THE NZ GEOLOGICAL SURVEY CRETACEOUS-CENOZOIC BASIN STUDIES PROGRAMME: OBJECTIVES, OUTLINE OF PROGRESS AND RESULTS

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The objectives of the programme are to identify New Zealand's mid Cretaceous to late Cenozoic sedimentary basins, interpret their geological history, and assess their fossil fuel potential.

For the purpose of basin analysis, the New Zealand plateau has been divided into eleven regions which are being investigated in turn. A monograph, which includes paleogeographic, isopach, and structure contour maps and a complete set of stratigraphic columns on microfiche, is being published for each region. There will be a final synthesis volume and maps covering most of the New Zealand subcontinent. Studies of three regions have now been completed and published (West Coast South Island, Canterbury, and Chatham Rise); a further three regions (Western Southland, Taranaki, and North Auckland) are in the process of final synthesis, and data compilation is proceeding in two others (East Coast and Clutha).

Results from isopach and lithofacies maps combined with maturation studies are used to give an indication of areas where hydrocarbons are inferred to have been generated. Suitable reservoir rocks are also identified in each region. In addition, subsidence and sedimentation rates are calculated, and geohistory diagrams drawn for each region. From these and other investigations is emerging a much clearer idea of the tectonic development of the New Zealand region. Some key aspects of this development will be addressed in this paper.

INTRODUCTION

The instigation of the NZ Geological Survey Basin Studies Programme was triggered primarily by the energy crises of the 1970s, when it was realised that regional knowledge of New Zealand's younger sedimentary basins, in which were likely to be concentrated any hydrocarbon resources, was woefully lacking. This same period coincided with intensified interest by oil companies in the petroleum prospects of New Zealand, including frontier areas, and a consequently accelerated programme of marine seismic exploration and offshore drilling. As a result of this activity, for the first time data covering the bulk of the New Zealand region, both onshore and offshore, became available. The Basin Studies Programme was the NZ Geological Survey response to the opportunities provided to capitalise on the flood of new data, in order to make regional geological syntheses over the whole of the New Zealand Plateau, as well as to promote the search for hydrocarbons.

Initially it was thought that all regional studies plus a New Zealand wide summary could be completed by the late 1980s, relying mainly on compilation of existing data, which was then thought to be adequate for the purpose. However, as the programme progressed it became obvious that the quality of the existing database was inadequate for a comprehensive study of this nature, and that to complete the programme to an acceptable scientific standard a considerable amount of new field work and data collection was needed. A policy decision was taken early in the programme to carry out the additional work needed to produce a high quality database from which reliable interpretations and syntheses could be made. As a result the time frame for the programme has had to be extended, and completion is now expected in the mid to late 1990s.

OBJECTIVES

The objectives of the programme are to investigate the younger stratigraphic rock sequences throughout New Zealand from the relatively simply-deformed Lower Cretaceous rocks (essentially post-Torlesse) up to and including Quaternary strata concordant with or deformed with underlying Pliocene rocks, but excluding young terrestrial and marine terrace deposits. These rocks, formed mainly during the last 110 million years, contain all our known coal and hydrocarbon resources and most of our non-metallic raw materials. The programme is essentially a study of younger sedimentary basins throughout New Zealand, which is intended to provide an insight into basin evolution, to pinpoint aspects of New Zealand's later geological history and earth resources needing further detailed investigation, and to provide a data base of high quality for future hydrocarbon and mineral exploration. It has therefore been designed as a research programme with expected economic fallout in terms of the search for hydrocarbons in particular.

OPERATION AND SCOPE OF THE PROGRAMME

For the purpose of basin analysis, the New Zealand continental area (onshore and offshore) has been divided into 11 regions (Fig. 1) corresponding to major tectono-sedimentary provinces, which are being investigated in turn, although at any one time work is proceeding in several areas. Each region has a Project Leader and one or more other compilers, whose task it is to collect and collate the raw data and produce a synthesis. The raw data comes from published maps and papers, existing university theses, oil company exploration data on open file, ongoing separate investigations by several sections of the Geological Survey, and new work especially designed for the programme. From time to time (when funding permits) graduate University students or other research workers are awarded short-term contracts to undertake specialist studies to benefit the programme. To date 11 contracts have been awarded to enable graduate students to complete M.Sc. or Ph.D. degrees in association with the Basin Studies Programme. The results of the compilation and synthesis for each region are being published as monographs in a new series, the final monograph in the series to be a synthesis of the whole of the New Zealand sub-continent based on the data presented in the preceeding 11 regional bulletins.

