

THE CHATHAM RISE: AN EXPLORATION FRONTIER

R A Cook, R A Wood and H J Campbell
New Zealand Geological Survey

The Chatham Rise is a submarine plateau that extends due east of the South Island for over 1100 km. The Rise now forms the northern side of a *failed rift* associated with the Mid to Late Cretaceous breakup of Gondwana.

A thick sedimentary sequence presumed to be of Early Cretaceous age is present in the vicinity of the Chatham Islands and is interpreted to be marine, and to have been deposited just prior to continental fragmentation. Cretaceous structures are dominated by east-west trending half-grabens, faulted on their northern margin containing Albian marginal marine and non-marine sediments. The graben sediments are overlain by a widespread sequence of Late Cretaceous and Cenozoic sediments with increasing marine influence and carbonate content. The thickness of this blanketing sequence increases southwards towards the Bounty Trough. Episodes of volcanism have occurred over the Rise throughout much of the Cretaceous and Cenozoic.

Limited exploration interest in the late 1960s and early 70s led to only moderate seismic coverage over the region with lines at best spaced 5-10 km apart. The completion of recent major studies of sedimentary basins in Canterbury to the west, and the Chatham Islands to the east, together with a major integrated interpretation of the seismic data over the Rise, have greatly improved our regional understanding of this area and should encourage renewed exploration of this frontier region.

INTRODUCTION

The Chatham Rise is a submarine plateau that extends due east of the South Island for 1100 km. The bulk of the Rise is shallower than 1000 m with average crest height at between 400 m and 600 m (Fig. 1). The Rise forms the northern margin of the Bounty Trough, which is a *failed rift* associated with the Mid to Late Cretaceous breakup of Gondwana (Wood *et al.*, 1989). The steeper northern margin faces into the Hikurangi Trough and probably represents a pre-breakup margin of the Gondwana continent.

GEOLOGICAL SETTING

The Chatham Rise is dominated by east-west striking mid to Late Cretaceous half-graben rift structures that are hinged on the south margin (Fig. 2). Basement to the Cretaceous-

Cenozoic sedimentary sequence of the region consists of late Paleozoic and Mesozoic greywacke and schists (Torlesse Terrane of the main islands of New Zealand). Windows into the Cretaceous and Cenozoic geology of the Rise are provided at each end, by onshore Canterbury (Field and Browne *et al.*, 1989) and the Chatham Islands (Hay *et al.*, 1970; Campbell *et al.*, in press; Herzer, 1975; Herzer *et al.*, 1989). In the centre of the Rise, a series of shallow banks have provided seafloor outcrop samples. In addition to this control, interpretations of the area are based on the oil industry regional reconnaissance seismic data (see Wood *et al.*, 1989, Table 1.1).

EXPLORATION AND RECENT DEVELOPMENTS

Exploration for hydrocarbons has been undertaken in the Canterbury onshore area since 1957, with extensive seismic

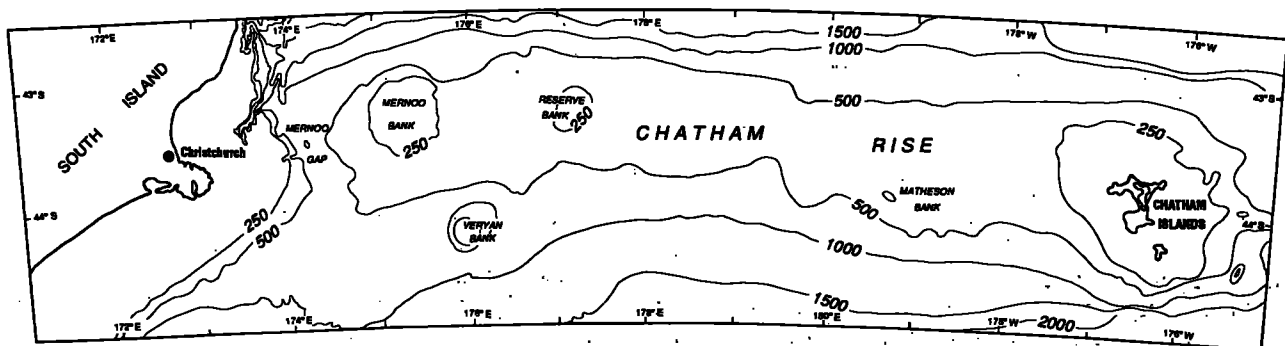


Fig. 1: Location map, Canterbury-Chatham Islands with bathymetry (after Wood *et al.*, 1989).

