SEDIMENTARY BASINS OF THE SOUTH PACIFIC: MANY QUESTIONS, FEWER ANSWERS

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Abstract

I treat regions and ages with hydrocarbon potential, and ask firstly have we recognised all types of basins we should be looking for, and secondly have we found them?

(i) Mid-to-late Cretaceous subduction beneath Gondwana; the accretion complex and slope basins are widely preserved, an arc remnant exists (Mt. Somers), but where are forearc and backarc basins?

(ii) Tasman spreading; precursor rifting was very widespread, but we have yet to document the full extent, or to recognise patterns or analogues. Time overlaps between (i) and (ii) need to be considered.

(iii) Tectonic quiescence and transgression, late Cretaceous to late Oligocene; we know about transgressive coal measures as source rocks, but how much do we know about quartz- and greensand-rich fan traps in the passive margin sequences, outer shelf sand bodies, external sea-level controls, transform-related basins outside southwestern South Island, the relation of South Fiji Basin to the apparently oblique subduction at the Tonga Trench (ODP site 841), and what was happening at the Kermadec/Colville arc?

(iv) Source basin for the Tangihua/Matakaoa ophiolites; where was (is) it? Several scenarios are possible.

(v) Miocene-Pliocene convergence; the system is rather completely preserved, but several things remain to be explained, such as the whereabouts of forearc basin(s), the non-recognition of back-arc basins, and the mismatch of a 25 Ma forearc in eastern North Island with a 1 to 2 Ma arc.

(vi) Major Pliocene re-organisation is implied, with dextral displacement and clockwise rotation of eastern North Island along the Vening Meinesz-North Island Shear Belt, inception of the Alpine Fault sensu stricto, growth of mountains, subsidence of the South Wanganui Basin, and new forearc basins, for example.

Introduction

This paper covers the period in which we expect to find hydrocarbons, i.e. in the last 100 million years in the southwest Pacific. The tectonic situation of the time is identified, and the following questions asked: "What basins should we expect to find? Have we found them?"

Mid-to-late Cretaceous

Figure 1 is a reconstruction of the region for the mid-to-late Cretaceous. The base map used is that of Kamp (1986), as modified by Spörli and Ballance (1989). There was clearly a significant overlap in time between the final phases of subduction of the Phoenix Plate beneath Gondwana and the initial phases of extension preceding the opening of the various marginal basins - Bounty, New Caledonia, Tasman. My interpretation of the tectonic situation of the period around 100 Ma is as follows: the main period of accretion of tectonostratigraphic terranes at the Gondwana margin (Torlesse, Murihiku etc; Bishop *et al.*, 1985) was finished. Subduction had stepped outboard of these terranes, resulting in the establishment of a new arc on the Torlesse terrane and a subduction complex along the eastern margin of the terrane. The arc is represented by the Mt Somers remnant of calc-alkaline volcanics in the South Island (Oliver and Keene, 1989) and possibly the Mt Camel Terrane volcanics in northern North Island (Isaac *et al.*, 1988), and by voluminous calc-alkaline detritus in the subduction complex (e.g. Barnes 1990). The latter comprises the Mata River Terrane of Spörli and Ballance (1989), which formed in response to subduction between the Neocomian (c. 120 Ma) and about 90 Ma (Kenny, 1986; Kenny *et al.* submitted; Ballance in prep.). Bradshaw (1989) suggested that subduction ceased because of the consumption of the Phoenix spreading ridge. The structural complexities likely to have resulted from that scenario have not yet been identified, but nevertheless it might provide an explanation for the subsequent over-development of back-arc spreading into the Tasman Sea spreading system.

