THE SOUTH WANGANUI BASIN - A NEGLECTED HYDROCARBON PROSPECT

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Exploration in the South Wanganui Basin occurred in the 1940s and 1960s, with four wells drilled to basement. Three of these wells were on basement highs against which the older basinal sequence wedges out along the flanks. The older sediments thus have only been tested in one well.

This 20 000 square kilometre basin, located on and offshore and immediately adjacent to the producing Taranaki Basin has a sedimentary column in excess of four kilometres. Palinspastic reconstruction suggests possible migration routes into the South Wanganui Basin, for hydrocarbons generated in deeper Taranaki source areas.

Additionally, new geochemical analyses indicate a systematic increase of TOC values of potential source rocks within the South Wanganui Basin, across the basin towards west and south where conditions for maturation and trap formation are improved. There is no shortage of potential reservoir sands with good poroperm characteristics, while muddy siltstones should provide adequate seals. In the light of recent tectonic studies and new structural interpretations, partly based on biostratigraphic revision of well sections, new concepts regarding the basin's prospectivity can be formulated. While widely neglected in the past, the South Wanganui Basin is now seen as an important geological province of undisputed exploration interest.

GENERAL BASIN SITUATION

Located in the south-central part of the North Island, between the oil and gas producing Taranaki Basin to the west and the Mesozoic basement greywacke belt of the Central Ranges to the east (Fig.1), the 20 000 km² South Wanganui Basin, half on and half offshore, is a back-arc basin in terms of its plate tectonic setting. Situated above the subducting Pacific Plate, its tectonics is directly affected by the subduction process (Stern and Davey, 1989). However, contrary to earlier opinions, and contrary to the opening back-arc basin of the Central Volcanic Graben to the north (or Taupo Volcanic Zone), the South Wanganui Basin is under compression and characterized by intense seismicity (Robinson, 1986). As a result, it has structurally developed into a typical foreland basin: markedly asymmetric in cross-section (Fig.2), it exhibits a 30 km wide, west-verging fold-thrust belt along the eastern side. Westwards this belt sharply terminates at the Western Boundary Thrust. And immediately adjacent, i.e. in front of the Thrust is the axis of greatest depression , called the Axis of Tectonic Subsidence. This is well defined on seismic sections between the area of the Rangitikei River mouth and Kapiti Island, where the basin is depressed to 4 km. Against the summit height of the Ruahine Range which is some 1700 m, and adding perhaps another 500-1000 m lost by erosion, the total vertical differential across the 30 km wide fold-thrust belt is about 6-7 km. This

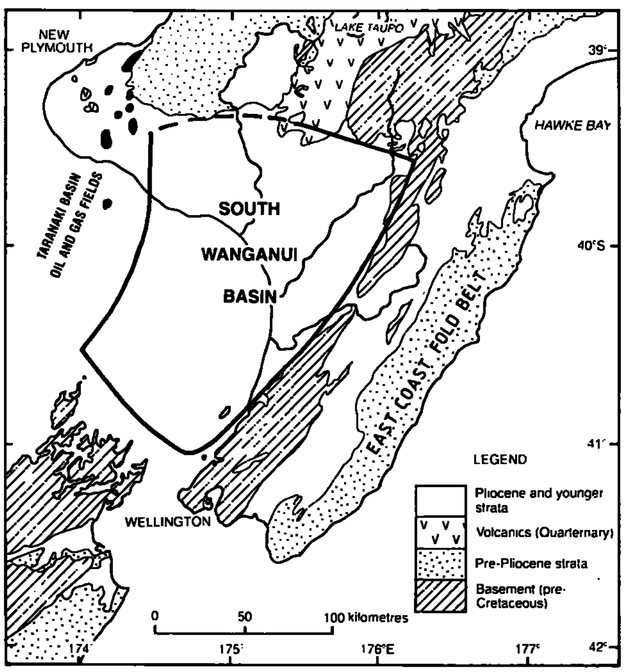

Fig. 1: Location of South Wanganui Basin, New Zealand

difference in elevation is thus attributed to the effects of tectonic compression.

Westwards from the Axis of Tectonic Subsidence, the floor of the basin gradually rises to the Patea High which forms the western boundary of the South Wanganui Basin. This gently east-dipping slope comprises 2/3 of the entire width of the basin, and is only interrupted by a few mostly normal faults of limited throw.

Along its longitudinal axis (north-northeast to south-southwest) the basin likewise represents a large crustal flexure (Stern and Davey, 1989). Contrary to what might be expected, the South Wanganui Basin is not the result of extension and thinning of the crust, but is caused by crustal down-bending. This is also reflected by the large and smooth, negative gravity anomaly of over 150 mgal. As was discussed by Stern and Davey (1989), crustal attenuation as opposed to flexure would cause a considerably more diffentiated and complex gravity anomaly.

PAST EXPLORATION AND PRESENT OUTLOOK

There were three periods of active exploration in the South Wanganui Basin.

