PALAEOGEOGRAPHY 33

AUSTRALIA

NEW ZEALAND: NOTES TO ACCOMPANY CRETACEOUS-CAINOZOIC STRATIGRAPHIC SUMMARY COLUMNS FOR THE NEW ZEALAND REGION

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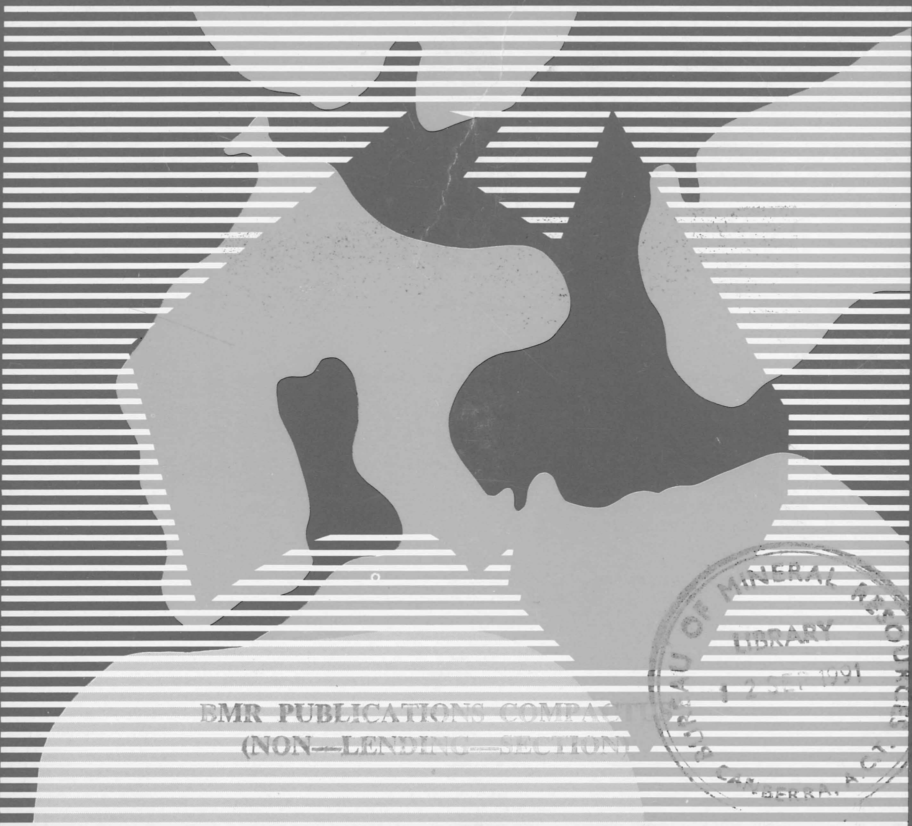

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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NEW ZEALAND

Notes to accompany
Cretaceous - Cainozoic stratigraphic summary columns
for the
New Zealand region

by

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

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SUMMARY

This report provides a brief summary of the Cretaceous - Cainozoic evolution of the New Zealand region, to accompany a stratigraphic chart. The stratigraphic columns were compiled in 1989-1990, as part of the Phanerozoic History of Australia Project, which is a joint project coordinated by the Bureau of Mineral Resources (BMR), in conjunction with APIRA, the Petroleum Division of the Australian Mineral Industries Research Association. The chart will form part of the data base for a series of interpretative palaeogeographic maps of the New Zealand region, which are in preparation.

During the early Early Cretaceous, New Zealand was dominated by convergent margin tectonics at the margin of Gondwana. Shortly after the collision of the final segments of this margin at about 105 Ma, extension began, associated with the breakup of Gondwana. Extension was in part transtensional and fault-controlled basins developed, filled with non-marine sediments. However, there was marine sedimentation on the continental margin in the northeast, but the tectonic setting is unclear.

Lithospheric cooling, subsidence and transgression proceeded over the New Zealand region from the Late Cretaceous to the Paleocene, coeval with sea-floor spreading in the Tasman Sea. In the Mid- to Late Eocene, there was a further extensional phase, which created a zone of basins along western New Zealand, aligned with a spreading ridge in the South Tasman Sea. The extension was again in part transtensional, possibly originating within a transform margin. Many of the basins were filled initially with non-marine sediments. Following the Eocene extension, there was regional subsidence and transgression through the Oligocene. By the Late Oligocene much of New Zealand was submerged, with widespread carbonate sedimentation.

The modern convergent Indo-Australian/Pacific Plate boundary became established in New Zealand in the latest Oligocene/earliest Miocene. There was a transition from an extensional to a compressional regime, and pre-existing basins were disrupted and inverted. Eastern North Island became a subduction complex. In the South Island, the initiation of the dextral transcurrent Alpine Fault marked the passage of the plate boundary through continental crust. During the Neogene, there has been clockwise migration of the plate boundary, with associated migration of volcanic arcs, depocentres and loci of compression. Since the Late Miocene, the Alpine Fault has been transpressive. During the Late Cainozoic compression, there has been a dramatic increase in rate of terrigenous sedimentation, derived from erosion of rapidly uplifted land. Large volumes of prograding sediment have been supplied to offshore areas, especially during the uplift of the Southern Alps from the latest Miocene onwards. Sediments deposited during Pleistocene glacial episodes have been superimposed upon the syntectonic Late Cainozoic sedimentation and the associated regression.

Many potential hydrocarbon-bearing basins are as yet under-explored. The Taranaki Basin contains the only commercial oil and gas fields discovered to date. However, the Cretaceous - Cainozoic history of many of New Zealand's sedimentary basins has much in common with that of the Taranaki Basin, and these basins warrant further exploration.

1. INTRODUCTION

This report provides a brief summary of the Cretaceous - Cainozoic evolution of the New Zealand region, to accompany a Cretaceous - Cainozoic stratigraphic chart. The stratigraphic columns were compiled in 1989-1990, during the Phanerozoic History of Australia Project, which is a joint project coordinated by the Bureau of Mineral Resources (BMR) in conjunction with APIRA, the Petroleum Division of the Australian Mineral Industries Research Association. These columns will form part of the data base for a series of interpretative palaeogeographic maps of the New Zealand region, for a number of Cretaceous and Cainozoic time intervals. The data and interpretative maps will be combined with compilations produced for other regions within the Indo-Australian Plate (for example, Struckmeyer, 1990), as part of the Phanerozoic History of Australia Project. These interpretations will be combined with palaeogeographic maps of Australia compiled during the BMR - APIRA Palaeogeographic Maps Project (for example, Bradshaw & others, in preparation; Wilford & others, in preparation). The final Phanerozoic History of Australia Project maps will be produced on a reconstructed base at 1:10 000 000 scale. These reconstructions are currently in progress (for example, Walley & Ross, 1991).

The present account is a synopsis. In the text, the reader is directed towards a selection of the more recent literature on the Cretaceous - Cainozoic history of New Zealand. 'The Geology of New Zealand' (Suggate & others, 1978) provides an excellent detailed overview and comprehensive bibliography up to that date. A more recent overview of the geology of New Zealand was presented in Korsch & Wellman (1988). Aspects of Cretaceous -Cainozoic tectonic development of the region have been covered in detail by numerous authors. Kamp (1986a) is a useful summary paper.

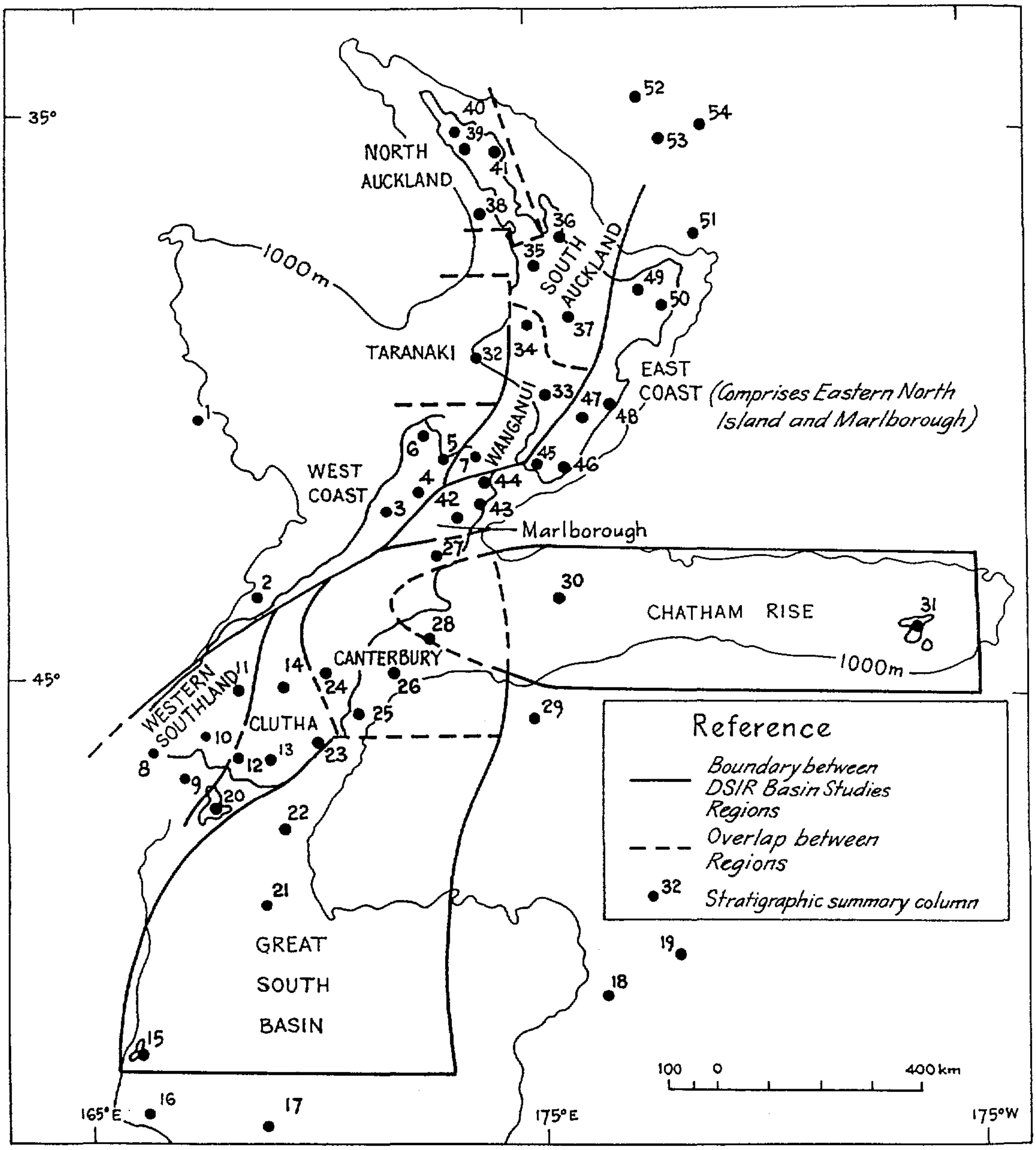
From the hydrocarbon exploration perspective, the Cretaceous to Cainozoic is the most critical period of New Zealand's history, as almost all New Zealand's known prospective sedimentary basins were established following the Early Cretaceous phase of the Rangitata Orogeny ('Rangitata-2'; Bradshaw & others,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

Fifty-four stratigraphic summary columns have been compiled for the Cretaceous to Cainozoic of the New Zealand region (Table I). The assistance and cooperation of DSIR (the Department of Scientific and Industrial Research), Geology & Geophysics, New Zealand (formerly known as the New Zealand Geological Survey), have been a valuable contribution to the project. Some of the current stratigraphic information compiled during the DSIR, Geology & Geophysics, Cretaceous - Cenozoic Basin Studies Programme has been included in summary form in the columns.

The distribution of the stratigraphic columns is indicated in Figure 1. Figure 1 also shows the eleven study regions currently under investigation by DSIR, Geology & Geophysics, as part of the Cretaceous - Cenozoic Basin Studies Programme. The following Basin Studies volumes have been published: Basin Studies 1 - West Coast South Island (Nathan & others, 1986); Basin Studies 2 - Canterbury (Field & others, 1989); and Basin Studies 3 - Chatham Rise (Wood & others, 1989). Figure 2 is a key to the column lithologies and stratigraphic boundaries.

The columns have been constructed alongside the latest New Zealand time scale (Edwards & others, 1988). This is a practical time scale used in the DSIR, Geology & Geophysics, Basin Studies Programme. DSIR, Geology & Geophysics, has correlated the New Zealand Cainozoic chart against the international time scale of Berggren & others (1985a, 1985b), with minor modifications. The Berggren & others (1985a, 1985b) time scale was also used for the Cainozoic stratigraphic chart by the BMR - APIRA Palaeogeographic Maps Project (Wilford & others, in preparation). For the Cretaceous, the Phanerozoic History of Australia Project is continuing to correlate using the international time scale of Harland & others (1982), as this was used for the Cretaceous palaeogeographic maps of Australia (Bradshaw & others, in preparation). DSIR, Geology & Geophysics, however, correlates the New Zealand Cretaceous time scale against the international scale of Kent & Gradstein (1985).

Biozones are not shown on the New Zealand stratigraphic summary chart because of difficulties in correlation between New Zealand and Australian zones (G.C.H. Chaproniere, BMR, personal communication, 1989). Correlation between New Zealand



SOUTH ISLAND REGION

1. Challenger Plateau, DSDP 593
2. Western Platform (south)
3. Paparoa-Buller
4. Murchison Basin
5. Golden Bay-Nelson
6. Pakawau Basin
7. Picton Outlier
8. SW Fiordland (Balleny Basin)
9. Solander Basin (Parara-1)
10. Waiau Basin
11. Te Anau Basin
12. Ohai-Winton
13. Gore
14. Queenstown-Cromwell
15. Auckland Islands
16. DSDP 277
17. Campbell Island
18. DSDP 275
19. Antipodes Islands
20. Stewart Island
21. Kawau Sub-basin
22. Central Graben
23. Kaitangata Sub-basin
24. Kyeburn
25. Galleon-1
26. Clipper Basin (Clipper-1)
27. Waipara Basin
28. Canterbury igneous rocks
29. DSDP 594
30. Mernoo Bank
31. Chatham Islands

NORTH ISLAND REGION

32. Taranaki Basin
33. S Wanganui Basin
34. N Wanganui Basin
35. South Auckland
36. Coromandel
37. Taupo Volcanic Zone
38. Northland offshore (W)
39. Northland W/NE
40. Northland Allochthon
41. Northland central/E

EASTERN STRUCTURAL BELT

42. SW Marlborough
43. E Marlborough
44. N Marlborough
45. Aorangi Block
46. Tora Block
47. Pongaroa Block
48. Coastal Block
49. Motu Block
50. East Coast Allochthon
51. Raukumara Forearc Basin

COLVILLE - KERMADEC RIDGES

52. Colville Ridge
53. Havre Trough
54. Kermadec Ridge

FIGURE 1 **Location of New Zealand region stratigraphic summary columns**

Base map adapted from data supplied by DSIR, Geology & Geophysics, 1990. The map shows the eleven study regions under investigation by DSIR, Geology & Geophysics, as part of the Cretaceous - Cenozoic Basin Studies Programme.

