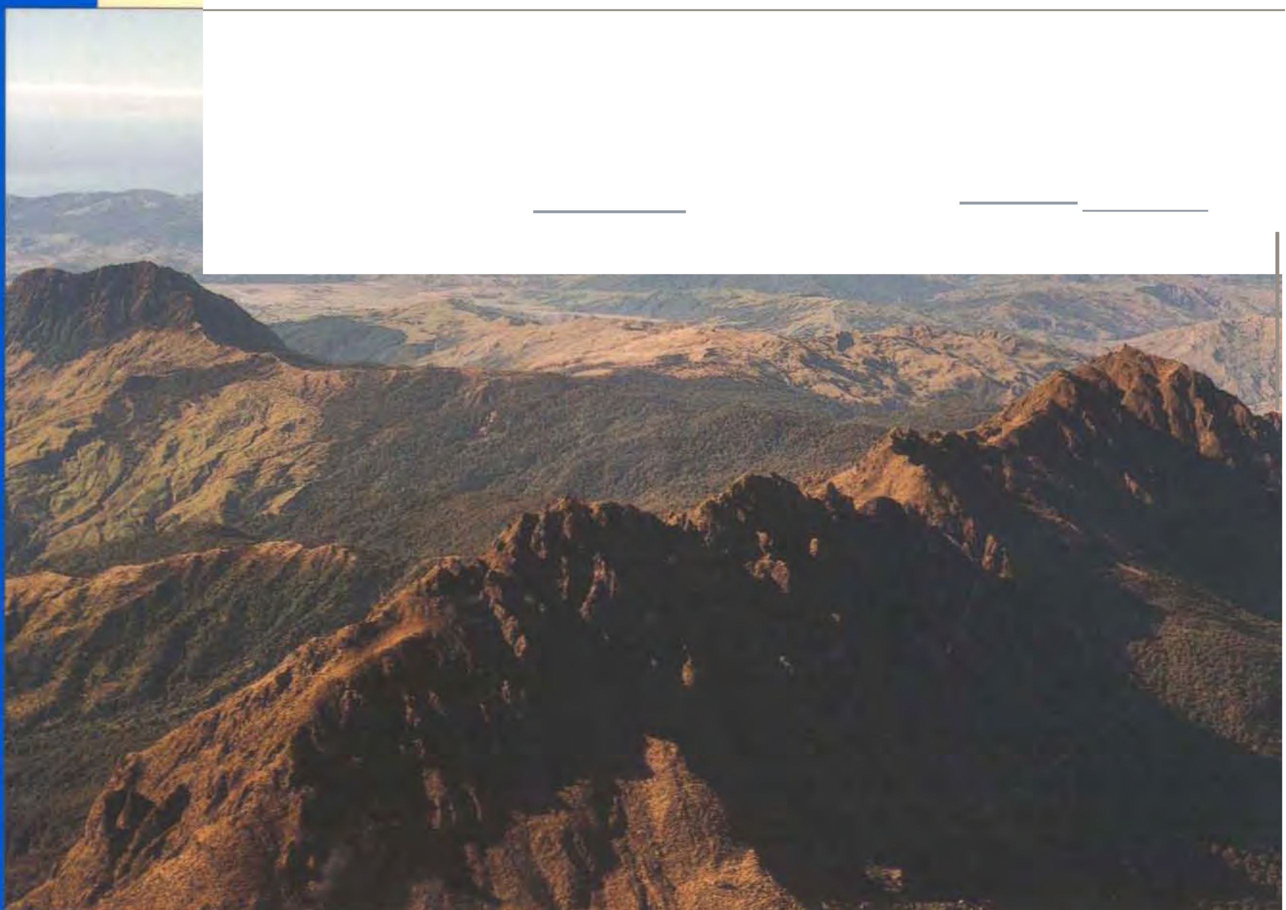
1:250000 geological map 6

GEOLOGY OF THE RAUKUMARA AREA



C. MAZENGARB
I. G. SPEDEN
(COMPILERS)

Institute of GEOLOGICAL & NUCLEAR SCIENCES Limited

Interim New Zealand geological time scale from Crampton et al. (1995), with geochronology after Gradstein & Ogg (1996) and Imbrie et al. (1984).

GEOLOGY OF THE

RAUKUMARA AREA

Scale 1:250000

C. MAZENGARB
1. G. SPEDEN
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Institute of Geological & Nuclear Sciences Limited
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Development and maintenance of ARCIINFO GIS database by D.W. Heron and M.S. Rattenbury

GIS operations by D.W. Heron, *l.A*. Lyall and *l*. Arnst

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Edited by D.W. Heron and MJ. Isaac

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FRONT COVER

Hikurangi (1752 m), the highest nonvolcanic mountain in the North Island, towers over the surrounding deeply dissected countryside. Hikurangi is interpreted as an isolated remnant (klippe) of a formerly more extensive thrust sheet of Torlesse rocks, which now overlies slightly younger, Eariy Cretaceous Waitahaia Formation. The high hill to the east (left) is Aorangi (1272 m). *Photo CN41042: D.L. Homer*

CONTENTS

INTRODUCTION

THE QMAP SERIES

This geological map of the Raukumara area is the sixth of a new national map series known as QMAP (Quarter-million MAP, Nathan 1993; Fig. I) being produced by the Institute of Geological & Nuclear Sciences Ltd. (GNS). QMAP supersedes the previous 1:250000 ("four miles to the inch" or "four mile") geological maps which are now dated (e.g. Kingma 1965, 1966). Since these maps were published new concepts have been developed, and there has been much detailed onshore and offshore geological and geophysical mapping by government, university and industry scientists. The requirement for geological information has also increased as a result of the ResQurceManagement Act, greater demands all geological resources, a new educational syllabus and the greater public awareness of natural hazards and their mitigation. This map presents a revised interpretation of the geology, geological history and structure of the Raukumara Peninsula and adjacent areas offshore.

The geology of the Raukumara area is in many places complex and considerable simplification has been necessary to make it appropriate for presentation at 1:250000 scale. Rock units are mapped primarily in terms of their age of deposition, eruption or intrusion. As a consequence the colour of the units on the map face reflects their age, with overprints used to differentiate some lithologies.

Letter symbols (in upper case, with a lower case prefix to indicate early, middle or late if appropriate) indicate the predominant age ofthe rock unit. The last lower case letter or letters indicates a formally named lithostratigraphic unit and/or the predominant lithology. Age subdivision is in terms of the international time scale. A time scale diagram showing correlation between the international and local time scales and absolute ages in millions of years (Ma) is shown inside the front cover (after Crampton *et „/.* 1995, 2000; Graham *et "I. 2000).*

The accompanying text is generalised and is not intended to be an exhaustive description of the various rock units mapped. For more detailed information the reader is referred to work cited throughout the text and listed in the references.

The QMAP geographic information system

The QMAP series uses computer methods to store, manipulate and present geological and topographical information. The maps are drawn from data stored in tJle QMAP geographic information system (GIS), a database developed and maintained by GNS. The QMAP database is complementary to, and can be used in conjunction with, other digital data sets, for example gravity and magnetic surveys, mineral resources and localities, fossil localities, active faults, and petrological samples. The primary software used is ARC/INFO®. Digital topographic data was obtained from EagleTechnology Ltd., Terralink, and Land Information New Zealand (LLNZ).

