# SEAFLOOR SAMPLING AS A WINDOW TO DEEPER STRUCTURE ALONG OFFSHORE ACCRETIONARY SYSTEMS: AN EXAMPLE FROM OFFSHORE EAST COAST, NORTH ISLAND, NEW ZEALAND

I C Wright, K B Lewis
National Institute of Water and Atmospheric Research
Wellington.

B Davy
Institute of Geological and Nuclear Sciences
Wellington

## Abstract

The imbricate frontal wedge of the East Coast, North Island (active since the Early Miocene) forms a complex structural system largely occurring offshore. Obliquely imbricated and thrust-bounded, uplifted, hanging-wall anticlines (many of which have seafloor expression) disrupt the late Mesozoic-Neogene sequence. Within such a tectonic regime, high-resolution seismic reflection data, sidescan sonar, and accurately located shallow seafloor sampling, along the hanging-wall anticlines, provide a relatively inexpensive means of establishing the stratigraphy, structure and organic geochemistry of the usually deeper seismic sequences, where they locally outcrop at the seafloor.

Such a sampling strategy on the continental shelf within Hawke Bay, under contract to New Zealand CQX Limited, has provided relevant data to assess the hydrocarbon potential of PPL 38321. Piston core and dredge material, sited from high-resolution seismic records, sampled a sedimentary sequence at least late Teurian (latest Paleocene) to late Haweran (late Pleistocene) in age. Gas chromatography and scanning fluorescence of these samples indicate significant oil seepage in the region.

Analogous to examples elsewhere, the recent reported occurrence of a "vent fauna" from offshore East Coast suggests the possible low-temperature seafloor seepage of hydrocarbon-enriched fluids in deeper water along faults, and hence provides further scope for seafloor sampling and investigation.

## Introduction

Onshore petroleum exploration normally follows a logical progression of:

- surface mapping and geochemical sampling;
- seismic acquisition and interpretation; and
- exploratory drilling.

In contrast, offshore petroleum exploration, for a variety of reasons, has usually bypassed seafloor mapping and sampling, and initiated more costly programmes of multi-channel seismic acquisition and exploratory drilling. However, in certain circumstances seafloor mapping and sampling can provide important reconnaissance data from which potentially more effective, and hence less expensive, exploratory offshore seismic and drilling programmes can be sited. The intent of this paper is:

- to show that opportunities for seafloor mapping and sampling exist within New Zealand, in particular along the eastern margin of the North Island;
- to give an example of the methods and results from one such survey conducted by New Zealand CQX Limited within PPL 38321 (Figure 1); and
- to highlight future prospects and targets for seafloor mapping and sampling to assess hydrocarbon potential along the eastern offshore margin of the North Island.

Prior to 1988 offshore petroleum exploration along the eastern margin of the North Island comprised principally contract and non-exclusive multi-channel seismic reflection surveying (Thrasher and Cahill, 1987), although one offshore exploratory well (Hawke Bay-1) was drilled in 1976 (Figure 1). Currently, five offshore prospecting licences (Figure 1) are held by three exploration companies.

## Bathymetry and Regional Structure

### Overview

The East Coast of the North Island (the Hikurangi Margin) forms an imbricate frontal wedge associated with oblique westward convergence of the Pacific Plate beneath the Australia Plate since 25 Ma (Lewis 1980; Davey *et al.*, 1986; Lewis and Pettinga in press). The general geometry of the margin is that of an imbricate-thrusted, seaward-thinning wedge-shaped sedimentary basin complex compressed against highly indurated lower Mesozoic rocks of the North