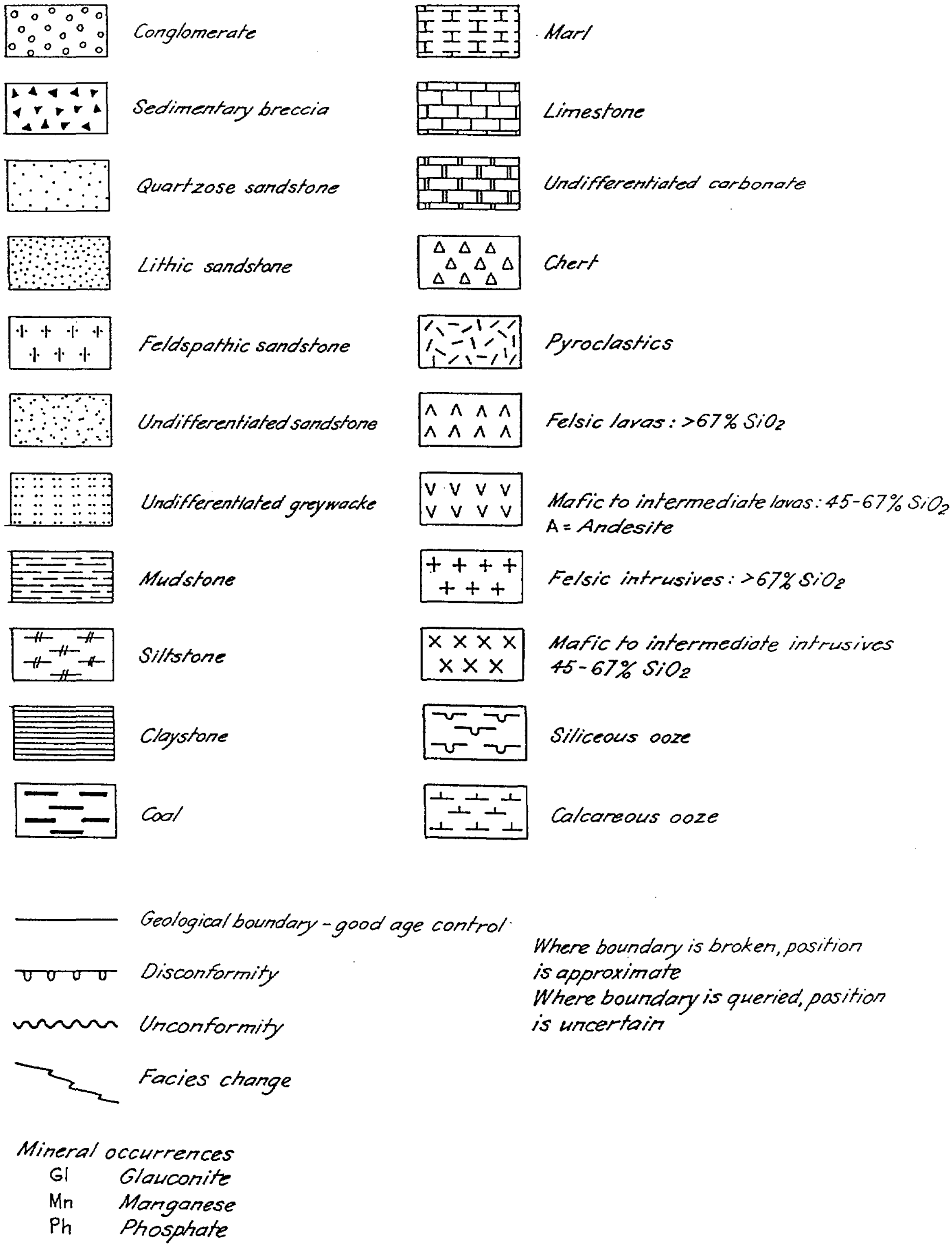


FIGURE 2 Key to accompany Table 1

and international biozones is also fraught with problems (A.R. Edwards, DSIR, Geology & Geophysics, personal communication, 1989).

In the following report, Phanerozoic History of Australia Project Cretaceous - Cainozoic time slices are referred to by 'K' for Cretaceous and 'Cz' for Cainozoic. The time slices are indicated on each of the stratigraphic summary column sheets (Table I, Sheets 1-4). These time slices are the same as those chosen during the BMR - APIRA Palaeogeographic Maps Project. They are based principally upon correlatable time breaks between sedimentologically significant intervals. During the Phanerozoic History of Australia Project some of the Australian time slices have been subdivided, where appropriate, to more clearly define plate-wide events.

2. CRETACEOUS TO CAINOZOIC GEOLOGICAL HISTORY OF NEW ZEALAND

The present-day plate tectonic setting of New Zealand is outlined below. A discussion of the early Early Cretaceous sequence and Rangitata Orogeny follows. The late Early Cretaceous to Neogene history of New Zealand is then described in more detail.

The Cretaceous to Cainozoic development of New Zealand is summarised in Table II.

2.1 Plate tectonic setting

New Zealand is astride the Indo-Australian/Pacific Plate boundary and therefore forms the southeastern edge of the Phanerozoic History of Australia study region (Figure 3). Along the plate boundary east of North Island, the Pacific Plate is being obliquely subducted beneath the Indo-Australian Plate. Farther south, the plate boundary passes through continental crust, forming a wide transform fault zone along which dextral transpression is occurring. South of the South Island, the Indo-Australian Plate is being obliquely subducted beneath the Pacific Plate.

2.2 The Early Cretaceous sequence and the Rangitata-2 Orogeny

From the Permian until the early Early Cretaceous, New Zealand was dominated by

TABLE II

SUMMARY OF PALAEOGEOGRAPHIC HISTORY

LATE EARLY TO LATE CRETACEOUS EXTENSION
Breakup of Gondwana
Predominantly thick non-marine clastics in grabens/half-grabens
Overlain by thick coal measures

LATE CRETACEOUS - PALEOCENE - EOCENE
Regional subsidence; transgression; quiescence
Marine mudstones, shales

MID - LATE EOCENE
Renewed extension - transform margin along western New Zealand?
Coal measures

OLIGOCENE
Regional subsidence
Marine sediments - much of New Zealand submerged

OLIGOCENE/MIOCENE BOUNDARY
Convergent plate boundary entered New Zealand
Emplacement of allochthons, North Island
Subduction complex in eastern North Island
Inception of Alpine Fault
Transpressional regime initiated
Basin inversion in western and central South Island, North Island

MIOCENE - PLIOCENE, THROUGH TO PRESENT DAY
Clockwise migration of volcanic arcs and depocentres, North Island
Increasing oblique compression
Increased sediment supply from rising hinterlands
Uplift of Southern Alps
Late Cainozoic regression in the now onshore New Zealand area
Prograding sediment wedges in offshore areas
Late Cainozoic intra-plate volcanism
Pleistocene glaciation

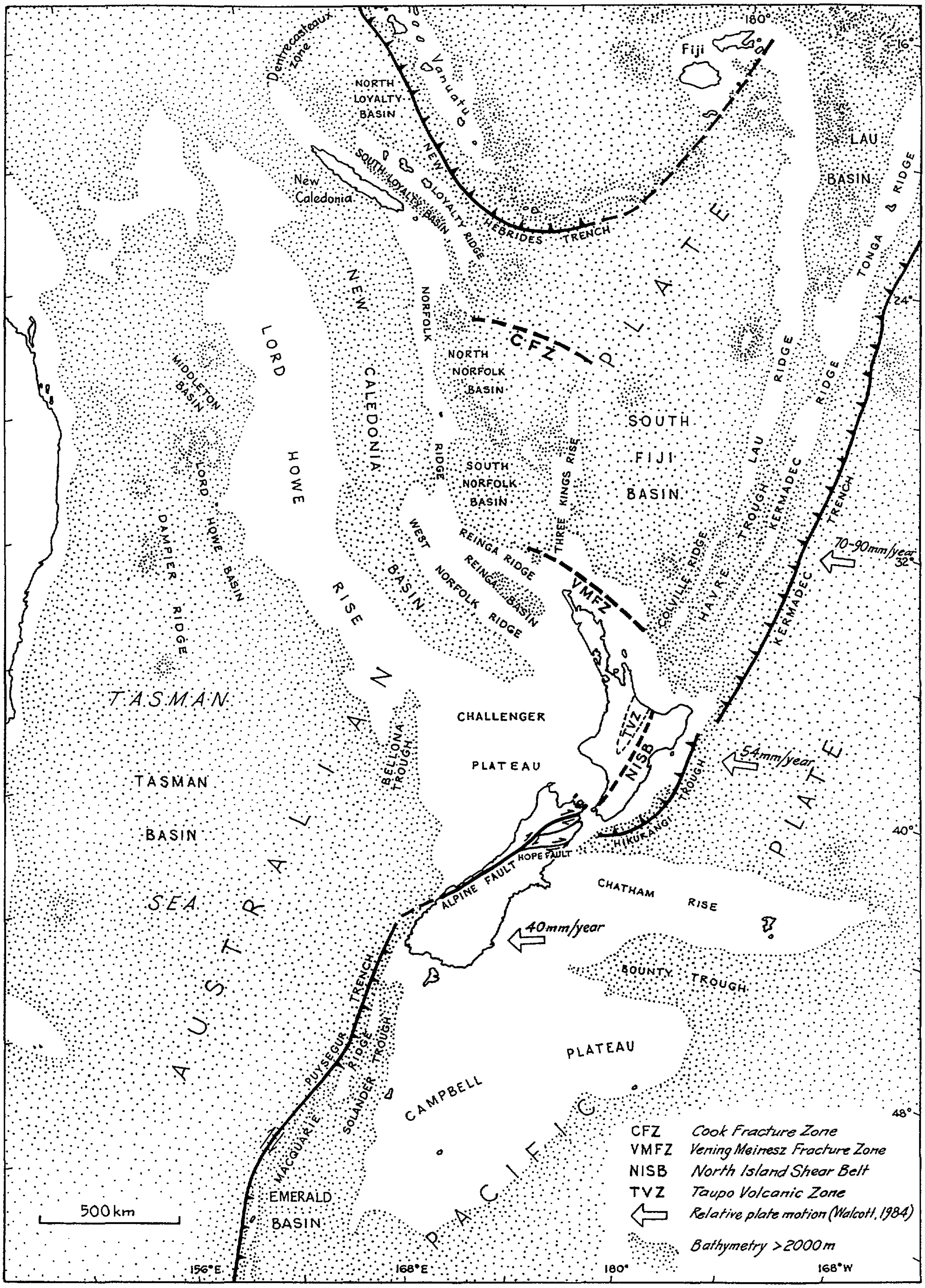


FIGURE 3 Plate tectonic setting of the New Zealand region

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

convergent margin tectonics, at the Gondwana margin. 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). There was intense erosion over most of New Zealand. There is now believed 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 place to place. Convergence is thought to have ceased in the Albian, at about 105 ± 5 Ma (Bradshaw, 1989), in time slice K7 (see Table I). Early Cretaceous convergent margin sediments are mainly quartzo-feldspathic, deposited by sediment gravity flows (MacKinnon, 1983). These are preserved in Marlborough and eastern North Island (Table I, Sheet 4). An Early Cretaceous marine volcanic and sedimentary sequence in Northland (Houhora Complex, Table I, column 39) is also considered to be a suspect terrane (Isaac & others, 1988).

In the South Island, final uplift occurred at the same time as rifting began, as recorded by the development of Cretaceous normal faults (N. Mortimer, DSIR, Geology & Geophysics, personal communication, 1989; see also Tulloch & Kimbrough, 1989). In northeastern South Island (Marlborough, Figure 1), the time gap between the culminating convergent event and the onset of an extensional regime is thought to have been less than 5 Ma, represented by a major angular unconformity in the New Zealand Motuan Stage (Laird, 1989; Table I, Sheet 4). The Motuan unconformity is also present in eastern North Island, although there are different interpretations as to its significance (see Speden, 1976; Feary, 1979; Moore & Speden, 1979, 1984; Barnes, 1988). In western Raukumara Peninsula (Table I, column 49) the main phase of the Rangitata Orogeny is thought to have occurred before the Aptian (Wilson & others, 1988), and in the northern part of that area current work indicates no break in sedimentation during the transition from a convergent to an extensional regime (see Mazengarb, 1989).

2.3 Late Early Cretaceous to Late Cretaceous

Extension began in the late Early to early Late Cretaceous (late Albian to Cenomanian, K7-K8) associated with the breakup of eastern Gondwana (Laird, 1981; Browne & Field, 1988; Bradshaw, 1989). Grabens and half-grabens developed at this time in both the

North Island (Taranaki Basin, offshore western Northland and possibly eastern North Island) and the South Island. The early half-grabens developed along both north-south and northeast-southwest trends west of the Taranaki Fault in the Taranaki Basin area, where the latter trend is thought to have been associated with sinistral transtension (Thrasher, 1989). Thrasher (1989, 1990) has related this extension to opening of the New Caledonia Basin to the northwest of the Taranaki Basin (Figures 4 and 5). In the South Island, these early fault-controlled basins developed in Marlborough, the West Coast Region, the Balleny Basin area, Great South Basin, Canterbury Basin, Chatham Rise and in the Waiau and Solander Basin areas (Figures 4 and 6; see, for example, Norris & Carter, 1980; Nathan & others, 1986; Carter, 1988; Pocknall & Lindquist, 1988; Cook, 1989; Field & others, 1989; Laird, 1989; Wood & others, 1989; Uruski & Turnbull, 1990). North-south grabens in the West Coast Region were filled with coarse clastics derived in part from uplifted Early Cretaceous plutons (Figure 7). Half-grabens of this age in the Chatham Rise area strike mainly east-west and are hinged to the south (Wood & others, 1989). Initial faulting in the Chatham Rise and in the Solander Trough is thought to have been listric. In the case of the Chatham Rise, this was associated with rifting in the Bounty Trough to the south (Wood & others, 1989).

