THE EXPLORATION POTENTIAL OF THE GREAT SOUTH BASIN

R A Cook and J M Beggs
New Zealand Geological Survey

Great South Basin, offshore SE New Zealand, has an area of 85 000 square km, in water depths ranging from 250 to 1500 m. It contains over 7500 m of mid to late Cretaceous and Tertiary age sedimentary fill, within a series of NE/SW-trending grabens and half grabens which formed during the breakup of the Gondwana supercontinent. Unlike most other New Zealand basins, the basin has not undergone extensive Late Tertiary tectonic activity.

Eight wells have been drilled since 1977. Shows of oil and gas were recorded in several of these and a gas-condensate accumulation was tested in Kawau-1A, with reserves calculated to be 461 BCF of gas (non-commercial in view of the water depth and remoteness).

Potential traps include large folds associated with basement block faulting, drape over buried highs, and a plethora of stratigraphic possibilities. Mature source rocks, as in other New Zealand basins, include late Cretaceous coal measures and marine shales. The Cretaceous and Cenozoic units contain potential reservoir sands mainly of granitic and quartzitic provenance. Exploration efforts since the early 1980s have not been helped by the harsh operating environment and difficult economics, but current overseas advances in deep-water production technology, combined with strong worldwide interest in late Mesozoic rift basins, should focus new attention on the Great South Basin.

INTRODUCTION

The Campbell Plateau, east and south of the South Island of New Zealand, contains a number of sedimentary basins. The largest of these is the Great South Basin. From the south Otago coast (Kaitangata area) it extends SE for 250 km with its southern limit about 400km from Dunedin. Its NE/SW trend parallels that of the South Island (Fig. 1).

Physically the Great South Basin extends as far south as 50° S. latitude, much of it beyond the lee of South and Stewart Islands (Fig. 2). Hence it is open to the strong westerly circum-Antarctic weather systems where severe wind and wave patterns make for difficult operating conditions. Most of the basin lies beyond the modern shelf area in water depths greater than 500 m (with about 1/3rd greater than 1000 m). Whereas in the 1970s these water depths and conditions were at the frontier of exploration, in the last decade deep-water exploration and production have become more routine. The basin contains over 7500 m of mid to late Cretaceous and Tertiary sediments within a series of NE-SW trending grabens and half grabens.

There is no geomorphic expression of this basin, and it was not until the geophysical research cruises of 1965-72 by the Lamont-Doherty research ship *Eltanin* that its existence was identified.

Exploration for hydrocarbons began in 1969 when Hunt International obtained a licence covering much of the Campbell Plateau. Up to 1979 some 42 500 km of seismic was shot over this extensive licence, of which 28 000 km covered the Great South Basin. Six wells were drilled in

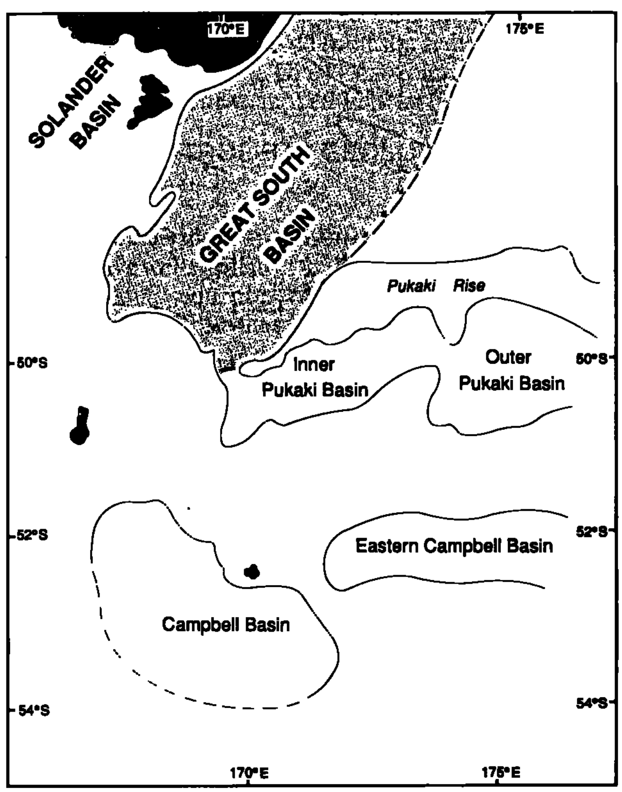

Fig. 1: Location map of the basins of the Campbell Plateau.

