

How good a source rock is the Waipawa (Black Shale) Formation beyond the East Coast Basin? An outcrop-based case study from Northland

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Abstract

The Paleocene Waipawa Formation is a known source of oil in the East Coast and north Taranaki basins. It is likely to be a significant source rock in adjacent basins in Northland and Canterbury and the Great South Basin. To determine the extent and character of the formation in northern Northland, we studied Waipawa-like dark-grey mudstones exposed in Price's and Black's quarries in the allochthonous sequence at Ohia, west of Taipa, and a shore platform exposure in the autochthonous sequence at Whatuwhiwhi, Karikari Peninsula.

Dinoflagellate biostratigraphy shows that the sequence in Price's Quarry is overturned and ranges in age from Late Cretaceous to late Paleocene. Although this age range encompasses that in which the Waipawa Formation was deposited, the distinctive geochemical signature of the formation is not evident in any of the Price's Quarry samples. Instead, the entire sequence is correlated with the siliceous mudstone facies of the Whangai Formation. In contrast, the typically high TOCs and heavy $\delta^{13}\text{C}$ values of the Waipawa Formation are found in petroliferous mudstone exposed in Black's Quarry, 1.5 km to the east. Dinoflagellates confirm a Paleocene age. Although a stratigraphic thickness of 40 m is suggested, it is difficult to confirm due to poor bedding and numerous faults. The formation here is immature (T_{max} 421–427 °C) and high TOC, S₂ and HI values indicate excellent potential for oil generation. At Whatuwhiwhi, the well-bedded Late Cretaceous–Paleocene Waiari Formation includes a lower chert-dominated facies and an upper mudstone-dominated facies. The former has a Whangai-type geochemical signature whereas the latter has a Waipawa-type signature. However, a lack of palynomorphs and almost completely exhausted petroleum potential indicate that the section has been thermally altered to an extent that makes correlation with the Waipawa Formation uncertain.

The Ohia and Whatuwhiwhi exposures are inferred to record distal and proximal deposition, respectively, off the northeastern margin of Northland within the so-called North Slope Basin. The results of this study indicate that good quality oil-prone Waipawa Formation source rock is likely to be present in the sedimentary succession offshore northeastern Northland. However, its thickness is uncertain and it is likely to grade laterally and vertically into organic-lean siliceous facies of the Whangai Formation. Seismic facies mapping and refined paleoenvironmental reconstructions are recommended to better define the extent and quality of this important source rock unit.

Introduction

In order to determine the extent and character of the Waipawa Formation in northern Northland, we have studied the Waipawa-like, dark-grey mudstones exposed in Price's and Black's quarries in the allochthonous sequence at Ohia, west of Taipa, and a shore platform exposure in the autochthonous sequence at Whatuwhiwhi, Karikari Peninsula (Fig. 1). The quarry outcrops are highly deformed,