Throughout much of New Zealand, 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 & others, 1989). In Northland and northeastern New Zealand, however, deposition was largely paralic to marine, although graben and half-graben sediments are likely to have been fluvial and lacustrine in offshore western Northland (Beggs & others, 1988). Unravelling the Cretaceous - Palaeogene stratigraphy of Northland is complex, as sediments of this age were incorporated into thrust sheets emplaced towards the southwest at the close of the Palaeogene (see below). Deposition in eastern North Island was in tectonically active shelf to slope environments. There are different interpretations as to whether some Early Cretaceous units in that area (Table I, column 47) were deposited as submarine fan-deltas in 'fault-angle depressions' during extension (Moore & Speden, 1979; 1984), or whether the units represent the youngest part of the convergent margin accretionary wedge (Barnes, 1988). The structural blocks used as a basis for the stratigraphic columns

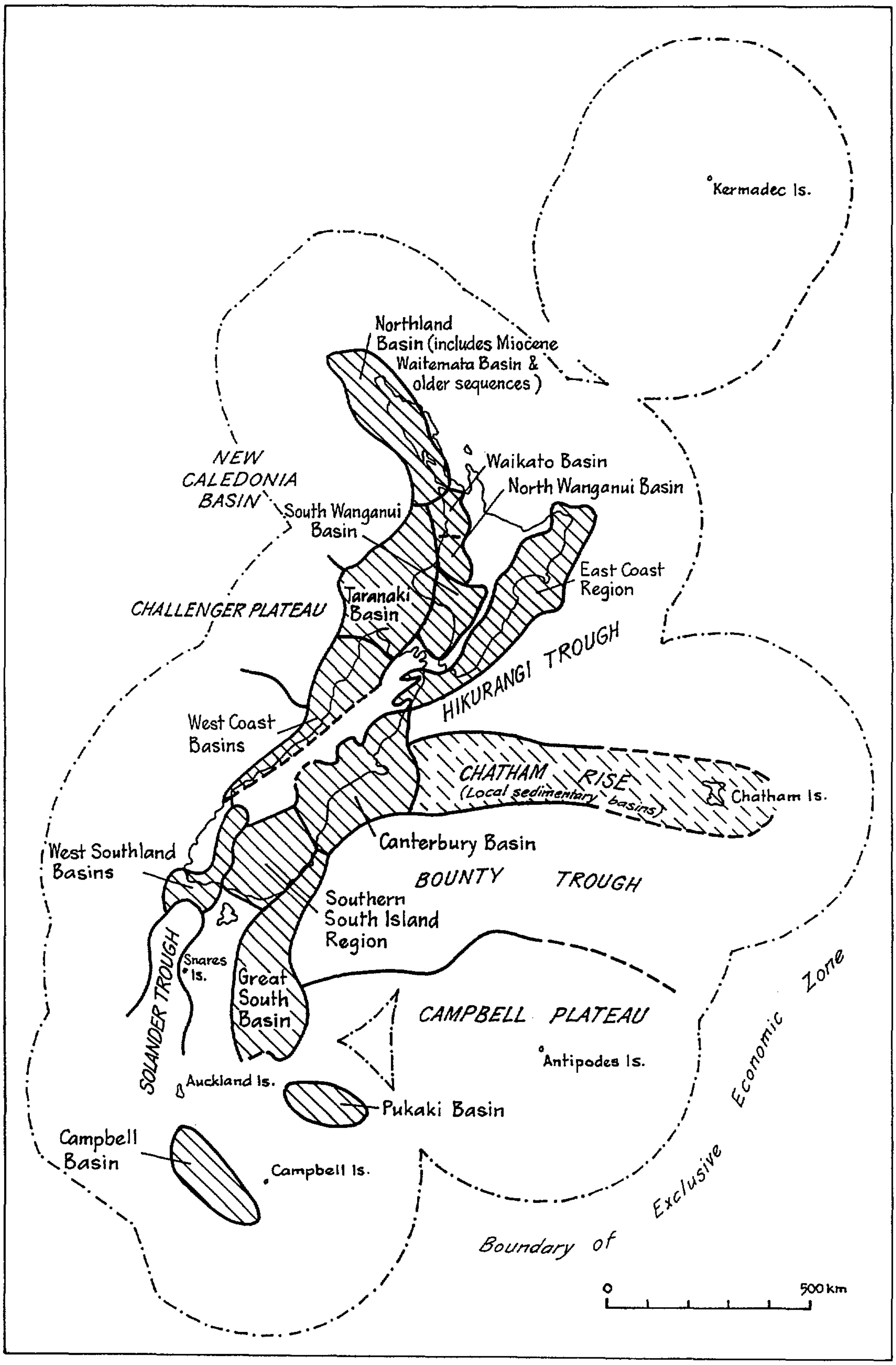


FIGURE 4 **Sedimentary basins of New Zealand**
Adapted from Petroleum Exploration in New Zealand Prospectus. Ministry of Commerce, New Zealand, 1990a

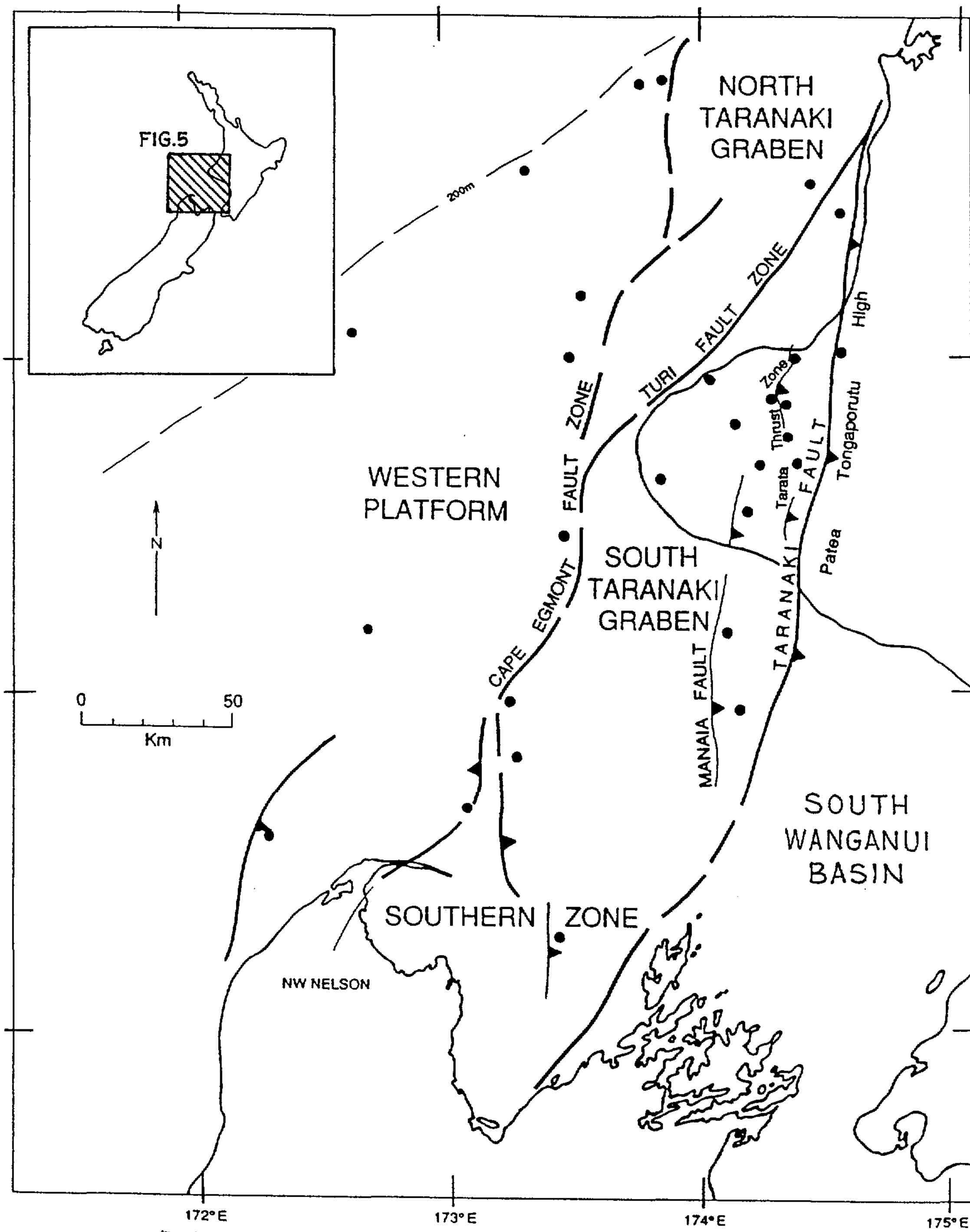


FIGURE 5 **Taranaki Basin - location and main structural elements From King (1990)**

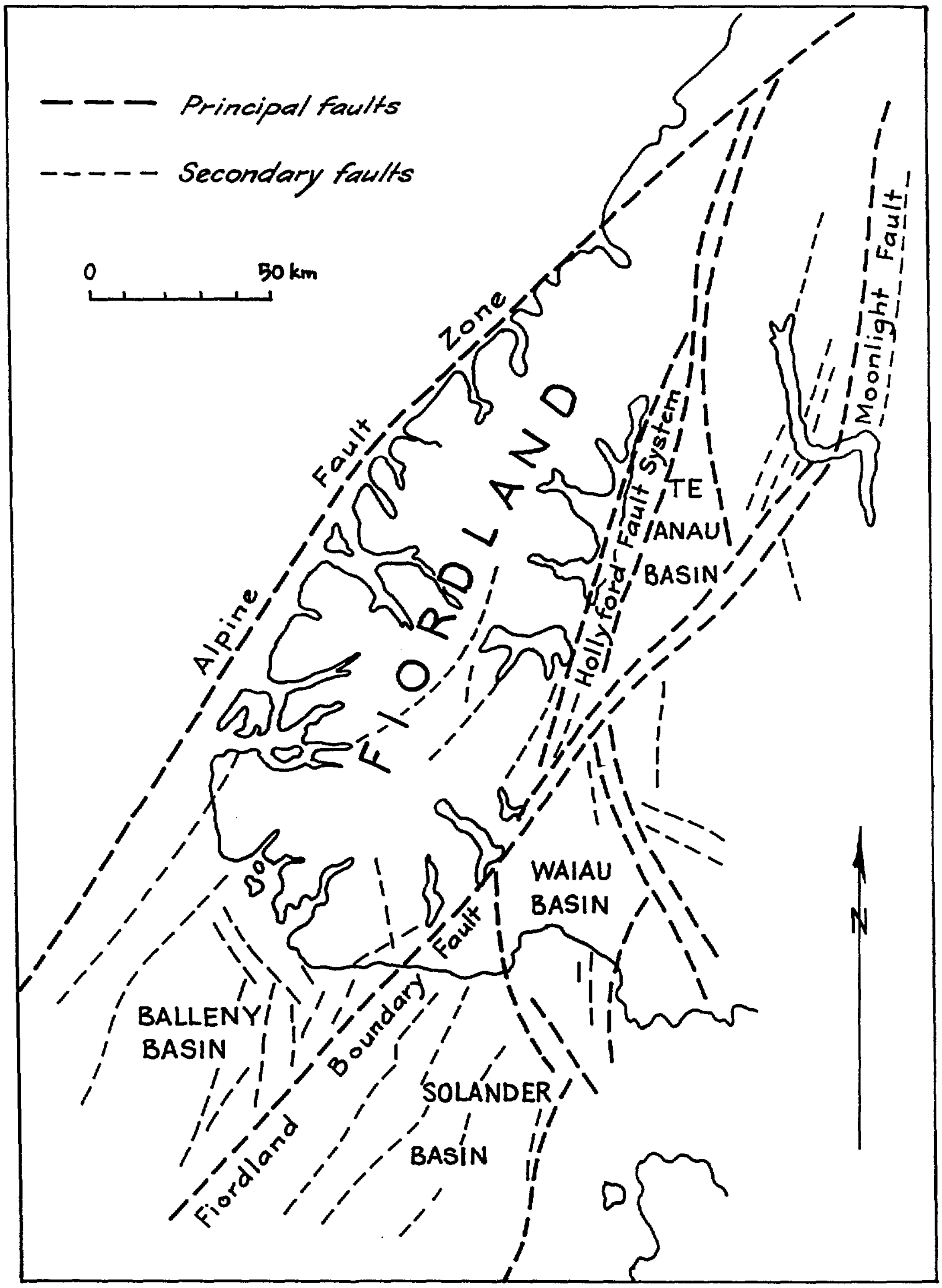


FIGURE 6 Regional structural map, southwestern South Island
Modified after Norris & Carter (1980)

