PALAEOGEOGRAPHY 42

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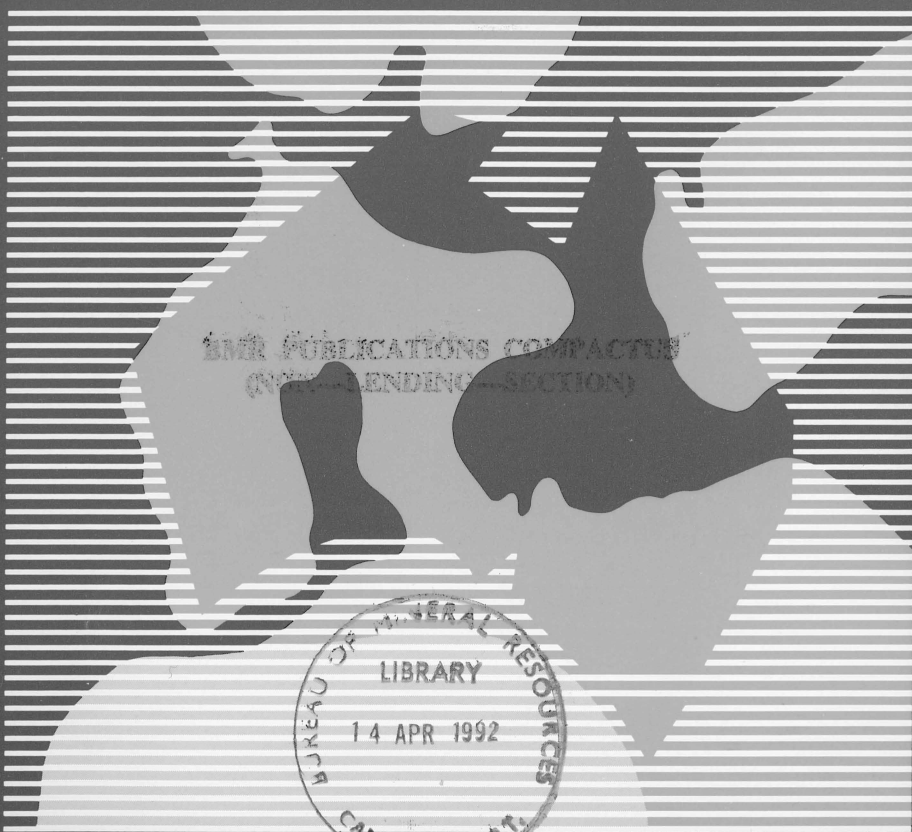
CRETACEOUS-CAINOZOIC PALAEOGEOGRAPHY OF THE NEW ZEALAND-NEW CALEDONIA REGION

ANNE M. WALLEY



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CRETACEOUS - CAINOZOIC PALAEOGEOGRAPHY OF THE NEW ZEALAND - NEW CALEDONIA REGION

by

Anne M. Walley

BUREAU OF MINERAL RESOURCES
AND
PETROLEUM DIVISION OF THE
AUSTRALIAN MINERAL INDUSTRIES RESEARCH ASSOCIATION
PHANEROZOIC HISTORY OF AUSTRALIA PROJECT

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This record is IN-CONFIDENCE until April, 1993.

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SUMMARY

Ten Cretaceous - Cainozoic time slice palaeogeographic maps of the New Zealand - New Caledonia region are presented in this report, which forms part of the Bureau of Mineral Resources (BMR)/Petroleum Division of the Australian Mineral Industries Research Association (APIRA) Phanerozoic History of Australia Project.

This research succeeds the BMR-APIRA Palaeogeographic Maps Project, during which interpretative palaeogeographic maps of Australia were produced for seventy Phanerozoic time slices. During the current study, interpretative maps were produced for the Indo-Australian Plate margin for selected Mesozoic and Cainozoic time slices.

The maps record changes in depositional environment, in association with changes in tectonic setting and climate through time. In the Early Cretaceous, prior to the breakup of eastern Gondwana, the New Zealand - New Caledonia region was part of a convergent margin. At this time, most of the region was emergent, undergoing non-deposition, or uplift and erosion. New Zealand moved southwards towards the South Pole during the Early Cretaceous and the climate was cool-temperate. Extension at the eastern Gondwana margin began in the late Early cretaceous, and widespread fault controlled terrestrial sedimentation took place in a climate that became warm and humid by the early Late Cretaceous. During the Late Cretaceous to Early Eocene, regional subsidence and transgression accompanied seafloor spreading in the Tasman Sea and Southern Ocean. New Zealand began to move northwards, away from its near-polar position, as seafloor spreading progressed. However, the climate became cooler as new ocean currents were generated during seafloor spreading. Temperatures rose in the Eocene. In the Mid- to Late Eocene, when the Tertiary climate was at its warmest, there was renewed extension in the New Zealand region, leading to the accumulation of coal measures in fault-controlled basins. At the same time, there was oblique plate convergence along northern Norfolk Ridge (New Caledonia). Following the Eocene extension in the New Zealand area, there was regional subsidence and transgression during the Oligocene. By the Late Oligocene much of New Zealand was submerged, with widespread carbonate sedimentation. Climatic cooling in the Oligocene reflected the complete separation of the Australian and Antarctic Plates, the generation of circum-Antarctic currents and the development of the Antarctic continental ice sheet.

The modern convergent Indo-Australian/Pacific Plate boundary was established in New Zealand in the latest Oligocene/earliest Miocene. From this time, until the present day, New Zealand has been dominated by a compressive regime. The regional clockwise shift in compression during this period has caused uplift of basins in some areas and extension and subsidence in other areas. Neogene climatic fluctuations reflect the complex interplay between the influence of Antarctic ice sheet development and circum-Antarctic currents, the continued northwards movement of the New Zealand - New Caledonia region, and the increasing area of emergence and highland which developed during compression in the plate boundary zone through New Zealand. Both terrestrial and marine sedimentary sequences in this region are potential hydrocarbon source rocks. In New Zealand, important structural traps were created when basins were inverted in the Neogene.

INTRODUCTION

Ten Cretaceous - Cainozoic time slice palaeogeographic maps of the New Zealand - New Caledonia region (Figure 1) are presented in this report. The study forms part of the Bureau of Mineral Resources (BMR)/Petroleum Division of the Australian Mineral Industries Research Association (APIRA) Phanerozoic History of Australia Project. This project succeeds the BMR-APIRA Palaeogeographic Maps Project (1984-1987), during which interpretative palaeogeographic maps of Australia were produced for seventy Phanerozoic time slices (BMR Palaeogeographic Group, 1990; Bradshaw & Yeung, in press; Bradshaw & others, in preparation; Brakel & Totterdell, in preparation; Cook, 1988; Cook & Totterdell, 1991; Olissoff & others, in preparation; Totterdell & others, in preparation; Walley & others, 1990; Wilford & others, in preparation; Yeates & Mulholland, in preparation).

During the current project, interpretative maps were produced for the Indo-Australian Plate margin for selected Mesozoic and Cainozoic time slices (Figure 2). New Zealand lies astride the Indo-Australian/Pacific Plate boundary (Figure 1) and therefore forms the southeastern edge of the study area. The maps were compiled at 1:10 000 000 scale and plotted on base maps depicting plate reconstructions for each time slice. The palaeogeographic maps for Australia were transferred on to these bases. Following the procedure used for the Australian maps, the maps for the Indo-Australian Plate margin show palaeoenvironments only. However, they have been annotated where appropriate and several supplementary explanatory figures accompany this text. The portions of the Cretaceous and Cainozoic palaeogeographic maps of Australia which appear on the maps in this report are from Bradshaw & others (in preparation) and Wilford & others (in preparation), respectively. They have also been published in BMR Palaeogeographic Group (1990).

From the hydrocarbon exploration perspective, the Cretaceous to Cainozoic is the most critical period of New Zealand's history, as almost all New Zealand's known prospective sedimentary basins were established following the Early Cretaceous phase of the Rangitata Orogeny ("Rangitata-2"; Bradshaw & others, 1981).

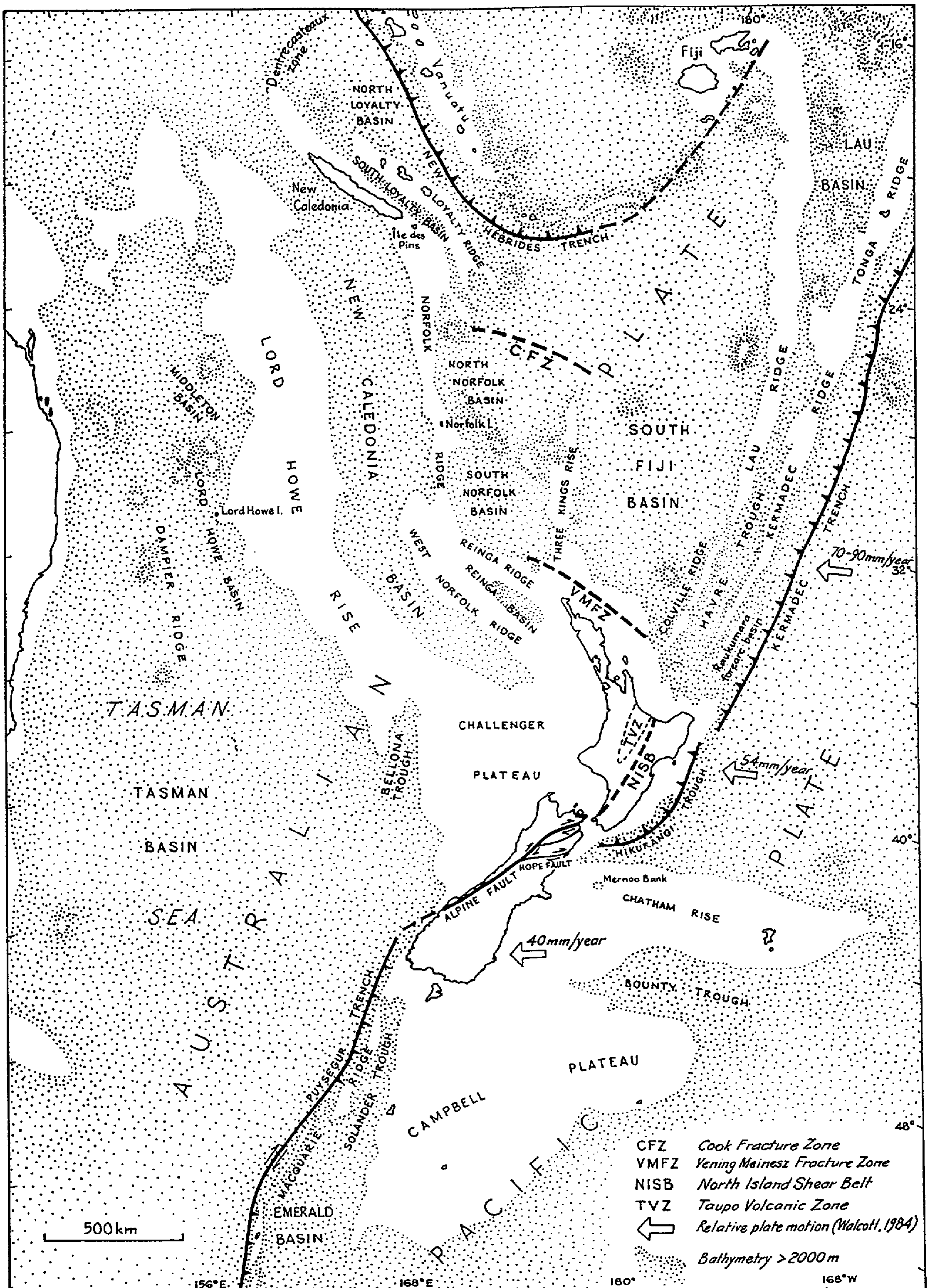


FIGURE 1 **Plate tectonic setting of the New Zealand - New Caledonia region**

Information compiled from: Circum-Pacific Map Project (1981), Launay & others (1982), Cole (1984, 1986), Walcott (1984, 1987), Gillies & Davey (1986) and Pelletier (1990)

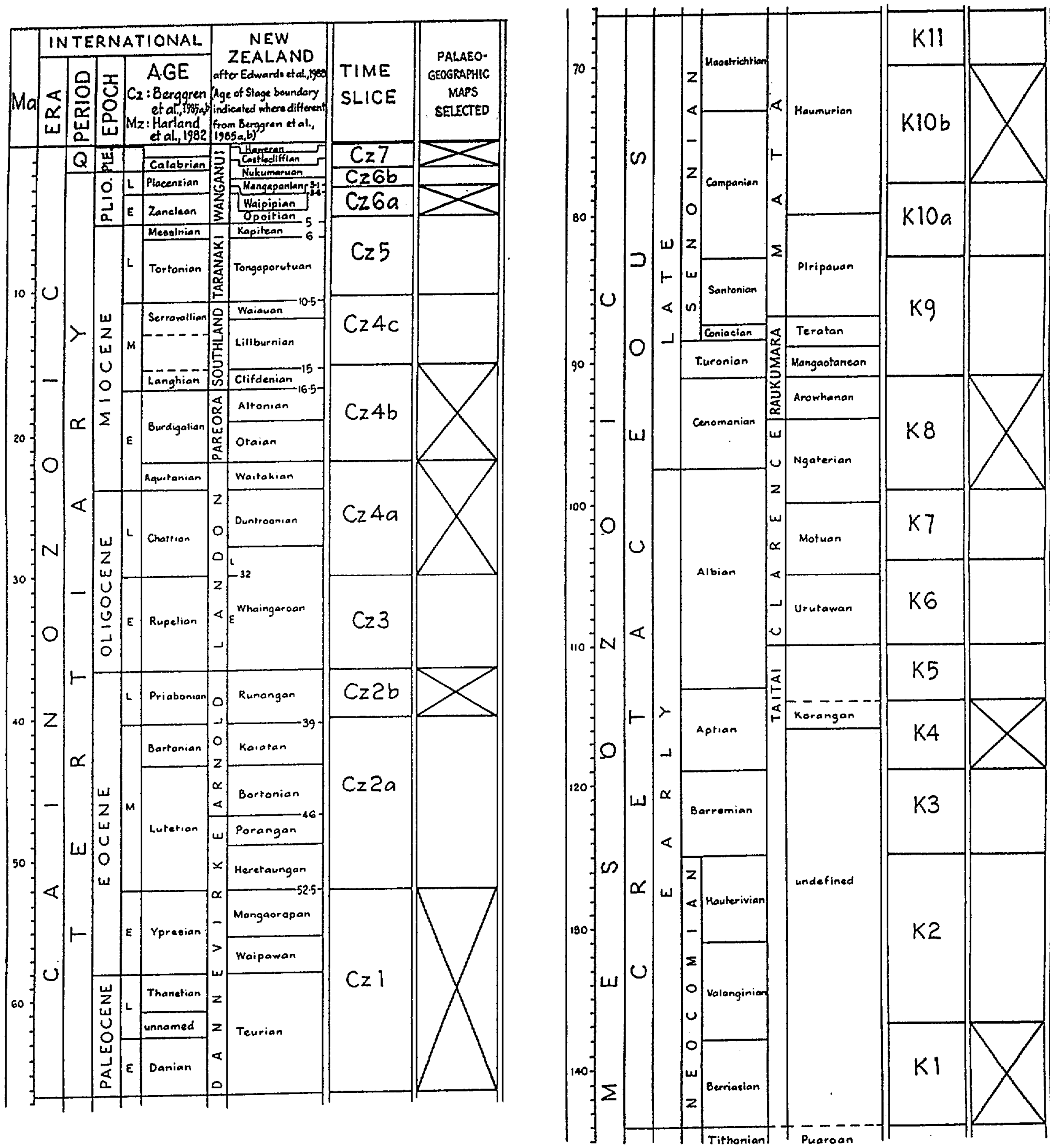


FIGURE 2 Cretaceous - Cainozoic time scale, showing time slices represented by palaeographic maps

This compilation has involved the preparation of summary stratigraphic columns (Walley, 1991a), data maps depicting outcrop and subsurface information, time slice structure base maps (Walley, 1991b) and plate reconstructions. The basis for the plate reconstructions of the New Zealand - New Caledonia region has been discussed in Walley & Ross (1991) and the tectonic elements used in these reconstructions are identified in Figure 3. Palaeogeographic maps for adjacent regions of the Indo-Australian Plate margin will be included in separate reports (Bradshaw, in preparation; Struckmeyer & Yeung, 1991).

As discussed in Walley & Ross (1991), the present-day shape of the tectonic elements has been used throughout the reconstructions. This has produced some anomalous overlap of elements, evident on some of the maps.

Time slices are selected on the basis of correlatable time breaks and palaeoenvironmentally significant intervals. The time slices represented by palaeogeographic maps are those chosen during the BMR-APIRA Palaeogeographic Maps Project. Some of these time slices have been subdivided for the current project to more clearly define major events in the evolution of the Indo-Australian Plate. For example, time slice Cz2 has been split into time slices Cz2a and Cz2b (Figure 2). Throughout the report, "K" denotes Cretaceous and "Cz" denotes Cainozoic. Figure 4 is a regional location map for New Zealand and Figure 5 illustrates sedimentary basins in the New Zealand region. Where north, south, east and west are referred to in the text, they pertain to present-day positions. Table 1 is a key to the depositional environments used on the maps. The plate tectonic evolution of the New Zealand - New Caledonia region has been outlined in previous BMR Records (Walley, 1991a, 1991b; Walley & Ross, 1991). Tectonic events and their effect on regional palaeogeography are also considered in the text of this report.

The assistance and cooperation of DSIR (the Department of Scientific and Industrial Research), Geology & Geophysics, New Zealand have been a valuable contribution to this project. Some of the palaeogeographic information published as part of the DSIR, Geology & Geophysics, Cretaceous - Cenozoic Basin Studies Programme has been included in summary form on the maps.