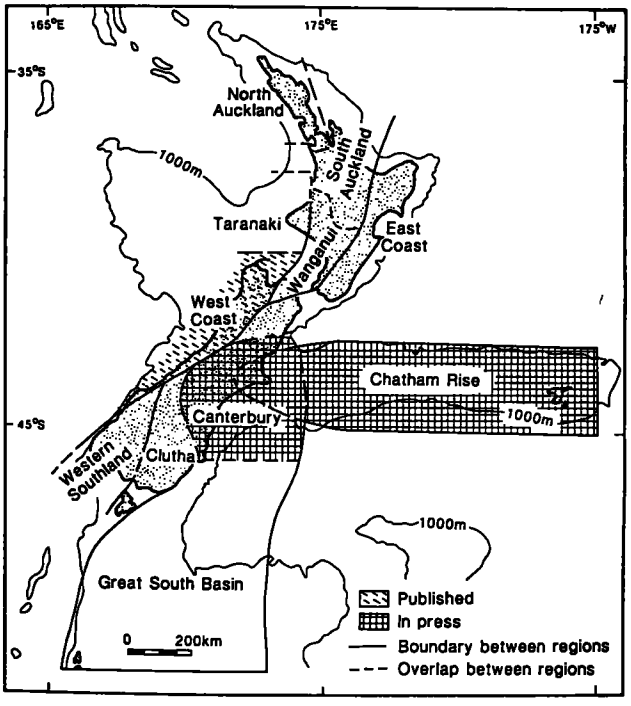

Fig. 1: Basin Studies Programme regions.

To date, three monographs have been published (West Coast, South Island; Canterbury; and Chatham Rise): three more are in an advanced state of compilation (Western Southland; Taranaki; and North Auckland): and field work is proceeding in two more (East Coast and Clutha). In addition, more than fifty related publications have directly resulted from the studies so far.

One of the most important products of the programme is the series of regional paleogeographic and isopach maps, on a scale of 1:2 million and 1:1 million respectively, which accompany each bulletin. Soon after the programme's inception it was decided to select five time horizons coinciding with New Zealand stage boundaries for special study, and for which paleogeographic maps would be drawn. These are: the Ngaterian-Arowhanan boundary (mid Cenomanian); the Cretaceous-Tertiary boundary; the Runangan-Whaingaroan (Eocene-Oligocene) boundary; the Altonian-Clifdenian (Early-Middle Miocene) boundary; and the Waipipian-Mangapanian boundary (early Late Pliocene). These particular horizons were selected because good paleontological control had already been established at these levels, and the stage boundaries could be recognised New Zealand-wide with little difficulty. By insisting on a small number of standard horizons it was hoped to achieve a degree of uniformity and a basis for comparison between regions, and a uniform database from which the New Zealand-wide paleogeographic maps could be drawn. The five selected time horizons are intended as a minimum, however, and additional paleogeographic maps are being drawn in each region where control is sufficiently good or where particular geological events affecting the region warrant it. Thirteen paleogeographic maps were finally drawn for the West Coast region, and twelve for the Canterbury region.

Where sufficient data is available, isopach maps are drawn for each epoch, and, at a minimum, for Cretaceous, Paleogene, and Neogene together with total sediment isopachs. In offshore portions of regions, however, because of paucity or absence of drillhole data, it is usually only possible to draw isopachs on seismic units situated between prominent reflecting horizons. These horizons often do not coincide with epoch boundaries. For example, in the Chatham Rise region, prominent reflecting horizons of regional extent occur at the top of basement, at a late Cretaceous unconformity, and at a mid Oligocene unconformity. In cases such as this the equivalents of the seismic units are identified onshore as closely as possible, and isopachs for the units drawn for the whole region. For the Chatham Rise region it was therefore possible to draw region-wide isopach maps roughly equivalent to the Upper Cretaceous, Paleogene, and Neogene sequences. Structure contour maps are also prepared for each region on basement, and on other horizons where feasible.