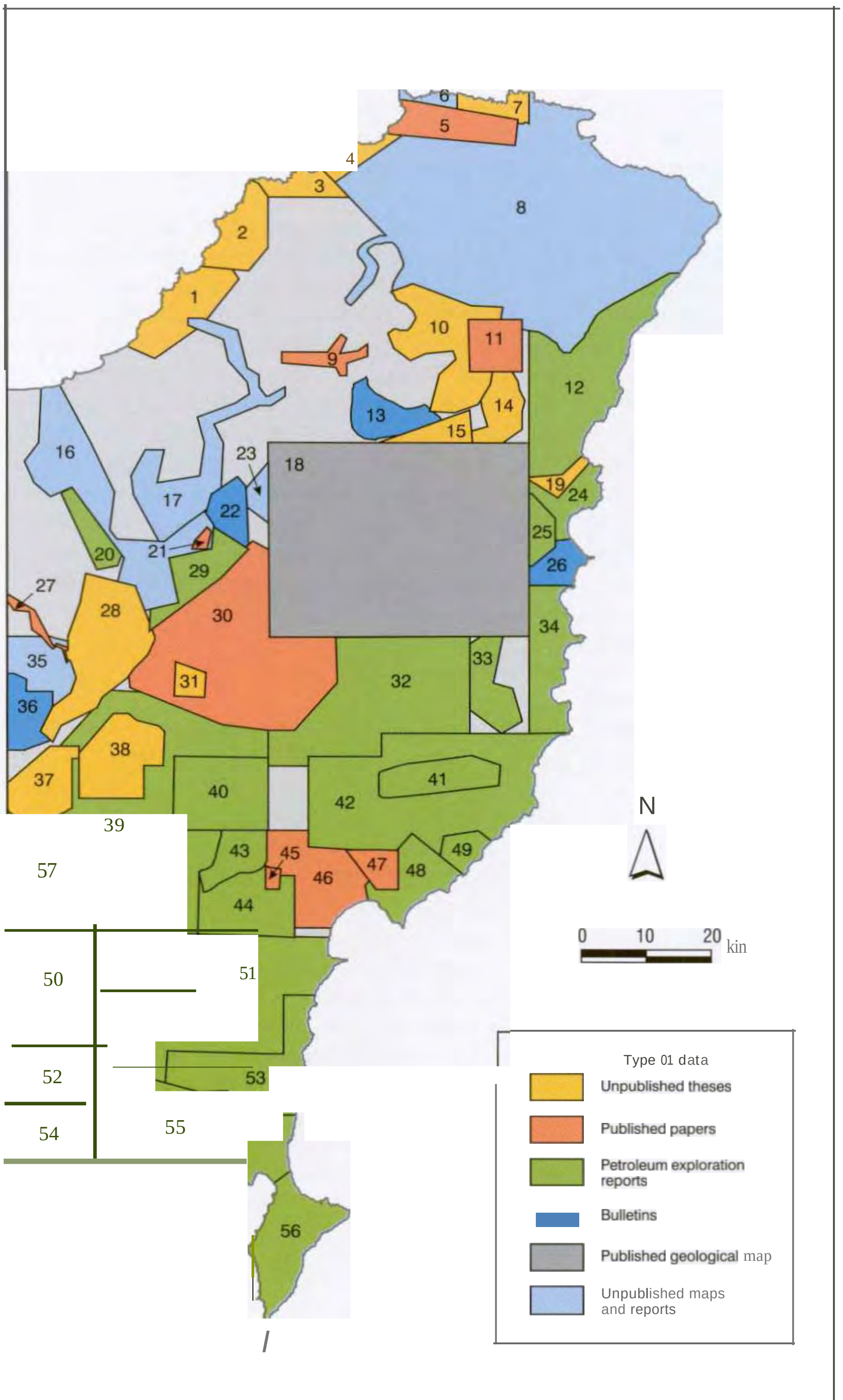
The QMAP series and database are based on detailed geological information plotted on the L1NZ Infomap 260 series 1:50000 topographic base maps. These data record sheets are available for consultation at GNS offices in Lower HUll and Dunedin. The 1:50000 data have been simplified for digitising during a compilation stage, with the linework smoothed and geological units amaJgamated to conform to a standard national system based on age and lithology. Point data (e.g. structural measurements) have not been simplified. All point data are stored in the GIS, but only selected representative structural observations are shown on the map. Procedures for map compilation and details of data storage and manipulation techniques are given by Rattenbury & Heron (1997).

Data sources

The map and text have been compiled from published maps and papers, unpublished university theses, GNS technical and map files, measured section column files, mining and petroleum exploration company reports, field trip guides, the New Zealand Fossil Record file in its digital form (FRED) and the GNS Geological Resources database (GERM). Additional field mapping was undertaken to attain a uniform minimum level of coverage over the map area and to solve problems. However, some areas remain unexplored and problems remain. Many of the landslides and faults were mapped from air photos, with limited field checking. Offshore data have been compiled from a published synlhesis (Field, Uruski *et al.* 1997) and from surveys by the National Institute of Water & Atmospheric Research Ltd (NIWA). Data sources are plotted on the accompanying diagram (Fig. 2) and identified in the references.

Reliability

The accuracy with which geological contacts, faults and folds are shown is diminished by the compilation and simplification process, and by the scale of publication. Point data are accurately located to within 100 m in terms of the NZMS 260 grid. The unpublished 1:50 000 data record maps have a higher standard of detail and accuracy. The 1:250000 map is of regional scale only and should not be llsed alone for land-use planning, planning or design of engineering projects, earthquake risk assessment or other work for which detailed site investigations are necessary. Some of the data sets



1 Hoolihan 1977
2 Hil11974
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5 Chapman-Smith & Grant-Mackie 1971
6 P.R. Moore & I.G. Speden unpublished maps
7 Gifford 1970
8 P.R. Moore & I.G. Speclen unpublished maps
9 Mazengarb 1988
10 Gibson 1986
11 Speden 197Gb
12 Pick 1962 & Vella 1959
13 Ongley & MacPherson 1928
14 Rail 1992
15 Kenny 1986
16 I.G. Speden unpublished maps
17 J. S. Crampton, M.J. Isaac, C. Mazengarb, & IoG. Speden unpublished reports
18 Mazengarb *etal.* 1991a
19 Rait 1992
20 Moore 1961
21 Moore 1989a
22 Ongley & MacPherson 1928
23 J.S. Crampton & C. Mazengarb unpublished maps
24 Pick 1962 & Vella 1959
25 Miller 1926
26 Ongley & MacPherson 1928
27 Feary 1979
28 Isaac *19n*
29 Moore 1961
30 Stoneley 1959, 1968
31 Mazengarb 1982
32 Hawkins 1963
33 Strong 1927
34 Strong 1927
35 I.G. $peden unpublished map
36 Speden 1975 & Moore 1978
37 Joass 1987
38 $avella 1992
39 Phizackerley 1962
40 Phizackerley 1962 & leach 1927
41 Jones 1940
42 Ridd 1963
43 Weymouth 1939
44 Haw 1959c & Phizackerley 1962
45 Bishop 1968a
46 Pullar 1962, Neef & Botlrill 1992 & Haw 1959c
47 Neel *et al.* 1996 & Macinnes 1963
48 Sloneley 1959 & Strong 1930
49 Evans 1945
50 Haw 1959b
51 Haw 1959d
52 Haw 1959a & Quenne1l1939, 1940
53 Haw 1959<:1 & Thoms 1939
54 Haw 1959c
55 Francis 1993b, Thoms 1940 & MacPherson 1927
56 Francis 19933 & Berryman 1989
57 Jablonski 1934

Figure 2 Distribution of principal data sources used in compiling the Raukumara map. Unpublished reports are held in the archives of GNS. Offshore data is from Foster & Carter (1997), Field, Uruski el *al.* (1997), and P. Barnes (pers. comm.).

incorporated with the geological data (for example, the Geological Resources Map of New Zealand data, see Christie 1989) have been compiled from old or unchecked information of lesser reliability.