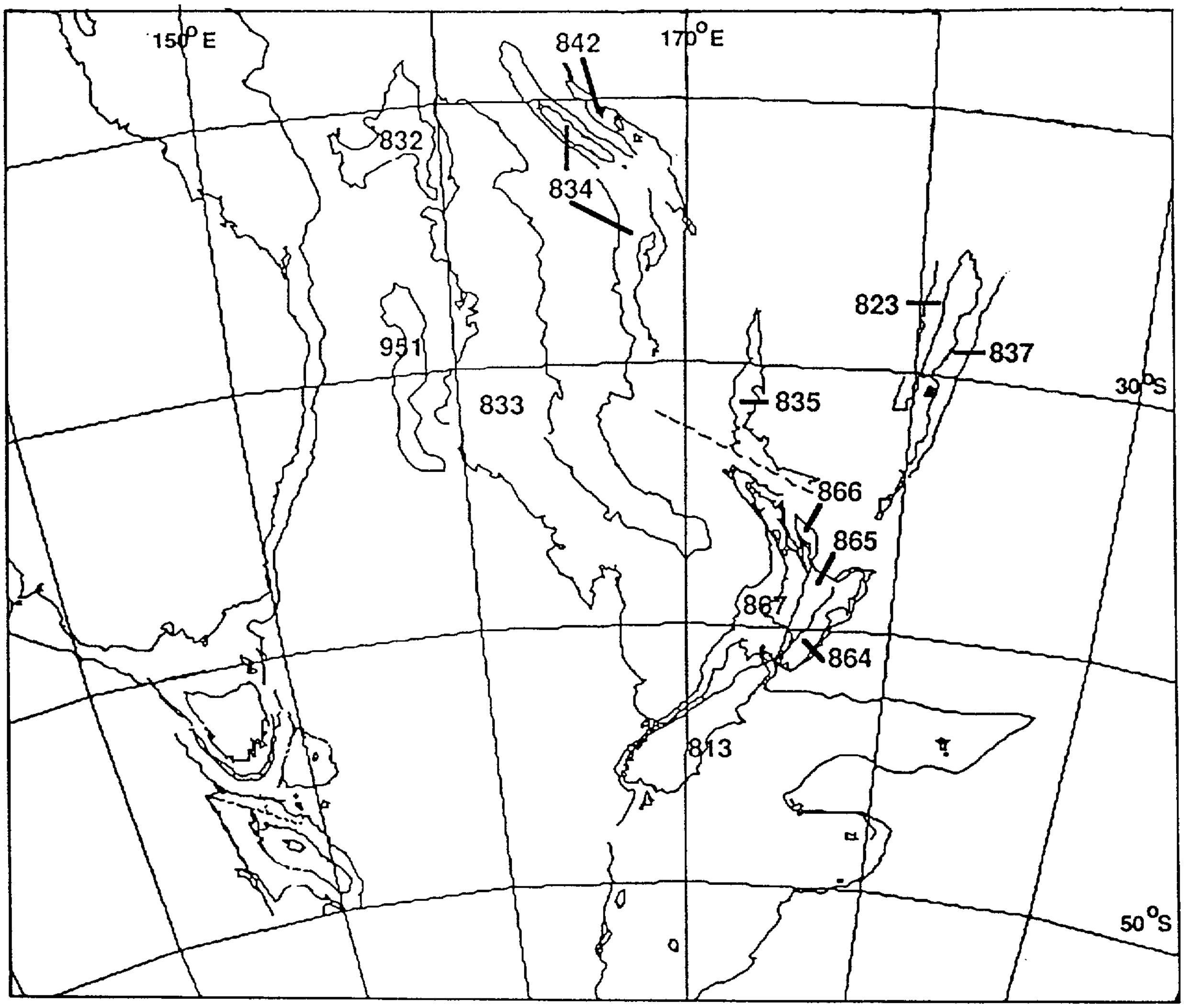


FIGURE 3 Tectonic elements of the New Zealand - New Caledonia region

813: Chatham Rise/Campbell Plateau
823: Colville-Lau Ridge
832: Bellona Plateau
833: Lord Howe Rise
834: Norfolk Ridge
835: Three Kings Rise
837: Kermadec Ridge
842: Loyalty Ridge
864: Eastern North Island
865: Taupo
866: Coromandel
867: Western New Zealand
951: Dampier Ridge

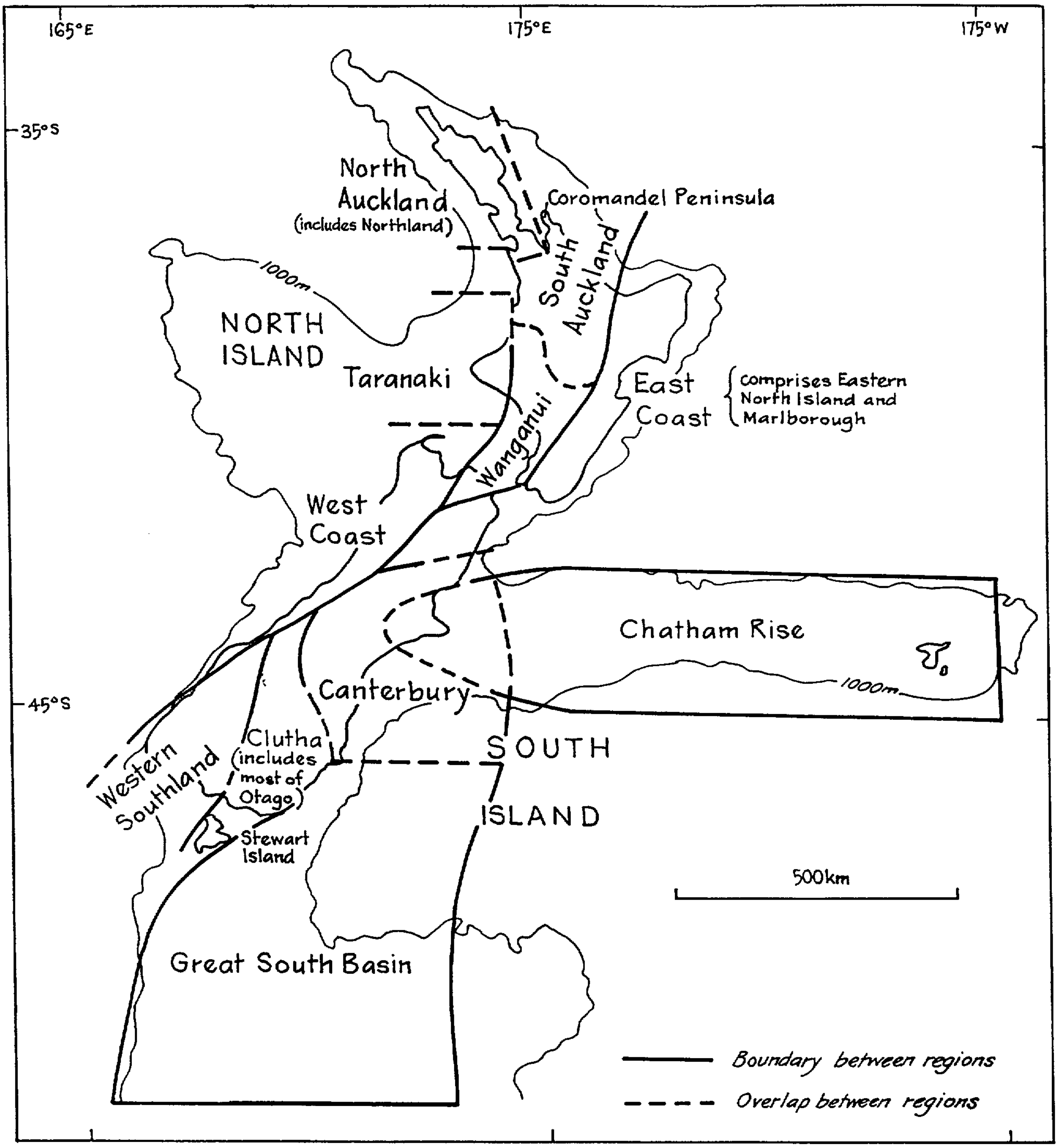


FIGURE 4 **New Zealand - regional location map**

Map from DSIR, Geology & Geophysics, New Zealand
The map shows the eleven study regions currently under investigation by DSIR, as part of the Cretaceous - Cenozoic Basin Studies Programme. The following DSIR Basin Studies volumes have been published:

Basin Studies 1 (West Coast) - Nathan & others (1986)
Basin Studies 2 (Canterbury) - Field & others (1989)
Basin Studies 3 (Chatham Rise) - Wood & others (1989)

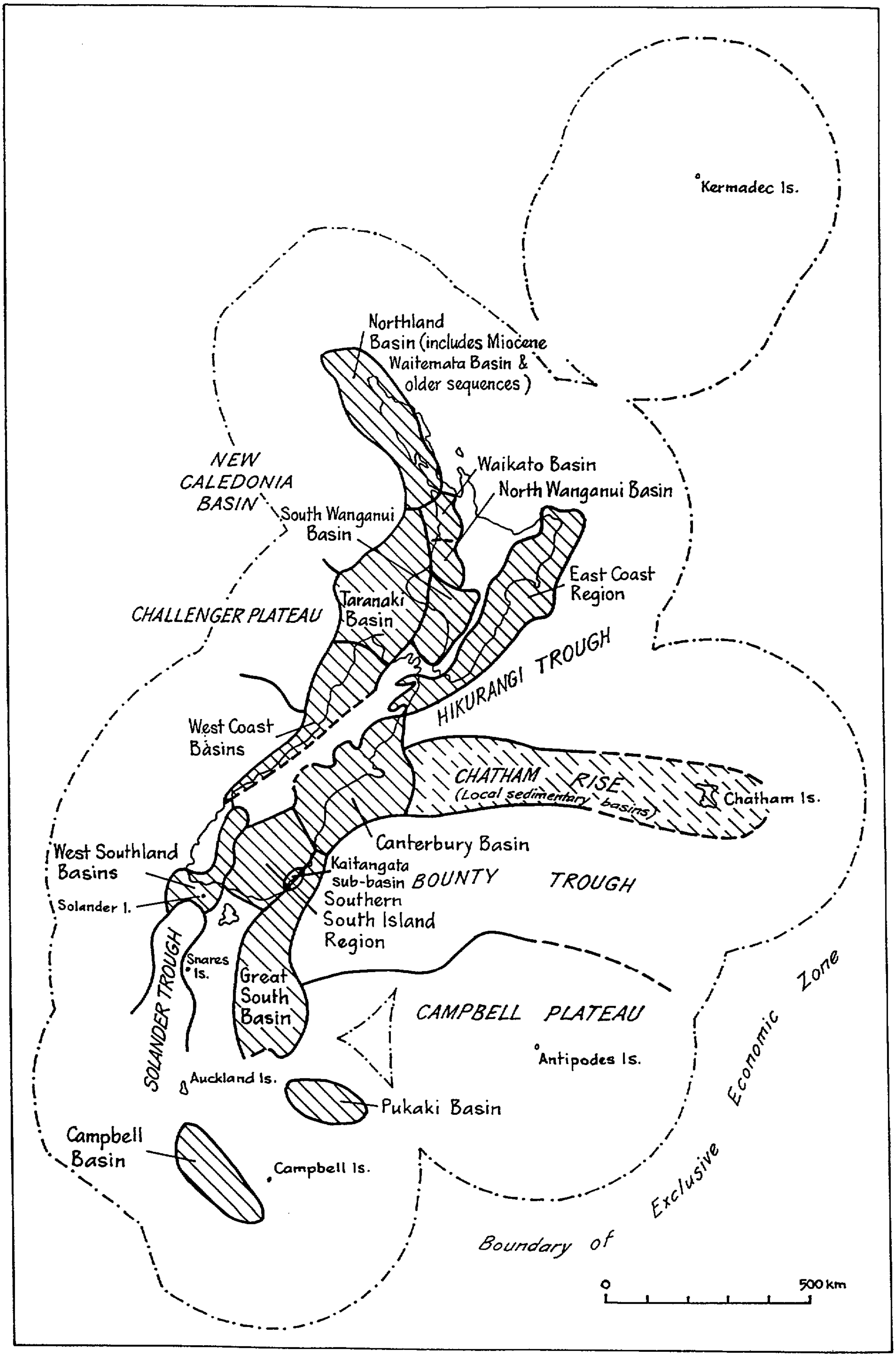


FIGURE 5 **Sedimentary basins of New Zealand**

Adapted from Petroleum Exploration in New Zealand Prospectus. Ministry of Commerce, New Zealand, 1990

Table 1 — DEPOSITIONAL ENVIRONMENTS

(adapted from BMR Palaeogeographic Group, 1990)

Code	Environment	Working definition
		LAND ENVIRONMENTS
LEU	unclassified	Areas with no preserved sediments of time-slice age; interpreted as land.
LEE	erosional	Highlands; inferred from palaeocurrents, provenance studies, tectonic setting, presence of igneous intrusions, etc.
LDU	depositional, unclassified	No indication of specific environment; often includes subaerial volcanics.
LDF	fluvial	River deposits such as alluvial fans, braided and meandering channel deposits and coarser overbank sediments; also sand-dominated continental sequences with no evidence of aeolian or lacustrine deposition.
LDFL	fluvio-lacustrine	Low-energy river environments such as channels, overbanks, backswamps and shallow lakes on low-gradient flood plains; typically sheets of fine-grained sediments and coal.
LDL	lacustrine	Deposits of persistent lakes, typically finely laminated mud and sand frequently containing freshwater fossils
LDA	aeolian	Generally sand deposited by wind action as dunes; characterised by large-scale cross-bedding, a high degree of sorting, and frosting of grains. Fossils rare. Local clay between dunes.
LDG	glacial/periglacial	Typically coarse, poorly sorted sediments, commonly with striated pebbles, cobbles, and boulders. Overall assemblage of sediments quite complex, ranging from aeolian sand flanking glaciers, river gravel, fine-grained mud with or without dropstones, to siliceous sediments.
		COASTAL ENVIRONMENTS
CDP	paralic	Coastal or marginal-marine environments, e.g. lagoonal, beach, intertidal, deltaic. Range from coarse cross-bedded beach sand, through sand deposited in tidal deltas, to finely laminated organic sediment deposited in lagoons and estuaries (includes deltaic and intertidal-supratidal environments).
CDIS	intertidal-supratidal	Tidal zone, indicated by finely interlaminated fine and coarse detritus, herring-bone cross-bedding, flaser bedding, evidence of periodic exposure, etc.
CDD	deltaic	Indicated by thickness patterns; upward-coarsening sequences, and the mapped pattern of adjacent environments.
		MARINE ENVIRONMENTS
MVS	very shallow (0–20m water depth)	Evidence of deposition above wave-base and/or occasional emergence, e.g. oolites, cross-bedding.
MS	shallow (0–200m water depth)	Continental shelf or flanks of volcanic islands, e.g. sand, mud and limestone containing fossils that typically lived in shallow water; includes young, active spreading ridges.
MBA	bathyal to abyssal (>200m water depth)	Deep-water deposition, e.g. condensed sequences, turbidites, monotonous shale; deeper-water organisms.
MA	abyssal (>1000m water depth)	Distal turbidite, clay, siliceous and calcareous ooze, ocean-floor basalt, etc.

TIME SLICES K1 AND K4 (EARLY CRETACEOUS)

K1: Berriasian to earliest Valanginian: 144 - 137 Ma (MAP 1)

K4: Aptian: 119 - 114 Ma (MAP 2)

Palaeoenvironments in Australia on these and subsequent Cretaceous maps are taken from the "Stage 1" Palaeogeographic Maps Project Cretaceous maps (Bradshaw & others, in preparation). The interpretation on these maps has been modified slightly at the edges to blend with the present interpretation of the surrounding area.

These two maps display a convergent tectonic setting in the New Zealand region, prior to the transition to an extensional regime which is represented in the map for time slice K8. There was a Permian to early Early Cretaceous convergent margin at the edge of eastern Gondwana. The collision of the youngest segments of the convergent margin with the remainder of New Zealand took place in the Early Cretaceous (Rangitata-2 Orogeny), associated with terrane deformation, granitoid intrusion, metamorphism and uplift (Bradshaw, 1989). Most of New Zealand was land undergoing intense erosion. There is now thought to have been only a short interval between the convergence and a change in tectonic regime to one of extension, although the age of the final deformational event varies from one region to another. Convergence ceased in the Albian, at about 105 ± 5 Ma (Bradshaw, 1989), in time slice K7. However, the timing of the final convergent event is controversial because of different interpretations as to both the significance of major unconformities and the depositional environment of some Cretaceous sequences (see, for example, Speden, 1976; Feary, 1979; Moore & Speden, 1979, 1984; Prebble, 1980; Barnes, 1988; Korsch & Wellman, 1988; Barnes & Korsch, 1991).

The final welding of most of New Zealand's terranes occurred by time slices K1 or K2, but accretion continued until time slice K7, associated with subduction and collision of a spreading ridge with New Zealand (Bradshaw, 1989). Building of the Pahau accretionary prism thus continued during this event and remnants of the Early Cretaceous segments of this prism are preserved in eastern North Island, Marlborough and North Canterbury (Speden, 1975; Smale, 1978; Crampton, 1988; Wilson & others, 1988; George, 1990). This prism is known as the Pahau Sub-Terrane of the Torlesse Terrane (Bishop & others, 1983). There are provenance links between the sediments and the older part of the Torlesse Terrane and hence the Pahau prism is thought to have accumulated close to the rest of New Zealand (Bradshaw, 1989). The Pahau Sub-Terrane has not been separated from the remainder of New Zealand on these maps, but the position of the converging terrane is indicated by annotation. Early Cretaceous convergent margin sediments are mainly quartzo-feldspathic, deposited by sediment gravity flows (Mackinnon, 1983). A shallow marine shelf environment has been interpreted in northeastern North Island (Speden, 1975) and there is palaeontological evidence for a nearshore river mouth depositional setting in northern Canterbury during the Neocomian (time slices K1-K2; Smale, 1978; Wilson & Helby, 1988).

An Early Cretaceous marine volcanic and sedimentary sequence in Northland, of inferred Neocomian to Albian age, is also considered to be a suspect terrane. Both felsic pyroclastic volcanics and basalt flows were extruded here, with associated clastic sediments, but the depositional setting is unclear (Isaac & others, 1988). This may be the only preserved piece, in Northland, of the accretionary prism represented in eastern North Island (Spörli, 1989).

Mafic and ultramafic complexes were emplaced in Western Southland and Stewart Island during time slice K1 (Cook, 1981; Mattinson & others, 1986). These were probably associated with convergent processes. Ages of granitoids in Marie Byrd Land, in neighbouring Antarctica, cluster around 90-105 Ma (time slices K6-K8), although some of these dates indicate uplift and cooling (Wade & Wilbanks, 1972; Katz, 1982; Grindley & Oliver, 1983). Earlier Cretaceous dates have also been obtained (Grindley & Oliver, 1983) and pluton emplacement may have been occurring from time slice K1 onwards. Early Cretaceous granitoids emplaced in western New Zealand approximately during time slice K4, or a little earlier or later, include both "I" type and "I-S" type suites. The latter are considered to be related to extension (see Tulloch & Kimbrough, 1989). As noted below (see "Time Slice K8"), the transition from a convergent to an extensional regime occurred over a very short period of time.

The presence of basins within Lord Howe Rise is discussed below ("Time Slice K8"). As a convergent regime dominated the eastern Gondwana margin during time slices K1-K4, the probable extensional basins along Lord Howe Rise are considered to have been a later development. A small area of fluvial sedimentation is tentatively inferred, however, adjacent to the area of erosion shown on the K4 map on the eastern margin of Australia. Rift stage sedimentation along Australia's southern margin was earlier than that along the eastern margin (see Willcox & Stagg, 1990 and references therein). Hence the Gippsland, Bass and Otway Basins were already depocentres, as shown on the Australian Cretaceous maps (Bradshaw & others, in preparation). An extensional basin flanking the northeastern edge of the South Tasman Rise (Figure 6; see Willcox & others, 1989) may have been active at this time, as indicated speculatively on the K4 map: if the rise gradually drifted westwards, as favoured by Veevers & Eittreim (1988) and as shown in these reconstructions, a zone of rifting is implied in this area (compare maps K4 and K8). This zone of extension may then have been associated with the rifting along Australia's southern margin, rather than with the rifting at the eastern margin of Gondwana which is shown and discussed below ("Time Slice K8").

The most extensive flooding of the Australian continent since the Cambro-Ordovician occurred in time slice K4 (Yeung, *in* BMR Palaeogeographic Group, 1990; Struckmeyer & Brown, 1990; Bradshaw & others, in preparation). The sea encroached from the north. There is no evidence of the extent of this transgression southwards within the New Caledonia region, and boundaries of marine environments are therefore inferred.

