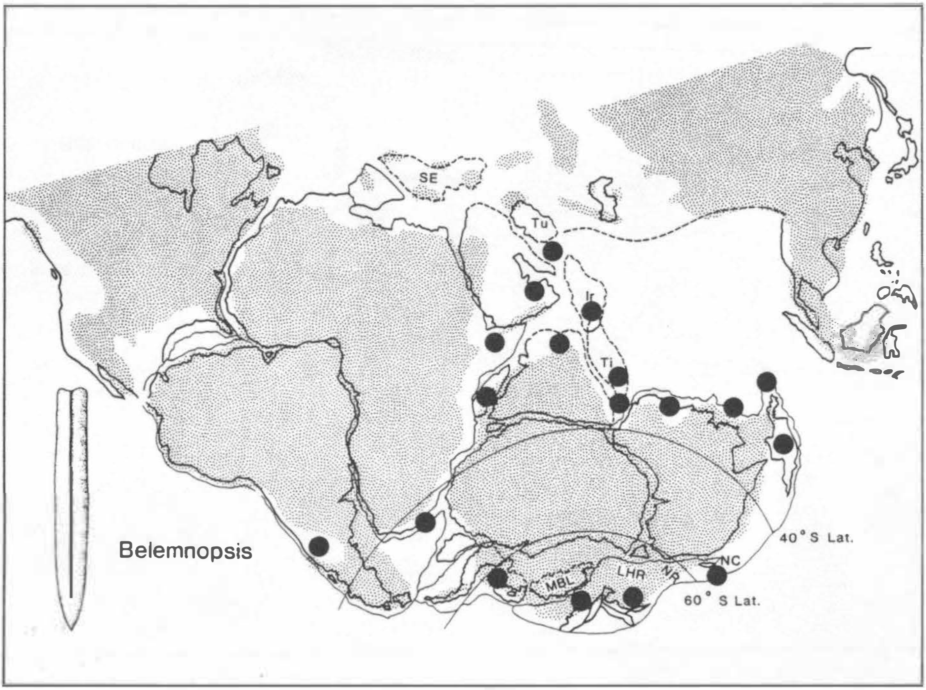
Nonetheless, if different reconstructions are used, for example, those of Owen (1976, 1983a, b), or more particularly Shieds (1983), the Tethys is dramatically reduced in width (Fig. 1), or reduced to narrow seaways (as proposed by Waterhouse 1987), considerably condensing and simplifying the immigration routes depicted in Fig. 19.

CONCLUSIONS

Although the faunal successions of the New Zealand Jurassic have been influenced by changes in palaeogeography, climate and tectonic activity, an even more pervasive influence has probably been exerted by eustasy.

The geographic, climatic and tectonic changes that occurred had the effect of facilitating faunal migration, by extending and expanding immigration routes and by equalising climatic differences. However, judging from the close correlation between faunal data and global sea level curves, particularly in the late Jurassic, eustasy has had an important role in faunal development.