REGIONAL SETTING

The Raukumara 1:250 000 geological map covers II 700 km' of eastern Bay of Plenty, Raukumara Peninsula and northern Hawke's Bay. Gisborne is the largest urban area and only city; in 1996 the population was 32 653. Wairoa is the next largest settlement (1998 population approximately 10600). There are a number of small coastal settlements (e.g. Te Kaha, Tolaga Bay and TeAraroa) and several small settlements inland (e.g. Ruatoria, Te Karaka, Matawai, Frasertown). Except for the coastal strip and the Waipaoa valley (Poverty Bay flats) the area is sparsely populated. The major land uses are sheep and beef farming, and exotic forestry. Horticulture, viticulture and cropping are restricted to the alluvial plains and terraces, mainly near Gisborne. Large tracts of land in the north and west are covered in native forest, as in the Raukumara Forest Park.

The Raukumara Range is the northeast extension of the axial ranges of the North Island. To the northwest of the axial ranges (and beyond the map boundaly) lies an active volcanic arc known as the Taupo Volcanic Zone. Late Jurassic to Early Cretaceous basement rocks of the Raukumara area and their Triassic-Jurassic equivaJents can be traced south along the axial ranges to Cook Strait and beyond. Similar basement rocks can also be found on the western side of the Taupo Volcanic Zone (for example, in Coromandel and NOlthland). Mid Cretaceous and younger cover sequences similar to those of the Raukumara area are present along the length of eastern North Island and in Northland.

The plate boundary between the Australian and Pacific plates propagated through the Northland and East Coast regions in Late Oligocene to earliest Miocene time. Raukumara Peninsula is adjacent to and above the present day active plate boundary (subduction zone) between the obliquely colliding Pacific and Australian tectonic plates (Fig. I). The seafloor expression of the plate boundary is the Hikurangi Trough, approximately 90 kill southeast of the peninsula. The land area is part of the overriding Australian Plate (the forearc), and it is being upliFted and deformed by the subduction process.

GEOMORPHOLOGY

The diverse landforms onshore are described in three geomorphic regions (Fig. 3; for place names see Fig. 4).

Raukumara Range

The North Island axial ranges extend northeast as the Urewera Range and the Raukumara Range, which terminates in the north near the Raukokore River (Fig. 5) and Raukumara (YI5/616693; 1413 m). The Raukumara Range is almost entirely covered in native forest, is over 35 km wide and has a maximum elevation of 1752 m al Hikurangi. Summit heights rise progressively from the Bay of Plenty coast toward the axis of the range. The topography is generaJly steep, though flat or gently dipping surfaces cap many hilltops (including Arowhana, which is 1439 ın high). The drainage is typically deeply incised wilh bluffs and deep gorges. Most rivers flow north 10 the Bay of Plenty, the major rivers being the Waioeka, Otara, Motu, Haparapara, Kereu and Raukokore. Several major east-flowing rivers also have their headwaters in the Raukumara Range (Tapuaeroa, Mata, Waipaoa and Wairoa). The eastern Bay of Plenty coastline flanking the range has small bays, with rugged headlands, wide shingled river mouths and gravel beaches, in contrast to the extensive, sandy beaches present near Opotiki and further west. Elevated marine terraces up to I km wide and 40 m above sea level are present along the coast.

Northern tip of Raukumara Peninsula

The northern tip of the peninsula is dominated by two ranges Formed of erosion-resistant Matakaoa Volcanics, separated by lowland valleys underlain by soft Cenozoic sedimentary rocks.The northern rangeextcnds ESE from Cape Runaway to Matakaoa Point, is 3-4 km wide, and up to 474 m high. A discontinuous apron of elevated terraces up to 60 m above sea level is preserved behind the rocky coastline. Further south the Pukeamaru Range extends inland from Haupara Point on the south side of Hicks Bay to Oweka Stream, is up to 7 km wide and 990 m high. Extensive marine terraces have been cut in the easily eroded sedimentary rocks present between the Raukokore River mouth and Cape Runaway; at Waihau Bay they are 3 km wide.

Eastern foreland

Almost aJi the area east and south of the Raukumara Range is less than 1000 m high. it contains a range of landforms many of which reflect the underlying geology. The area is deeply incised. All three main catchments (Waiapu, Waipaoa and Wairoa) extend to the flank ofthe Raukumara Range, but smaller coastal catchments include the Awatere, Uawa and Nuhaka rivers. Hillside erosion, landsliding and stream aggradation are major problems in many parts of this area. Terrace development