There was a hiatus over much of the New Zealand - New Caledonia region and there are considered to have been large areas of land undergoing uplift and erosion. New Caledonia was probably emergent. A large hiatus there, between time slices K1 and K8, represents the "Neo-Cimmerian Orogeny" (Paris, 1981). This was coeval with the "Rangitata-2 Orogeny" in New Zealand (Bradshaw, 1989), but persisted in New Caledonia a further 10 million years after extension commenced in New Zealand (see "Time Slice K8"). There was low temperature metamorphism of the "Central Chain" Permo-Triassic mafic massifs at this time (Paris, 1981).

Between time slices K1 and K4, therefore, a convergent tectonic regime persisted in the New Zealand - New Caledonia region, at the eastern margin of Gondwana. The youngest segments of the convergent margin were colliding with the remainder of New Zealand. Clastic marine sediments accumulated as an accretionary prism at this margin, but most of

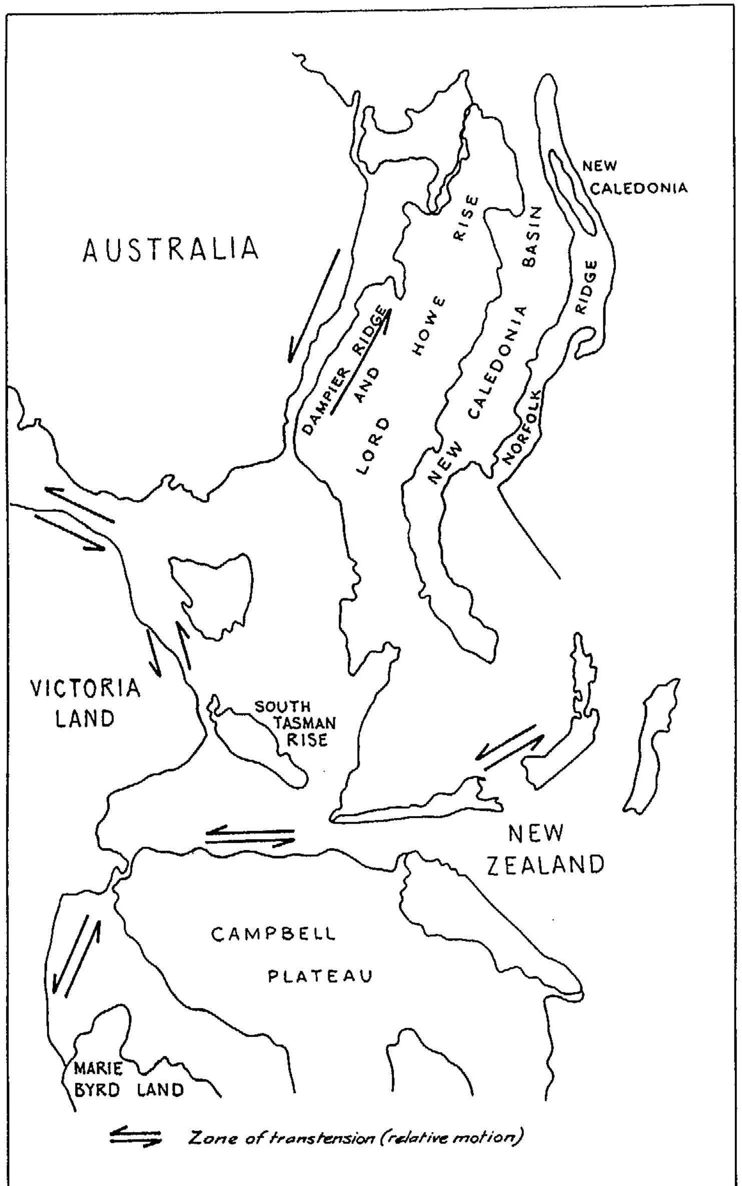


FIGURE 6 **Early extension, Gondwana margin: Time Slice K8**

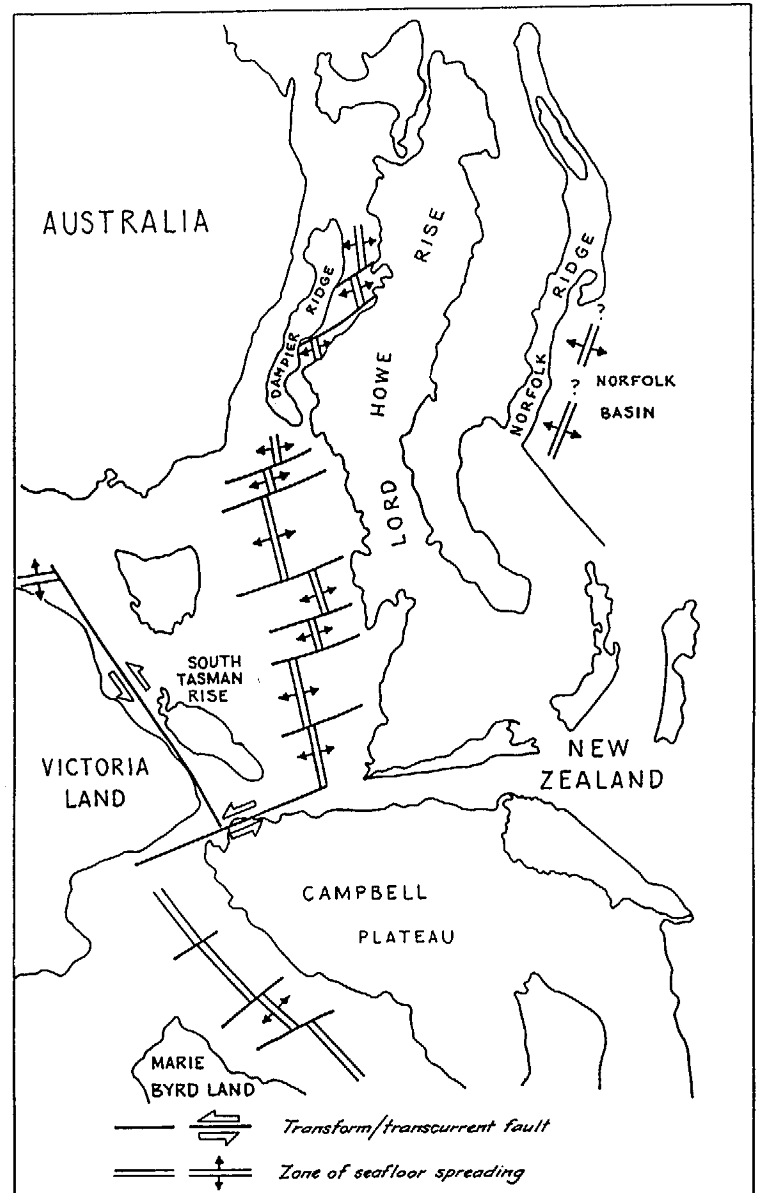


FIGURE 7 **Diagrammatic representation of seafloor spreading: Time Slice K10b**

the region was emergent, undergoing non-deposition or erosion. By time slice K4, pluton emplacement and associated uplift were widespread.

The southward movement of the Gondwana landmasses which was under way by the Late Jurassic continued during the Early Cretaceous. Faunal evidence indicates that the climate became cool-temperate in the New Zealand region (Suggate & others, 1978). New Zealand moved nearer the South Pole between time slice K1 and time slice K8.

TIME SLICE K8 (LATEST EARLY TO EARLY LATE CRETACEOUS) latest Albian to Cenomanian: 99 - 91 MA (MAP 3)

This map illustrates early extension at the eastern Gondwana margin, which began at approximately 105 Ma (latest time slice K6/time slice K7; see also Figure 6). The transition from a convergent regime to one of extension in the New Zealand region is discussed in Bradshaw (1989), and a brief summary and relevant references are presented in Walley (1991a). Seafloor spreading between Australia and Antarctica began during this time slice, at about 95 Ma (Cande & Mutter, 1982). Rift stage sedimentation along Australia's southern margin was earlier than that along the eastern margin (see Willcox & Stagg, 1990 and "Time Slices K1 and K4").

Coeval with the early extension, there was uplift and cooling of granitoid plutons in Marie Byrd Land, where there is a concentration of radiometric dates between ~105-90 Ma (Wade & Wilbanks, 1972; Katz, 1982; Grindley & Oliver, 1983). Granites and felsic porphyries were emplaced or reset in western South Island, the Great South Basin area and Stewart Island during time slices K6 to K8 (Cook, 1981; Anderton & others, 1982; Nathan & others, 1986). Uplift and cooling on the eastern Gondwana margin are also reflected in a cluster of time slice K6-K8 fission track ages in southeastern Australia (see summary of fission track data in Bradshaw & Vizy, 1991).

Grabens and half-grabens developed throughout the New Zealand region (Northland: Isaac & others, 1988; offshore western Northland: Beggs & others, 1988; Herzer & others, DSIR, Geology & Geophysics, personal communication, 1990; Taranaki: Thrasher, 1989, 1990; southern New Caledonia Basin, associated with the opening of this basin: Wood & Uruski, 1989, 1990; Uruski & Wood, 1991; western South Island [the West Coast Region]: Nathan & others, 1986; western Southland [Balleny Basin; Figure 8]: Pocknall & Lindquist, 1988; the Great South Basin: Anderton & others, 1982; southeastern Otago: Suggate & others, 1978; Carter, 1988; Canterbury: Field, Browne & others, 1989; Chatham Rise: Wood, Andrews, Herzer & others, 1989; Marlborough: Suggate & others, 1978; Laird, 1989). The basins were filled with fluvial (including alluvial fan) and lacustrine sediments, with thin coal or lignite beds. Preserved thicknesses exceed 5000 m (for example in the Canterbury region; Field, Browne & others, 1989).

The age and trend of the sedimentary basins shown in Stewart Island and Auckland Island is unclear, but Stewart Island fluvial clastic sediments are of post-Early Cretaceous age and the deposits on Auckland Island may be coeval. These basins are here inferred to correlate with others in this region.

Extensional basins of probable Cretaceous age also flank South Tasman Rise and these, possibly filled with fluvial-deltaic sediments and syn-rift volcanics (Willcox, 1981, 1986; Willcox & others, 1989), are shown tentatively on this map. The rise itself is presumed to have been emergent. Seismic information also indicates the presence of a zone of extensional basins along western Lord Howe Rise. The zone is up to 200 km wide and the individual basins are up to 50 km wide, along a present-day north-northwesterly trend (Jongsma & Mutter, 1978; Willcox & others, 1980; Willcox, 1981; Symonds & Willcox, 1989). The age of these basins and the nature of the sedimentary fill are conjectural, but the sediments may be correlative with units in the Gippsland Basin and are possibly fluvio-lacustrine (Symonds & Willcox, 1989). These basins are here interpreted to have been active depocentres during this time slice and an indication of their presence is given schematically on the map, after Symonds & Schlüter, *in* Roeser & others (1985). It is highly likely extensional basins also formed along western Dampier Ridge, filled with fluvial clastics derived from highland areas undergoing erosion in eastern Australia. Seismic data suggest the presence of basins in that area (Willcox, 1981). Farther north, the fluvial rift sedimentation in the Capricorn Basin may have extended to the area of probable rifting on the Kenn Plateau (see Willcox, 1981; Davies

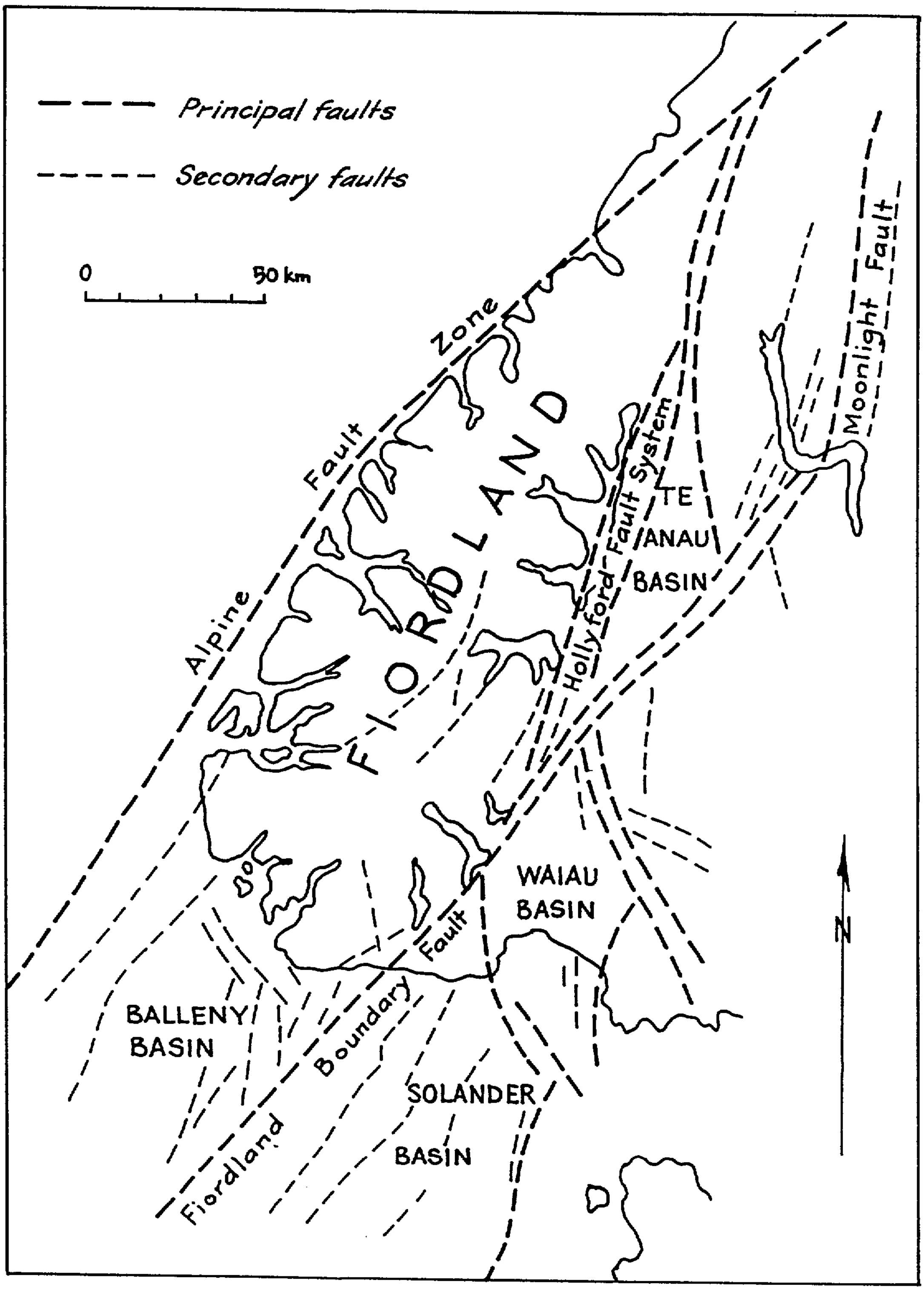


FIGURE 8 **Regional structural map, southwestern South Island Modified after Norris & Carter (1980)**

& others, 1989). Grabens on western Norfolk Ridge may also be coeval with the others already described, and there may have been a fluvial or fluvio-deltaic sedimentary fill (see Symonds & Willcox, 1989).

In the southern part of the map area, there was half-graben development and probable terrestrial to paralic early breakup sedimentation in the Ross Sea area (between Victoria Land and Marie Byrd Land). The age control on these sediments, seen only on seismic data, is at present poor (Cooper & others, 1987; Davey, 1987). Early extension in the Ross Sea area is considered to have occurred correlative with breakup between Antarctica and Australia/New Zealand, and transtensional rifting is indicated on the map (compare maps for time slices K8 and K10b; see Kamp, 1986a; Storey, 1991; Tessensohn & Wörner, 1991).

Deposition in eastern North Island was in tectonically active shelf to slope environments (see, for example, Mazengarb, 1989). This area was probably at the edge of the continental margin. Rifting may have occurred here, too: there was minor accompanying mafic and felsic volcanism (Black, 1980; Moore & Speden, 1984). Bimodal volcanism also accompanied extension in the Canterbury/Chatham Rise area (Andrews & others, 1987; Sewell & others, 1988; Oliver & Keene, 1989). There was basaltic volcanism in Marlborough (Suggate & others, 1978), explosive rhyolitic activity on Lord Howe Rise (Burns, Andrews & others, 1973) and subaerial rhyolitic volcanism at the southern edge of the map, in Marie Byrd Land (Grindley & Oliver, 1983).

The palaeogeography of Northland has been constructed using that for time slice K10b as a guide, together with the limited outcrop and subsurface information (Hornibrook & others, 1976; Isaac & others, 1988). The Taranaki area has been interpreted using information in Nathan & others (1986), King & Robinson (1988) and Thrasher (1990). West Coast Region environments are based upon Nathan & others (1986), the Canterbury region palaeogeography is modified after Field, Browne & others (1989), and Chatham Rise environments are adapted from Wood, Andrews, Herzer & others (1989). The palaeogeography of the Great South Basin and the Campbell Basin (south of Campbell Island) are based upon Anderton & others (1982).

A "rift" pattern is clear on the map. The Western New Zealand/New Caledonia Basin segment and the Campbell Plateau/Chatham Rise segment together appear to form a triple rift junction, at the rifted continental margin. The western edge of New Zealand (the West Coast Rift of Laird, 1981) appears to have been one arm of the rift and the trend of the other two arms can be seen in the pattern of fluvial basins to the north and south. The word "rift" is used rather loosely here. There is evidence for a sinistral transtensional component to the extension in the Taranaki Basin (Thrasher, 1989, 1990). It is apparent from the map that the Alpine Fault - see "Time Slice Cz4b" - approximately followed a zone of Cretaceous extension. However, the trend of the future fault was oblique to earlier extensional basins, as discussed by Kamp, 1986b. If one compares the maps for time slices K8 and K10b, sinistral transtension is required in this zone to accommodate the pattern of early opening of the Tasman Sea and Southern Ocean.

The position of the South Tasman Rise on the Cretaceous maps is uncertain. It may have formerly been adjacent to the East Tasman Plateau and gradually drifted westwards, as favoured by Veevers & Eittreim (1988) and as shown in these reconstructions. Alternatively, it may have been a part of the Antarctic Plate, juxtaposed against the Otway Basin until drifting commenced. The two areas have similar seismic stratigraphy (Willcox & Stagg, 1990). In either scenario, the rise could have remained part of the Antarctic Plate until the onset of fast drifting between Antarctica and Australia in the early Tertiary. The western margin of the rise is thought to have formed as a left-lateral strike-slip zone when the Australian and Antarctic Plates became completely separated in the mid-Oligocene (~ 32 Ma; Willcox & Stagg, 1990).

The area on the map which later became part of the Tasman Sea is problematical. The Gippsland Basin was apparently connected to an eastern seaway at this time (see Yeung, *in* BMR Palaeogeographic Group, 1990) and a marine embayment has been interpreted here. A conjectural marine connection has also been shown on the map between the probable embayment that later became the Tasman Sea, and the incipient Indian Ocean. This interpretation would imply that a former area of rifting between South Tasman Rise and East Tasman Plateau (compare the maps for time slices K4 and K8) had by now subsided. There is also an implication that a former area of rifting within the zone that later became part of the Tasman Sea sagged prior to seafloor spreading.