One of the major tasks facing compilers has been to evaluate all available suitable stratigraphic sections in the onshore portion of each region and, where necessary, upgrade knowledge of each section to an acceptable standard. It has been found that the quality of the database in almost every case has been inadequate for the present studies, and almost all stratigraphic sections have had to be remeasured and resampled. Often data essential to the programme had not been recorded by earlier workers, or not recorded in sufficient detail. Consequently, a large proportion of the time available for compilation has been spent in remeasuring sections and drafting new stratigraphic columns. Stratigraphic columns relevant to each region have been included as a microfiche appendix in each bulletin. As a result of the re-evaluation of large numbers of columns, and the necessity to achieve correlation of lithologic units region-wide, an added task for compilers has often been to prepare a new synthesis of lithostratigraphic nomenclature, including, where necessary, new definitions and re-evaluation of previous definitions. A newly revised lithostratigraphic framework has been prepared and published for the Canterbury region, for example. Up to date earth science bibliographies for specific regions are also being prepared and published where time permits, as is the case for the Canterbury region.

INTERDISCIPLINARY INPUT AND PROBLEM SOLVING

In association with stratigraphic section measuring, new collections for petrological, geochemical, sedimentological, and paleontological study have been made where appropriate.

In addition to providing new dating to better pin down key horizons for the programme, paleontologists have also been working on allied projects which have been of direct assistance to basin studies. One of these has been the Cretaceous/Tertiary boundary project, which has served to delineate this important boundary throughout Marlborough and north Canterbury and also for parts of the East Coast, North Island. Study of paleoecological changes at the boundary have also been of value. Similar studies are also being carried out on the Eocene/Oligocene boundary.

In addition to dating, valuable input on paleoenvironments has been made by paleontologists, and this has closely complemented sedimentologic studies. Of particular importance has been the refinement of knowledge of factors which influence foraminiferal distributions, and this in turn has resulted in systematic definition of marine paleoenvironments and paleobathymetry based on the study of fossil microfauna (Hayward, 1986). A logical progression from the ability to construct paleobathymetric curves from drillhole sampling is the construction of subsidence curves, and these, after allowing for the effects of compaction and sea level change, provide not only a geohistory analysis for individual well sites, but when combined, lead to conclusions on paleogeography and tectonic history for a whole region (Hayward, 1987). A relatively new field which is having increasing input into the basin studies programme is that of palynofacies research, being carried out as part of the Palynology Project. This is being applied primarily to paralic sequences, and, in association with sedimentary facies analysis, is becoming a powerful and innovative tool. One direct result of close association of the Paleontology Programme with the Cretaceous-Cenozoic Basin Studies Programme has been a revision of New Zealand Cretaceous-Cenozoic biostratigraphy, including a revised geological time scale and international correlation chart (Edwards *et al.*, 1988).

In addition to general sedimentological input into the programme, particularly to determine paleoenvironments and sedimentary processes, specific research projects into various aspects of basin studies are being carried out. A reconnaissance study of Neogene flysch basins on the East Coast of the North Island is in the final stages of completion, and should be published next year. Heavy mineral studies are carried out as a matter of course in Cretaceous-Cenozoic strata in each region in order to determine provenance of the sediments, and a review manuscript on heavy mineral studies throughout the South Island has been completed. Studies of clay mineralogy, carbonate analysis, and grain size and sorting of sedimentary deposits is carried out routinely by the NZGS Sedimentology Laboratory. In addition, diagenesis studies have been carried out for key formations in the Taranaki region in order to assess their reservoir capabilities.

In order to gain additional insight into the tectonic environment under which evolution of basins proceeded, special studies of the geochemistry and petrology of various igneous suites have been commissioned for the programme. Some of this work has been completed under contract at universities by graduate students, and other work has been carried out by Geological Survey staff.