1940-1942

Superior Oil Co. carried out field work which established the lithostratigraphic subdivision that is still basically in use today. They also ran one of the first commercial seismic surveys in the country, which established several drilling targets in the lower Rangitikei River area. Two were tested by Stantiall-1 and Young-1 wells, which both went to basement, but were dry and abandoned.

1960-1964

Champlin Oil & Refining Co. did a new seismic survey in the same area as Superior before, but added an offshore line parallel to the coast. One well was drilled, Santoft-1A, on what was perceived as a separate closure down the plunge of the same anticlinal axis of Superior's Stantiall-1 well. Santoft-1A, located close to the coast, went to basement but was dry and abandoned.

Shell BP and Todd Oil Services Ltd., after their discovery of the Kapuni gas-condensate field in Taranaki, extended their exploration eastwards with two seismic lines parallel to the coast, on and offshore, to join up with Superior's and Champlin's area of exploration. In addition, two sidelines were shot up the Waitotara and Wanganui river valleys. In the latter a small reversal was found and, after some detailing, a closed structure established where the lowermost sediments were draped over a buried basement hill. This target was drilled by the Parikino-1 well down to basement. The well was dry and abandoned.

1970

Bounty Oil Ltd. undertook a new seismic survey, again in the same small area (30 x 40 km) as Superior and Champlin before. However, this now was a multichannel survey with digital recording and was vastly superior in quality than the previous surveys. But the company apparently ran out of funds and relinquished the acreage without drilling a well.

At about the same time (1967-71) Esso and Mobil Oil conducted marine reconnaissance seismic surveys across the entire offshore part of the South Wanganui Basin. Their combined line-length was some 1900 km, which resulted in a grid with a spacing of about 10-15 km.

No other exploratory work was carried out since that time, apart from some recent geochemical studies on samples from the Parikino and Santoft wells. These were done by Robertson Research commissioned by Petrocorp, and independently by Analabs on a proprietary basis. The reports from both studies, as all others from oil company work in the South Wanganui Basin, are now on open file and available (see separate list under References).

Thus indeed the exploratory status of the South Wanganui Basin has remained very low, and no exploration at all was done in the last nearly 20 years. This, therefore, is truly a most neglected area, inspite of the fact that it is adjacent and closely related to the producing Taranaki Basin.

The present study is designed to redress this situation and provide the basis for a modern and up-to-date assessment of the basin's prospectivity. To this end, all available but widely scattered information on the South Wanganui Basin has been compiled and critically examined. In addition, important sets of new data have been acquired, which include:

(a) A modern, state-of-the-art seismic line across the basin (obtained by Geophysics Division DSIR and fully processed and migrated by GECO, cf. Stern and Davey 1989).
(b) Re-definition of the biostratigraphy and correlation of wells.
(c) Seismic interpretation based on the new stratigraphic data, leading to new structural definitions and concepts.
(d) Sampling and geochemical analysis (TOC and rock-eval pyrolysis) of potential source rocks.
(e) Thermal modelling of maturation, identification of mature kitchen area.

The careful study and incorporation of all the data, old and new, has led to the development of new concepts of tectonic evolution and structure. Areas of possible hydrocarbon generation have been identified, as well as the most likely migration routes and prospects for entrapment. In short, the general prospectivity and play concepts can now be discussed on a much wider basis, and with a greater measure of confidence.

Some preliminary results will be outlined below. For greater detail and the full results of these studies, the reader is referred to the comprehensive proprietary report now available from the authors.

STRATIGRAPHY OF THE SOUTH WANGANUI BASIN: SEDIMENT FILL AND DISTRIBUTION

The South Wanganui Basin is surrounded by Miocene and Oligocene, and even older sediments: thick Oligo-Miocene in the North Wanganui Basin which appears to dip south underneath the Pliocene of the South Wanganui Basin, and Oligocene in fault slivers at the southern and eastern margins of the basin. Eocene sediments occur in the Taranaki Basin to the west, and there is Late Miocene in the northeastern corner of the South Wanganui Basin, and from there across the ranges into the Hawkes Bay area. However, within the South Wanganui Basin the stratigraphic sequence where known from wells and outcrop consists exclusively of Plio-Pleistocene rocks resting directly on basement. In the centre