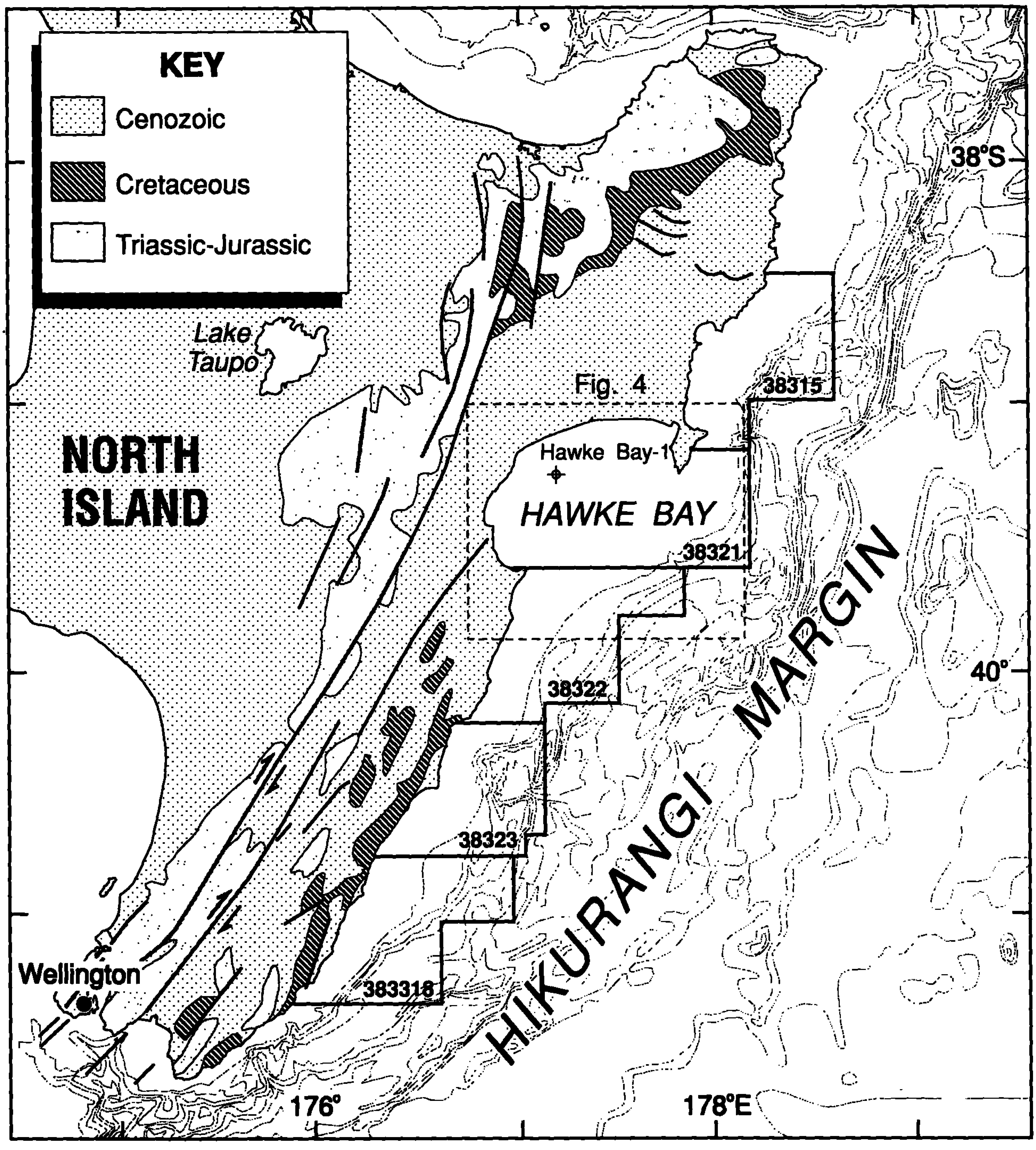


Figure 1: Bathymetry and simplified onshore geology of the convergent Hikurangi margin, East Coast, North Island. Current offshore PPL's (as of September 1991) are shown.

Island axial ranges. The sedimentary succession of the Hikurangi margin is subdivisible into three sequences;

- lower Mesozoic basement;
- pre-subduction upper Cretaceous and Paleogene passive margin sediments; and
- Neogene sediments concomitant with subduction that are either offscraped trench-fill or slope basin in-fill (Lewis and Pettinga, in press).

The Cenozoic successions comprise the predominant part of the imbricate frontal wedge with the subduction-related deformation both disrupting and incorporating sediments younger than the late Cretaceous.

**Bathymetry and Structure**

The Hikurangi margin structure has a marked topographic expression (e.g. Kamp, 1988). Offshore, bathymetric trends (Baldwin and Lewis, 1991; Arron in press) form a complex series of slope-parallel ridges and basins which mark the surface expression of the imbricate thrusting (Lewis and Bennett, 1985). The imbricate wedge of slope-parallel ridges and basins changes both in width and trend along the margin (Figure 2). South of Hawke Bay the wedge is 160 km wide and basement structures trend 070°, whilst at northern Hawke Bay the wedge is only 100 km wide and basement structures trend 030°. Consequently, the margin as a whole has a sigmoidal form in plan, with the structural axes of individual