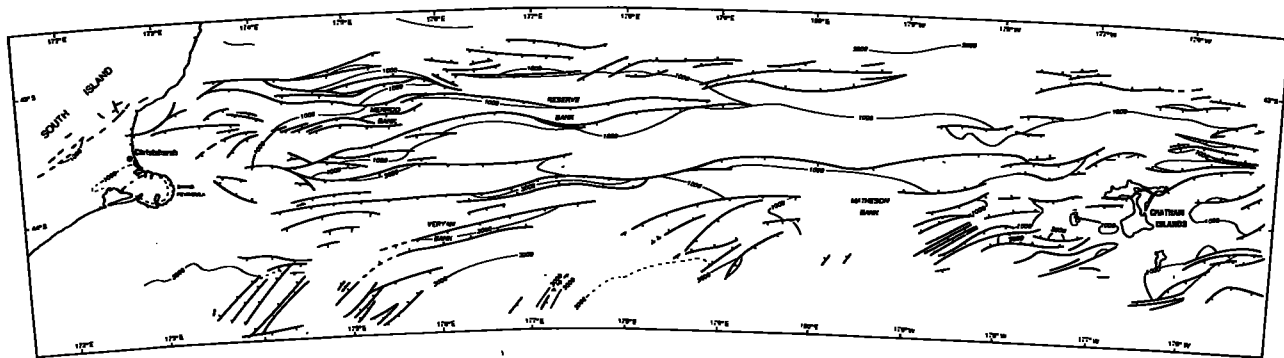


Fig. 2: Structure contour map on basement of the Chatham Rise (after Wood *et al.*, 1989).

coverage and a number of wells being drilled. Limited exploration of the Chatham Rise has taken place since 1965 with only reconnaissance seismic surveys being gathered in several licences before the area was relinquished in the early 1970s.

Two major studies of the Chatham Rise area have recently been completed by NZ Geological Survey. One is a regional seismic and geological compilation of the Cretaceous and Cenozoic basin history as part of the Basin Studies programme (Wood *et al.*, 1989), and the other a detailed study of the onshore geology of the Chatham Islands (Campbell *et al.*, in press). These studies provide for the first time a detailed, integrated interpretation of both the onshore geology and the regional seismic data, which should give an impetus for renewed exploration of the area.

STRATIGRAPHY

The upper surface of the basement greywacke/schist provides a good high amplitude seismic reflector marking acoustic basement. In the Chatham Islands area, seismic interpretation shows a thick sequence, in excess of 3 km, of folded and faulted sediments between blocks of acoustic basement. Based on their reflection characteristics, these sediments are thought to be marine. Although they are not seen in outcrop, they can be no younger than middle Cretaceous as they are stratigraphically lower than middle Cretaceous rocks exposed on Pitt Island (Wood *et al.*, 1989). Delineation and sampling of this sequence will probably be an important objective for future exploration.

The half grabens formed along the length of the Rise have been filled by 1000-2500+ m of mid to Late Cretaceous, largely fluvial deltaic to marginal marine sediments. The sequence as seen in exposures on Pitt Island, contains some lignites and carbonaceous sands and also basaltic volcanics. A low-lying land mass must have existed in the western part of the Rise, to produce such a widespread blanket of lagoonal and marginal marine sediments. The geometry of these sediments suggests that the Rise has been an arch since at least the Late Cretaceous. During latest Cretaceous time several large alkaline basalt volcanoes erupted, forming much of the Chatham Islands.

