THE EAST COAST: AN OLD CHALLENGE WITH NEW PROSPECTS

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Abstract

Serious petroleum exploration in the East Coast area started in 1884, and has continued in spurts since then. Present day explorers face good prospects with most of the essential ingredients for an oilfield present.

The 350 or so gas seeps, oil seeps, and oil-impregnated formations are distributed throughout the East Coast, from near East Cape to southern Wairarapa. Their distribution closely parallels that of the Cretaceous to Miocene source rock sequences. The gas is dominantly thermogenic and the oil in the seeps is generally mature, although derived from several source regimes.

The East Coast offers a range of good structures of varying intensites and in several distinct provinces. Good exposure allows surface mapping to enhance seismic interpretation.

The prospective stratigraphy is dominantly marine, and consists of Aptian to Campanian passive and active margin proximal to distal sediments overlain by a thinner Late Cretaceous to Oligocene passive margin distal sequence, succeeded by very thick (3 - 7 km) Miocene to Pliocene proximal to distal active margin sediments. The Neogene sequence was deposited during initiation and development of a wrench-compressive plate boundary regime, with significant pulses of rapid sedimentation in the middle and late Miocene.

Most of the sequence is fine-grained, although paleoshorelines with potentially attractive sandstones are discernible at various levels. Other good reservoir prospects include thick-bedded submarine fan sandstones of Oligocene to Pliocene age, porous Pliocene limestones, and fractured Upper Cretaceous and Oligocene shale and limestone.

Introduction

The North Island's East Coast (referred to simply as "The East Coast") has a number of features making it highly attractive for oil exploration. These basic factors have led to an active programme of exploration dating back to 1884, with pulses of well drilling in the early 1900s, during the 1930s, and during the 1970s. To date only 38 wells have been drilled, including many shallow holes sunk near seeps in the period from 1884 to 1920.

This paper aims to review key features of the geology of the East Coast as they relate to petroleum prospects of the region. As considered here, the "East Coast" comprises the area from East Cape in the north to Cape Palliser in the south. The onland part is 520 km long (southwest to northeast), and 40 to 100 km wide. The prospective offshore parts (down to 200 m water depth) add a strip generally 20 to 50 km wide, but in places slimmer or much broader.

The positive features of the East Coast include:

(i) good quality potential source rocks at two or more levels in the sequence (Paleocene and Lower-mid Cretaceous);
(ii) rapid late burial by a thick (generally 4-7 km) Miocene to Pliocene sedimentary wedge;
(iii) plenty of structure, and a favourable wrench-compressive structural regime;
(iv) hundreds of gas seeps, several oil seeps, and dozens of sites with oil-impregnated formation. These are widespread regionally, and correspond to the distribution of probable source rocks; and
(v) various paleogeographic conditions favourable to reservoir.

Factors which have (rightly or wrongly) discouraged explorers in the past have been:

(i) lack of adequate reservoir, or good reservoir too high in the sequence;
(ii) structure too complex to be worth considering;
(iii) Eocene bentonites which compound structure and deaden seismic;
(iv) inability to match oil to source; and
(v) lack of knowledge about the geology of the whole area.

Summary of Stratigraphy

To aid the discussion of problems, key features of the stratigraphy of the East Coast basin are given below. There are three distinct tectono-stratigraphic phases in the East Coast; firstly a slightly mobile suite of Lower to late Upper Cretaceous sedimentary rocks deposited on the Gondwana margin; secondly a passive margin sequence extending from latest Cretaceous to Oligocene in age; and thirdly a sequence of the active forearc, with very thick marine sediments of early Miocene to Quaternary age (Figure 1).