In view of the facts that early extensional basins were filled with fluvial sediments, and that seafloor spreading had not yet commenced at the eastern Australian margin, there were probably large areas of land in this region during this time slice. A number of areas of highland undergoing erosion are shown on the map and there were undoubtedly more areas of erosion. New Caledonia was probably emergent (see Paris, 1981).

This time slice map thus shows palaeoenvironments during the phase of early rifting at the eastern Gondwana margin, prior to the onset of seafloor spreading in the Tasman Sea. Seafloor spreading on Australia's southern margin started during this time slice. There were extensive areas of emergence, and there was widespread fault control on sedimentation, with deposition of thick terrestrial clastic sediments which today provide potential source rocks and reservoirs for hydrocarbons. Extension of the New Caledonia Basin occurred during this time slice and probably ceased when seafloor spreading began in the Tasman Sea (see "Time Slice K10b"). At least the southern part of this basin has remained thinned continental crust (Wood & Uruski, 1989; Uruski & Wood, 1991).

New Zealand was close to the South Pole during this time slice. However, there was a warming of marine palaeotemperatures during the Clarence - Raukumara Series (Figure 2) to a maximum similar to that near Norfolk Island at the present day (see Clayton & Stevens, 1968; Field, Browne & others, 1989). A climatic optimum was reached by time slice K9 (Suggate & others, 1978). During time slice K9, there is considered to have been a warm, humid climate in the Great South Basin area (Anderton & others, 1982) and eastern North Island was warmer than it is today, with a warm-temperate to sub-tropical climate (Moore, 1988b).

TIME SLICE K10B (LATE CRETACEOUS)
mid-Campanian to mid-Maastrichtian: 78 - 70 MA (MAP 4)

The major feature of this time slice is seafloor spreading at the Australian margins and south of New Zealand (Figure 7). Seafloor spreading commenced in the Tasman Sea at ~86 Ma and formed the Tasman, Middleton and Lord Howe Basins (Weissel & Hayes, 1977; Shaw, 1978, 1990; Symonds & Willcox, 1989). There are insufficient data on marine depths in these basins and these are inferred. It should also be noted that the basement of the Middleton and Lord Howe Basins may be extended continental, rather than oceanic, crust (J.B. Willcox, BMR, personal communication, 1991). New Zealand also began to separate from Marie Byrd Land at about this time, and slow spreading of the southeast Indian Ocean continued between Australia and Antarctica (Cande & Mutter, 1982). The seafloor spreading south of New Zealand may have been generated from a ridge that formed a triple junction with the southeast Indian Ocean and Tasman Sea ridges (Veevers & others, 1991).

In the New Zealand region, there was a marked climatic deterioration through the Campanian into the late Maastrichtian (Suggate & others, 1978), coinciding with seafloor spreading and the generation of new ocean currents. However, New Zealand began to move northwards, away from its near-polar position, as seafloor spreading progressed. Eastern North Island remained warm and humid, becoming subtropical during this time slice (Moore, 1988b), but there was now a cool climate over the Campbell Plateau (Kennett, Houtz & others, 1975).

There is no recorded sedimentation during this time slice in Marie Byrd Land and Victoria Land, which were probably emergent and undergoing erosion (see, for example, LeMasurier & Rex, 1983; Tessensohn & Roland, 1987). Cretaceous sedimentation probably continued in the Ross Sea area. There are, as indicated in the discussion for time slice K8, seismically identified successions of probable Cretaceous age and early breakup association in that area (Cooper & others, 1987; Davey, 1987), and a marine environment is inferred for this time slice.

The South Tasman Rise is inferred to have remained emergent and its flanking Early Cretaceous(?) extensional basins were probably inundated by the Late Cretaceous, but conditions were likely to have been restricted (see Kennett, Houtz & others, 1975; Hinz & others, 1985; Willcox, 1981, 1986).

Dampier Ridge was not yet detached from the Australian margin and rift stage sedimentation may have prevailed here during much of this time slice, in view of the area of erosion in Australia to which it was adjacent. The fluvial rift sedimentation north of the map area in the Capricorn Basin may have extended to the area of probable rifting on the Kenn Plateau (see Willcox, 1981; Davies & others, 1989; Bradshaw & others, in preparation).

Deep sea drilling information indicates that at least part of the Lord Howe Rise was now submerged, but that circulation was restricted (Burns, Andrews & others, 1973). It has here been speculated that a portion of western Lord Howe Rise was probably still emergent. Fluvial to paralic sedimentation, which may have continued into this time slice in the southern New Caledonia Basin (Wood & Uruski, 1989, 1990) suggests the presence of a nearby area of emergence, as indicated on the map. Rifting within the New Caledonia Basin and Bounty Trough probably ceased at about the time seafloor spreading began in the Tasman Sea (see "Time Slice K8").

From the Late Cretaceous onwards, until the Early Eocene, there was back-arc spreading in the New Caledonia region, marked by basalt extrusion along the west coast, with the opening of marginal basins (Paris, 1981; Launay & others, 1982; Maurizot & others, 1985). Although Launay & others (1982) suggest there was an associated east-dipping subduction zone along western Norfolk Ridge, there is little evidence for this and it is equally likely that the extension was related to major plate boundary movements outside this region. The Norfolk Basin was probably opening during this time slice and may have been a back-arc basin (Launay & others, 1982). Weak magnetic anomalies indicate this oceanic basin opened between ~85 Ma and ~75 Ma (see discussion in Walley & Ross, 1991). The Late Cretaceous palaeogeography of New Caledonia is adapted from Paris (1981). Over much of New Caledonia a restricted coastal sedimentary facies accumulated, around portions of the emergent "Central Chain" of mountains. A thicker sedimentary prism was deposited in the north, on the edge of what was probably the rifted continental margin. Apart from the west coast basaltic volcanism discussed above, some bimodal volcanic extrusion accompanied sedimentation both in the northwest and in the south of the island.

In the New Zealand region a broadly extensional regime persisted, but there was less movement on faults controlling sedimentation during this time slice (see, for example, Field, Browne & others, 1989; Wood, Andrews, Herzer & others, 1989). Much of New Zealand was still emergent (see, for example, Moore, 1988b). As areas such as the Lord Howe Rise and Campbell Plateau began to subside with the onset of seafloor spreading, paralic zones developed at the expense of areas of former terrestrial sedimentation. The regional rifting pattern established in the late Early Cretaceous (see "Time Slice K8") was still evident. However, as seafloor spreading became well established, as discussed above, the earlier rift system was gradually abandoned (compare map for time slice Cz1). The area shown as unclassified land within New Zealand's former expanse is conjectural. It is possible there was a marine embayment between eastern North Island and eastern South Island, but there is no evidence to confirm this. If the continental crust between eastern North Island, western North Island and eastern South Island was thinned by extension in the late Early Cretaceous, and if this extension was substantial, shallow marine sediments may have occupied this area during time slice K10b. An additional argument for Cretaceous extension within this area, marked as unclassified land on the map, is that subsequent convergence, from time slice Cz4b onwards, would not then have resulted in unusually thickened crust (the North Island ranges are considerably lower than the South Island Alps).

Reconstruction of Northland palaeogeography is complicated by the fact that much of the pre-Miocene onshore sequence is allochthonous. Information on autochthonous units has been combined with the position of the shoreline suggested in Moore (1988b). Siliceous mudstone was deposited here in a starved marine basin (Isaac & others, 1988). Deposition of fluvial to paralic sediments, including coal measures, continued in fault-controlled sub-basins and half-grabens in the Taranaki Basin. Marine sediments gradually interfingered with the terrestrial sediments, as the sea transgressed from the north (King, 1990). The Taranaki Basin palaeogeography has been constructed from Pilaar & Wakefield (1978), Palmer (1985), King & Robinson (1988) and Thrasher (1990). Seismic information indicates that sediments similar to those in the Taranaki Basin were deposited west of Northland (R.H. Herzer & others, DSIR Geology & Geophysics, personal communication, 1990).

In southeastern Taranaki Basin and western South Island (the West Coast Region), non-marine deposition continued (including coal measures), with a strong north-northeast fault control on subsidence. A regional transgression occurred in the southern part of this area towards the end of this time slice, accompanied by basaltic volcanism, but elsewhere there was subaerial erosion (Nathan & others, 1986).

Sandstone and siltstone sediments were deposited in a high energy tidal to shallow shelf environment throughout eastern North Island during the early part of this time slice. Conditions became rather more restricted during the late Campanian, with widespread deposition of siliceous mudstone which was more calcareous in the east, in the offshore direction (Speden, 1976; Black, 1980; Johnston, 1980; Moore, 1980, 1986, 1988b). There was penecontemporaneous alkaline volcanism in the far south of eastern North Island (Suggate & others, 1978; Moore, 1980).

The palaeogeography of the Canterbury and Chatham Rise regions are adapted principally from Field, Browne & others (1989), Herzer & Wood (1988) and Wood, Andrews, Herzer & others (1989). Environments in the Great South Basin are modified after Anderton & others (1982) and the Campbell Island/Campbell Plateau area has been interpreted from data in Beggs (1978), Cook (1981) and Anderton & others (1982). A block-faulted topography persisted on Chatham Rise, but faulting was much reduced and there was regional subsidence, with a gradual transgression and erosion of fault-block highlands. The landscape on Chatham Rise was one of low relief, with broad floodplains and restricted marginal marine embayments. Seismic data indicate large volcanic centres were active near the rise (Wood, Andrews, Herzer & others, 1989). Movements on faults in the Canterbury region eased during this time slice and transgression proceeded over part of the area. Fluvial quartzose coal measure deposition passed seawards into shelf sands and, farther offshore, into bathyal silts (Field, 1989; Field, Browne & others, 1989). The bathyal embayment on the map represents the Clipper Basin (see Field, Browne & others, 1989). Pyroclastic extrusive activity occurred in the shallow offshore area. On the opposite coast to the Chatham Rise, in Marlborough, glauconitic sediments accumulated slowly under reducing conditions (Suggate & others, 1978; M.G. Laird, DSIR Geology & Geophysics, personal communication, 1990).

Coal measures also accumulated in Western Southland, in a fault-controlled depression (Suggate & others, 1978). In the Kaitangata Sub-basin (Figure 5) of southeastern Otago, fluvial to estuarine coal measures formed in local basins after the main episode of basin faulting (time slices K8 - K9) was complete (Suggate & others, 1978; Carter, 1988).

There was much more subdued movement on the controlling faults of the Great South Basin in the Campanian - Maastrichtian, and there was also a more subdued land relief. The principal depocentre was near the zone of most intense sediment input, south of Otago and Stewart Island. However, significant detritus was still entering the basin from river systems in the southwest. Sedimentary facies included fluvial coal measures and paralic to shallow marine silts and sands. Prograding Campanian deltaic facies were overlapped by Maastrichtian shallow marine sediments along the northern margin of the basin, but the marine environment within the basin was restricted (Anderton & others, 1982).

The stratigraphy of Campbell Island (Beggs, 1978; Cook, 1981) provides the only control on sediment types within the Campbell Basin. In this basin, as in the Great South Basin, a progression from continental to marine sedimentation occurred in the Late Cretaceous (Anderton & others, 1982).

Time slice K10b therefore spans a time of transition from an extensional regime to one of regional subsidence accompanying seafloor spreading. Fault control on sedimentation had diminished, but large areas were still emergent, although relief was more subdued. Where parts of a former land area were now submerged, oceanic circulation was commonly restricted. Seafloor spreading was well under way in the Tasman Sea, southeast Indian and Southern Oceans, and marginal basins were opening in the New Caledonia region. Fluvial sediments deposited during this time interval are potential terrestrial source rocks for hydrocarbons, and the overlapping fine-grained marine facies provide potential seals.

TIME SLICE CZ1 (PALEOCENE - EARLY EOCENE)

Danian to Ypresian: 66.4 - 52 MA (MAP 5)

Seafloor spreading in the Tasman Sea and Southern Ocean continued. The associated lithospheric cooling, regional subsidence and transgression, which began towards the end of the Cretaceous, was a dominant feature of time slice Cz1. There was widespread deposition of siliceous shale, reflecting the relatively quiescent environment. Spreading in the Tasman Sea ceased by the Early Eocene (~55 Ma; Shaw, 1990), but spreading continued between the Indo-Australia/Pacific and Antarctic Plates, as a result of which New Zealand continued to move gradually northwards. Stewart Island was at approximately 60°S by the Late Paleocene. The climate remained cool-temperate, but there were warm marine currents and temperatures rose at the beginning of the Eocene (see Hornibrook, 1971; Molnar & others, 1975; Field, Browne & others, 1989; maps in Walley & Ross, 1991).

In Northland, glauconitic sand and siliceous mudstone were deposited in a starved marine basin (Hornibrook & others, 1976; Brook & others, 1988; Isaac & others, 1988). Sedimentary environments in the Taranaki Basin ranged from broad coastal plain to shoreface and shallow shelf. Quiescent sedimentation prevailed, but intercalated muds and lensoid sands indicate a fluctuating Paleocene shoreline (Palmer, 1985; King & Robinson, 1988; Robinson & King, 1988). Now that the former rift landscape was inundated, this region became a large embayment, open to the sea in the New Caledonia Basin.

In southeastern Taranaki Basin and western South Island (the West Coast Region), non-marine deposition continued (including coal measures), with a strong north-northeast fault control on subsidence. A regional transgression occurred in the southern part of this area, accompanied by basaltic volcanism, but elsewhere there was subaerial erosion (Nathan & others, 1986).

Deposition of siliceous mudstone and black shale characterised eastern North Island during the Paleocene. Marine conditions were restricted, with reduced oxygen circulation, abnormal salinity and elevated water temperature (Moore, 1988b, 1989). The Paleocene Waipawa Black Shale is potentially a significant petroleum source rock. Similar sediments were deposited in New Caledonia at this time (discussed below). By the Eocene, much of eastern

North Island lay at bathyal depths and conditions were less restricted (Moore & Morgans, 1987). There was penecontemporaneous alkaline volcanism in the far south and far north of eastern North Island, but the Matakaoa Volcanics in the north have faulted contacts and may be allochthonous. Stratabound manganese mineralisation associated with these volcanic rocks tends to support their possible origin in deeper ocean farther from New Zealand than their present position (see Suggate & others, 1978; Moore, 1980; Pirajno, 1980; Strong, 1980; Brothers & Delaloye, 1982; Moore, 1988a).

The large areas of land exposed during the Cretaceous were reduced in extent during this time slice. The palaeogeography of the Canterbury region is modified after Field, Browne & others (1989) and that of the Great South Basin (Campbell Plateau) is adapted from Anderton & others (1982). A fine-grained fluvio-deltaic coal measure system covered much of southern Canterbury, and mudstone and greensand were deposited in restricted conditions in the paralic zone. These sediments passed basinwards into organic-rich mudstone. Widespread basaltic volcanism accompanied sedimentation (Field, Browne & others, 1989). In the Great South Basin, clastic sediment input was now restricted to the northern flank, where rivers carried material through several delta systems into the basin. Lithologies and depositional environments were similar to those in Canterbury: fluvial to paralic coal measures, progradational deltaic fans and restricted marine shale. Well information records a vertical gradation from paralic to marine environments during this time slice, as subsidence and transgression proceeded (Anderton & others, 1982). Fine-grained silicified calcareous sediments were deposited in Marlborough and, again, record slow regional subsidence (M.G. Laird, DSIR Geology & Geophysics, personal communication, 1991).

Palaeogeographic information for Chatham Rise is sparse. Isopachs indicate that much of western Chatham Rise was emergent during the Paleocene and at least part of the area remained emergent into the Eocene. In the Chatham Islands area, Paleocene glauconitic sands were succeeded by Eocene shelf to bathyal carbonates, as subsidence of the Rise progressed. Basaltic volcanics were erupted in marine waters near the Islands (Campbell & others, 1988; Wood, Andrews, Herzer & others, 1989). Gradual subsidence during time slice Cz1 is also recorded in the Campbell Island area, where estuarine and shallow marine sediments are overlain by bathyal siliceous ooze. Authigenic phosphorite occurs in Early Eocene marine sediments on Campbell Island, above a Late Paleocene to earliest Eocene hiatus (Beggs, 1978; Cook, 1981). A Late Paleocene hiatus is also recognised in part of Canterbury, the Great South Basin, part of the West Coast Region and the New Caledonia Basin, and there is no recorded deposition of this time slice age on Mernoo Bank, Chatham Rise (Burns, Andrews & others, 1973; Anderton & others, 1982; Nathan & others, 1986; Field, Browne & others, 1989; Wood, Andrews, Herzer & others, 1989). Uplift occurred at the time of this hiatus in part of both the Great South Basin and the Canterbury region (Anderton & others, 1982; Field, Browne & others, 1989). Field, Browne & others (1989) correlated the hiatus with a relative sea level fall shown on the Haq & others (1987) chart. This is corroborated by Anderton & others (1982), who suggested that the Great South Basin was occupied by a brackish, euxinic lake in the latest Paleocene. It should also be noted that there was apparently a hiatus throughout this time slice in much of southern South Island (Southland and Clutha) and latest Paleocene and/or Early Eocene deposits are absent in the bulk of the West Coast Region. A latest Paleocene to Early Eocene hiatus is also evident in the Tasman Sea (DSDP 283, Kennett, Houtz & others, 1975) and on the Lord Howe Rise (Burns, Andrews & others, 1973). The hiatus and relative sea level fall appear to correspond approximately with the cessation of spreading in the Tasman Sea and the plate rearrangement which commenced at this time.

Siliceous argillite and black shale were deposited throughout New Caledonia during time slice Cz1, with the exception of a portion of the uplifted "Central Chain" which was probably still emergent, although a source area of mature relief (see Paris, 1981). The sediments are similar to those of eastern North Island (Moore, 1988b).

The bathymetry shown for the region between New Zealand and New Caledonia is speculative. Areas of probable Cretaceous rift-valley sediments (see Willcox, 1981) would have been gradually inundated during the latest Cretaceous and throughout this time slice. These areas are tentatively indicated as bathyal marine. South Tasman Rise is inferred to have remained emergent until the Late Eocene (time slices Cz2a/Cz2b), when shallow marine detrital sediments were deposited on the Palaeozoic continental basement core of the rise (Kennett, Houtz & others, 1975; Willcox, 1981, 1986).

Time slice Cz1 was thus a period of lithospheric cooling, subsidence and transgression in the New Zealand region, associated with seafloor spreading in the Tasman Sea and Southern Ocean. There is some evidence, however, for extension with marginal basin formation in the New Caledonia area. Sedimentary facies indicating restricted oceanic circulation were widespread in the Paleocene (Moore, 1988b). Episodes of basaltic volcanism in the South Island may be associated with both the final stages of opening of the Tasman Sea and the increase in spreading rate between Australia and Antarctica which closely followed cessation of spreading in the Tasman Sea (see Cande & Mutter, 1982; Field, Browne & others, 1989; Shaw, 1990).