The early Cenozoic sequence on the Chatham Islands consists of marine tuffs and limestones, which along the crest of the Rise are generally less than a few hundred metres thick. On the flanks, however, they thicken to a kilometre or more. During the Eocene, mild tectonism reactivated many of the Cretaceous normal faults and generated a phase of clastic sedimentation. Sporadic localised basaltic volcanism continued throughout the Cenozoic.

Neogene sedimentation on the Rise is dominated by biogenic and authigenic lithologies which form thin (generally less than 500 m) sequences reflecting a predominantly submarine oceanic history and tectonic stability. The only factors affecting the uniform sedimentation were localised basaltic volcanism.

STRUCTURE AND TECTONICS

Prior to the Motuan (mid Albian; mid Cretaceous) the New Zealand block was part of Gondwana, the Late Triassic to Early Jurassic basement sediments and metasediments being accreted as a set of clastic wedges from a likely provenance of Marie Byrd Land, Antarctica (Bradshaw *et al.*, 1981). In the mid and Late Cretaceous (110-75 Ma), regional thinning and rifting of the crust beneath the Campbell Plateau and the Chatham Rise, to 20 km or less (Adams, 1962), produced not only the Bounty Trough and other basins of the Campbell Plateau, but also the resulting east-west structural grain along the crest of the Chatham Rise (Fig. 2), largely defined by the half grabens. The fault block rotations on their southern hinges imply listric faulting consistent with rifting to the south in the Bounty Trough. The rapid sedimentation rates for the Cretaceous sediments within these half grabens (Fig. 3) reflect this initial tectonic activity (Wood *et al.*, 1989).

Separation of the New Zealand block from Antarctica in the Late Cretaceous (initiated about 85 Ma) was also associated with thermal contraction of the crust that caused subsidence of the Chatham Rise, the Campbell Plateau and the Bounty Trough. By latest Cretaceous the sedimentation rate on the Chatham Rise had slowed considerably (Fig. 3) and the depositional facies were then more influenced by sea-level fluctuations. The similarity of the sedimentation rates between Canterbury and the Chatham Rise indicates that