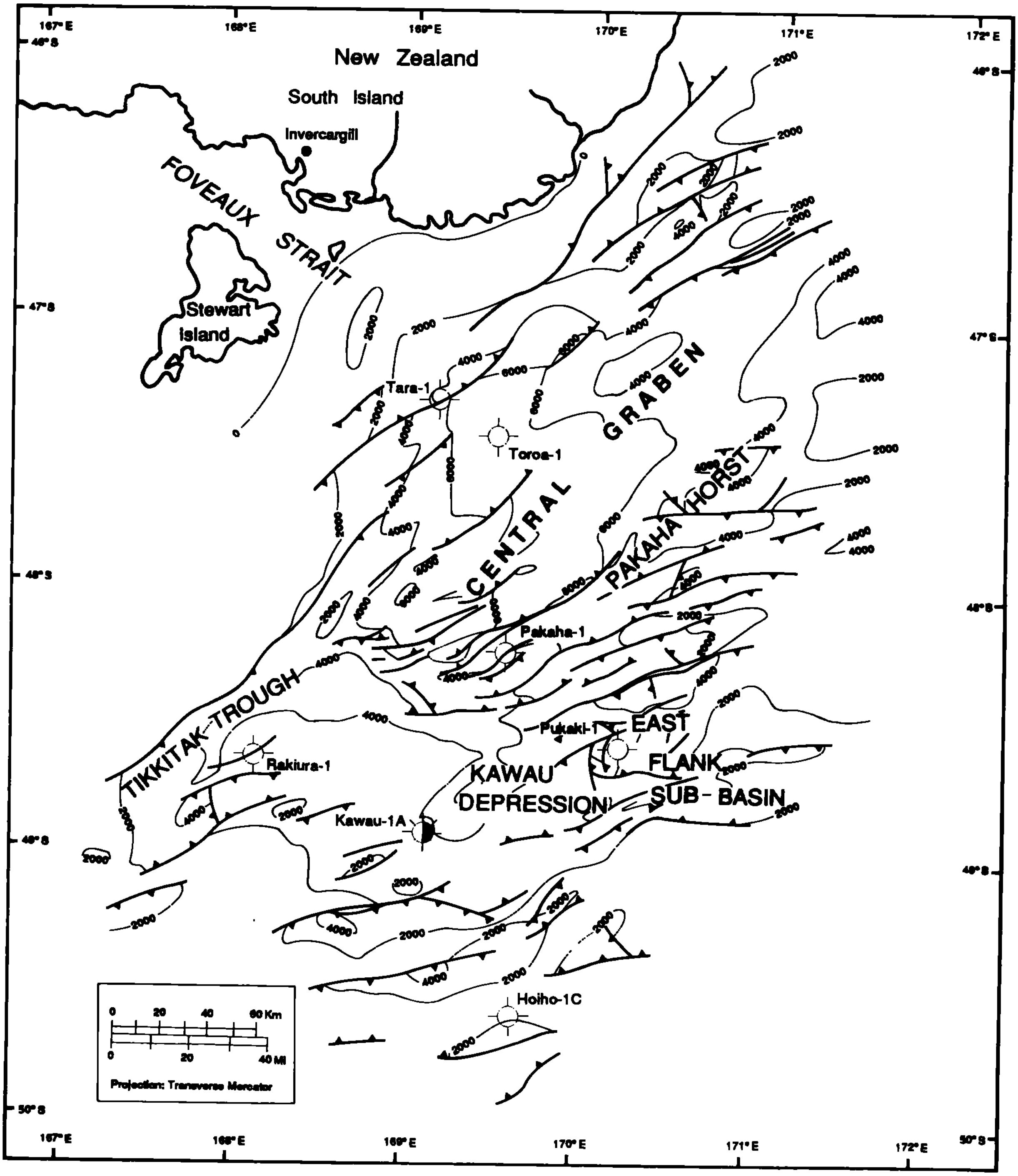

Fig. 2: Total sediment isopach and structural subareas of the Great South Basin (after Anderton *et al.*, 1982).