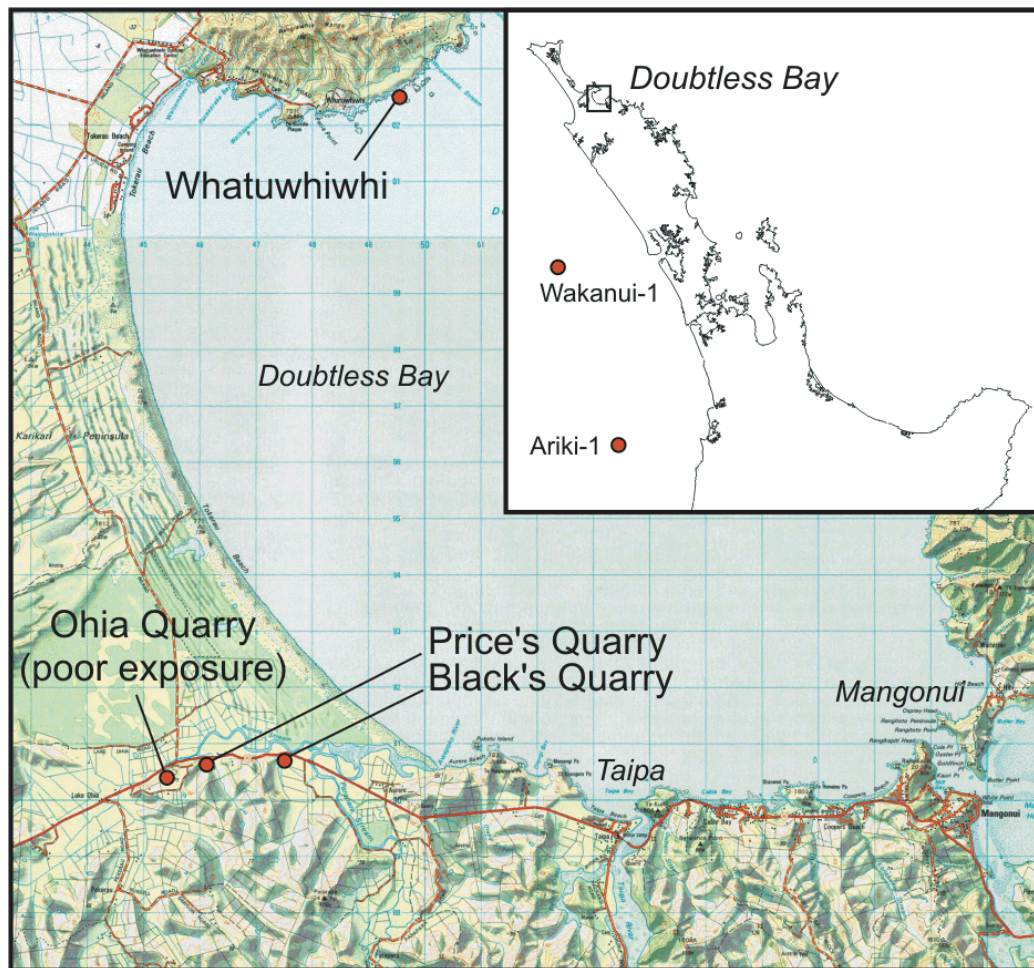


Figure 1. Location of sample sites.

making determination of stratigraphic orientation and thickness difficult. A detailed field survey was undertaken and 90 rock samples were collected from the three localities. Selected samples were processed for palynological and micropaleontological study and for source rock geochemistry (Rock-Eval and carbon isotope analysis).

Biostratigraphy

No age-diagnostic foraminifera or radiolarians were recovered from any samples but age-diagnostic dinoflagellate cysts were recovered from the Price's quarry samples.

Dinoflagellate biostratigraphy shows that the sequence in Price's Quarry (NZ 1:50,000 map grid reference O04/459905) is overturned and ranges in age from Late Cretaceous to late Paleocene (upper Haumurian to upper Teurian). No new age data were obtained for Black's Quarry (O04/475908). Previous dinoflagellate-based age control indicated a late, possibly early late Paleocene age (Wilson in Isaac et al. 1994).

All palynology and micropaleontology samples from Whatuwhiwi (O03/495026) were barren, apparently due to the thermal effects of a nearby intrusion (see below). Previous age control from sparse foraminifera indicate a Late Cretaceous–Paleocene (Haumurian–Teurian) age (Isaac et al. 1988).

Geochemistry

All samples from Price's and Black's quarries and the Whatuwhiwi section were analysed for total organic carbon (TOC) and organic $\delta^{13}\text{C}$ by mass spectrometry in the Stable Isotope Laboratory, GNS Science. All measurements are normalised to VPDB using NIST 123 Bovine Liver (International Standard) and ANU-beet sugar (International Standard) with a precision of $\pm 0.1\%$ for $\delta^{13}\text{C}$. Rock-Eval