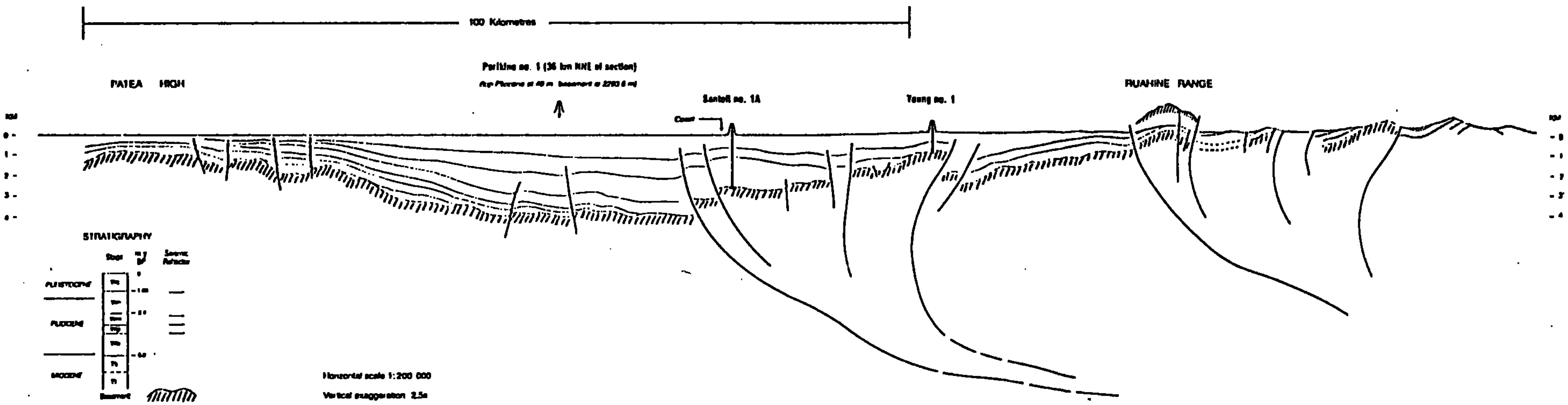

Fig. 2: Cross section through the South Wanganui Basin, from the Patea High in the west to the Ruahine Range in the east.

of the basin these are 4-5 km thick and mainly shallow-marine consisting of sand-silt-mudstone and common thin shellbed-limestones. The stratigraphic sequence as exposed in the Rangitikei River area is shown in Fig.3.

Yet it should be noted that the contact with the underlying basement is only exposed in the northeast and east. As shown by seismic, the three wells drilled in the lower Rangitikei River area are all on old basement highs: here the lower part of the sedimentary sequence wedges out against the flanks of these highs, and thus has not been penetrated in the wells. Only one well in the entire basin, Parikino-1 in the Wanganui River and located on the northern up-slope of the basin, has drilled through the whole Pliocene section which here was found resting on basement. And while there is no seismic coverage over most of the northern half of the basin, also the southern, offshore part is only covered by a very widely spaced, reconnaissance grid. The age of the oldest sediments in the South Wanganui Basin really is unknown.

STRATIGRAPHIC WELL CORRELATION: TECTONIC EVOLUTION AND AGE OF EASTERN FOLD-THRUST BELT

New Zealand Geological Survey carried out micropaleontological and palynological studies of mainly core and side-wall core samples from Santoft-1A and Stantiall-1 wells, for this project. They indicate that sediments no older than of Mangapanian age (Table 1) overlie basement in these wells. Correlation of seismic reflectors shows that in the eastern-most well, Young-1, not even Mangapanian is present. Only the upper part of the Nukumaruan section exists here above basement, besides mainly Castlecliffian sediments (Fig.4). In other words, virtually only Pleistocene is found here above basement.

Based on these findings, a re-examination of Bounty Oil seismic sections in the Rangitikei and Manawatu River area, i.e. from Santoft-1A well to Palmerston North, suggests that no older Pliocene occurs across the entire fold-thrust belt. Thus in the Early Pliocene basement was exposed over most of this eastern area. Even in the Late Pliocene some linear trends of islands still persisted in the now encroaching sea, perhaps until the beginning of the Pleistocene. Early to Middle Pliocene sediments (Opoitian and Waipipian, Table 1) are only known from further west, and on seismic evi-

