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NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

Field Trip Guide

Northland, New Zealand: Onset of A New Subduction Regime

Northland
25-29 November 2010

Leaders:
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NORTHLAND, NEW ZEALAND: ONSET OF A NEW SUBDUCTION REGIME

Bernhard Spörli and Dan Hikuroa

View NE across the Hokianga Harbour from Opononi. Maungataniwha Tangihua Massif in the middle and the Puketi Forest basement block in the right hand background (K.B. Spörli photo)

INTRODUCTION

Because northernmost New Zealand lies away from the present zone of active deformation along the Alpine Fault transform boundary, it has preserved a unique record of the processes operating at the inception of subduction along a continental fragment, as the present plate boundary was established. This event took place as New Zealand was transferred from the edge of Gondwana to its present position. The tectonic situation was strongly influenced by the complexities of the Southwest Pacific adjacent to northern New

Zealand (**Fig. 1**). It is the aim of this field trip to illustrate the long-distance transport and mobility which has affected this region.

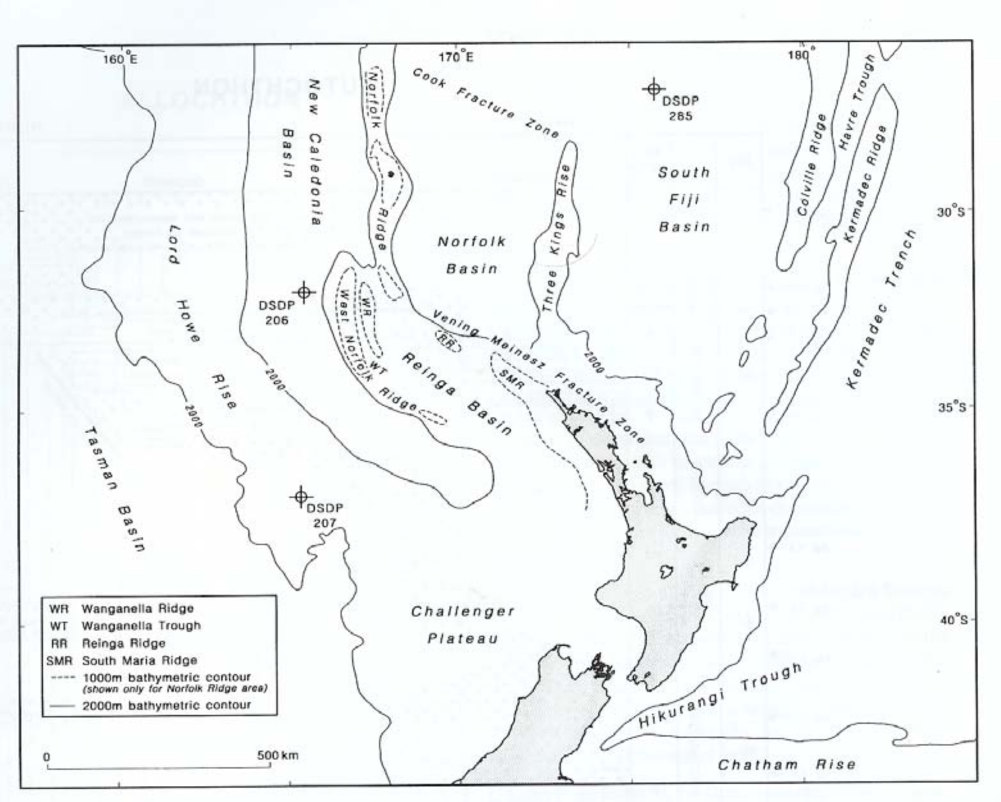


Fig. 1: SW Pacific features around the North Island after Isaac et al. (1994)

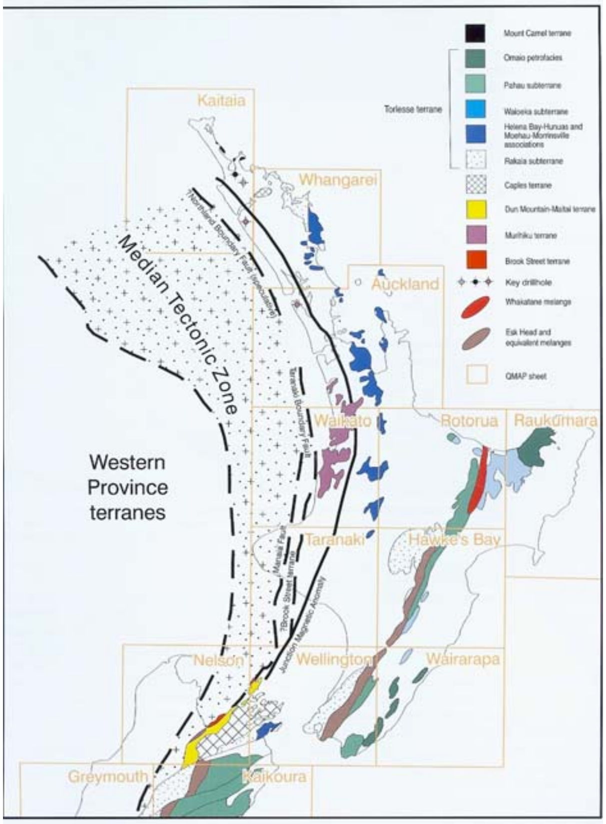


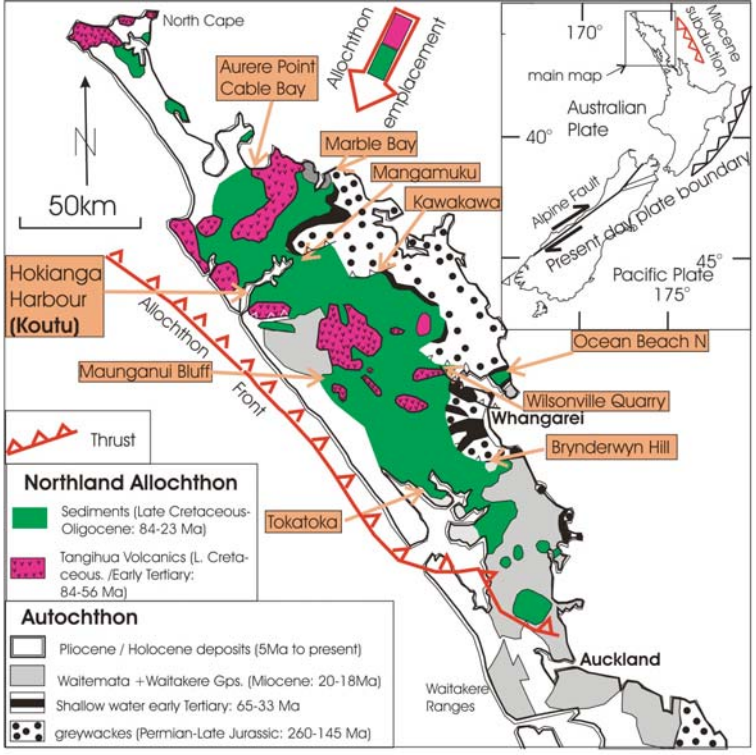
Fig. 2: Basement terranes of the North Island after Isaac (1996): Geology of the Kaitaia Area. IGNS 1: 250 000 Geological Map 1 (brown rectangles show map supdivisions)

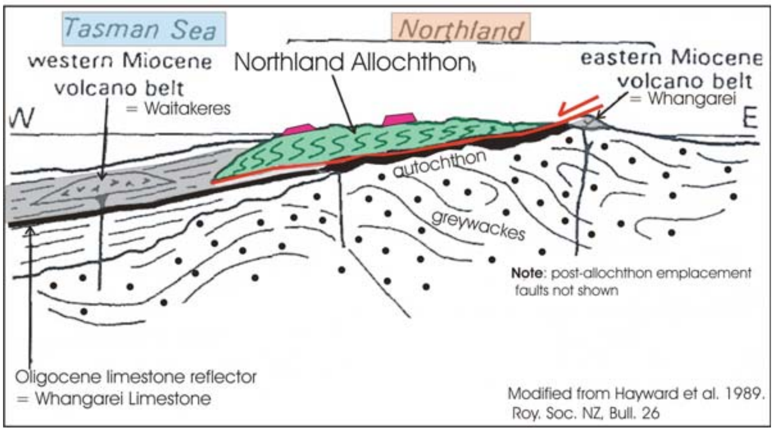
Basement

New Zealand basement can be subdivided into a Western and Eastern Province (e.g. Bradshaw et al. 1996). **The Western Province** is only exposed in the South Island and consists dominantly of Paleozoic rocks with strong affinities to easternmost Australia. **The Eastern Province** is dominated by Mesozoic rocks which can be traced throughout New Zealand. Late Paleozoic to Cretaceous basement rocks (greywackes, cherts limestones and basaltic lavas) of the Eastern Province were welded onto Gondwana in an accretionary belt associated with long-lived subduction (Spörli 1978, Wandres and Bradshaw 2005). The greywackes are terrigenous clastics while the basalts, limestones and cherts represent the incoming ocean floor (Spörli et al. 1989, Aita and Spörli 1992). The **Dun Mountain Belt/Matai terrane** with its Permian ultramafics separates the accretionary prism in the east from the fore-arc Murihiku terrane in the west. It forms the **Junction Magnetic Anomaly** which can be traced throughout New Zealand and records the Cenozoic Z-bending of the micro-continent and dextral strike slip displacement along the Alpine Fault.

The accretion prism sequences east of the Junction Anomaly can be subdivided into a number of terranes which however are not equally prominent everywhere (**Fig. 2**). For our excursion the **Waipapa terrane** (Spörli 1978, Adams and Maas 2004) is the most important, but the **Caples terrane** (Adams and Maas 2004) immediately to the west also plays a role.

Fig. 3: Northland Allochthon and major stops. Modified from Hayward et al. (1989)





Modified from Hayward et al. 1989. Roy. Soc. NZ, Bull. 26

The Northland Allochthon

Subduction ceased in the late early to mid Cretaceous and the New Zealand micro-continent **rifted and drifted away from Gondwana** from 80 Ma to 50 Ma (Spörli, 1989a, Gaina et al.1998). During this long period of extensional tectonics during New Zealand **acquired a thinned crust and anomalous mantle** (e.g. Holt and Stern 1991) which has profoundly influenced its subsequent tectonic fate.

In mid-Tertiary time, a new convergent system propagated into New Zealand from the north, eventually forming the present Alpine Fault plate boundary (King, 2000). The initial lithosphere break was accompanied by an **obduction event** marked by emplacement of the **Northland Allochthon (Fig. 3)** in the late Oligocene (Ballance and Spörli, 1979; Herzer and Mascle, 1996; Rait, 2000).

Northland Allochthon has a tectonic thickness ranging up to slightly more than 4km (Isaac et al.1994) and consists of:

(1) Late Cretaceous to mid-Tertiary sedimentary sequences,
(2) the Late Cretaceous/Early Tertiary Tangihua volcanics (= Tangihua Complex,)
(3) the Cretaceous /Early Tertiary rocks of the exotic (?) Mount Camel terrane (Toy et al. 2002) in northernmost Northland.

The stratigraphic sequence of the Northland Allochthon (excluding Mount Camel terrane which we will not visit) is summarized in **Figs. 3 and 4**. The older sedimentary sequences (= **Mangakahia Complex**) are dominated by terrigenous clastics in the lower part. Finer grained and more distal units follow through the **Cretaceous / Tertiary boundary** and constitute the regional **Whangai Formation**(Isaac et al. 1994). Eocene to Oligocene sediments (=**Motatau Complex**) consist of various mudstones, often red and green, some of which are siliceous. Calcareous mudstones and micritic limestones occur in the Eocene and also form the youngest, Oligocene rocks (**Mahurangi Limestone**) in the sequence. The diagenetic history of the sequence is restricted to effects of their burial and was not modified by obduction (Aadil et al. 2001).