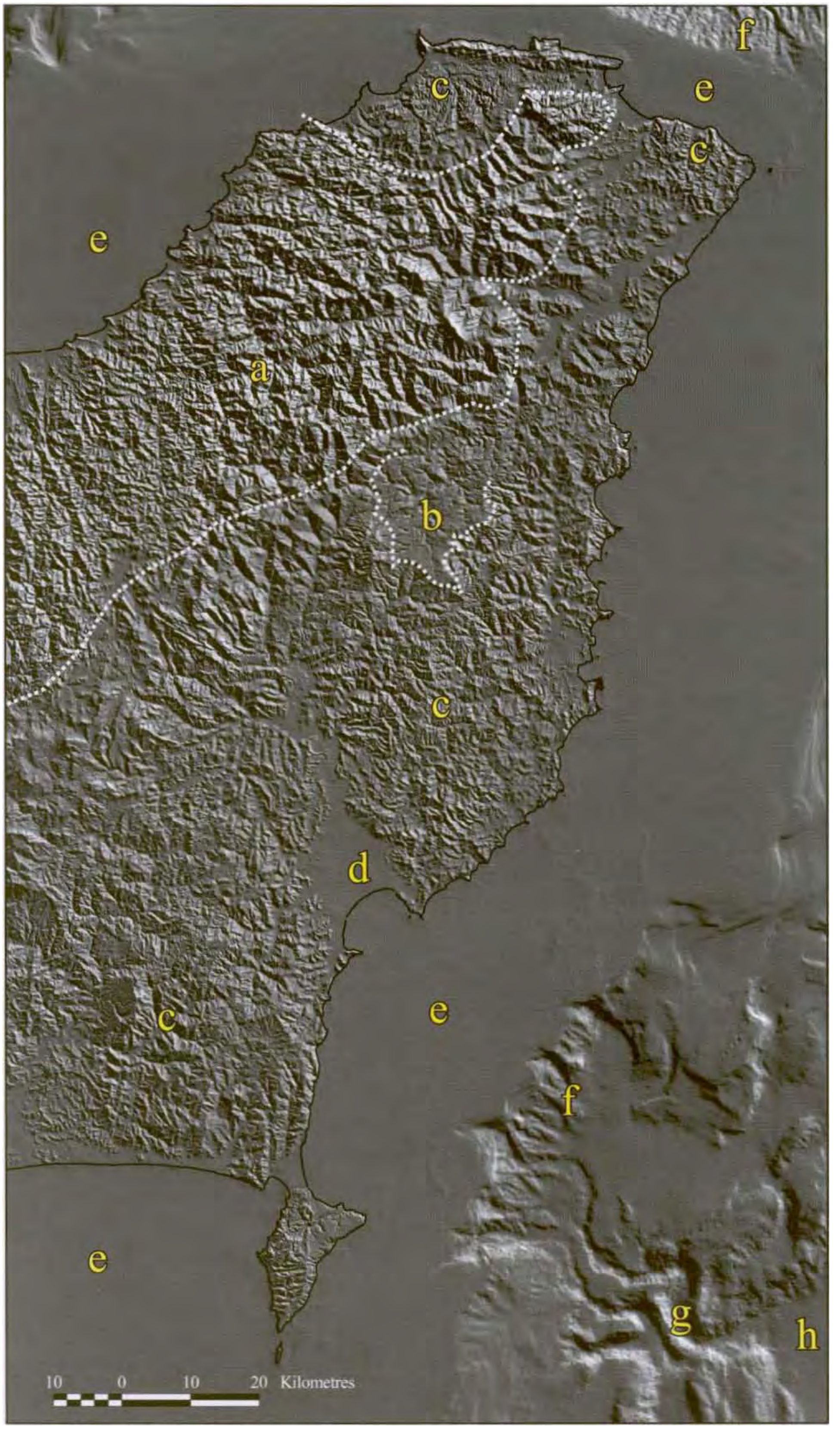

Figure 3 Computer·generated digital terrain model of the Raukumara area. The major geomorphological features labelled are the Raukumara Range including the Pukeamaru Range at the northern tip (a), the tableland in the Tauwhareparae area (b), Eastern Foreland (c), Poverty Bay flats (d), the continental shelf (e) and continental slope (I), the Poverty sea valleys (g), and the western margin 01 the Hikurangi Trough (h).

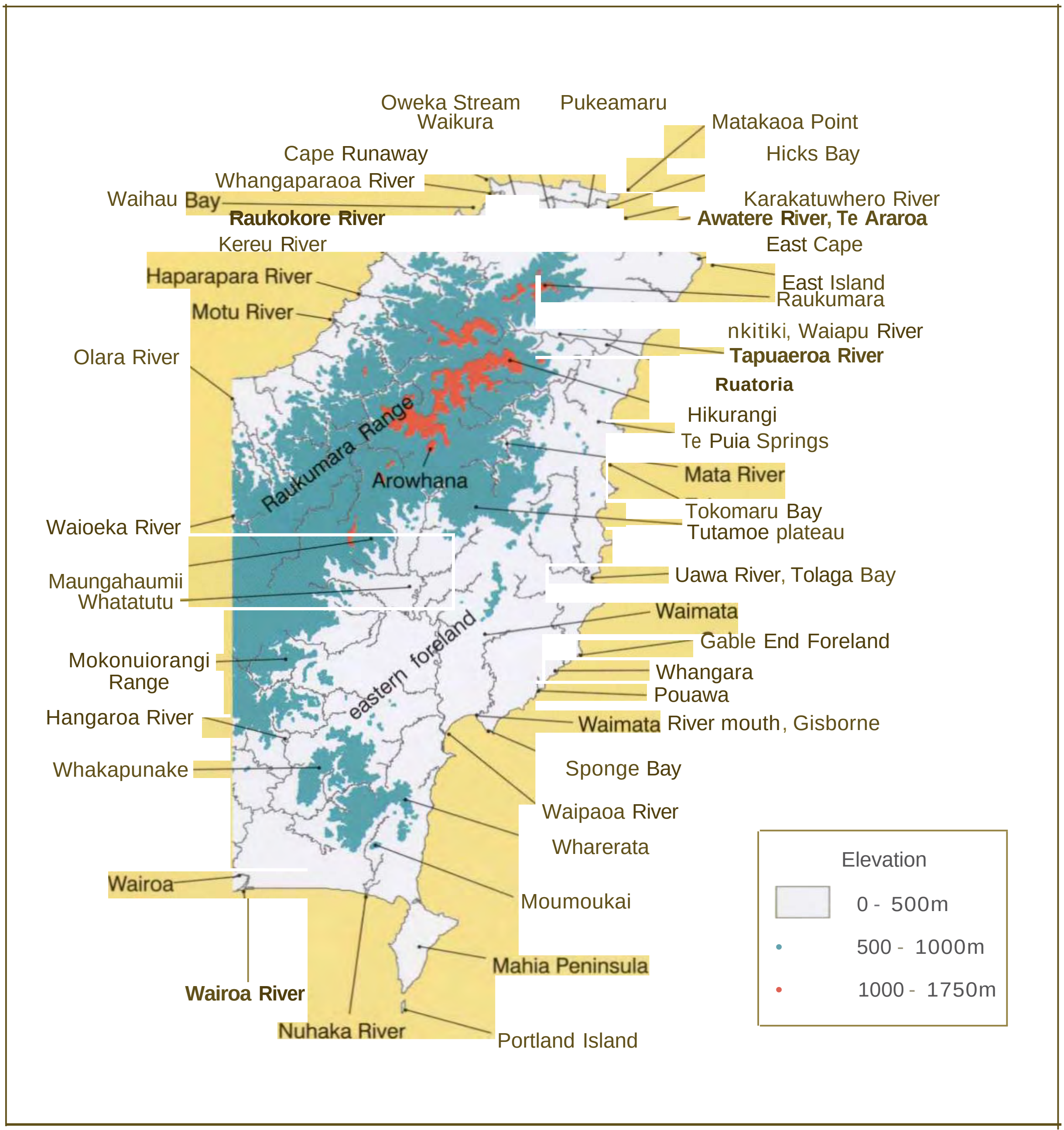

Figure 4 Location map for places mentioned in the section on geomorphology.

is extensive in many of the catchments, notably the middle Waipaoa River area near Whatatutu (Fig. 6).

An extensive erosion surface of relatively flat-lying to rolling topography is present in the Mata and Waipaoa headwaters at about 500 m elevation (Yoshikawa *et al.* 1988). A similar but smaller and deeply incised surface is present in the Wharerata area. A zone of extreme erosion typified by extensive gully erosion, earthflows and hillside slumps extends northward from the headwaters of the Waipaoa River in the vicinity of Mangatu Forest (e.g. Fig. 7), along the Mata and Tapuaeroa catchments to Waikura and Ruatoria. Similar but smaller areas of erosion are present between Waimata and Whangara, and between Pouawa and Sponge Bay. They correspond to areas of strongly fractured and faulted rocks which locally include smectitic claystones. Where rocks of different types are juxtaposed and mixed the topography has a distinctive hummocky appearance (Fig. 7).

East of Te Araroa and north of Tikitiki (including East Cape and East Island) is a distinctive area with deeply incised drainage and tablelands rising up to 393 m. South of Te Puia gently dipping and synclinal Miocene and

Pliocene sandstones (and minor limestones) form distinctive, steep landforms with remnant plateaux, as at Tokomaru Bay, Tutamoe plateau and Moumoukai. Prominent dip slopes are present at Whakapunake (limestone with karst structures). Maungahaumi (limestone). Mokonuiorangi Range (sandstone). Gable End Foreland (sandstone) and in the coastal cliff beside the Tolaga Bay wharf (sandstone). In contrast, extensive areas underlain by mudstone have more subdued topography.

In coastal areas eroding rocky headlands are separated by sandy bays. The Waiapu. Karakatuwhero, Uawa, Wairoa. and Waipaoa rivers have extensive floodplains. Dunes and back swamps are locally well developed in Poverty Bay, in the Mahia tombolo and between Nuhaka and Wairoa (Fig. 8). Marine terraces are well preserved at Mahia Peninsula and Portland Island where they range up to 200 m elevation (Fig. 9). Near Te Araroa marine terraces are preserved between 200 m and 300 m above sea level.