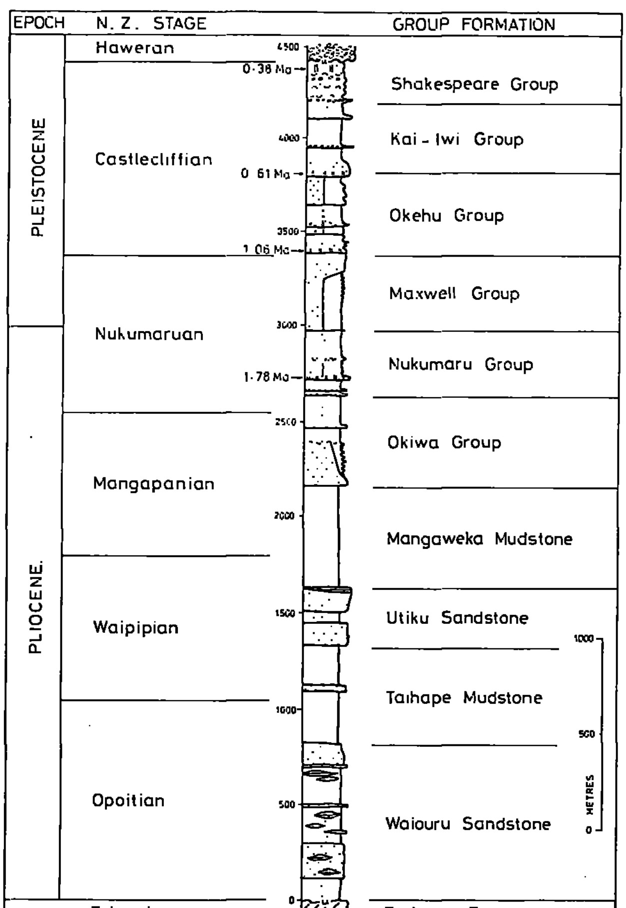

Fig. 3: Stratigraphic sequence exposed in the Rangitikei River area.

EPOCH	NZ SERIES	NZ STAGE	AGE (Ma)	SYMBOL
PLEISTOCENE	WANGANUI	Haweran		Wq
			0.4	
		Castlecliffian		Wc
			1.06	
		unconformity at Wanganui		
			1.40	
PLIOCENE		Nukumaruan		Wn
			2.40	
		Mangapanian		Wm
			3.10	
		Waipipian		Wp
			3.45	
		unconformity at Mangapoike		
			3.75	
		Opoitian		Wo
			5.00	
MIOCENE	TARANAKI	Kapitean		Tk
			5.75	
		no consensus		
			6.30	
		Tongaporutuan		Tt
			(± 10)	

Table 1: New Zealand time-stratigraphic subdivision and correlation of Late Miocene and Plio-Pleistocene (from Edwards 1987).

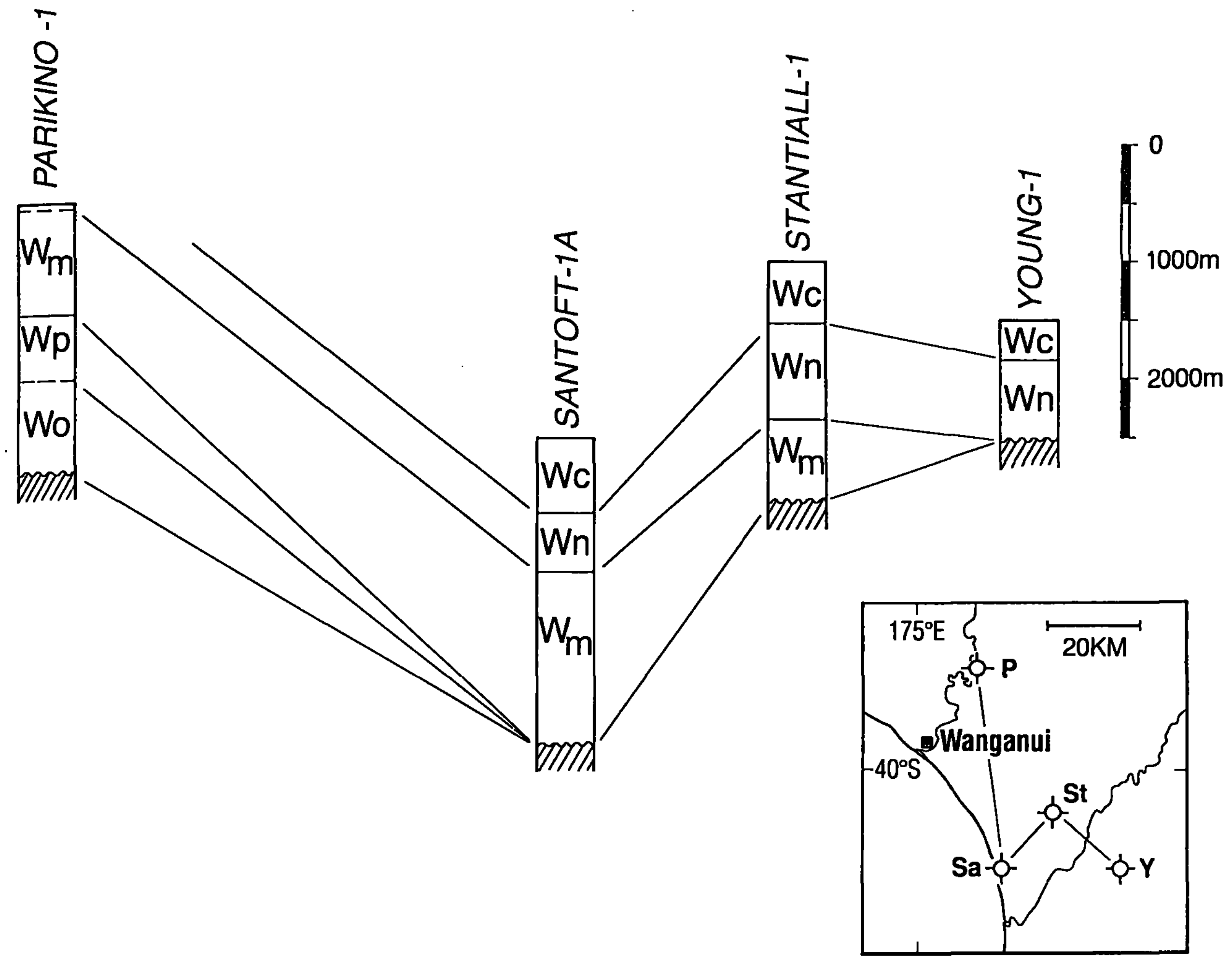

Fig. 4: Stratigraphic correlation of well sections in the South Wanganui Basin, based on recent micropaleontological and palynological evidence.