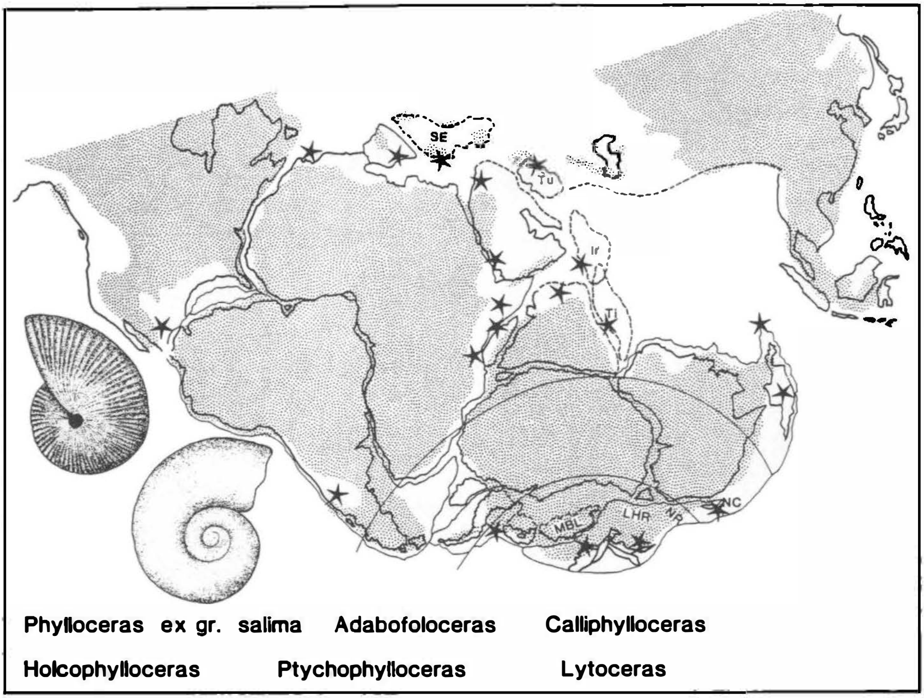
Biological indicators for marine transgression that are present in the New Zealand Jurassic faunal data include high faunal diversity, appearances of new taxa, and influxes of taxa with wide-ranging affinities. Indicators for regression include low faunal diversity, extinctions, biostratigraphic gaps and endemism. Judging from these bi-