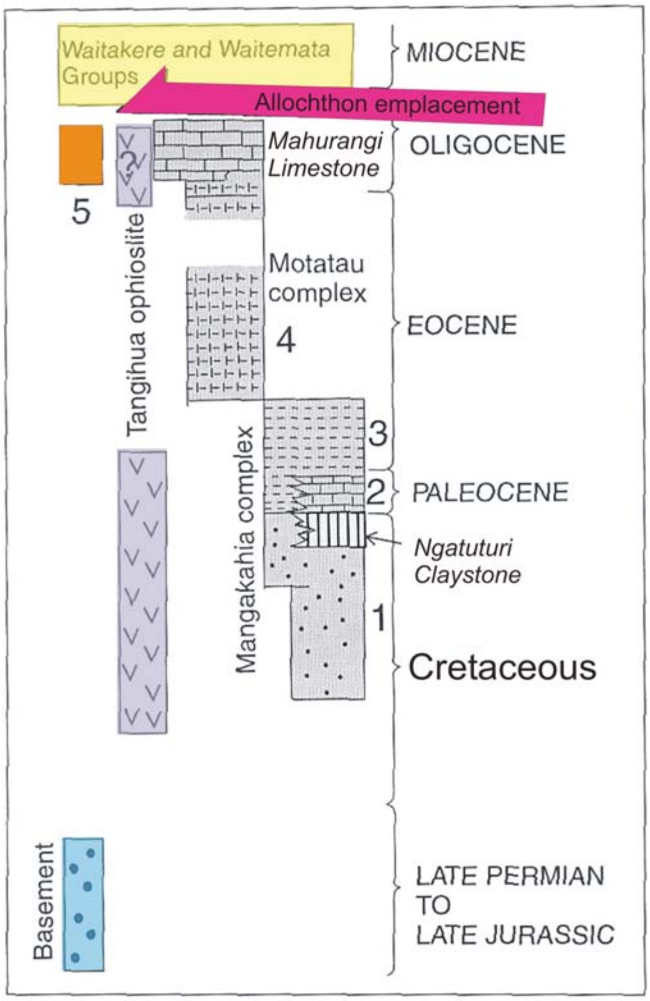
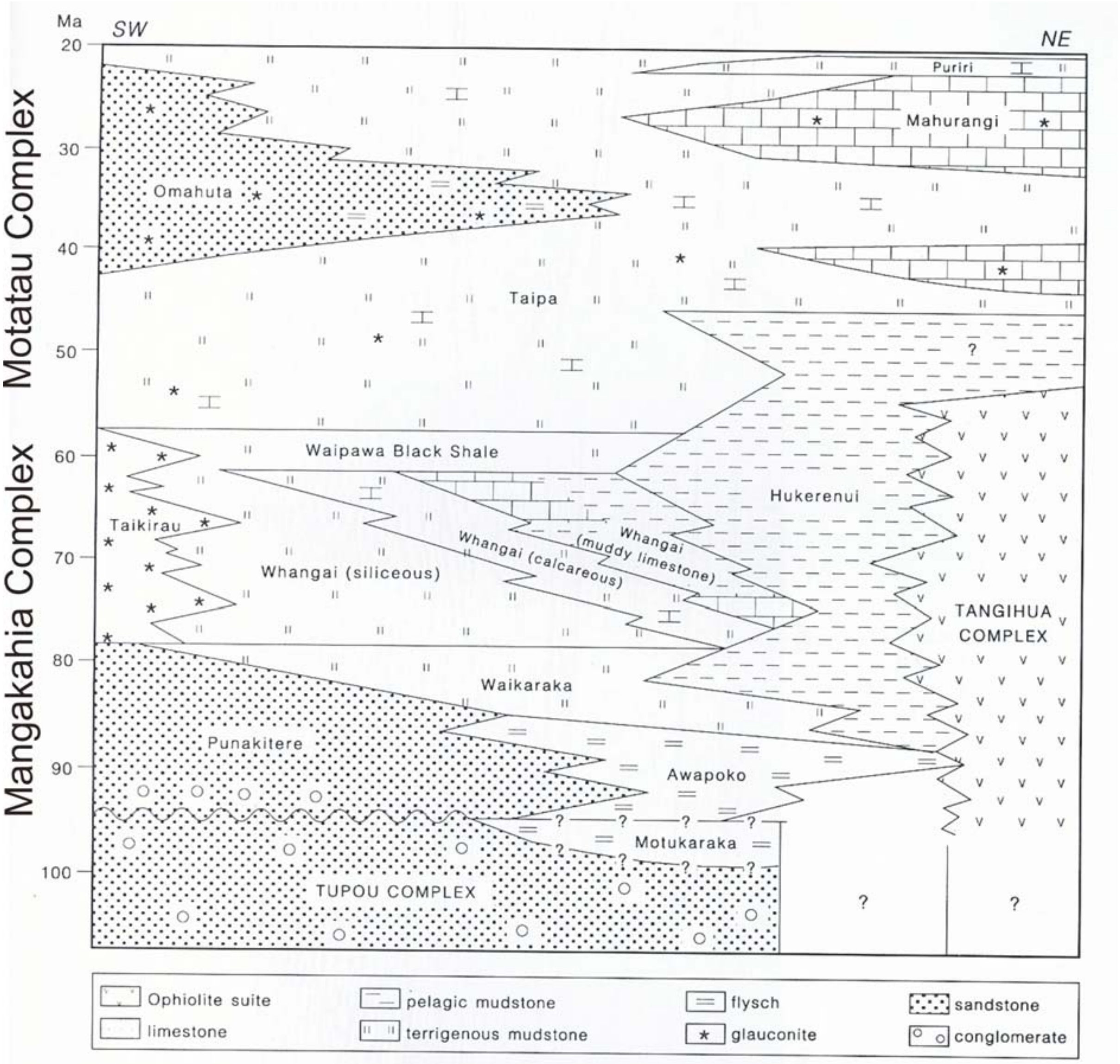


Figure 2. Simplified regional stratigraphy (after Hayward et al., 1989) and position of Ngatuturi Claystone. Lithologies in the Northland Allochthon: (1) terrigenous clastics; (2) muddy limestone, (3) non-calcareous mudstone, (4) calcareous mudstone. Autochthon: (5) shallow water limestone and siliciclastic rocks. Exposed basement is mainly the Permian to Late Jurassic Waipapa terrane (Spörli, 1989a).

Fig. 3: Simplified tectonostratigraphy of the Northland Allochthon. (After Spörli, 2007, Fig.2)



gure 4.3: Sketch reconstruction of original facies relationships, Northland Allochthon (no horizontal scale implied). Almost all ntacts are inferred, since units are typically juxtaposed with faulted contacts.

Fig. 4: Nomenclature of stratigraphic units and facies in the Northland Allochthon. (After Isaac et al. 1994, Fig. 4.3)

Overall, the highest thrust sheets of the allochthon are in the north and consist of older rocks, while the younger rocks form the southern lower (and younger?) sheets. A thrust sheet dominated by the Ngatuturi Claystone underlies the Ngawha area of Northland (Bayrante and Spörli, 1989). Northland Allochthon sediments are usually assumed to have been deposited on the northeastern passive margin of New Zealand during its rifting away from Gondwana (Isaac et.al. 1994), however Toy et al. (2002) and Bradshaw (2004) have recently suggested that there was an accretionary prism.

The main bodies of **Tangihua volcanics structurally overlie the sediments** and represent an ophiolite sequence that, except for one sliver, at North Cape (Bennett 1976), has been **detached from its lower, ultramafic portions**. They appear to have been formed in a supra-subduction environment (Whattam et.al, 2005), and were considered to be Late

Cretaceous /Paleocene in age until recently (Isaac et al. 1994) but Whattam et al. (2005) consider a proportion to be as young as Oligocene. Small bodies of **Tangihua volcanics near the base** and within of the allochthon indicate a complex mechanism of ophiolite emplacement.

Still during or shortly after the obduction, the inception of the new subduction system led to formation of a **volcanic arc** today preserved in the **Waitakere Group** (Hayward, 1993), in the volcanic centres of **Tokatotoka, Maunganui Bluff** along the west coast of Northland and many more volcanoes offshore (**Fig. 5**). Along the east coast, the **centres of Whangarei and Whangaroa** were also active. They were associated with an **intra-arc turbidite basin** in which the **Miocene Waitemata Group** and equivalents were deposited. Continued movement of the allochthon led to establishment of a piggy-back situation and to complex deformation in the Waitemata Group (Spörli, 1989b, Spörli and Rowland 2007).

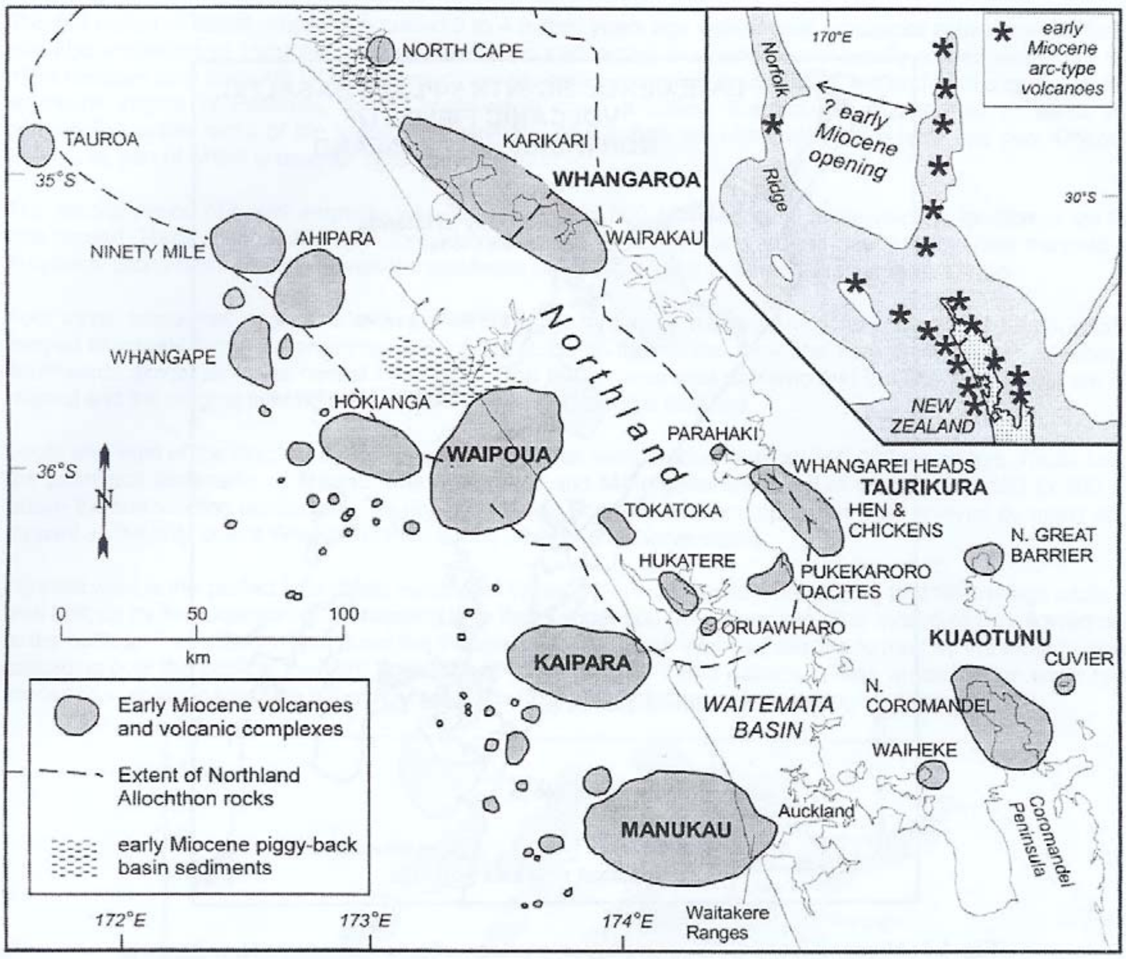


Fig. I.4: Distribution of early Miocene arc-type volcanic centres in northern New Zealand (after Hayward 1993, Herzer 1995). Location of main early Miocene marine sedimentary basins on top of and to the south of the Northland Allochthon is also shown.

Fig. 5: Miocene arc volcanic centres (Spörli and Hayward 2002, Fig.1.4)

Shallow water early Tertiary sedimentary sequences deposited on autochthonous basement of northern New Zealand (**Te Kuiti Group**) contrast with the bathyal / pelagic nature of the youngest sedimentary rocks (Mahurangi limestone in **Figs**.) in the allochthon (Hayward, 2004). This indicates that just prior to obduction, **the continental crust of New**

Zealand was pulled down to 1-2 km depth to allow low angle overthrusting of the Northland Allochthon. Shallow water basal Waitemata sediments record **renewed uplift shortly after the emplacement**. This was followed by a second episode of rapid subsidence leading to deposition of the main, bathyal part of the Waitemata Group (Ricketts et al. 1989, Hayward, 2004). These elevation oscillations may be due to **transient down-dragging events during forced subduction** (Gurnis and others 2204; Stern, 2004) associated with such an initiation of a plate boundary.

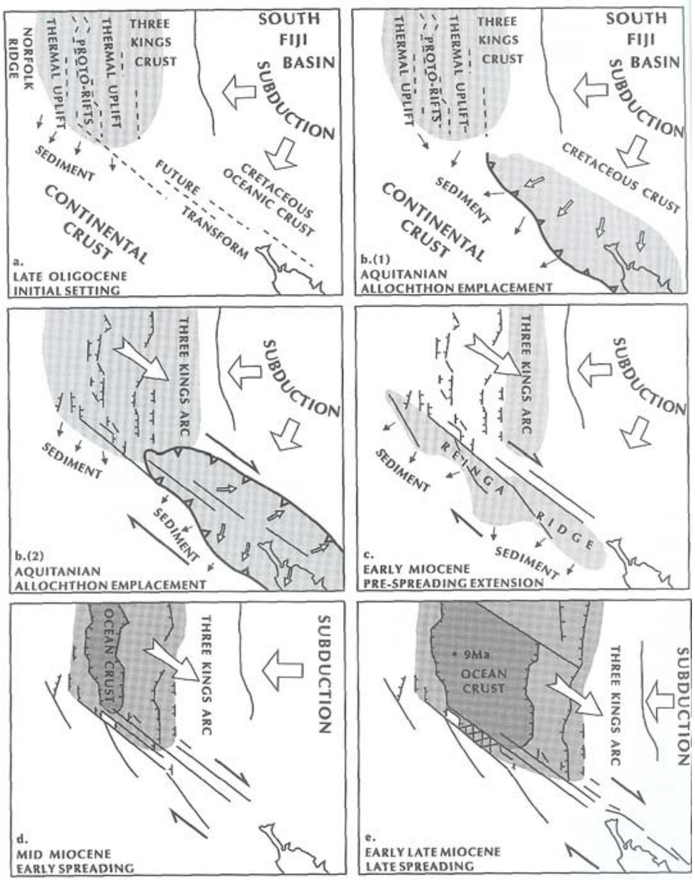


Fig. 6: Emplacement of a bi-vergent Northland Allochthon after Herzer and Mascle 1996.

Paleogeographic and tectonic considerations require a **derivation of the allochthon from the E or NE**, with emplacement mechanisms including both thrusting and gravity sliding. Rait (2000) proposed a uniform direction of movement from NE, based on shear sense indicators in prominent shear zones. This, however, contrasts with evidence of NE-trending regional cleavage and fold trains implying other directions of movement (Spörli and Kadar, 1989; Bayrante and Spörli, 1989) and of re-activation of the allochthon during or just after deposition of the Waitemata Group (Spörli, 1989b; Isaac et al. 1994), indicating **changes in direction during emplacement.** The autochthonous basement underneath the allochthon in the northeast also shows evidence of reactivation (Hayward, 1989; Spörli and Harrison, 2004). Hayward (1986) interpreted the southernmost exposures of disturbed Cretaceous /Early Tertiary rocks **(Fig. 1b)** as **blocks shed into the Waitemata basin** off the front of the allochthon. There is no doubt that syn- or post-Waitemata movements were from NW to SE and even from W to E (Spörli, 1989b).

Initially, the allochthon was envisaged as a unidirectional thrust system, but Herzer and Mascle (1996) suggest that it is a **bi-vergent flower structure** (**Fig. 6**) due to strike-slip on the offshore **Vening Meinesz Fracture zone**. Such a structure could explain the **extreme**

width-to-thickness ratio of the allochthon and might provide a niche for fitting in the enigmatic metamorphic rocks of the **Cavalli Seamount** (Mortimer et al. 2003).

There is some disagreement about the configuration of the down-going slab during these events. Schellart (2007) has summarized the various patterns proposed earlier (**Fig. 7)** which all hinge on subduction in a generally westward direction, but has himself proposed a transient event of eastward subduction (**Fig. 8**).