1977-1978 to test large structures within this basin. Shows of oil were recorded in Toroa-1 but could not be tested due to mechanical failure. At Kawau-1A, a drillstem test of a 33m interval flowed gas at up to 6.8 MMCF per day, with 48° API condensate. This test indicated a gas accumulation about half the size of the Kapuni Field in Taranaki.

Following a comprehensive technical review by Phillips Petroleum on behalf of the Hunt consortium, two further wells were drilled by Placid, in 1983, without success. Since then the Great South Basin has not seen further exploration. However, given that several analogous Mesozoic rift basins have in the last decade seen substantial successful hydrocarbon exploration renewed interest in the Great South Basin in the next few years is expected.

TECTONICS

The Great South Basin is an intra continental rift extending to the north into the Canterbury Basin and northeast into the Bounty Trough. It is a large complex half graben which formed between the South Island and the submergent

Campbell Plateau, during the mid Cretaceous rifting phase prior to the separation of the New Zealand crustal mass from West Antarctica (Weissel *et al.*, 1977).

The basement rocks of the region are continental in origin with meta sedimentary rocks of Paleozoic age intruded by Cretaceous granites (Beggs *et al.*, manuscript).

The western edge of the basin coincides with a zone of major northeasterly-trending normal faults, (Fig. 2) some of which have a throw of up to 3 km (Anderton *et al.*, 1982); the thickest sedimentary sequence (approaching 8000 m) occurs in the fault-angle depression immediately southeast of the boundary fault system (Sanford, 1980). A group of structural subdivisions has been recognised (Fig. 2).

Since the Cretaceous the major part of the Great South Basin has remained tectonically quiet with regional subsidence and waning supplies of clastic sediment allowing marine transgression and sedimentation reflecting progressively deeper water. Most mapped structures are related to compaction, with drape of the latest Cretaceous over faulted basement blocks. In the northwest margin of the basin there has been some local tectonic activity during the Paleocene -Miocene (Suggate *et al.*, 1978), including reverse movement on the nearshore and onshore NW-SW trending faulting (Anderton *et al.*, 1982; Carter, 1988a). Seismic lines reveal, volcanic bodies within the Tertiary section but these are not precisely dated. (Carter, 1988a). Miocene and younger alkaline volcanism has occurred in several localities, such as Campbell, Auckland and Antipodes Islands and the Pukaki Knoll (Summerhayes, 1969; Adams *et al.*, 1979).

SEDIMENTARY SEQUENCES

As yet no formal stratigraphy has been developed for the Great South Basin however, with new paleontology currently being completed out on the latest two wells, together with updates of the earlier wells; NZGS intends to develop a formal stratigraphic framework as part of its Cretaceous-Cenozoic programme in the near future.

Outlines of sedimentary events are given in Anderton et al. (1982) (Fig. 3) and Carter (1988a), and a preliminary compilation of the onshore and nearshore stratigraphy of Otago and Canterbury is given by Carter (1988b).

The oldest dated sedimentary sequence in the basin is Mid Cretaceous (Cenomanian-Santonian) in age and is limited to the graben areas. The deepest fault-angle depressions contain wedge-shaped bodies, inferred to comprise talus slope continental type deposits infilling the initial rift valleys. In Tara-1 and Hoiho-1C these are represented by muddy conglomerates. Infill of the fault-angle depressions proceeded with thick non-marine sandstone and coal measure sequences being deposited in units of increasing lateral extent. The top of this basal unit is not a clear seismic break although it is unconformable where mapped (Anderton *et al.*, 1982), and possibly equates to the *post rift* unconformity (Falvey, 1974). The upper Cretaceous interval has a much more widespread distribution than the underlying unit and overtops the main horst blocks by the end of the period. The unit includes sandstones, siltstones and minor shales, with carbonaceous bands and coals towards the western parts of the basin. Compared to the mid-Cretaceous sequence these are more mature quartzose coal measures and sandstones, representing fluvial and paralic environments.