dence are seen to extend eastwards to just before the Western Boundary Thrust (Fig.2), onlapping basement and pinching out further east.

Thus the lower part of the Pliocene section has not been intersected in any of the Rangitikei wells. On this background, too, the question of flushing which for long has been regarded as of overriding importance and one of the main negative aspects of the South Wanganui Basin, takes on a very different dimension (Katz, 1988).

Since Early Pliocene time the basement in the eastern fold-thrust belt was emergent, and it is possible that compression and uplift had already started. But the distribution and thickness relationship of sediments suggest that the main upthrust and thus depression of the basin around the Axis of Tectonic Subsidence only began in Mangapanian time, i.e. about 3 Ma ago. It continues today as is demonstrated by the actively growing anticlines in the eastern fold-thrust belt, by transcurrent fault movements and continuing uplift of the Ruahine Ranges. Also by the strong seismicity in this part of the basin (Robinson, 1986). The tectonic episode of compression and the establishment of an asymmetric foreland basin thus is a very recent event.

SOURCE ROCKS AND THE GENERATION OF HYDROCARBONS

The most likely source rocks in the South Wanganui Basin are the Taihape Mudstones (Fig. 3), where Superior Oil geologists had noted *fleeting petroliferous odors* (Feldmeyer *et al.*, 1943). This grey and rather uniform mudstone formation, of outer shelf to bathyal depositional environments (Collen, 1972), is about 500 m thick and probably extends across most of the basin. It is exposed on the northern, uplifted flank in a 30 km wide belt and for 150 km from west to east (Fig. 5). In this outcrop area samples have been collected so as to provide for a reasonable spread through the formation both laterally and vertically. Geochemical analyses (TOC and rock-eval pyrolysis, by Analabs) have for the first time provided a basis for basin-wide source rock evaluation.

One result is the systematic increase in TOC values towards the west and south. While generally well below 1% in the northeastern part of the basin, TOC increases to just over 1% in Parikino-1 well and, for a comparable stratigraphic level in the lower part of the Pliocene, to 5-12% in Kupe-1 (Fig. 5). In addition to this marine mudstone, seismic facies interpretation suggests a distinctly different formation at the base