Lower to Upper Cretaceous

Much of the Urewera Group greywacke in Raukumara Peninsula is Early Cretaceous in age (Wilson *et al.* 1988),

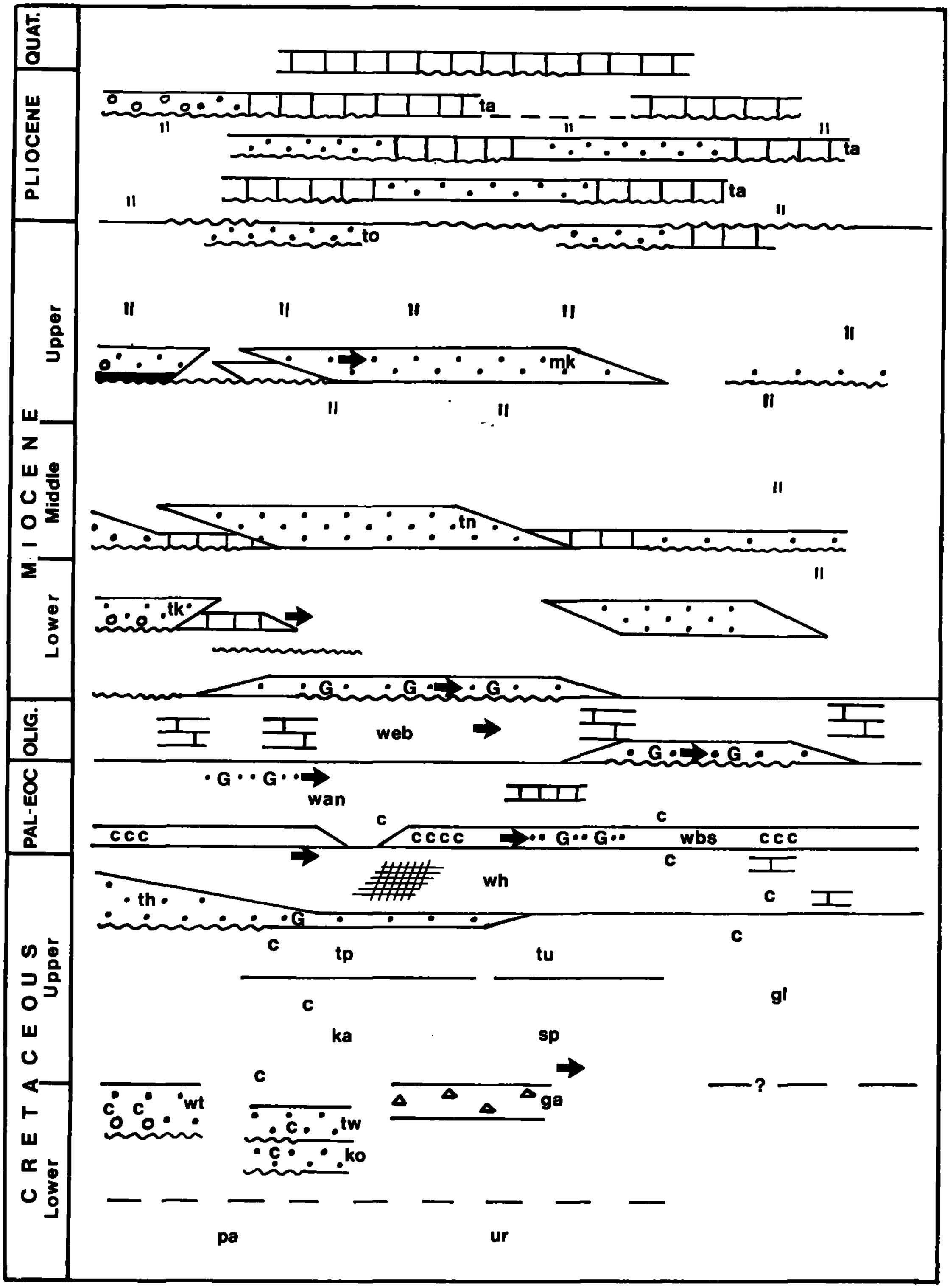


Figure 1: Generalised stratigraphy of the East Coast, emphasizing potential reservoir and source formations. Arrows indicate formations which are oil-impregnated in parts of the basin. The left of the figure represents the west or northwest, and the right is the east or southeast. Various formation names omitted. Unconformities indicate erosion beneath wavy line to varying extent. Cretaceous and Paleogene largely after Moore et al. (1986, 1989); Neogene compiled from the author from original work and various sources. Key to abbreviations: c: carbonaceous G: glauconitic ga: Gentle Annie Formation gl: Glenburn Formation ka: Karekare Siltstone ko: Koranga Formation mk: Makaretu Sandstone pa: Pahaoa Group sp: Springhill Formation ta: Te Aute th: Tahora Formation tk: Takiritini Formation tn: Tunanui Sandstone to: Tokomaru Sandstone tu: Tangaruhe Formation tp: Tapuwaeroa Formation tw: Te Wera Formation ur: Urewera Group wan: Wanstead Formation wbs: Waipawa Black Shale web: Weber Formation wh: Whangai Formation wt: Whatarangi Formation.

and in the south, the Pahaoa Group is probably Albian (Johnston 1980, Moore & Speden 1984). Because of intense structure both of these units are economic basement and are not considered further here.