TIME SLICE CZ2B (LATE EOCENE)
Priabonian: 40 - 36.5 MA (MAP 6)

During this period there were major palaeogeographic changes in the southwest Pacific as a result of a reorientation of plate rotation vectors at about 43 Ma (see Wells, 1989). The plate boundary along the northern Norfolk Ridge became obliquely convergent and this convergence continued throughout time slice Cz2b, until the Early Oligocene (Brothers, 1974; Paris, 1981; Brothers & Lillie, 1988). The South Fiji Basin began to open at the end of this time slice (Malahoff & others, 1982; see "Time Slice Cz4a" and Figure 9). Spreading began along an extension of the southeast Indian Ridge to the southwest of New Zealand, creating the Emerald Basin, and to the north of this spreading ridge a zone of extension developed through western New Zealand (see Kennett, Houtz & others, 1975; Kamp, 1986a, 1986b; Nelson & others, 1986; Walley, 1991a). The resulting palaeogeographic environments are discussed below.

The *Kaiatan* and *Runangan* Stages (late time slice Cz2a and time slice Cz2b) mark the warmest episode of the whole Tertiary. Conditions were probably tropical in Northland and New Caledonia (Kear & Schofield, 1978; Suggate & others, 1978; Paris, 1981). There was, however, a cooling of marine waters at around the Eocene/Oligocene boundary, reflecting the development of circum-Antarctic currents (see Kennett, 1980).

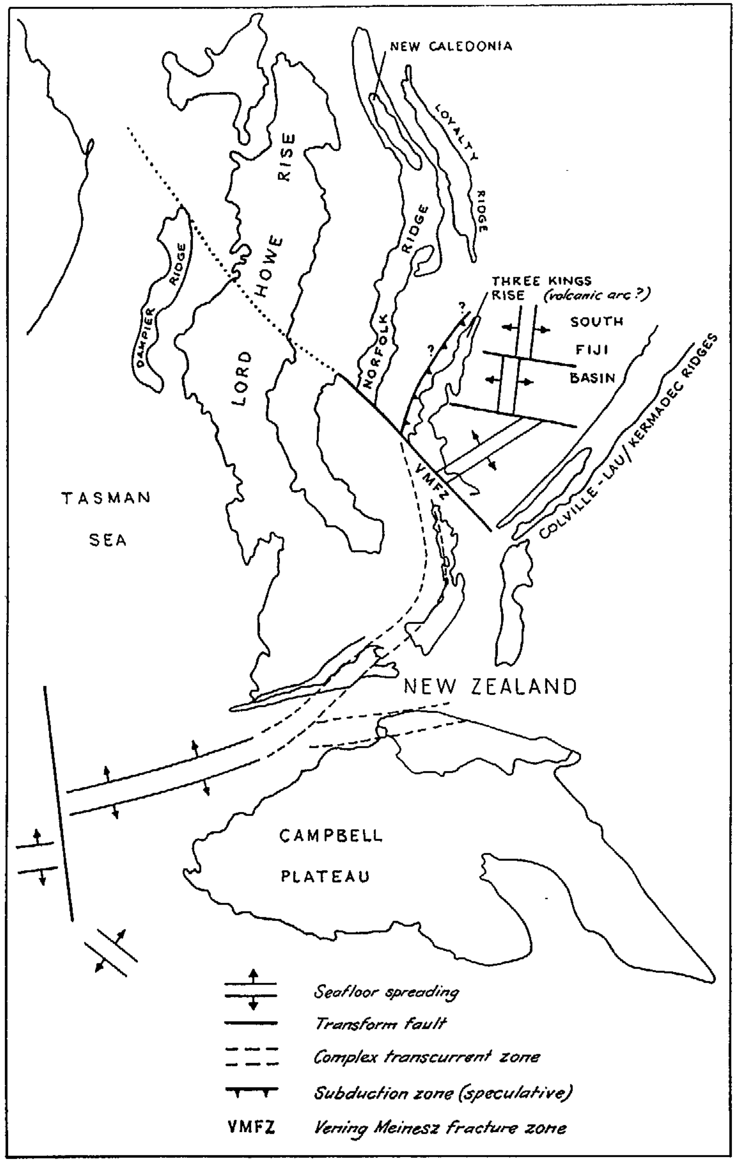


FIGURE 9 Diagrammatic representation of seafloor spreading and associated tectonic setting: Time Slice Cz4a

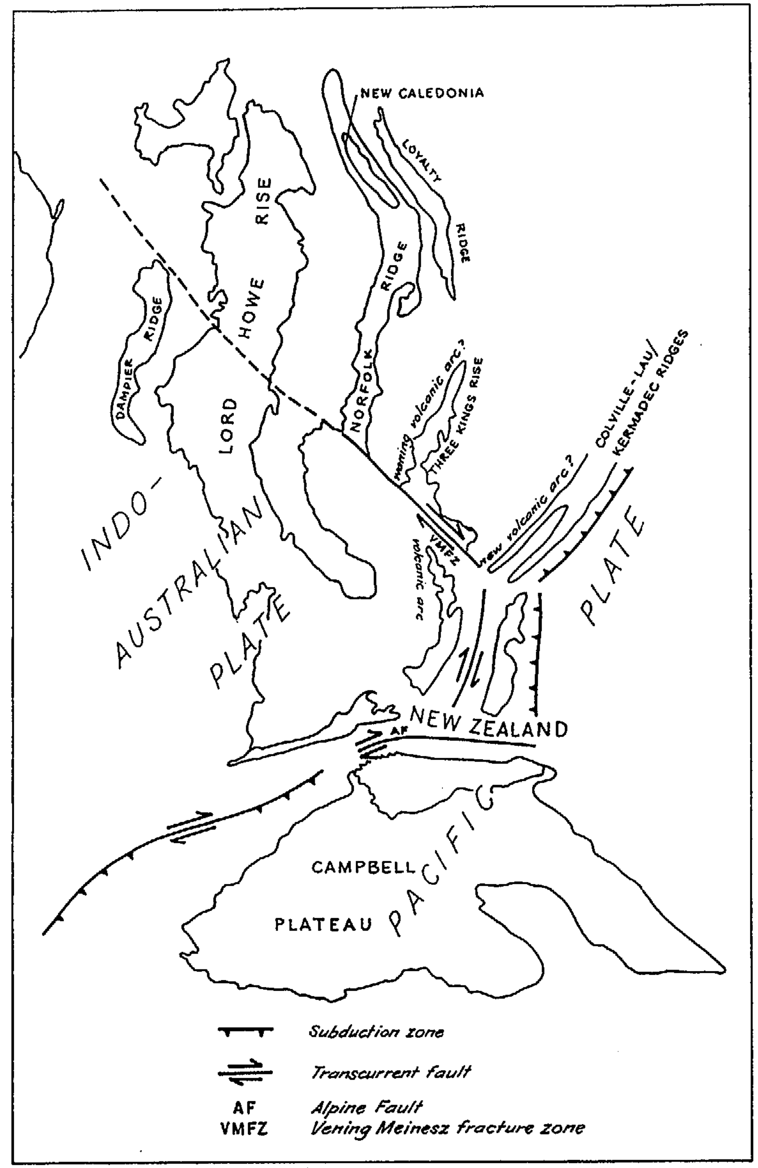


FIGURE 10 Plate tectonic setting: Time Slice Cz4b

Following an Early to Mid-Eocene hiatus over much of New Zealand, there was a further extensional phase during time slices Cz2a and Cz2b. A zone of actively subsiding basins developed along the western margin of New Zealand, parallel with and to the north of the spreading ridge referred to above. Accompanying the extension, basaltic volcanism occurred in Canterbury, Chatham Rise, southwestern New Zealand, Challenger Plateau and southern Lord Howe Rise (see discussion and references in Walley, 1991a).

Coal measures accumulated in a terrestrial to paralic environment in western North Island, Clutha and western South Island, in basins of similar trend to those of the early Late Cretaceous (Kear & Schofield, 1978; Suggate & others, 1978; Nathan & others, 1986). Fluvial coal measures also formed in the newly-created Te Anau and Waiau Basins (Figure 8), where sediment was derived from central and northern Fiordland (Turnbull, 1985; Turnbull & others, 1989). West of the Te Anau Basin, the fluvial sediments interfingered with deltaic and probable shallow marine sandstone (Turnbull, 1986). This area has been displayed as paralic on the map. The distribution of terrestrial and paralic environments was less extensive than that during time slice Cz2a, as transgression proceeded (for example, Anderton & others, 1982; Robinson & King, 1988; Field, Browne & others, 1989). Shallow marine environments of restricted circulation prevailed in the Taranaki Basin and Canterbury region (Shell BP and Todd Oil Services Limited, 1975; Field & Browne, 1986). Glauconite, indicative of slow shallow marine sedimentation, was common (see Map 6).

The palaeogeography of Northland is adapted from Hayward & others (1989), western South Island (the West Coast Region) is modified after Nathan & others (1986), and the Canterbury and Chatham Rise regions are modified after Field, Browne & others (1989) and Wood, Andrews, Herzer & others (1989). Paralic environments in the Canterbury/Clutha regions and the Great South Basin were probably quite extensive (see also Suggate & others, 1978; Anderton & others, 1982). The Chatham Rise had by now become a marine plateau. Bioclastic limestone accumulated on banks, and chalk and chert were deposited on the bathyal part of the platform, where there was local erosion (Wood & others, 1989). Calcareous mudstone and micritic limestone sedimentation predominated in the Canterbury region and similar sediments were deposited in the Great South Basin (Anderton & others, 1982).

There was a hiatus during time slice Cz2b in part of the marine area between New Zealand and New Caledonia and this probably reflected the major tectonic events along the northern Norfolk Ridge. Deformation occurred in the New Caledonia Basin and this is represented by an unconformity in the sequence at Deep Sea Drilling Bore 206 (Burns, Andrews & others, 1973; Eade, 1988). Boundaries of marine environments in this region are, in view of the lack of data, approximate and inferred from bathymetric control in older and younger time slices.

The North and South Loyalty Basins opened in the Middle Eocene, immediately prior to time slice Cz2b, as back-arc basins to an east-dipping subduction zone along Norfolk Ridge (see Weissel & others, 1982; Walley & Ross, 1991). In New Caledonia, the locus of maximum subsidence moved from the north to the south at about the same time, and this change persisted during time slice Cz2b. Turbidites were deposited in the fault-controlled bathyal marine environment. During the change in configuration of this plate boundary to one of oblique convergence, newly-formed oceanic crust was obducted from the northeast onto New Caledonia. Clasts of reworked serpentinite in uppermost Eocene littoral sands indicate that there was penecontemporaneous progressive uplift, and by the close of this time slice much of New Caledonia was emergent (Paris, 1981).

The d'Entrecasteaux Zone was probably a marginal basin from the Middle Eocene until the early part of this time slice and may have been contiguous with the North Loyalty Basin. During the latest Eocene and earliest Oligocene the zone is thought to have been the arcuate continuation of the convergent plate boundary discussed above (Daniel & Katz, 1981; Maillet & others, 1982). This zone has accordingly been displayed as an inferred bathyal bathymetric feature on the map. Andesitic volcanism in the northernmost North Loyalty Basin suggests the presence of a nearby island arc, which is possible if the convergent plate boundary was situated along the arcuate trend of the d'Entrecasteaux Zone (see Andrews & others, 1975; Kroenke & Rodda, 1984).

During this time slice, therefore, there was oblique plate convergence along the northern Norfolk Ridge, whereas extension occurred in the New Zealand region. The coal measures which accumulated in the New Zealand basins are potential terrestrial hydrocarbon source rocks, and the fine-grained sediments deposited in paralic to restricted marine environments also have source rock potential (see, for example, Nathan & others, 1986; Field, Browne & others, 1989). In Canterbury, however, potential source rocks younger than the latest Cretaceous are probably immature for hydrocarbon generation (Field, Browne & others, 1989).

TIME SLICE CZ4A (LATE OLIGOCENE TO EARLIEST MIOCENE)
Chattian to Aquitanian: 30 - 22 MA (MAP 7)

The 22 Ma boundary between time slices Cz4a and Cz4b is approximate, because the major plate reorganisation in the eastern Pacific which occurred at about this time was reflected in tectonic events which occurred over several million years. The Alpine Fault was initiated at this time (see "Time Slice Cz4b"). Movement on this sector of the Indo-Australian/Pacific Plate boundary is thought to have commenced at about ~23 Ma (see Kamp, 1986a) and may have begun at ~25 Ma (Kamp, 1991). In order that this map is more representative of the bulk of time slice Cz4a, Late Oligocene, pre-Waitakian Stage (i.e., 30 - 24 Ma) environments are shown in New Zealand.

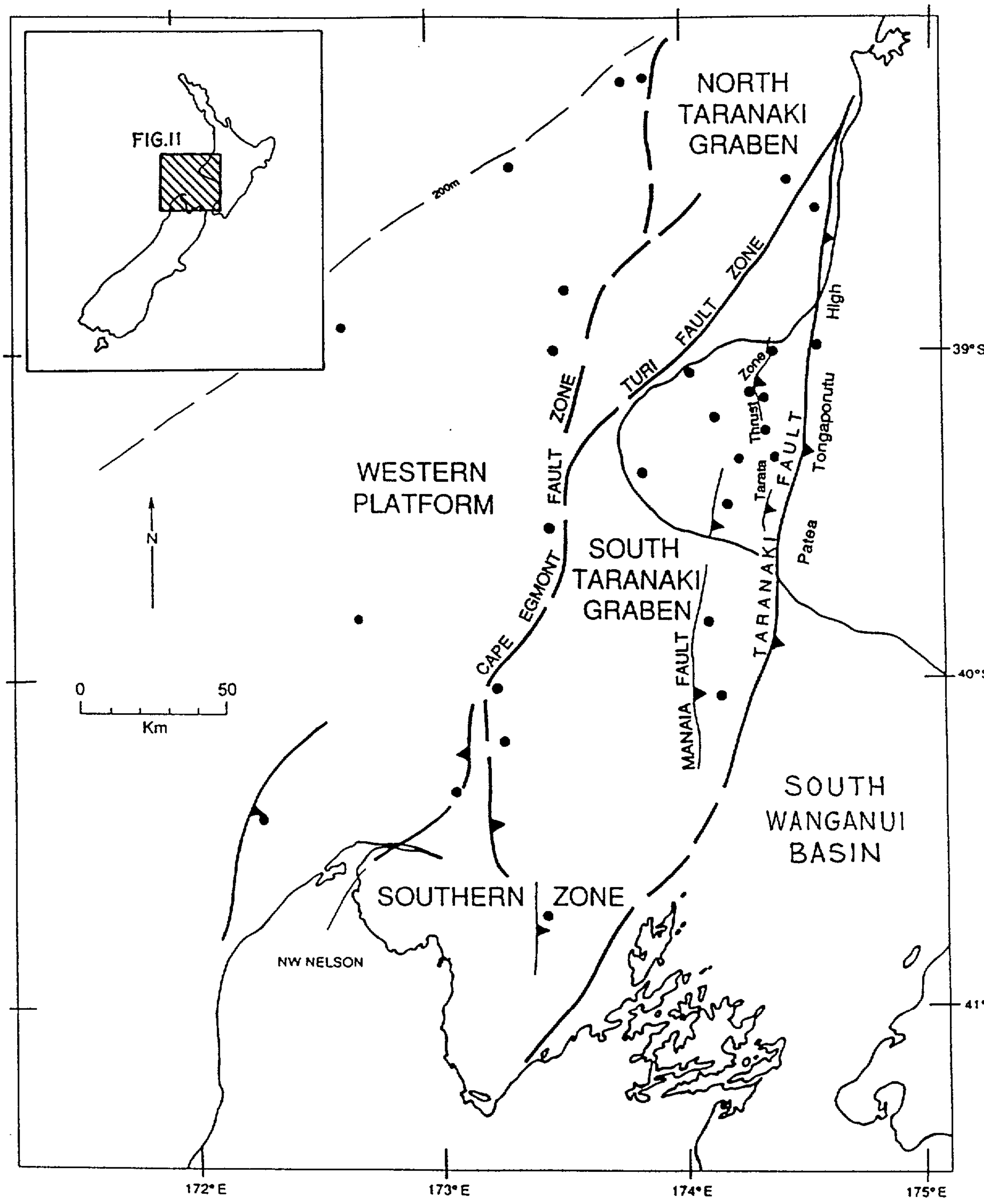
There was a climatic cooling in this region during the Oligocene, reflecting the development of circum-Antarctic currents (Kennett, 1980), although the climate was probably still warmer than the present climate of New Zealand (Suggate & others, 1978). The Australian and Antarctic Plates became completely separated in the mid-Oligocene (see Willcox & Stagg, 1990). The Antarctic continental ice sheet existed by that stage and may have been developing from the Early Oligocene onwards (Barrett, 1986). Northwards movement of both the New Zealand - New Caledonia region and Australia progressed, in association with the continued spreading of the southeast Indian and Southern Oceans.

The spreading ridge in the south Tasman Sea and Emerald Basin was still active. By time slice Cz4a, the area of extension through western New Zealand to the north of this spreading ridge had become a more complex zone of probable transcurrent movement (see King, 1990; King & Thrasher, in press and Figure 9). Some of the associated complex depositional environments are outlined below.

After the Eocene extension in the New Zealand region, there was regional subsidence and transgression through the Oligocene. Crustal extension continued in Western Southland, where there was probably transtensional movement on basin margin faults (Norris & Carter, 1980; Uruski & Turnbull, 1990), and within the Canterbury region (Sewell & Gibson, 1988). By the Late Oligocene much of what is now onshore New Zealand was submerged, with widespread carbonate sedimentation (see Suggate & others, 1978; Kamp, 1986b and stratigraphic chart in Walley, 1991a). Glauconite, indicative of slow stable deposition, is common. For example, in southeastern Otago, thin shallow marine phosphatic and glauconitic sands were deposited on a stable platform (Anderton & others, 1982). The extent of marine environments across the presumed area of unclassified land between the present-day shapes of New Zealand is not known. Within most of the Campbell Plateau, there was an open marine bathyal environment (Kennett, Houtz & others, 1975; Anderton & others, 1982; Cook & Beggs, 1990).

There were, during this time slice, early manifestations of a new stress regime through the New Zealand region which became fully developed during time slice Cz4b. In the Taranaki Basin, sudden basin deepening occurred west of the reactivated Taranaki Fault (Figure 11) and this may have marked the onset of compression, with foreland basin development west of this now compressive fault (King & Robinson, 1988; King, 1990). Fault-controlled rapid basin deepening also occurred in Western Southland (Turnbull & others, 1989). Thick deep-water carbonate sediments accumulated in the Murchison Basin (West Coast Region), which had a faulted eastern margin during the Oligocene (Nathan & others, 1986). There was differential movement of fault-blocks during sedimentation in the North Wanganui Basin and a southerly shift in the zone of maximum sediment accumulation with time (Nelson & Hume, 1977).

There were areas of paralic coal measure formation in eastern Southland (Clutha region) and western Canterbury. The extent of these on the map is inferred, but modified after Suggate & others (1978). The youngest Brunner Coal Measures (West Coast Region) were still accumulating in a fluvial environment during the early part of this time slice in northern South Island (Nathan & others, 1986).



