New Zealand basin development and depositional systems evolution: quantification and visualisation

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Abstract

Systematic mapping of Cretaceous and Cenozoic sediment thickness data outline areas of sediment accumulation and record the development and depositional systems of New Zealand's sedimentary basins. Three data sources have been used; 1) regional seismic interpretations in prospective basins close to New Zealand, 2) gravity models in areas with poor seismic coverage, and 3) the National Geophysical Data Centre (NGDC) global sediment thickness database in distal areas. Analysis of these data indicates that in the New Zealand region (from 160°E to 170°W and between 30°S and 57°S) there is more than 6 million km^3 of Cretaceous and Cenozoic strata, with between 10% and 20% of this volume comprising carbonate deposits. About half of the total volume occurs in the northwest quadrant of the region – the Taranaki, Northland, Reinga, Deepwater Taranaki and New Caledonia basins. There is about 400,000 km^3 of sediment in the Taranaki Basin and a similar volume in the Great South Basin. Each of the Northland, East Coast and Canterbury basins contain approximately 200,000 km^3 of sediments.

All the prospective basins close to New Zealand are characterised by rapid subsidence in the Cretaceous and early Cenozoic. The sediments that filled the basins at this time are major source rocks. Through the mid-Cenozoic, the proportion of carbonate steadily increased and these fine-grained sediments developed as seals over many of New Zealand's largest petroleum accumulations. In the late Cenozoic, development of the Australia/Pacific plate boundary through New Zealand resulted in widespread deformation and subsidence in many basins. This tectonism resulted in the deposition of reservoir formations, the creation of structural traps and rapid burial that enhanced hydrocarbon generation and expulsion in basins close to the active plate boundary. By contrast, little deformation and burial occurred during the late Cenozoic in basins distal from the plate boundary, where hydrocarbon expulsion and entrapment occurred within Cretaceous strata during Late Cretaceous and early Cenozoic time.

Introduction

New Zealand's present day area of 250,000 km^2 represents only the tip of a much larger submerged continent of approximately 3,500,000 km^2. Although sediments overlie most of this vast area, large parts of it are virtually unexplored for potential resources. Systematic mapping of Cretaceous and Cenozoic sediments highlights areas of significant sediment accumulation and recorded the development of New Zealand's sedimentary basins. A key to understanding sedimentary basin development is the quantification of sediment deposition and erosion (sediment flux). This allows regional-scale analysis of basin evolution, and enables petroleum explorers to develop petroleum systems models for ranking relative prospectivity of basins. Visualisation tools can be used to better understand basin development as part of the tectonic evolution of the New Zealand region.

The sediment distribution in prospective basins close to New Zealand has been surveyed by basin-scale seismic mapping projects (Cook *et al*., 1999; Field *et al*., 1989; Field *et al*., 1997; Isaac *et al*. 1994; King and Thrasher, 1996; Nathan *et al*. 1986; Thrasher *et al*., 1995; Turnbull *et al*., 1993; Wood *et al*., 1989). Eight sedimentary basins have been mapped in this way (Figure 1) and the work is ongoing in frontier areas as more seismic reflection data become available. The compilation of these interpretations has spanned 20 years, and the results reflect the evolution of thinking about New Zealand geology. One consequence of this is that different seismic horizons were often mapped within each basin, making compilation difficult. The amount of information available for each basin depends primarily on the level of petroleum exploration effort. Consequently Taranaki Basin has the greatest amount of data and Chatham Rise the least (Figure 1).

These individual basin interpretations have now been compiled to form the basis of a data set of New Zealand-wide sediment distribution. In areas beyond that covered by regional seismic mapping, estimates of the total sediment

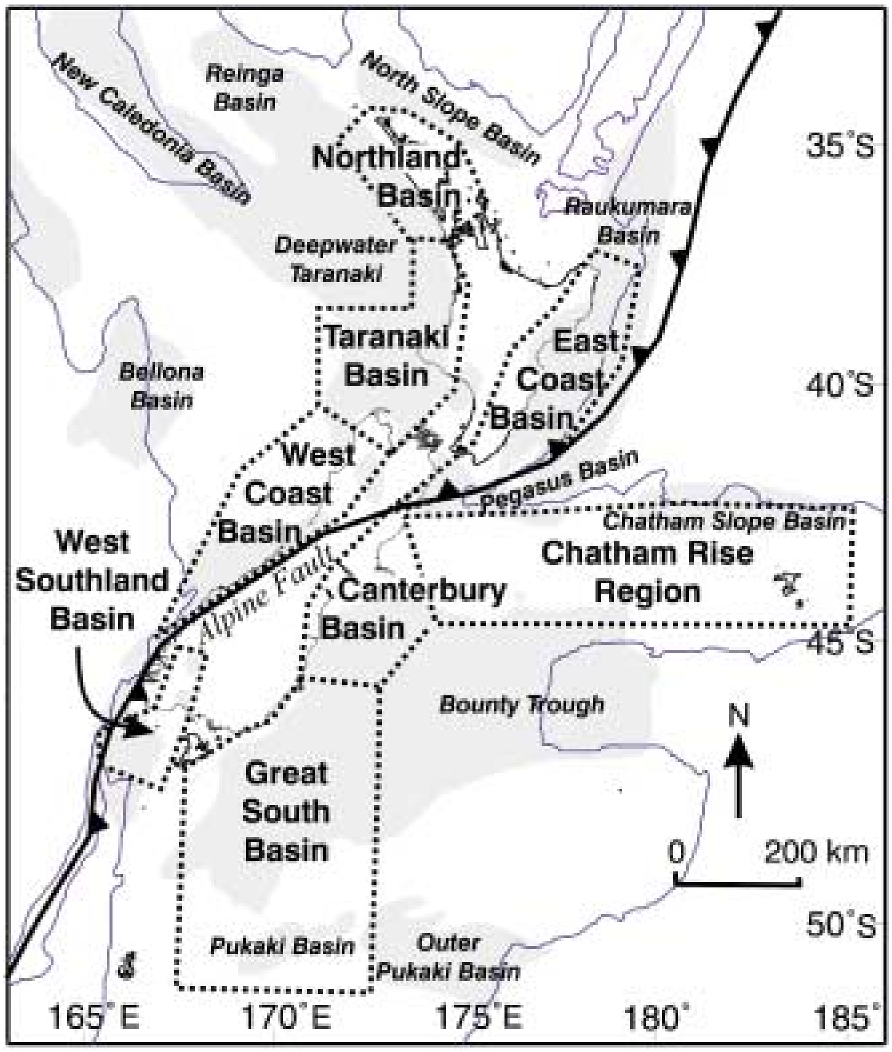

Figure 1: Map showing the general distribution of sedimentary basins (grey shading) in the New Zealand region. Prospective basins close to New Zealand (bold text) that have been surveyed by seismic mapping are delineated with the dotted lines. Most deepwater frontier basins (italic text) have been surveyed with widely spaced seismic lines and gravity modelling techniques. Bathymetry is indicated by the 2500m isobath (fine line) and present-day plate boundary is indicated by the bold line.

thickness are derived from gravity modelling (Wood and Woodward, 2001) and from widely spaced regional seismic data (NGDC). Thus the compilation includes some data from the deepwater frontiers.