Although Neogene relative structural displacement of blocks is considered to have been insignificant in the completed West Coast, Canterbury, and Chatham Rise regions, it is clearly more critical in other regions being studied. In the East Coast region, for example, where potentially large dislocations may have occurred, specific structural studies have been initiated in order to obtain information on the amount of strike-slip movement on transcurrent faults. Some work is also being done on the degree of potential rotation of discrete blocks with respect to each other using paleomagnetic studies. The structural studies are necessary in order to carry out palinspastic reconstructions not only of regions which are highly structurally deformed, but also for the final reconstruction of the whole New Zealand subcontinental area for the purposes of paleogeographic interpretation. An example of structural research designed for the basin studies programme is the recent mapping of the northeastern end of the Hope Fault system (Marlborough) by an M.Sc. student (Van Dissen, 1989). The studies confirmed previous suspicions that the fault branched at its northeastern end into a number of splay faults with only minor strike-slip displacement, and it is likely that displacement along the whole fault is minor and will have little effect on paleogeographic reconstructions.

More challenging structural problems occur in Northland and in the Raukumara Peninsula, where allochthonous sequences, which have been displaced perhaps hundreds of kilometres and which cover much of each region, occur. In Northland, where the allochthon represents most of the outcrop area, detailed special mapping has been locally necessary in advance of section measuring in order to determine the extent and order of superposition of allochthonous sheets. Needless to say, preparation of isopach maps is not possible for much of the region, and paleogeographic maps can only be limited in extent. In the case of Raukumara Peninsula, which is part of the East Coast region, it has been expedient to compile a provisional 1:250 000 geological map delineating the extent of the allochthon and other major structures in conjunction with compilation for the region. The allochthonous sheets in both regions may well conceal prospective autochthonous strata, but unfortunately little seismic data exists on which to base interpretations.

An area in which the Geological Survey has been steadily improving its skills, and has also been involved in some staff retraining, has been in the field of seismic interpretation. As much, perhaps most, of the area covered by the programme regions is offshore, seismic interpretation is of critical importance. As a result of government petroleum legislation all seismic data and reports produced by oil companies must be lodged with the Ministry of Energy, and the NZGS has access to all open file information. The open file seismic and well data is used extensively for offshore interpretation, and a great deal of the raw data is interpreted or reinterpreted by NZGS geophysicists and geologists as an essential part of regional studies. As an example, the existing seismic data from oil company surveys in Taranaki has now been completely reinterpreted, and a comprehensive synthesis tied in with open-file data from all available wells is now available covering the whole Taranaki Basin (Thrasher and Cahill,

1989). No new offshore data acquisition has been commissioned in any region, partly because of cost, but also because in almost all cases existing seismic coverage is more than sufficient for the reconnaissance nature of the programme. In the regions so far published Geophysics Division staff have provided additional seismic and gravity information for basins both onshore and offshore, and they have been represented as co-authors in published monographs. Geophysics Division input has also been valuable in a team interpretation of the geology of offshore western Northland.

Results from isopach and lithofacies maps combined with organic geo-chemistry and maturation studies are being used to give an indication of areas where hydrocarbons are inferred to have been generated. A typical example is given here from the Canterbury region (Fig. 2). Suitable reservoir rocks are also identified in each region, as are critical structural and stratigraphic data which may lead to the pinpointing of potential traps. From this information, together with geohistory and associated interdisciplinary studies of lithofacies relationships, igneous geochemistry, and structure, is emerging a much clearer idea of the tectonic development of the New Zealand region.

SYNOPSIS OF REGIONAL SCIENTIFIC RESULTS

Details of scientific results are best left to be discussed in papers dealing with specific Basin Studies regions (see elsewhere in this volume). However, there are a number of features common to all regions completed or at present under study to which it is worth drawing attention.

It has been clear for some time that economic *basement* is represented in every region so far studied by early mid Cretaceous (early Motuan) or older rocks, which typically are separated from younger rocks by a major regional unconformity. The older rocks are structurally more deformed as a result of an Early Cretaceous period of compression, deformation, and uplift (Rangitata Orogeny II - Bradshaw *et al.*, 1981) followed by erosion.