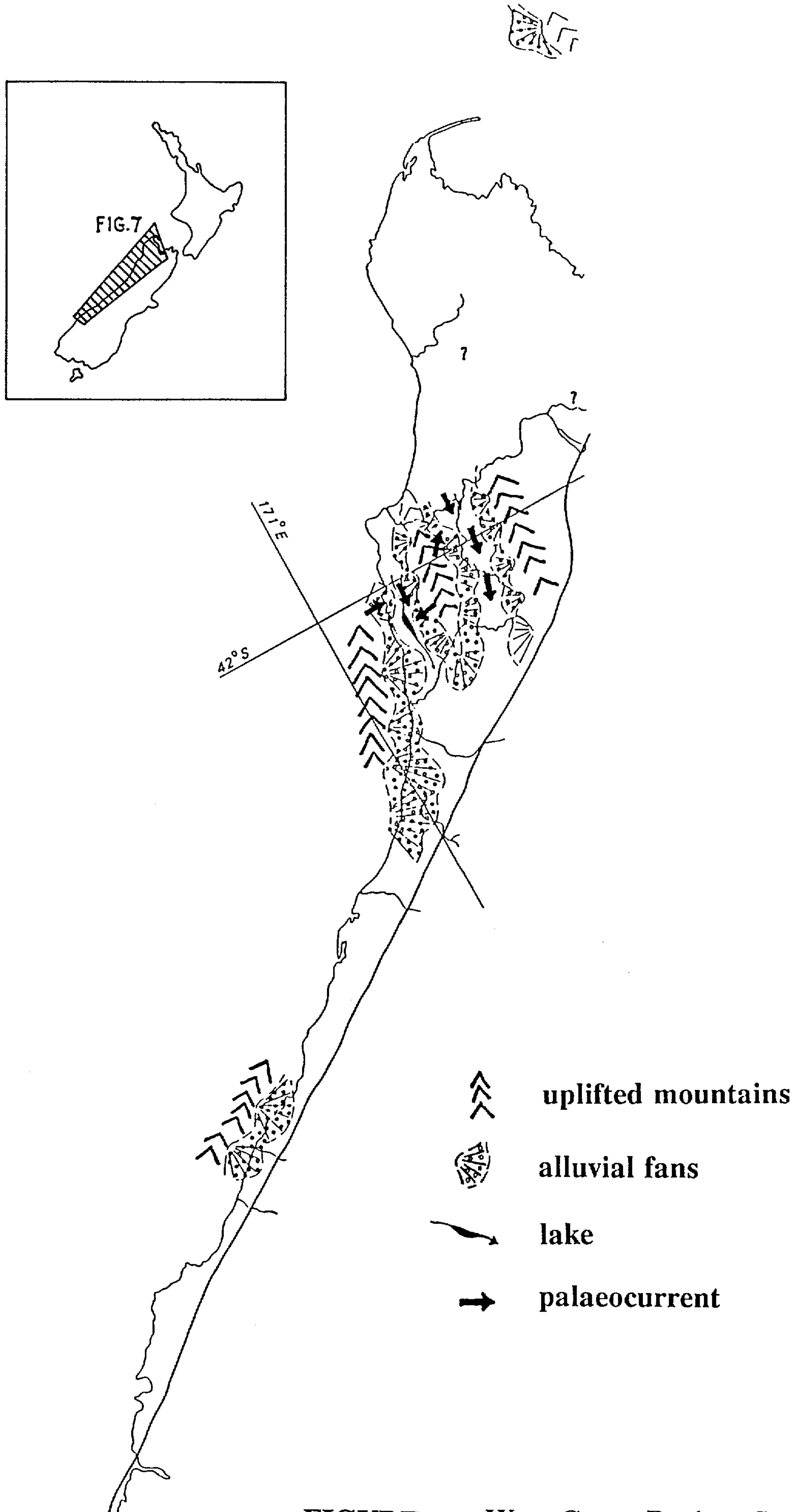


FIGURE 7 West Coast Region, South Island
Latest Albian palaeogeography
From Nathan & others (1986)

for eastern North Island were defined in Moore (1988a) and are based on significant contrasts in Cretaceous - Palaeogene stratigraphy and structure.

Extensional faulting continued into the Late Cretaceous, although movements on faults eased to generally less than 200 m in the Canterbury region, in the Campanian-Maastrichtian (Field, 1989). In some areas, there appears to have been a hiatus between the Albian-Cenomanian and Campanian-Maastrichtian extension: for example, in the West Coast Region, where mafic dykes were intruded during an interval of presumed non-deposition (see Laird, 1981; Nathan & others, 1986).

During this period of crustal stretching, mafic and felsic volcanics were extruded in central and northern Canterbury, Chatham Rise, Marlborough and the western platform (West Coast Region). The Late Cretaceous sequences comprise predominantly fluvial sands and fluvio-lacustrine to paralic coal measures. In the Great South Basin and Chatham Rise, the thickness of these sediments exceeds 2000 m (Table I, column 22; Anderton & others, 1982; Cook, 1989). As lithospheric cooling, subsidence and transgression proceeded from the Late Cretaceous to the Paleocene, coeval with sea-floor spreading in the Tasman Sea, restricted marine to open marine deposition overlapped the earlier half-graben deposits (Figures 8 and 9). Marine deposition dominated the Late Cretaceous in Northland, Marlborough and eastern North Island.

2.4 Paleocene

Very fine-grained offshore quiescent sedimentation characterised the Paleocene to Eocene in eastern North Island, the northern Taranaki Basin, the Canterbury Basin and part of the Great South Basin (Table I; Anderton & others, 1982; Browne & Field, 1988; Isaac & others, 1988; King & Robinson, 1988; Laird, 1989; Cook & Beggs, 1990). Of particular note is a Paleocene black shale unit deposited throughout eastern North Island (Waipawa Black Shale; Table I, Sheet 4; Moore, 1989). Restricted oceanic circulation appears to have been a major feature of the entire southwest Pacific region in the Late Cretaceous - Paleocene (Moore, 1988b).

There was terrestrial deposition during the Paleocene in the southern Taranaki Basin

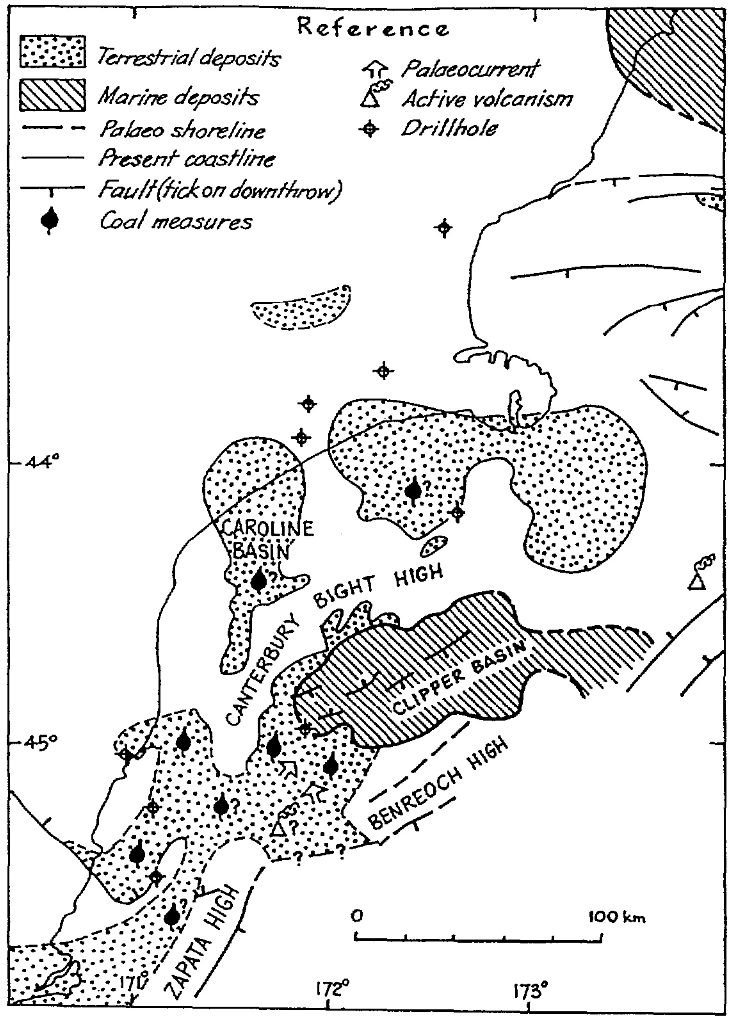


FIGURE 8 **Palaeogeography, early Piripauan (Late Santonian), Canterbury**
Modified after Field (1989)

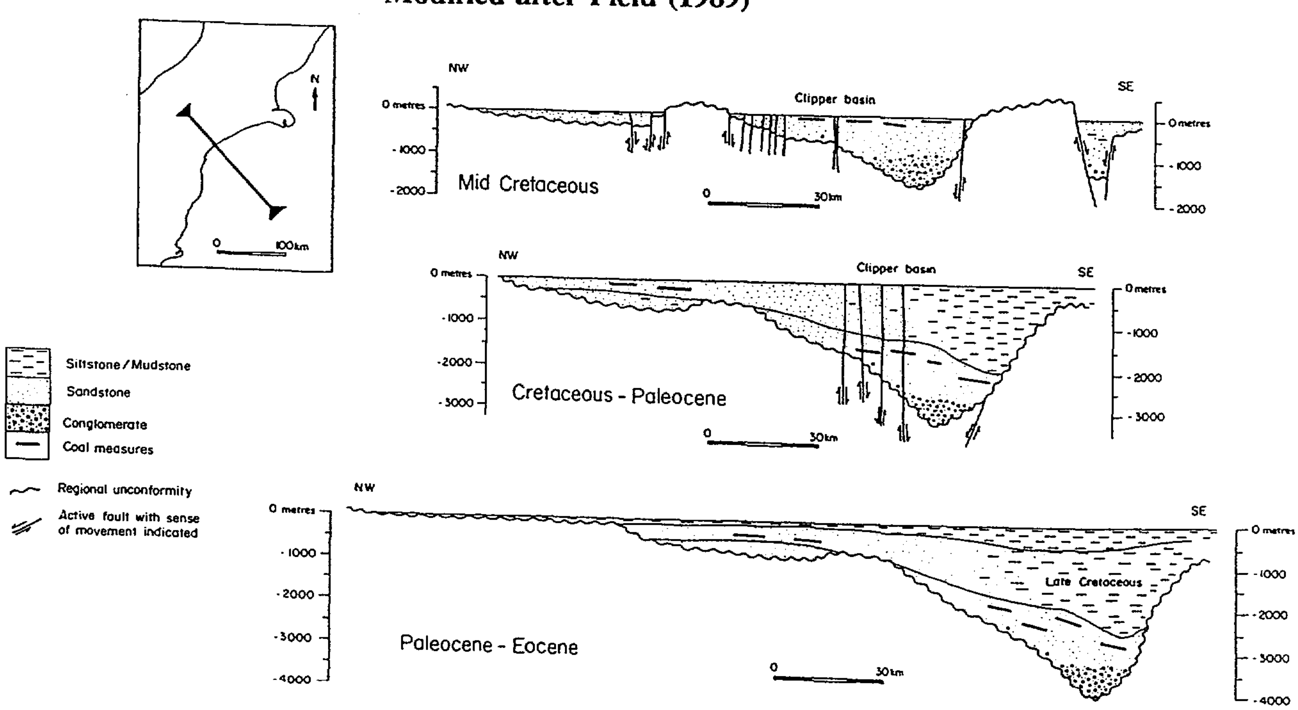


FIGURE 9 **Clipper Basin, Canterbury**
Adapted from Browne & Field (1988)

and the northern part of the West Coast Region (Table I, Sheets 1 and 3; Nathan & others, 1986; King & Robinson, 1988).

2.5 Eocene to Oligocene

There was a widespread hiatus in the Early to Mid Eocene (time slices Cz1-2a) throughout much of the West Coast Region, Western Southland, Clutha, Auckland and Northland, but elsewhere this was evident only locally.

There was a further extensional phase in the Mid to Late Eocene (time slices Cz2a-2b), reflected in small fault-bounded basins in western South Island and western North Island and minor extension in the Canterbury, Chatham Rise and Clutha areas (McQuillan, 1977; Suggate & others, 1978; Kear & Schofield, 1978; Palmer, 1985; Nathan & others, 1986; Beggs & others, 1988; Browne & Field, 1988; Wood & others, 1989; Cook, 1989). However, there is not thought to have been any rifting in the Taranaki Basin at this time (King, 1990; King & Thrasher, in press). The Taranaki Basin is considered to have evolved as a passive margin intra-continental basin during much of the Paleogene, contiguous with the southern part of the New Caledonia Basin (King, 1990).

There was renewed Mid- to Late Eocene basaltic volcanism in Canterbury, Chatham Rise, the Challenger Plateau and the western platform (Table I, columns 1, 2, 28 and 31), which continued into the Oligocene in Canterbury and Chatham Rise. Note that there was Late Eocene to Early Oligocene volcanism, associated with sea-floor spreading, in the South Tasman Sea (Nelson & others, 1986).

Coal measures were deposited in the West Coast Region, where localised uplift and subsidence continued on major faults through the Oligocene. The trend of the Eocene basins was similar to that of the early Late Cretaceous basins (see Nathan & others, 1986). There was also coal measure deposition in western North Island and, very locally, in the Clutha region (Table I, Sheets 1 and 3).

In the southwest South Island, normal faulting at this time (mid-Eocene to Oligocene) controlled the development of the Waiau, Te Anau Basin, Solander and Balleny Basins

(Norris & Carter, 1980; Turnbull, 1985, 1986; J.K. Lindqvist, DSIR, Geology & Geophysics, personal communication, 1989; Table I, Sheet 1; Figure 6). The Te Anau Basin appears to have formed in the Mid-Eocene. Recent work by the DSIR, Geology & Geophysics, indicates that transtensional movement probably occurred along some of the controlling faults of the Waiau and Te Anau Basins. Detritus was shed from the emergent Fiordland Block and deposited as alluvial and later submarine (bathyal) fans within these basins (Uruski and Turnbull, 1990). Eocene - Oligocene transtensional movement on faults in southwestern New Zealand was also noted by Norris & Carter (1980). In western North Island, the Waikato Basin was initiated in the Mid-Eocene and the North Wanganui Basin became a depocentre in the Early Oligocene (McQuillan, 1977; Kear & Schofield, 1978; Nelson, 1978; Figure 4).

There was, therefore, a zone of actively subsiding basins along the western margin of New Zealand, parallel with and to the north of a spreading ridge in the South Tasman Sea (Kamp, 1986a, 1986b; Figure 10). These basins have been viewed as originating in a transform setting, associated with initiation of the Alpine Fault as an extensional transform margin (see, for example, Norris & Carter, 1980). However, Kamp (1986b) provided evidence for an intra-plate extensional setting. If there was a Mid-Eocene - Oligocene transform margin along the western edge of New Zealand, it is unlikely to have been along the line of the Alpine Fault, because the Alpine Fault dislocated this extensional system in the earliest Miocene (see Kamp, 1986b).