The methods used to quantify the sediment volumes, including estimates of clastic, carbonate and organic matter content, are described in this paper. In addition, the broad-scale controls that sedimentation has had on the development of petroleum systems are discussed.

Evolution of New Zealand's sedimentary basins

The Cretaceous and Cenozoic were a period of great tectonic activity in the New Zealand region, and consequently most basins exhibit multiple phases of deformation and sediment deposition (King, 2000). New Zealand basin evolution can be broadly divided (from oldest to youngest) into rifted margin, passive margin, and convergent margin episodes (Figure 2), that reflect the plate tectonic development of the New Zealand sub-continent.

Rifted margin

The break-up of Gondwanaland in the mid-Cretaceous, and spreading in the Tasman Sea and southwest Pacific in the Late Cretaceous and Paleocene initially led to rapid subsidence and the formation of rift basins up to several kilometres deep. These basins (100 to 115 Ma) filled with syn-rift, terrestrial sediments (e.g. Cook *et al.*, 1999; Nathan *et al*. 1986) and marine transgressive clastic sediments (e.g. Field *et al.*, 1997). As subsidence progressed a widespread regional marine transgression began (80 Ma) and by the early Paleogene (60 Ma) marine flooding had advanced over wide areas. Paralic and shallow marine conditions in the Late Cretaceous resulted in extensive deposition of coal measures and transgressive sands. By the Late Paleocene, dysaerobic conditions persisted around most of the New Zealand sub-continent, promoting the deposition of organic rich shales (Killops *et al.*, 2000).

Passive margin

Spreading stopped in the Tasman Sea in the Paleocene (about 55Ma) and the New Zealand sub-continent became remote from any plate boundary. Basin development was characterised by regional post-rift thermal subsidence and widespread deposition of fine-grained clastic and carbonate sediment.

Convergent margin

A major regional tectonic plate re-configuration occurred in the Middle Eocene (about 45 Ma) with the initiation of the present-day Australian-Pacific plate boundary in the New Zealand region (Sutherland, 1995). In most areas, a hiatus in deposition occurred at the beginning of the Oligocene (about 35 Ma).

Pacific Plate subduction began northeast of New Zealand from mid-Oligocene time (Holt and Stern, 1994) and is characterised by rapid and widespread regional subsidence. Oligocene rocks are generally carbonate rich, reflecting a reduction of available clastic material. In most areas, the carbonate-dominated interval is generally very thin (typically less than 100 m) compared with clastic successions above and below, even though it spans 10 million years.