Figure 5 View southeast toward the mouth of the Aaukokore River *(Y14/390826)* and the northern Raukumara Range showing the typical steep, forested hill country underlain by Torlesse rocks. The Aaukokore Thrust (outlined) separates Torlesse rocks in the hanging wall (to the right) from Tikihore Formation in the footwall. *Photo CN9086114: D.L. Homer*

Onshore physiography and geology

East of Raukumara Peninsula the continental shelf is 12-35 km wide. The shelf includes aClive folds and faults, subsiding basins (e.g. Hawke Bay. incorporating the Lachlan Basin) and fault-controlled structural highs (e.g. Ariel Bank and Lachlan Ridge, near Gisborne) (P. Barnes pers. comm.; Fosler & Carter 1997; Katz 1975). The boundary with the continental slope is at approximately 200 In water depth. The continental slope is irregular and hUlllllIlocky. with structurally controlled ridges, canyons (e.g. Poverty Canyon) and large re-entrants (semicircular indentations along the continental shelf), at least some of which are the headscarps of major submarine debris flows (e.g. Rualoria debris avalanche; Col1ot *el al.* 1996; Lewis *el al.* 1997). Beyond the continental slope lies Ihe Hikurangi Trough which, further la the northeast, links with the Kermadec Trench. The trough is 3500-4500 m deep and the trough/slope boundary is taken to represent the position of the plate boundary. Southeast of the Hikurangi Trough the Pacific Plate seanoor has low relief, except where there are seamounts and debris flow deposits. The geology is poorly known, except for Hawke Bay where there is a good network of oil industry seismic surveys and a single petroleum exploration well (Hawke Bay-I, 23 km south of Wairoa and jusLoutside the map boundary). The offshore area is structurally complex wiLh lhick Miocene to Quaternary sedimenLs in fault-controlled basins. A thick sequence of Cretaceous and Paleogene rocks is probably also present (Field, Uruski *el al.* 1997).

Figure 6 The meandering Waipaoa River nearTe Karaka (looking north towards Whatatutu). When this photograph was taken (1988), the lowest terrace (of Holocene age) was covered by silt deposited during Cyclone Bola. Four terraces, labelled 1, 2, 3 and 4, represent aggradational culminations of 14700, 28 000, 57000 and 90 000-110 000 years respectively. Older Quaternary lake and river deposits (Mangatuna Formation - c. 600 000 years) cap hill tops locally. *Phato CN13129121 : D.L. Homer*

North of the peninsula the continental shelf is narrow (minimum 5 km) and water depth increases rapidly to 2200 m, beyond which is the extensive Raukumara Plain (north of map area). The continental slope is broken by the c. 50 km wide Matakaoa Re-entrant, the semicircular headscarp of the Matakaoa debris flow (Blackmore 1996; Carter 1998). The Raukumara Plain is underlain by some 13 km of sediment known as the Raukumara Basin (Gillies & Davey 1986; Davey *et ",. 1997).*

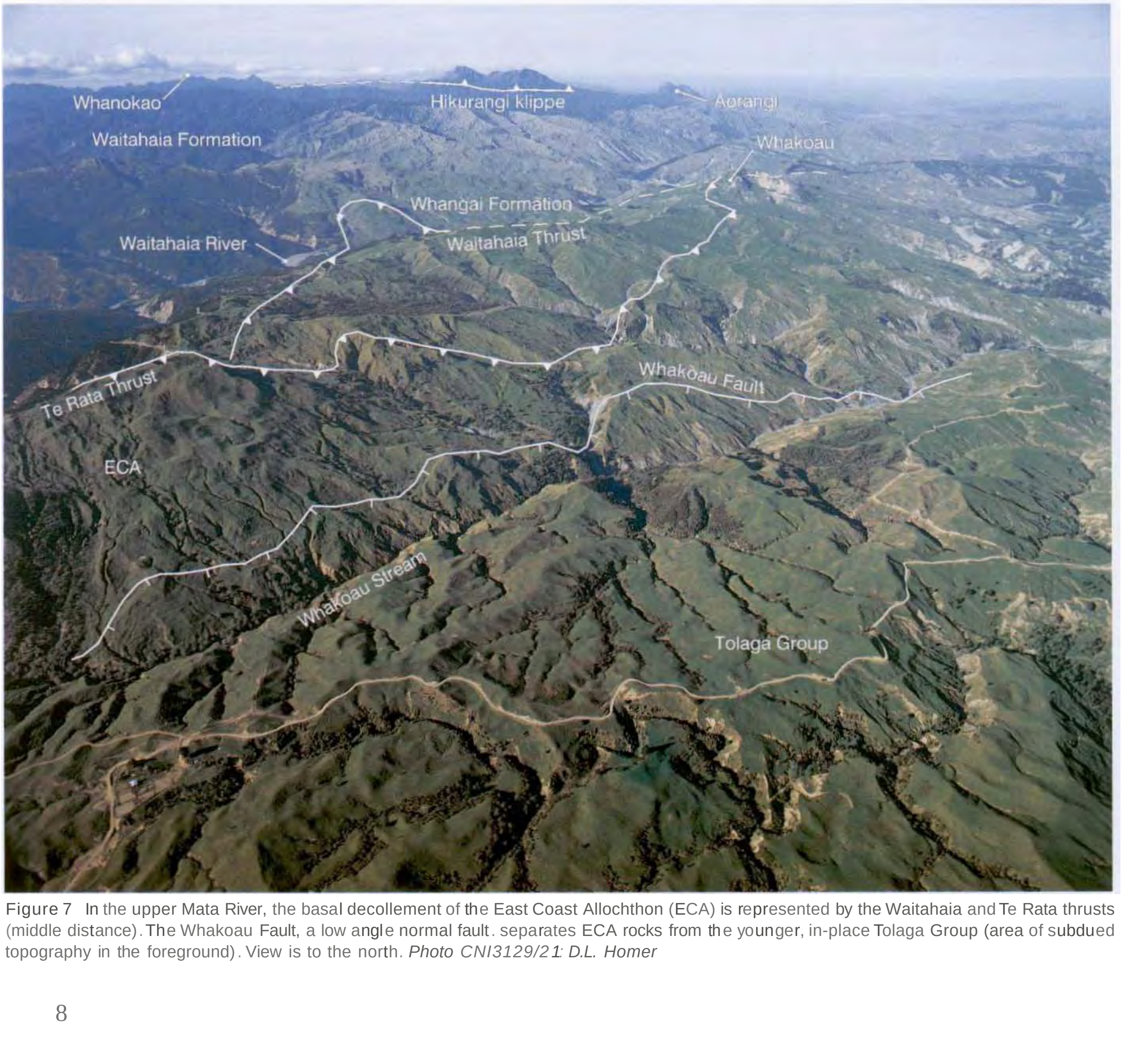

Figure 7 In the upper Mata River, the basal decollement of the East Coast Allochthon (ECA) is represented by the Waitahaia and Te Rata thrusts (middle distance). The Whakoau Fault, a low angle normal fault. separates ECA rocks from the younger, in-place Tolaga Group (area of subdued topography in the foreground). View is to the north. *Photo CNI3129/21: D.L. Homer*

Figure 8 East of Wairoa the coastal plain is advancing seaward; former sea cliffs are visible on the inland shore of the Whakaki Lagoon (left). Mahia Peninsula (far distance) is part of a rising structural high. *Photo CN47895125: D.L. Homer*

Figure 9 The flat surfaces of Portland Island (foreground) and Mahia Peninsula are marine terraces cut into the Late Miocene rocks. The terrace on Portland Island is 125 000 years old and about 110m above sea level. Terraces at southern Mahia Peninsula are tilted to the WNW; the tilting and uplift are related to active growth of the Lachlan Ridge, the crest of which is offshore, immediately east (right) of the peninsula. *Photo: Stephen Jones, Treble Court Photos, Gisborne*

The rocks of the Raukumara area are here subdivided into and described as five major units. based mainly on their age and their structural history:

- Lale Jurassic to Early Cretaceous basement
- in-place Cretaceous to Oligocene rocks
- the Easl Coasl Allochthon (Early Cretaceous 10 Oligocene displaced rocks)
- Miocene and Pliocene rocks. and
- Quaternary sediments.