Likely sites for basin development in an arc system are fourfold: thrust-ridge-ponded basins on the accretionary trench slope , forearc basins, basins within the arc, and backarc spreading basins. Basins within an arc are generally shallow, aerated, overwhelmed with volcanic debris, and poor hydrocarbon prospects. In this case very little of the arc has survived, anyway. Trench-slope basins are mapped along the on-land portion of the terrane (Figure 1) (Mazengarb 1991; Kenny *et al.* submitted; Ballance in prep.). They fine upwards into a subsiding passive margin sequence discussed

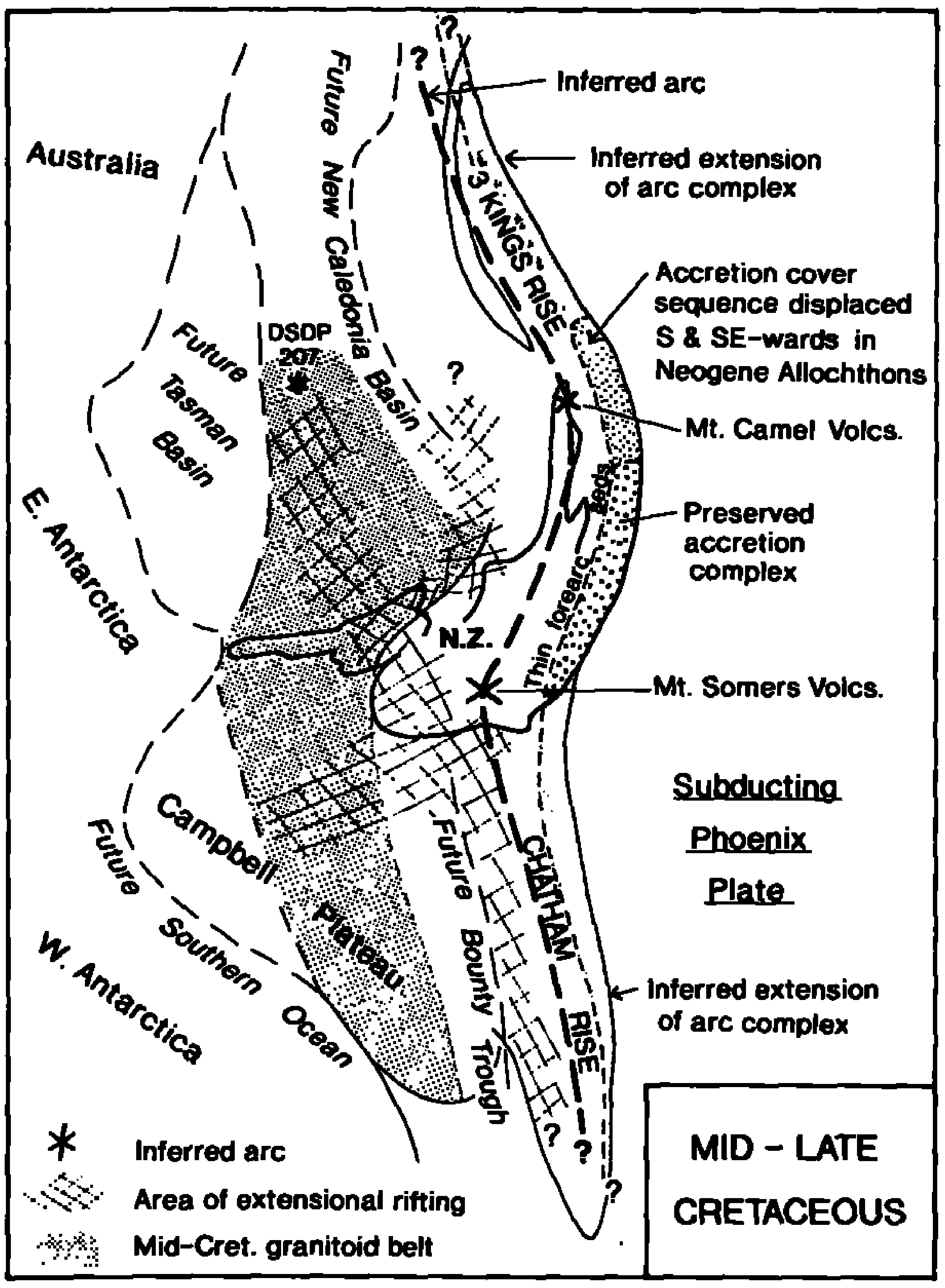

Figure 1: Reconstruction of the New Zealand region for the mid-to-late Cretaceous. Extent of granitoid belt and rift-basins taken from sources cited in the text.