By the uppermost Cretaceous marine transgression from the south and east had overrun much of the basin, with widespread deposition of restricted marine shales. By the end of the Paleocene the shoreline had moved west to the Toroa-1 area with the Paleocene in Tara-1 represented by thick paralic coal measures whereas the Pakaha-1, Kawau-1A and Hoiho-1C sequences comprise marine shale with thin sandstones and limestones.

Through the Eocene the western part of the basin continued to receive prograding clastic wedges from the west, as seen on seismic sections (Carter, 1988a) which indicate possible deltaic environments. Shoreline fluctuations were controlled by the interplay of subsidence, sediment supply, and eustatic sea level movements.

During the period from Paleocene to Oligocene, the eastern and southern parts of the basin (in Hoiho-1C and Pukaki-1) became open marine with pelagic nanno-foram chalk deposited over a widening area indicating a dwindling supply of clastic detritus from the landmass.

The pelagic chalk progressively encroached westward as far as the Toroa-1 area by the Oligocene (Fig. 3). While marine regression commenced in the Canterbury Basin in early Miocene (Vella, 1967) fed by terrigenous material derived from the uplifting landmass along the newly active Alpine plate boundary (Carter and Norris, 1976; Norris *et al.*, 1978), regression did not reach beyond the immediate offshore Otago area.

A wedge of Neogene sediment has prograded out from the Otago coast and the continental shelf edge lies along a line above or just east of the Great South Basin boundary fault system. To the east of that wedge clastic sedimentation has been absent, with thin Late Cenozoic pelagic oozes accumulating over the Campbell Plateau (Carter, 1988).

PETROLEUM GEOLOGY

Reservoirs

Clean sandstone beds of up to 49 m thick are recorded in four of the first five wells drilled in the basin in both the Paleocene and Cretaceous sequences (Anderton *et al.*, 1982). Log derived porosities from these sands show a normal decrease with depth (Fig. 4). Kawau-1A and Tara-1 have up to 33% porosity at 1700 m and Tara-1 10% at 4000 m. Toroa-1 has porosity about 5% lower over the same depth range. The optimum reservoir potential for the Cretaceous section depends on the distribution of the sands, their environment of deposition, and their sedimentation rate. Winnowing by reworking of the upper parts during the beginning of the marine transgression may have significantly improved the upper 50-100 m: this is the situation of the reservoir sandstone in Kawau-1A. However in the Toroa-1 area the rate of sediment influx was greater, so that reworking was limited.

Hydrocarbon distribution

Hydrocarbon indications have been restricted to the Cretaceous intervals of the Toroa-1, Tara-1, Pakaha-1 and Kawau-1A wells. In Kawau-1A predominantly methane with some condensate was tested at up to 6.8 MMCFPD. The