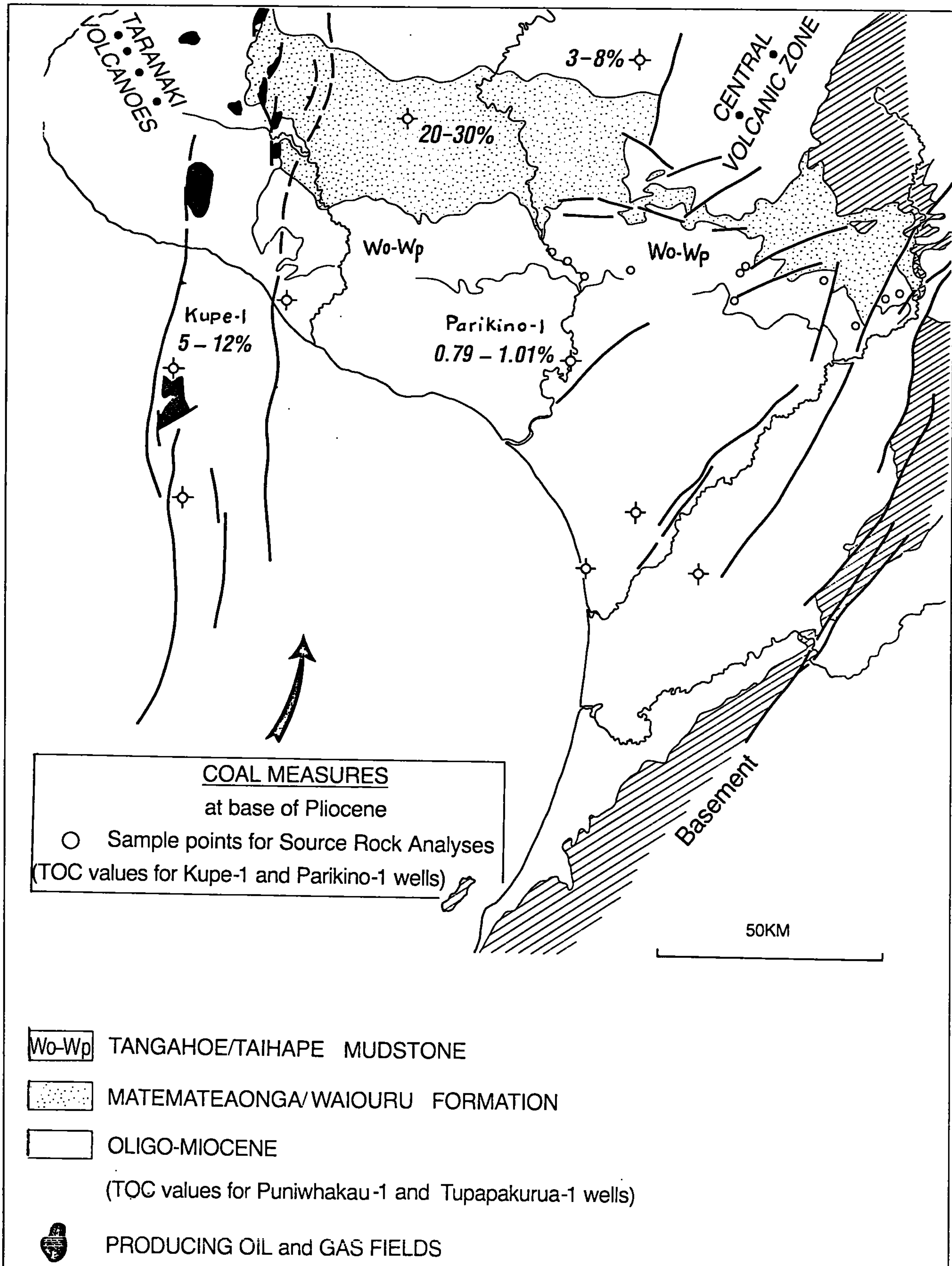

Fig. 5: Generalized map of the South Wanganui Basin, showing wells and sample locations for source rock analyses. TOC values for outcrop and well samples with indication of their respective ages.

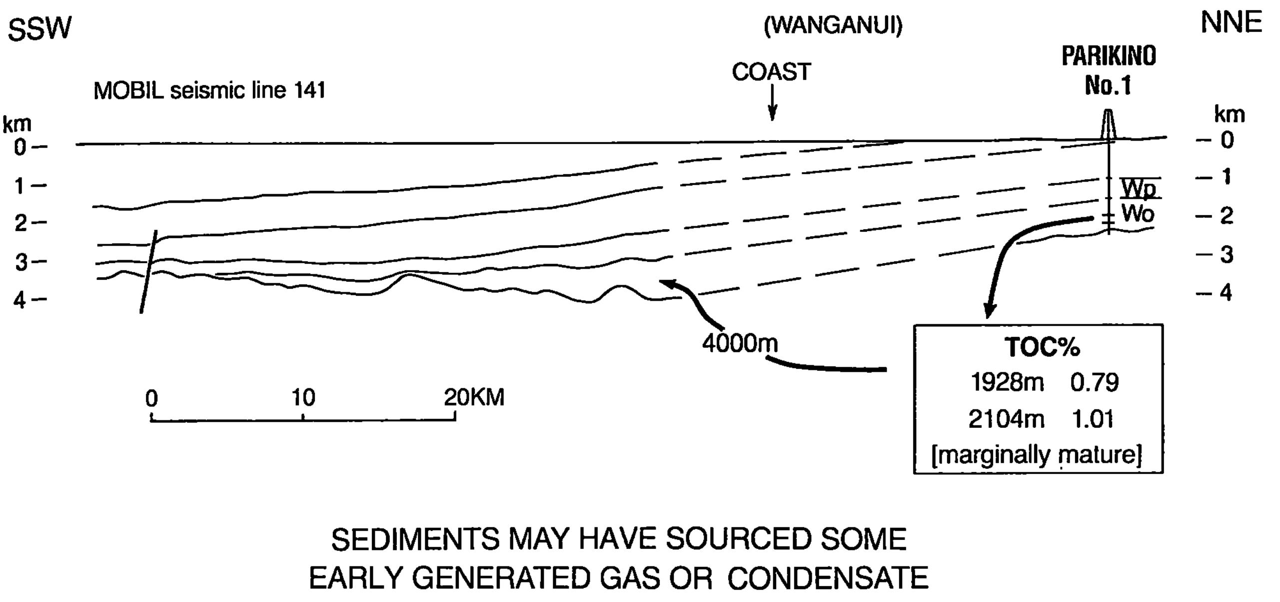

Fig. 6: Profile from Parikino-1 well to the south showing area of potentially mature source rocks.

of the sedimentary sequence, i.e. probably older than Taihape Mudstone, which with discontinuous high amplitude reflectors exhibits characteristics of terrestrial beds, possibly including coal measures. These basal deposits, up to 500 m thick, are typically developed in local basement depressions which often are elongate valleys descending to the north-northeast: in the course of subsequent marine transgression, their situation would have been not unlike the present-day Marlborough Sounds (northwest of Wellington, Fig.1). Thus an environment of restricted circulation may have dominated the scene, providing appropriate conditions for source rock development. In short, the deeper parts of the basin are now seen to include potentially very favourable areas for the sourcing of hydrocarbons, of possibly both marine and non-marine environments.