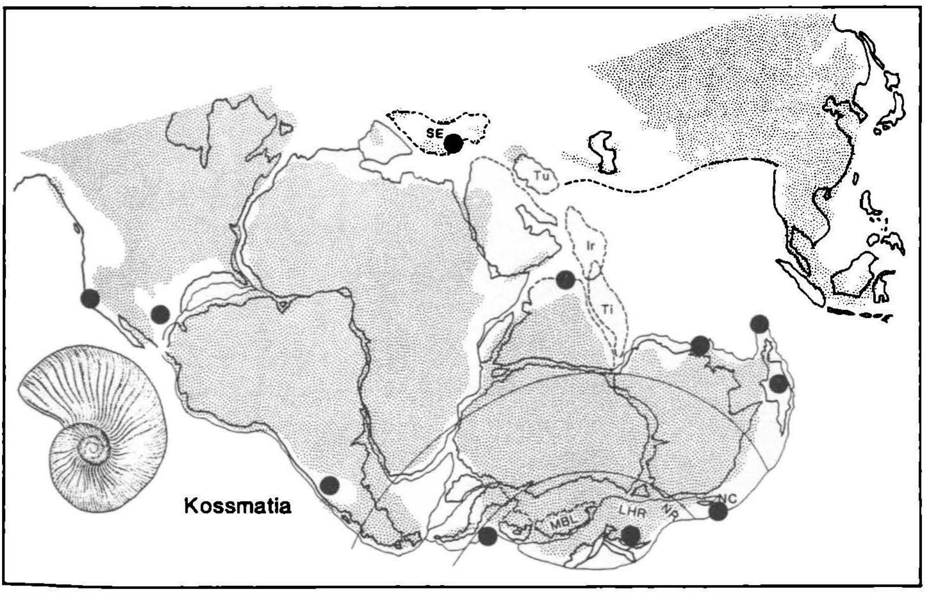


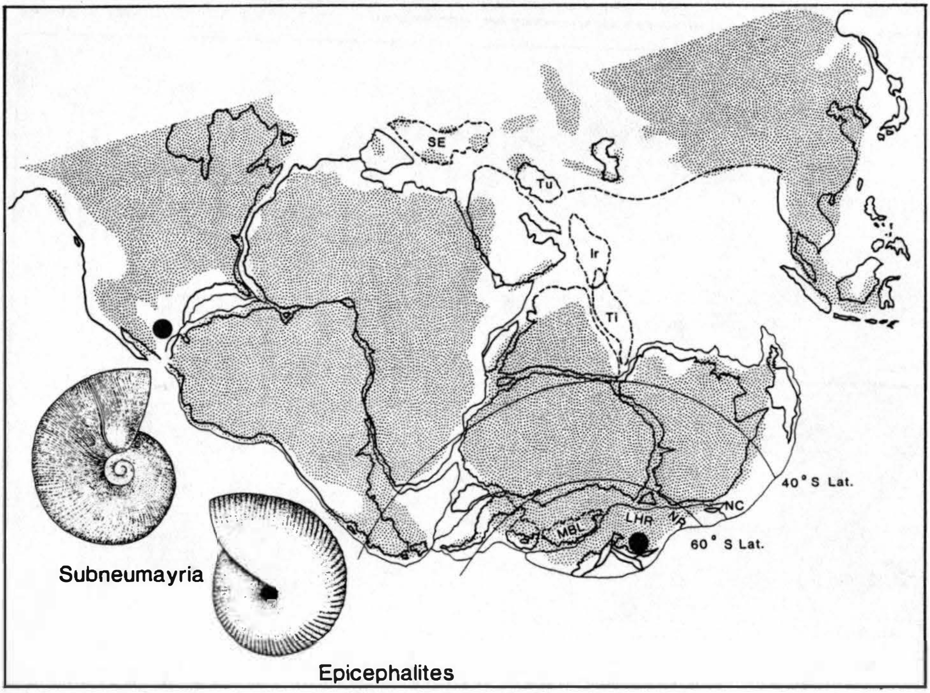
Figures 8-18 - Diagrammatic summaries of the affinities of representative New Zealand taxa of middle and late Jurassic age (named in the diagrams), the affinities of which are well defined on the basis of recent taxonomic revisions (cited in the caption to Figs 2-5). The affinities summarised in the diagrams relate only to the New Zealand representatives of the named taxa and do not present a complete picture of the entire range of affinities of the taxa elsewhere in the world.

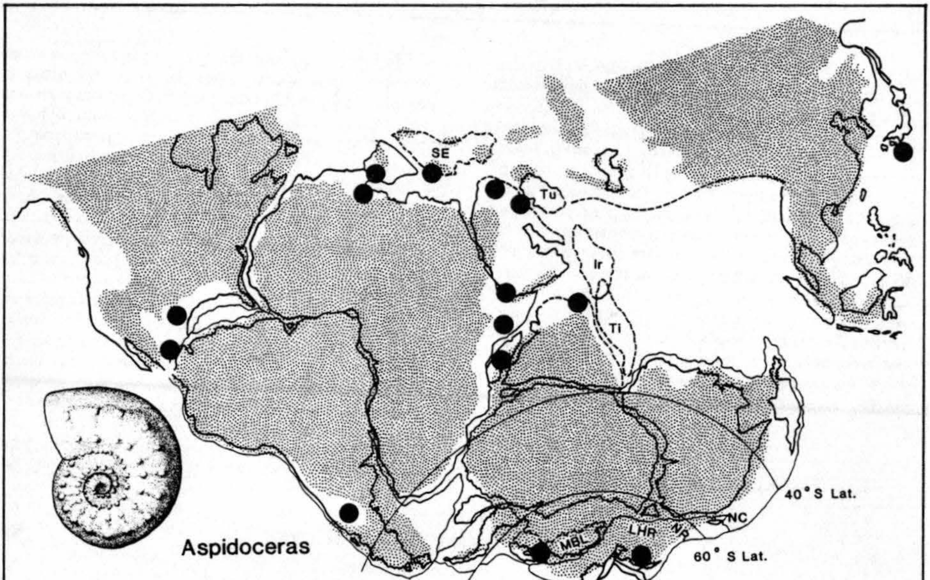
The reconstruction is based on that of Howarth (1981, Fig. 13.9), with modifications from Lawver & Scotese (1987) and Grunow, Dalziel & Kent (1987). The stippled patterns indicate areas presumed to have been land in the middle and late Jurassico.