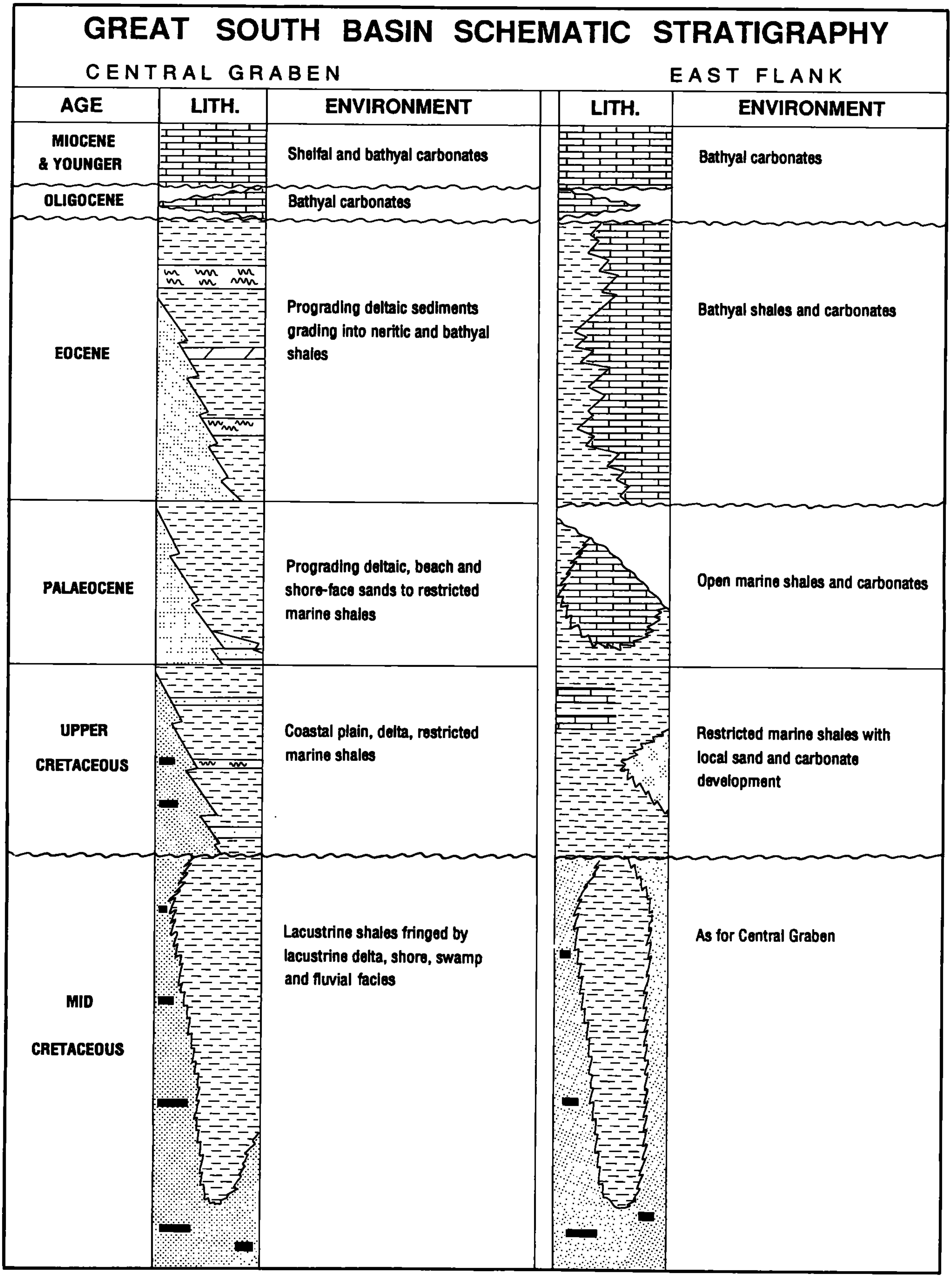

Fig. 3: Sedimentary sequences of the eastern and western parts of the Great South Basin (after Anderton *et al.*, 1982).