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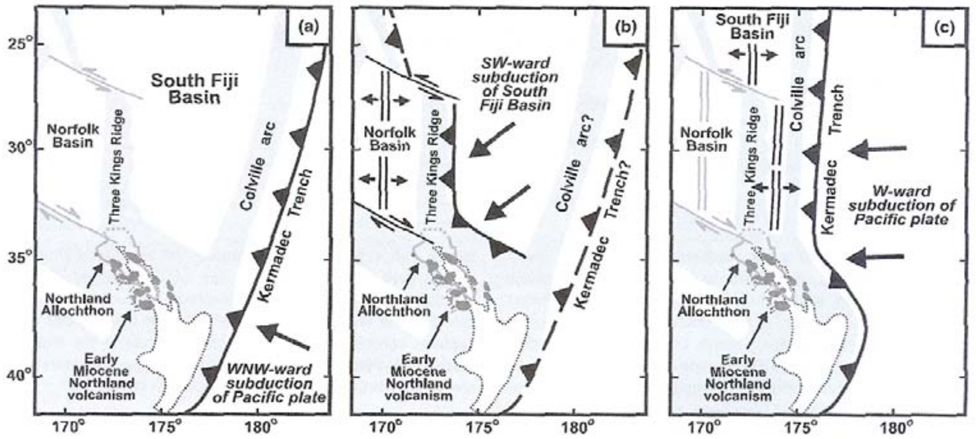

Fig. 1 Schematic diagrams of three different Early Miocene tectonic models to explain Early Miocene volcanism in Northland, New Zealand. (a) West–north-west-directed subduction and progressive steepening of the Pacific plate (e.g. Brothers, 1984; Kamp, 1984). (b) South-west-directed subduction of the South Fiji Basin (e.g. Malpas *et al.*, 1992; Herzer, 1995; Ballance, 1999; Whattam *et al.*, 2005). Variations exist with subduction underneath Northland during or after opening of the southern South Fiji Basin and coexistence or non-coexistence of the Kermadec and Northland-Three Kings subduction zones. (c) West-directed subduction of the Pacific plate (e.g. Mortimer *et al.*, 1998, 2007; King, 2000; Herzer *et al.*, 2000; Bradshaw, 2004). Variations exist with opening of either the Norfolk Basin or the southern South Fiji Basin or both basins opening simultaneously during Northland volcanism.

Fig. 7: Various suggestions Northland Allochthon emplacement scenarios. After Schellart 2007, Fig.1)

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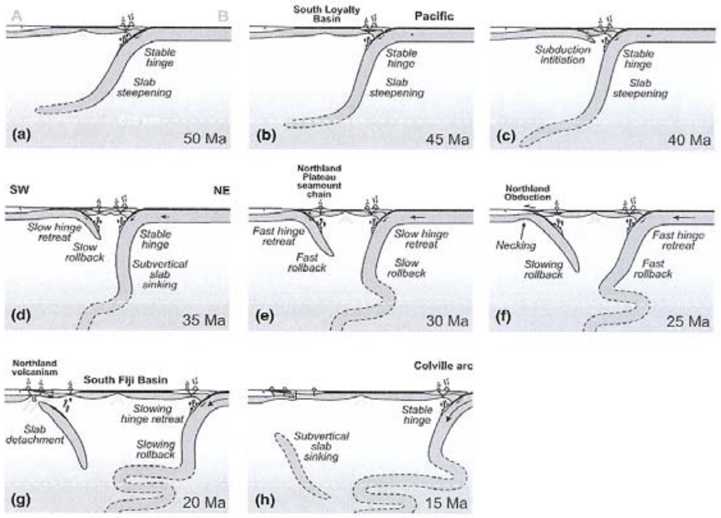


Fig. 8: Slab rollback and tranient eastward subduction after Schellart 2007.

Subsequent tectonics

Post Northland Allochthon tectonics initially involved some open cross-folding on NE and NW-trending axes followed by **considerable block-faulting**, including **uplift of the eastern basement belt** of Northland relative to the allochthon (**Fig. 9).**

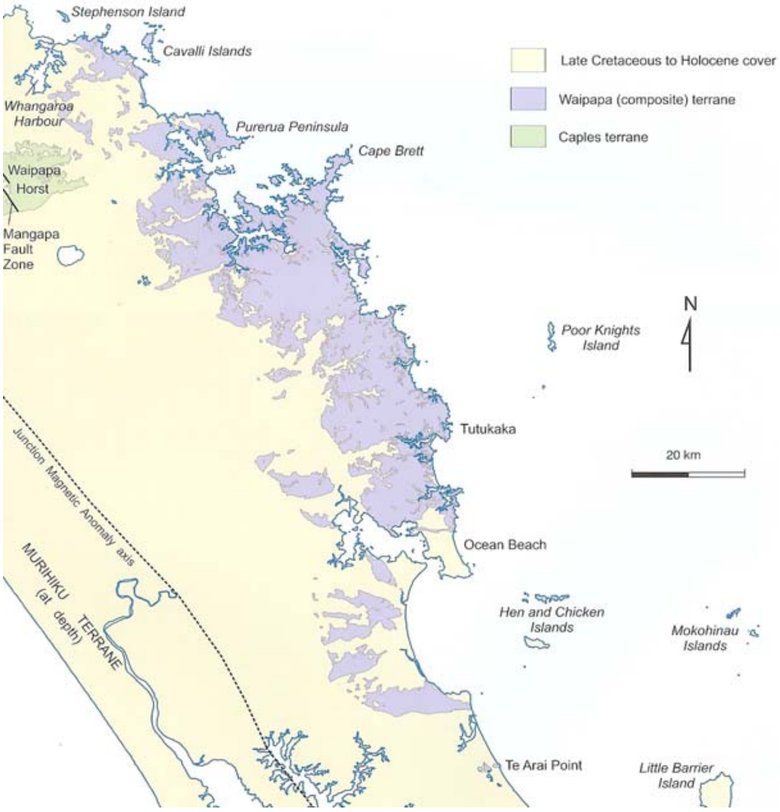


Fig.9: Uplifted basement blocks of eastern Northland. (Edbrooke and Brook 2009)

However, as the northern part of New Zealand was shifted into a behind-arc position, tectonic activity died down. Recent earthquakes are small (**Fig. 10**) and active e faulting is confined to the Hauraki Rift separating the Northland /Auckland peninsula from the

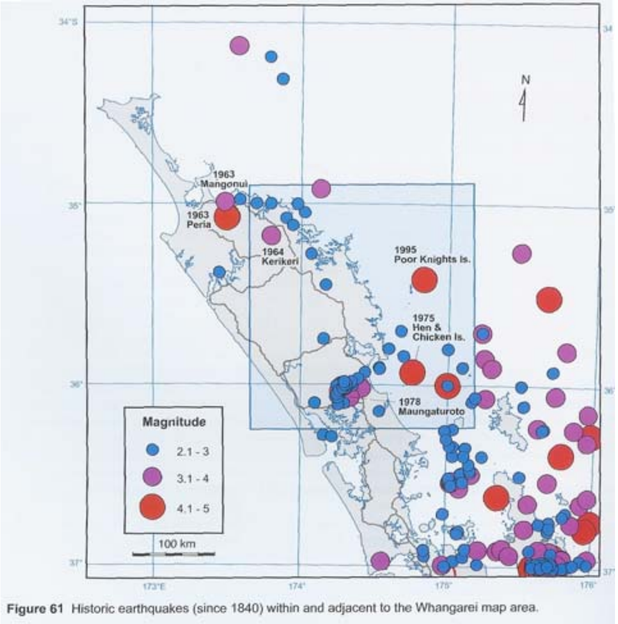


Figure 61 Historic earthquakes (since 1840) within and adjacent to the Whangarei map area.

Fig. 10. Earthquake activity in northern North Island
(Fig 6.1, Edbrooke and Brook 2009)

Coromandel Peninsula in the east (Hochstein and Ballance 1993). With the migration of the subduction system and the associated volcanic arc to its present position along the east coast of the North Island, a number of small fields of behind-arc alkali basalt volcanoes, e.g. the Auckland, Whangarei, Kerikeri and Kaikohe volcanic fields became active.

TRIP LOG

Thursday 25 Nov. Auckland-Omapere, 262 km

Auckland- Brynderwyn Hill

The first part of our trip goes through the **sandstones and mudstones of the Miocene Waitemata Group** as seen on the pre -Conference Field trip 1. From Auckland Harbour Bridge we can also see the western ranges formed by the Waitakere Group, representing the western volcanic arc associated with the Waitematas. **The southernmost exposure of Northland Allochthon** material appears from underneath the Waitematas in the area of the Autobahn petrol station , the Snow Planet indoor skiing facility and the Silverdale turnoff. At the toll registration **after the Orewa turnoff**, we are firmly back in the Waitemata Group. There are **good exposures** on new toll motorway in the Chin Hill cuts after the 'Pukeko' bridge, then again as the old road climbs up the ridge after the Mahurangi West turnoff and after that, in the Pohuehue incline.

At **Warkworth,** deformation and erosion has laid bare **a window of the Northland Allochthon** underneath the Waitemata Group **(Fig. 3)**. In the park opposite the traffic lights at the northern end of town (Sandspit turnoff), there are the remains of a 19th century lime works in the Oligocene pelagic **Mahurangi limestones**. As we proceed north we are in the Waitematas again.

By the time we pass **Kaiwaka, we are in the Northland Allochthon proper**. Note the small white quarry pits in the countryside where farmers have extracted lime from the Oligocene Mahurangi limestone.

After the **Brynderwyn turnoff** where State Highway 12 heads left to Dargaville, Highway 1 traverses an E-W trending chain of Miocene subaerial dacite domes, the **Pukekaro Hills** (Edbrooke and Brook 2009) which are mined for gravel at **Bald Hill**. These are aligned along a fault marking the southern boundary the of the northward-tilted **Waipu basement block**, indicating that this **fault is at least of Miocene age**. As the road climbs up the steep southern greywacke slope, there are good views down into the lowlands occupied by the Northland Allochthon.

Brynderwyn turnoff - Brynderwyn Hill 30min

Stop 1 : View from Brynderwyn Hill

Weather permitting, this stop provides a magnificent view north and east to Whangarei with its jagged peaks made of the eastern **Miocene volcanic arc** extending from Bream Tail (Whangarei Heads) out to Hen Island. Further **tilted greywacke blocks** lie straight below us and to the left we can see **Allochthon country topped with Tangihua volcanic massifs**.

We are standing on the **crest of the Waipu block**. The less steep northern side of the **tilted blocks are dip-slopes** on the early Tertiary Te Kuiti Group which unconformably overlie the greywackes of the Waipapa terrane. The distribution of the allochthon between the blocks indicates that the uplift and tilting of the eastern basement belt postdate allochthon emplacement. Therefore those **faults** inherited from the Miocene (see above) **must have been reactivated at this time**. There is some indication that from here on north, this eastern autochthonous basement becomes increasingly parautochthonous (Hayward 1989; Spörli and Harrison, 2004)

Brynderwyn Hill –Brynderwyn turnoff 30min

The road now winds its way west through Northland Allochthon country. The sediments are dominated by the Late Oligocene **Mahurangi limestone** which shows up in numerous white farm quarries, road cuts and the material spread on gravel roads.

Mahurangi limestone is a pelagic, muddy micritic limestone that can contain glauconitic clastic layers (Isaac et al, 1994). It can consist of up to 50% of planctic foraminifera in a matrix rich in coccoliths with radiolarians and sponge spicules.

We pass the towns of **Maungaturoto** (large dairy factory), **Paparoa** and **Matakohe**, in the northern headwaters of the **Kaipara Harbour**. With an area of 947 km^2, a length of 60 km and a shore line at least 800 km long, **this is the largest enclosed harbour in New Zealand** and one of the largest in the world. It has been closed off towards the west by huge propagating sand spits which are due to the long shore transport of sand from the volcanoes in the central North Island, in particular the voluminous (multi- km^3) rhyolitic eruptions in the Taupo Volcanic Zone. We will encounter evidence of this transport again further north (see stops 5 and 13). It is planned to establish a battery of tidal turbines for electricity generation at the entrance of the Kaipara Harbour.

As we travel westward, the road eventually leaves the hills and crosses the extensive flood plains of the Kaipara Harbour. As we drive towards the town of **Ruawai**, **look towards the NW** (right) to get the first view of **two steep pinnacles**: **Tokatoka** on the left (Stop 2) and **Maungaraho** on the right, part of the Miocene Tokatoka Volcanic Centre (see Stop 2)

Brynderwyn turnoff to Tokatoka 55 km.

Stop 2 : **Tokatoka volcanics** :

First stop at the **rest area south of Tokatoka**, then up to the eastern base of the plug. **Those willing and conditions permitting, climb Tokatoka**. View Northland Allochthon, Waipoua basalts and north end of Kaipara Harbour and its sand dune system. Look north towards Dargaville, Wairoa river once went straight out, and has been diverted by the sand dunes.

This is an **eroded sub-volcanic centre resulting** from the new Miocene subduction **(Fig. 5)**. Tokatoka and Maungaraho are the most prominent of 140 basaltic, andesitic and dacitic plugs, dikes, sills and pyroclastic breccia pipes (Black 1966, 1967), intruding Northland Allochthon sedimentary rocks, which here are dominated by the Oligocene Mahurangi limestone (one of the youngest units in the allochthon) along several structural directions. Age of intrusion is 19 to 16.5 Ma (Hayward et al. 2001).

Lunch

.

Stop 3 : Maunganui Bluff volcanics :
HT **1250h,** first access 1500h ?, **LT 1911h**

We will be looking at an exposure of the **Miocene Waipoua Volcanic Centre** (**Fig. 5**) at **Aranga Beach**. This is a large shield volcano which forms the uplands in this region, including the **Waipoua Forest** and the remote **Tutamoe Plateau** to the SE. The shield volcano consists of extensive subaerial basalt lava flows and thin interbedded pyroclastic fall deposits (Hayward, 1975, Wright 1980). The total area of the volcano, which extends offshore, is 60 x 40km., with a centre several km offshore from Maunganui Bluff. The sequence at Maunganui Bluff is ~ 450m thick. K-Ar dates and biostratigraphy indicate activity from 19-18Ma (Hayward et al. 2001).