Dots mark location of key wells

FIGURE 11 **Taranaki Basin - location and main structural elements From King (1990)**

Local hiatuses occurred during this time slice and particularly affected the South Island, Campbell Plateau and Chatham Rise (for discussion and stratigraphic chart see Walley, 1991a). Some of the hiatuses can be linked to changes in oceanic circulation related to regional tectonic events: for example, towards the end of this time slice, coincident with the reorganisation of the Indo-Australia - Pacific Plate boundary in the New Zealand area, there was a major increase in bottom-water circulation over the Campbell Plateau, causing substantial submarine erosion and non-deposition (see Kennett, Houtz & others, 1975). Doming and uplift of Mernoo Bank (Chatham Rise) probably began towards the end of this time slice, associated with impaction of Chatham Rise against the plate boundary (Herzer & Wood, 1988). This area is shown as possibly shallow marine on the map.

North of New Zealand, the South Fiji Basin opened in the Oligocene, from ~36 - 26 Ma (Malahoff & others, 1982). This spreading has been associated with movement along the Vening Meinesz Fracture Zone (dashed line on map; Cole, 1986; Kamp, 1986a). There does not appear to have been volcanic activity on Lau Ridge at this time, and it is possible that the South Fiji Basin opened as a back-arc basin to an arc along Three Kings Rise (as shown on Map 7). The island arc volcanics along the rise may in fact be related to an east-dipping subduction zone (Kroenke & Dupont, 1982; Kroenke & Eade, 1982), in possible association with subduction of Norfolk Basin seafloor under the rise from the west (Eade, 1988). The terminal obduction of Norfolk Basin oceanic crust over the southern half of Three Kings Rise (see Korsch & Wellman, 1988) probably occurred at about the time of obduction of oceanic crust on to Northland (Brothers & Delaloye, 1982; see below). These events are speculative, as there are no age data for the Three Kings Rise (see "Time Slice Cz4b" and Walley & Ross, 1991). The Colville-Lau and Tonga-Kermadec Ridges were probably bathymetric features at this time, as there were areas of probable shallow marine limestone deposition on these ridges during the Late Eocene (see Katz, 1986; Dupont, 1988).

The obduction of oceanic crust onto Northland and eastern North Island at the close of this time slice (see discussion and references in Walley, 1991a; Walley & Ross, 1991) is not shown on the map. This event was probably triggered by movement along the Vening Meinesz Fracture Zone (dashed line on the map; also see Figure 9; Brothers & Delaloye,

1982) and was associated with the development of the modern convergent plate boundary in New Zealand (see "Time Slice Cz4b").

There are no Oligocene sediments preserved in New Caledonia. Dated granodiorites cutting the peridotite indicate that emplacement of the ultramafic nappe was complete well before this time slice (see Paris, 1981). It is inferred that New Caledonia underwent regional uplift following the obduction of the peridotite nappe and that it was largely emergent during this time slice (see Brothers & Lillie, 1988). Peneplanation of the island began towards the end of this time slice and is discussed in "Time Slice Cz4b". Detritus began to accumulate in a fluvio-deltaic environment on the west coast in the earliest Miocene (Paris, 1981).

The Loyalty Ridge existed as a sea floor rise prior to the Late Eocene (Katz, 1986). The islands were probably developing by the Early Miocene, in view of the presence of Early Miocene reef limestone and the probable commencement of volcanism on the southernmost island during this time slice (Paris, 1981).

A pelagic open ocean environment prevailed in marine regions between New Zealand and New Caledonia (see Burns, Andrews & others, 1973; Kennett, von der Borch & others, 1986). Volcanic ash (Kennett, von der Borch & others, 1986) indicates there may have been volcanism within central Lord Howe Rise, although the ash may have been transported from elsewhere. Basaltic intraplate volcanism commenced in the northern Tasman Sea due to a mantle hotspot. During subsequent time slices, this volcanism moved southwards along the Tasman seamount chain, tracking the northwards movement of the Indo-Australian Plate over the hotspot (McDougall & Duncan, 1988).

There was alkaline basaltic oceanic volcanism in the Auckland Islands (Cook, 1981). Late Oligocene tholeiitic volcanism in Canterbury is considered to have been associated with crustal extension, referred to above (Sewell & Gibson, 1988).

Time slice Cz4a was thus a period of maximum marine inundation of the present-day New Zealand land area, with widespread carbonate platform sedimentation. However, this was not a quiescent period. Crustal extension continued in parts of the South Island region and there were also early manifestations of a new stress regime which dominated the New Zealand region from time slice Cz4b onwards, associated with a reorganisation of the Indo-Australian/Pacific Plate boundary. The plate boundary had moved away from New Caledonia prior to this time slice and the island was now emergent. There was seafloor spreading both to the south (South Tasman Sea - Emerald Basin) and north (South Fiji Basin) of New Zealand. The complex way in which these zones of spreading were linked through the New Zealand region has not been entirely resolved (see, for example, Norris & Carter, 1980; Kamp, 1986a, 1986b; King, 1990; King & Thrasher, in press).

TIME SLICE CZ4B (EARLY MIOCENE TO EARLY MID-MIOCENE)
Burdigalian to Langhian: 22 - 15.2 MA (MAP 8)

In the latest Oligocene to Early Miocene (late in time slice Cz4a to time slice Cz4b), there was a major change in the New Zealand tectonic regime. At this time, the Indo-Australian/Pacific Plate boundary migrated southwards from the Tonga-Kermadec subduction system into New Zealand. A subduction complex developed in eastern North Island and the Alpine Fault was initiated at this time, marking the continuation of the plate boundary through the South Island (see Kamp, 1986b; Figure 10).

This event was reflected in the change from an extensional regime to a compressional regime in New Zealand, with the inversion of some sedimentary basins and the creation of new depocentres. For example, west of the Alpine Fault, the Paparoa Trough was inverted at the end of time slice Cz4a and its former eastern flank became the new depocentre, the Grey Valley Trough (Figure 12; Nathan & others, 1986). There was also a regional change in rate and type of basin sedimentation. In contrast to time slice Cz4a, thick clastic sediments were now deposited in North Island basins (including the Taranaki Basin), west of the Alpine Fault and in Canterbury and Marlborough.

Basins in the North Island were also uplifted and inverted. In Northland, ophiolites, which originated by transform motion at the Vening Meinesz Fracture Zone (Figure 10) were obducted from the northeast and carried with them an allochthon of Cretaceous - Oligocene

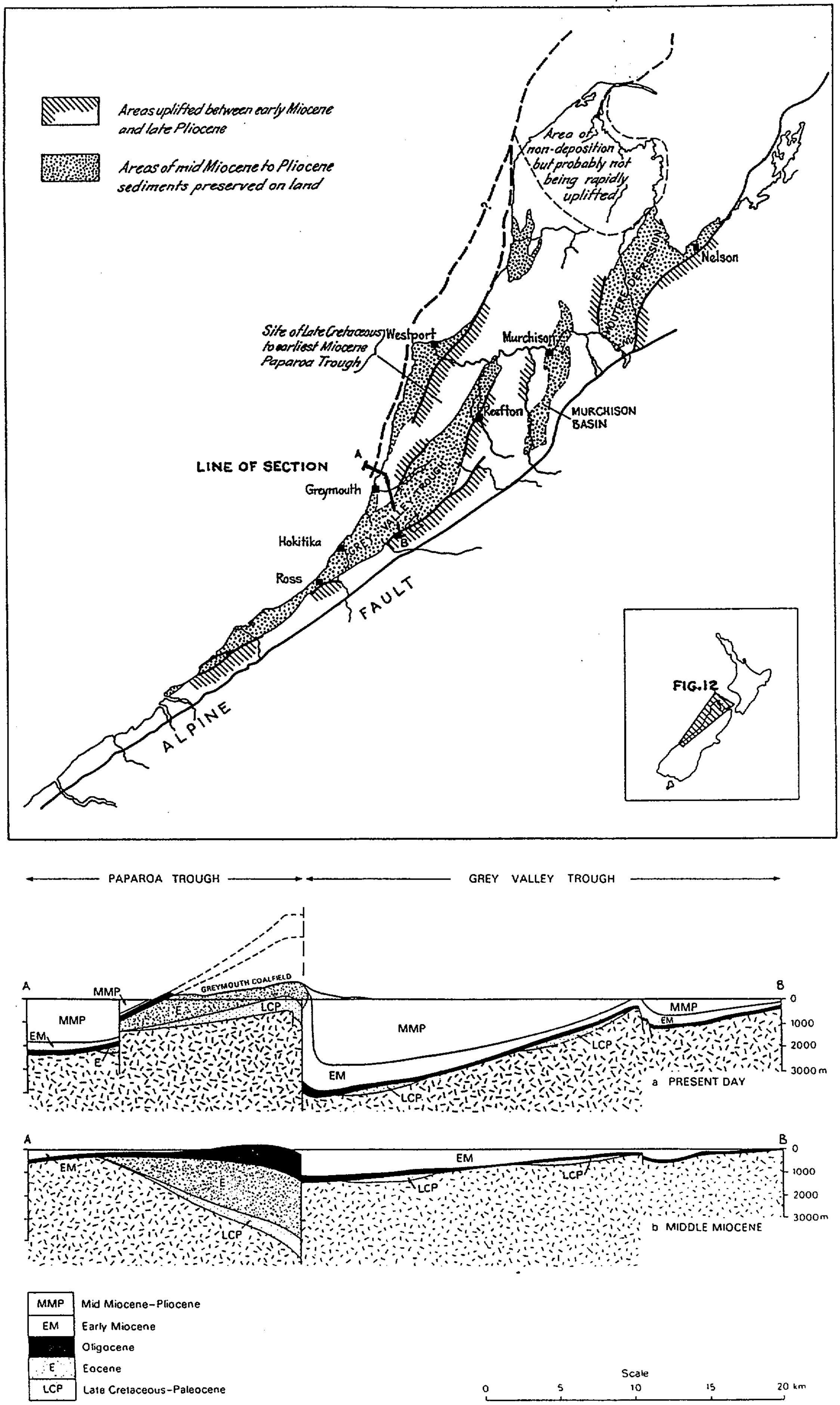


FIGURE 12 Neogene basin inversion, West Coast Region, South Island
Modified after Nathan & others (1986)

sediments (Brothers & Delaloye, 1982). A Miocene arc developed in Northland above the westerly-dipping subduction zone and the deep-water inter-arc Waitemata Basin formed. Emplacement of the Northland allochthon continued during deposition of the early part of the Waitemata Basin sequence (Ballance, 1974; Hayward, 1979; Hayward & others, 1989). Farther south, there was a clockwise rotation of the basin depocentre in the North Wanganui Basin, where terrigenous sedimentation predominated, with southward-directed turbidity flows entering the basin (McQuillan, 1977; Nelson & Hume, 1977). The depositional pattern here is more complex than that shown on the map: during the *Altonian* Stage paralic to fluvial coal measures (which today form a good potential reservoir unit) were deposited in a local fault-controlled depression (McQuillan, 1977). There was a marine connection between the North Wanganui and Taranaki Basins, across a saddle in the Patea-Tongaporutu High (McQuillan, 1977; Figure 11). Oblique compression accelerated on the Taranaki Fault in the Early to Mid-Miocene and, as a result, there was a substantial increase in clastic sediment supply to the Taranaki Basin adjacent to that fault. Most of Taranaki Basin was bathyal marine during this time slice (see Hayward, 1987; King & Robinson, 1988; King, 1990; King & Thrasher, in press).

The environmental interpretation for Canterbury is adapted from Field, Browne & others (1989). Non-marine coal measures formed locally both in Canterbury (Bishop, 1974) and Otago. A lake occupied most of central Otago during this time slice (Turnbull & Forsyth, 1988). Its former extent is uncertain because of later uplift and erosion in that area. Major uplift along the Alpine Fault did not begin until about 10 Ma, associated with transpression which started at about that time (see King & Robinson, 1988; Kamp & others, 1989; King, 1990; King & Thrasher, in press). However, there were clastic sources from east of the Alpine Fault in western South Island (Cutten, 1979; Nathan & others, 1986) and palaeocurrents in eastern South Island also suggest source areas adjacent to the Alpine Fault. Thus it is likely that much of the area along the Alpine Fault sector of the plate boundary was an area of uplift and erosion. This has been interpreted on the map. Macquarie Ridge may have formed a bathymetric high during this time slice (as shown). However, the main uplift of this ridge has occurred since the Pliocene, during oblique compression on the plate boundary (Kamp, 1986b).

Since the beginning of time slice Cz4b, eastern North Island has comprised an accretionary prism, associated with the onset of west-dipping subduction along the eastern side of the North Island (Hikurangi Trough). The boundaries of marine environments shown in this complex area on the map are approximate and generalised. Eastern North Island lay nearer Northland prior to the onset of dextral clockwise movement which accompanied the rotation of the subduction system to its present trend (see discussion in Walley & Ross, 1991). This movement was achieved by a combination of strike-slip faulting and dip-slip shortening along reverse faults, within a broad zone of distributed shear (Lewis, 1980; Kamp, 1987; M. Rattenbury, BMR, personal communication, 1991). On later time slice maps the movement is shown as having occurred along one structural boundary, because of the constraints used for the computerised reconstructions. In addition, the distance between western and eastern North Island prior to this movement is probably exaggerated. However, if the crust in this region was fairly thin prior to the dextral movement, then the two halves of North Island could have moved to their present positions from the distance shown without the creation of mountain ranges the height of the South Island Alps (also see "Time Slice K10b"). An area of unclassified land is tentatively placed within the former space between the present-day portions of New Zealand.

During the Early - Mid-Miocene, there was basaltic intraplate volcanism both in the northern Tasman Sea/western Lord Howe Rise area, and also east of the Alpine Fault within Campbell Plateau, Chatham Rise and Otago (Slater & Goodwin, 1973; Cook, 1981; McDougall & others, 1981; Coombs & others, 1986; Campbell & others, 1988; McDougall & Duncan, 1988).

Pelagic sedimentation characterised the bathyal to abyssal region between New Zealand and New Caledonia and most of Campbell Plateau/Chatham Rise. Little sediment is preserved within the Great South Basin and Campbell Plateau, where there was substantial submarine erosion during the Neogene because of a major increase in bottom-water circulation (Kennett, Houtz & others, 1975; Anderton & others, 1982). Uplift of Mernoo Bank (Chatham Rise), which began during time slice Cz4a, continued (Herzer & Wood, 1988).

As discussed above, the volcanic arc associated with the eastern North Island accretionary prism was in Northland. The position of the northerly continuation of this arc is controversial. It is shown on this map located along the Three Kings Rise, but this is by no means certain. The controversy surrounding the age and affinity of Three Kings Rise is discussed in Walley & Ross (1991) and "Time Slice Cz4a". There was an island arc along Lau Ridge during time slices Cz4c and Cz5 (Cole, 1986; Katz, 1986), but volcanism may have begun earlier, at about 22 Ma (Kroenke & Rodda, 1984). Thus it is possible that the arc related to the northerly continuation of the eastern North Island accretionary prism during time slice Cz4b lay along Lau Ridge.

Subsidence and peneplanation of the whole of New Caledonia continued until at least the Mid-Miocene, as indicated by high flat erosion surfaces which cut across the tectonically emplaced ultramafic massifs. Nickel concentration at the base of laterite horizons is considered to have begun during the peneplanation (Paris, 1981; Brothers & Lillie, 1988). The only preserved deposits of Cz4b age are in western New Caledonia, where there was a large delta and reef complex to the southwest of a hinterland undergoing erosion. The sea level around New Caledonia is thought to have been 100 to 150 m above that at the present day (Paris, 1981; Brothers & Lillie, 1988). There was alkali-basalt volcanism on Loyalty Ridge during time slice Cz5 (Late Miocene), but volcanism probably began earlier (Paris, 1981; Katz, 1986) and is therefore inferred during time slice Cz4b. It is not clear whether the volcanism was intraplate or arc-related. In the case of the latter, there does not appear to be any supporting evidence for a subduction zone near the Loyalty Ridge. This is discussed further in Walley & Ross (1991).

This time slice was therefore a period when there were major changes in sedimentary environment associated with a transition, in the New Zealand region, from an extensional regime to a compressive regime, in turn related to a reorganisation of the Indo-Australian/Pacific Plate boundary. Thick clastic sedimentation now predominated and a volcanic arc formed in Northland. The major Neogene regression on what is now onshore New Zealand had commenced. The plate boundary had moved away from New Caledonia during the Oligocene and that area became one of subsidence and peneplanation.

There was a temporary return to a warmer climate in the Early Miocene, when the northern North Island was probably tropical. Neogene climatic fluctuations, discussed in Suggate & others (1978), reflect the complex interplay between the influence of Antarctic ice sheet development and circum-Antarctic currents, the continued northwards movement of the New Zealand - New Caledonia region, and the increasing area of emergence and highland which developed during tectonic events in New Zealand.

TIME SLICE CZ6A (EARLY PLIOCENE)
Zanclean: 5 - 3 MA (MAP 9)

The subduction system, including the associated volcanic and island arcs and zones of back-arc extension, rotated further clockwise during this time slice. As a result, compression increased on the Alpine Fault sector of the plate boundary.

Transpression continued along the Alpine Fault and the western and eastern halves of South Island (New Zealand) moved nearer to their present-day positions. Major uplift along the Alpine Fault began immediately prior to this time slice (from 7 to 5 Ma onwards), forming the Southern Alps. Detritus from the rising Alps was shed both to the north and south of the Alpine Fault, forming vast prograding sediment wedges which entered basins in the West Coast region (South Island), Canterbury and Taranaki region (Nathan & others, 1986; Browne & Field, 1988; Robinson & King, 1988; Field, Browne & others, 1989; King, 1990). Fluvial sediments derived from nearby uplifted areas were also deposited in the Te Anau Basin (Turnbull, 1985).

The increased rate of compression along the plate boundary in the South Island was probably associated with the back-arc extension of the Havre Trough, north of New Zealand, which commenced at about 4 Ma (see Cole, 1986). At approximately this time (5 Ma or a little earlier), the southern part of the Taranaki Graben and the North Wanganui Basin were inverted and, coeval with this uplift, both the North Taranaki Graben and the South Wanganui Basin were created (Anderton, 1981; King & Robinson, 1988; King, 1990; King & Thrasher, in press; Figure 11). The rapidly subsiding North Taranaki Graben was bathyal marine during this time slice (Hayward, 1987; King & Robinson, 1988). A shallow sea transgressed across the South Wanganui Basin, which began to progressively subside to the south (Anderton, 1981). There were marine connections with the shallow sea covering eastern North Island (Suggate & others, 1978; Beu & others, 1980; Anderton, 1981; Kamp, 1982; Kamp & Vucetich, 1982). Shell banks accumulated approximately parallel to the coast in eastern North Island. These coquinas comprise one of the best potential petroleum reservoirs in that area (Harmsen, 1990). Seismic evidence indicates that Cook Strait (south of North Island) is unlikely to have provided a marine connection between western and eastern North Island during this time slice (Anderton, 1981). On the map, an area of unclassified land is shown blocking this marine connection.

The Hauraki inter-arc basin (between Northland and the Coromandel Peninsula) opened in the Late Miocene (Skinner, 1986) and during time slice Cz6a fluvial and paralic sediments accumulated in the new depression (Kear & Schofield, 1978).

The active island arc moved eastwards to Kermadec Ridge. In New Zealand the volcanic arc had been centred on Coromandel since the Mid-Miocene, but there was a progressive southwards movement of the focus of volcanic activity (Skinner, 1986). Intraplate, predominantly basaltic, volcanism occurred in western North Island (in a back-arc setting) and Norfolk Island, eastern South Island, Chatham Rise and Campbell Plateau (Jones & McDougall, 1973; Cook, 1981; Briggs, 1983, 1986; Campbell & others, 1988; Sewell & Gibson, 1988). There may also have been explosive volcanic activity on the eastern edge of Lord Howe Rise (Kennett, von der Borch & others, 1986).