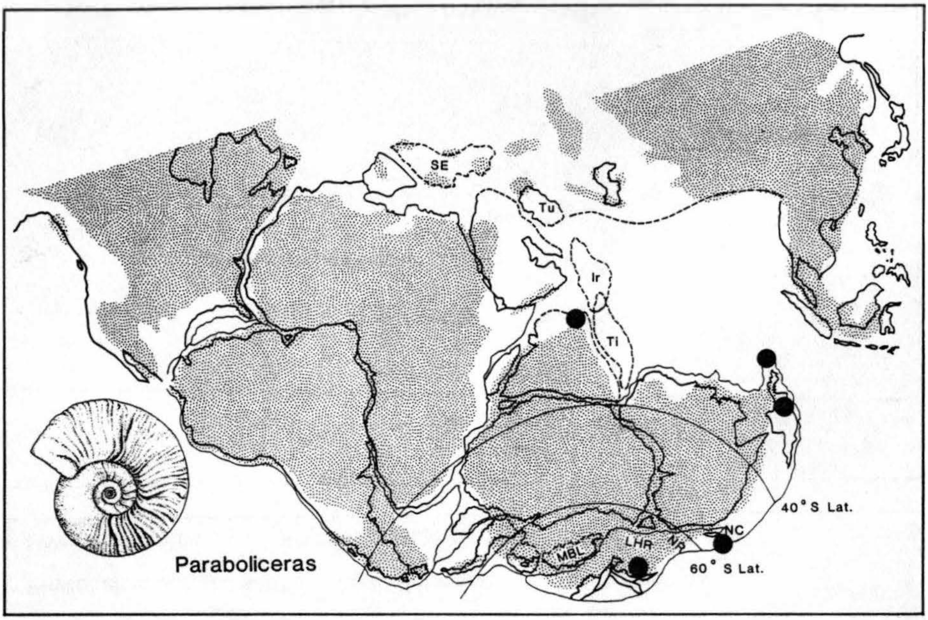
Abbreviations: SE = Southern European block; Tu = Turkish block; Ir = Iranian block; Ti = Tibetan block; MBL = Marie Byrd Land; LHR = Lord Howe Rise; NR = Norfolk Rise; NC = New Caledonia.

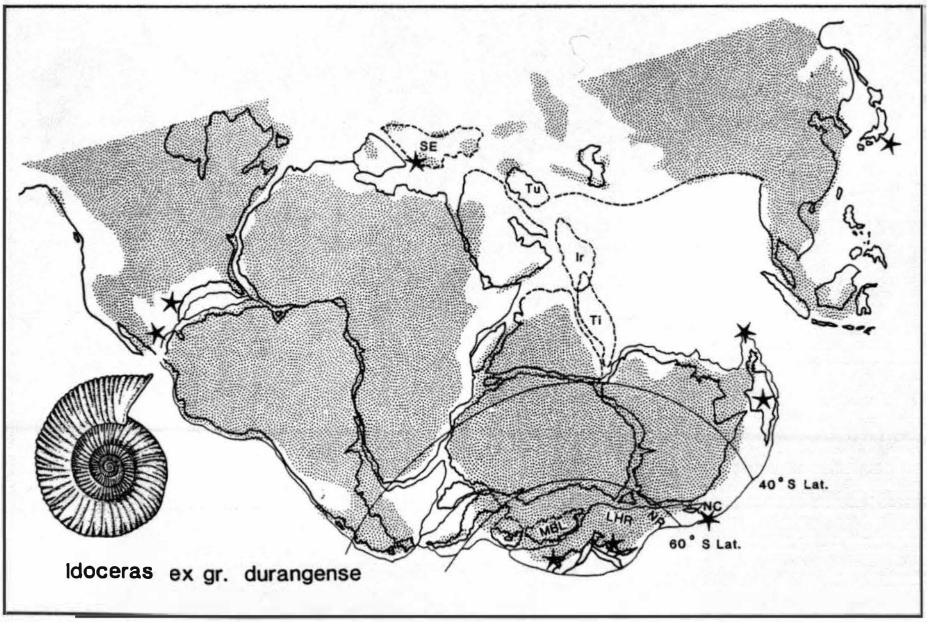

SE
Tu
Ir
Ti
MBL
LHR
NR
NC
Phylloceras ex gr. salima
Adabofoloceras
Calliphylloceras
Holcophylloceras
Ptychophylloceras
Lytoceras