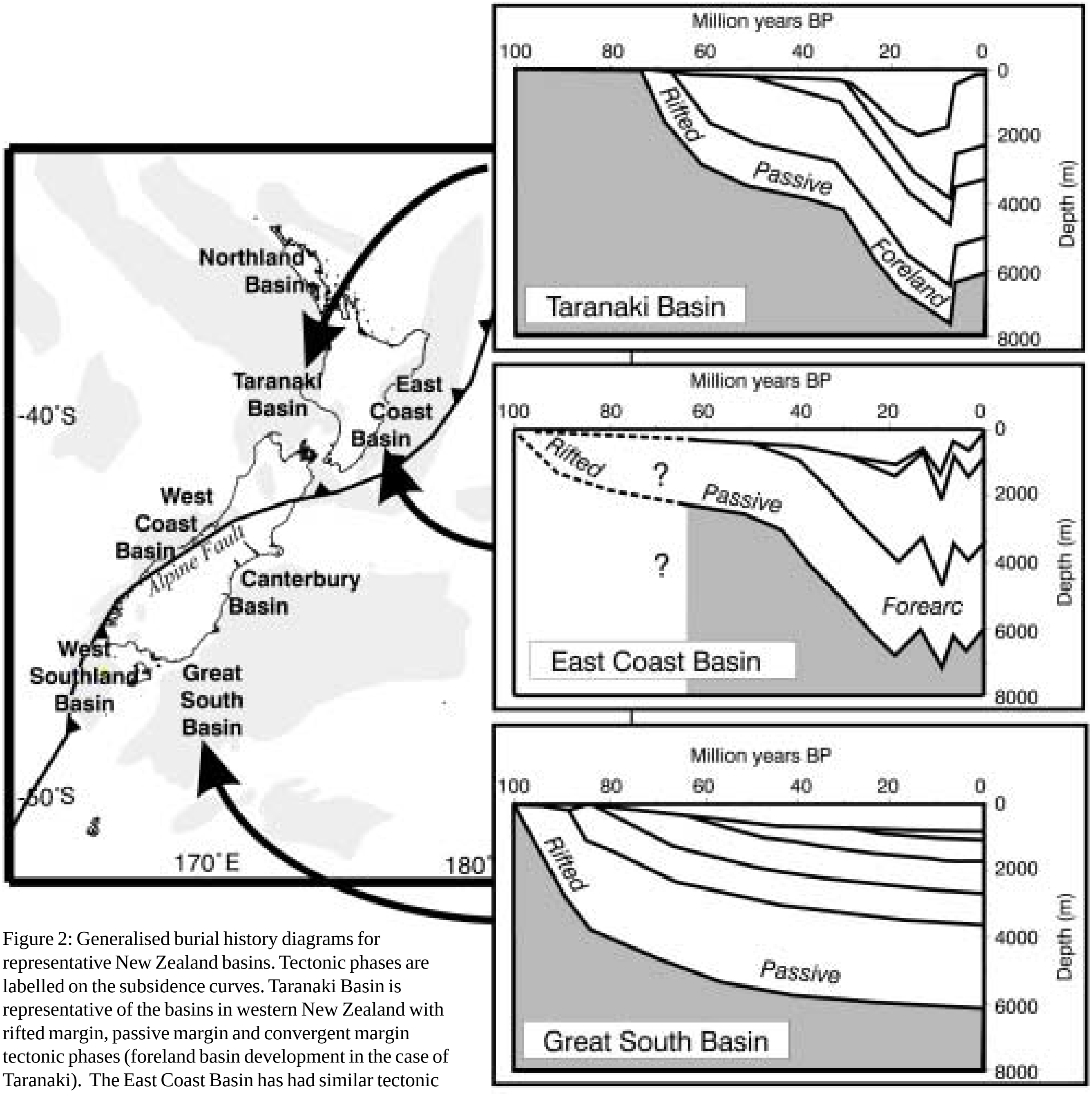

Figure 2: Generalised burial history diagrams for representative New Zealand basins. Tectonic phases are labelled on the subsidence curves. Taranaki Basin is representative of the basins in western New Zealand with rifted margin, passive margin and convergent margin tectonic phases (foreland basin development in the case of Taranaki). The East Coast Basin has had similar tectonic phases, but with development as a forearc basin in the Neogene. The Great South Basin is representative of a passive margin basin remote from the modern Australia-Pacific plate boundary.

As the plate boundary evolved in the Neogene, the Alpine Fault (Figure 1) developed to form a link between westward-dipping subduction in the north and spreading and oblique extension in the southwest (King, 2000). Seafloor spreading south of New Zealand became increasingly oblique until it was superseded by strike-slip motion and subduction of the Australian Plate beneath the Pacific Plate. More than 450 km of dextral strike-slip motion has occurred on the Alpine Fault.

Neogene convergent margin tectonics triggered uplift and subsidence, with rapid deposition and erosion occurring in areas close to the active margin. In the North Island, back-arc extension and local volcanism developed and has continued to the present day. The Neogene succession in most New Zealand basins is generally thick, mainly clastic (locally volcaniclastic), and regressive. This interval characteristically reflects the progressive infilling of new and previously formed marine basins, and progradation of continental shelves

Present-day sediment distribution

Figure 3 shows the present-day sediment distribution in the New Zealand region. The major sediment accumulations occur northwest and southeast of New Zealand (Taranaki and Great South basins), although the map does not include Cretaceous sediment thickness on the East Coast, North Island. The total volume of Cretaceous and Cenozoic sediment in the figure is

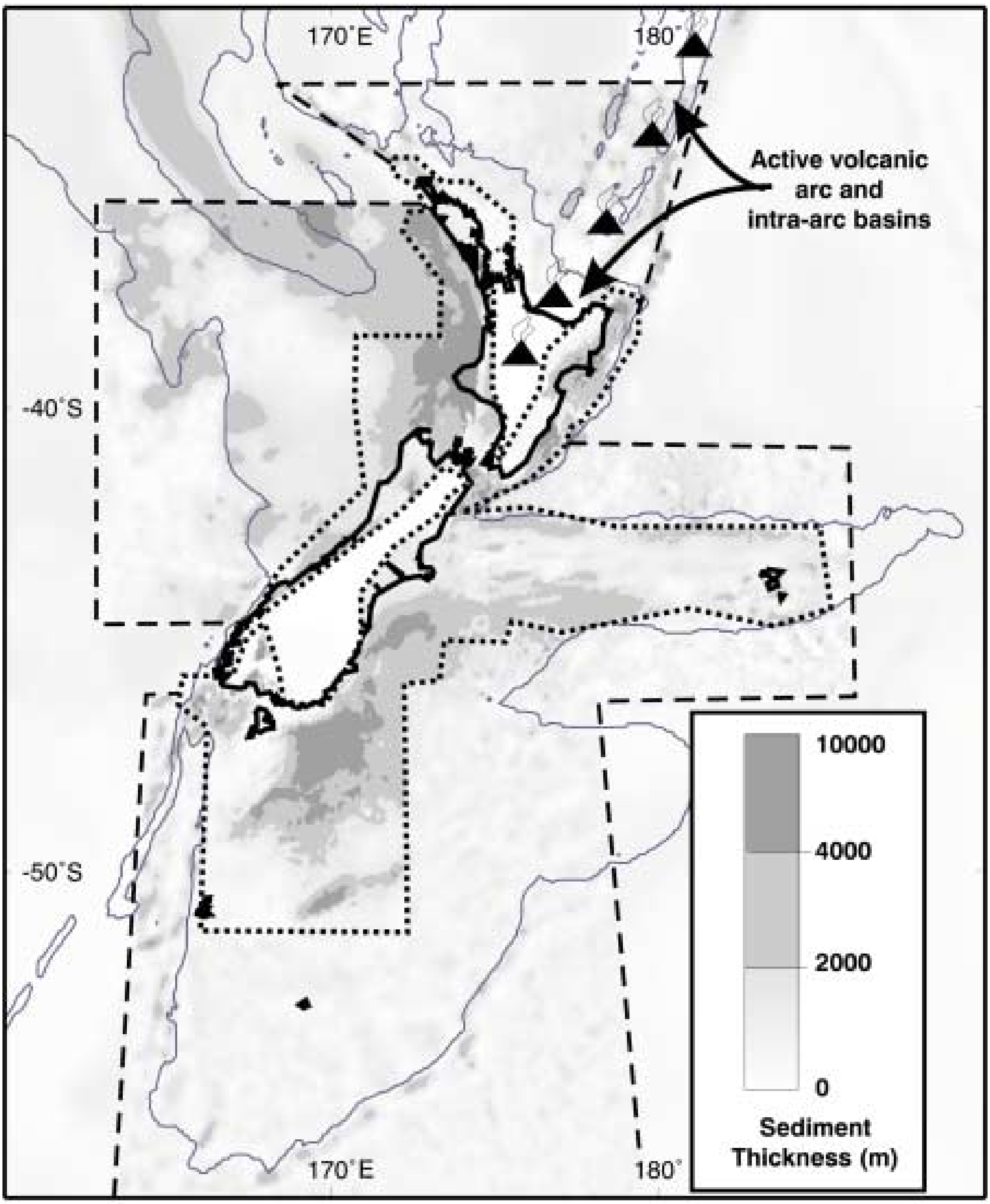

Figure 3: Map showing the present-day sediment distribution in the New Zealand region. Most of the Cretaceous and Cenozoic sediment accumulations occur close to New Zealand (Taranaki and Great South basins). Data are from basin-wide seismic interpretations (enclosed in bold dotted line), gravity modelling (enclosed in bold dashed line) and NGDC data in remote areas. The volume of material in active arc and intra-arc basins northwest of New Zealand has not been quantified at this study.

more than 6 million km^3. As a comparison, the total volume of New Zealand land above sea-level is about 130 000 km^3, of this 35 000 km^3 in the North Island and 95 000 km^3 in the South Island. About half the volume of sediments in Figure 3 occurs in the northwest quadrant of the region – the Taranaki, Northland, Reinga, Deepwater Taranaki and New Caledonia basins, with most of the rest occurring in the Canterbury and Great South basins.