Lower Cretaceous transgressive formations west of Gisborne include the carbonaceous Te Wera and Koranga formations, which overlie Urewera Group unconformably. In the extreme south of the East Coast similar carbonaceous and conglomeratic Whatarangi Formation overlays older basement unconformably (Bates 1969; Moore & Speden 1984). What happens in the intervening 350 km is unknown because of younger cover, but it is an interesting question worthy of some thought.

Succeeding Lower to Upper Cretaceous units are dominantly marine, and include the Springhill, Karekare, and Glenburn formations (and other formations not listed here), succeeded by the sandier Tapuwaeroa and Tangaruhe formations (and others). The Tahora Sandstone forms thick deposits of shallow transgressive facies near the western margin of the East Coast basin around Lake Waikaremoana, although it becomes thinner and more glauconitic northwards (Isaac *et al.* 1991). It is also concealed by younger rocks eastwards.

Upper Cretaceous to Oligocene

Because of relatively stable conditions, the various formations of this period are recognisable throughout the East Coast, with minor local lithological variation.

The Upper Cretaceous to Lower Paleocene siliceous shale of the Whangai Formation is widespread over the whole of the East Coast, and is almost everywhere succeeded by the thin (10-50 m) but very carbonaceous and sulphurous Waipawa Black Shale of Paleocene age (Moore 1988, 1989). Most field geologists consider the Waipawa Black Shale to be the obvious source rock for the East Coast, but presently available analytical work does not favour this formation.

The Upper Paleocene to Eocene Wanstead Formation consists dominantly of calcareous mudstone, in places carbonaceous near the base, and bentonitic towards the top. It is overlain by the widespread and highly calcareous Weber Formation, of generally deep-water depositional facies. The Weber Formation is in a few places more crystalline and fractured in outcrop.

Miocene to Quaternary

The East Coast is characterised by Miocene mobility, with basins developing rapidly and locally, in stark contrast to the stable conditions evident from Late Cretaceous to Oligocene. In a few places, the sedimentary record indicates submarine relief in the Oligocene, but generally the major change occurred at the start of the Miocene.

The beginning of the Miocene saw a substantial change in the tectono-sedimentary environment, with rapidly subsiding local basins and an abundant supply of dominantly fine-grained sediment. Rhyolitic volcanics added significantly to the clastic sediment supply at most levels of the Neogene, but are particularly important components of Upper Miocene and Pliocene rocks.

Most of the Miocene sedimentary sequence consists of deep-water massive mudstone, mudstone with thin sandstone interbeds, or thin-bedded turbiditic alternating sandstone/ mudstone. However, there are important exceptions.

Submarine fans derived from the west and consisting dominantly of fine sandstone formed at various places along the basin axis, and some reached several hundred metres in thickness. These will be discussed in more detail below in relation to reservoir. The more important formations include the Takiritini Formation in the south, Mid-Miocene Tunanui Formation north of Hawke Bay, and the Mid-Upper Miocene Makaretu Sandstone southwest of Gisborne. There are many unnamed units equally as important.

Definite non-marine Miocene beds are known only in the Upper Miocene in Wairarapa in the south of the East Coast, where a transgressional sequence consists of conglomerate, lignite and shallow facies sandstone. Shallow marine deposits of Lower, Middle, and Upper Miocene age are more common, and tend to be more prevalent towards the west of the East Coast basin (although this is not universally true).