In the late mid Cretaceous (late Motuan : late Albian - early Cenomanian), as a result of crustal extension probably associated with an early period of rifting predating the separation of the New Zealand continental block from Gondwana in the Late Cretaceous (Laird, 1981), regional subsidence accompanied by half-graben formation occurred throughout the South Island and at least the western side of the North Island (Fig. 3) (Nathan *et al.*, 1986; Field & Browne *et al.*, 1989; Wood, Andrews, and Herzer *et al.*, 1989; Thrasher, 1989). The majority of these half-grabens were filled with up to several thousand metres of non-marine sediments consisting of alluvial fan deposits, fluvial sediments, and lake deposits, many of them highly carbonaceous. The Cretaceous and Tertiary overburden in most cases is such that the graben fill deposits have reached sufficient maturity to have generated hydrocarbons. The Pororari Group graben fill deposits of the West Coast of the South Island include carbonaceous lake beds at both the base and the top of the succession. The lake in which the youngest mid Cretaceous sediments (300 m thick) formed occupied an area in excess of 100 square km (Laird, 1988). A further example is offered by the Kyeburn Formation, a sequence

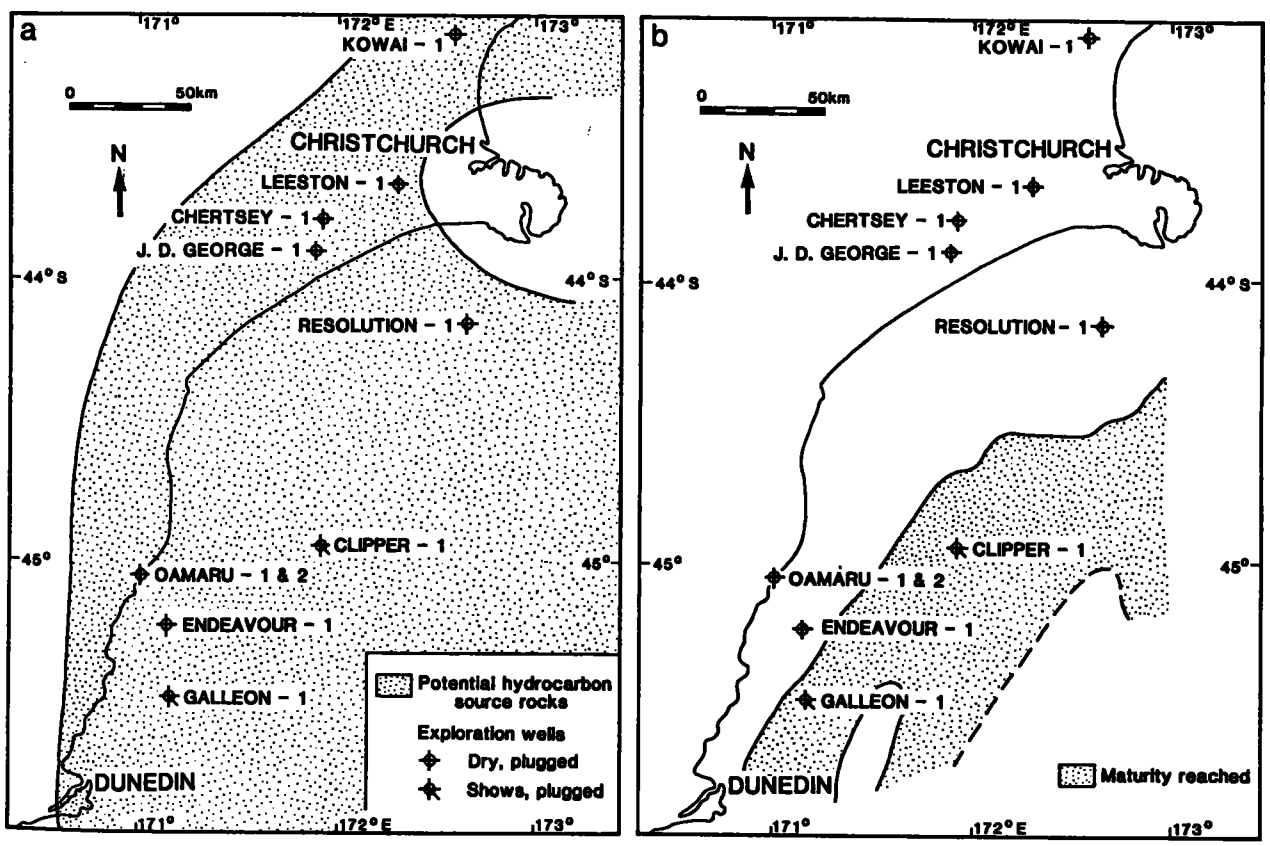

Fig. 2: Part of the Canterbury region showing a) distribution of potential hydrocarbon source rocks; b) distribution of sediments that have reached sufficient maturity to have generated hydrocarbons. b) is also equivalent to the overlap area of the maps showing these two parameters, and indicates the region containing suitable source rocks that have reached sufficient maturity to have generated hydrocarbons.