below. Such basins have the potential to intersect an oxygen-minimum zone (OMZ) and accumulate carbon-rich sediments. Testing on one sequence in southern Hawkes Bay was not encouraging (Adams and Ballance, 1988), but relatively high reflectances were recorded in Rere-1 well (de Bock *et al.*, 1986). Nevertheless, how extensive was the trench-slope? Figure 1 suggests that it possibly extended thousands of km beyond the North Island. It could be sought along the northern margin of the Chatham Rise and the eastern flank of the Three Kings Rise, and possibly even farther afield. There is some evidence that the arc extended to the vicinity of the Chatham Islands (pumice and lava fragments in latest Cretaceous sediments, Meek, 1991), but none for the northern extension.

Forearc sequences are preserved in Raukumara Peninsula and Marlborough (e.g. Mazengarb, 1991) but are thin shallow marine sediments. The only known contender for a deep forearc basin underlies the later passive margin sequence on the southern side of the Chatham Rise, but is known only from seismic profiles (Wood and Herzer, in press). Any such basins on the mainland most probably shared the fate of most of the arc and were eroded, unless they are preserved beneath Banks Peninsula or the Northland or East Coast Allochthons. They could be sought along the west side of the Three Kings Rise or further east along the Chatham Rise. Perhaps the Norfolk Basin is, or began life as, a Cretaceous forearc basin.

Backarc basin sequences are not at present known. However, the question of late Cretaceous backarc basins needs to be discussed. Figure 1 shows the known and strongly inferred extent of the extensional rift basins which heralded the opening of the late Cretaceous marginal basins (Tasman, New Caledonia, Bounty). There seems to be a broad belt of rifts related to each basin, and they could be predicted to extend much further along the basin margins than shown. In northeastern South Island they occur very close to the accretionary complex, thus allowing for more than one interpretation of the tectonic scenario (e.g. Laird 1980). The nascent New Caledonia and Bounty troughs are clearly backarc in position, and I suggest that they should be regarded as late Cretaceous extensional backarc basins. Uruski and Wood (1991) similarly proposed that the early development of the New Caledonia Basin took place in a backarc environment, and noted that rift sediments extend as far as the Northland shelf and may include coal measure source rocks. However, the opening of the New Caledonia Basin did not proceed to the formation of new ocean crust. In further consideration of this phase of extension it would be useful to look for the various patterns of listric, antithetic and transfer faults that have been documented in rift regimes elsewhere (e.g. Gibbs, 1984; Lister *et al.*, 1986; Morley *et al.*, 1990). Uruski and Wood (1991) note the possibility that transverse faults have influenced the bend in the New Caledonia Basin.

Latest Cretaceous to Paleogene

Figure 2 shows a generalized paleogeography for this time. The dominating factor over the whole region was relative tectonic stability combined with thermal relaxation and subsidence. Figure 1 shows the great extent of mid-Cretaceous granitoids and extensional rifting. It would appear that the crustal heating associated with those two phenomena, combined with heat from terrane accretion and crustal thickening (Bradshaw, 1990), and establishment of the Mt Somers arc, led to the proto-New Zealand continent being high-standing at, and prior to, the time of separation from Gondwana. Extension and erosion caused marked crustal thinning, to give regional thicknesses of 15 to 20 km (Uruski and Wood, 1991). The New Zealand continent was thus poised for spectacular thermal relaxation, which is amply documented by deepening sequences on all margins, and by the eventual near-total submergence of the New Zealand landmass (Fleming, 1979).

There are several points of potential basin/hydrocarbon interest at this time. First, the sequence on the paleo-Pacific margin contains evidence of upwelling and high bio-siliceous productivity between about 85 and 60 Ma (Whangai and related facies, Moore, 1988; Meek, 1991). The Waipawa Black Shale facies (Paleocene) is widespread along that margin, suggesting the development of an OMZ. Known portions of this sequence are generally immature to marginally mature (Moore, 1988), but are there places where this sequence may have been more deeply buried, such as beneath the East Coast Allochthon (Stoneley, 1968; Moore *et al.*, 1989)? Did the OMZ develop earlier in deeper portions of the margin, before lapping onto the New Zealand platform?