Pelagic sedimentation characterised the bathyal to abyssal region between New Zealand and New Caledonia and most of Campbell Plateau/Chatham Rise. Little sediment is preserved within the Great South Basin and Campbell Plateau, where there was substantial submarine erosion during the Neogene (Kennett, Houtz & others, 1975; Anderton & others, 1982). Mernoo Bank (Chatham Rise) probably remained a shallow marine area (see Wood, Andrews, Herzer & others, 1989). Ice-rafted material present in the southern Emerald Basin from the Late Miocene onwards (Kennett, Houtz & others, 1975) indicates the climatic cooling of this region and the presence of icebergs near southernmost Campbell Plateau.

The peneplanation surface in New Caledonia underwent differential faulting, uplift and erosion during the Late Miocene and Early Pliocene. There was uplift to at least 1300 m in the central part of the island, but less on the western side (Dubois & others, 1974; Brothers & Lillie, 1988). The peneplain is thought to have been tilted down along its southwestern edge and up along its northeastern edge. Terrestrial breccias accumulated in the fault-controlled depressions (Brothers & Lillie, 1988). Lateritic breccia deposited in a fluvial to intertidal environment may have accumulated either during one of the quiescent phases in the uplift of the region (Paris, 1981), or may be a redeposited product of the Miocene peneplanation and deep weathering. The Loyalty Islands also underwent differential uplift, and the earliest and most substantial amount of uplift was in the most southerly island. Differential uplift of this region has been related to lithospheric bulging of the Indo-Australian Plate before its subduction at the New Hebrides trench (Paris, 1981; Brothers & Lillie, 1988). It is significant that, coeval with the uplift within the New Caledonia - Loyalty Ridge region, the Loyalty Ridge began to collide with the New Hebrides arc at about 8 Ma, due to commencement of clockwise rotation of that arc (Daniel & others, 1990).

Thus the Early Pliocene was a period during which there were clockwise movements of sectors of the Indo-Australian/Pacific Plate boundary, which involved creation of new zones of extension north of New Zealand, transpressional uplift in southern New Zealand, and differential uplift due to vertical tectonism in the New Caledonia region.

TIME SLICE CZ7 (PLEISTOCENE)
1.7 - 0.01 MA (MAP 10)

This interpretative map portrays the palaeogeography of the New Zealand - New Caledonia region during the last Quaternary glacial period. In New Zealand this was the Otira Glacial, the later glacial advances of which occurred between before 22,300 B.P. to 14,000 B.P. (Suggate & others, 1978).

The shoreline around New Zealand lay beyond the present day coastline, and part of the Taranaki Basin between North Island and South Island was emergent (see Suggate & others, 1978).

Late Quaternary glacial stages, when sea level was low, were characterised by extensive erosion and aggradation of river beds, with deposition of predominantly fluvial sediments. During the warmer interglacial stages of high sea level, coastal terraces were formed (Suggate & others, 1978). Within the last glacial period, sea level fell to approximately 135m below its present level (Suggate & others, 1978; Stevens, 1980). A maximum glacial low sea level stand of this magnitude has also been well documented around Australia (see discussion and references in Langford, 1990).

Suggate & others (1978) show the distribution of vegetation types in New Zealand during the Otira Glacial. Cool-temperate forest and sub-alpine grassland predominated. Periglacial conditions were widespread and there was deforestation in areas such as the North Island highlands (Suggate & others, 1978).

In the South Island, there was major uplift along the transpressional Alpine Fault from 7 to 5 Ma onwards (Kamp & others, 1989), forming the Southern Alps. This highland was the site of a major ice cap during the Otiran Glacial. The rate of uplift of ranges in eastern North Island increased in the Pleistocene (see Beu & others, 1980) and small ice caps developed on the highest peaks (see Suggate & others, 1978). Uplift and erosion of these highlands supplied large quantities of fluviatile gravel to surrounding areas. This process continues today in the building of the Canterbury and South Island west coast plains (Carter & Norris, 1976). Near the South Island ice caps, fluvioglacial sediments and till were deposited (see, for example, Suggate & others, 1978; Turnbull, 1985, 1988).

The extent of ice within the continental plateaus southeast of South Island is unclear, but moraine deposits on both Campbell Island and the Auckland Islands (Beggs, 1978; Cook, 1981) suggest the presence of local ice caps. Icebergs are considered to have been present within the bathyal to abyssal marine environment both in that area (see Stevens, 1980) and in the Emerald Basin west of the Campbell Plateau (Kennett, Houtz & others, 1975).

Uplift of land to the east of the Taranaki Basin continued to provide a large volume of sediment to the marine environment. As a result, shallowing of the basin continued and the shelf edge continued to prograde to the northwest during the Pleistocene, a process which continues to the present day (see Hayward, 1987; King & Robinson, 1988).

Volcanic activity continued west of the plate boundary in the North Island and east of the plate boundary in the South Island. Extension in the North Island ensialic back-arc basin and activity within its associated volcanic arc (which together comprise the Taupo Volcanic Zone) commenced less than 1 million years ago (see Cole, 1984; 1986; 1990; Stern & Davey, 1987). Back-arc intra-plate basaltic to andesitic volcanics were extruded in western North Island. They bear the same spatial relationship to the active volcanic arc of the Taupo Volcanic Zone as the Lau Basin does to the Tongan volcanic arc (Tonga Ridge). The basalts are explained as products of progressive melting of mantle diapirs formed by convection in the mantle wedge to the rear of the Taupo Volcanic Zone (Heming, 1980). Pyroclastic debris spread from these volcanic centres throughout North Island (particularly eastern North Island), where it was interbedded with fluviatile and paralic sediments (Fleming, 1953; Kear & Schofield, 1978; Suggate & others, 1978; Neef, 1984). Rhyolitic ash from the Taupo Volcanic Zone was also deposited as far east as the Chatham Islands, where it was interbedded with peat (Hay & others, 1970).

There was mafic intra-plate volcanism within Chatham Rise and Campbell Plateau (Field, Browne & others, 1989; Wood, Andrews, Herzer & others, 1989). Island-arc type volcanism on Solander Island, which began in the latest Pliocene, continued. This volcano is situated behind the east-dipping subduction zone south of the South Island (Puysegur Trench).

The major depocentres in the New Zealand region during the Quaternary have been controlled by crustal stresses related to the plate boundary. In the North Island, these significant areas of subsidence and thick sedimentation include the Hikurangi Trough accretionary prism (Lewis, 1980), the Raukumara Forearc Basin (Gillies and Davey, 1986) and the South Wanganui Basin. Since the Late Pliocene, the South Wanganui Basin has evolved as a foreland basin to the west of a fold-thrust belt (Katz & Leask, 1990). In the South Island, the Waiau Basin has also developed as a foreland basin, to the south of basement overthrusts

(Uruski & Turnbull, 1990). The Solander Basin, which is south of the Waiau Basin, has also been overthrust along its northern margin (Uruski & Turnbull, 1990). The Waiau and Solander Basins are in a similar position relative to the Puysegur Trench subduction zone as the South Wanganui Basin is to the Hikurangi Trough subduction zone.

Within the marine area to the north of New Zealand, environments have been depicted assuming a last glaciation sea level low stand. Thus the area now within the 1000m isobath is assumed to have then been a little larger. Some areas now at a depth of 200m or less were possibly emergent. On Lord Howe Island (Lord Howe Rise), a large bevelled platform was exposed around the island and was a source for calcareous material carried by wind and deposited on the island (McDougall & others, 1981). A similar exposed bevelled platform probably existed around Norfolk Island, where there are also Pleistocene aeolian calcarenites (Jones & McDougall, 1973). Palaeocurrents on Lord Howe Island (Standard, 1963) and the distribution of wind-blown Taupo volcanic ash in the Chatham Islands (Hay & others, 1970) indicate that prevailing winds south of the Tropic of Capricorn appear to have been, as they are now, from the northwest.

Pleistocene aeolianite is also present on Île des Pins, south of New Caledonia, and aeolianites were also deposited during glacial stages on the west coast of New Caledonia (Paris, 1981). Following Upper Miocene to Pliocene uplift of New Caledonia, there was subsidence there during the Pleistocene, with the submergence of some valleys and the development of the Great Barrier Reef. There was fluvial deposition along the western edge of New Caledonia, where poorly dated terraces and piedmont slopes are preserved. These are not present in eastern New Caledonia and their location in the west indicates differential subsidence of the west coast. New Caledonia had by now moved into low tropical palaeolatitudes, during the continued northwards movement of the Australia - New Caledonia - New Zealand region. Reef growth occurred during warm interglacial stages. During the arid glacial periods, there was regression and emergence of the reef, with deposition of reef-derived material as aeolianite (Coudray, 1976; Paris, 1981; Brothers & Lillie, 1988).

Reefs in the Loyalty Islands (Loyalty Ridge) and southern New Caledonia have been raised to various heights above sea level during Quaternary tectonic movements. This differential uplift has been related by Paris (1981) and Brothers & Lillie (1988) to bulging near the edge of the Indo-Australian Plate.

CONCLUDING REMARKS

In the Early Cretaceous, prior to the breakup of eastern Gondwana, the New Zealand - New Caledonia region was part of a convergent margin. There were marine environments at the margin, but most of the region was emergent, undergoing non-deposition, or uplift and erosion. New Zealand moved southwards towards the South Pole between time slices K1 and K8 and the climate was cool-temperate. Early extension at the eastern Gondwana margin began in the late Early Cretaceous (by time slice K7). There was widespread fault controlled deposition of thick terrestrial clastic sediments, which today provide potential source rocks and reservoirs for hydrocarbons.

The climate ameliorated during time slices K8 to K9, when southern New Zealand became warm and humid. A climatic deterioration from time slices K10a to K11 coincided with seafloor spreading and the generation of new ocean currents. New Zealand began to move northwards, away from its near-polar position, as seafloor spreading progressed. Regional subsidence accompanying seafloor spreading in the Tasman Sea and Southern Ocean continued during time slice Cz1. The fine-grained marine facies which overlapped the earlier terrestrial deposits are potential hydrocarbon seals. Oceanic circulation remained restricted during time slice Cz1 and widespread black shale, deposited during this relatively quiescent interval, is a rich potential source rock. The climate was cool-temperate during the latest Cretaceous and Paleocene. Temperatures rose in the Eocene and by time slice Cz2b the Tertiary climate was at its warmest. There was renewed extension in the New Zealand region, leading to subsidence and deposition of coal measures which are potential hydrocarbon source rocks. At the same time, there was oblique plate convergence along northern Norfolk Ridge (New Caledonia).

During the Oligocene, there was maximum inundation of the New Zealand land area, with carbonate platform sedimentation in time slice Cz4a. Climatic cooling in the Oligocene reflected the complete separation of the Australian and Antarctic Plates and the development of circum-Antarctic currents. However, the New Zealand - New Caledonia region continued to move northwards, in conjunction with continued spreading of the southeast Indian and Southern Oceans. There was a reorganisation of the Indo-Australian/Pacific Plate boundary in latest time slice Cz4a and, from time slice Cz4b onwards, New Zealand was dominated by a compressive regime. The plate boundary had by now moved away from New Caledonia, which in time slice Cz4b was an area of subsidence and peneplanation. Differential uplift of the New Caledonia area during time slices Cz5 to Cz7 has been associated with lithospheric bulging near the edge of the Indo-Australian Plate.

Neogene climatic fluctuations reflect the complex interplay between the influence of Antarctic ice sheet development and circum-Antarctic currents, the continued northwards movement of the New Zealand - New Caledonia region, and the increasing area of emergence and highland which developed during compression in the plate boundary zone through New Zealand.

During the Tertiary and Quaternary there have been clockwise movements of the plate boundary system. The regional clockwise shift in compression has caused uplift of older basins in some areas and extension and subsidence in other areas. Structural traps have been created by this tectonism. Most of the hydrocarbon accumulations in the Taranaki Basin occur in such Neogene structural traps (King, 1990).

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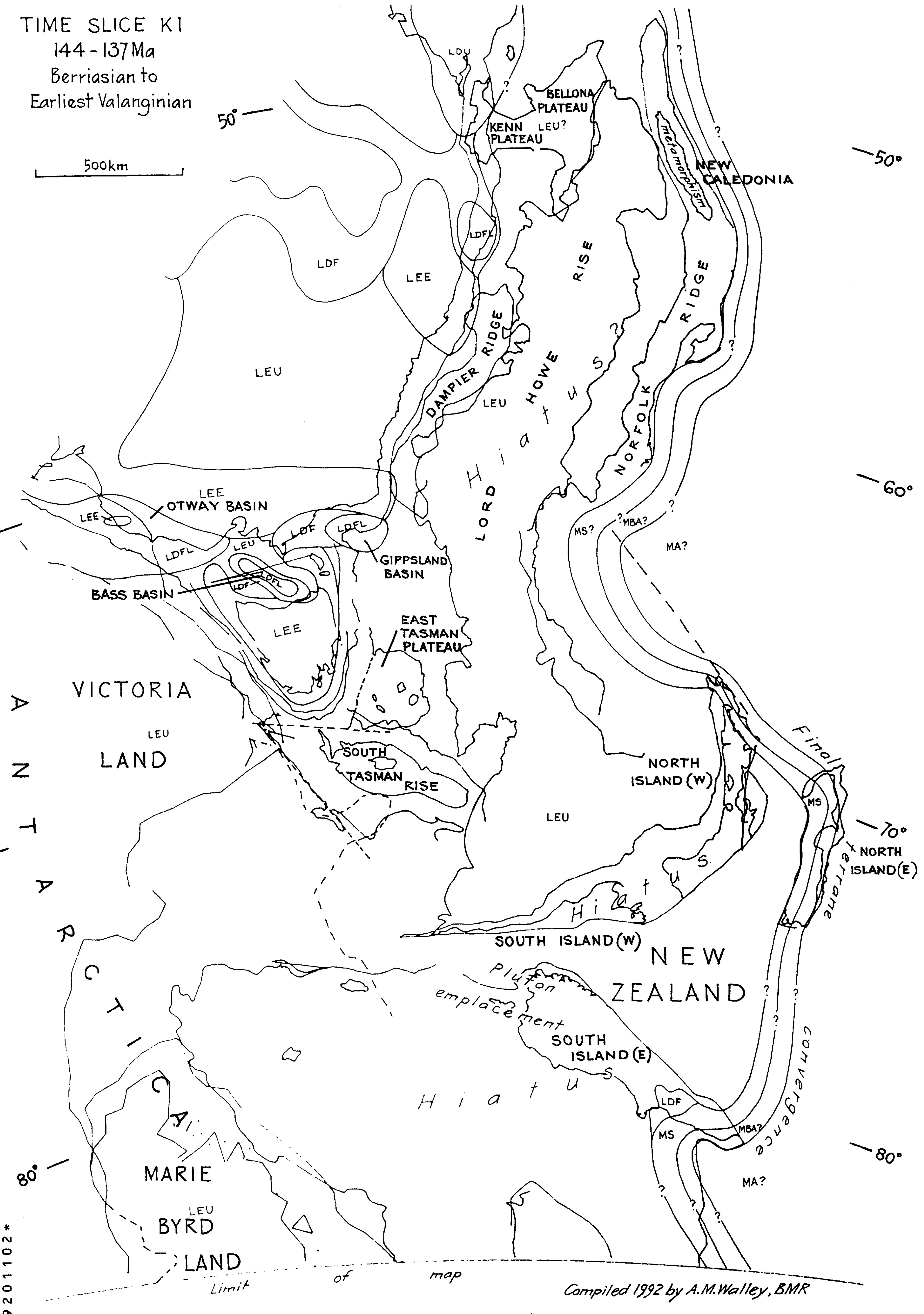
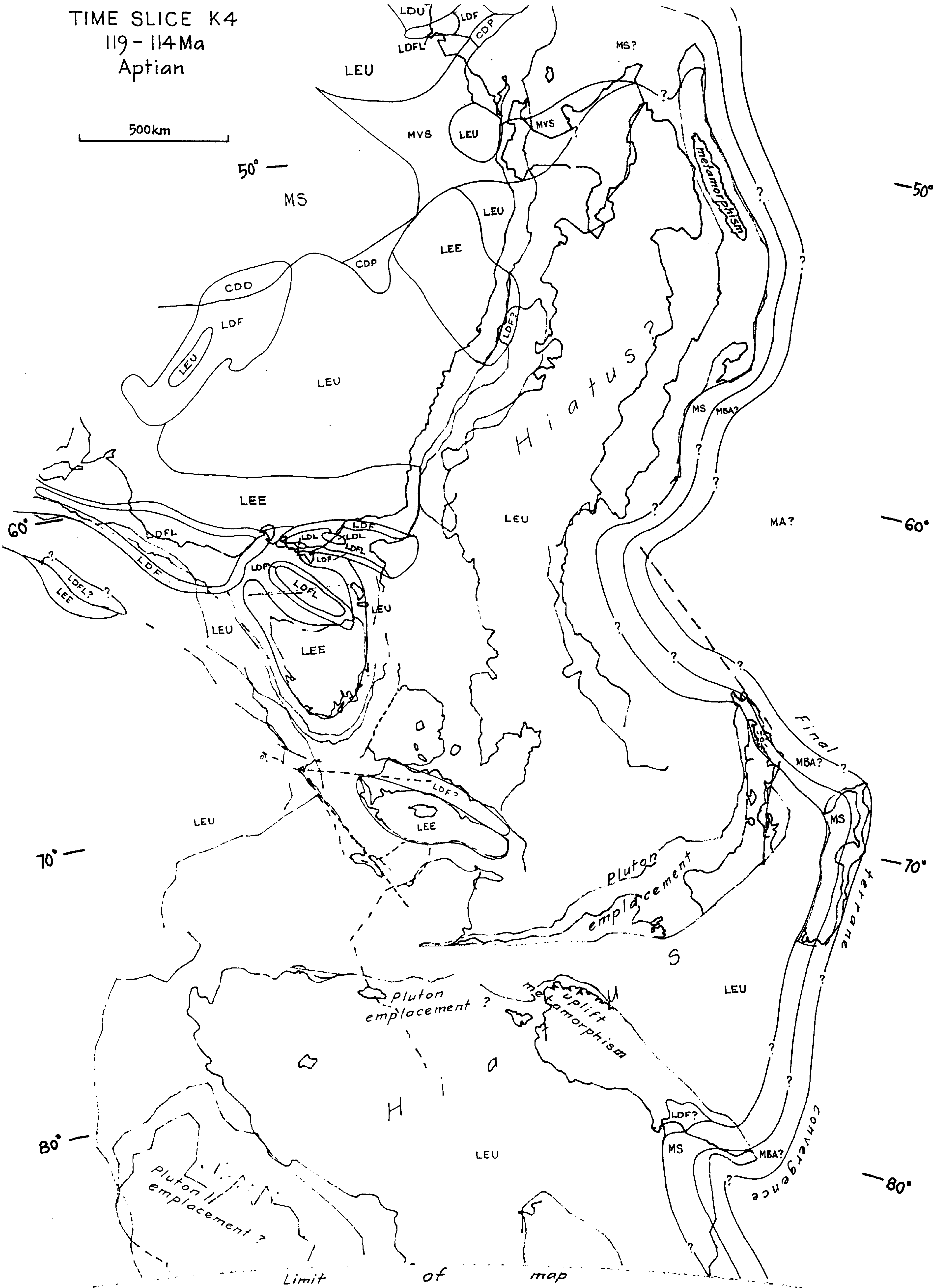
MAP 1