Three data sources have been used:

1. Basin-wide seismic interpretations in prospective basins close to New Zealand (GNS Cretaceous – Cenozoic basin monograph series).
2. Three-dimensional gravity models in areas with poor seismic coverage (Wood and Woodward 2001).
3. The National Geophysical Data Centre (NGDC) global sediment thickness database in distal areas.

The basin-wide seismic interpretations form the highest quality data set. By far the greatest quantity of good quality data is from the Taranaki Basin (e.g. Thrasher *et al*., 1995; King and Thrasher 1996). Data from Canterbury (Field, *et al*., 1989) and offshore Western Southland (Turnbull, *et al*., 1993) are generally of good quality. Data from the East Coast (Field, *et al*., 1997), Great South Basin (Cook *et al*., 1999), Northland (Isaac *et al*. 1994), Westland (Nathan *et al*. 1986) and Chatham Rise (Wood *et al*., 1989) are of variable quality, with much of the seismic data being pre-1985 vintage, low-fold and widely spaced. Depth conversion usually used a single TWT/depth relation for the whole basin, derived from either stacking velocities and/or well check-shot data. Analysis of well tie errors indicates that the uncertainty in the depth to horizons is roughly proportional to depth, and is typically about 5%. In many cases, however, the age control of seismic horizons is poor, particularly for pre-Cenozoic strata, and uncertainties may be in excess of 10% in places.

Several regional seismic horizons were mapped in each basin and the stratigraphic succession subdivided into several Cretaceous and Cenozoic units. The exception to this is the East Coast, where horizons below the top Cretaceous have not been systematically mapped. The subdivision into seismic units allows the interpretation of the structure and pattern of sediment distribution, as well as the determination of sedimentation rates within basins.

Three-dimensional gravity models (Wood and Woodward, 2001) use satellite-derived gravity anomalies, constrained by widely spaced seismic lines and bathymetric data, to interpret crustal structure. The models have been used to estimate total sediment thickness and thus predict areas of thick sedimentary accumulations in remote frontier areas. The petroleum potential of many of these frontier areas has yet to be assessed, and awaits, the acquisition of more data.

The NGDC global sediment thickness database (http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html) is derived from previously published isopach maps of the Pacific based on ocean drilling results and regional seismic reflection data. In the New Zealand region the data coverage is relatively sparce, but provides some constraint on sediment thickness in regions not covered by regional modelling or gravity modelling.

Quantification of sediment volume

The volume of Cretaceous and Cenozoic sediment derived from regional mapping of the major New Zealand sedimentary basins is presented in Table 1. The values listed are the total porous volume (volume including pore space), the total solid volume (volume at 0% porosity), and the volume of clastic, carbonate and organic carbon components of the sedimentary succession. Sediment volume calculations are based on two-kilometre square grids generated from a database of interpreted seismic reflection, well and measured section data. Paleogeographic interpretations calibrated to wells are used to define the spatial distribution of lithologies, and thus determine the clastic/carbonate/organic matter content of each grid cell. Diagenesis and deposition of biogenic siliceous sediments are considered negligible on a basin-wide scale, although these processes can be locally important. Uncertainties are estimated by comparing interpretations to well and outcrop data. In some basins these data are scarce and consequently the uncertainties are large.

Organic carbon content

The largest proportion of organic carbon in New Zealand basins is generally within coal measure formations, which have a net thickness of hundreds of metres in some basins (Cook *et al*., 1999). The thickness of coal seams, identified from wire-line logs, were summed and used to calibrate paleogeographic interpretations based on seismic mapping. Coal seams are assumed to comprise 70% organic carbon, coaly shales and black shales are assumed to contain less than 10% organic carbon (Sykes, 2001). Most organic carbon sources in New Zealand basins are Cretaceous in age, although there are also important coal measures of Paleocene, Eocene and Miocene age. On a basin-wide scale, the uncertainty in organic carbon content in each grid cell used for volumetric calculations is estimated to be ± 50%.

Carbonate content

Samples from 24 wells in New Zealand basins were analysed for weight-% carbonate using a treatment of weight loss from acidification and carbon dioxide evolution. Conversion from

Table 1: Volume of Cretaceous and Cenozoic sediments in New Zealand Basins. Volumetric calculations were undertaken over an area listed in column 3 within the geographic boundaries listed in column 2. Porous volume is the present day in-place volume including pore space. Solid volume is the calculated volume at 0% porosity.

				Solid volume			
Basin/region	**Boundaries longitude/latitude**	**Area (km^2)**	**Total porous volume (km^3)**	**Total (km^3)**	**Clastic (km^3)**	**Carbonate (km^3)**	**Organic carbon (km^3)**
Northland	172.2/175/-37/-34	69207	180000 ± 30000	135000 ± 26000	120000 ± 24000	9000 ± 4500	500 ± 250
Taranaki	171.5/174.75/-41.5/-37	110597	390000 ± 55000	300000 ± 52000	260000 ± 50000	40000 ± 12000	1700 ± 800
East Coast	176.5/179/-42/-37.5	84315	235000 ± 40000	175000 ± 33000	160000 ± 32000	15000 ± 5000	200 ± 200
Westland	168/173/-45/-40.5	41036	85000 ± 15000	60000 ± 11000	55000 ± 10000	6000 ± 3000	300 ± 300
Canterbury	171/174/-46/-43	54246	130000 ± 25000	93000 ± 22000	82000 ± 20000	10000 ± 5000	400 ± 300
Great South	166/172.4/-51/-45.7	196524	450000 ± 60000	330000 ± 58000	280000 ± 55000	45000 ± 10000	1200 ± 600
Chathan Rise	174/185/-45/-42	196524	210000 ± 35000	125000 ± 32000	105000 ± 30000	20000 ± 8000	300 ± 300