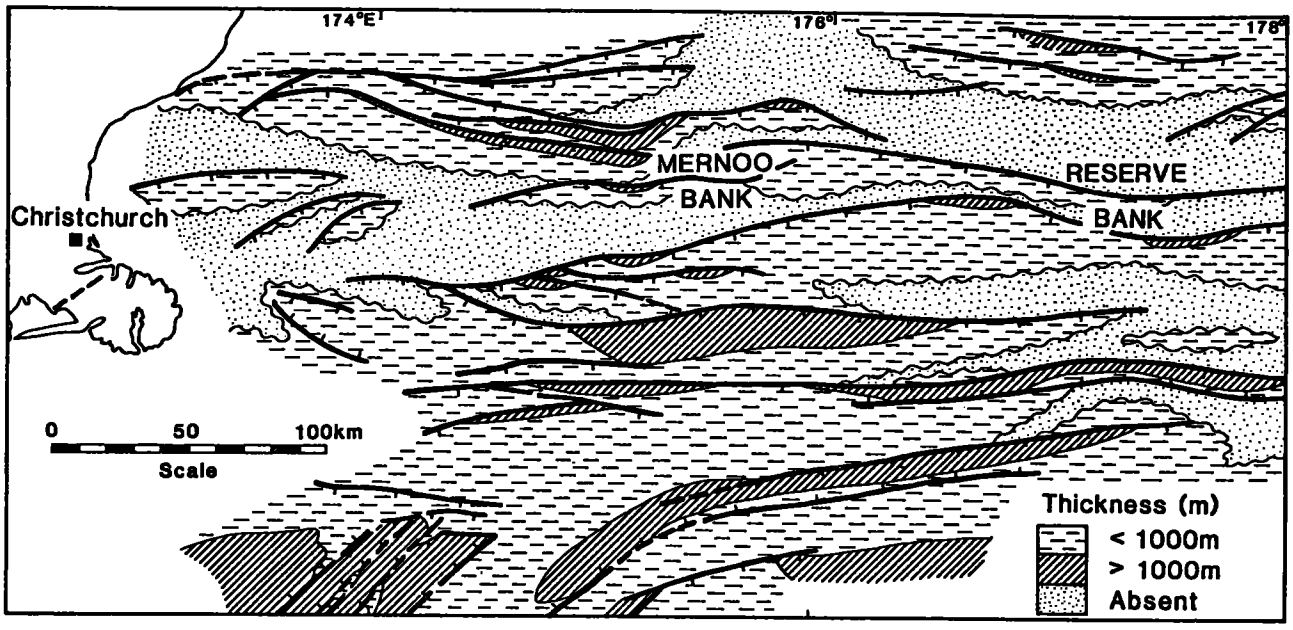

Fig. 3: Western portion of Chatham rise region showing Cretaceous half-graben formation and Cretaceous infill.

several thousand metres thick occupying a half graben in north Otago. Here about 65 m of calcareous and carbonaceous lake beds occur within the sequence. By analogy, it is probable that similar carbonaceous lacustrine deposits, in addition to already identified coal measures, occur in offshore half grabens, with potential for hydrocarbon generation.

A further period of extension occurred in the Late Cretaceous at about 80 m.y. BP as sea floor spreading between Australo/Antarctica and New Zealand occurred. This resulted in subsidence and transgression in most areas of New Zealand, and renewed rifting in some, particularly in the western and southern South Island. Coal measures and lake beds preserved in these Late Cretaceous grabens and half grabens are also potential targets for hydrocarbon exploration, as many of the deposits show sufficient maturity for hydrocarbon generation.