Second, peneplanation of the dwindling New Zealand land mass gave rise to quartzose sands, sediment starvation, and extensive development of shell carbonates and glauconite on the wide shelves (Nelson, 1978). Much of the quartz sand and shell carbonate seems to have remained on the shelves, but much glauconite was shed onto the surrounding slopes as turbidites. Eocene greensand fan systems are potential traps, and could have overlain Waipawa Black Shales. The overlying deep water ooze facies (Weber and Mahurangi Formations) could have acted as a seal. At present we know the fans best on the Pacific margin, and they are particularly well developed in the Northland Allochthon (Ballance and Spörli, 1979; Hayward *et al.*, 1989). Where else should we look for these fan systems, and in what situations could they have achieved sufficient burial? If they are best developed in the Northland Allochthon, could they be present further north on the Three Kings Rise? Are such fans developed on the other passive margins? Are they present beneath the Northland and East Coast Allochthons? On the north flank of the Chatham Rise?

Paleogene Plate Boundary Considerations

Plate tectonic analyses require an Australia/Pacific plate boundary during the Eocene and Oligocene (35 to 23 Ma, Stock and Molnar, 1987). This is generally believed to have been coincident with the Moonlight Tectonic Zone of Norris *et al.* (1978); Challenger Rift of Kamp (1986) in southwestern South Island. Slow rifting, or slow oblique transtension is indicated by the basin histories. The Challenger Rift (Figure 2) pre-dates the Alpine Fault offset, and was formerly continuous as a linear series of rifts from southern South Island, through the Taranaki region, to offshore central North Island. If, as suggested by Spörli (1988), the rift was a link between spreading systems to the south (Solander-Emerald) and north (South Fiji Basin), did it then continue further north towards the South Fiji Basin, to be concealed by the early Miocene emplacement of the Northland Allochthon? There seem to be a number of possibilities inviting a high-quality seismic investigation through the Northland and East Coast Allochthons.

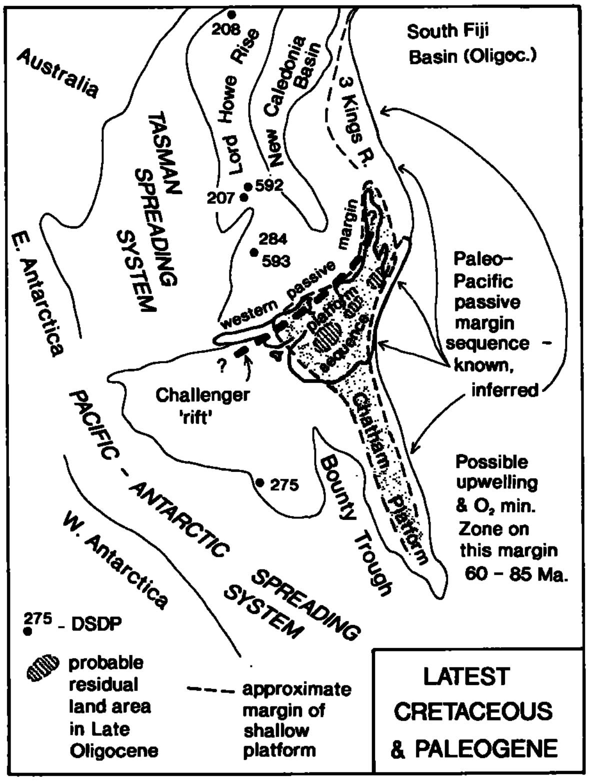

Figure 2: Reconstruction of the New Zealand region for the latest Cretaceous and Paleogene.

Tangihua and Matakaoa Volcanics

These allochthonous slices of sea-floor ophiolite occur in the Northland and East Coast Allochthons, respectively. They are of Cretaceous to Paleogene age (Hayward *et al.*, 1989; Mazengarb, 1991) and indicate the former existence of a marginal basin to the northeast of the North Island, and of the same age as the Tasman spreading basin. Was it backarc to something, and if so what? Was it simply an older part of the South Fiji Basin? Was it a failed arm pointing to a triple junction somewhere to the northwest? Has it all subsequently been subducted, or is it lurking in the Norfolk Basin? Did it acquire its metamorphism (Black, 1989) in the Vening-Meinesz 'fracture zone' or in another fracture zone/transform since lost? Was it downlapped by New Zealand-derived sediment, as claimed by Brook (1989)?