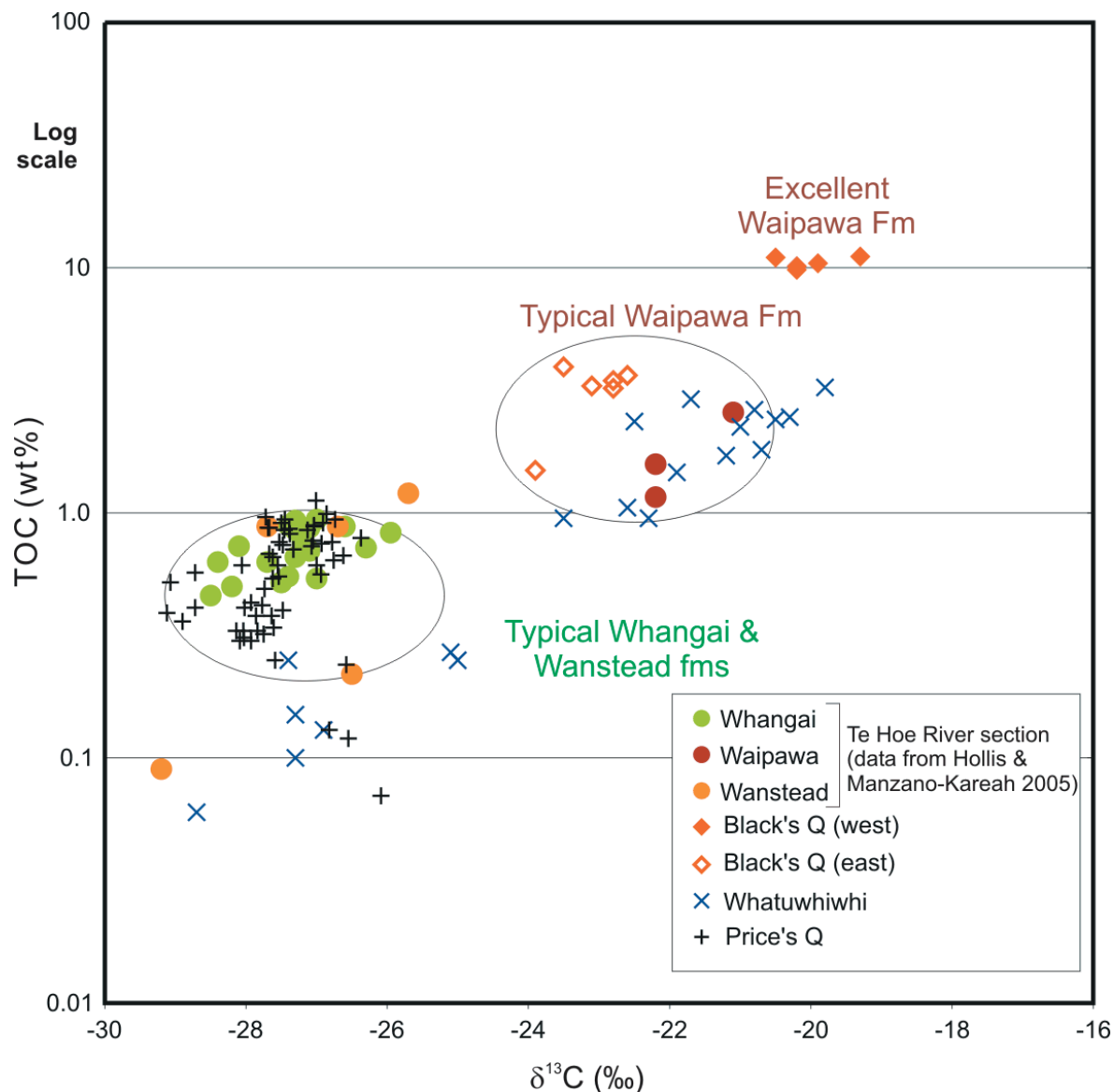


Figure 2. Total organic carbon contents and stable carbon isotope values for the Waipawa Formation and associated formations, North Slope and East Coast basins.

analysis was undertaken for four samples from Black's Quarry, 18 Waiari Formation samples from Whatuwhiwhi and 12 samples that span the Waipawa Formation interval in north Taranaki exploration well Wakanui-1. All samples were mudstone. The samples were milled to powder and representative subsamples sent to Geological Survey of Canada (Calgary) for Rock-Eval analysis. Approximately 70 mg load sizes were analysed on a Rock-Eval 6 machine.