Major breaks in the marine Miocene sequence are present at several horizons, but are often only detectable as gaps in the elsewhere more complete biostratigraphy. For example, there are large gaps in the Lower Miocene, and an angular unconformity within the very thick Upper Miocene around Gisborne (Francis 1988). The Lower Miocene and much of the mid-Miocene is missing in coastal southern Hawkes Bay (Francis *et al.* 1987) and in Hawke Bay-1 well (Hornibrook 1976); in both places Oligocene is overlain directly by mid-Miocene sandstone. In the intervening synclines, a more complete Miocene sedimentary pile is present, but with breaks in different parts (Francis 1990a).

A general shallowing trend occurred around the beginning of the Pliocene, and a major unconformity is often present at or near the Miocene-Pliocene boundary (Francis & Scott 1987). Deposits of Pliocene and Lower Quaternary age consist mainly of siltstone with intervals of calcareous sandstone and barnacle-plate coquina limestones, and vary in thickness from 500 to 2000 m. The limestones are generally termed "Te Aute", whether as a facies name (Beu et al. 1980) or group name (Harmsen 1985). Non-marine Upper Quaternary silts, lignites and clays generally succeed the Lower Quaternary marine rocks.

Geological Solutions to Perceived Problems

There are more encouraging answers to some of the problems given above. They will be discussed in turn. A summary of the stratigraphy of the East Coast region showing potential reservoirs and stratigraphic position of oil impregnations is given in Figure 1.

Reservoir Characteristics

A review of reservoir in the northern East Coast prospects was presented by Duff (1990) at the last Petroleum Exploration Conference. Additionally, encouraging results have been reported from the Upper Cretaceous Tahora Sandstone west and northwest of Gisborne; Isaac *et al.* (1991) report 22 % porosity and 112 md permeability from a single sample.

Pick (in Haw 1959a) records porosities of 18-28 %, with horizontal permeabilities of 6 to 198 md from only four samples from the Upper Cretaceous Tapuwaeroa Formation in the Ruatoria area, north of Gisborne.

Fractured reservoir is a distinct possibility in the upper Cretaceous to Paleocene Whangai Formation; Duff (1990) noted log-derived porosities of up to 30 % in wells drilled near Ruatoria. Many outcrops of Whangai Formation in complex, almost diapiric cores north of Gisborne are pervasively fractured.

Greensands in the Paleocene to Eocene sequence (upper Whangai Formation, Waipawa Black Shale, and Wanstead Formation) around southern Hawkes Bay and Wairarapa are oil-saturated in many localities, and are therefore inferred to have some reservoir characteristics. Although often structurally complex in outcrop, some of these could be well situated elsewhere in the basin.

Glauconitic sandstone occurs also in the Oligocene in some places, and on the coast east of Dannevirke it has both a good smell and good visual porosity. Duff (1990) suggested that the glauconitic sandstone or greensands at the base of the Miocene sequence (then considered to be Oligocene) could have reservoir potential in the northern East Coast basin. These sandstones were the target of some old oil exploration wells, since outcrops smell of oil in several places.

Six samples of the Mid-to Upper Miocene Makaretu sandstone from near the Makaraeo Structure (southwest of Gisborne) produced porosities of 14 to 29 %, and permeabilities of 38 to 184 md (Haw 1959b). In the Dannevirke area, oil-impregnated sandstone of Lower Miocene age had porosities of 22-25 % and permeabilities of 42-84 md (Laing 1961).

Logs indicate excellent porosity and permeability (up to 30 % and 2 darcies) in the Pliocene limestones of Hawkes Bay (Katz 1989, Harmsen 1990), and these limestones also exhibit excellent visual porosity. Associated or coeval coarse sandstones of the same age should also be regarded as reservoir targets.

Distribution of Reservoirs

The Upper Cretaceous sandstones of the Tahora and Tapuwaeroa Formations have rather restricted distribution in outcrop, and fringe the northwestern margin of the East Coast. However, thick Miocene beds could conceal southeastern extensions towards the Wairoa Syncline.

The distribution of Paleocene to basal Oligocene glauconitic sandstones and greensands is not well known, but most horizons in this part of the sequence tend to be widespread areally.

The basal Miocene glauconitic sandstone that forms a prominent marker in the onshore Gisborne region could extend some distance east offshore, west into the Wairoa Syncline, and south into Hawke Bay. A correlative is known from Hawke Bay-1 well, and from outcrops in southern Hawkes Bay.