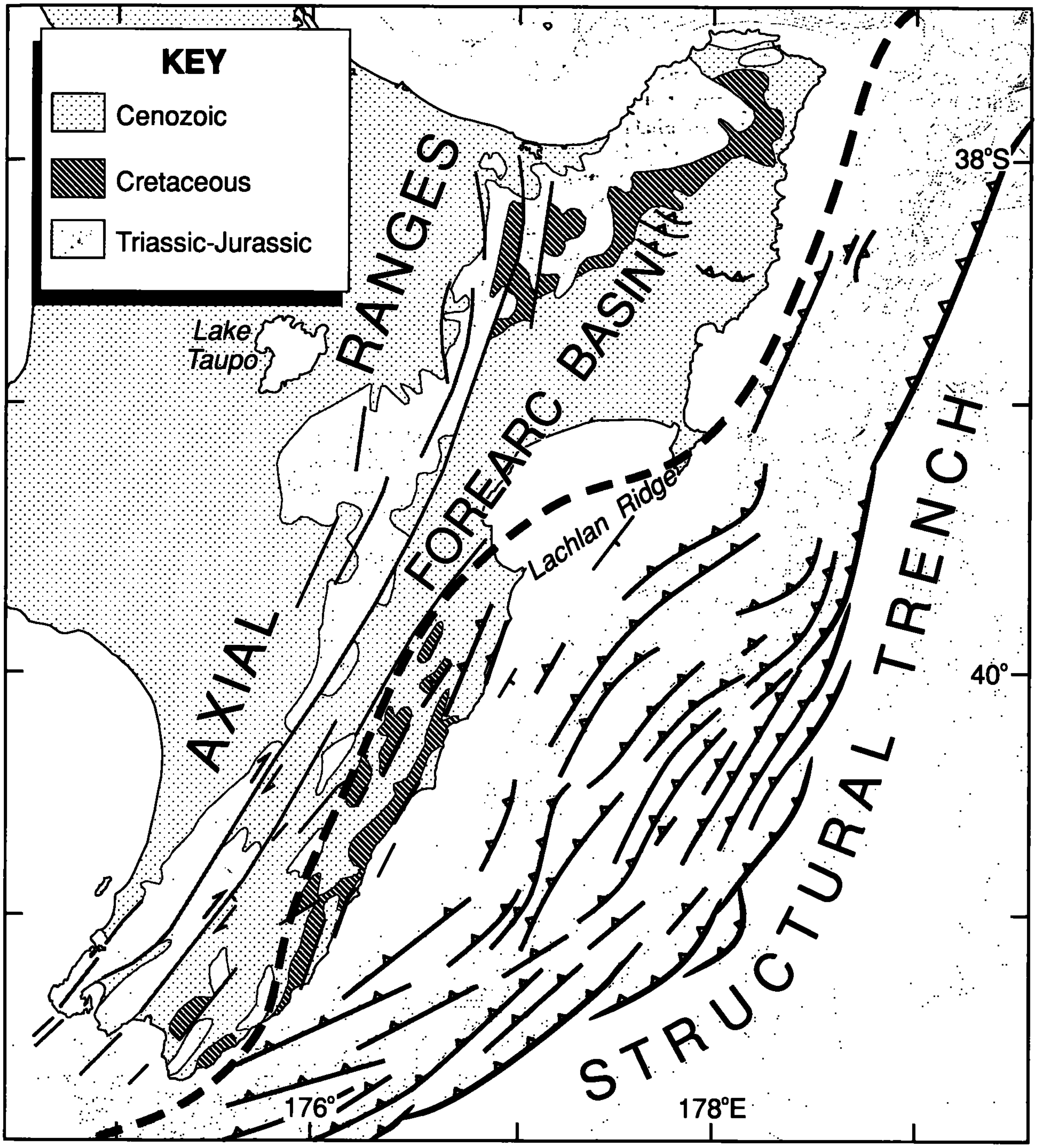


Figure 2: Simplified offshore structure of the Hikurangi margin

ridges and basins generally subparallel to the regional trend. At its widest the offshore margin comprises up to ten sets of seaward-verging, thrust-bounded, anticlinal ridges and intervening landward-tilted slope basins (Lewis and Bennett, 1985; Davey *et al.*, 1986; Lewis and Pettinga, in press), with a further one to three sets onshore (Pettinga, 1982). Individual ridges can be mapped along slope for 50 to 80 km, but failing or plunging ridges create considerable structural complexity. In detail the thrusts are composite features which comprise a series of step thrusts or repeated *en echelon* thrusts (Lewis and Pettinga, in press). However, older seismic sequences forming the core of hanging-wall anticlines are consistently exposed along the bounding thrusts.

**Previous Seafloor Sampling**

Previous sampling along the thrust bounded ridges of the offshore Hikurangi margin has retrieved a considerable suite of rocks (Pantin, 1966; Lewis, 1974; Collen and Vella, 1985; Lewis, 1985). Typical lithologies comprise cemented mudstones, some with plant fragments, limestone, cemented sandstone, chert, and silicified siltstone. Rocks from the lower and mid-slope are early Pleistocene to early Pliocene (and possibly Miocene), whilst rocks from the upper slope and continental shelf have early Miocene to late Cretaceous ages. Small rare offshore islands (e.g. Bare Island) are composed of late Cretaceous rocks. Onshore, anticlinal thrust zones have early Miocene to early Cretaceous cores

(Pettinga 1982). Dredge samples from the thrust zones thus display a general progression of increasing age landward away from the subduction front.

The boundary between the amalgamated pre-subduction upper Cretaceous and Paleogene passive margin sediments, and accreted Neogene sediments, within the imbricate wedge, thus lies offshore. This boundary is considered to lie on the mid to upper slope (Lewis and Pettinga, in press), apparently coinciding with a steep bathymetric scarp. Seismic data show this boundary to be a major thrust. Landward of this boundary thrust, it is generally more difficult to resolve seismic reflection profiles for the anticlinal ridges, due to either steep dips or the development of ridge duplex structures.

**Conquest Survey**

It is this regime of compressional thrust tectonics that dominates the structural setting of the current offshore east coast petroleum prospecting license areas, and in particular PPLs 38321 and 38322 where the Hikurangi margin is the best-developed. The existence of actively growing thrust-bounded anticlinal ridges, where late Cretaceous–Paleogene rocks may protrude through soft sediment overburden, provides an opportunity to sample reflectors as part of a programme of reconnaissance hydrocarbon assessment. Limited offshore stratigraphic control from drillhole data is provided by only Hawke Bay-1 which bottoms at 2305 m below the sea-bed in basal mid-Oligocene strata. Thus there was a need to acquire samples to establish the stratigraphy of the seismic section. Such was the basic rationale of an 11-day, high-resolution seismic and sampling survey of PPLs 38321 and 38322 using the DSIR research vessel *Rapuhia* under contract to New Zealand (CQX) Limited, carried out in 1988.

Since rock dredge sampling is totally restricted to seafloor outcrops, an additional facet of the CQX programme was to core through thin soft sediments on the continental shelf to the underlying consolidated sedimentary sequences using a conventional 6 m long Kullenberg piston corer. Prior to the CQX survey, New Zealand Oceanographic Institute (unpublished data) indicated significant areas of PPL 38321 have older sedimentary sequences with less than 5 m of overlying Quaternary sediments (Figure 3). These areas of thin overburden could potentially be sampled by piston coring.

**High-Resolution Seismic Survey**

A prerequisite of any seafloor sampling programme is to locate potential sample sites and unambiguously tie these sites to particular sequences identifiable within seismic data. For the CQX survey, single-channel high-resolution seismic reflection data, totalling 1205 line km (Figure 4) were profiled to:

- determine the distribution of exposed or near-exposed seafloor outcrops within specific regions of PPL 38321;
- relate the sampled sites to shallow single-channel airgun seismic data which would allow the samples to be tied to subsequently acquired deeper multi-channel seismic data;