In comparison with a typical Whangai-Waipawa-Wanstead succession from the East Coast Basin (Te Hoe River, northern Hawkes Bay; data from Hollis and Manzano-Kareah 2005), the carbon contents and isotopic signatures of samples from the three Northland localities indicate that (Fig. 2):

- Waipawa Formation appears to be absent from Price's Quarry. Instead, the low TOC and low $\delta^{13}\text{C}$ values are typical of Whangai or Wanstead formations;
- The Whatuwhiwhi section appears to consist of a Whangai-Waipawa succession. The highly siliceous Whangai mudstone has low TOC and $\delta^{13}\text{C}$ values whereas the overlying dark grey silty mudstone has high TOC and $\delta^{13}\text{C}$ values typical of the Waipawa Formation;
- Black's Quarry consists of typical Waipawa Formation in the east face, but the west and main quarry face consists of a Waipawa Formation facies that is highly enriched in TOC and $\delta^{13}\text{C}$.

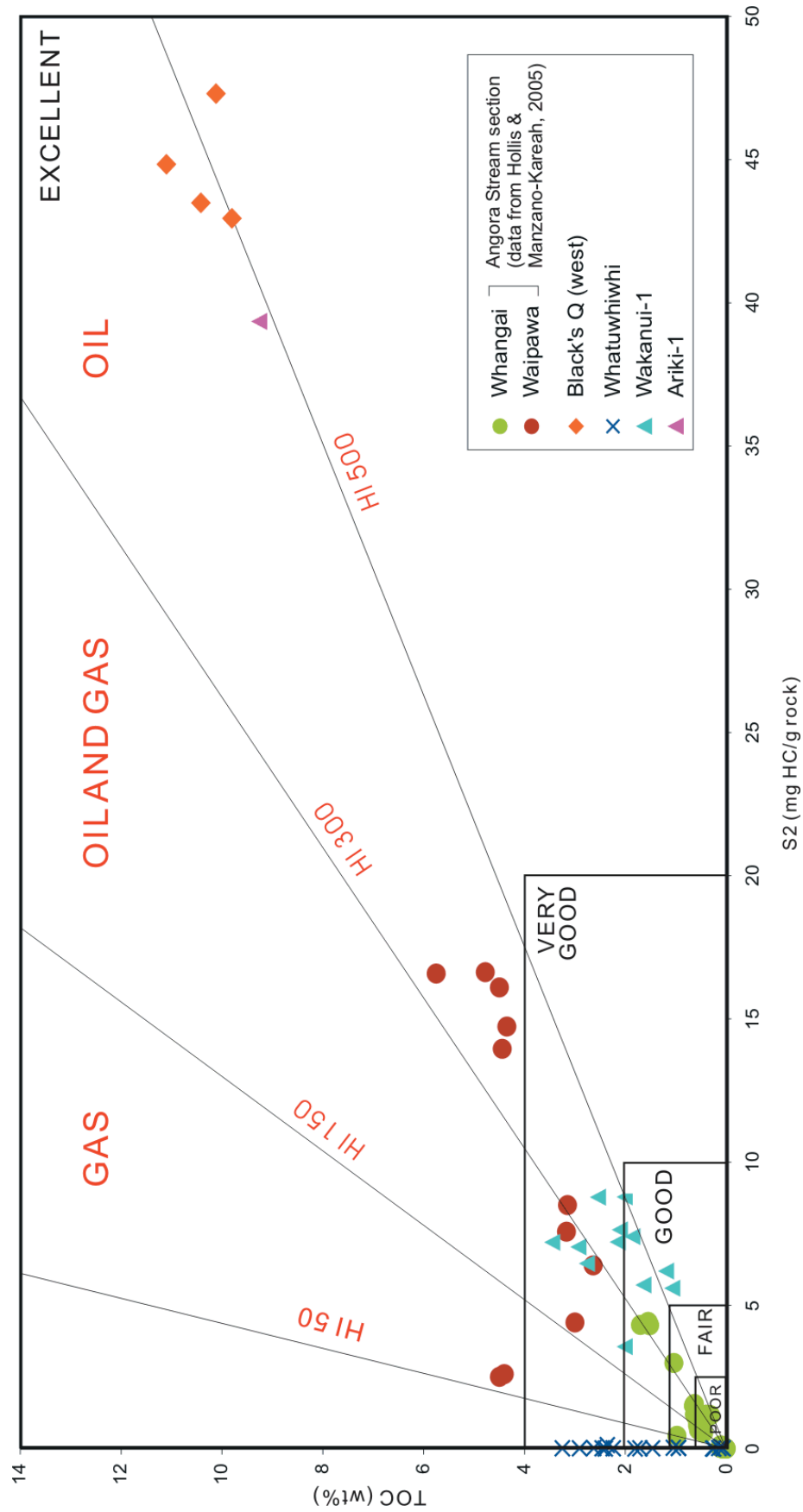


Figure 3. Source rock quality for the Waipawa Formation and associated formations, Northland, North Slope and East Coast basins. Source rock quality classification of Peters and Cassa (1994).