After the Eocene extension, there was regional subsidence and transgression through the Oligocene, and by the Late Oligocene much of New Zealand was submerged, with widespread carbonate sedimentation (see Suggate & others, 1978; Kamp, 1986b; Table I). Water depths reached bathyal in the Oligocene in, for example, the Great South Basin (Cook & Beggs, 1990), Campbell Plateau (Beggs, 1978; Cook, 1981), Western Southland (Turnbull & others, 1989) parts of the Canterbury Basin (Field & others, 1989), Taranaki Basin (Hayward, 1987) and Northland (Hayward & others, 1989). Most of northeastern New Zealand was an area of bathyal deposition throughout the Eocene and Oligocene (Kenny, 1984; Moore & Morgans, 1987; Moore, 1988c). In the Taranaki Basin (Figure 5), sudden basin deepening occurred west of the reactivated Taranaki

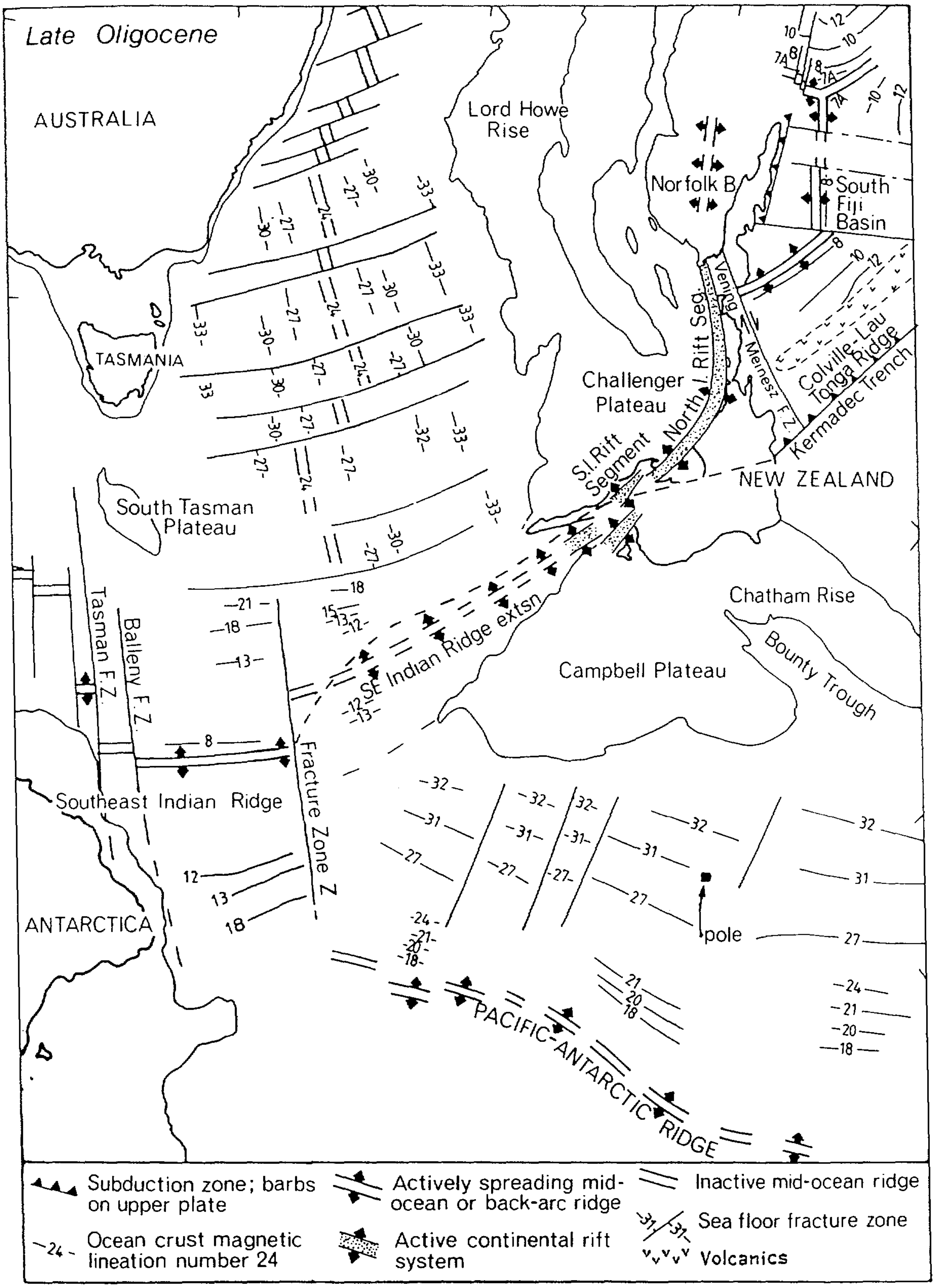


FIGURE 10 **Plate tectonic reconstruction for the southwest Pacific in the Late Oligocene (magnetic anomaly 7 time - 26 Ma) From Kamp (1986a). (Copyright: Elsevier)**

Fault in the Late Oligocene (time slice Cz4a; King & Robinson, 1988). This may have marked the onset of compression in the Taranaki Basin (foreland basin development west of the now compressive Taranaki Fault) and signified the first manifestation here of a new stress regime through the New Zealand region (King, 1990). In the Late Oligocene in Western Southland, a rapidly deepening, elongate marine basin developed along the active Moonlight Fault (Table I, column 14; Figure 6; Turnbull & others, 1989). There were correlative events in Papua New Guinea at this time (see Struckmeyer, 1990 and below).

A rapid sea level rise at roughly the Eocene/Oligocene boundary is evident in the West Coast Region, Western Southland (particularly in the Balleny Basin), the Great South Basin and Canterbury area. There were, however, as can be seen from the correlation chart, local hiatuses at various times during the Eocene and Oligocene. There was, in particular, a widespread hiatus in the Early to Mid-Oligocene, although this does not appear to have affected most of the North Island. The regional extent and significance of the Oligocene hiatus (or hiatuses) have been the subject of much debate. Carter and Landis (1972) and Carter (1985) recognised a regional Mid-Oligocene unconformity that occurs widely in eastern South Island. The hiatus, the 'Marshall Paraconformity', is principally between the base of the late Whaingaroan Stage and the base of the Duntroonian Stage, but the time gap may be more than 10 Ma (see Table I, columns 23-24). The same authors correlated the Marshall Paraconformity with global events, including the rifting between Australia and Antarctica which resulted in strong eastward-flowing currents in the southwest Pacific (the proto-circum Antarctic current system; see Carter, 1985). A major hiatus in Papua New Guinea at this time reflects the collision of the Australian continent with the Pacific Plate (see Struckmeyer, 1990). Findlay (1980) argued that the Marshall Paraconformity is but one of many extensive intra-Oligocene unconformities and that dating of many of the unconformities is too imprecise for proposal of one as regionally significant. The large 'global' Mid-Oligocene sea level fall dated by Vail & Hardenbohl (1979) at 29 Ma was correlated with the Marshall Paraconformity by Loutit & Kennett (1981). However, Carter (1985) correlated the proposed Marshall Paraconformity with a regional sea level highstand.

2.6 Neogene

In the latest Oligocene to Early Miocene, 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. Eastern North Island became a subduction complex and the Alpine Fault was initiated at this time, marking the continuation of the plate boundary through the South Island (Figure 3; see Kamp, 1986b; Spörli, 1988).

This event was reflected in a hiatus or unconformity in many parts of New Zealand (see Table I). In Western Southland, a locally-developed Late Oligocene unconformity marked the change from a transtensional to a transpressional regime at this time (Uruski & Turnbull, 1990). Recent work by DSIR, Geology & Geophysics indicates that the western bounding faults to the Te Anau, Waiau and Solander Basins (see Figure 6) probably evolved as splays of the Alpine Fault to the north, along which dextral strike-slip movement was occurring (Uruski & Turnbull, 1990).

The change from an extensional to a compressional regime caused the inversion of some sedimentary basins. In the South Island, there was inversion of some basins west of the Alpine Fault. For example (Figure 11), the Paparoa Trough was inverted in the earliest Miocene and the former eastern flank of this basin became the new depocentre, the Grey Valley Trough (Nathan & others, 1986; Table I, composite column 3). Basin inversion also occurred in Western Southland, close to the plate boundary (Uruski & Turnbull, 1990).

Basins in Northland and Auckland were also uplifted and inverted. In Northland, ophiolites, which originated by transform motion at the Vening Meinesz Fracture Zone (Figure 12), were obducted from the northeast and carried with them an allochthon of Cretaceous - Oligocene 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 (Ballance, 1974; Hayward, 1979; see Table I, Sheet 1; Figure 4). Emplacement of the Northland allochthon continued during the New Zealand Otaian Stage (time slice Cz4b), coeval with deposition of the Waitemata Basin

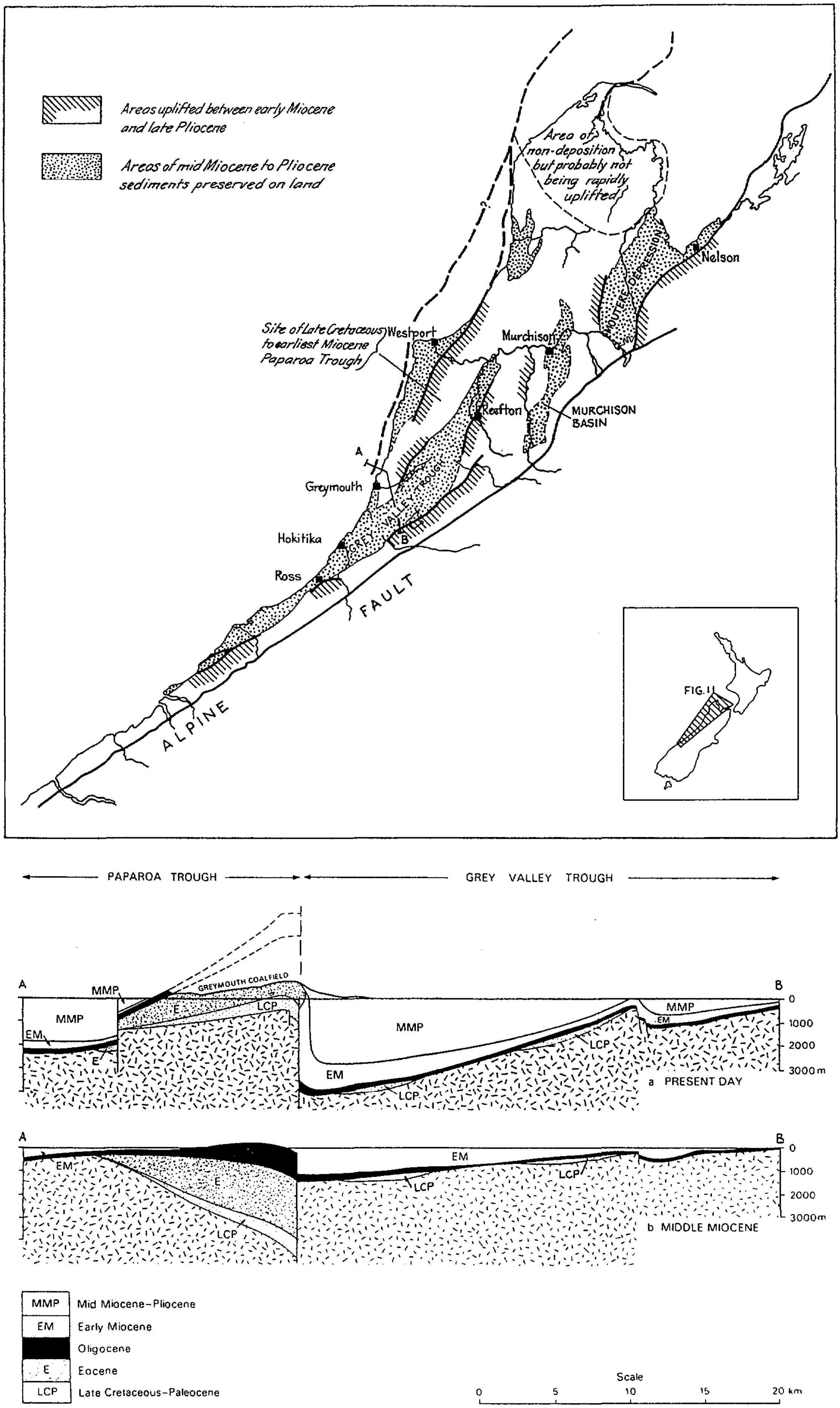


FIGURE 11 **Neogene basin inversion, West Coast Region, South Island Modified after Nathan & others (1986)**