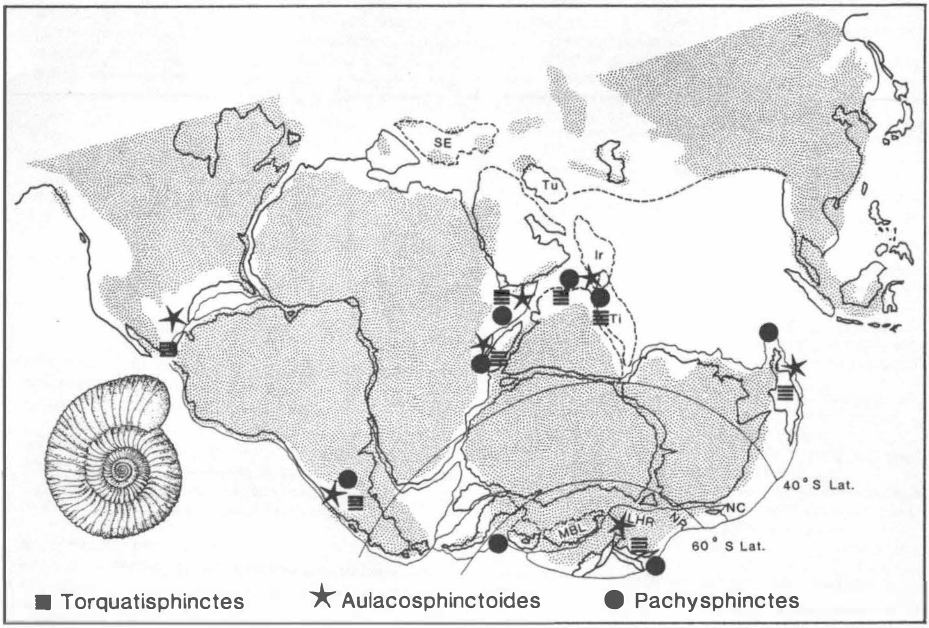

SE
Tu
Ir
Ti
MBL
LHR
NR
NC
Kossmatia

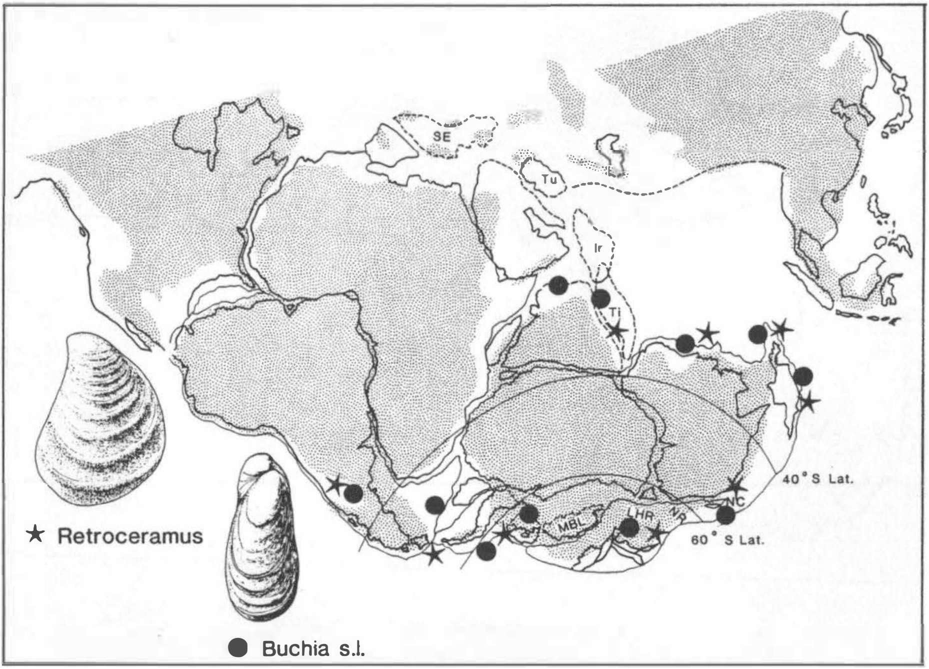

SE
Tu
Ir
Ti
40° S Lat.
NC
NR
LHR
MBL
60° S Lat.
Subneumayria
Epicephalites

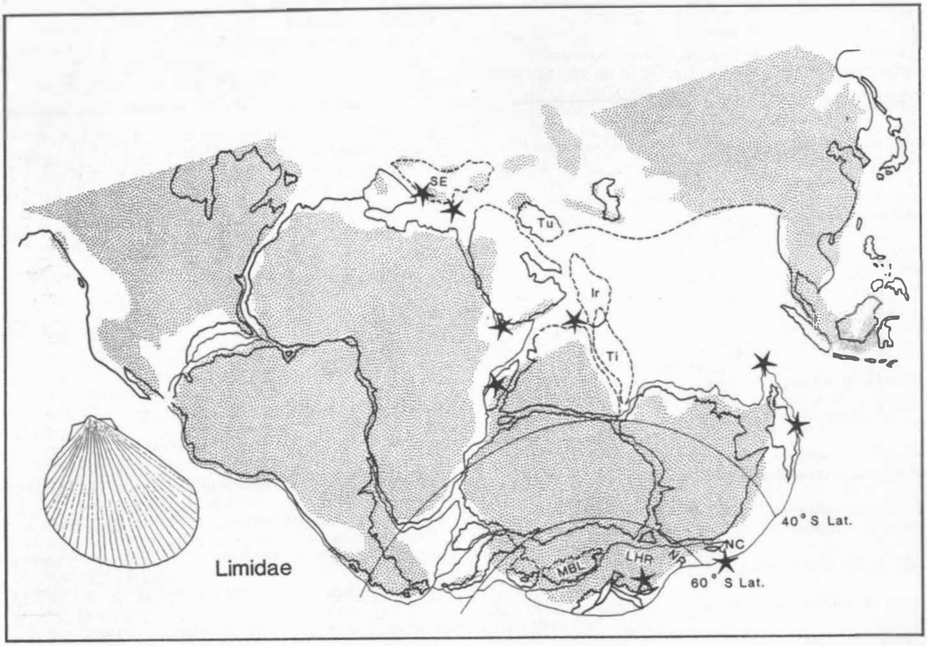

SE
Tu
Ir
Ti
40° S Lat.
NC
NR
LHR
MBL
60° S Lat.
Aspidoceras

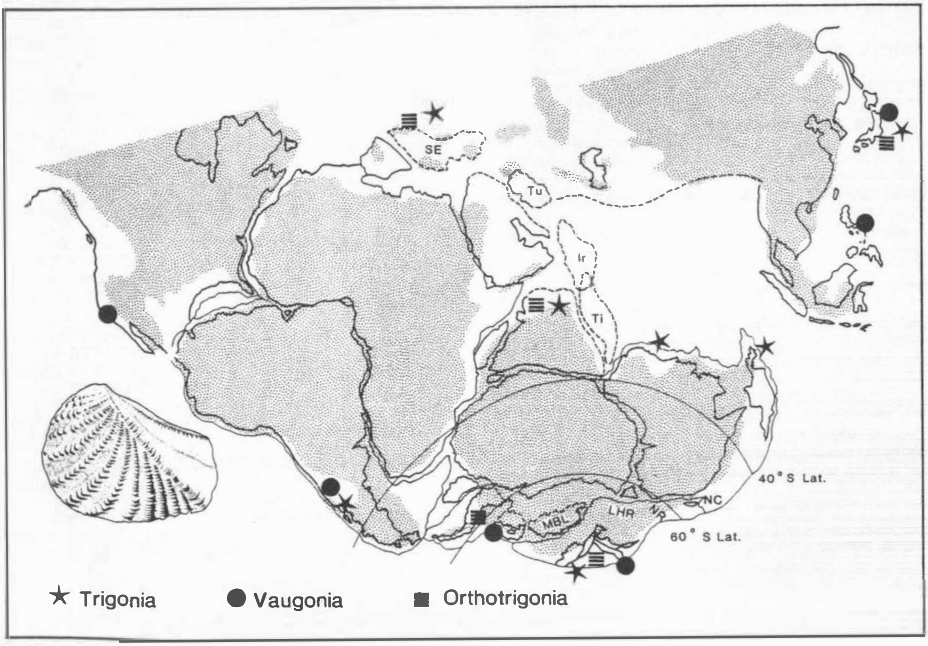

SE
Tu
Ir
Ti
40° S Lat.
NC
LHR
NR
MBL
60° S Lat.
Paraboliceras


SE
Tu
Ir
Ti
40° S Lat.
NC
LHR
NR
MBL
60° S Lat.
Idoceras ex gr. durangense


SE
Tu
Ir
Ti
LHR