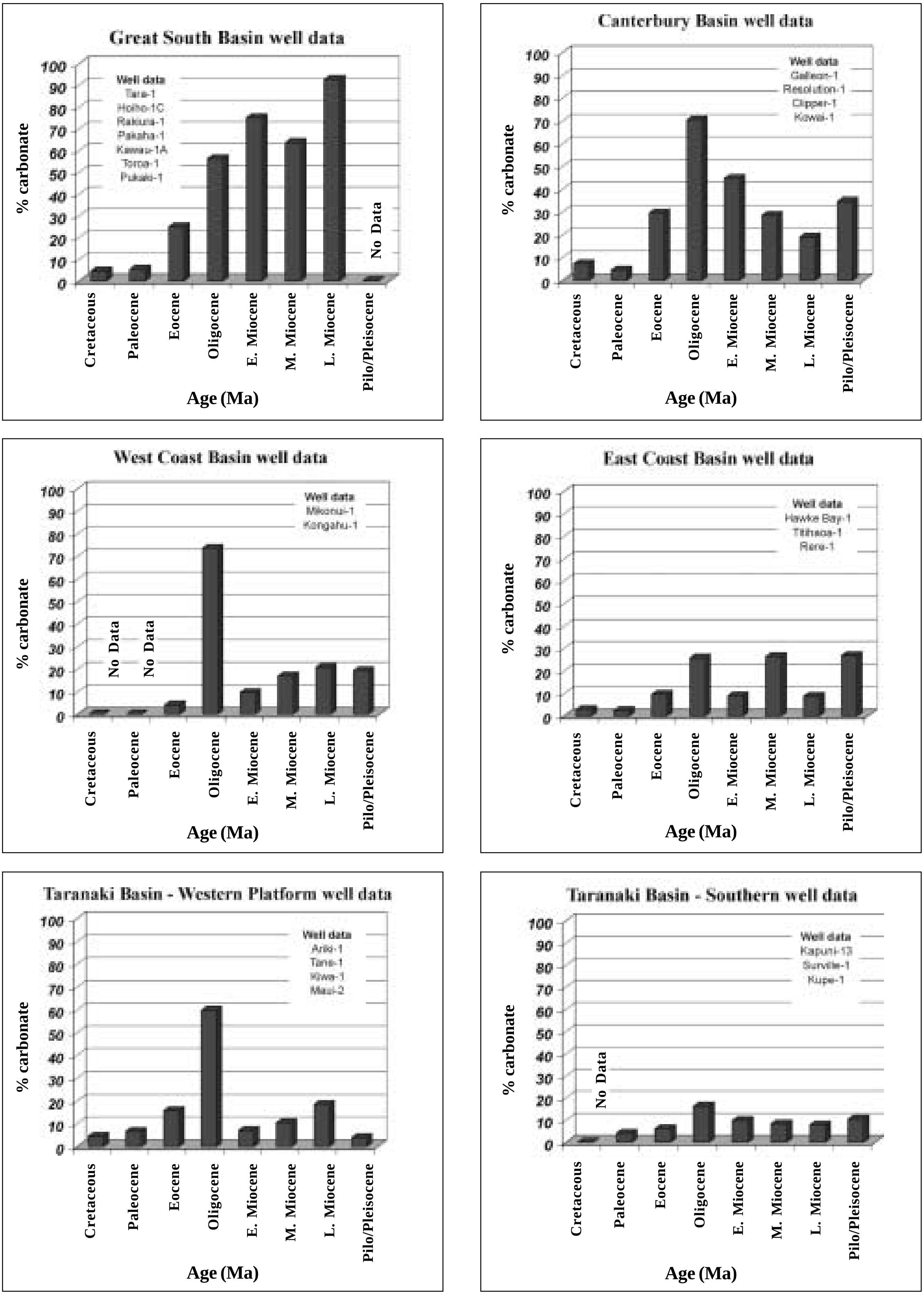

Figure 4: Weight-% carbonate in exploration wells. In most basins the proportion of carbonate reaches a maximum in the Oligocene. The exception is the Great South Basin where carbonate content has steadily increased.

weight-% to volume assumed a particle density of 2650 kg/m^3. Results are summarised in Figure 4, and indicate that in most New Zealand basins the proportion of carbonate is a maximum in the Eocene and Oligocene, except in the Great South Basin, where carbonate content has steadily increased over time. Data from DSDP and ODP wells indicates that the proportion of carbonate in remote areas of the New Zealand region increases through time and is almost pure (> 95%) carbonate in late Cenozoic strata.

Well data were used to calibrate basin-wide paleogeographic interpretations derived from seismic facies analysis. The uncertainty in carbonate content attributed to each grid cell used for volumetric calculations is estimated to be ±20%.

Volcanic rock content

The volume of volcanic rocks erupted into basins is included in the clastic component of the basin fill, and is generally minor compared to the total volume of sediments. For example, Stagpoole and Funnell (2001) estimate the solid volume of volcanic rock derived from the Miocene Mohakatino Volcanic Centre in the Taranaki Basin to be 7000 ± 3000 km^3. The Mohakatino volcanic cones cover an extensive area in the northern part of the Taranaki Basin and had a significant effect on the local petroleum system, yet they amount to about 3% of the total volume of sediments in the basin and less than 10% of the volume of Miocene sediments. Volcanic rocks comprise a similar or smaller proportion of the total rock volume in other basins.

Basins in the Bay of Plenty and the Taupo Volcanic Zone are the exception and appear to be filled almost entirely with volcanic material (Davey et al., 1995). The volume of material in these active arc and intra-arc basins northeast of New Zealand (Figure 3) has not been quantified in this study.

Sediment compaction

To determine the solid volume of rock a lithology-based compaction function is used in which porosity (f)decreases exponentially with increasing burial (Athy, 1930; Sclater and Christie, 1980):

$$f = f_0 \exp(-z/c)$$

where z is burial depth in metres, f_0 is the porosity at the surface and c is a compaction constant. Values for f_0 and c are determined empirically from well logs and laboratory observations, but care has to be taken where erosion and uplift of compacted sediments has caused significant lateral porosity variations across a basin (Armstrong *et al.* 1998).

Funnell *et al.* (1996) used sonic logs from wells in the Taranaki Basin to determine values of $f_0 = 0.54$ and $c = 2000$ mudstone lithology. For carbonate lithology we use values of $f_0 = 0.70$ and $c = 1400$. These values are applied in all solid volume calculations in this paper. A comparison between the porosity determined from sonic logs (points) and the empirical functions (lines) for Great South Basin wells is shown in Figure 5. In the Great South Basin the top 500 to 1000 m of section is predominantly chalk, hence the better fit with the carbonate curve. The effect of pore fluid overpressure, which occurs in most New Zealand basins, is assumed to be small.