Late Eocene to Oligocene Marginal Basins

There are two of these; the Emerald-Solander Basin to the present southwest of New Zealand and the South Fiji Basin to the present north. The Emerald-Solander is linked with the development and eastwards extension of the Southeast Indian Ridge towards southwestern New Zealand (Kamp, 1986), and was later transected by the Miocene convergent plate boundary. The South Fiji appears to have been an independent spreading system, but as noted above may have linked with the Emerald-Solander via the Challenger Rift system. As presently located, the South Fiji is backarc in position with respect to the Tonga-Kermadec arc. However, the status of that arc in Oligocene time is in doubt - ODP hole 841 on the mid-slope forearc terrace penetrated a section back to late Eocene, but most of the Oligocene is missing (G.C.H. Chaproniere, written comm.), and very few rocks of Oligocene age have been recovered during dredging on the Tonga arc (Chaproniere in press). Thus while plate convergence was undoubtedly taking place in the region during the Oligocene, the Tonga arc may have been a mainly transcurrent boundary, and its relation to the South Fiji spreading system may have been similar to that between the Hunter Fracture Zone and the North Fiji Basin today.

Related questions include: where was the Australia/Pacific plate boundary to the north of New Zealand during the Oligocene? Was it indeed a Tonga-arc transform? If so, how did it translate to the Challenger Rift? What caused the synchronous inception of voluminous arc volcanism on the Tonga arc and in northern New Zealand about 23 Ma? On the global scene the only changes at that time were a slight clockwise shift in the trajectory of the Australia Plate (Gordon and Jurdy, 1986) and a barely perceptible bend in the Hawaiian-Emperor and Louisville hotspot chains on the Pacific Plate (Lonsdale, 1988).

Miocene Plate Convergence

The early results of the new subduction regime in the north of New Zealand are quite well constrained (papers in Spörli and Kear, 1989). Much of the late-Cretaceous-to-late-Oligocene Pacific passive margin sequence was compressed and uplifted. In the earliest Miocene it slid south and southeastwards as a stack of nappes following the diverticulation principle – youngest rocks form the lowest nappe. The resulting allochthon covered a large area, and was subsequently separated by late Neogene tectonic activity (discussed below) into the Northland and East Coast Allochthons (Hayward *et al.*, 1989; Moore *et al.*, 1989). One now-dismembered piggy-back basin on the Allochthon contains deep-water sediments and volcanic sediments (Puriri/Wainui basin). Much allochthon material was removed by erosion, especially in eastern Northland, before arc volcanism became well-established along two parallel northwest-trending arcs in the Otaian, c. 22 Ma (Ballance, 1988) (Figure 3).

Apart from basins between the arcs (Waitemata, North Cape), most early Miocene basins line up adjacent to the proto-Alpine Fault transform (Figure 3). Those that were newly instituted (LW, T, M, W, NC, EC on Figure 3) share some common features, principally rapid initial subsidence to bathyal depths during the Otaian stage. Later histories differ, however. The four most closely associated with the arcs (M, W, NC, EC) were uplifted without significant compression around 15 Ma, at roughly the same time as activity ceased on the western Waitakere arc. The Taranaki Basin (T) was compressed (from present-day east) at an ill-defined time in the later Miocene (Spörli, 1988) to form a foreland-type basin (Stern and Davey, 1990). Further south the Little Wanganui Basin was also compressed from the east in the Pliocene (Neef, 1982). The history of the South Island basins, including the Moonlight Tectonic Zone (Norris *et al.*, 1978), accords closely with the opening-and-closing cycle typical of strike-slip pull-apart basins (Reading, 1980). The rapid early subsidence of the North Island basins (e.g. Ricketts *et al.*, 1989) raises the question of whether there was strike-slip influence in those basins, also. The transform system responsible for these basins (Figure 3) did not correspond exactly with the present-day Alpine Fault, which may thus be a late feature, responsible for the growth of South Island mountains in the Pliocene (v. Cutten, 1979).