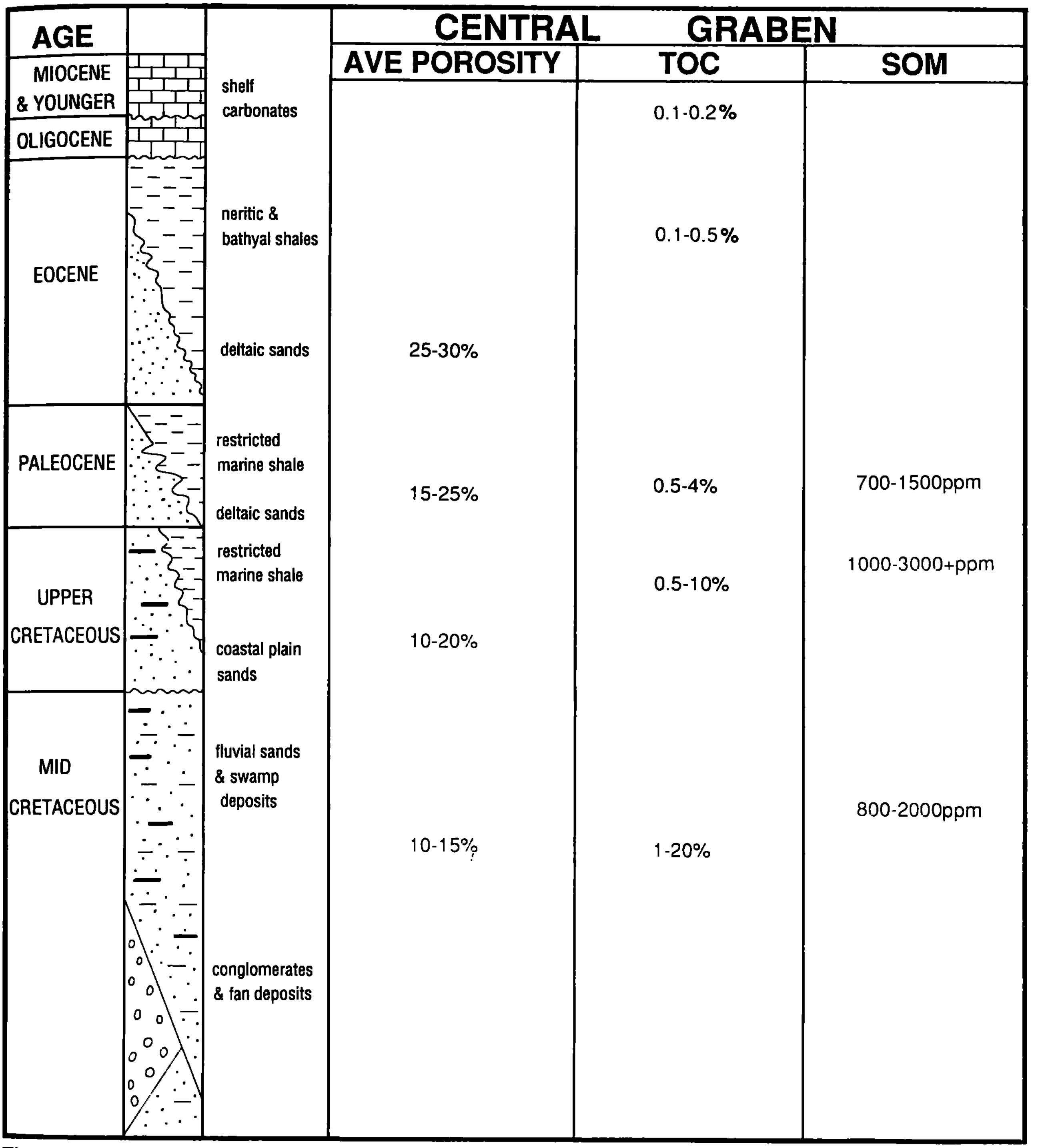

Fig. 4: Stratigraphy porosity, total organic carbon and soluble organic matter levels within the Central Graben.

reserves of this accumulation are given as 461 BCFG (Anderton *et al.*, 1982). Geochemical analysis of the gas and condensate indicates it was derived from terrestrial, coaly organic material (Anderton *et al.*, 1982; Cook, 1982). Extracts of non-indigenous marine oils were extracted from shales above the gas sands, within the Cretaceous and Paleocene section.

In Tara-1 and Pakaha-1, minor fluorescence and moderate gas readings (up to C5) were recorded in the Cretaceous intervals.

In Toroa-1 much stronger indications of oil staining again occurred in the Cretaceous (3350-3600m) but could not be tested due to mechanical failure of the hole.

No traces of hydrocarbons were found in Hoiho-1C, Rakiura-1 or Pukaki-1, downgrading the hydrocarbon potential for these regions.