Reworked sediments

In basins close to the Australia-Pacific plate boundary, uplift, erosion and re-deposition of sediments occurred in the late Cenozoic. Quantification of the amount of reworked sediment is important for the evaluation of net sediment flux. For example, in the Taranaki Basin region, Cretaceous and Cenozoic sediment volume amounts to about 425 000 km^3

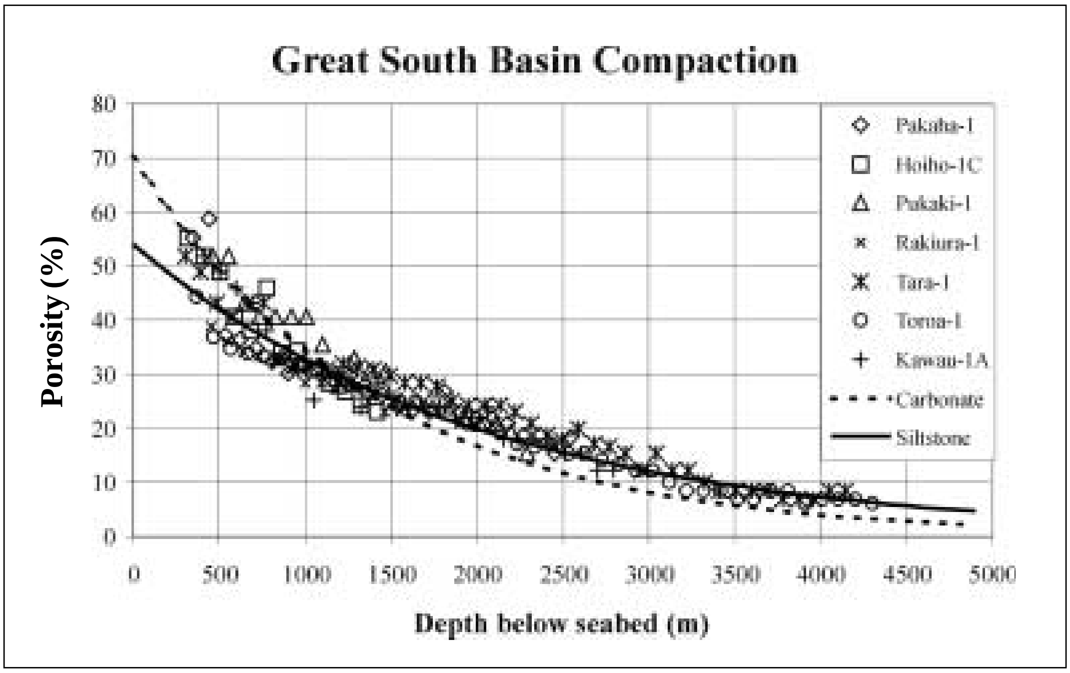

Figure 5: Comparison between the porosity determined from sonic logs from Great South Basin wells (data points) and the empirical porosity functions (lines). In the Great South Basin the top 500 to 1000 m of section is predominantly chalk, hence the better fit with the carbonate curve.

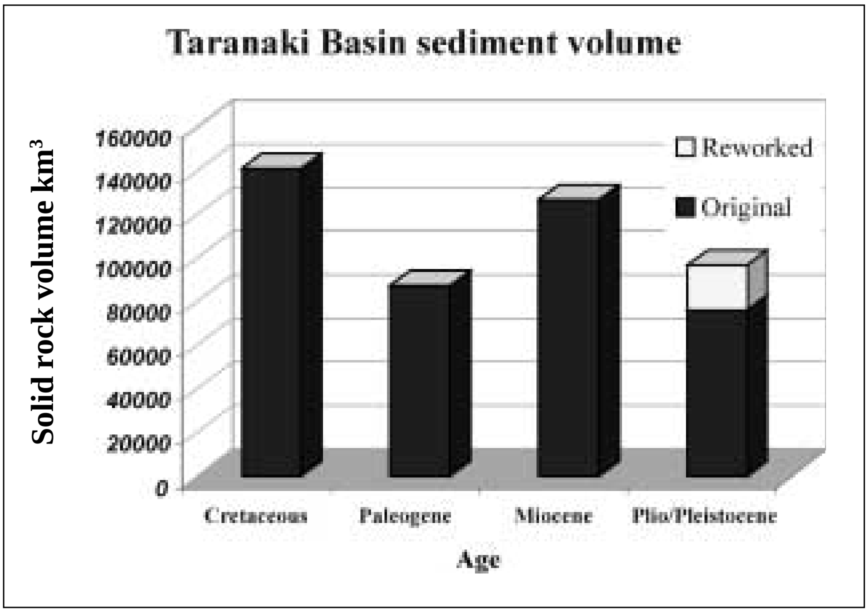

Figure 6. Solid volume of Cretaceous and Cenozoic sediments in the Taranaki Basin. An estimated 20 000 km^3 of Cretaceous and Tertiary sediments were reworked into the basin during Pliocene and Pleistocene uplift and erosion. Most of this reworked sediment was originally deposited in the Miocene.

(Figure 6). Pliocene and Pleistocene sediment comprise about 90 000 km^3 of this total, but about 20 000 km^3 of this volume is estimated to be reworked of older sediments (predominantly of Miocene age). This sediment reworking has no impact on the total volume of Cretaceous and Cenozoic sediments within the basin, but is important when determining the rate that sediment has entered the basin. In the Taranaki Basin region, the volume of Pliocene and Pleistocene sediment derived from outside the basin is actually about 70 000 km^3, and correspondingly the volume of older sediment derived from outside the basin is underestimated by about 20 000 km^3 in Figure 6.

Although estimates of denudation are well documented for many parts of New Zealand (e.g. Wellman, 1979; Pillans, 1986; Tippett and Kamp, 1993; Armstrong *et al*., 1998) systematic mapping and quantification of missing section on a basin-wide scale has only been undertaken in the Taranaki Basin, primarily for maturation studies (Wood *et al*., 1998; Funnell *et al*., 2001). Other basins where reworking is known to be a significant factor are the East Coast and Wanganui basins, and onshore parts of the Western Southland, West Coast, Northland and Canterbury basins. Sediment reworking appears to have occurred in the Great South Basin and the Chatham Rise on a much smaller scale than in other areas.

Basin-wide sedimentation rates

Regional mapping subdivided the seismic stratigraphy into several units generally defined by regional horizons. This allows interpretation of the pattern of sediment deposition through time as well as the comparison of overall sedimentation rates for basins in the New Zealand region. The sedimentation calculations are, however, affected by the mapping interval, and this leads to averaging of the sedimentation rates in basins with only a few mapped horizons.