The nature of the contact between the first two units is disputed in some areas. The Early Cretaceous to Oligocene rocks are subdivided on the basis of structural history. In the southwest of lhe map area basement rocks are unconformably overlain by an in-place (autochthonous) sedimentary sequence of Early Cretaceous to Oligocene age. However, in the northeast (nonheasl of Matawai-Te Karaka) equivalent rocks are presenl as a series of thrust sheels (the East Coasl Allochthon of Moore I988a) some of which are displaced at least tens of kilometres from their original locations and, over large areas, thrust over the equivalent autochthonous sequence. In the southwest a regional unconformity is present between the Early Cretaceous to Oligocene in-place sequence and the overlying Miocene-Pliocene unil. The thrusl sheels of lhe East Coast Allochthon are also overlain by Miocene-Pliocene beds.

LATE J RASSIC TO EARLY CRETACEOUS BASEMENT

Torlesse composite terrane

Terrane nomenclature

The indurated qumtzofeldspathic and lithic sandstone and mudslone ("greywacke") of the nonhwestem Raukumara area have commonly been mapped as Torlesse Supergroup (e.g. Suggate *et al.* 1978). Torlesse rocks form the orth Island axial ranges and much of the Soulhern Alps; they range in age from Carboniferous 10 Early Cretaceous.

The basement rocks of New Zealand are also mapped in terms of tectonostratigraphic terranes (e.g. Coombs *el al.* 1976; Bishop *et al.* 1985; Bradshaw 1993; Fig. 10). The Late Jurassic to Early Cretaceous basement rocks of lhe Raukumara area are a part of the Torlesse composite terrane, one of several Late Paleozoic to Early Cretaceous. fault-bounded tectonostratigraphic units of low grade metasedimentary rocks which constitute the Eastern Province of ew Zealand. The monOlOnous sequences of indurated, interbedded sandstone and mudstone typical of the Torlesse are inferred to have accumulated mainly in deep marine environments, within an accretionary prism.

The original definition of the Torlesse terrane was given by Coombs *el al.* (1976). Later workers subdivided lhe Torlesse rocks into a number oft.erranes and subterranes but for some areas contlicting interpretations have been given. Bradshaw *el al.* (1981), Bradshaw (1989) and Silberling *et. al.* (1988) subdivided the Torlesse into subterranes, the easternmost of which (Pahau subterrane) included the basement rocks of the Raukumara area. Others subdivided the Pahau subterrane inlO two units. both of which they termed terranes - Pahau terrane. of Late Jurassic to Early Cretaceous (?Barremian) age. and a younger (Aptian-Albian) Mata River terrane (Sporli & Ballance 1985, 1989). The boundary between Pahau and Mata River terranes was originally placed near the Whakatane Fault, i.e. west of the area of the Raukumara map (Sporli & BaJiance 1985, 1989). but laler moved easlward by 40 km. to inlersecl the Bay of Plenty coast nearTorere. 18 kill eaSI of Opotiki (Aila & Spörli 1992).

The validity of "Mata River terrane" remains unproven. If Mata River terrane is found to be a valid tcclOnostratigraphic unit, the name is inappropriate, since the Mata River catchment lies entirely within middle Cretaceous and younger cover strata. Mortimer (J995) subdivided the Torlesse rocks of the eastern North Island, based on differences in sandstone petrographic modes. age. bulk chemical composition and the known and inferred extent of melange belts; his work suggested there may be no basis for a distinct Mata River terrane. He defined two major basement units east of the Taupo Volcanic Zone. namely the Pahau subterrane and a previously unrecognjsed Waioeka subterrane, both of Late Jurassic to Early Cretaceous age. The boundary between the Pahau and Waioeka sllbterranes was drawn at a major zone of mélange inferred to extend south from the Bay of Plenly coast as far as a poinl WSW of Lake Waikaremoana (the Whakatane melange; Mortimer 1995). All basement rocks of the Raukumara area are east of lhe Whakalane melange and within his Waioeka subterrane. Two distinct petrofacies were differentiated (Waioeka petrofacies and Omaio petrofacies). This subdivision into subterranes and petrofacies was accepted by Field, Uruski *et al. (1997).*

Begg & Johnslon (2000) elevated units formerly known as sllbterranes (e.g. Pahau subterrane) to full terrane status. on the basis of their presumed discrete geological origins, and applied the name "Torlesse (composite) terrane" for Torlesse rocks in general. Kamp's (1999) work on fission track lhermochronology of lhe Raukumara basement rocks found Mortimer's (1995) subdivision to be appropriate; he also elevated the subterranes to full terrane status. Following Mortimer (1995), Begg & Johnston (2000) and Kamp (1999) the basement rocks of the Rallkllmara area are here mapped as Waioeka terrane, a part of the Torlesse composite terrane.