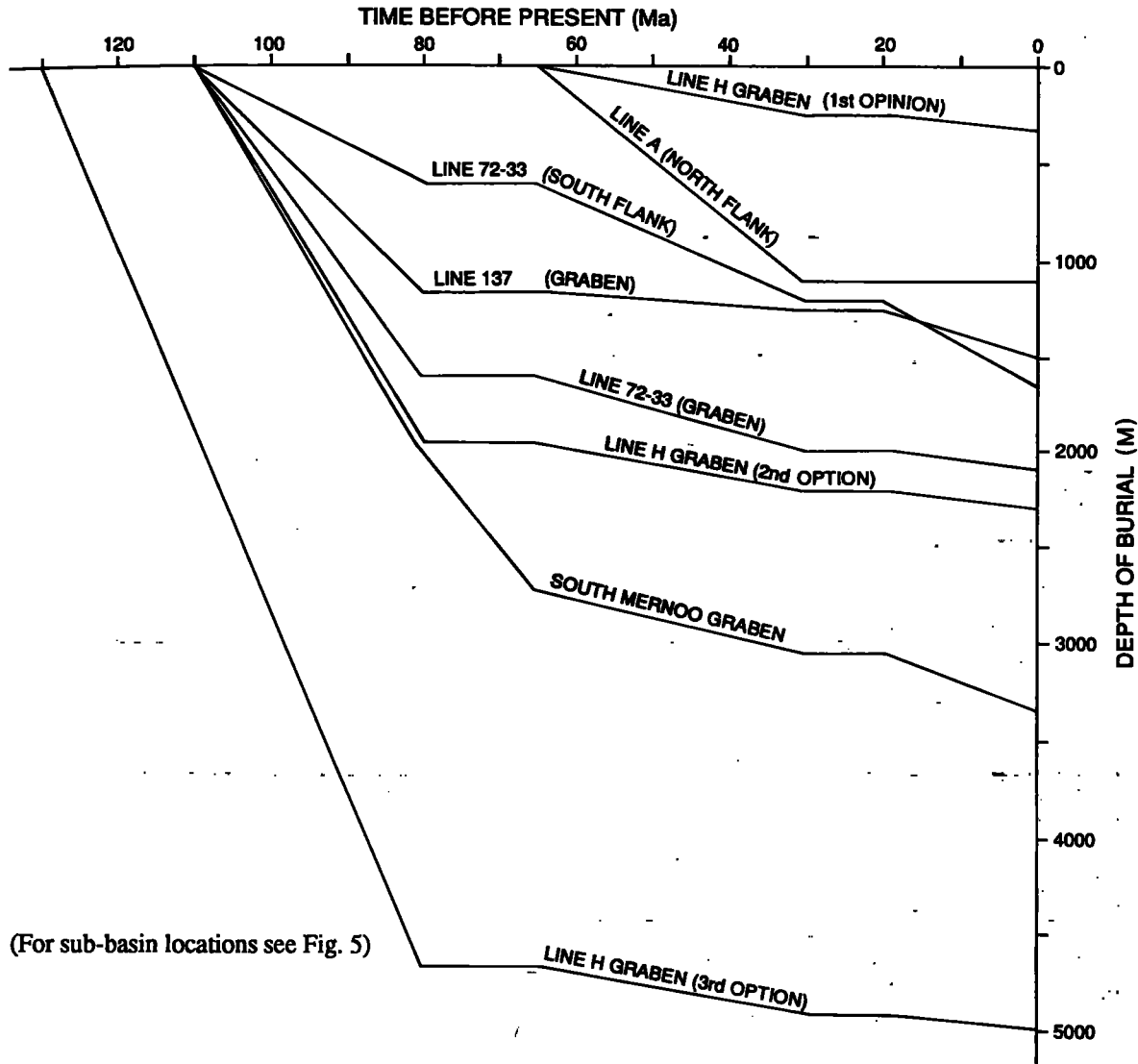


Fig. 3: Burial history curves for the sub-basins within the Chatham Rise (after Wood *et al.* 1989).

subsidence was regional and was the response to the broad tectonic events associated with separation from Antarctica.

Although the Chatham Rise appears to have been relatively stable throughout the Cenozoic after rifting had ceased, there is evidence for episodic volcanism (Grindley *et al.*, 1977; Campbell *et al.*, 1988)(Fig. 4), faulting, and relative sea-level changes during this period (Wood *et al.*, 1989). However, this volcanism and faulting, especially the Eocene reactivation of Cretaceous faults, are possible responses to changes in plate motion related to the change of spreading in the Tasman Sea and to subduction and transcurrent motion along the Alpine Fault (Wood *et al.*, 1989).

A number of thick sedimentary accumulations have been identified within the Rise as a result of rift tectonics (Fig. 5) and while they do not look large their size can be appreciated when compared with the size of the Taranaki Basin (Fig. 5). The detailed structural development of these sedimentary basins has yet to be defined as the seismic coverage is insufficient to show any possible closures of the size the exploration industry is normally interested in.