Maunganui to Waimamaku through the Waipoua Forest 50 km, 45 min.

Stop 4: **Waimamaku**

Ambler Road turnoff: This will be just a brief stop to point out the site of the **Waimamaku drill hole,** which provided key information on the Northland Allochthon **(Fig. 11)** It is located in the core of the E-W trending **Waimamaku anticline** which appears to be a late structure affecting the

Northland Allochthon. It drilled 2.5km of late Cretaceous-Early Eocene allochthon rocks comprising two to three thrust sheets. This overlies a 450m thick mélange of Cretaceous-Oligocene lithologies and a Tangihua dolerite (in an unusually low position in the allochthon!), Below this there was an autochthon sequence consisting of 200m of mid- to late Eocene greensand overlying lower Cretaceous mudstones (Murihiku basement)

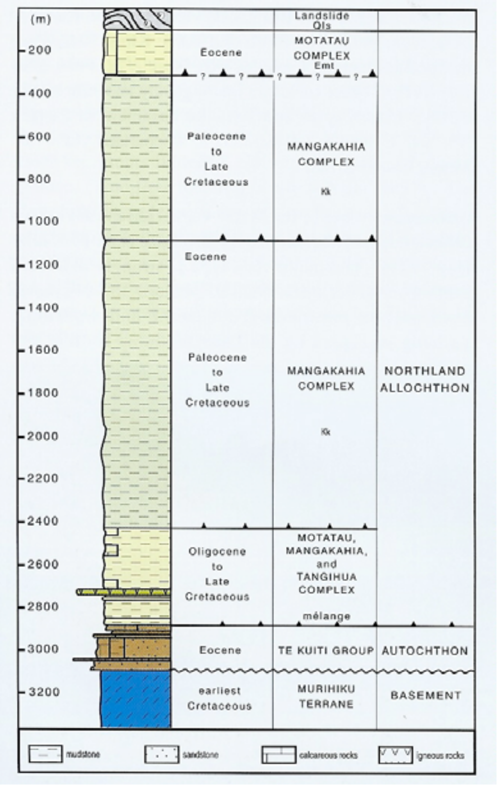


Fig. 11. Log of the Waimamaku drill hole (from Isaac1996)

Waimamaku to Hokianga South Head

Where the road reaches the Hokianga Harbour, turn left onto **Signal Station Road** and drive out to **Arai Te Uru Recreation Reserve**.

<u>Stop 5: Hokianga South Head</u>:

Here we have a spectacular view of the **Hokianga Harbour entrance** and the sand dunes on the north side. They are all part of the **great dune system** that extends along the west Coast of the North Island from the mouth of the Waikato River to Cape Reinga (including Ninety Mile Beach) and around this headland to Parengarenga Harbour and beyond on the east coast of Northland. The sands are derived from the andesitic volcanoes along the Taranaki west coast, and in especially copious amounts from the rhyolitic super-eruptions in the Taupo Volcanic Zone which have been brought down into the Tasman Sea by the Waikato River. The denser mafic minerals (e.g. titanite, pyroxene) are winnowed out by the long-shore drift and the sands become lighter coloured as one proceeds north until there is mineable pure white quartz sand at Parengarenga Harbour.

Otherwise, the landscape is dominated by two prominent Tangihua massifs : The nearby **Waima (Whirinaki) massif** (781m) to the east of us, and the **Warawara massif** (709m) on the north side of the Hokianga entrance (nomenclature of Tangihua massifs after Isaac et al. 1994 p. 65). We will see later on this trip (Stop 11) that there may have once been a connection between the two. With binoculars it is possible to see discontinuous white Mahurangi limestone cliffs along the waterline below the great dunes.

On the smaller, pointed hills just south of us (e.g. Pukekohe), evenly layered Omapere Conglomerate dips away from the Waima massif . This is debris shed from the Tangihua Volcanics in the Miocene. We will be having a close-up look at these deposits tomorrow evening.

Hokianga – Omapere 5 min.

Accommodation: Copthorne Omapere

Stop 6: Special Tane Mahuta visit

Friday 26 Nov. Omapere-Omapere

Stop 7 : Mahurangi limestone, Northland Allochthon Hokianga foreshore:
LT 0727h, last access 1030h, **HT 1337h** 3.3m

At the north end of Omapere, Oligocene Mahurangi limestone is visible in almost continuous cliff exposures and several shore platforms. Bedding in the micritic limestone is variably well visible, but there are some thin glauconitic beds. Glauconite also outlines some trace fossils. Dominant dips are to the north.

Deformation is typically strong and complex. In the middle part of the cliff section, where bedding is not so well developed and the rocks appear to be more clay rich, an **incipient pressure solution cleavage** is developed. Such cleavages are very prominent in other Mahurangi limestone slabs elsewhere in the allochthon, and most commonly have NE-SW strikes and dips to the NW. (Spörli 1982, Spörli and Kadar 1989, Clarke et al. 1989)

At one locality the cleavage is deformed (i.e. predates) a chevron fold. The rocks are then cut by a multitude of fault planes. The earlier ones are clay seam faults, the youngest are marked by fault breccias. Low angle down-to-the-south extensional faults are common.

This outcrop can be considered to be reasonably typical of most Mahurangi limestone bodies elsewhere in the Northland Allochthon.

Also note the strong sub-horizontal erosion surface, overlain by thin terrace deposits, cut across the top of these outcrops

Hokianga- Taheke- Kaikohe- Ngawha . 60 km

We now drive along the south side of the Hokianga Harbour through Opononi and along the north side of the Waima Tangihua Massif. We will be looking at this situation more closely tomorrow. After the turnoff to Rawene Hwy 12 turns inland.

At Taheke, the road reaches the north-western most lava flows of the Kaikohe group of the Kerikeri Volcanic field. We drive up a flow which fills the valley of a northern branch of the Waima River.

In general, the basaltic volcanoes of the Kaikohe group are younger (less than 1 Ma) than the others in the Kerikeri Volcanic Field where ages range (Mulheim 1973, Ashcroft 1977). They are also interesting in that they include a rhyolite dome (Putahi, south of Lake Omapere)

Drive through Kaikohe to Ngawha:

Stop 8 : Ngawha Springs:

These springs (**Fig. 12**) are the only active geothermal manifestation in any of the behind-arc volcanic fields in Northland and Auckland regions. Surface manifestations are neutral to acid hot pools, gas seeps and cold lakes. There is a modest mercury resource. Thermal features are aligned along NE-trending structures (Browne et al. 2002). The geothermal reservoir is at 500m to 600m

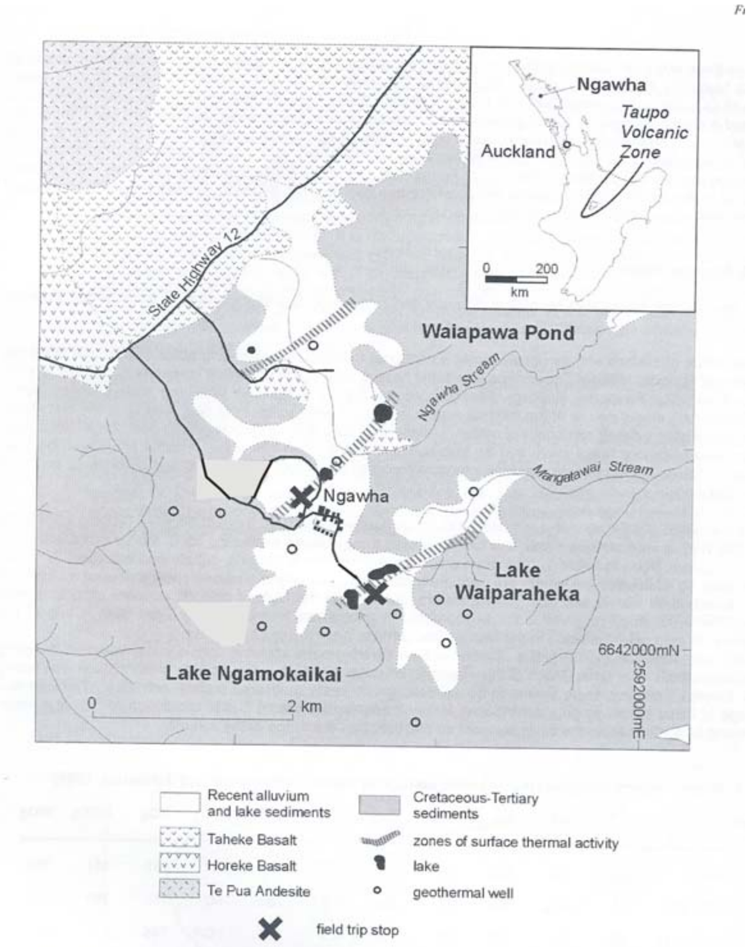
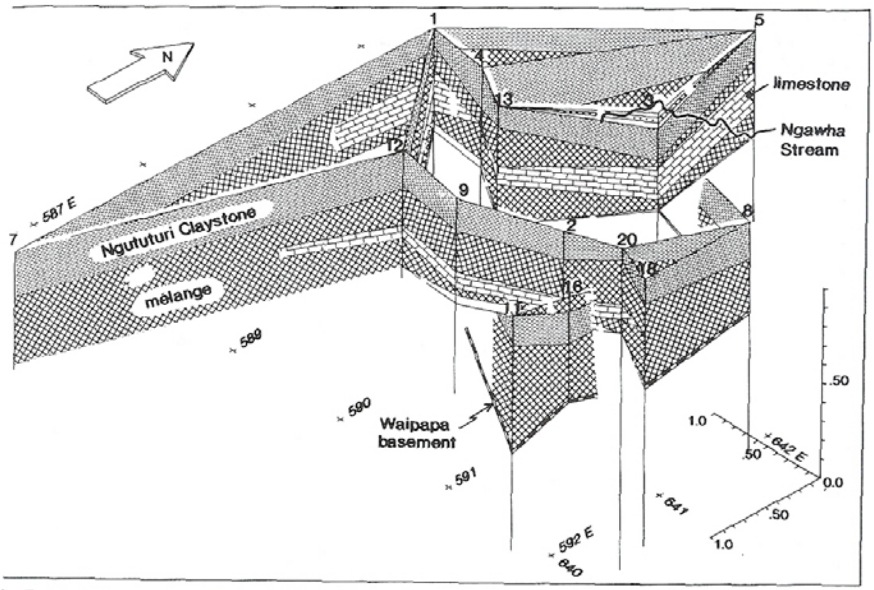


Fig. 6.5: Simplified geological map of the Ngawha area showing the location of lakes, zones of activity and geothermal wells. Inset shows North Island, New Zealand (modified from Harris, 2001).

Fig. 12: Geological Map of the Ngawha springs area after Fig. 6.5 of Browne et al. (2002)



ig. 7 Fence diagram intergrating drillhole information (For localities of drillholes see Fig.2). Data after Petty 985).

Fig.13: Then Northland Allochthon at Ngawha. From Fig. 7 in Bayrante and Spörli (1989).

depth in fractured greywacke of the autochthonous Waipapa terrane which is overlain by Northland Allochthon, which at outcrop dominantly consists of ‘Ngatuturi Claystone’ (Whangai facies, **Fig. 4**). In the subsurface there is a significant slab of Mahurangi limestone (**Fig. 13)**. The geothermal resource is used for bathing and for a small geothermal power station generating about 10 MWe.

HAVE A DIP!!

Ngawha to Mangamuka Bridge

Drive to **Ohaewai**, turn left onto Hwy 1 which passes east of the ephemeral Lake Omapere.
The high forested range ahead is the uplifted and northward-tilted **Puketi basement block**. It is surrounded in the south, west and north by Northland Allochthon which also occurs on its top surface, indicating that the uplift took place after emplacement of the allochthon.
West of Waihou Valley, the Waipapa River flows out of the Puketi Forest. Unfortunately, its basement rocks are not Waipapa terrane but **Caples**! (Jennings 1991)
Proceed around the western, fault controlled end of the Puketi block to Mangamuku Bridge. The next rugged high range in the north is the Maungataniwha Tangihua massif

<u>Stop 9</u> : **<u>Mangamuku Bridge-Otangaraoa Road</u>:**

We will examine outcrops of Mahurangi limestone for their structural development at the Mangataipa Reserve , Mangamuku Bridge (**Figs. 14 and 15**) and, if time allows on the Otangaroa road sections to the east for comparison with the outcrops seen along the Hokianga Harbour seen earlier today.

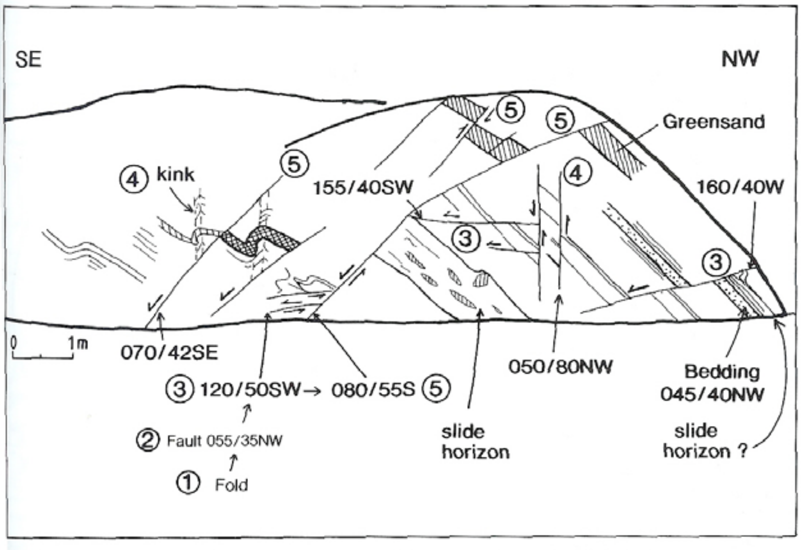


Fig. 4 Road exposure (location see Fig. 3), south end Mangataipa Reserve (Field sketch by KBS). Numbers in circles indicate sequence of deformations (Note: the numbering only applies to this figure). Selected marker horizons have been highlighted by patterns. Most of them are greensand beds. Note the change from shortening to extension in the NW-SE direction. Structures belonging to deformations (1) and (2) (in small print) are not shown in the exposure.