Big questions remain in the north. What was the tectonic relationship between the two northwest-trending active arcs (Figure 3) in the early Miocene? How did they relate to the northeast-trending Colville/Kermadec arc, which is known to have been active in the mid-Miocene? Where is (are) the forearc(s) related to the New Zealand arcs? At present there is no ready answer to the first two questions, but there may be one to the third. Eastern North Island and Marlborough comprise a forearc accretionary complex spanning the Neogene (Pettinga, 1982), but the presently-adjacent arc (Taupo Volcanic Zone) is probably little more than one million years old (Wilson *et al.*, 1984). This mismatch is equalled in northwestern North Island where the arcs span the Neogene but an adjacent forearc terrain is not to be found. Parsimony then puts eastern North Island adjacent to Northland/Coromandel during the Miocene, because the latter have not rotated, whereas many parts of the former have rotated clockwise by up to 60 degrees (Walcott, 1987) (Figures 3 and 4).

Where, then, were the forearc basins of the Miocene arc-trench system? In eastern North Island they may comprise the onland basins north of Hawkes Bay (Spörli, 1988). However, the continued trenchward gliding of Neogene bathyal flysch sediments here (Kenny, 1984, 1986) may indicate that this is also a trench-slope sequence like that south of Hawkes Bay (Pettinga, 1982). Thus any Miocene forearc basins may have been destroyed during the dextral displacement of eastern North Island discussed below. Could remnants survive along the Vening-Meinesz and North Island Shear Zones?