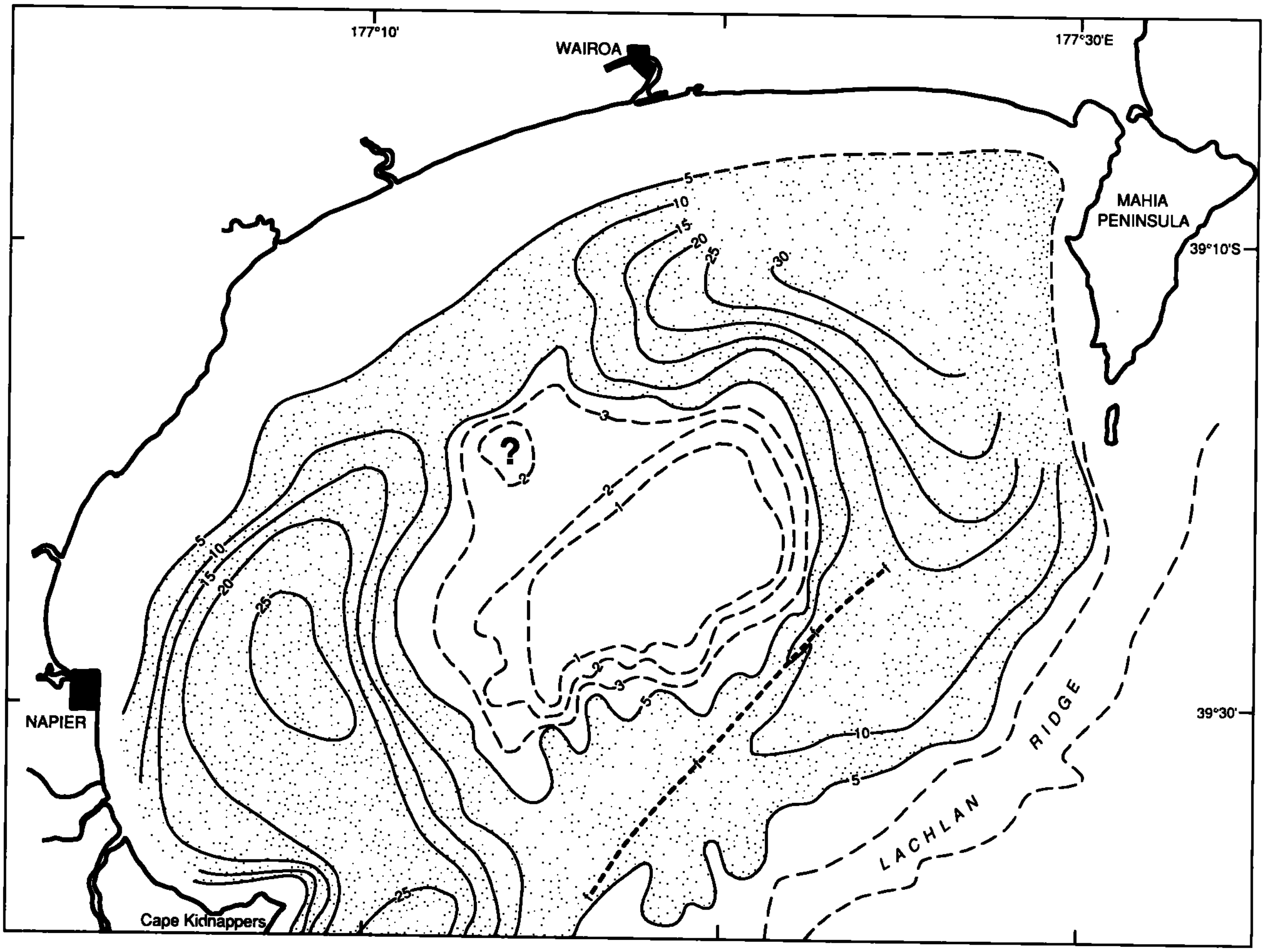


Figure 3: Isopachs (in metres) of late Pleistocene sediments within Hawke Bay.

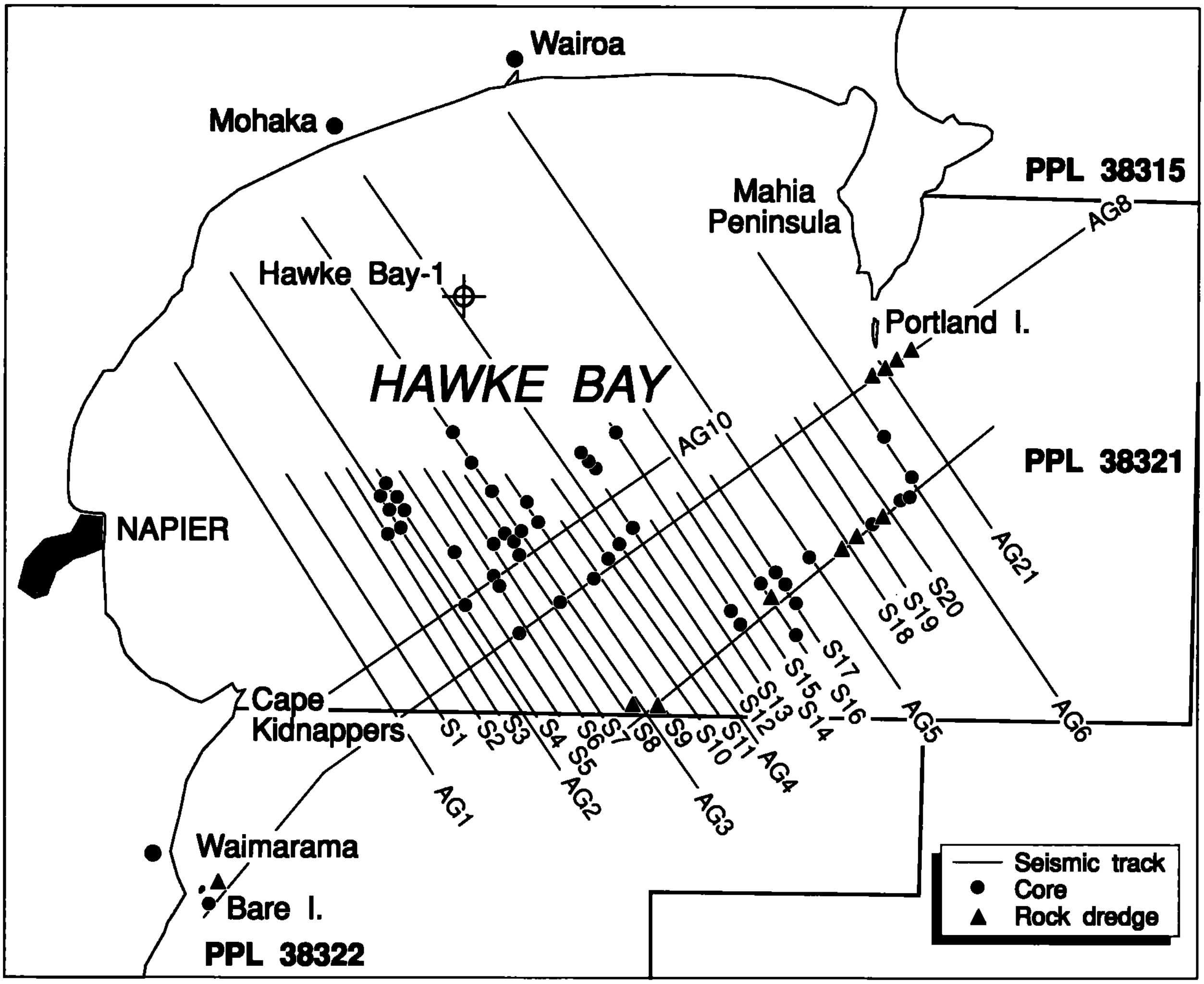


Figure 4: Location of the high-resolution seismic profiles and seafloor samples from the 1988 CQX survey within PPL 38321.