The Mid-to Upper Miocene Makaretu Sandstone outcrops over a significant part of northern Hawkes Bay, and has correlatives to the south in the Hawke Bay-1 well, and in Silver Range Sandstone onshore.

A particularly interesting feature of the poroperm data from the Makaretu Sandstone is that essentially similar lithological assemblages deposited as deep sea fans are repeated at several well placed stratigraphic levels (Lower, Middle, and Upper) of the very thick Miocene, and are widespread regionally: from Wairarapa in the south to Tolaga Bay, north of Gisborne.

Similar sandstones in Taranaki and the West Coast include the Oligocene Tariki Sandstone (de Bock *et al.* 1990), the Mid-Miocene Niagara Sandstone (Matthews 1990) and the Miocene-Pliocene Moki sands (Sissons and Forder 1991).

The Lower Miocene sandstone in the Dannevirke area is part of a suite of shallow depositional facies extending at least 80 km, and it is likely that thicker deposits of similar well-sorted sandstone are structurally well situated nearby.

The Pliocene and Lower Quaternary Te Aute limestones form at least four different sheets of variable thickness (5 m to 150 m thick) in Gisborne, throughout Hawkes Bay, and south to Northern Wairarapa. Outliers at Castlepoint and Cape Turnagain hint at their presence offshore as well. Although these limestones and associated sandstones are relatively high in the sequence, their excellent reservoir characteristics make them favourite exploration targets where there is sufficient seal. Thus the lowermost limestones of this suite (Lower Pliocene) are particularly interesting.

Structure

A major structural boundary marks the western limit of the prospective East Coast basin south of Hawkes Bay: the series of Mokonui, Waewaepa, Oruawharo faults has only thin Upper Miocene and Pliocene cover on basement to its west, but the much more complete Cretaceous, Paleogene and Neogene to its east. Further north, in Hawkes Bay, this boundary is concealed, but roughly defined by wells drilled south west of Napier (Figure 2).

Within the prospective zone, many structures exposed on the surface are too intense to be worth investigation. However, there are certainly areas where structures are quite gentle at the prospective horizons; certainly more gentle than some of the producing structures of Taranaki.

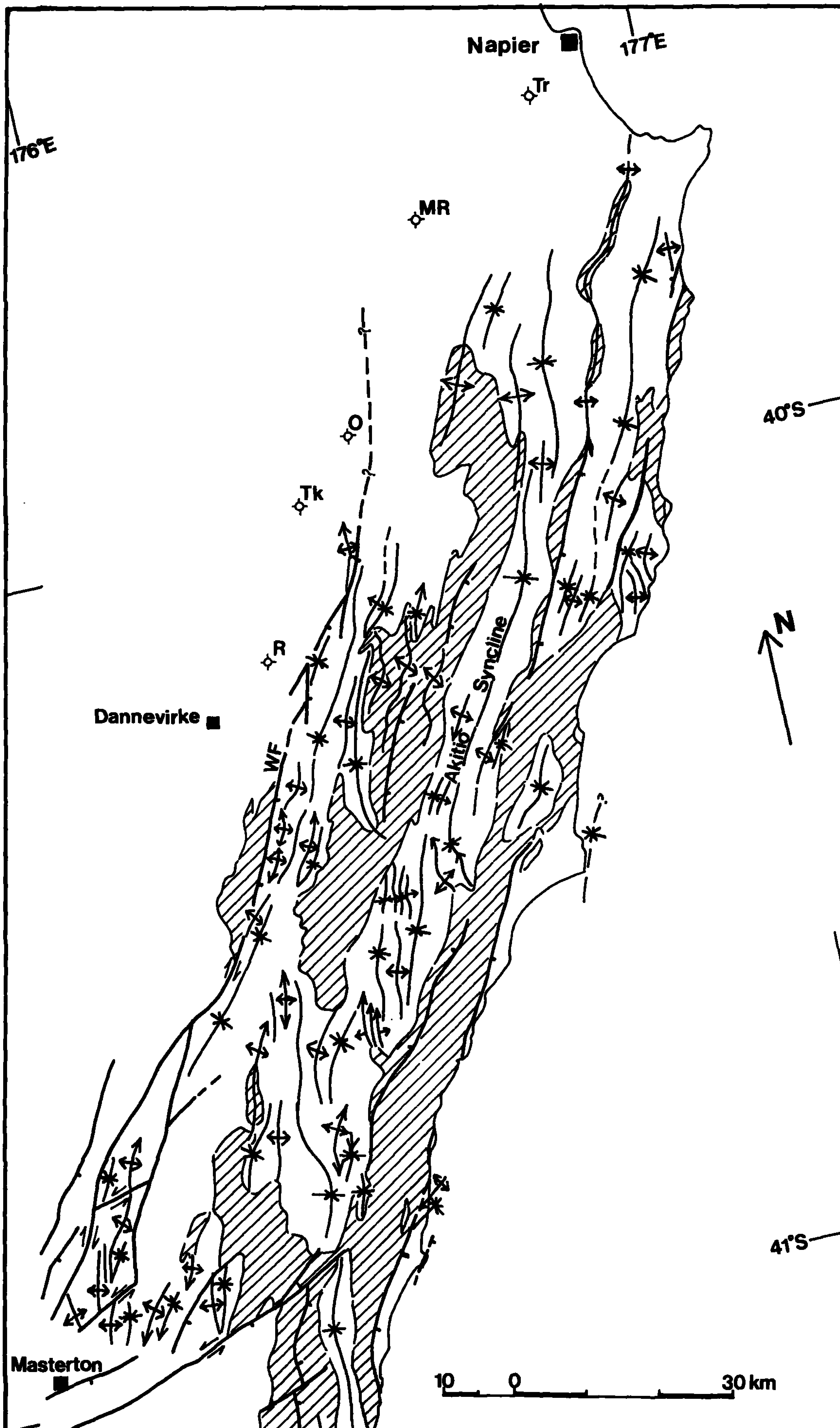
In the Akitio Syncline (a long, synclinorial structure) some quite gentle structures defined by Lower Miocene at the surface are flanked by complex highs to the west and east.