NR
MBL
NC
40° S Lat.
60° S Lat.
Torquatisphinctes
Aulacosphinctoides
Pachysphinctes


SE
Tu
Ir
Ti
LHR
NR
MBL
NC
40° S Lat.
60° S Lat.
Retroceramus
Buchia s.l.


SE
Tu
Ir
Ti
40° S Lat.
NC
LHR
NR
MBL
60° S Lat.
Limidae


SE
Tu
Ir
Ti
40° S Lat.
NC
LHR
NR
MBL
60° S Lat.
Trigonia
Vaugonia
Orthotrigonia

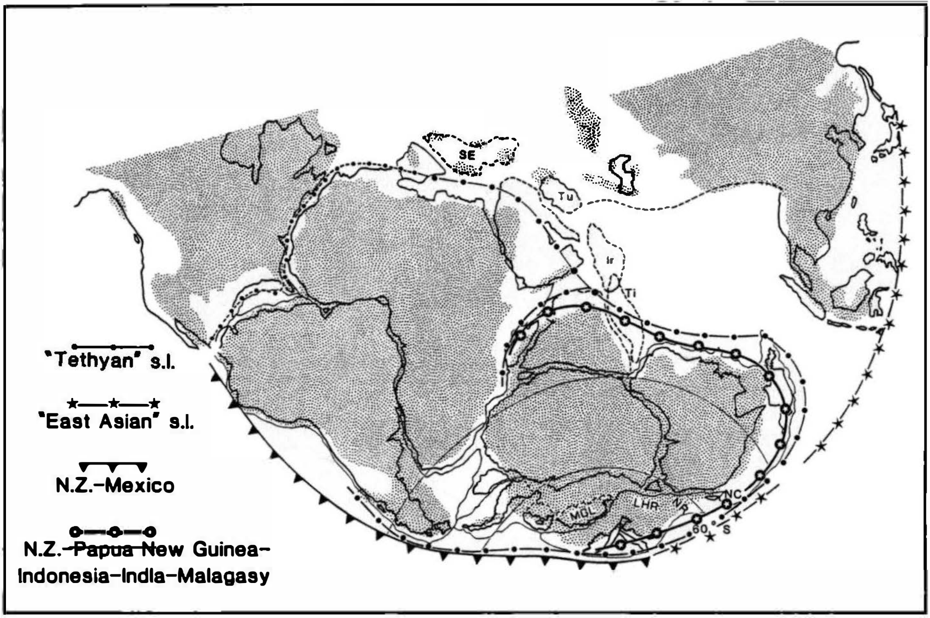


Figure 19 - A summary diagram of the overseas affinities of New Zealand taxa of middle and late Jurassic age, representative examples of which are illustrated in Fig. 8-18.

ological indicators, major transgressive peaks occurred in the middle Heterian and lower Puaroan, corresponding to peaks identified elsewhere in the world in the Kimmeridgian and lower Tithonian. Other smaller transgressive peaks occur at stratigraphic intervals in the New Zealand succession that correspond to peaks identifed elsewhere in the world in the Callovian, Bajocian, Toarcian, early Sinemurian and late Hettangian.

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