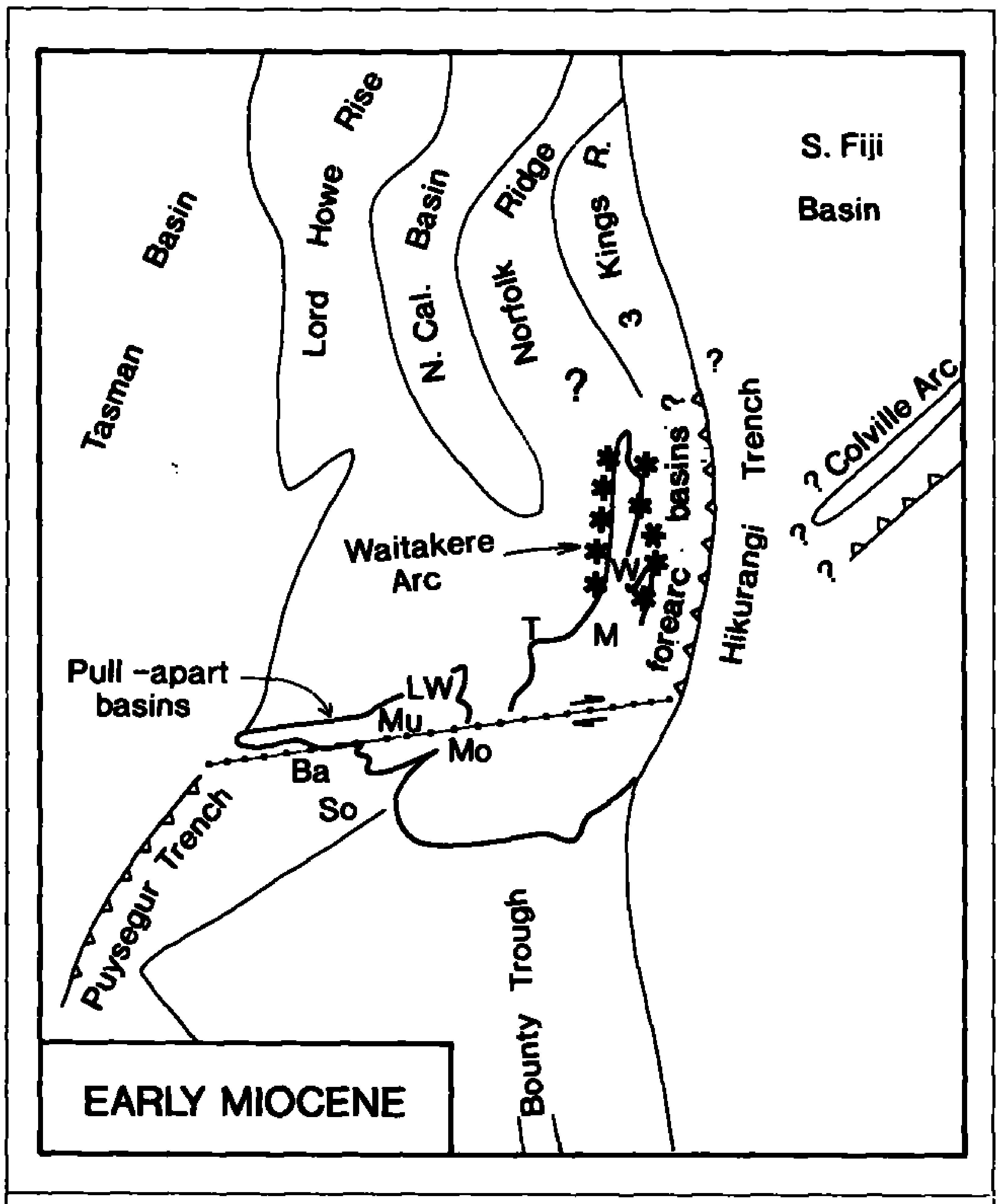

Figure 3: Reconstruction of the New Zealand region for the early Miocene. Line-and-dot symbol is the proto-Alpine Fault transform. Shaded area is the known accretionary complex.