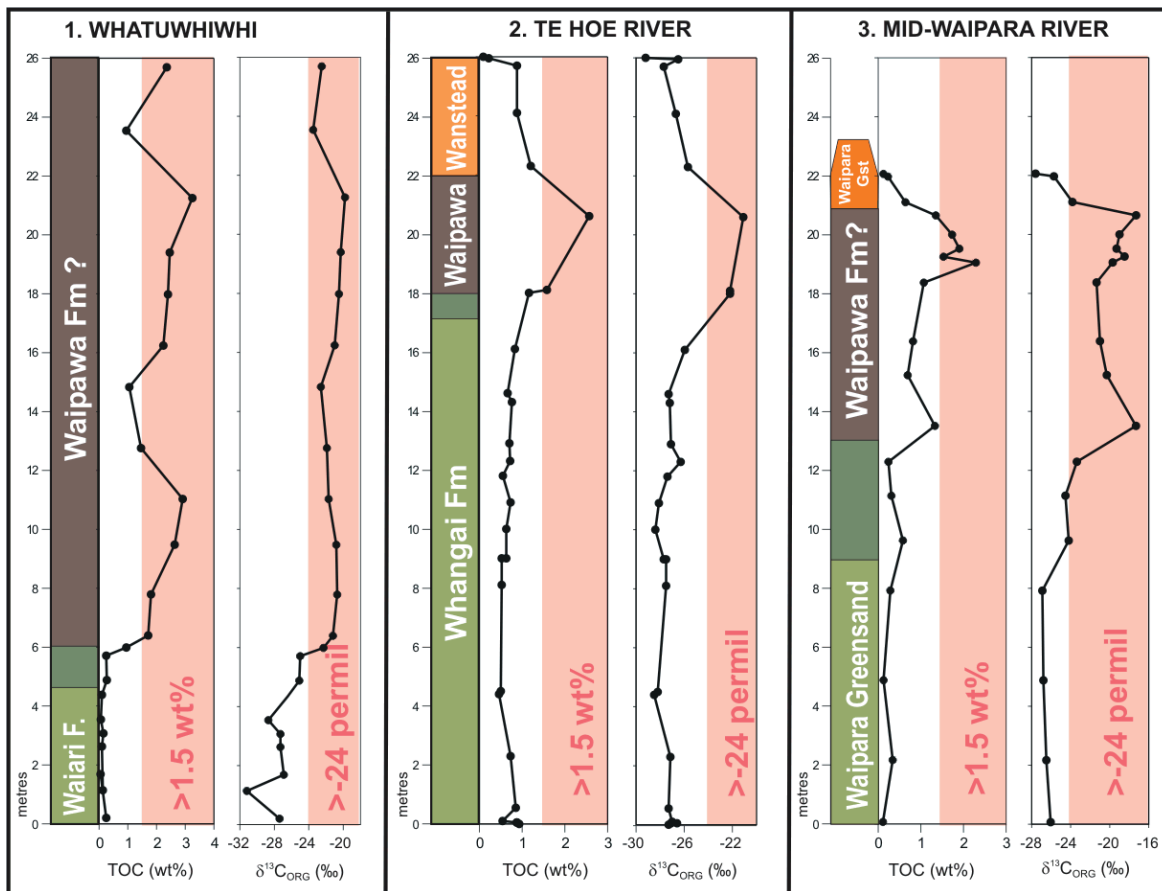


Figure 4. Geochemical signature of the Waipawa Formation in the North Slope, East Coast and Canterbury basins. Te Hoe River data from Hollis and Manzano-Kareah (2005); mid-Waipara data from Crouch et al. (2005).

It is surprising that although the dinoflagellate biostratigraphy for Price's quarry indicates that the succession encompasses the age range in which the Waipawa Formation was deposited, the distinctive geochemical signature of the formation is not evident in any of the quarry samples. Despite an oily smell and sulphurous efflorescence, all samples have low TOC and light organic $\delta^{13}\text{C}$ values ($< 1\%$ and $< -26\text{‰}$, respectively). Based on these features, the entire sequence here is correlated with the siliceous mudstone facies of the Whangai Formation.

In contrast, the petroliferous mudstone exposed in Black's Quarry has moderate to high TOCs and heavy $\delta^{13}\text{C}$ values ($> 3\%$ and $> -24\text{‰}$, respectively), typical of the Waipawa Formation. A suggested stratigraphic thickness of 40 m (Isaac et al. 1994) is difficult to confirm due to lack of bedding and the presence of numerous faults. Rock-Eval analyses for samples from the west face (only) indicate that the formation here is an immature source rock ($T_{\text{max}} 421\text{--}427\text{ °C}$), with TOC and HI values of 10–11% and 426–445 mg HC/g TOC, respectively, indicating excellent potential for oil generation (Fig. 3).

At Whatuwhiwhi, the Waiari Formation has a minimum thickness of 26 m and is a well-bedded mudstone. The lower 4-6 m is highly siliceous and chert-rich whereas the upper part (20 m+) is nonsiliceous and carbonaceous (Fig. 4). The lower siliceous interval has a Whangai-type geochemical signature (isotopically light, TOC $< 1\%$), whereas the latter has a Waipawa-type geochemical signature (isotopically heavy, TOC $> 1\%$). However, black palynomorphs and almost completely exhausted petroleum potentials ($S_2 < 0.15\text{ mg HC/g rock}$) indicate that the sequence has been thermally altered, presumably by nearby Miocene intrusives, to an extent that makes correlation with the Waipawa Formation uncertain. The palynomorphs are too altered to permit palynological dating.