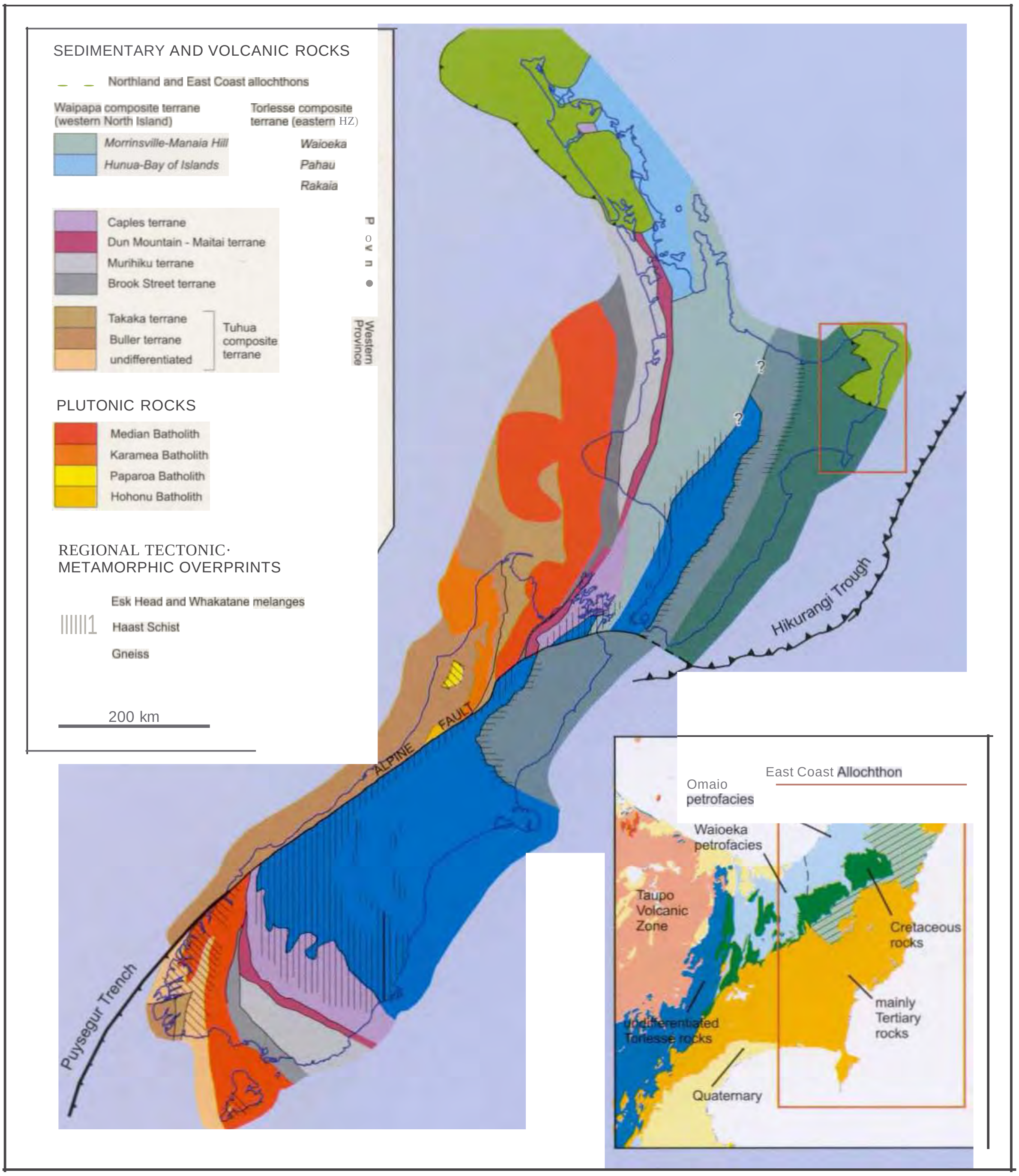

Figure 10 Basement (pre·Late Cretaceous) geological map of New Zealand. Nomenclature and boundaries of North Island Torlesse and Waipapa terranes are controversial; parts of Morrinsville-Manaia and Pahau units may be correlative. Adapted from Black (1994), Mortimer (1995), Mortimer *et al.* (1997, 1999), Kamp (1999) and references therein; the basement terranes were in mutual juxtaposition by the late Cretaceous. The exlent of the Northland and East Coast allochthons is also shown; they were emplaced in Early Miocene time. The inset map shows present day geology of the Raukumara area.

Torlesse rocks of the Raukumara area

The major lithologies present are indurated, ahernming, thinly bedded. fine-grained sandstone and l11udstone (Fig. I I), thick sandstone and massive mudstone, with minor conglomerate and pcbbly mudstone. Broken formation is relatively common (Fig. 12), while melange (containing exotic rocks) is rare. Melange includes blocks of chen, spilitic basalt and limestone. Metamorphic minerals identified include pumpellyite. prehnite, epidote, laumontite, datolite, heulandile and stilbitc; laumontitc is by rar the 1110st cOl11l11on (Feary 1974; Hill 1974;

Figure 11 Steeply dipping beds of centimetre- to metre-bedded Torlesse sandstone and mudstone beside the highway south of Omaio *(X/51168654)* show the fraduring and faulting typical of these rocks. They are unconformably overlain here by Quaternary colluvial and tephric material. *Photo* 42148/25: *D.L. Homer*

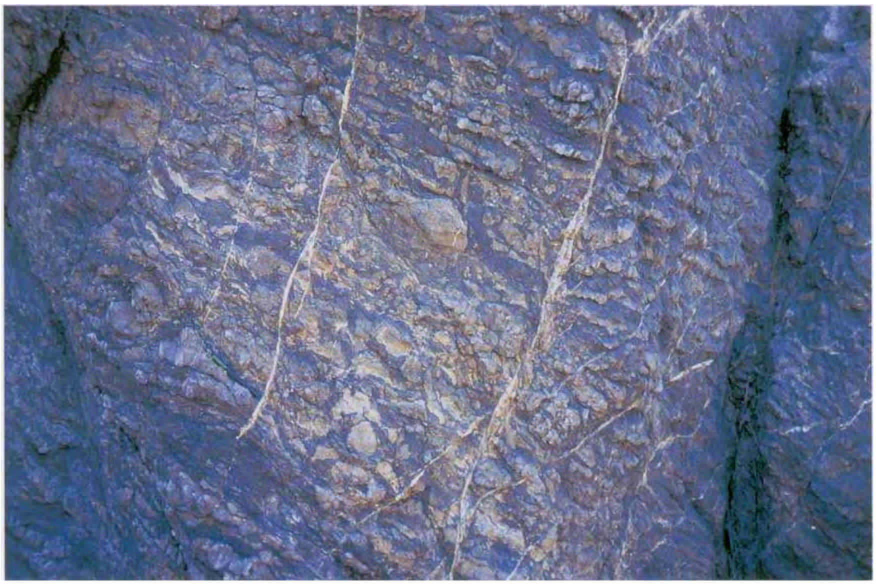

Figure 12 Torlesse sandstone (pale grey) and mudstone at Torere Beach *(X15/010505)* have been disrupted to form broken formation. The cross-cutting veins (white) are almost undeformed and must, therefore, postdate the deformation which produced the broken formation. The area shown is about 1.7 m across.

Hoolihan 1977; Isaac 1977). Waioeka petrofacies sandstones arc quartz-pool' «20%), volcanic litharcnites and Omaio petrofacies sandstones are quartz-rich (>20%) feldsarenites (Mortimer 1995).

The predominant sandstone and ll1udsLOne lithofacies ranges from centimetre- to decametre-bedded. with a highly variable ratio of sandstone to mudstone. Some intervals are almost totally composed of massive sandstone (as at the summits of Arowhana and Hikurangi). Fine-grained sandstones predominate, but SQmcare medium- or coarse-graincd. Carbonaceolls plant material and sedimentary structures are common in thinner sandstone beds. Veining, jointing and fracturing are prevalent.

Conglomerate is common between the Raukokore River mouth and Waikawa Point (Fig. 13, X 141270805), where it is present in beds up to 100 m thick. Clasts are typically well rounded pebbles and cobbles, and there is a significant proportion of granitoid, silicic volcanic and basic volcanic lithologies (Moore 1957). Peralkaline rhyalite clasts from Whanarua Bay have the trace element signature characteristic of, and are inferred to have been derived from, the Early Cretaceous Houhora Complex continental-silicic volcanic rocks of northernmost Northland (Mortimer 1995). Minor occurrences of conglomerate have been mapped between Koranga and the Waioeka Gorge (isaac 1977; Moore 1978). Beds of pebbly mudstone with angular and rounded clasts of sandstone and concretionary mudstone in mudstone matrix are well exposed along the Petipeti Road (e.g. X 17/ 100320) and at Haumiaroa Point (X 16/085553); they are interpreted as debris flow deposits.

Spilitic basalt, chert and red and green argillite present at Te Kaha are associated with an extensive area of broken formation and melange (Hill 1974; Aita & Sporli 1992). Similar rocks in the Motu River (e.g. X 161250450) are associated with the Big Unknown Fault. Sheared sandstone with pods of massive pyrite and chalcopyrite, maroon tuff and cherL present at Te Kumi (Y I5/497684) were tentatively mapped as Mokoiwi Formation by Pirajno (1979), but are now believed Lo be a part of the Torlesse.

Macroscopic fossils other than plant material are very rare (Speden 1976a; Wilson *et al.* 1988). The Korangan stage indicator fossil *Aucellina* cf. *radia/os/rima* has been collected from pebbly sandstone at Haumiaroa Point, northeast of Hawai River, but the stratigraphic position and relationships of the fossiliferous beds are still ambiguous; they may be a part of a younger, channel-fill sequence (Speden I972a, 1976a; Hoolihan 1977; M.G. Laird and J.D. Bradshaw, pers. comm.). The Puaroan (Late Jurassic) stage indicator fossil *Buchia* aff. *plicara* has been collected from thinly bedded sandstone and mudstone in the Matawai area (Speden I972a), but dinoflagellate microfossils recovered from concretions and mudstones suggest much of the Waioeka terrane rocks of the Raukumara area are Early Cretaceous. Radiolaria in chen from Te Kaha indicate an Early Cretaceous age (late Valanginian-early Barremian; AiLa & Sporli 1992). However, the chertlbasalt/coloured argillite associations typicatiy present in melange are inferred to be ocean floor material faulted into the clastic sequences as a part of subduction processes. Ages derived from radiolaria in chert blocks are commonly not representatitive of the ages of the enclosing clastic rocks (Aita & Sporli 1992).