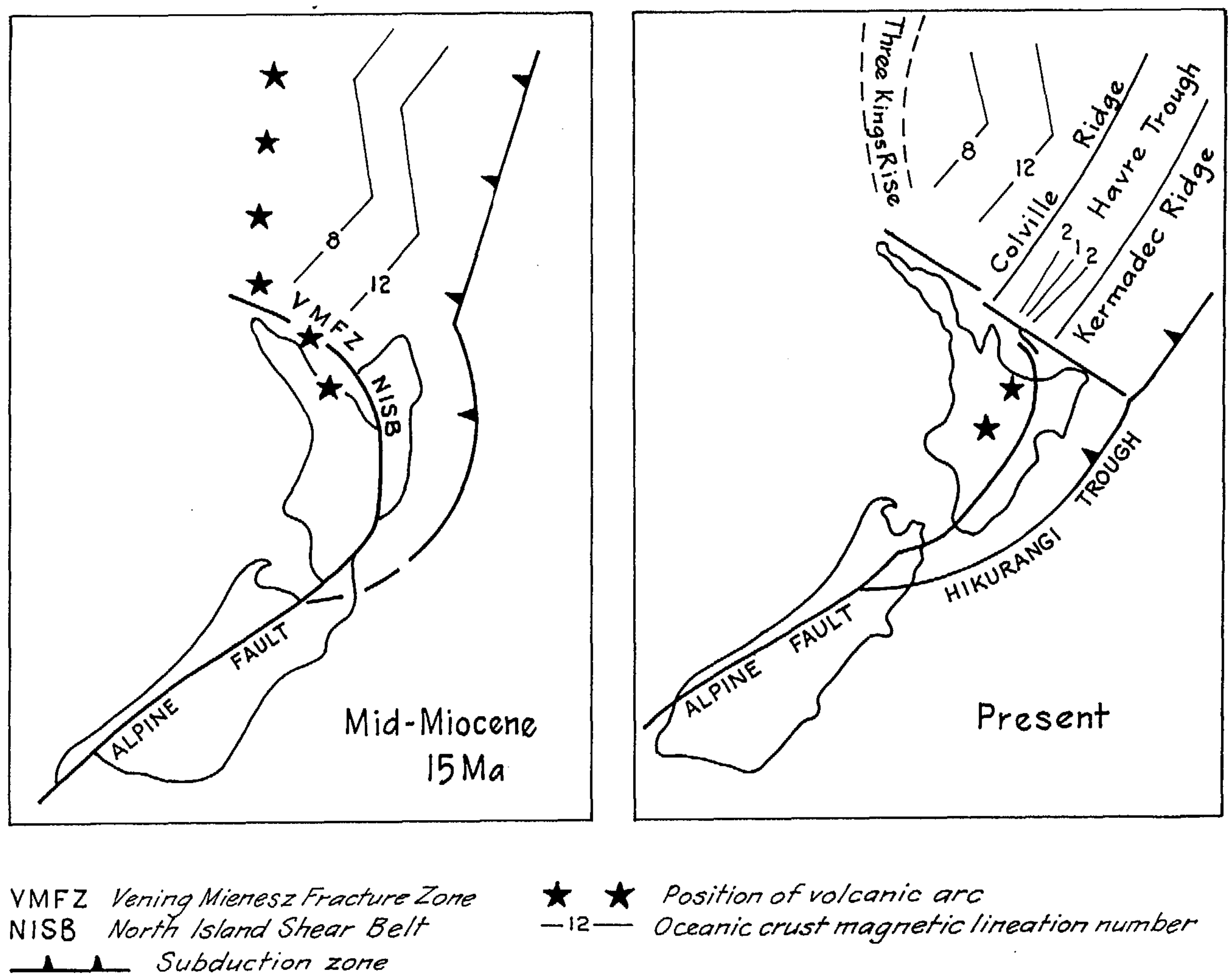


FIGURE 12 Tectonic development of New Zealand since the Mid-Miocene
Modified after Cole (1986)

sequence (Hayward & others, 1989). Eastern North Island, representing the accretionary prism and forearc basin sequence, is thought to have been adjacent to Northland at this time (see Ballance & others, 1982; Cole, 1986) and to have rotated to its present position due to dextral movement along the Vening Meinesz Fracture Zone and North Island Shear Belt (Figure 12) during clockwise movement of the subduction system in the Neogene (see Cole, 1986; 1990). The North Island Shear Belt of Cole (1986) is interpreted by Kamp (1987) as a 100 km-wide mega shear zone. The 480 km of Alpine Fault strike-slip movement (Wellman & Willett, 1942) is thus represented in the North Island by a wide zone of distributed deformation.

An allochthon of ophiolitic rocks and sedimentary wedges was also emplaced in the East Cape region of eastern North Island during the earliest Miocene and Mid-Miocene (Brothers & Delaloye, 1982; Kenny, 1984), thus supporting the theory that Northland and eastern North Island were closer together at that time. These ideas are discussed further in Walley & Ross (1991).

The Neogene pattern of sedimentation in the North Island reflected the clockwise rotation of eastern North Island. Volcanic arcs and depocentres moved southeastwards/clockwise (Figure 12): the Waitemata Basin closed by the Mid-Miocene (late time slice Cz4b). By the late Mid-Miocene the volcanic arc and inter-arc basin had moved farther clockwise: the volcanic arc was now centred on Coromandel and the Hauraki inter-arc rift opened. The associated volcanic arc bounding the western side of this rift is dated 11.5 Ma to 5.6 Ma (Skinner, 1986). Farther clockwise again, the Havre Trough to the north of New Zealand began to open at approximately 4 Ma as a back-arc basin to the Kermadec arc (time slice Cz6a; Table I, columns 53 and 54). The present andesitic volcanic arc and back-arc basin (the Taupo Volcanic Zone) are offset slightly to the southeast of the Havre Trough: extension in the ensialic Taupo-Rotorua Depression and activity in the associated arc commenced less than 1 million years ago (see Cole, 1984; 1986; 1990; Skinner, 1986; Stern & Davey, 1987).

As the subduction zone has rotated clockwise, accompanying slope sedimentation in eastern North Island has stepped out in a similar direction. As a result, older 'flysch'-

filled Miocene basins have been capped by younger shelf sediments (see Van der Lingen & Pettinga, 1980).

In western North Island, there has also been migration of basin depocentres, reflecting the rotational dextral shear regime. This appears to be the case, for example, in the North Wanganui Basin (Figure 4; Table I, column 34), where isopachs for the Oligocene to Miocene show a southwards/clockwise rotation of the basin depocentre. Oblique compression accelerated on the Taranaki Fault in the Early to Mid-Miocene and, as a result, there was a huge increase in clastic sediment supply to the Taranaki Basin adjacent to that fault (see King & Robinson, 1988; King, 1990; King & Thrasher, in press).

The pattern of Neogene sedimentation in the South Island has reflected compression along the Alpine Fault. Northeastern South Island (Marlborough; Table I, columns 42 to 44) is a very complex region, as it marks the southern end of the subduction system. In this area, throughout the Late Cainozoic, there has been dextral transpression and rotation of large crustal blocks, accompanying the rotation of the edge of the subduction system to its present trend (Lamb & Bibby, 1989; Figure 13). This rotation has led to an increasing obliquity of compression on the Alpine Fault. The entire Marlborough region is regarded as a distinct rotating block in King (1990).

Upon the inception of the Alpine Fault, there was a dramatic increase in the rate of sedimentation in South Island basins, especially in the Murchison Basin adjacent to the Alpine Fault (Table I, column 4; Figure 11). Rapid subsidence continued there until at least the end of the Miocene, and a shallowing upward of the sequence was due to increased sediment supply rather than a decrease in the rate of subsidence (Nathan & others, 1986).

An increase in rate of sedimentation in the Late Cainozoic also occurred in the Canterbury region, where sedimentation reached a peak in the Plio-Pleistocene. The locus of maximum sedimentation migrated eastwards with time, consistent with a prograding sedimentary wedge and related to uplift to the west of the basin (Browne &

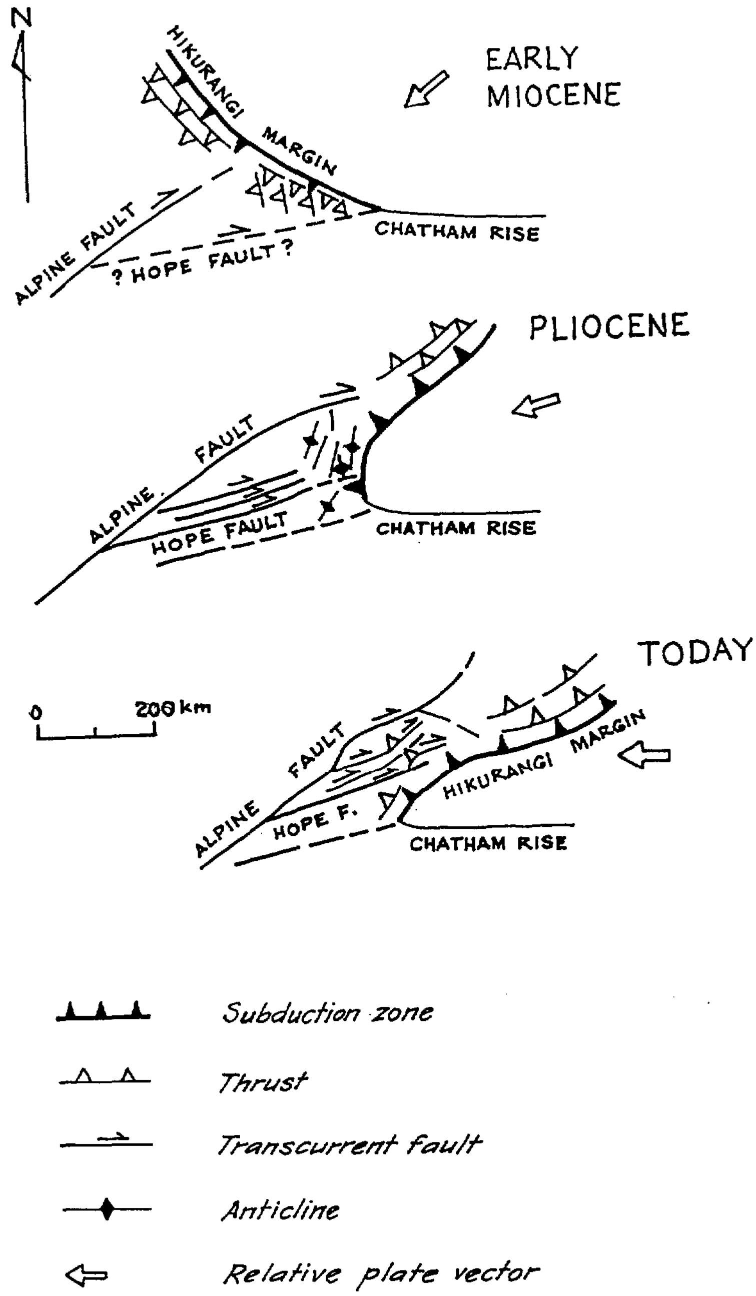


FIGURE 13 **Late Cainozoic structural evolution: Marlborough region, northeastern South Island**
Adapted from Lamb & Bibby (1989)

Field, 1988; Field & others, 1989; Figure 14).

The Neogene was a time of much erosion in southern offshore areas, particularly in the Campbell Plateau and the Great South Basin, due to a major increase in bottom-water circulation, which commenced at about the time of the inception of the plate boundary through New Zealand (see Kennett & others, 1974).

During the Neogene, predominantly in the Early to Mid-Miocene, lignite and coal accumulated in association with clastic deposition in parts of Clutha (Douglas, 1986; Isaac & Lindqvist [in press]), Canterbury (Field & others, 1989) and the West Coast Region (Nathan & others, 1986). There was also lignite formation in part of North Island: North Wanganui Basin and locally in northern Northland (McQuillan, 1977; Suggate & others, 1978).

At about 10 Ma (time slice Cz5), or at approximately the time of the opening of the Hauraki Rift in the North Island, there was an influx of gravels, following a hiatus, in Western Southland (Te Anau Basin) and Clutha (Table I, Sheet 1). Depocentres moved from south to north in Marlborough. The gravels reflect increasing uplift in the source areas and the <u>oblique</u> compression (transpression) on the Alpine Fault which started at about this time. Farther north, oblique compression on the Taranaki Fault <u>ceased</u> at about 10 Ma as a result of a southwards/clockwise shift in the focus of compression towards the Alpine Fault (King & Robinson, 1988; King, 1990; King & Thrasher, (in press). In the Murchison Basin, there was a clastic source from east of the Alpine Fault from the earliest Miocene onwards (Cutten, 1979; Nathan & others, 1986).

During the Late Miocene and into the Pliocene, coarse clastic detritus spread into Canterbury, the onshore western fringe of the Great South Basin and the West Coast Region.

Due to increasing transpression, there was major uplift on the Alpine Fault from 7 to 5 Ma onwards (Kamp & others, 1989) forming the Southern Alps. By the Late Pliocene (time slices Cz6a - 6b), therefore, a vast gravel plain extended west and north from the

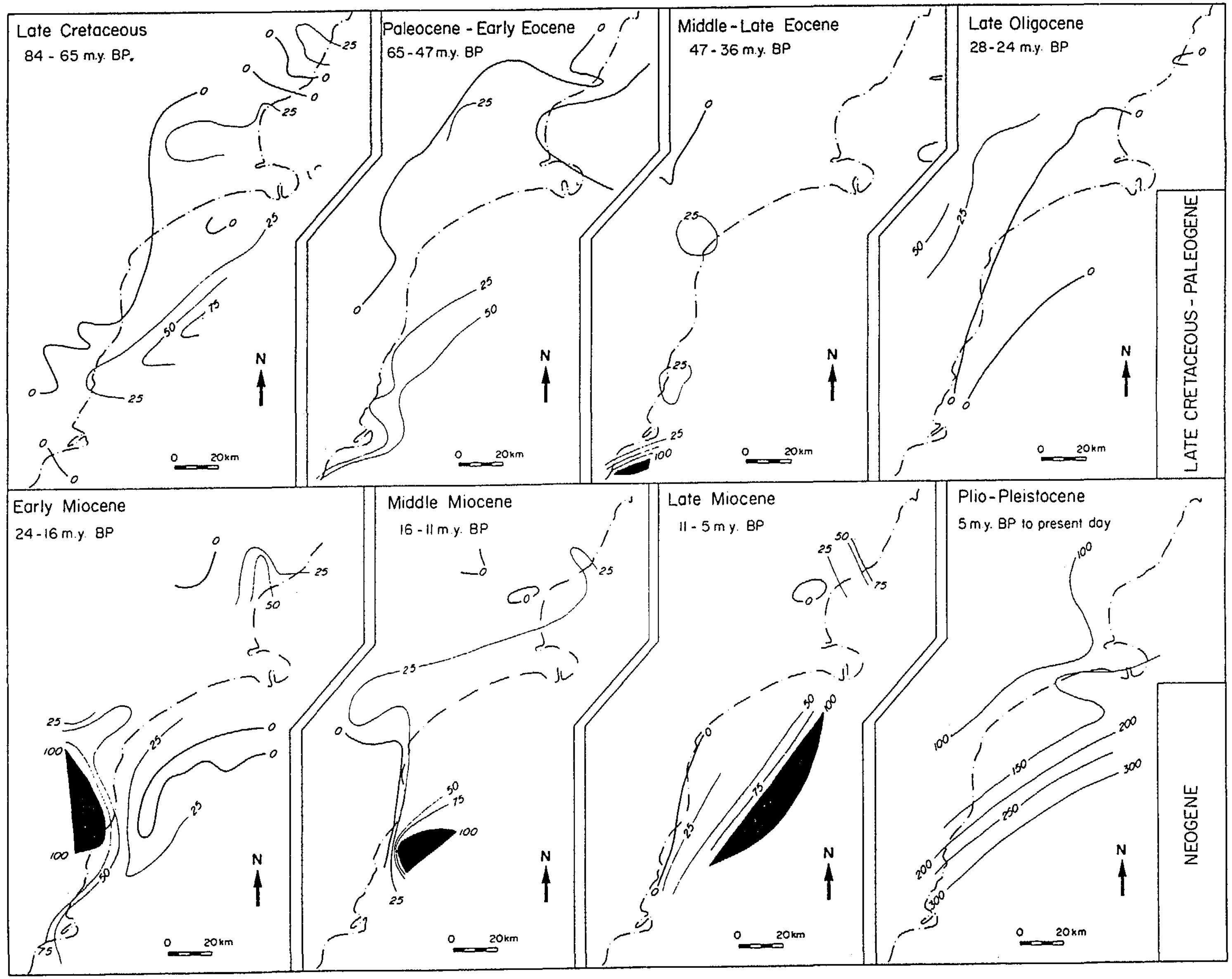


FIGURE 14 **Sedimentation rates for the Canterbury region, east central South Island (in mm/1000 years) From Browne & Field (1988)**

Alpine Fault in the West Coast Region and gravel plains also stretched across Canterbury, Clutha and Southland. The western platform (West Coast Region) was uplifted and the Murchison Basin was inverted in the Late Pliocene (see Nathan & others, 1986).