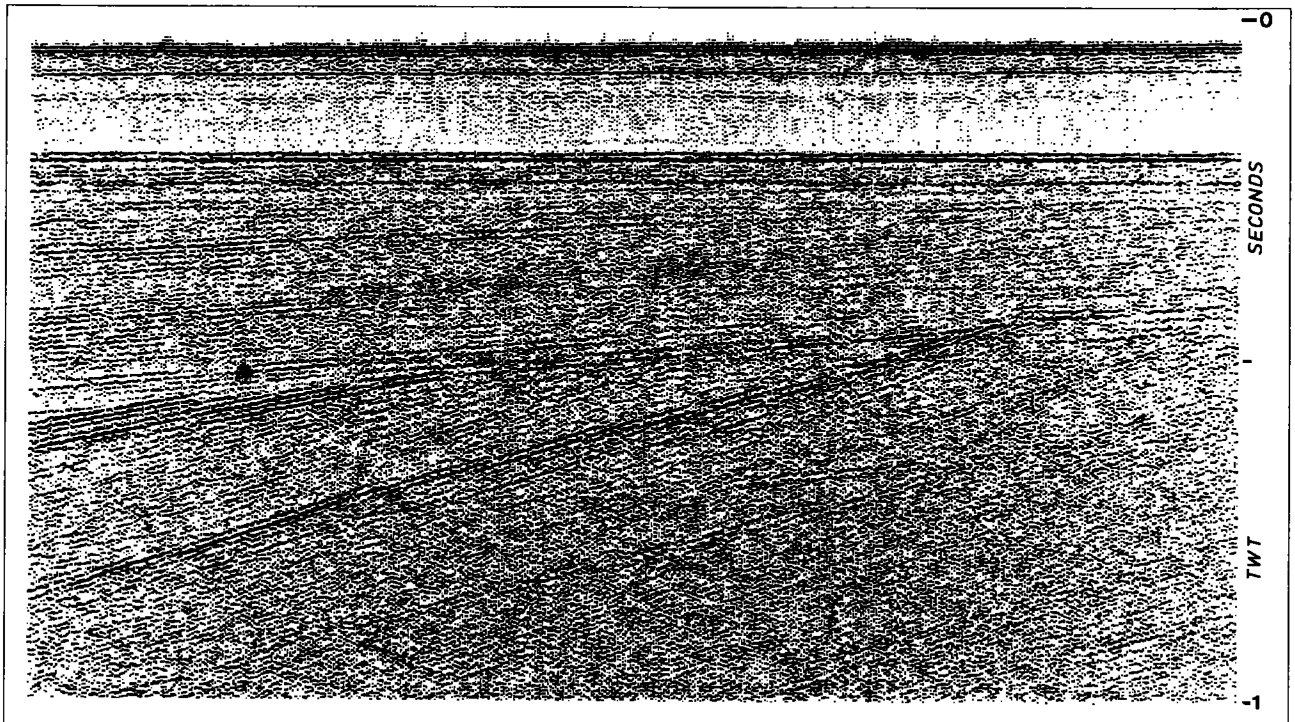


Figure 5: Part of the single-channel seismic reflection data (line AG4). Data have been processed to remove sea and swell motion, the bubble pulse, and seafloor multiples.

- delineate at reconnaissance level the shallow subsurface structure to assist planning of a subsequent phase of multi-channel data acquisition (these data were subsequently acquired in 1990).

Two high-resolution seismic systems, a 3.5 kHz and 40 cu$^3$ air-gun with single channel streamer, were used concurrently to determine the detailed thickness of surficial late Quaternary sediments, and the top 1 second of seismic sequence, respectively (Figure 5). The 3.5 kHz data clearly identify the shallowest sub-surface structure and the seafloor sampling prospects by either rock dredging (Figure 6A) or piston coring (Figure 6B).

**Side-scan Sonar Survey**

Side-scan sonographs, which provide a plan image of the seafloor, were acquired concurrently with the seismic data along survey tracks known to cross extensive seafloor outcrops (i.e. Lachlan Ridge; Figure 7). Sonographs can provide structural and lithological data relevant to hydrocarbon exploration. The strike of both bedding and subsequent deformational structures (i.e. faults and joints) can be clearly identified from the PPL 383231 data (Figure 7A). Such data, if of sufficient quantity, can potentially map surface outcrop patterns and hence the attitude of fold structures. Sonographs can also potentially provide a semi-quantitative ratio of differing lithologies. Again, the PPL 38321 sonograph data can clearly differentiate between massive (?sandy) and thinly bedded (alternating ?silt/sand) lithologies (Figure 7B).

**Biostratigraphy and Hydrocarbon Analysis**

Following interpretation of the air-gun and 3.5 kHz seismic reflection data, seafloor samples (46 cores and 20 rock dredges) were acquired for biostratigraphic and hydrocarbon analysis (Figure 4). Of the 58 samples analysed for fauna, 11 have biostratigraphic (foraminiferal and calcareous nannoplankton) ages older (Table 1) than the surficial late Pleistocene–Recent sediments (Strong *et al.* 1989). These ages are generally consistent with ages of rocks from the upper slope and continental shelf anticlines.