TIME SLICE K1
144 - 137 Ma
Berriasian to
Earliest Valanginian
500km
50°
60°
70°
80°
LDU
BELLONA PLATEAU
KENN PLATEAU
LEU?
metamorphism
NEW CALEDONIA
LDFL
LDF
LEE
LEU
RISE
HOWE
LORD
Hiatus?
NORFOLK RIDGE
DAMPIER RIDGE
OTWAY BASIN
LDFL
LDF
GIPPSLAND BASIN
BASS BASIN
EAST TASMAN PLATEAU
MS?
MBA?
MA?
VICTORIA LAND
ANTARCTICA
SOUTH TASMAN RISE
NORTH ISLAND (W)
Final terrane convergence
MS
NORTH ISLAND (E)
Hiatus
SOUTH ISLAND (W)
NEW ZEALAND
pluton emplacement
SOUTH ISLAND (E)
MBA?
MARIE BYRD LAND
Limit of map
Compiled 1992 by A.M.Walley, BMR
incorporating data supplied by DSIR, Geology & Geophysics, New Zealand

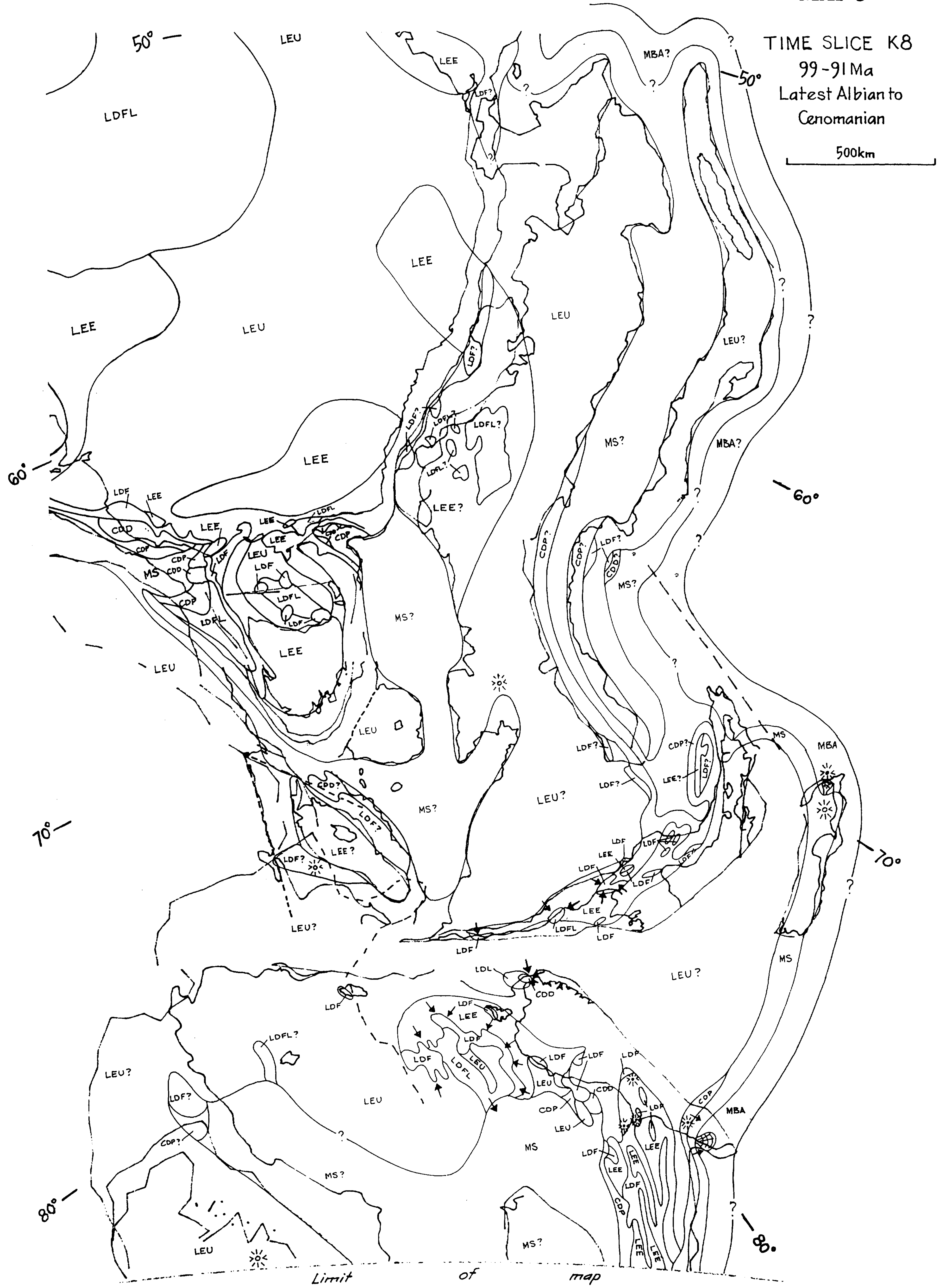
MAP 2



Compiled 1992 by A.M.Walley, BMR

incorporating data supplied by DSIR, Geology & Geophysics, New Zealand

MAP 3



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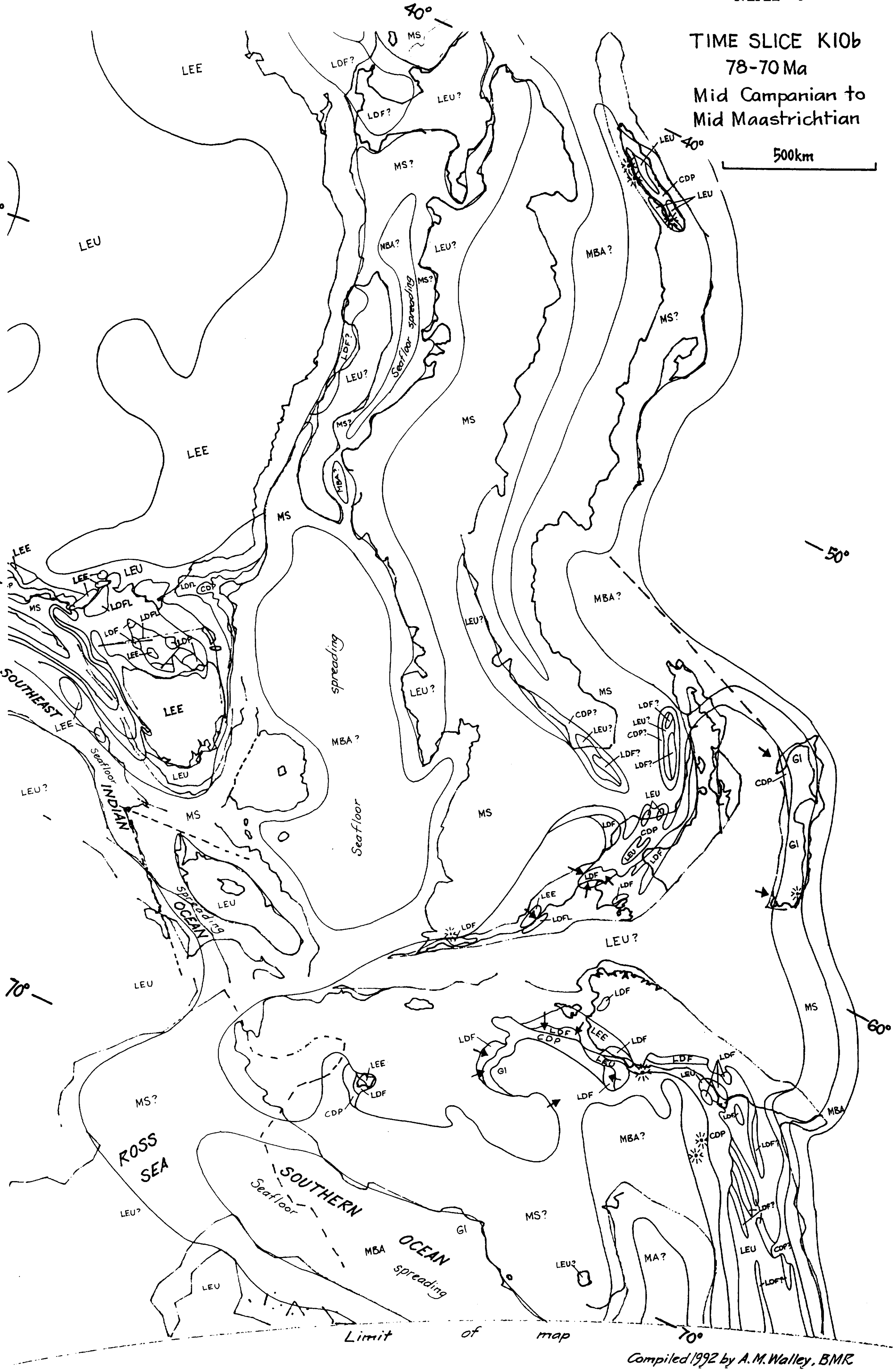
MAP 4

TIME SLICE K10b
78-70 Ma
Mid Campanian to
Mid Maastrichtian



Compiled 1992 by A.M. Walley, BMR
incorporating data supplied by DSIR, Geology & Geophysics, New Zealand

MAP 5

TIME SLICE Cz1
66·4 – 52 Ma
Paleocene to Early Eocene

Compiled 1992 by A.M. Walley, BMR

incorporating data supplied by DSIR, Geology & Geophysics, New Zealand

MAP 6

Compiled 1991 by A.M. Walley, BMR

incorporating data supplied by DSIR, Geology & Geophysics, New Zealand

MAP 7

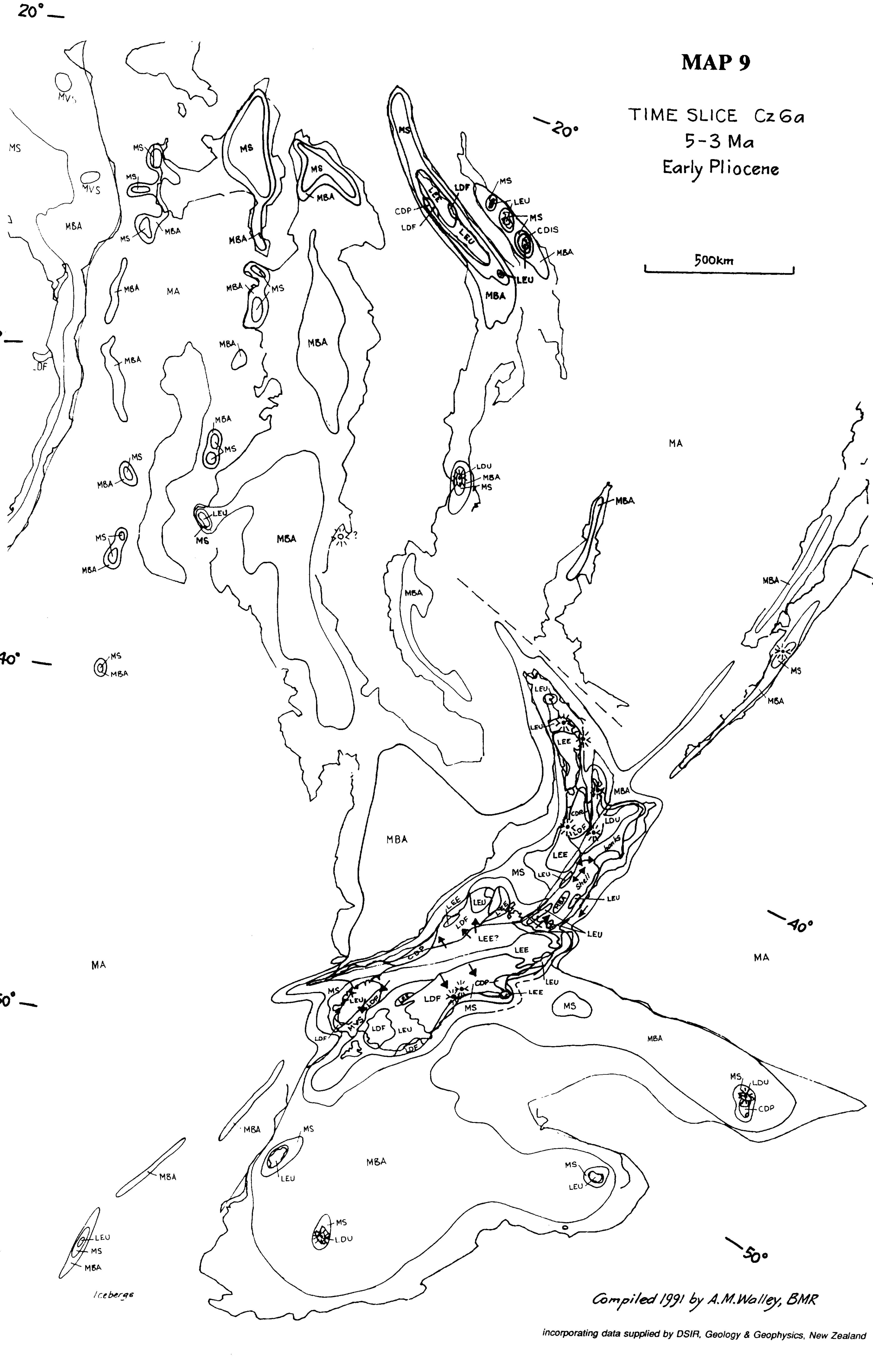
TIME SLICE Cz4a
30 – 22 Ma
Late Oligocene to Earliest Miocene

Compiled 1991 by A.M. Walley, BMR

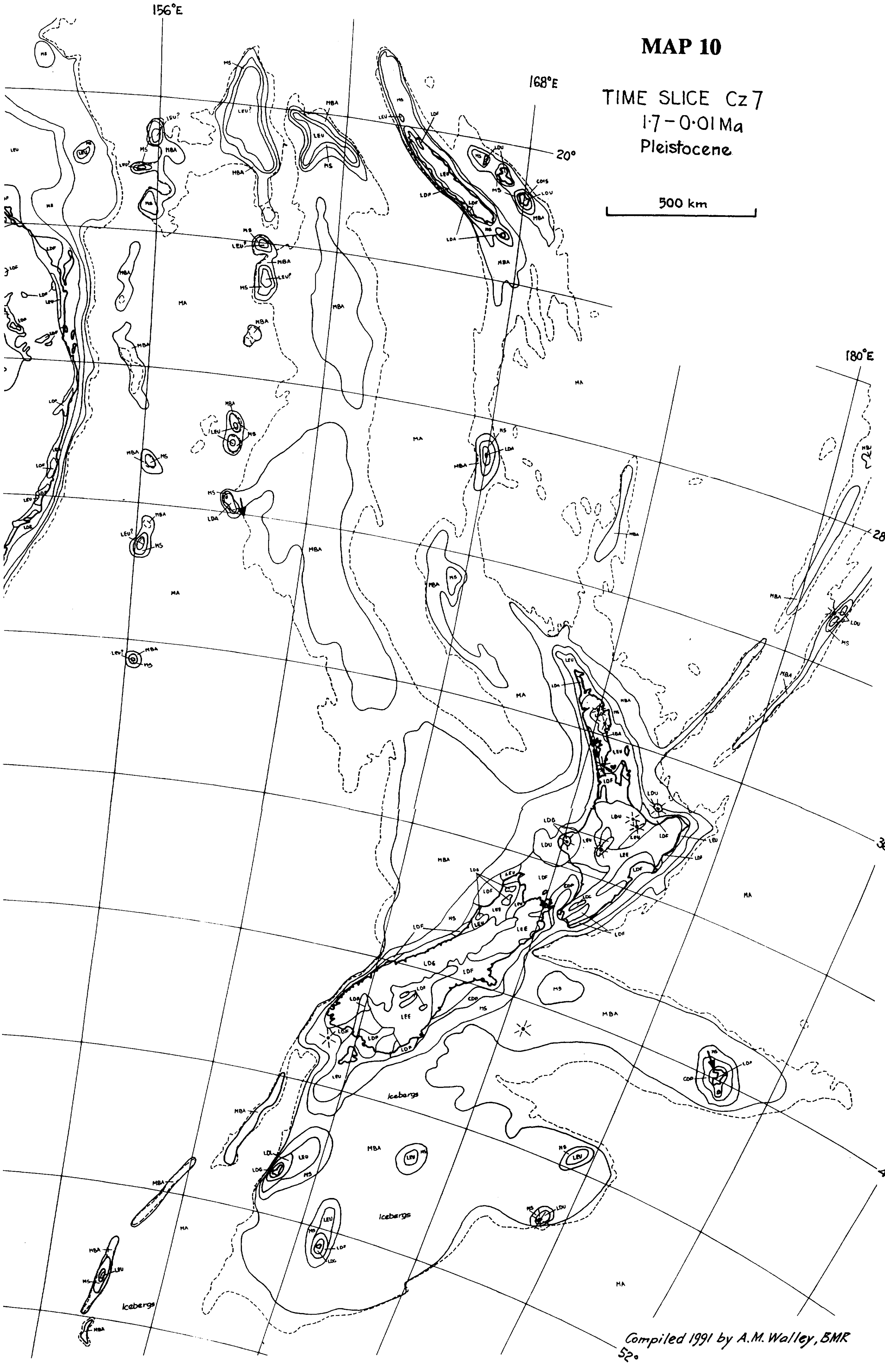
incorporating data supplied by DSIR, Geology & Geophysics, New Zealand

MAP 8

incorporating data supplied by DSIR, Geology & Geophysics, New Zealand



MAP 9
TIME SLICE Cz6a
5-3 Ma
Early Pliocene
500km
20°
30°
40°
50°
MS
MVS
MBA
MA
LDF
LEE
LEU
LDU
CDP
CDIS
Shell
banks
LEE?
Icebergs
Compiled 1991 by A.M.Walley, BMR
incorporating data supplied by DSIR, Geology & Geophysics, New Zealand



incorporating data supplied by DSIR, Geology & Geophysics, New Zealand

TABLE 2

MAP LEGEND

LAND

UNCLASSIFIED

LEU	

HIGH RELIEF

LEE	*Erosional*

DEPOSITIONAL

LDU	*Unclassified*
LDF	*Fluvial*
LDFL	*Fluvio-lacustrine*
LDL	*Lacustrine*
LDA	*Aeolian*
LDG	*Glacial*

Gl	*Glauconite*
Mn	*Manganese*
Ph	*Phosphorite*

COASTAL

DEPOSITIONAL

CDP	*Paralic*
CDIS	*Intertidal-supratidal*
CDD	*Deltaic*

MARINE

MVS	*Very shallow (0-20m)*
MS	*Shallow (0-200m)*
MBA	*Bathyal-abyssal (>200m)*
MA	*Abyssal (>1000m)*

	Volcanic centre
	Volcano-inferred
	Submarine fan
→	*Palaeocurrent*
—50°	*Palaeolatitude*

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