In the onland area north of Hawke Bay and south and southwest of Gisborne, structures are generally gentle in comparison to the structures south of Hawke Bay. North of Gisborne, structures defined by Neogene outcrops vary from very gentle to intense (Figure 3).

Recent seismic work in the Gisborne Plains area (Lennox 1990) has shown some particularly gentle structure as deep as 3 seconds twt, whereas structures northeast of the plains exposed in outcrop are very steep. Therefore the presence of locally complex structures in some regions cannot be used to downgrade a whole area; the pattern is one of reasonably gentle structures between or next to tectonic zones.

Balanced cross-section techniques have been applied to parts of the East Coast by Cutten (1991; this conference), and

Figure 2 (see over): Structure as defined by Miocene–Pliocene strata in the northern part of the East Coast (north of Hawke Bay). Pre-Miocene shown cross-hatched, late Quaternary alluvium cover dotted. Relatively gentle structures are present near East Cape, under the extensive alluvial cover west of Gisborne, and in the extensive area between Gisborne and Wairoa. Althougth there is a predominant NNE-SSW trend, a secondary, probably later, E-W trend is evident in faults and folds. From Francis *et al.* (1991) in the north, and recent unpublished compilations by the author.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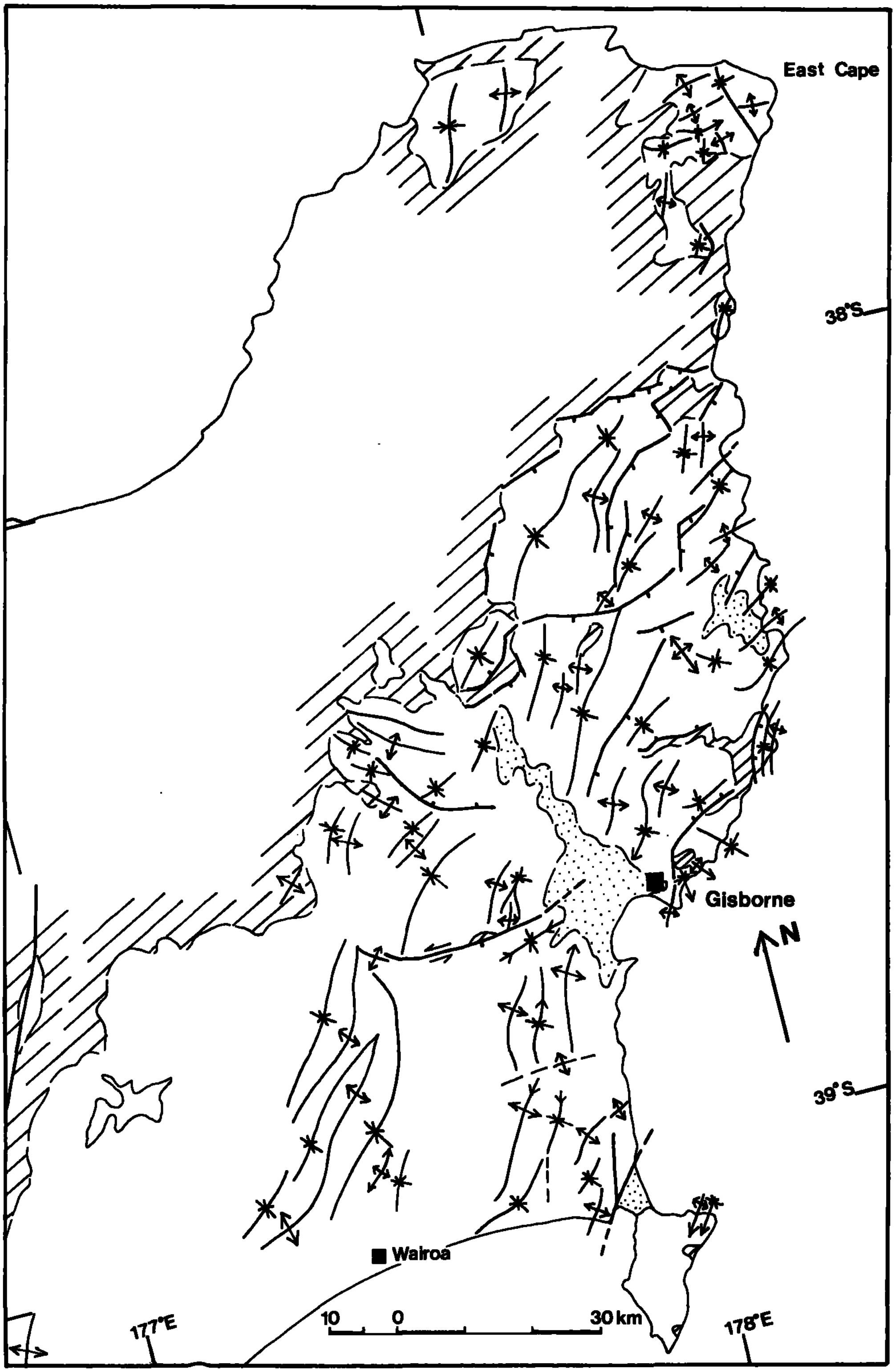

Figure 3: Structure as defined by Miocene - Pliocene strata in the southern part of the East Coast (from south of Hawke Bay to Masterton). Pre-Miocene shown cross-hatched. The major, bounding Waewaepa Fault system (WF; about 10 km east of Dannevirke) forms the western limit to thick Cretaceous-Miocene prospective sequences, but is concealed by Late Quaternary deposits northward. Wells shown are Rakaiatai-1 (R), Takapau-1 (Tk), Ongaonga-1 (O), Mason-Ridge-1 (MR), and Taradale-1 (Tr). Three of these (R, Tk, and O) were drilled west of the fault system, and encountered only Quaternary and Pliocene above basement. The dominant trend is NNE-SSW, with elongate fold axes exhibiting varying plunge directions. From unpublished compilations by the author.

will undoubtedly improve the interpretation of deeper structures. Low-angle thrusts are most likely to have passed through Cretaceous and Paleogene source rock sequences, and therefore will have provided ideal migration pathways.

Structural configuration of the area south of Hawke Bay indicates a dextral-compressive regime, and in Gisborne and possibly northern Hawke Bay there is an extensional regime superimposed on an older compressive pattern. Thus Hawke Bay itself lies in a transitional zone between the two regimes (compare Figures 2 & 3).