Extensive seepage of hydrocarbon fluids has been documented from the onshore Hikurangi margin (e.g. Kvenvolden and Pettinga 1989). Little data, however, exist from the offshore Hikurangi margin although geochemical exploration of marine sediments can provide a regional indicator to oil or gas generation. Offshore reconnaissance geochemical data, from the immediate vicinity of inferred gas hydrate accumulations (Katz, 1981, 1982), show no evidence of significant gas migration (Kvenvolden 1988). In contrast, hydrocarbon analysis by gas chromatography and scanning fluorescence of the 46 CQX cores, indicate significant oil seepage in PPLs 38321 and 38322 (Texas A&M University Geochemical & Environmental Research Group 1989). Summary analytical statistics and a typical chromatogram are given in Table 2 and Figure 8, respectively. The fluorescence intensity data indicate the presence of medium to high levels of mature aromatic hydrocarbons with fluorescence ratios typical of aromatic

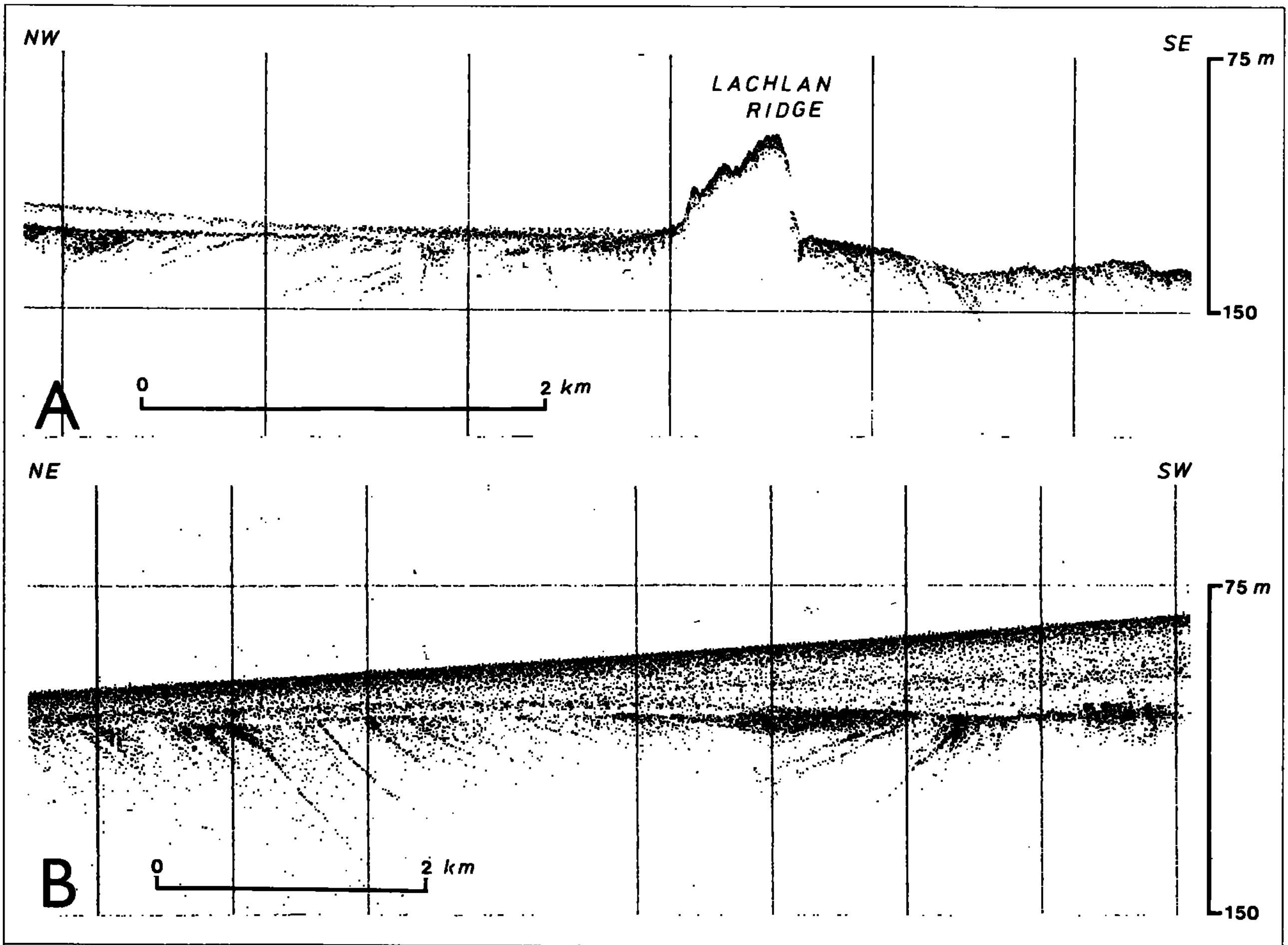


Figure 6: High-resolution 3.5 kHz seismic profiles from (A) across Lachlan Ridge(line S17) and (B) northeast of Cape Kidnappers (line AG10).

mixtures in oil and condensates. These data are important because they:

- show that surface geochemical exploration can be successfully undertaken over New Zealand's offshore sedimentary basins;
- represent the first comprehensive set of hydrocarbon geochemical data from the offshore Hikurangi margin;
- show that, contrary to earlier reconnaissance work, significant oil seepage does occur within the offshore Hikurangi margin, at least within PPLs 38321 and 38322.