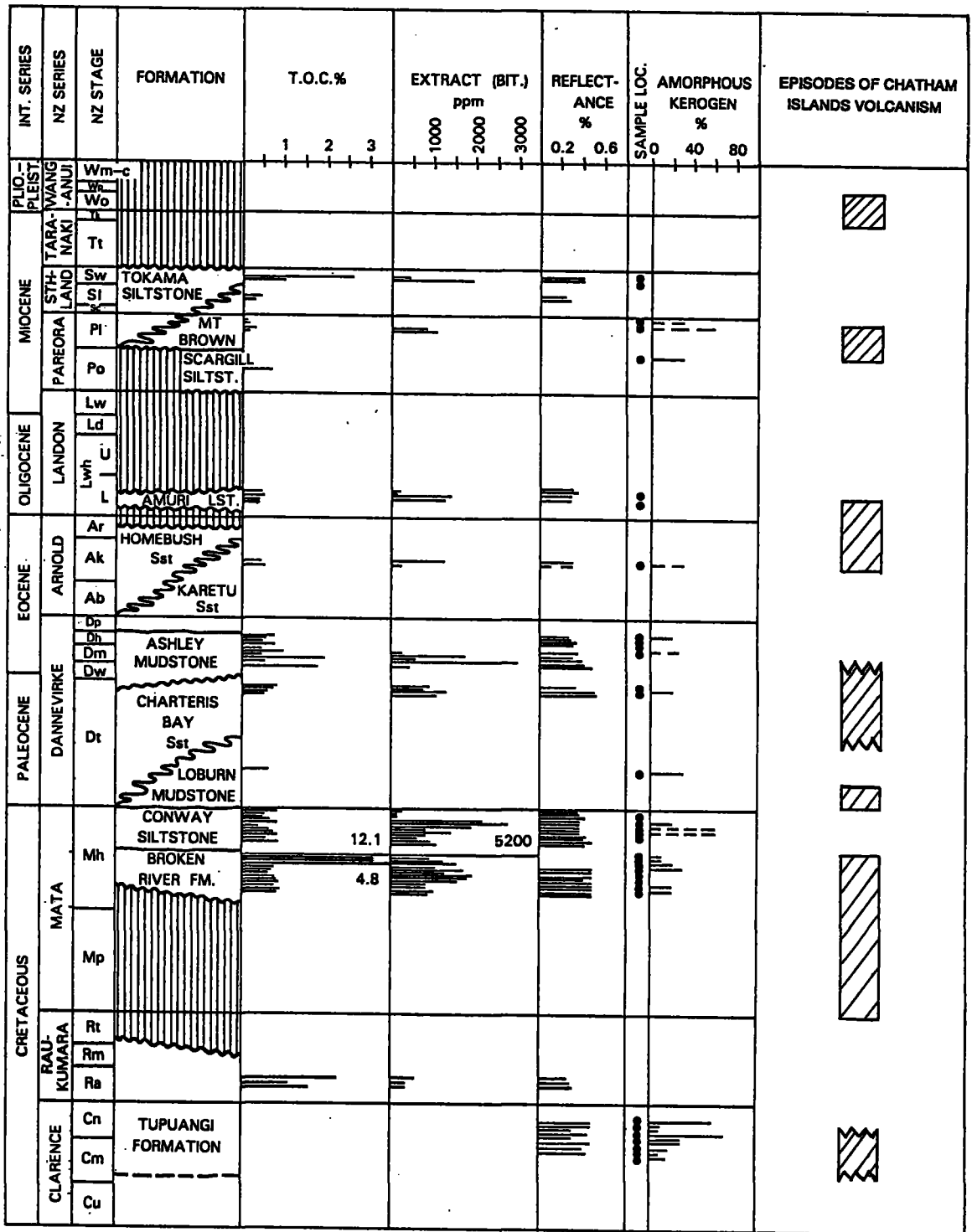
HYDROCARBON POTENTIAL

Source rocks

Petroleum geochemistry has been carried out on a few samples from Pitt Island and from a number of wells and field samples from the Canterbury area. Although some Cenozoic rocks contain enough organic carbon to be marginal sources (TOC > 0.5%), the Cretaceous sequence contains the only potentially mature rocks.

The Cretaceous Tupuangi Formation of Pitt Island consists of carbonaceous siltstone and sandstone of good source potential (TOC 1.1-2.3%), but in outcrop they are immature with reflectances of only 0.37-0.47%. However offshore seismic interpretation shows that the Tupuangi Formation occurs significantly deeper on the Chatham Rise where they will be more mature.

The Late Cretaceous Broken River and Conway Formations sampled in Canterbury wells both have good TOC (0.6-12%) and extract (>1000ppm) source characteristics, with



----- DOMINANT KEROGEN IDENTIFIED
BUT NOT QUANTIFIED

Fig. 4: Petroleum geochemistry and volcanism through the Cretaceous and Cenozoic of the Chatham Rise (after Wood *et al.*, 1989).

the Broken River showing terrestrial kerogens and the Conway a dominance of amorphous kerogen.