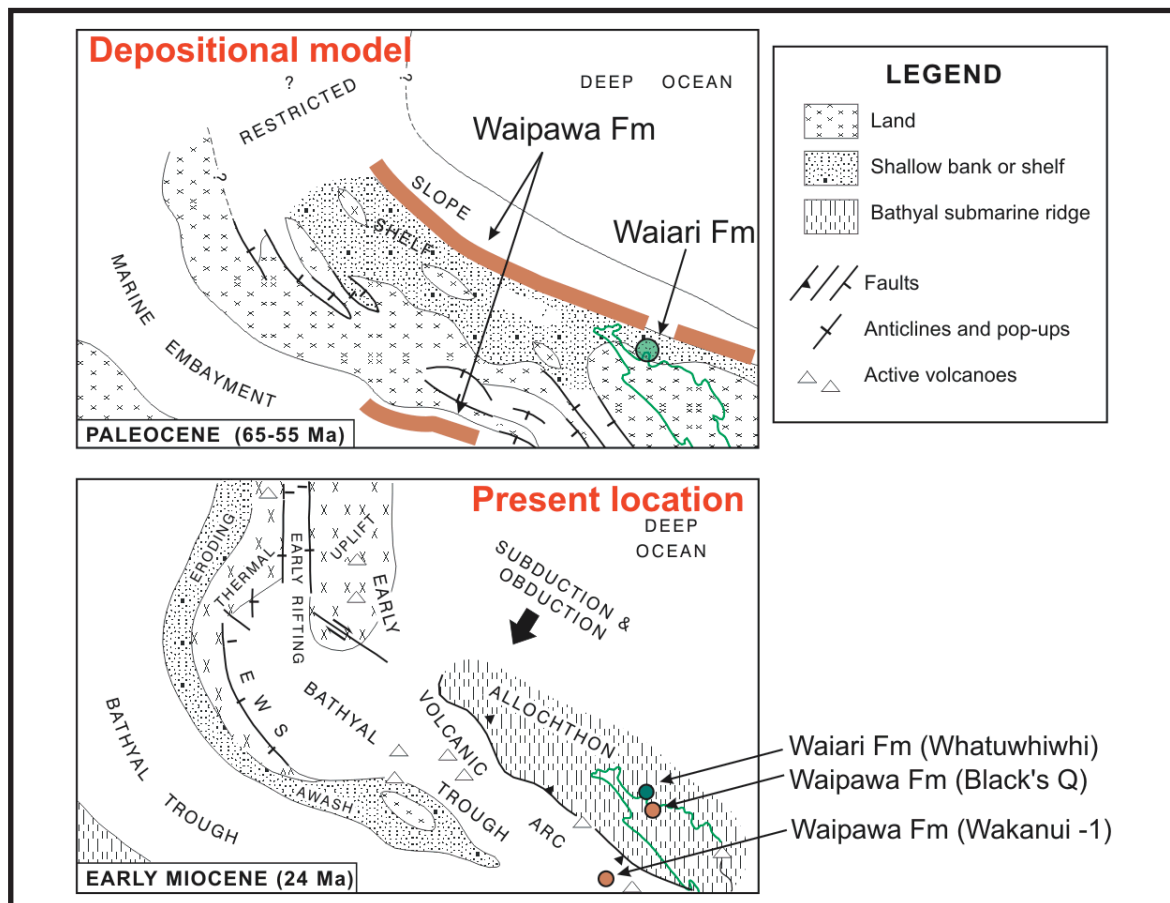


Figure 5. Paleogeography of the North Slope Basin during Paleocene deposition of Waipawa facies and in the early Miocene following the emplacement of the Northland Allochthon (after Herzer et al. 1997).