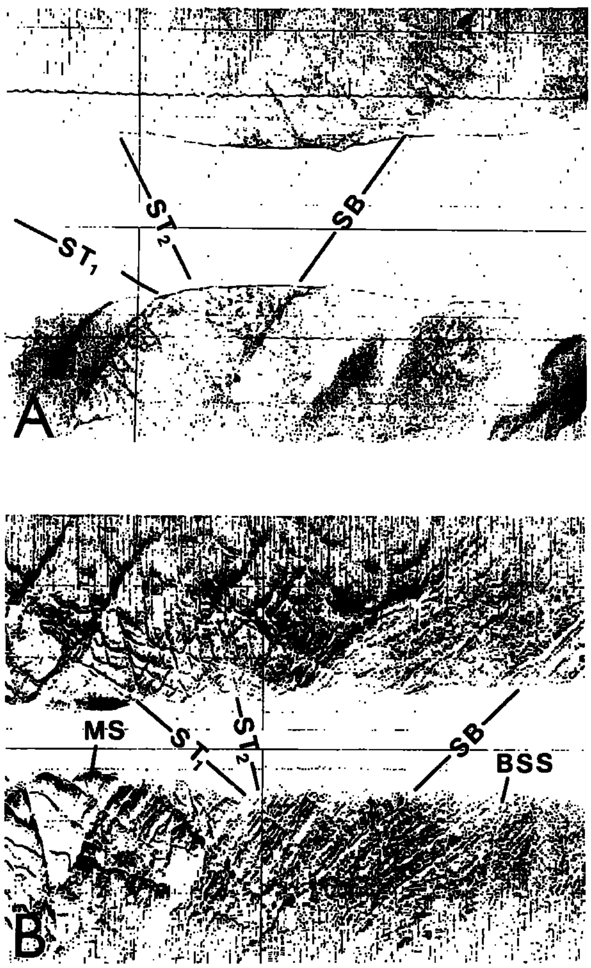


Figure 7: Side-scan sonographs from parts of the Lachlan Ridge; (A) is part of line AG7, (B) is part of line AG8. Across track distance is 100 m either channel, while the along track distance is approximately 1000 m. BSS=Bedded ?sandstone-siltstone lithologies; MS=Massive ?sandstone; SB=Strike of bedding; ST$_1$ and ST$_2$=Strike of two sets of tectonic structures; the relative age of ST$_1$ and ST$_2$ is unknown.

## Future Prospects for Seafloor Sampling

As shown by the CQX survey, future prospects for seafloor sampling for reconnaissance hydrocarbon assessment along the offshore Hikurangi margin are promising. Two broad sampling strategies are possible. The first, in the manner of the CQX survey, is to acquire samples from exposed seafloor outcrops from the growing thrust-bounded, anticlinal ridges and relate this to regional seismic information. This would establish an initial age and lithostratigraphy for the offshore seismic sequences. Such sampling would be best restricted to the upper slope and continental shelf anticlinal ridges which have cores of pre-subduction Paleogene sediments. The second sampling strategy is to acquire surficial sediment samples for hydrocarbon geochemical analysis so as to establish the regional existence, nature and extent of

| Sample | N.Z. Stage | International age |
|---|---|---|
| Dredge 1 | Wo-Wp | early Pliocene |
| Dredge 2 | Wn-Wc | Pleistocene |
| Dredge 4 | Tk-Wm | early Pliocene |
| Dredge 5 | Wp-Wm | late Pliocene |
| Dredge 6 | 1Sl-eTt | mid Miocene |
| Dredge 7 | 1Dt | Late Paleocene |
| Dredge 8 | Sl-Sw | mid Miocene |
| Dredge 10 | Sc-eSw | mid Miocene |
| Dredge 12 | Tt-Tk | late Miocene |
| Grab 6 | 1Lw-ePo | late Oligocene-early Miocene |
| Core 6 | 1Lw-ePo | late Oligocene-early Miocene |
| Core 16 | Wo | early Pliocene |

Table 1: Summary biostratigraphy of pre-Pleistocene CQX samples.

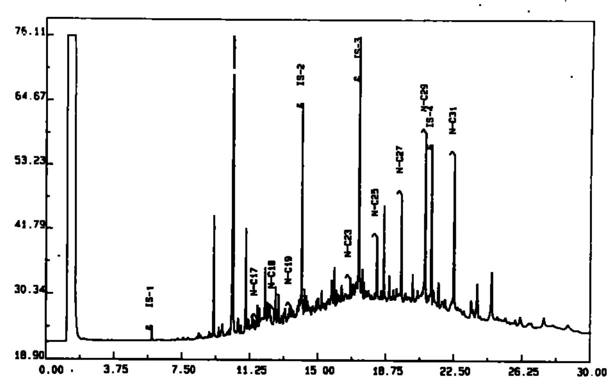


Figure 8: Representative gas chromatogram from analysis of Core 20.

| Statistic | Fluorescence data Max Int | Max Ex | Max Em | R | Total C1 to C4 (ppm) | Total alkanes <N-C23 (ppb) | >N-C23 (ppb) | N-C15 to N-C23 (ppb) |
|---|---|---|---|---|---|---|---|---|
| Average | 633 | 327 | 364 | 1.58 | 10.26 | 433.9 | 795.8 | 1229.7 |
| Minimum | 127 | 310 | 350 | 0.96 | 1.58 | 45 | 138 | 255 |
| Maximum | 1550 | 340 | 380 | 2.65 | 35.23 | 3552 | 3030 | 6582 |

Table 2:Summary hydrocarbon analytical results of CQX samples

hydrocarbon maturation and seepage. Amoco New Zealand have undertaken such seafloor sampling within PPL 38318.

Future sampling for hydrocarbons along the Hikurangi margin may be better sited by recent research on hydrogeologic processes within accretionary systems (e.g. Langseth and Moore 1990). A significant aspect of this research is the recognition that migration and expulsion of fluids from the accretionary system is controlled by thrust faulting which in part leads to venting of fluids along the thrust bounded, seaward flank of anticlinal ridges. The venting fluids are principally admixtures of water and dissolved methane, the latter having both biogenic and thermogenic origins. Some vent sites support a localized, unique chemosynthetic biological community (Lewis and Cochrane 1990). Similar biological faunas have been recently reported from the Hikurangi margin (Lewis and Marshall 1990) and indicate, by analogy, the localised venting of hydrocarbon-enriched fluid occurs along offshore East Coast North Island. It is probable that the chemistry of sediment and water from the seaward flank of the thrust-bounded, anticlinal ridges would provide further insight into the hydrocarbon component of these fluids.