The increased rate of compression was probably associated with the opening of the Havre Trough, north of New Zealand, at about 4 Ma (see Cole, 1986). At approximately this time (about 5 Ma or a little earlier) the southern part of the Taranaki Graben was inverted and at the same time the North Taranaki Graben began to form, due to movement on the Cape Egmont and Turi Fault Zones (King & Robinson, 1988; King, 1990; King & Thrasher, in press; Figure 5). The North Taranaki Graben may have formed as a rift related to back-arc extension (King, 1990). Coeval with this deformation, east of the Taranaki Fault the North Wanganui Basin was uplifted, and subsidence to the south created the South Wanganui Basin (see Anderton, 1981). The increased uplift resulted in the supply of huge quantities of sediment to the Taranaki and South Wanganui Basins (Table I, columns 32 and 33). As the North Taranaki Graben (Figure 5) was filled, the shelf edge prograded to the northwest during the Pliocene and Pleistocene, a process which continues to the present day (King & Robinson, 1988).

Depocentres in South Wanganui Basin have also migrated clockwise from the Pliocene to the Late Pleistocene (see Anderton, 1981; Figure 15). At the same time, northwest North Island has rotated anti-clockwise since about 3 Ma (Late Pliocene; Ballance, 1976; Nelson & Hume, 1977). Both these rotations are probably related to the opening of the Havre Trough and Taupo back-arc basin, which are still extending (Cole, 1986, 1989). Crustal downwarping in the South Wanganui Basin is thought to represent an early stage in the formation of a back-arc basin (Stern & Davey, 1989). Since the Late Pliocene, this basin has developed as a foreland basin to the west of a fold-thrust belt (Katz & Leask, 1990), which is perhaps comparable to the tectonic setting of the South Taranaki Graben during the Late Oligocene to Late Miocene (see King, 1990).

There has been 480 km of dextral displacement on the Alpine Fault since its inception (Wellman & Willett, 1942; Kamp, 1987). There is evidence for substantial offset (~100

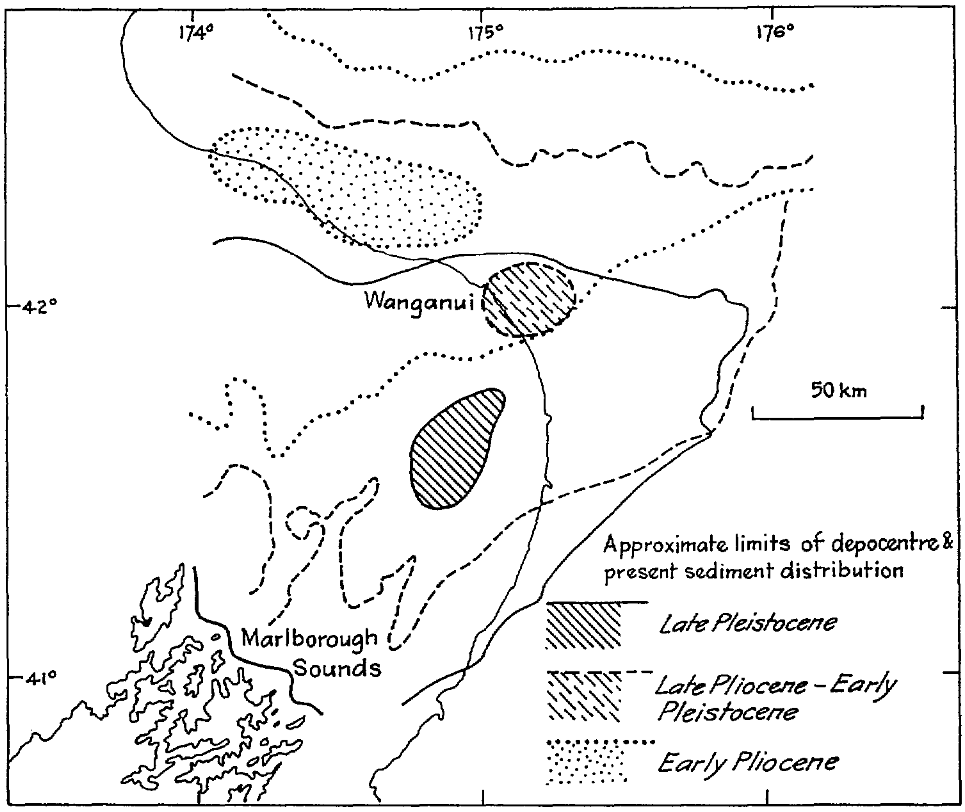


FIGURE 15 **Early Pliocene to Late Pleistocene depocentres, South Wanganui Basin Modified after Anderton (1981)**

m) less than 10 000 years ago (R.J. Norris, personal communication, 1989; see also Norris & others, 1990) and the last major displacement on the Alpine Fault was ~260 years ago (Cooper & Norris, 1989).

Sediments deposited during Pleistocene glacial episodes have been superimposed upon the syntectonic Late Cainozoic sedimentation and the associated regression. The youngest gravels in much of the South Island region are outwash deposits related to glacial advances. The glacial episodes are fully described in Suggate & others (1978).

Late Cainozoic volcanism in the South Island has occurred only east of the Alpine Fault: Miocene to Pliocene dominantly mafic, but minor felsic, intra-plate volcanism in the Canterbury and Chatham Rise regions and the Campbell Plateau (Cook, 1981; Field & others, 1989; Wood & others, 1989) and latest Pliocene to Pleistocene island-arc type volcanism on Solander Island (Bishop, 1986; Reay, 1986). Large shield volcanoes were formed, including those at Dunedin and Banks Peninsula (Coombs & others, 1986; Sewell, 1988). Volcanism may have continued into the early Pleistocene in the southwestern Chatham Rise. Some of the late Neogene Canterbury - Chatham Rise volcanism may be related to the change in relative plate motion at about 10 Ma that led to the commencement of compression on the Alpine Fault (Herzer & others, 1989). The South Island intra-plate volcanism appears to young towards the east and may represent passage of the southeastern New Zealand continental plateau over a 'hot zone' in the mantle (Adams, 1981).

3. NOTES ON HYDROCARBON POTENTIAL

The early Late Cretaceous to Palaeogene history of many of New Zealand's sedimentary basins has much in common with that of the Taranaki Basin, which contains the only commercial oil and gas fields discovered to date (Ministry of Commerce, 1990a). Moreover, the late Early to early Late Cretaceous rift sequences may be correlatives of units in the Gippsland Basin (see, for example, Lowry, 1987).

It is clear, from papers presented at the 1989 New Zealand Oil Exploration Conference

(Ministry of Energy, 1989; Ministry of Commerce, 1990b), that many potential hydrocarbon-bearing basins within the New Zealand continental shelf have as yet been little explored. These areas include western offshore Northland, which is immediately north of the Taranaki Basin and could be reasonably expected to have many features in common with the Taranaki Basin (see Beggs & others, 1988). In addition, deeper water areas within the New Zealand Exclusive Economic Zone, such as the Challenger Plateau, New Caledonia Basin, Chatham Rise and Campbell Plateau (Figure 4) have some potential for petroleum (Ministry of Commerce, 1990a).

Mid to Late Cretaceous and Palaeocene sequences comprise good potential source rocks. For example, up to 20% T.O.C. occurs in Mid Cretaceous sequences in the Great South Basin (Cook & Beggs, 1990), up to 12% T.O.C. in Late Cretaceous sediments in the Chatham Rise area (Wood & others, 1989) and up to 12% T.O.C. in the Paleocene Waipawa Black Shale, which has a widespread distribution in eastern North Island (Moore, 1989). There are known gas reserves within these intervals in the Great South Basin (Anderton & others, 1982). Potential source rocks are also mature in central and eastern Canterbury Bight and hydrocarbon shows have been found in two of the few offshore wells which have been drilled there (see Field & others, 1989). There have been many gas and oil shows in wells in eastern North Island, but to date only one well has been drilled offshore in that area (Ministry of Commerce, 1990a). There are also numerous oil and gas shows in the West Coast Region (Nathan & others, 1986). None of the offshore half-grabens in deep water within the Chatham Rise has been drilled. There are also good potential reservoir rocks in many of the New Zealand basins, particularly in Cretaceous sequences. Miocene turbidite sands provide a reservoir in the West Coast Region, where a recent exploratory well intersected oil flowing at approximately 80 bbl/day (Matthews, 1990). Pliocene shelf sediments are also an important reservoir objective in eastern North Island (Harmsen, 1990).

Tectonism resulting from the propagation of the convergent plate boundary through New Zealand in the Neogene has caused inversion of Cretaceous and Palaeogene basins, particularly west of, but also close to, the plate boundary zone. These inversion structures are important hydrocarbon traps. A complex Neogene tectonic history has affected not only the Taranaki Basin, but also many of the other New Zealand Cretaceous - Cainozoic basins, including the neighbouring and under-unexplored South Wanganui Basin, as discussed by Katz & Leask (1990).

Away from the plate boundary zone to the southeast, however, the Canterbury Bight, Chatham Rise and Campbell Plateau were comparatively stable during the Neogene. As pointed out by Cook & Beggs (1990), the lack of post-Cretaceous tectonic events in the Great South Basin allows a clearer understanding of the timing and complexity of the Cretaceous structures than is possible in, for example, the Taranaki Basin.

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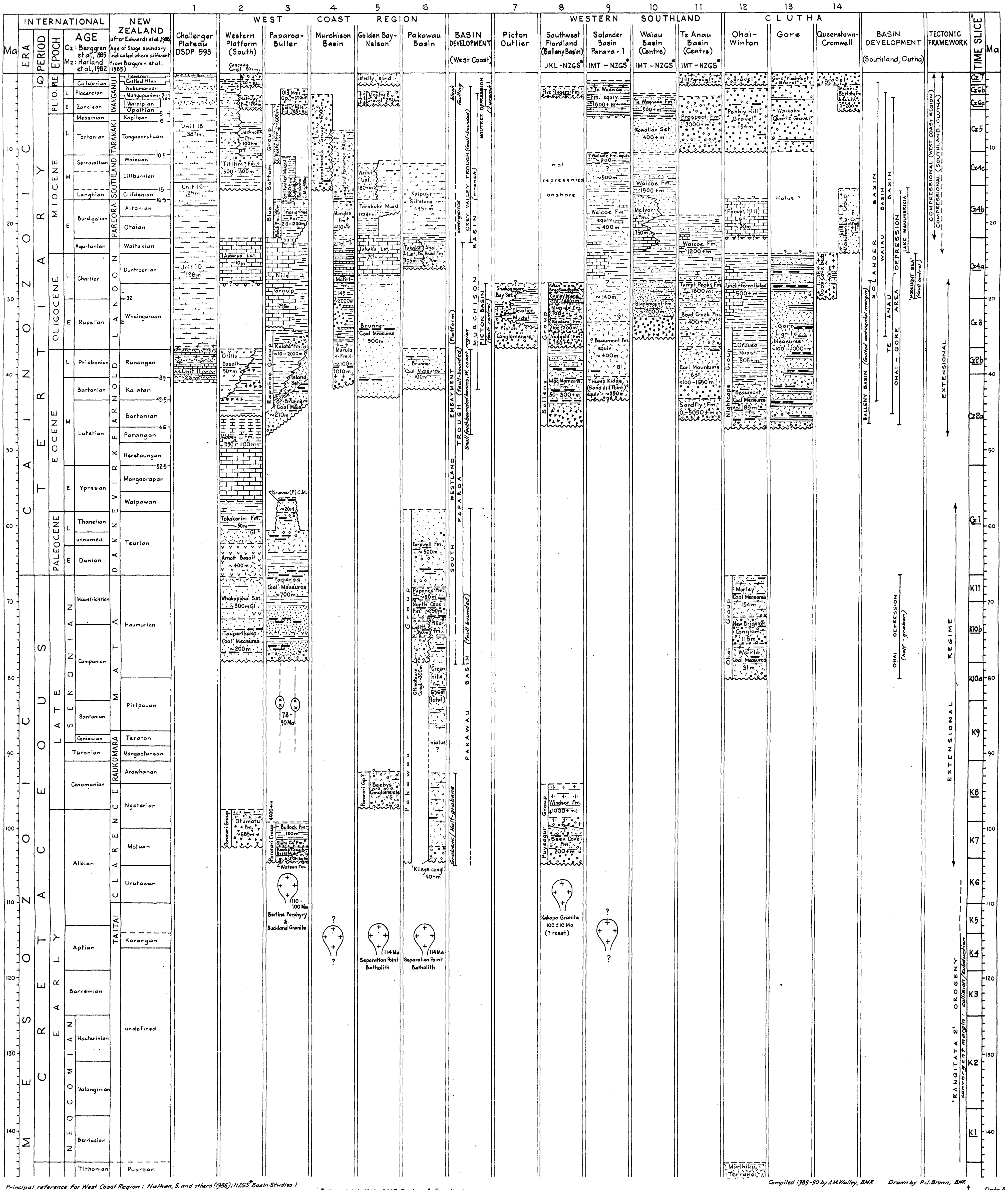
CRETACEOUS — CAINOZOIC STRATIGRAPHIC SUMMARY COLUMNS: NEW ZEALAND—SOUTH ISLAND SHEET 1