Fig. 14: example of structural sequences at Mangataipa. From Clarke et al, 1989, Fig. 4)

At Mangataipa, the following sequence can be recognised (**Fig. 14):** 1: local soft-sediment bedding-parallel sliding. 2. formation of south-verging chevron and kink folds associated with southward thrusting. 3. refolding by open, N-S trending folds (Clarke et al, 1989).

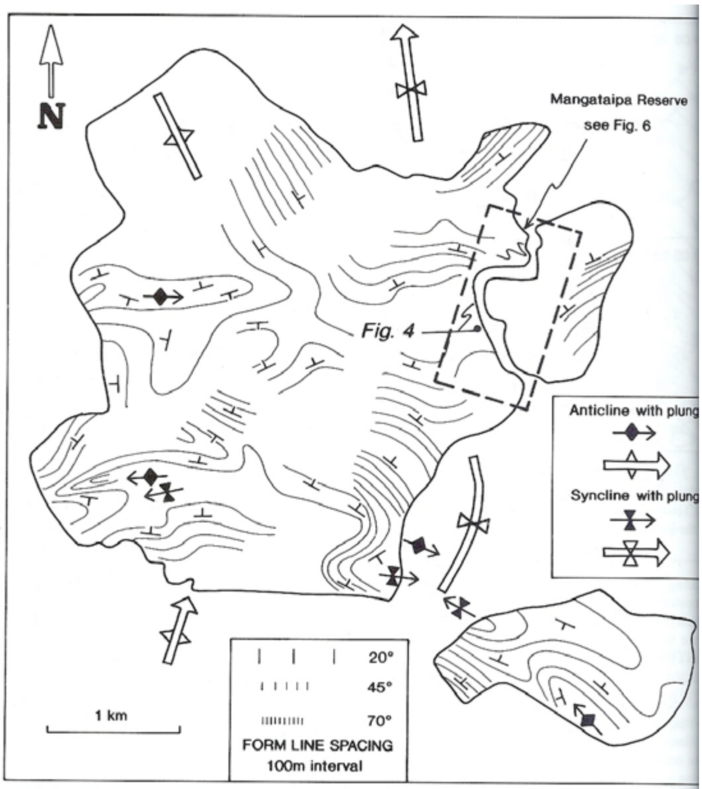


Fig. 3 Form line map on the Mangataipa limestone block (location see Fig. 1), indicating south-verging fo (filled axial trace symbol), refolded by open, non-cylindrical symmetrical folds trending north-south. Closen of form lines gives approximate dips. The locations of Figs. 4 and 6 are indicated.

Fig.15: Refolding in the Mangataipa limestone slab (from Clarke et al. 1989, Fig.3)

At the scale of this large 25 km^2 block of limestone, form lines show refolding of E-W trending folds by N-S trending folds (**Fig. 15**) .

Backtrack to Kaikohe via the west side of Lake Omapere and by Putahi rhyolite dome
Mangamuka to Omapere 80 km, ~ 1hour, 10 min

Stop 10 : Omapere Conglomerate southwest of the Copthorne

HT 1337h 3.3m, first access 1700h, **LT 2003h**

Walk (10-15 min.) along the shore line from the hotel to study the **Miocene Omapere Conglomerate**, which we saw from a distance yesterday at Stop 5. The Omapere Conglomerate is the uppermost of three conglomeratic or coarsely clastic units about 300 m thick, unconformably overlapping the Northland Allochthon (Isaac, 1996). While the lower units have dominant clasts derived from the sediments of the Allochthon, Omapere Conglomerate chiefly contains Tangihua Volcanics debris. Early Miocene ages have been determined from foraminifera.

Accommodation: Copthorne Omapere,

Saturday 27 Nov. Omapere-Doubtless Bay

Omapere – Koutu boulders

Stop 11 : Northland Allochthon lithology and structure, Koutu

LT 0800, last access 1100h , **HT 1415h**

Drive north to Pakanae, turn left onto Koutu Loop Road ,then left again onto Waione Road and park at the first beach access near a large Macrocarpa tree,

While the spectacular **concretions** accumulated as an erosional lag deposit are the main attraction here, visited by numerous tourists, this shore platform exposure also is a good example of the structural relationships between various rock types in the Northland Allochthon.

At the beach access , we encounter a flat reef of '**Ngatuturi claystone'**, siliceous mudstones of the **Whangai Formation** of the Mangakahia Complex (**Figs. 3 and 4)** (This is also the chief lithology underlying the Ngawha Hot Springs visited yesterday). Note the dense network of small scale shear planes associated with more prominent 'consolidated fault zones'. This type of structure is typical for the Ngatuturi Claystone' throughout the allochthon (Spörli 2007).

Eastwards along the beach there are grey, red and green relatively **thinly bedded siliceous sequences equivalent to the Hukerenui facies** (**Fig. 4**) . In part they are intensely folded and faulted (broken formation?). There is also at least one lens of **Waipawa Black Shale**, the most important **hydrocarbon source rock** in the allochthon.

There is one mass of more solid, dark rocks, which on inspection turns out to be igneous. These are **basaltic rocks of the Tangihua ophiolites** (**Figs. 3 and 4)** and once must have been continuous with the dark rocks of the little unnamed conical islet offshore. Therefore we must be skimming just below the contact between the Tangihuas above and the allochthon sediments below. It is extremely rare to get as close to such a contact in Northland. Most likely these igneous rocks represent the (thinned-out ?) slab formerly connecting the **Warawara Tangihua massif** (709m) in the north with the nearby **Waima massif** (781m) in the south.

Further east the concretions increase in size and we see sandstones and mudstones equivalent to the **Punakitere facies** (**Fig. 4**). These are the **host rocks of the concretions**, as we can conclude from swarms of small concretions and at least one outcrop of massive sandstone with a large in-situ concretion. Bedding is well visible, strikes are northerly and dips steep. These concretions are roughly equivalent to the Moeraki boulders of Otago (South Island) .

Koutu boulders to Rawene 24 km, 20 min.

Drive back via Koutu Loop Road to the junction with Hwy 12 at Motutoa and then turn left (east).

The road now goes over a saddle to Whirinaki. Light gray and brown soils indicate that the **nearby hills are all underlain by allochthon sediments**. One or two concretions can be seen in the paddocks. Therefore the basal contact of the Tangihuas we have just seen on the shore platform **must rise up at least 160m and then descend again** to about below 100m to join the Tangihuas of the **Waima/Whirinaki Massif,** dark outcrops of which we can see to the right as we descend to Whirinaki. This complexity is in part due to an N**E-SW trending anticlinal fold** similar to the one at Waimamaku (see Stop 4), but **normal faulting down-dropping** the northern edge of the Waima Massif against the allochthon sediment also plays a role. Such normal faults are very common at the outer edges of the Tangihua massifs and in the early days caused much confusion about the tectonic situation.

Note the prominent **quarry in Mahurangi limestone** to the left, as the road meets the Omanaia river estuary.

Rawene Ferry 1130h or 1230h
Lunch at Kohukohu

On the Kohukohu-Rawene Road, we traverse monotonous sandstones and mudstones of the Punakitere facies. We are now in the **highest of the thrust sheets** with sedimentary rocks of the allochthon, with the oldest ages.

At the turnoff to Mangamuka Bridge near Mohuiti turn left. View north into the precipitous southwestern end of the **Maungataniwha Massif**. This is the largest of the on-land massifs. Only two submarine massifs, one extending NW from Ahipara and the other from Cape Reinga, are larger (Isaac et al 1994).

Stop 12: **Runaruna Mud Volcano**

Drive west along the SW-end of the Maungataniwha Massif through Broadwood **then turn off to the left (south) on onto Pawarenga Road**. Proceed to junction with Runaruna Road , then drive a few hundred metres along it to a ridge-top point for a view of the steep eastern end of the Warawara Tangihua Massif.

Drive back to the junction, park and walk 10 min. to the **mud volcano**. Produces saline (probably connate) water, carbon dioxide, methane and some paraffinic wax and is one of the few true hydrocarbon seeps in the Northland area (Isaac et al 1994, Isaac 1996).

Drive back to the main road and continue north, past Herekino at the head of the narrow Herekino Harbour, then through the **Herekino Gorge.** This marks a NNW-SSE trending fault zone in which the Ahipara Massif in the east and the southern end of the large submarine massif have been pushed together, squeezing up the underlying Allochthon sediments in the space between. We are now driving precisely along the **Junction Magnetic Anomaly** buried below us, with Murihiku basement to the west of us and Caples to the east.

*After the gorge take the **Roma short cut** (left) to **Ahipara Bay**.*

Stop 13: **Ahipara Bay comfort stop**

Tide will be high, but we may still see some of the Tangihua rocks. This massif is topped by a pronounced Cenozoic erosion surface on which the gum-diggers mined kauri gum (Gumfields Road and reserve) .

We are at the southern end of **Ninety Mile Beach**, which extends north to Cape Reinga. The peninsula north of here is essentially a group of **tombolos linked together by sand dunes**.

Drive back to Kaitaia

Kaitaia to Aurere Point

Flat plains to the left and Maungataniwha massif to the right. Major river and Hwy 1 turnoff to Cape Reinga at Awanui. Mount Camel of the **Mount Camel suspect terrane** (Isaac et al. 1994, Toy et al. 2002) on the distance to the NE.

Lake Ohia and **Inland Road turnoff to Cape Karikari** on the left. **Petroliferous Whangai shales**, with quarries, on the right.

Next road cut: Well bedded **Hukerenui facies** on both sides of the road.

Stop 14 : Aurere Point /Cable Bay Northland Allochthon

LT 1910h, first access 1500h

Drive out to Aurere Beach access and walk out to Aurere Point. First outcrops: sandstones, fine conglomerates and mudstones (some with plant debris) of the **Awapoko facies** (**Fig. 4**). CHECK YOUNGING! Follow sandy beach to the point with Puketu Island on the left. **Tangihua Volcanics** with pillow lavas, harrisitic gabbro, and interbedded red sediments. Considered to be thrust up onto the Awapoko facies sediments.

On the horizon: **Karikari Pluton** associated with the **Whangaroa centre of the Miocene volcanic chain** (**Fig. 5**)

Aurere Point- Cable Bay 15 min

Drive through **Taipa**. A small Miocene volcano has produced garnet-bearing andesites.
Over the hill to Cable Bay.

Stop 15 : Tangihua Volcanics and mélanges Cable Bay
LT 1910h, first access 1500h

Good exposure of low portions of the Maungataniwha Massif, with **dark sedimentary rocks in mélange contact with coarse Tangihua igneous rocks**. **Berghan Point** to the SE, with even more complex sediment/igneous relationships and intruded by Miocene dikes associated with a Karikari type pluton.

Cable Bay to Mangonui 12 km, 10 min

Drive through **Coopers Beach**. Road cuts on the right: Miocene clastic sediments with **fossil coconuts**.

Accommodation Mangonui Hotel, 112 Waterfront Drive
Dinner at Fish Shop Mangonui

Sunday 28 Nov. Doubtless Bay – Whangarei

Mangonui to Tauranga Bay 45 km, 45 min

Drive south through large tracts of Tangihua Volcanics of the **Maungataniwha Massif,** mostly weathered to orange brown soils.

Turnoff to Taupo Bay on the left. Further south, jagged hills on the left and the spectacular flat-topped block of **Mount Taratara** (302m) on the right mark the erosional outer rim of the Early Miocene **Whangaroa Volcanic Complex**, unconformably deposited on both Waipapa basement and Tangihua volcanics. It consists of laharic clastic rocks associated with basaltic to rhyolitic intrusions, flows and ejecta, with andesite compositions dominating (Hayward 1991).

At the turnoff to Totara North we reach the Whangaroa Harbour, with the settlement of Whangaroa SE across the harbour and **St. Stephens Roc**k (Ohakiri, 213m) behind it, another outlier of the Whangaroa Volcanics.

Hwy 10 now follows the upper shore line of the Whangaroa Harbour and heads straight east towards a range of hills which mark a **northward tilted block of autochthonous basement**. At the T-junction with the Whangaroa Road, good exposures of north-dipping **Oligocene Ruatangata glauconitic sandstones.** These onlap directly onto **Waipapa terrane greywackes** which are exploited in quarries nearby.

We turn left , follow Whangaroa Road. Turn right onto Wainui Road (to Tauranga Bay) . This road follows the boundary between the tilted basement block on the right and the overlying Northland Allochthon sediments to the left.

In Tauranga Valley, turn left onto Tauranga Bay Road. The cliffs on the side of the valley are **Miocene Whangaroa Complex clastics** overlying Waipapa basement rocks.

Park vans and walk over the hill to Spooner property and down to Wherowhero Point

Stop 16 : Wherowhero Point, Tauranga Bay- Marble Bay basement rocks:
LT 0726h, last access 1100h

The **Permian fusulinid limestones (Fig. 16)** mark the **oldest rocks exposed in the North Island** (e.g. Leven and Grant-Mackie 1997). They all occur embedded in basaltic lavas. Map distribution of the different basement lithologies, basalts, red cherts and argillites, and overlying ‘greywackes’ (**Figs. 17 and 18**), clearly shows a thrust imbrication pattern, which has been attributed to **accretion tectonics on the Gondwana margin** (Spörli 1978, Spörli and Gregory 1980, Spörli et al. 1989, Aita and Spörli 1992).

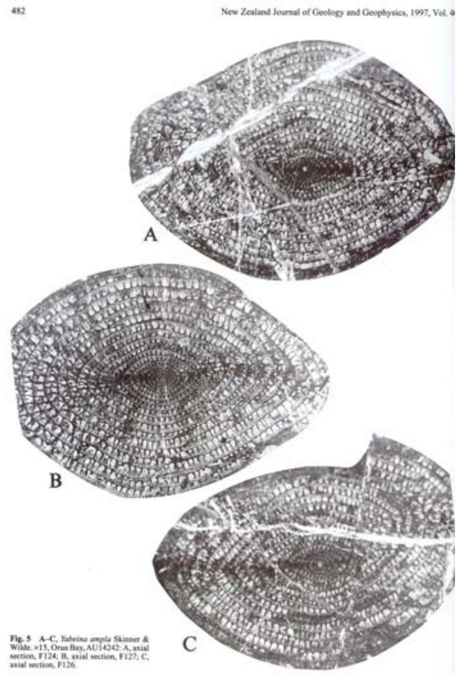

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Fig. 5 A–C, *Yabeina ampla* Skinner & Wilde. ×15, Orua Bay, AU14242: A, axial section, F124; B, axial section, F127; C, axial section, F126.