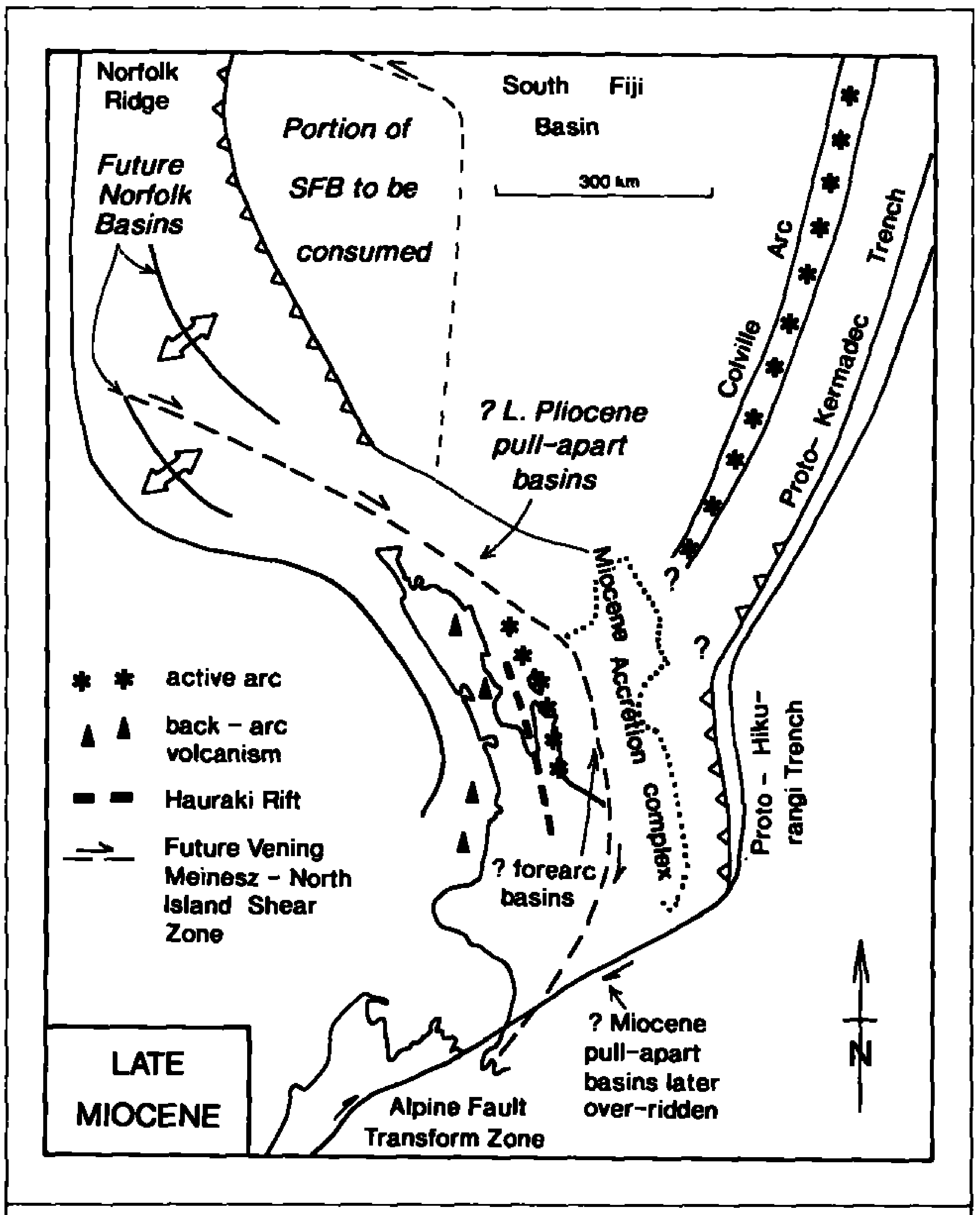

Figure 4: Reconstruction of the New Zealand region for the late Miocene. Dashed line is the future Vening-Meinesz/North Island Shear Belt.

Where, also, were Miocene back-arc basins? None have been identified yet, but it is known that the extensional block-fault and backarc basaltic volcanic regime typical of the late Neogene in the northern North Island dates back to the late Miocene (Nelson *et al.*, 1988; I.E.M. Smith, pers. comm.). Perhaps the backarc regime, being in a continental crust environment, was/is a diffuse region of extension and volcanism, and there were/are no discrete basins, apart from the Hauraki Rift, as argued by Hochstein and Ballance (in prep). Is there a back-arc element in the Norfolk and New Caledonia Basins?

At the other end of the Miocene plate boundary the Solander Trough is backarc in position to the Macquarie arc. It may be older and part of Kamp's (1986) Challenger Rift or Norris *et al.*'*s* (1978) Moonlight Tectonic Zone, in which case there could be Paleogene or Miocene basin fills in it. Does the Paleogene passive margin sequence extend down its eastern margin?

A major consequence of renewed convergence across New Zealand in the early Miocene was uplift and the development of regressive depositional systems from the mid-Miocene onwards. A number of these were coal-bearing (Crosdale, in prep.).

Pliocene Re-organisation of the System

The mismatch between eastern and northwestern North Island has already been mentioned. The corollary of that mismatch is the postulation that eastern North Island has undergone a substantial dextral displacement and clockwise rotation during the Pliocene along the Vening Meinesz 'fracture zone' and North Island shear belt (Figure 4). Parallel changes include:

- the Coromandel arc became extinct;
- the Havre Trough opened;
- the Kermadec arc extended southwards into the Taupo Volcanic Zone;
- the Kermadec Trench linked up directly with the Hikurangi Trough;
- increased compression across the obliquely convergent boundary resulted in the inception of the Alpine Fault sensu stricto and the uplift of axial mountains, first in the South Island 4-5 Ma, and later in the North Island (<1 Ma);
- formation of new forearc basins (from the north, Raukumara Plain, Hawkes Bay, Ruataniwha Plains to Palliser Bay);
- formation of a major cross-structure linking the new South Wanganui Basin with Hawkes Bay (Spörli, 1988);
- marked uplift of the accretionary complex, caused perhaps by underplating of increased quantities of sediment shed from the newly rising Southern Alps via the Hikurangi Trough, or by subduction of the enigmatically shallow sea floor presently entering the Trough.

Basin-wise, the main possibilities to emerge from the above scenario concern pull-apart basins along the Vening Meinesz-North Island shear zone. Were the two Norfolk Basins produced by pull-apart at the end of that shear, as Figure 4 suggests?

Conclusions

This brief review, which could be described as 'all fun and no responsibility', has highlighted the fact that at all periods during the last 100 million years there are many uncertainties about what we do have, what we do not have, what we ought to have, and what we might have, in the way of sedimentary basins. The message to basin and hydrocarbon seekers is clear—let not your thinking be blinkered by preconceptions.

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