Maturation

From the wells drilled in the Canterbury Basin where the geothermal gradient is 18° to 26°C/km (Pandey, 1981), reflectance data shows Ro 0.6 would be reached at nearly 3 km (Field and Browne *et al.*, 1989). On the Rise, the geothermal gradient could be much higher because of the close association of the axis of Cretaceous rifting, and

because of widespread volcanism present along the Rise throughout the Cretaceous and Cenozoic. With this knowledge it is now possible to model the sedimentary basins within the Rise to see if they could be mature under different thermal conditions.

Modelling

While much debate presently surrounds the detail of the Lopatin/Waples type modelling (Tissot *et al.*, 1987; Wood, 1988) it can still be used as a guide to the potential of frontier

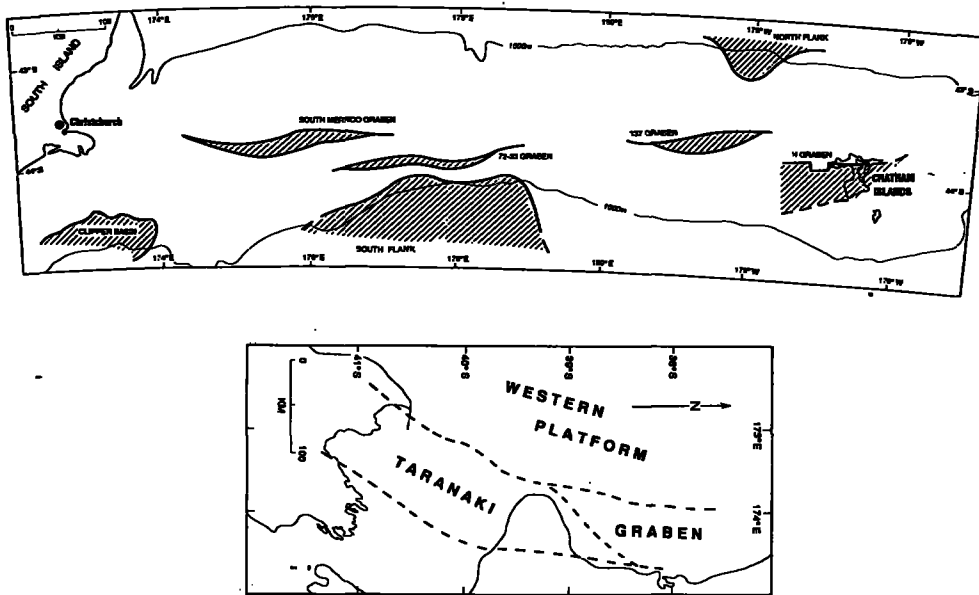


Fig. 5: Sedimentary sub-basins of the Chatham Rise and size comparison with the Taranaki basin.

sedimentary basins. Using the seismic interpretation of Wood *et al.* (1989), a range of geothermal gradients of 26°C/km, 30°C/km and 35°C/km have been modelled. These are within the measured range for the rift origin basins of New Zealand (Pandey, 1981) (Table 1) and similar overseas basins (Wood, 1988). The results of this modelling for the various rift basins within the Rise (Fig. 6) are listed in Table 2.

These show that even under the low thermal regime of 26°C/km, the South Mernoo Graben and H Graben have entered the oil window with the H Graben being significantly beyond it. With the thermal regime of 35°C/km, the South Mernoo Graben has moved to the hottest part of the oil window while the 72-33 Graben has moved through the onset of generation. Clearly these basins must be considered reasonable exploration prospects at this frontier stage, and some of the others may improve with better knowledge of the local thermal regime and their source rock type.

	Range	Average
New Zealand Basins (after Pandey, 1981)		
West Coast	25-38°C/km	34°C/km
Great South Basin	31-48°C/km	36°C/km
Taranaki		
western platform	22-29°C/km	26°C/km
graben	22-41°C/km	30°C/km
World basins (after Wood, 1988)		
Geothermal gradients °C/km back through time		
Ma before present	0 25 50 100	
Recent delta/pull apart	36 36	
Passive margin	27.5 30 40	

Table 1: Geothermal gradients of New Zealand and world basins.