Basin-wide sedimentation rates were generally high during Cretaceous rifting. Rates declined during the early and mid-Cenozoic as the land subsided, reducing the supply of clastic detritus. During late Cenozoic, basins close to the present day plate boundary experienced rapid uplift/ erosion and subsidence/deposition during Neogene convergent margin tectonism.

Overall sedimentation rates for two basins with contrasting histories – the Taranaki and Great South basins – are shown in Figure 7. Whereas the Great South Basin has experienced a steady decline in sedimentation rates throughout the late Cenozoic, rates in the Taranaki Basin have dramatically increased. This increase is a result of the large volume of sediment shed from the rapidly rising Southern Alps, carried northward by sea currents and deposited in the basin in the last 5 million years.

Depositional systems

The distribution of sediment accumulations and types of depositional systems have been controlled by the location of active plate boundaries or major tectonic elements, such as rifts and transform faults. Basins close to the evolving Australia-Pacific plate boundary (see Figure 1) have had different subsidence and depositional histories to basins remote from this margin (see Figure 2 for examples).

Rifted margin phase

Rapid subsidence in the Cretaceous and early Cenozoic resulted in deposition of large volumes of mainly clastic material, commonly in paralic and shallow marine environments. These sediments are volumetrically significant in the New Zealand basins. In the Great South Basin, for example, the Cretaceous and Paleocene rocks of the Hoiho and Pakaha groups are, in places, over 5 km thick. They comprise about two-thirds of the total solid volume of sediments in the basin (Figure 8).

Rift-related sediments are important components of petroleum systems in New Zealand basins. These organic rich sediments and transgressive sands are major source and reservoir rocks in the New Zealand region. In the Taranaki Basin hydrocarbons sourced in Cretaceous and early Cenozoic strata are trapped in Paleocene and Eocene coastal facies sands in the Maui, Kupe and Kapuni fields.

Passive margin phase

Subsidence continued at a decreasing rate during the mid-Cenozoic, decreasing the land area and reducing the supply of clastic material to sedimentary basins. A distinct seaward shift occurred with the widespread deposition of shelf, slope and bathyal facies. The proportion of carbonate in sediments

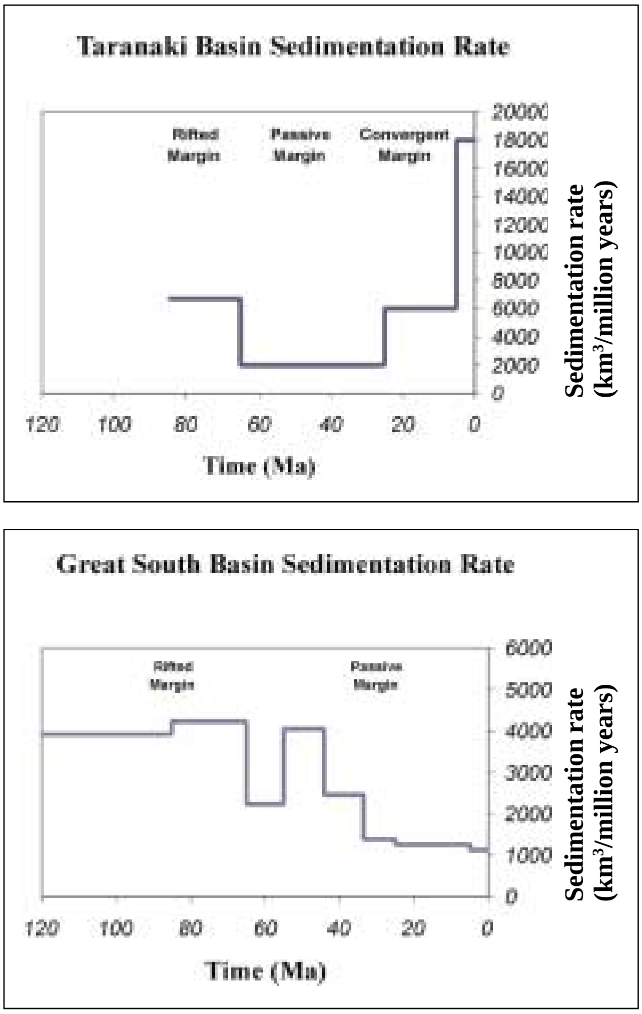

Figure 7: Basin-wide sedimentation rates (km^3 of solid rock volume/million years) for the Taranaki and Great South Basins. The Great South Basin experienced a decline in overall sedimentation rates throughout the late Cenozoic, whereas rates in the Taranaki Basin rose in response to increased sediment supply from uplifted of the Southern Alps. Note different vertical scales.

steadily increased, reaching a maximum in the Oligocene in most basins (Figure 4). The fine-grained, clay-rich sediments deposited during this phase form seals in many of New Zealand's petroleum basins.

Convergent margin phase

Development of the plate boundary through New Zealand in the late Cenozoic was complicated by the rapid change in relative plate motions. This resulted in temporal and spatial variations in structural style along the boundary, with rapid subsidence and deposition occurred simultaneously with uplift and erosion, often within the same basin. A period of marine regression ensued as plate convergence increased. Sediments derived from the eroded hinterland were deposited in basins close to the plate boundary and prograded the continental shelf. This first-order landward facies shift continues today (King, 2000).

A wide range of sedimentary facies are represented in Neogene strata, ranging from coastal plain sands to slope and bathyal limestones, including volcanic tuffs and breccias. The volumes of these sediments are significant. In the Taranaki Basin, for example, the volume of Neogene strata comprise about half the total solid volume of sediments in the basin. By contrast, in basins remote from the plate margin (e.g. Great South Basin) the volumes of Neogene strata are about 10% the volume of Cretaceous strata, and are almost exclusively bathyal muds and ooze.

Convergent margin tectonism is a critical component of the petroleum systems in these basins. It created structural traps and the rapid burial enhanced hydrocarbon generation and expulsion. Productive reservoir formations occur in Neogene strata in both the Taranaki and East Coast basins. By contrast, in basins distal from the plate boundary, hydrocarbon expulsion and entrapment occurred within Cretaceous strata during Late Cretaceous and early Tertiary time.

Deepwater frontier basins

New Zealand's deepwater frontier lies beyond the shelf edge in water depths up to and beyond 2500 m (Figure 1). To date, most deepwater frontier basins have only been surveyed with a few widely spaced seismic lines, a scattering of wells (DSDP and ODP) and satellite derived gravity, but as interest in the petroleum potential of the region grows more data are becoming available (Uruski, 2000).