Principal reference for West Coast Region: Nathan, S. and others (1986); NZGS* Basin Studies 1
Column 7 is based on Nicol, A and Campbell, J.K. (in press)
Columns for Western Southland compiled by I.M. Turnbull & J.K. Lindqvist, NZGS*. Further comments from IMT & JKL, March 1990

* From 1 July 1990, DSIR Geology & Geophysics

Compiled 1989-90 by A.M. Walley, BMR

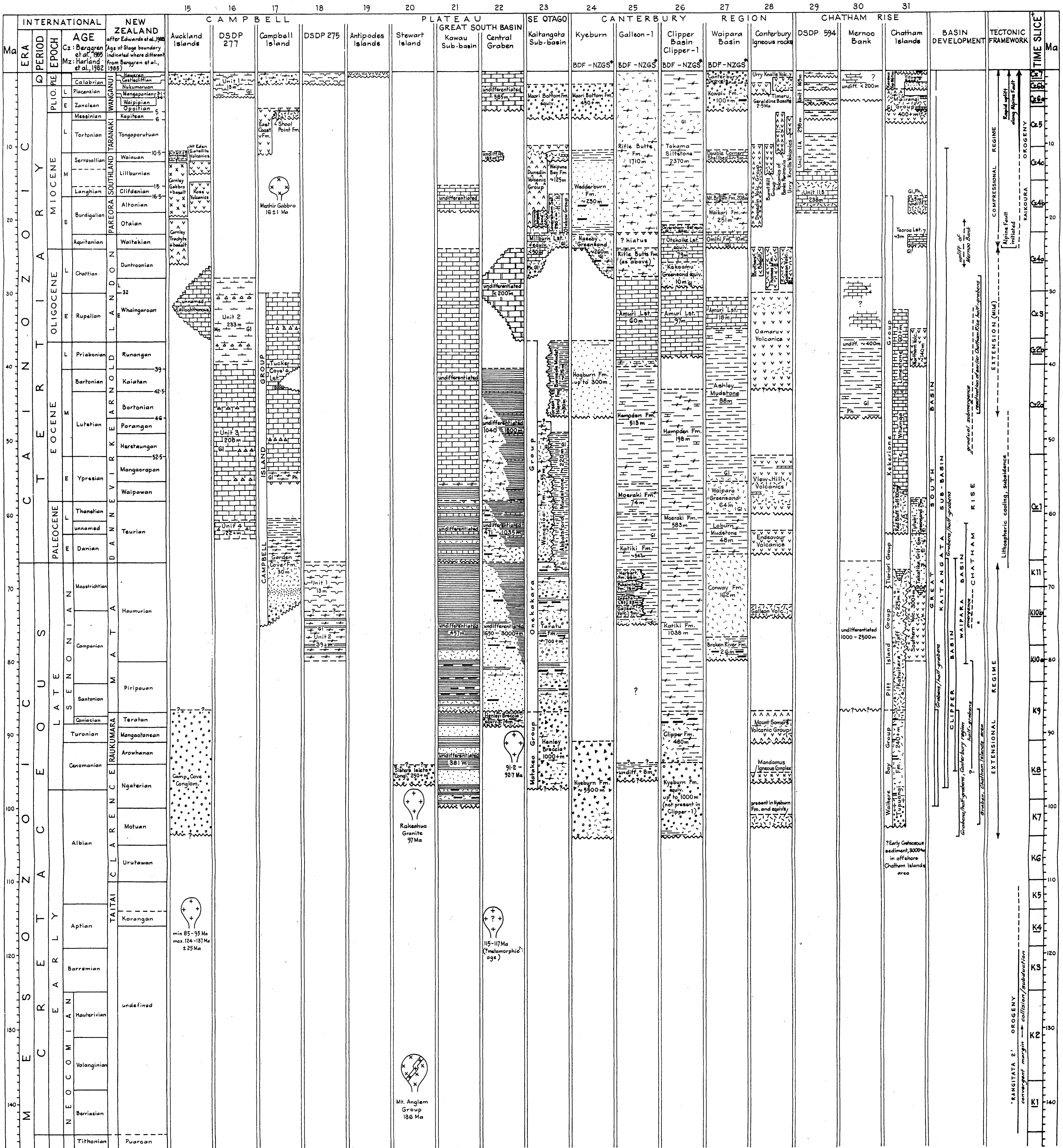
Drawn by P.J. Brown, BMR

+ —— Data & Interp. maps

TABLE I Sheet 1

CRETACEOUS – CAINOZOIC STRATIGRAPHIC SUMMARY COLUMNS: NEW ZEALAND – SOUTH ISLAND

SHEET 2



Column 16 compiled by M. Yeung, BMR
Main reference for Columns 15, 17 & 19: Cook (1981) NZGS* Report 97 and for Column 17: Beggs (1978)
Additional comment on Columns 15-19 by J.M. Beggs, NZGS*
Column 22 based in part on Cook, R.A. & Beggs, J.M. (in press) 1989 NZ Oil Exploration Conference Proceedings
Columns 24-27 compiled by B.D. Field, NZGS*
Column 31: Campbell and others (1988)
Additional comments from H.J. Campbell, B.D. Field, R.H. Herzer & M.G. Laird, NZGS*, March 1990

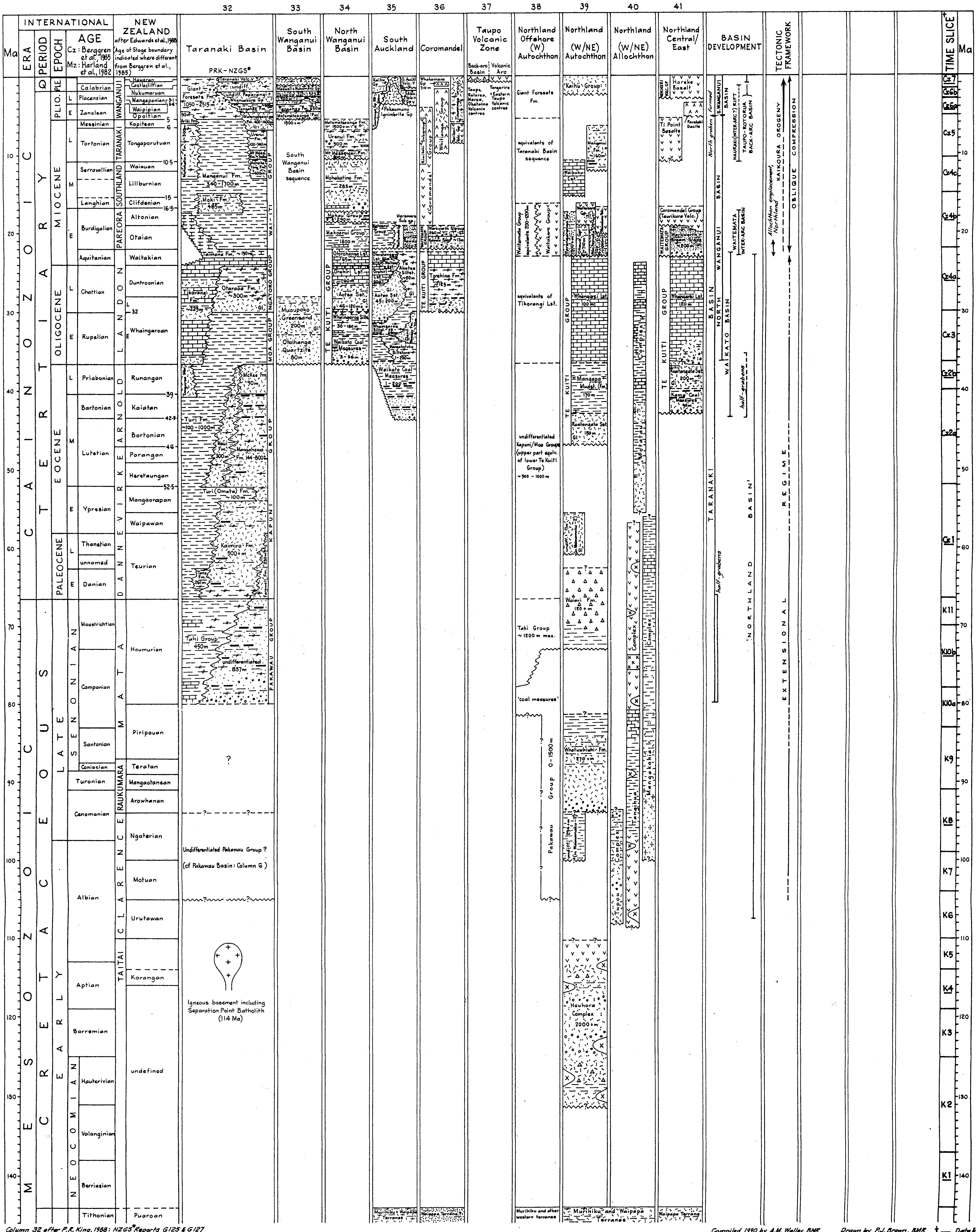
* From 1 July 1990, DSIR Geology & Geophysics

Compiled 1989/90 by A.M. Walley, BMR   Drawn by P.J. Brown, BMR

+ — Data & interp. maps

TABLE I Sheet 2

CRETACEOUS - CAINOZOIC STRATIGRAPHIC SUMMARY COLUMNS: NEW ZEALAND-NORTH ISLAND SHEET 3



Column 32 after P.R. King, 1988: NZGS Reports G125 & G127*
Contributions to Columns 33 & 34 by P.R. King, NZGS; and to Columns 35 & 36 by S.W. Edbrooke & A.M. Sherwood, NZGS;**
*Column 38 after R.H. Herzer, M. Beggs, P.R. King & B.W. Hayward, NZGS;**
*Substantial information for Columns 39, 40 & 41 was compiled by M.J. Isaac, F.J. Brook & B.W. Hayward, NZGS.**

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† — Date & Interp. map

TABLE I Sheet 3

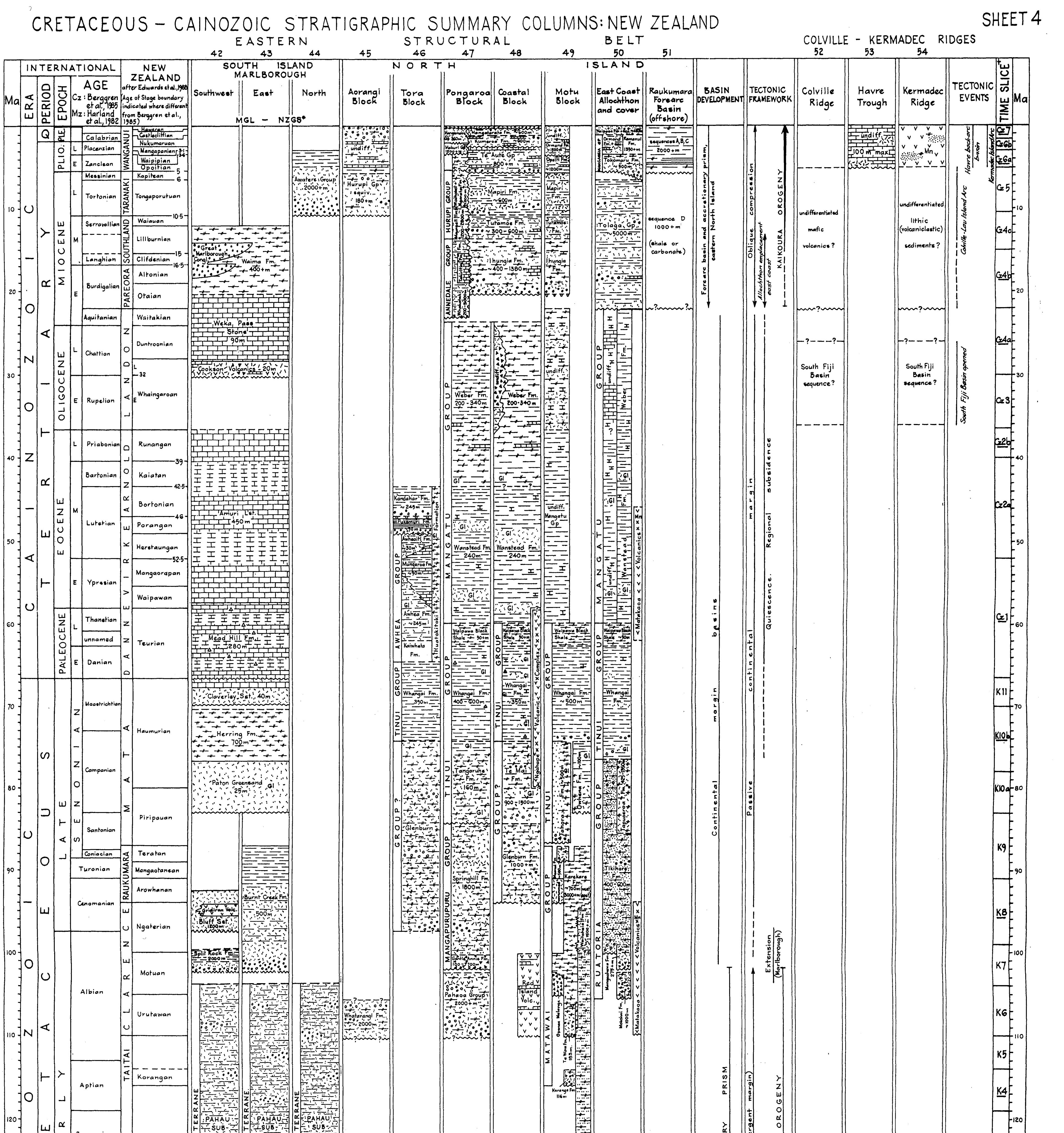

TABLE I Sheet 4