Source rocks

Average total organic carbon (TOC) values measured on well samples (other than coals) of the northern and central parts of the basin are above the world average and commonly exceed 2% (Fig. 4). Considering also the coals which are especially abundant in the northwest, there is more than adequate organic matter preserved within the basin to source commercial volumes of hydrocarbons. Source rock occurrence may be a problem in the south (Hoiho-1C), the East flank (Pukaki-1) and Rakiura subbasins as none of these wells had consistently good TOC levels. The kerogen class (indicating the hydrocarbon type likely to be produced from a source) is dominated by humic material for the middle and Late Cretaceous sequences in the Central Graben favouring gas/condensate potential. In the more widespread Late Cretaceous and Paleocene marine paleoenvironments, the kerogen is more sapropelic and thus more oil-prone.

Maturity

Reflectance measurements have been made in most of the wells. The top of the oil window (Ro 0.6) is indicated at about 1.9-3 km below the sea floor with the peak of oil generation (Ro 1.0) reached at 2.4-4.2 km depth (Anderton *et al.*, 1982) (Fig. 5). This suggests that the Cretaceous sequences of the Central Graben and Kawau Basins are buried to at least the peak of oil generation and now exceed the base of the oil window (Ro 1.3). The marine sequences of the Late Cretaceous and Paleocene have also reached peak oil generation. Modelling done by Phillips (Anderton *et al.*, 1982), suggests that some of the sequence has been mature since the Late Cretaceous; since structure development (drape over basement highs) was complete by this stage early maturation does not preclude entrapment. The low maturation level in Rakiura-1 (Ro 0.55 at 2380 m) and in Pukaki-1 (Ro 0.62 at 3220m) were claimed to indicate that there was low thermal maturity in both sub-basins, but it is our contention that they do not condemn the deeper portions of the main basin. The indications of the presence of hydrocarbons in both the Central Graben and Kawau sub-basins together with the analytical data show that both gas-prone and oil-prone sediments are mature in these areas, which will no doubt be the focus for future exploration in the Great South Basin.

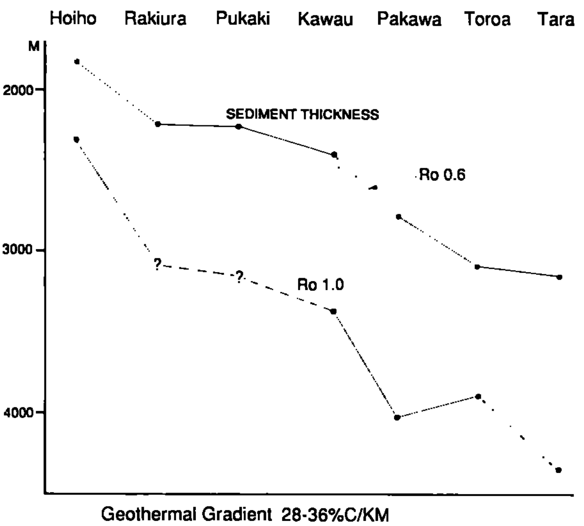

Fig. 5: General threshold depths measured in the levels of the Great South Basin.

COMPARISON TO OTHER NEW ZEALAND BASINS

The mid Cretaceous rift setting is analogous to several other basins in New Zealand of which the Taranaki basin and the West Coast basins have already proven to hold commercial and subcommercial hydrocarbon accumulations. The Late Cretaceous and Early Tertiary sequences of different parts of the Great South Basin have affinities with different NZ basins. The south and east of the basin, where the sediments are chalk-dominated, are comparable to the Tertairy sequences of North Canterbury and Marlborough. The central part of the basin has an East Coast style of stratigraphy with siliceous shales similar to the Whangai Formation (Moore, 1988), and shales akin to the Waipawa black shales present. The western part of the basin has thick carbonaceous clastic sequences comparable to the Taranaki, West Coast and north Otago/south Canterbury areas. The major difference of the Great South Basin, is the unique lack of post mid Cretaceous tectonic events which, in turn, allows a clearer understanding of the timing and complexity of the structures compared to the Taranaki or East Coast basins.