Fig. 16: Permian Fusulinids from Wherowhero Point (Leven and Grant-Mackie 1997, Fig. 5)

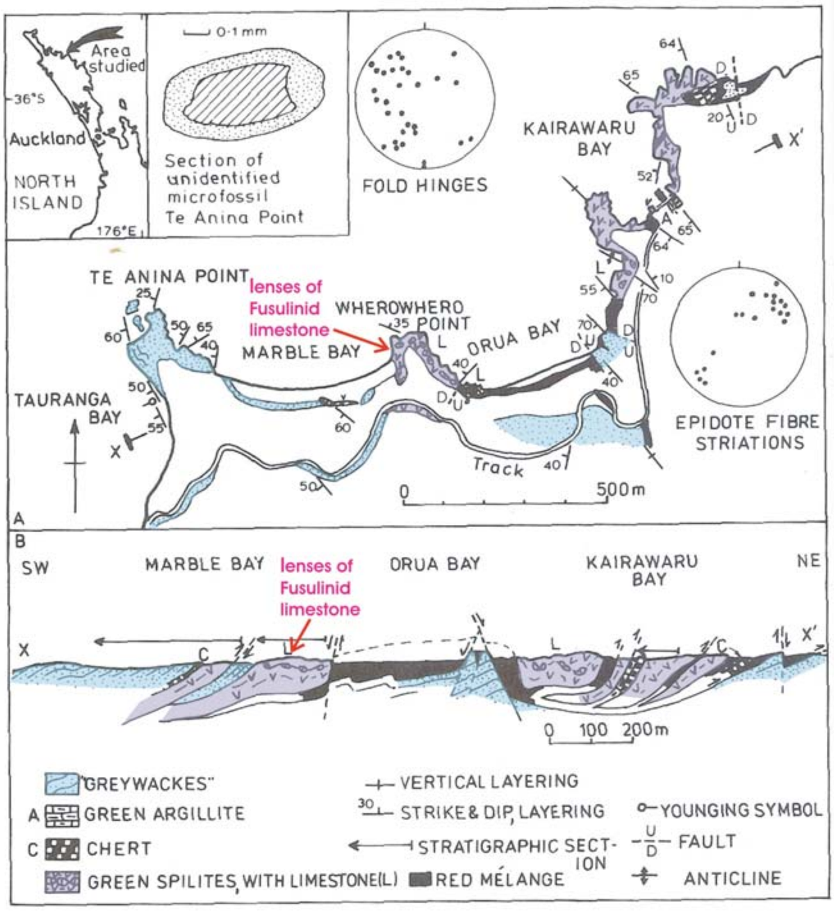

Fig.17: Map and cross section of the Marble Bay area (from Spörli and Gregory 1980)

There is the question of whether the basalts in the sequence **represent true ocean floor material** generated at a spreading ridge or whether they are **seamount-derived (Fig. 18)**. and geochemical work (Jennings 1991, Sakakibara and Black 2007) and the presence of the highly tuffaceous 'red mélanges' favour the seamount interpretation. That implies that the true spreading ridge-derived sea floor material must be even older.

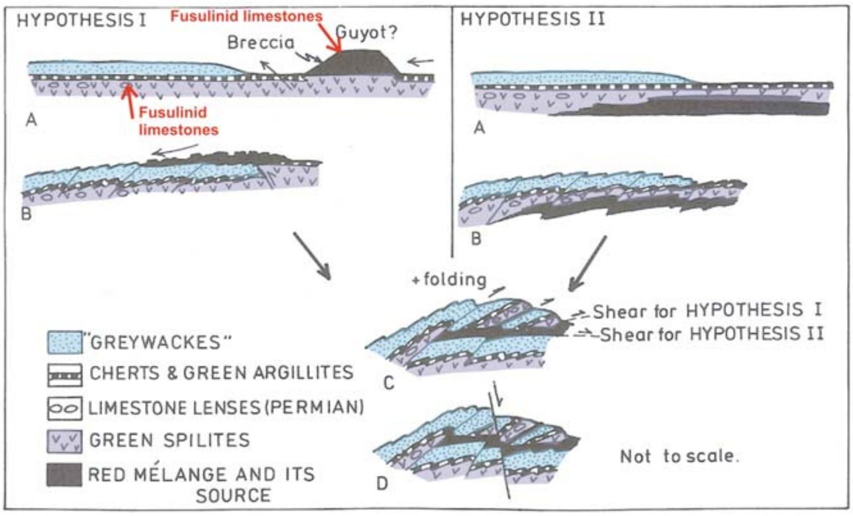

Fig. 2--Hypothetical development of structure near Marble Bay during underthrusting and imbrication of uppermost oceanic crust in a subduction zone along the Gondwana margin. I: Both top and bottom contacts of red mélange are shear zones. II: Shear along base of red mélange, top contact stratigraphic. For stages A and B in both hypotheses, the join between converging plates (trench?) can be visualized to the left of the diagram; in subsequent stages the material has been transferred to the Gondwana side. Note that direction of folding and imbrication in stage B may be at right angles to that in stage C.

Fig.18: Two accretion scenarios for Marble Bay (from Spörli and Gregory 1980, Fig.2)

There is a **striking contrast** between the **warm climate** (tropical?) environment indicated by the fusulinid limestones and the **polar position** of the New Zealand Gondwana margin in the Permian, indicating **long distance plate transport** of the volcanics limestone and cherts before the terrigenous clastics were deposited on them.

Note the island of **Arrow Rocks** (Oruatemanu) just offshore, where a chert-dominated sequence containing the **Permian –Triassic boundary** has been intensively studied by a Japanese-New Zealand group, using radiolarian, conodont fossils and geochemical techniques (e.g. Aita and Spörli 2007, Spörli et al. 2007). Some important results are the definition of two oceanic anoxic events, discovery of early Triassic radiolarian P-T catastrophe survivors and the realisation that the basalts can be intrusive into the fusulinid-bearing limestones.

Walk back to vans, drive around to Tauranga Bay.

Exposure of the **Whangaroa Complex Miocene volcaniclacstics** at the west end of the beach

Marble Bay to Kawakawa via Kerikeri 73 km

Drive back to Hwy 10 and then south through **Kaeo** on through the **autochthonous basement block** studied at Tauranga Bay. Highest summits on the left are still **Miocene volcaniclastics**. Their southernmost outcrop is the **pinnacle of Orotere** (313m) where the road makes a sweeping left turn. Good views down to the west onto the **Cenozoic erosion surface** on the **Puketi Forest Block** (seen from the bottom, i.e. south, on Friday) which is down-dropped relative to the block we are driving on.

Matauri Bay turnoff on the left. The road still follows the top surface of the upper block, with some **black Kamo Coal Measure** outcrops (Mid-Late Eocene) of the **basal Te Kuiti Group** on the right hand side. They are interspersed with white clay exposures due to alteration underneath the

Kerikeri basalts (we saw their eastern termination on Friday) which cover the Tertiary sediments. The high grade clays are exploited for ceramics in a quarry to the east.

Kerikeri is a centre of horticulture located on a plateau of fertile soil developed on the **Kerikeri Volcanics**. As we drive south, we reach the edge of the plateau and the road drops down onto the Cenozoic erosion surface carved on the autochthonous Waipapa terrane.

Cross the Waitangi River

Puketona Junction: note large greywacke quarry in the distance to the left

Kaikohe Road Junction: The road on the left leads back to Ngawha (seen on Friday) .Volcanic cones of the **Kaikohe sub-field** of the Kerikeri Volcanics on the right with **Pouerua** (270 m) most prominent. There are outcrops of Northland Allochthon scattered over this plateau.

Stop 17 : Kawakawa fault line (Hundertwasser toilets)

The road makes a sharp left hand turn into a steep ENE-SSW-trending scarp of the Kawakawa Fault and descends to Moerewa (former freezing works on the right), The fault down-drops the greywacke block in the south by at least 200m. The main movement probably post-dates the emplacement of the Northland Allochthon

We drive over a Kaikohe lava flow has infilled the lower side of the fault line. Small weathered outcrops and old quarry in the Waipapa terrane greywackes on the left.

Enter the **town of Kawakawa** with its railway to Paihia on the main road. Visit the **Hundertwasser toilets**:

Frederick Hundertwasser first visited New Zealand in the 1970's . he decided to make it his second home, purchasing an isolated rural property east of the Kawakawa. Initially he was to still spend most of his time in Europe , Vienna in particular. But later he spent more and more time at his New Zealand home. He felt for the town and its entrapment in the rural decline. In 1998 the Kawakawa Community Board accepted his concept for reconstruction of the public toilets and construction was completed later that year, with the artist personally lending a hand in construction supervision, including the provision of materials from his own studio. With the untimely death of the artist in February 2000 on a sailing trip between Europe and New Zealand, the building is the only Hundertwasser structure in the Southern Hemisphere, and his last major project. Creative New Zealand gave the project the "premier" certificate in the Creative Places Awards 2000 contest. (After Flat Rock: To Toil et Art (Chaotic Web Development))

Kawakawa to Ocean Beach 85 km, 1 hour 25 min

Where the road turns right to head south after Kawakawa, small disused **greywacke quarry** on the left with onlapping Te Kuiti Group sediment just visible at the top

From here on, the road will be sub-parallel or following the boundary between **autochthonous basement on the left** and (overlying, but down-faulted) **Northland Allochthon on the right** all the way to Hukerenui (see below)

Waiomio: **Kawiti Glow-worm Caves** in the hills to the left. Karst in the bioclastic **Whangarei Limestone** (Oligocene) of the autochthon. Some blocks of this limestone can be seen in the fields to the left a km or so to the south.

This is the area where superposition of older on younger rocks was first recognised in the nineteen-forties (Isaac and Grieve 1989) on drilling evidence and a **Kawakawa Overthrust** was named.

Maromaku: Motatau turnoff on the right: Hilly country underlain by resistant allochthon lithologies. Motatau is the type are for the carbonate-rich **Motatau complex** (**Figs. 3 and 4**). As we went south, we have now dropped down into a lower thrust sheet of the allochthon, with the youngest (Oligocene) rocks becoming dominant.

View out west (right) into the allochthon country with the **Tangihua Massif** in the distance. As the road descends to flatter lowlands of the Hukerenui swamps light grey/yellowish outcrops in road cuts on the right with dark hydrocarbon stains: **Waipawa Black Shale** of the allochthon**.**

Ruapekapeka turnoff on the left: A large Pa (Maori fortification). In 1845-46 site of one of the first trench warfare battles in the world. Outcrop of folded chert in Waipapa terrane basement

Hukerenui: The road now runs along a fault separating a lower block of autochthonous basement on the right (west) from an up-thrown block to the right

Wilsonville: site of tomorrow's quarry visit.

Hikurangi: view of the two Pleistocene dacite domes of Parakiore (0.45 Ma) and Hikurangi (1.25 Ma)

We now **drive into Whangarei**, one of the geologically most complex cities in New Zealand, with autochthonous basement blocks, Northland Allochthon sediments, Miocene arc volcanics and Quaternary Dacite to basalt volcanoes.

Drive out to North Ocean Beach: First along the NE side of Whangarei Harbour, controlled by the hypothetical curved Harbour fault.

Onerahi Peninsula: The peninsula owes it shape to a 2-4 Ma old lava flow from Parahaki (outlook to be visited tomorrow morning) which protected Mahurangi limestone from erosion. **Onerahi Chaos** was the name used for the complexly structured material in the Northland Allochthon before their true nature was recognised (Ballance and Spörli 1979).

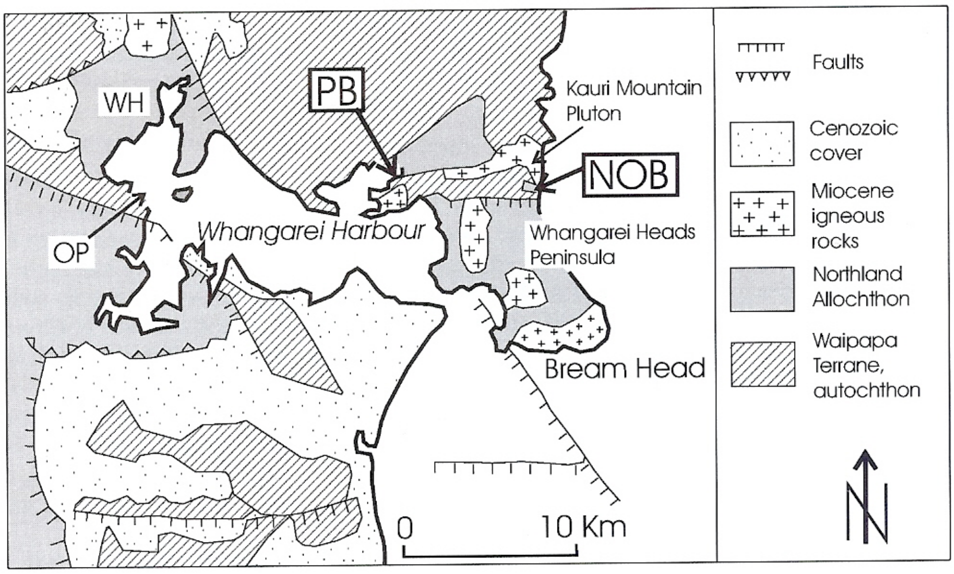

Fig 19: Map od the Whangarei area with Parua Bay(PB) and **North Ocean Beach (NOB).** From Spörli and Harrison (2004).

We now drive along **Whangarei Heads** Road through Waipapa terrane basement to **Parua Bay**: At the Marina, red Waipapa terrane cherts on the seashore. Bay on the opposite shore (**Fig. 19)**: **western allochthon inlier** (Spörli and Harrison 2004).

After Parua Bay, the road changes its name to **Pataua South Road**: follow this through rolling allochthon country to

Kauri Mountain turnoff (on the right): This gravel road takes us south over a small saddle through the Miocene **Kauri Mountain Pluton** to the access for the next stop.

Stop 18 : Ocean Beach basement/Allochthon relationships:

HT 1319h 2.6m, first accesss 1500h, **LT 1933**

Here the Northland Allochthon, which overlies and 'autochthon' consisting of basal Waitemata calcareous clastics onlapping unconformably onto the Waipapa basement is **jammed tightly in a synform between two basement blocks** (Spörli and Harrison 2004).The structure also contains a Miocene porphyritic dacite dike, probably associated with the nearby Kauri Mountain Pluton (**Figs. 5 and 19**).