**References**


ARRON, E. in press. Mahia Bathymetry, 2nd Edition. N.Z. Oceanogr. Inst. Chart. Coastal Series, 1:200,000.

BALDWIN, R.P. & LEWIS, K.B. 1990: Cook Bathymetry 2nd Edition. N.Z. Oceanogr. Inst. Chart. Oceanic Series, 1:1,000,000.

COLLEN, J.D. & VELLA, P.P. 1985: Foraminiferal micropalaeontology of rocks from the Hikurangi Margin, New Zealand. In: Lewis, K B. (Comp.) New seismic profiles, cores, and dated rocks from the Hikurangi Margin, New Zealand. New Zealand Oceanographic Field Report 22: 51-53.

DAVEY, F.J., HAMPTON, M., CHILDS, J., FISHER, M.A., LEWIS, K.B., PETTINGA, J.R 1986: Structure of a growing accretionary prism, Hikurangi margin, New Zealand. Geology 14: 663-666.

KATZ, H.R. 1981: Probable gas hydrate in continental slope east of the North Island, New Zealand. Journal of Petroleum Geology 3: 315-324.

KATZ, H.R 1982: Evidence of gas hydrates beneath the continental slope, East Coast, North Island, New Zealand. New Zealand Journal of Geology and Geophysics 25: 193-199.

KVENVOLDEN, K.A. 1988: Hydrocarbon gas in sediment of the southern Pacific Ocean. Geo-Marine Letters 8: 179-187.

KVENVOLDEN, K.A. & PETTINGA, J.R. 1989: Hydrocarbon gas seeps of the convergent Hikurangi Margin, North Island, New Zealand. Marine and Petroleum Geology 6: 2-8.

LANGSETH, M.G. & MOORE, J.C. 1990: Introduction to special section on the role of fluids in sediment accretion, deformation, diagenesis, and metamorphism in subduction zones. Journal of Geophysical Research 95: 8737-8741.

LEWIS, B.T.R & COCHRANE, G.C. 1990: Relationship between the location of chemosynthetic benthic communities and geologic structure on the Cascadia subduction zone. Journal of Geophysical Research 95: 8783-8793.

LEWIS, K.B. 1974: Upper Tertiary rocks from the continental shelf and slope off southern Hawkes Bay. New Zealand Journal of Marine and Freshwater Research 8: 663-670.

LEWIS, KB. 1980: Quaternary sedimentation on the Hikurangi oblique- subduction transform margin. Special Publication of International Association of Sedimentologists 4:171-189.

LEWIS, K.B., 1985. New rock samples and cores from the Hikurangi Margin Geology Cruise 1121. In: Lewis, K.B. (Comp.) New seismic profiles, cores, and dated rocks from the Hikurangi Margin, New Zealand. New Zealand Oceanographic Field Report 22: 37-49.

LEWIS, K.B. & BENNETT, D.J. 1985: Structural patterns on the Hikurangi Margin: and interpretation of new seismic data. In: Lewis, K.B. (Comp.) New seismic profiles, cores, and dated rocks from the Hikurangi Margin, New Zealand. New Zealand Oceanographic Field Report 22: 3-25.

LEWIS, K.B. & MARSHALL, B. 1990: A seep fauna from the slope off Hawke Bay. (Abstract). p 81. in: Programme and Abstracts, Geological Society of New Zealand Annual Conference. Geological Society of New Zealand Miscellaneous Publication 50A.

LEWIS, K.B. & PETTINGA, J.R, in press: The emerging, imbricate frontal wedge of the Hikurangi margin. In: P.F. Ballance (Editor), South Pacific Sedimentary Basins. Sedimentary Basins of the World. Elsevier.

NZOI/VP. 1988: Hawke Bay shallow seismic and bottom sampling survey (PPLs 38321 and 38322), New Zealand. Cruise Report. New Zealand Oceanographic Contract Report.

PANTIN, H.M. 1966: Sedimentation in Hawke Bay. New Zealand Oceanographic Institute Memoir 28. 67p. DSIR Wellington.

STRONG, C.P., SCOTT, G.H. & EDWARDS, A.R 1989. Foraminifera and calcareous nannoplankton from Hawke Bay sea floor samples, PPLs 38321 and 38322. New Zealand Geological Survey Paleontology Report 141.

TEXAS UNIVERSITY GEOCHEMICAL & ENVIRONMENTAL RESEARCH GROUP 1989. Conquest Exploration NZ samples. Fluorescence, rankings, gas chromatograms, calculations and headspace analyses. New Zealand Geological Survey Closed file Petroleum Report 1469.

THRASHER, G.P. & CAHILL, J.P. 1987. New Zealand Geological Survey seismic data catalogue, East Coast Basin, north of 40°S. New Zealand Geological Survey Petroleum Report 1251.

**Acknowledgements**

Thanks are due to the permission and encouragement of New Zealand CQX Limited and American Exploration Company to publish the PPL 38321 survey data. The officers and crew of the RV. *Rapuhia*, and NZOI technical staff, are commended for their professionalism. An earlier draft of the manuscript was read by L. Carter. K. Majorhazi produced the figures and N. Edwards completed the photography.

**Authors**

IAN WRIGHT is a scientist with the New Zealand Oceanographic Institute, DSIR Marine and Freshwater. He is currently researching active submarine tectonism and volcanism within the Bay of Plenty. He holds a Ph.D. in geology from Victoria University of Wellington.

KEITH LEWIS has been employed with NZOI since 1963. He holds a Ph.D. from Victoria University of Wellington. His work has been concerned mainly with tectonic and sedimentary process along New Zealand's active plate boundary between Bay of Plenty and Kaikoura.

BRYAN DAVY is a marine geophysicist with the DSIR Geology and Geophysics. He has a Ph.D in geophysics from Newcastle-upon-Tyne and is involved in most aspects of marine, inshore and freshwater geophysics.