Extension and rift basin formation continued in some regions into the Oligocene, when a major change of tectonic regime to one of compression or transpression occurred at about the Oligocene/Miocene boundary throughout New Zealand. At this time dextral strike-slip movement along the Alpine and subsidiary faults was initiated together with large-scale thrusting and reverse movements on most major faults. There were concommitant major changes in depositional regimes, often best illustrated by study of successive isopach maps for different time periods in a particular region, as these tend to emphasise changes in orientation of basin axes, or change in the locus of deposition of sediments. A good illustration of the latter case is the ending of deposition in the Paparoa Trough (West Coast, South Island) in late Paleogene times, and the formation of new depocentres to the west and east from Miocene times onwards (Figs. 4 and 5) (Nathan *et al.*, 1986). These changes indicate the sedimentary response to changes in plate movement in the southwest Pacific, causing a change from extension to compression in the New Zealand region. This compressional regime has continued until the present day.

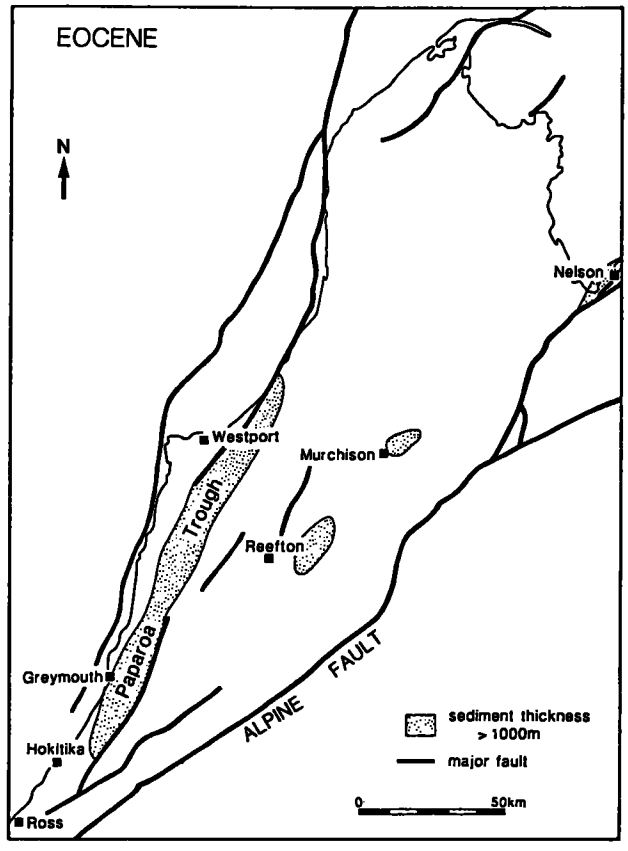

Fig. 4: Depocentres in the northern portion of the West Coast region during Eocene times (extensional regime).

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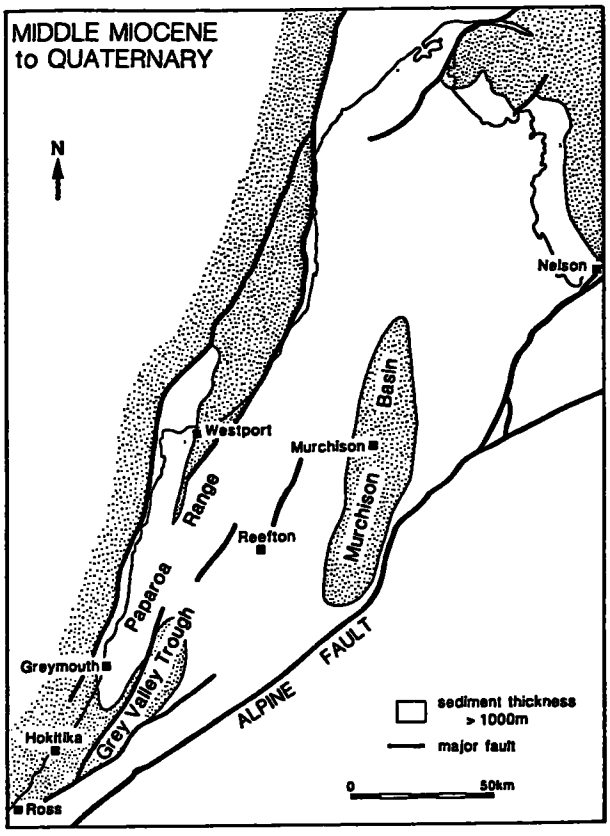

Fig. 5: Depocentres in the northern portion of the West Coast region during Middle Miocene to Quaternary times (compressional regime).

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