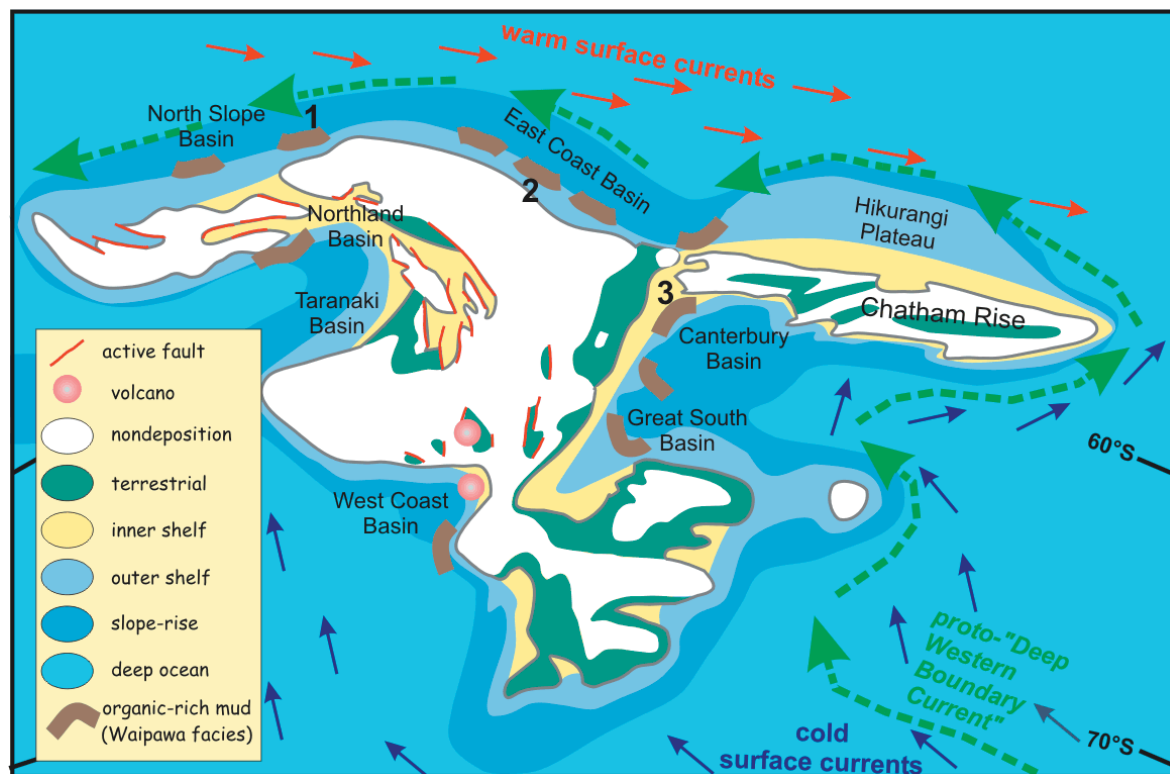


Figure 6. Paleogeographic reconstruction for New Zealand subcontinent in the Paleocene (65-55 Ma). From Hollis (2003); after King et al. (1999). Distribution of Waipawa Formation based on Killops et al. (2000), Hollis et al. (2005) and Crouch et al. (2005).

In comparison with a typical Whangai-Waipawa succession in the East Coast Basin (Angora Stream, Wairarapa; data from Hollis and Manzano-Kareah 2005), source rock potential for Waipawa-like facies in Northland is:

- Poor at Whatuwahiwi. TOC values suggest that original potential may have been very good in some intervals, but in this section potential appears to have been lost as a result of heating from nearby intrusions;
- Excellent in Waipawa Formation from the west face of Black's Quarry. The similarly excellent sample from the Ariki-1 exploration well (north Taranaki Basin; Figs. 1 and 3) is based on a concentrate of dark mudstone in cuttings (Killops et al. 2000);
- Generally good to very good in cuttings from a Whangai-Waipawa-Wanstead succession in Wakanui-1 well (western Northland Basin; Figs. 1 and 3; GNS unpublished data).

Paleogeographic considerations

Occurrences of Waipawa Formation in allochthonous strata in Doubtless Bay (Black's Quarry) and in the western Northland Basin (Wakanui-1), as well as the occurrence of Waipawa-like facies within autochthonous Waiari Formation, imply that organic-rich mud may have been deposited at outer-shelf to upper-slope depths over much of the Northland and North Slope basins during the late Paleocene (Fig. 5). These new records in Northland and another new record of the Waipawa geochemical signature in late Paleocene mid- to outer-shelf sediments in the mid-Waipara River section in north Canterbury (Crouch et al. 2005), greatly increase the known regional extent of the Waipawa Formation. The formation or similar Late Paleocene organic-rich mudstone facies are now known from all of New Zealand's major sedimentary basins (Fig. 6). Deposition probably occurred at outer-shelf to upper-slope depths around much of New Zealand in Paleocene times. The organic-rich Waipawa facies may be the local consequence of an episode of late Paleocene global cooling, which intensified oceanic circulation and regional upwelling in this region (Hollis 2003).

Conclusion

The results of this study indicate that good quality oil-prone Waipawa Formation source rock is likely to be present in the sedimentary succession offshore northeastern Northland. However, its thickness is uncertain and it is likely to grade laterally and vertically into organic-lean siliceous facies of the Whangai Formation. Seismic facies mapping and paleoenvironmental reconstructions are recommended to better define the extent and quality of this potentially important source rock.

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