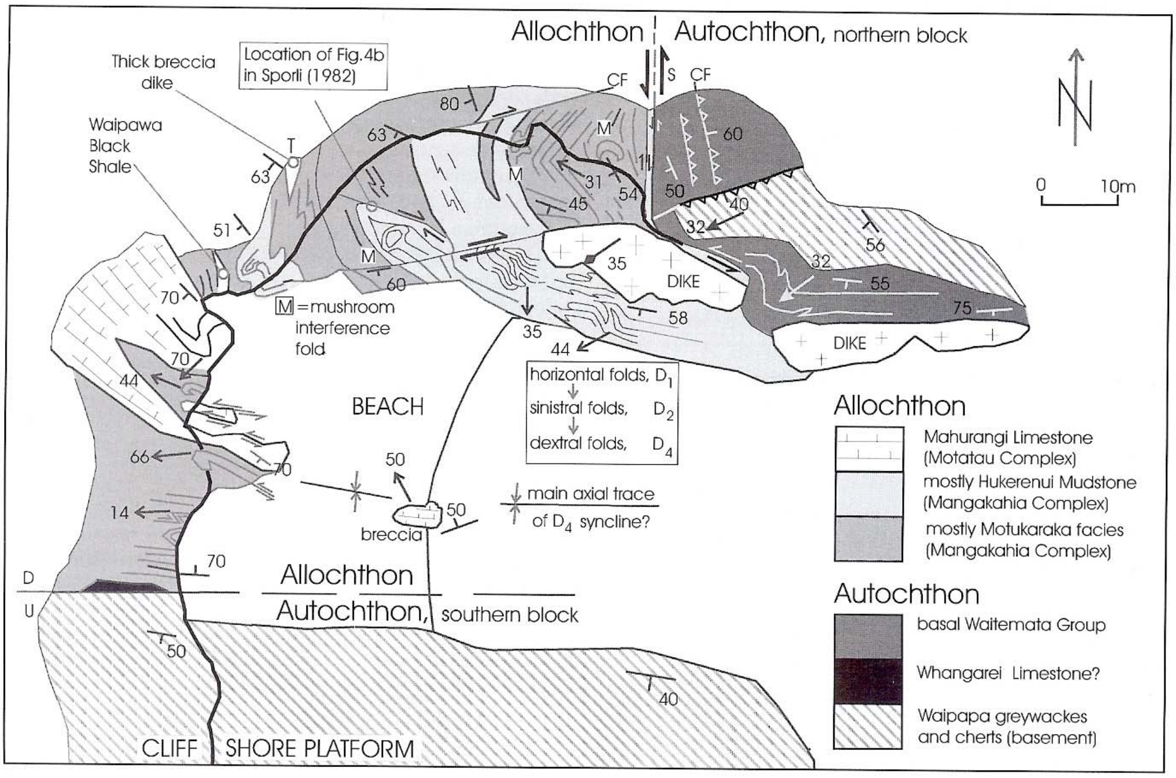

Fig. 4 Geological map of the north Ocean Beach site (location see Fig. 2). Geology at the northern end of the beach has been assembled from observations at various stages of sand cover. Some minor rock units are directly labelled onto the map. Arrows show orientation of selected fold axes (open arrowheads for allochthon, solid arrowheads for Waitemata Group). Arrow with diamond = representative axis of dike neck. CF = Late (D_5?) conjugate thrust faults. The line labelled "main axial trace of D_4 syncline?" separates the steep, thinned-out limb of the D_4 syncline in the south from the thicker normal limb in the north.

Fig. 20: Map of infolded Northland Allochthon, North Ocean Beach (Spörli and Harrison 2004, Fig. 4)

After a short walk to the beach, we will head north along the shore line. The first section is through **Waipapa Terrane greywackes** with **several layers of chert** and one exposure of ocean floor volcanics.

The southern contact of the allochthon is a **fault with a displaced sliver of Whangarei limestone** along it. We then can study the various lithologies of the allochthon and their complex folding. Note the presence of **clastic dikes**.

At the northern contact, **Waipapa basement is overlain by basal Waitemata** (early Miocene) calcareous sandstones which describe an almost 90° turn in strike pattern, indicating the nose of a **steeply plunging dextral fold**. Calcite fibre striations on small faults support this interpretation. Disrupted **Northland Allochthon rocks overlie autochthonous Waitematas** along shear zones with sinistral sigmoidal shear sense indicators.

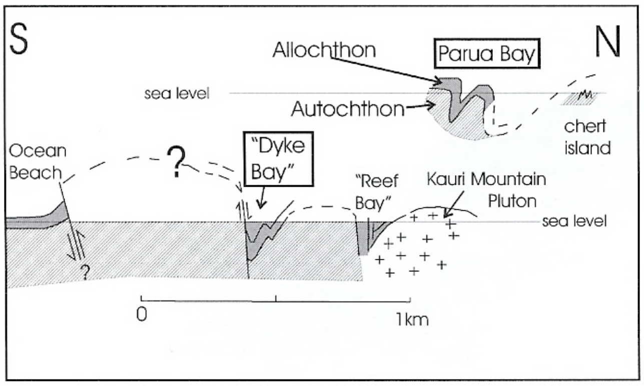

Fig. 21: Structural interpretation, Ocean Beach/Parua Bay (from Spörli and Harrison 2004)

We will discuss the significance of these outcrops in the field. However considerable mobility of the autochthonous basement is indicated (also see Hayward 1989).

Ocean Beach to Whangarei 30 km, 40 min.
Accommodation: Bella Vista Hotel

Monday 29. Nov. Whangarei – Auckland

Stop 19 : Weather permitting: drive up to Mt Parihaka (259m) for view of southern Northland Geology

Whangarei to Wilsonville 18 km, 25 min

Stop 20 : Wilsonville quarry : (Hard hats)

Note that the basal coal measures exploited in nearby, now defunct mines have cut down right onto the greywackes, i.e. there are no Cretaceous sediments left on the autochthonous basement in Northland and all the Cretaceous rocks present are exotic, being part of the Northland Allochthon.

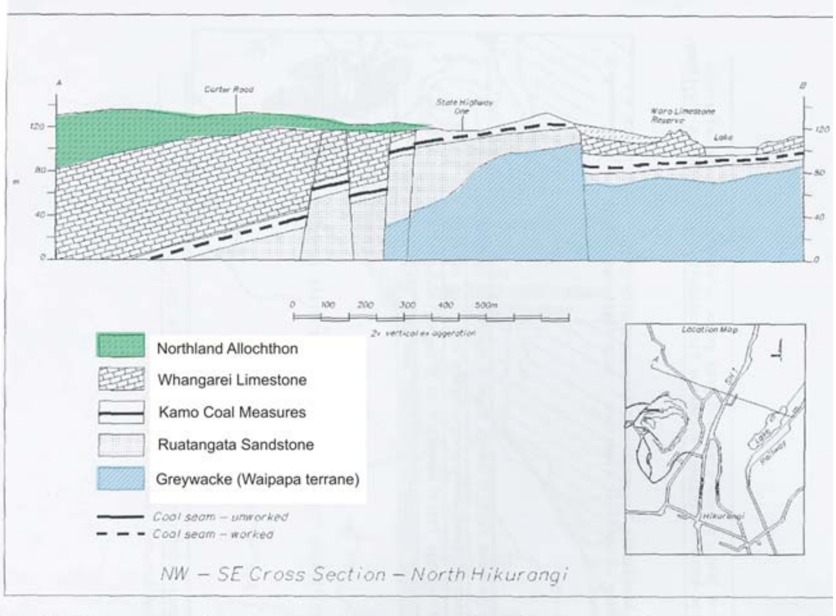

Fig. 3-5.3: West-east geological cross-section through the Wilsonville Quarry – Waro Rocks area (STOP
Wilsonville Quarry is located just west of Carter Rd (from K. Miller unpubl.).

Fig. 22: Cross-section through Wilsonville Quarry. From Hayward et al. 2002, Geol. Soc. NZ Miscellaneous Publ. 112B:27-32, Fig. 3-5.3.

This exposure (**Fig. 22**) allows us to study the Oligocene Whangarei limestone of the autochthonous Te Kuiti Group and its relationship to the overlying Northland Allochthon (Onerahi Formation).

The **Whangarei Limestone** (which is also exposed in the nearby Waro karst reserve) is a stylolitic, bioclastic ‘ crystalline’ limestone, mostly consisting of bryozoan calcarenite with 50% bryozoan fragments, 20% echinoid and 20% benthic foraminifera and is interpreted as an inner shelf deposit. It is typical of the cool water limestones of New Zealand.

The limestone of this quarry is transported to the Portland Quarry south of Whangarei as an admixture to the micritic clay-rich Mahurangi limestone mined there for cement production.

Northland Allochthon consists of the usual multicoloured units, including siliceous claystones (Whangai), red, brown and green siltstones and flint (Cretaceous-Paleocene) and rare lenses of Mahurangi limestone. The fabric is typical broken formation which is deformed into west-verging folds.

Wilsonville to Waipu Cove 65 km, 1 hour, 10 min

Stop 21: Waipu Cove
HT 1412h, first access 1700h, **LT 2029h**

At Waipu Cove we can study the Waipapa basement of the tilted Brynderwyn block (See Stop 1) and the overlying Whangarei limestone.

Waipu Cove to Brynderwyn Hill 25 km, 25 min

Brynderwyn Hill to Symonds St 115 km, 1.5 hours
Total driving 3.5 hours

(**Optional Stop**: Waiwera Waitematas)

Airport.