Reservoir studies

No reservoir studies have been made of the Cretaceous rocks of Chatham Island but reasonable reservoir conditions should be present in the marginal marine sequence (Tupuangi Formation) and adjacent to the various volcanic islands that formed during deposition of later parts of the sequence (Kahuitara Tuff, Southern Volcanics equivalents).

FUTURE EXPLORATION

Exploration should now be able to build on the major basin studies of the Chatham Rise produced by NZGS. Plays may be developed within the various grabens and on the flanks of the Rise, and new detailed seismic data will allow better definition of structural and stratigraphic traps. Certainly the sampling of the seismically defined pre-mid to Late Cretaceous unit, and the definition of the Cretaceous to Recent geothermal gradients will be important in evaluating this region.

Time-Temperature Index (TTI) levels at various geothermal gradients

	°C/km = 26	30	35
South Mernoo	23	54	154
72-33 graben	3.5	5.9	11.2
South Flank	1.0	1.5	2.3
137 graben	1.2	1.7	2.5
North Flank	0.5	0.6	0.8
H Graben (Chatham Islands)	715	2700	14500

Oil window after Waples (1980) and Wood (1988)

onset of oil generation	Ro 0.6	TTI 10
maximum generation	Ro 1.0	TTI 50
top of oil generation	Ro 1.3	TTI 150

Table 2: Model results for Chatham Rise sub-basins.

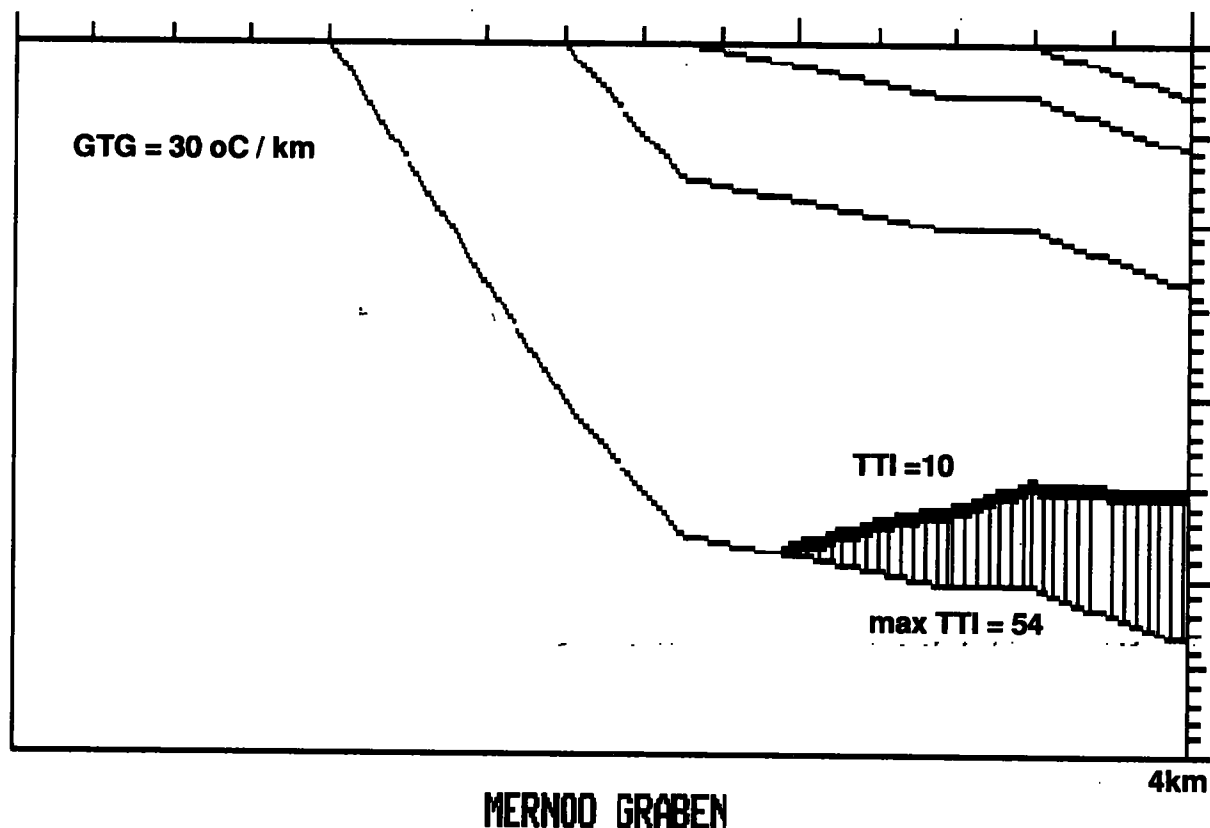


Fig. 6: Maturation window plot for the Mernoo graben using a median geothermal gradient 30°C/km.