Regarding maturity Robertson Research had found, near the base of the sedimentary sequence in Parikino-1 (at 1928 and 2104 m, Fig. 5), that sediments with a *fair oil with gas generating potential* were marginally mature and would require *only a minor increase in level of thermal maturity for this potential to be fully realised.* As towards the south from Parikino, over a distance of 36 km, the section deepens from 2000 m to 4000 m (Fig.6), it was considered most likely that there towards the centre of the basin these source rocks would be mature. Indeed, maturity modelling has shown that an area of considerable extent, and a vertical sediment column of over 1 km are presently in the oil generating window.

POSSIBLE HYDROCARBON CHARGE FROM OUTSIDE THE BASIN.

Fig. 7 shows the intimate structural interfingering between Taranaki and South Wanganui Basins. While the Kapuni and Kupe South gas/condensate and oil fields are typically Taranaki Basin accumulations, the Manganui Graben where both fields are located gradually rises to the south and opens up into the South Wanganui Basin. Here the Taranaki Fault

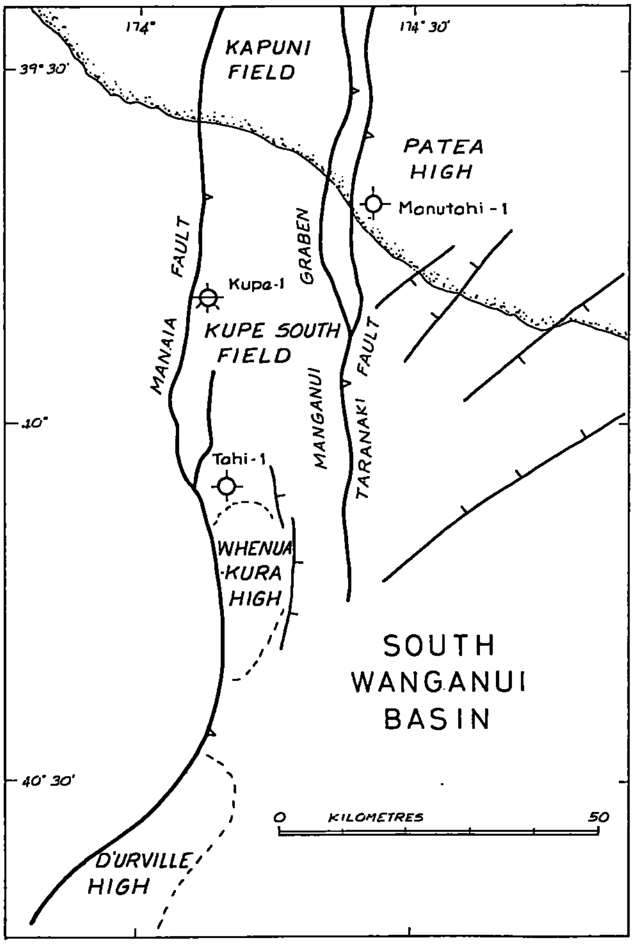

Fig. 7: Structural sketch map of area around the western margin of the South Wanganui Basin, showing relation with the Taranaki Basin.