FUTURE EXPLORATION EFFORTS

No work has been carried out on the Great South Basin since 1983. The drilling of the two last wells, together with the improved understanding of the regional geology and tectonics of New Zealand have dated the Phillips basin study (Anderton *et al.*, 1982), so this work needs to be brought up to date.

The extensive seismic data set (acquired in the late 60s to early 80s) should now be responsive to reprocessing and reinterpretation. Drilling and production technology is now also catching up on the challenge of the deep water and harsh operating conditions present in the Great South Basin. Furthermore since the early 1980s, an extensive infra-structure supporting exploration has developed in New Zealand.

Lodgement of data, previous interpretations, and well samples means that future explorers can pick up where earlier licencees left off. Will the Great South Basin challenge be picked up and the 1990s become the decade of southern exploration?

REFERENCES

ADAMS, C.J.; MORRIS, P.A.; BEGGS, J.M. 1979: Age and correlation of volcanic rocks of Campbell Island and metamorphic basement of the Campbell Plateau, south-west Pacific. *New Zealand Journal of Geology and Geophysics, 22*:679-691.

ANDERTON, P. W.; HOLLOWAY, N. H.; ENGSTROM, J. C.; AHMAD, H. M.; CHANG, B. 1982: Great South and Campbell basins, New Zealand. Evaluation of geology and hydrocarbon potential. Unpublished Petroleum Report 828, New Zealand Geological Survey.

BEGGS, J. M.; CHALLIS, G. A.; COOK, R. A. (Manuscript) Basement geology of the Campbell Plateau: Implications for correlation of the Campbell Magnetic Anomaly System. submitted to *New Zealand Journal of Geology and Geophysics.*

CARTER, R.M. 1988a: Plate boundary tectonics, global sea-level changes and the development of the eastern South Island continental margin, New Zealand, Southwest Pacific. *Marine and Petroleum Geology, 5(2)*:90-107.

CARTER, R.M. 1988b: Post-breakup stratigraphy of the Kaikoura Synthem (Cretaceous-Cenozoic), continental margin, southeastern New Zealand. *New Zealand Journal of Geology and Geophysics 31*:405-429

CARTER, R. M.; NORRIS, R. J. 1976: Cainozoic history of southern New Zealand: an accord between geological observations and plate-tectonic predictions. *Earth and planetary science letters 31*:85-94

COOK, R. A. 1982: An oil seep at Leask Bay, Stewart Island, New Zealand. *New Zealand Journal of Geology and Geophysics 25*:115-119.

FALVEY,D.A. 1974 : The development of continental margins in plate tectonic theory. *APEA Journal, 14*: 95-106.

MOORE, P.R. 1988: Stratigraphy, composition and environment of deposition of the Whangai Formation and associated Late Cretaceous- Paleocene rocks, eastern North Island, New Zealand. *New Zealand Geological Survey Bulletin 100*: 100pp.

NORRIS, R.J.; CARTER, R. M.; TURNBULL, I. M. 1978: Cainozoic sedimentation in basins adjacent to a major continental transform boundary in southern New Zealand. *Journal Geological Soc. London 135*:191-205.

SANFORD, R.M. 1980: Exploration results off S. New Zealand. *Oil and Gas Journal 78(5)*: 83-90

SUGGATE, R. P.; STEVENS,G. R.; TEPUNGA, M. T., 1978: The Geology of New Zealand. New Zealand Govenment Printer,Wellington, 2 vols.

SUMMERHAYES,C.P. 1969: Marine geology of the New Zealand Subantarctic Seafloor. *New Zealand Oceanographic Institute Memoir 50*.

VELLA,P. 1967: Eocene and Oligocene sedimentary cycles in New Zealand. *New Zealand Journal Geology and Geophysics. 10*:119-145.

WEISSEL,J.K.; HAYES,D.E.; HERRON,E.M. 1977:Plate tectonics synthesis:the displacements between Australia, New Zealand and Antarctica since the Late Cretaceous. *Marine Geology 25*: 231-277.