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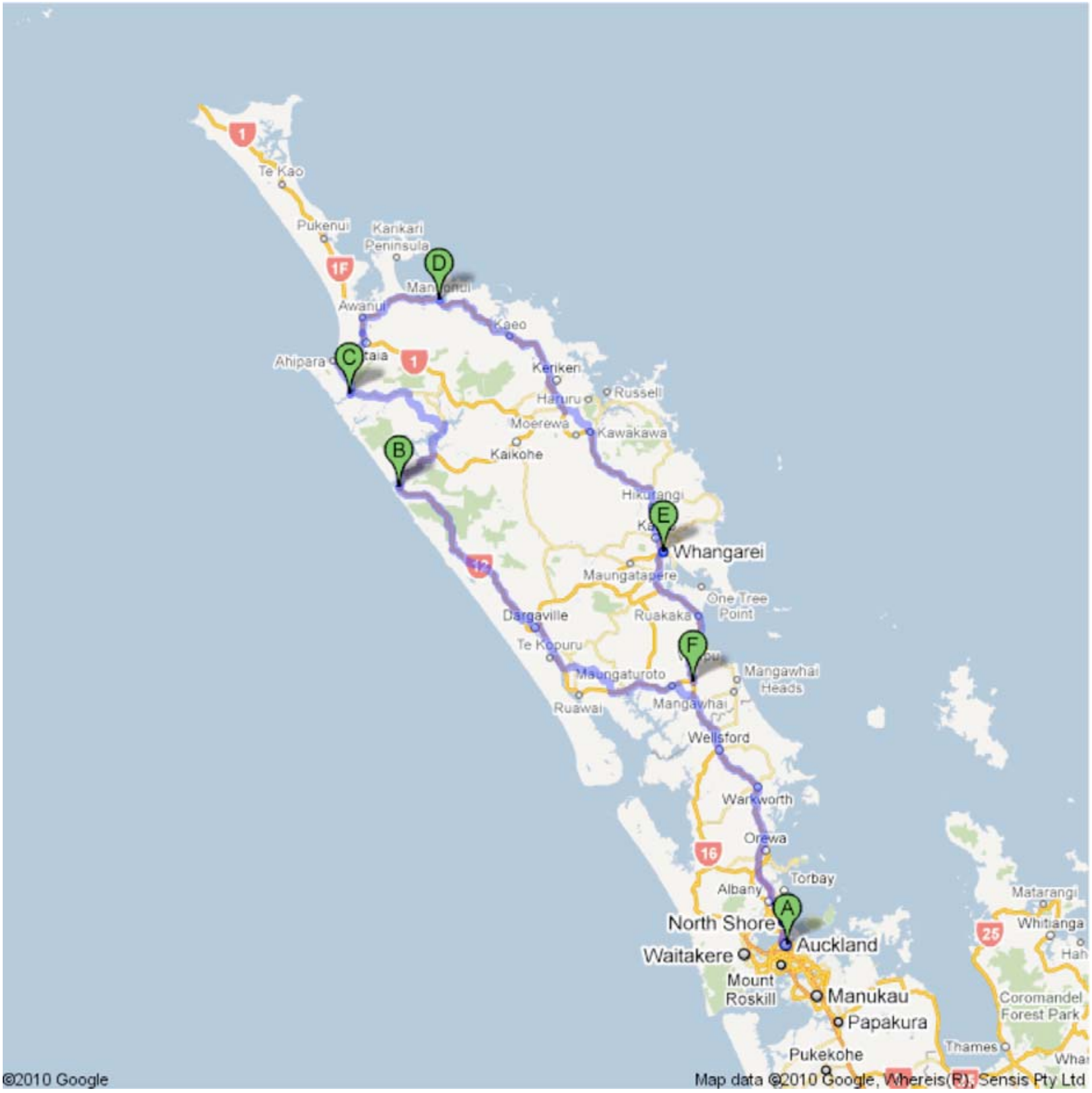
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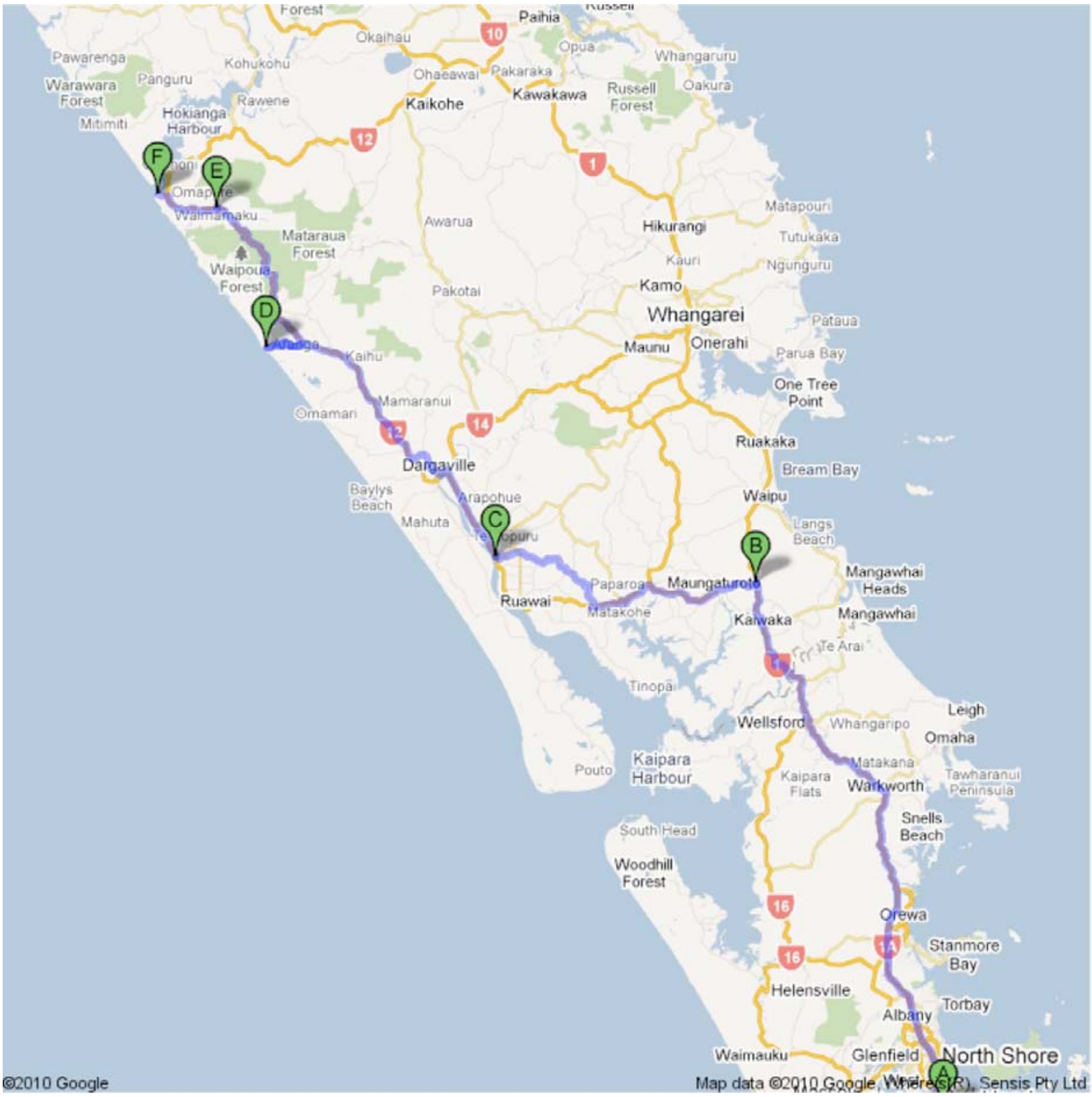
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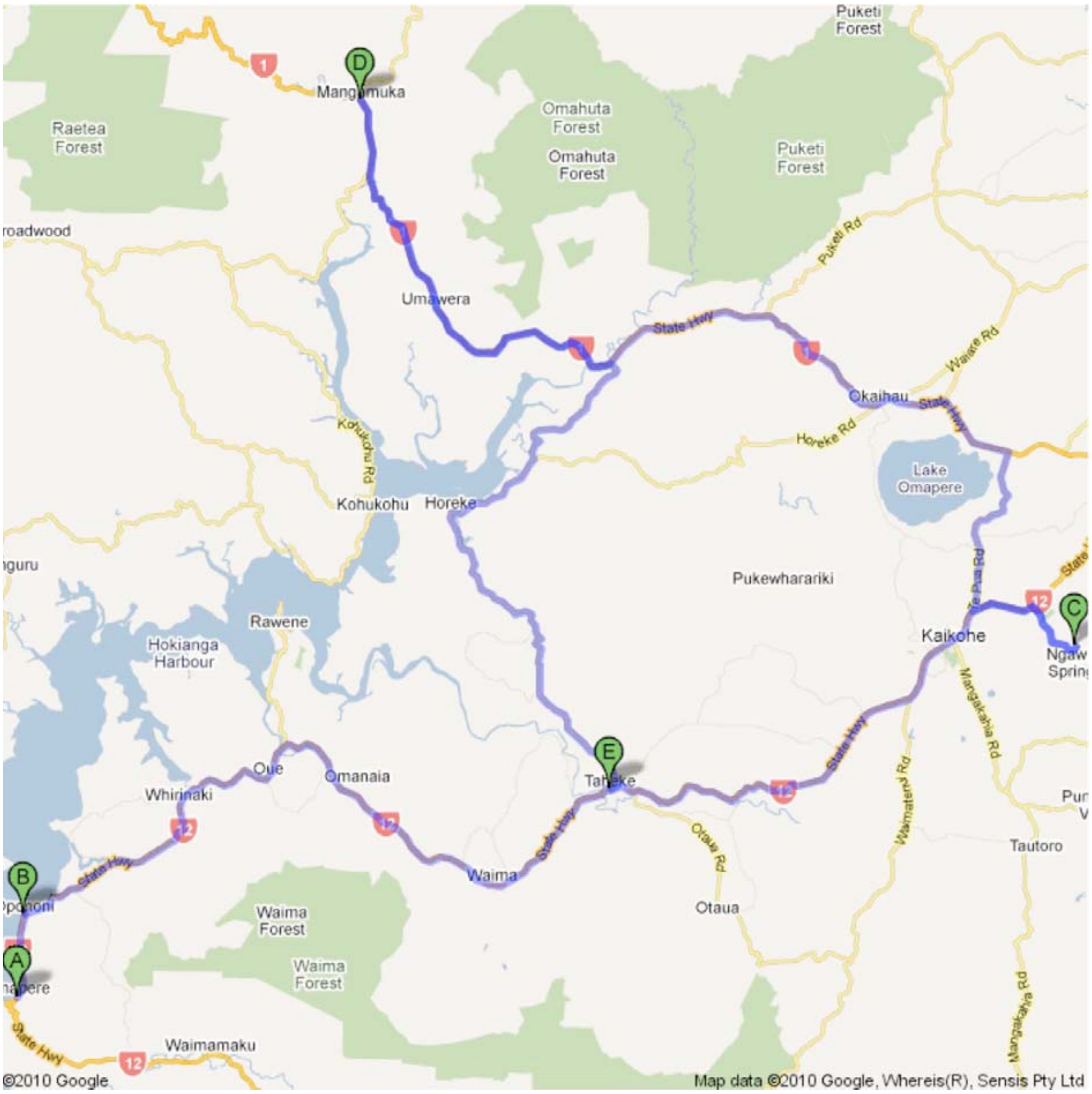
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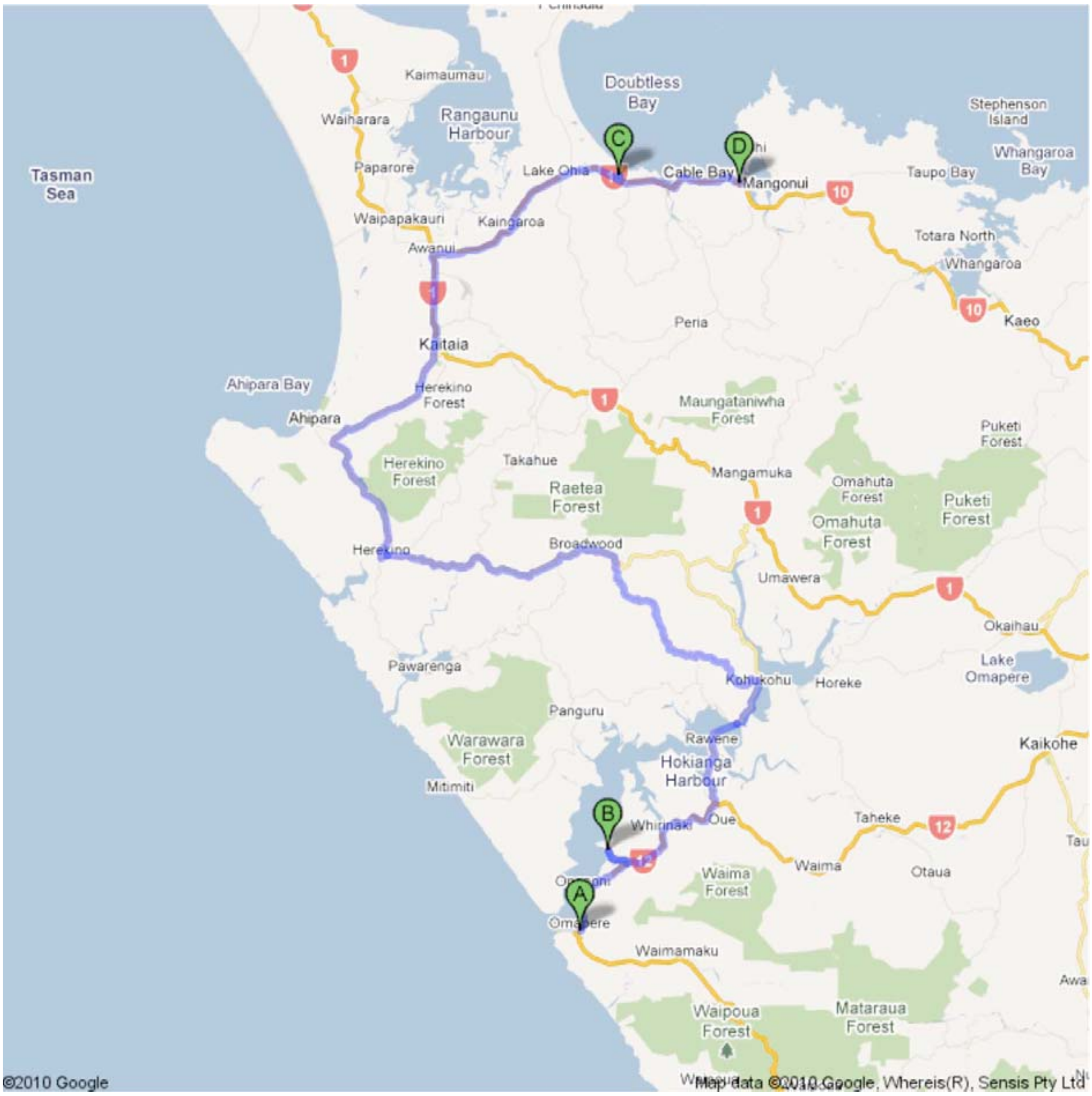

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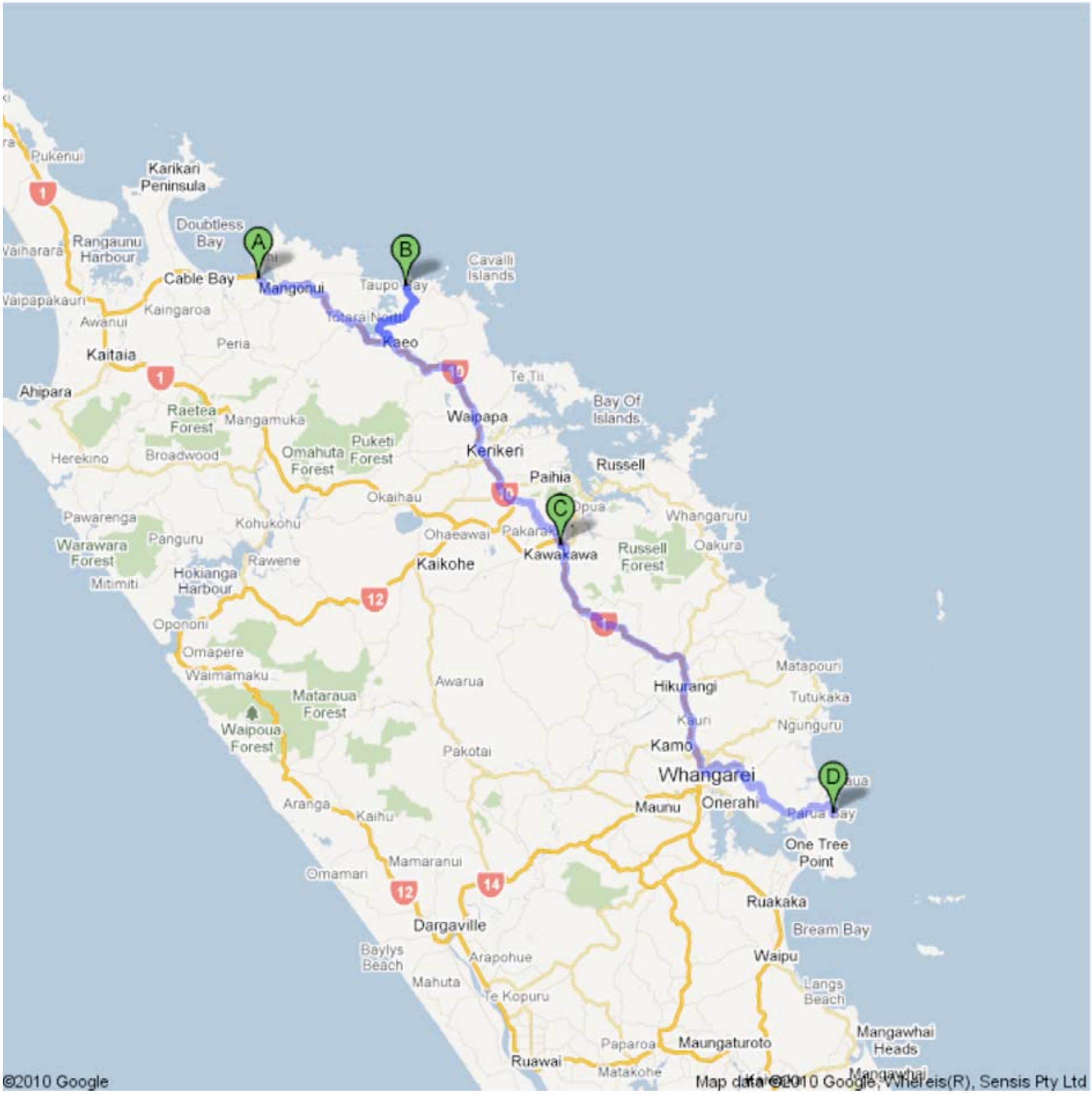
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