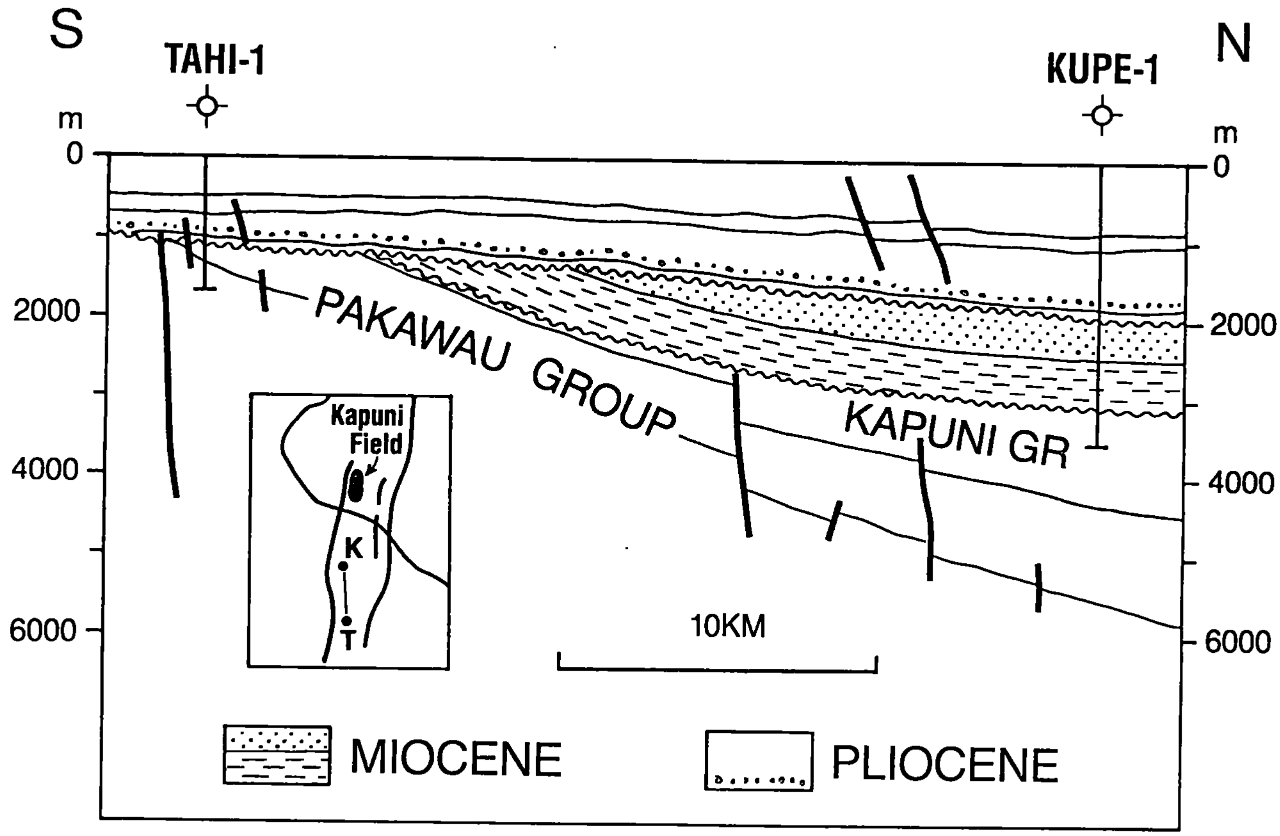

Fig. 8: North-south section from Kupe-1 to Tahi-1 wells (cf. Fig.7).

is virtually non-existent, i.e. inactive in the Early Pliocene.

While the structure of the Kupe South field was formed in the Late Miocene, the trap is sealed by the Lower Miocene Mahoenui mudstone formation. Up-dip to the south, however, this seal is breached, and accordingly the Tahi-1 well was dry. Here the Pakawau and Kapuni Group source formations are open, i.e. directly underlying the unconformable (and sandy) Urenui and Matemateaonga formations, of Late Miocene and Pliocene age (Fig. 8). These are carrier beds through which hydrocarbons would have escaped. It follows that for hydrocarbons generated from Late Cretaceous to Eocene source rocks in the area south of Kupe, there may have been an undisturbed and natural migration path through basal Pliocene sandstones (with Taihape Mudstone equivalent as topseal) up-dip into what was later to become the South Wanganui Basin. They would finally be trapped where these beds pinch out against basement to the east (Fig. 2). When later that area subsided and the regional dip reversed, renewed migration would have taken hydrocarbons to accumulate in the various traps along the eastern flank of the Patea High. Here there is a multitude of different, potential trapping situations: drape and fault structure, unconformities, sand lenses, pinchouts etc. In short, a host of perhaps subtle but possibly very real and effective traps. With the excellent poroperm characteristics that are encountered in the sandstones of the South Wanganui Basin, porosities of over 30% and permeabilities of 400 mD have been measured, and cap rocks that would not be lacking given the common silt-mudstone intercalations, the potential for good and sealed reservoirs seems to be excellent.

Structural traps in four-way dip closures, furthermore, are not all that scarce as previous opinion would have it. Although offshore seismic coverage is not dense enough to map structural closures, there are very many good leads which may form traps of considerable size.

Lastly, a rich source potential is found in Miocene and Oligocene rocks in the North Wanganui Basin (Fig. 5). Regionally those formations dip south underneath the Pliocene of the South Wanganui Basin. While there is no subsurface information for the entire area from the Puniwhakau and Tupapakurua wells all the way to Parikino-1 (where Pliocene rests directly on basement), the possibility cannot be ignored that such Oligocene-Miocene rocks are deeply buried underneath the northwestern quadrant of the South Wanganui Basin. If so, they may be mature and generating oil in that area.

In summary, the present investigation clearly shows that there is no justification to further neglect the South Wanganui Basin, and to deny it any prospectivity. Quite to the contrary: the basin simply is under-explored. But the comprehensive and critical examination of the existing database, together with crucial new information recently acquired, suggest that previous assessments are in urgent need of revision. Based on the present study, the South Wanganui Basin is now recognized as an important geological province with good prospects for hydrocarbon accumulations, and thus of undisputed exploration interest.

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