Sediment accumulations in the deepwater frontier have not been systematically mapped, and there are probably some basins that have not been discovered. The volume of sediment in the deepwater region is considerable, although probably less than the volume of sediment in basins already explored close to New Zealand (Figure 3). Volumetric calculations for the deepwater frontier presented in this paper are based solely on estimates of sediment thickness derived from modelling gravity anomalies. More accurate determination of the sediment flux in this region is in progress.

Depositional systems of deepwater frontier basins are predicted to be similar to the prospective basins close to New Zealand, although deep-sea currents have modified the pattern of sedimentation in some areas, particularly east of New Zealand (Carter and McCave, 1997). Basins remote from the Pacific-Australia plate boundary, such as the deepwater Taranaki Basin (Stagpoole *et al*., 2000), appear to have broadly similar histories to the Great South Basin, with rapid Cretaceous subsidence and deposition followed by a period dominated by thermal subsidence and reducing sedimentation rates. Interpretation of seismic reflection data suggests terrestrial and coastal facies at the base of the sedimentary succession are overlain by shelf, slope and bathyal strata.

Some deepwater basins, appear to be a seaward extension of present-day prospective basins close to New Zealand. For example, while terrestrial sediments were being deposited in the Taranaki Basin during the Late Cretaceous, shelf and deltaic sediments were probably being deposited in the area that is now part of the Deepwater Taranaki Basin (C. Uruski, *pers. com*., 2002).

Deepwater basins adjacent to the plate boundary, for example the Reinga and Pegasus basins (Herzer *et al*., 2000; Uruski,

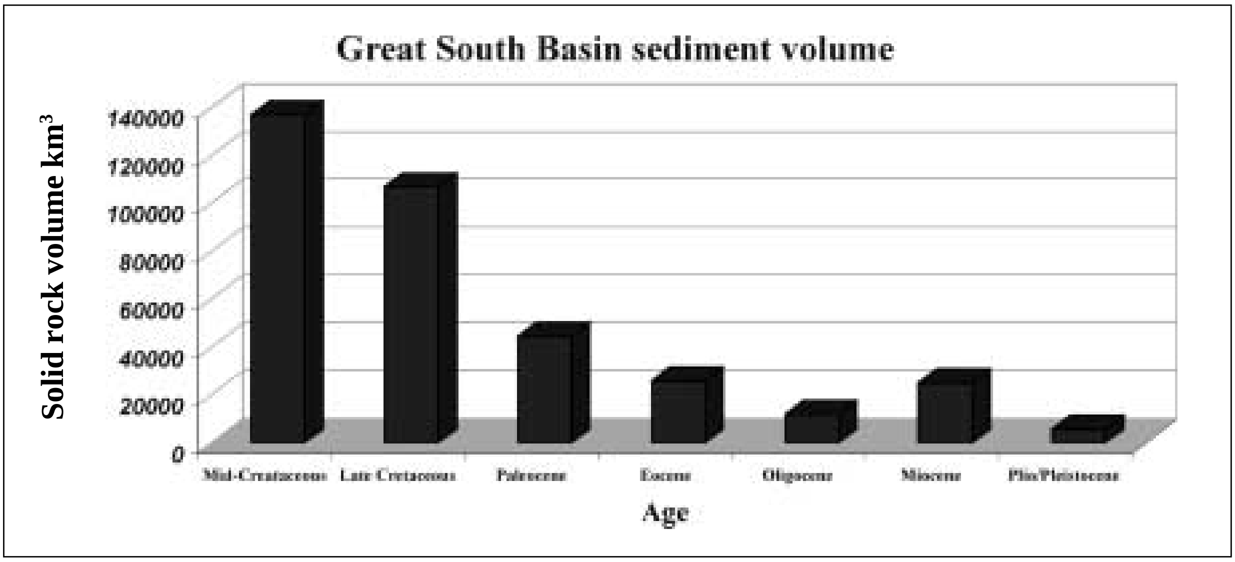

Figure 8: The solid volume of Cretaceous and Cenozoic all sediments in the Great South Basin. Most sediment was deposited in the Cretaceous rifted margin phase of basin development.

2000), often experienced rapid Cretaceous sedimentation followed by a second period of rapid deposition in the Neogene. The pattern of sedimentation in these basins is interpreted to be roughly similar to the Taranaki Basin, although there are often important differences in both the basin forming mechanisms and the timing of tectonic events. In general, terrestrial and shallow marine strata at the base of the sedimentary succession are overlain by deep water facies with a carbonate maxima occurring at mid-Cenozoic levels.

It is likely that petroleum accumulations will be found in many of the deepwater frontier basins. Analysis of the available gravity and seismic data indicates that there is a considerable thickness of sediment in many of the basins beyond the continental shelf. Interpretation of the seismic data suggests that depositional systems are similar to many of the basins around New Zealand where there have been hydrocarbon discoveries. In some deepwater basins, potential source and reservoir units have been identified and there are abundant structures, leading to the view that there is potentially large volumes of oil that has yet to be discovered in New Zealand's deepwater frontier (Uruski, 2000).

Conclusions

Quantification of sediment volumes in New Zealand basins has required compilation of the present-day distribution of sediments, estimation of the lithology distribution, and removal of the effects of compaction. Using the procedures outlined in this paper, we estimate the volume of Cretaceous and Cenozoic sediment in the New Zealand region (160°E to 170°W and 30°S to 57°S) is more than 6 million km^3. The timing of deposition and the lithologic composition of sediments depends on the tectonic history of the basin.

The distribution of sediment, the types of depositional systems and the rates of sedimentation have been controlled by the location of active plate boundaries or major tectonic elements. Basins remote from the evolving Australia-Pacific plate boundary had the greatest subsidence and sedimentation in the Cretaceous and early Cenozoic (rifted margin phase). During the middle and late Cenozoic (passive margin phase), sedimentation rates decreased and the carbonate content increased as the supply of clastic material declined. In these basins hydrocarbon expulsion and entrapment occurred within Cretaceous strata during Late Cretaceous and early Cenozoic time.

Basins close to the modern Australia-Pacific plate boundary experienced similar Cretaceous and Cenozoic rifted and passive margin histories, but a second pulse of sedimentation occurred in the Neogene, coincident with uplift and erosion of the New Zealand landmass (convergent margin phase). Convergent margin tectonism resulted in increased sedimentation, the formation of structural traps and enhanced hydrocarbon generation and expulsion.

Deepwater basins have experienced tectonic and depositional histories similar to many of the prospective basins close to New Zealand. Many of the deepwater basins probably contain complete petroleum systems and, as exploration moves into deeper water, are attractive exploration targets.

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