REFERENCES

ADAMS, R.D. 1962: Thickness of the earth's crust beneath the Campbell Plateau. *New Zealand journal of geology and geophysics* 5: 74-85.

BRADSHAW, J.D.; ANDREWS, P.B.; ADAMS, C.J. 1981: Carboniferous to Cretaceous on the Pacific margin of Gondwana-land; the Rangitata phase of New Zealand. *5th International Gondwana Symposium, Wellington, New Zealand*; 217-221.

CAMPBELL, H.J.; ANDREWS, P.B.; BEU, A.G.; EDWARDS, A.R.; HORNIBROOK, N.DEB.; LAIRD, M.G.; MAXWELL, P.A.; WATTERS, W.A. 1988: Cretaceous-Cenozoic lithostratigraphy of the Chatham Islands. *Journal of the Royal Society of New Zealand*. 18: 285-308.

CAMPBELL, H.J.; ANDREWS, P.B.; BEU, A.G.; EDWARDS, A.R.; HORNIBROOK, N.DEB.; LAIRD, M.G.; MAXWELL, P.A.; MILDENHALL, D.C.; WATTERS, W.A. (in press) Cretaceous-Cenozoic geology of the Chatham Islands, New Zealand. *New Zealand Geological Survey bulletin*.

FIELD, B.D.; BROWNE, G.H. ET AL. 1989: Cretaceous and Cenozoic sedimentary basin and geological evolution of

the Canterbury region, South Island, New Zealand. *New Zealand Geological Survey basin studies* 2.

GRINDLEY, G.W.; ADAMS, C.J.D.; LUMB, J.T.; WATTERS, W.A. 1977: Paleomagnetism, K-Ar dating and tectonic interpretation of Upper Cretaceous and Cenozoic volcanic rocks of the Chatham Islands. *New Zealand journal of geology and geophysics* 20(3): 425-467.

HAY, R.F.; MUTCH, A.R.; WATTERS, W.A. 1970: Geology of the Chatham Islands. *New Zealand Geological Survey bulletin* 83.

HERZER, R.H. 1975: Uneven submarine topography south of Mernoo Gap-the result of volcanism and submarine sliding. *New Zealand journal of geology and geophysics* 18: 183-188.

HERZER R.H.; CHALLIS G.A.; CHRISTIE, R.H.K.; SCOTT, G.H.; WATTERS W.A. 1989: The Urry Knolls, late Neogene alkaline basalt extrusives southwestern Chatham Rise. *Journal Royal Society of New Zealand* 19: 181-192.

PANDEY, O.P. 1981: Terrestrial heat flow in New Zealand. PhD thesis, Victoria University of Wellington, New Zealand.

TISSOT, B.P.; PELET, R.; UNGERER, P.H. 1987: Thermal history of sedimentary basins, maturation indices, and kinetics of oil and gas generation. *AAPG bulletin 71*: 1445-1466.

WAPLES, D.W. 1988: Time and temperature in petroleum formation: Application of Lopatin's method to petroleum Exploration. *AAPG bulletin 64*: 916-926.

WOOD, D.A. 1988: Relationships between thermal maturation indices calculated using Arrhenius equation and

Lopatin method: Implications for petroleum exploration. *AAPG bulletin 72*: 115-134

WOOD, R.A.; ANDREWS, P.B.; HERZER, R.H. and others 1989: Cretaceous and Cenozoic geology of the Chatham Rise region, South Island, New Zealand. *New Zealand Geological Survey basin studies 3*.