Bentonites

The Eocene bentonitic formations are present in widespread localities, but not everywhere. A significant late Eocene or early Oligocene event led to their removal by erosion in many places. The bentonites do deaden seismic energy, but can be tuned out to some extent. Good drilling mud will allow successful drilling through bentonitic formations, if targets are that deep.

Oil (and Gas) to Source Correlation, and Maturity

Some work has been done on oil-to-source correlation and maturity of oil and gas, particularly by Jackson and Fry (1982) and Weston *et al.* (1988). Deuterium, carbon, and sulphur isotopes have been used by Lyon (1989), Hirner & Lyon (1989), Hirner & Robinson (1989) and Kvenvolden & Pettinga (1989) to characterise oils and gases from the East Coast, and significant advances are reported at this conference from studies by Johnston *et al.* (1991) on oils, and Lyon *et al.* (1991) on the natural gases.

According to these authors, the Waipawa Black Shale is not the source of oils that were analysed. However, the source is certainly more marine than that of the producing Taranaki fields. There is evidence from the East Coast oils of some variability in the source, and it is possible that Lower Miocene rocks are mature in deeper parts of the basin. Deep weathering of the Waipawa Black Shale could also add to difficulty in obtaining suitable extracts to allow correlation.

Although the source (or sources) have not positively been identified, it is clear that mature oils are widespread in the East Coast, from East Cape in the north to southern Wairarapa in the south.

Gas and Oil Seeps

There are about 250 gas seeps in the East Coast, at least four major oil seeps, and about 40 localities where formations (mainly porous sandstones, but also some fractured formations) are impregnated with oil (Francis 1990b). The extent of these localities over the region is impressive, and they coincide exactly with the distribution of the source rocks. The Hawkes Bay region has fewer seeps, but this is mainly because of thicker remaining cover. Good oil or gas indications are present north, west, and south of Hawkes Bay. The present phase of exploration is likely to reveal more gas and oil seeps.

State of Knowledge

Some effort at a regional understanding of the East Coast basin and its evolution has been made by various workers, and the state of knowledge of the area is now much better, and improving. A new lithostratigraphic 1:250000 geological map of the northern East Coast has been compiled by Moore *et al.* (1989), and other maps are being prepared by the author, and by others.

Comparison with Taranaki

Many explorers and geologists active in New Zealand are familiar with the geology of Taranaki, so much so that if an area does not have some of the characteristics of Taranaki, it tends to be a reason for downgrading. For example, one senior geologist who had worked extensively on New Zealand's West Coast once commented to me that there would never be any oil found in the East Coast because there was no coal there!

In the East Coast, there are many interesting comparisons to be made with Taranaki, and these are summarised below:

(i) a general paucity of coal measures and associated paralic sandstones in the East Coast (exceptions: Lower Cretaceous in the north and south, and upper Miocene in the south);
(ii) good source rocks (or good potential source rocks) with a distinctly more marine influence than the coal sources of Taranaki; sources could be Lower Cretaceous, Upper Cretaceous-Paleocene, or a mixture. The Paleocene Waipawa Black Shale appears to be the best source rock, and it is also possible that the Miocene is mature in parts of the basin;
(iii) good surface exposures, enabling regional mapping, sampling and analysis of most of the sequence;
(iv) relatively high topographic relief, therefore relatively difficult country to get good seismic data from (unless aided by surface mapping);
(v) a very thick (up to 7 km measured stratigraphically) Neogene sequence; and
(vi)reservoir potential in Cretaceous nearshore marine sandstones, Oligocene glauconitic sandstone, Miocene submarine fan sandstones, Pliocene coquina limestones and sandstones, and possibly Cretaceous-Paleocene fractured shale.

Conclusions

The East Coast is a relatively unexplored, highly prospective basin. Factors which have in the past discouraged petroleum prospecting, particularly the perceived lack of reservoir, are unlikely to be a problem. The structure, burial history, source rocks, and extent of mature hydrocarbon seeps point to good prospects in both onshore and offshore areas.

The old challenge of the East Coast has now been made more prospective with new and better knowledge of offshore areas, advanced geochemical techniques, an understanding of regional stratigraphy and paleogeography, and refined structural interpretation. Present and future explorers are faced with a combination of prospective features quite different to those on the Taranaki side of New Zealand.

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