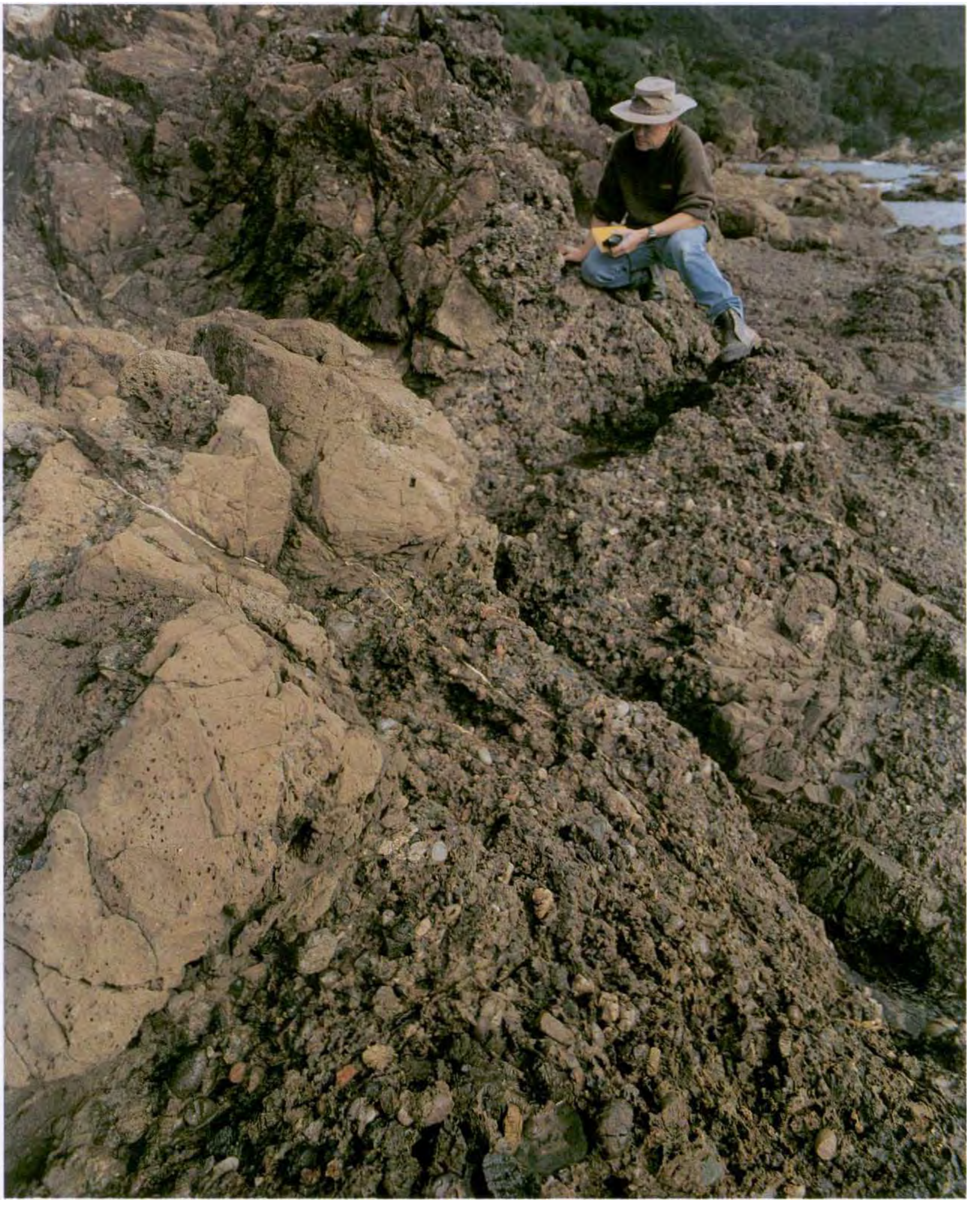

Figure 13 Conglomerate with both sedimentary and igneous clasts is common within the Torlesse rocks between Waikawa Point and the mouth of the Raukokore River. At Whanarua Bay (Y141329802) conglomerate and sandstone are interbedded.
Photo CN42t40150: D.L. Homer

Waioeka petrofacies sandstones collected from the Waioeka Gorge - Matawai area include zircons dated by the fission track method at 125 ± 2 Ma (Kamp 1999). A single Omaio petrofacies sandstone gave a zircon fission track age of 108 ± 6 Ma. Zircons from an Omaio petrofacies sandstone from Whanarua Bay are as young as c. I()() Ma (SHRIMP UlPb method; Cawood *el at.* 1999). The Omaio petrofacies zircons are significantly younger than any yet dated from the Waioeka petrofacies, confirming that the Omaio petrofacies comprises the youngest parts of the Waioeka terrane (Mortimer 1995; Kamp 1999).

In summary, the fossil and zircon ages indicate Waioeka terrane rocks are of Early Cretaceous age, though perhaps locally as old as Late Jurassic if the accepted age range of *Buchia* aff. *plicata* is correct.

The contact between Torlesse and overlying rocks

In the west of the Raukumara map area (i.e. west of the Moutohora Fault), Late Jurassic to Early Cretaceous Waioeka terrane Torlesse rocks are overlain unconformably by gently to moderately dipping conglomerate. sandstone and olistostrome breccia of Early to Late Cretaceous age (the Matawai Group; Isaac 1977; Speden 1972b; Speden 1975; Fig. 14). Between Koranga and Matawai, basal Matawai Group beds are locally as old as Korangan (Aptian) but generally of Urutawan-Motuan (Albian) age. In the east, between Moutohora Fault and Kokopumatara Stream, Torlesse rocks are succeeded by an Early and Late Cretaceous sequence dominated by mudstone and decimetre-bedded sandstone and mudstone. East of Kokopumatara Stream Torlesse and Matawai Group strata arc in fault contact.

Figure 14 West of Matawai Torlesse composite terrane sandstone and mudstone are unconformably overlain by gently dipping Koranga Formation conglomerate and sandstone; the contact is indicated by the dashed line. Matawai Quarry (centre, *X17/009033)* works a Koranga Formation sandstone. State Highway 2 can be seen in the centre right; the river is the upper reaches of the Motu. *Photo CN42 149/3: D.L. Homer*

In the Koranga-Matawai area the high angle unconformity (Fig. 15) belwccn Torlesse rocks and Matawai Group strata marks changes in the degree of deformation. induration. fossil content and lithology. These changes are interpreted to represent a significant break in deposition resulting from a period of deformalion, uplift and erosion, followed by marine transgression. The nature of the equivalent contact east of Mourohora Fault is more contentious. Some workers favour a gradation, based on the lack of a proven angular discordance, the perceived gradational changes in lithology and induration, overall similarity of lithologies. and the gradual upward increase in fossil content (as at Pakihi River, X 16/013276; Moore 1961 ; Mazengarb 1993). Olhers note the OCCurrence of thick olistostrome breccia and soft sediment slumping at or near the boundary, consider there is a difference in induration, tectonism and fossil content, and argue there is a sharp contact between Torlesse rocks and overlying Matawai Group rocks (e.g. Laird & Bradshaw 1996).

Though the argument is unresolved, some aspects are accepted by most workers:

- no single unconfonnity surface of Early Cretaceous age is proven to exist across the whole region
- angular unconformities separate Torlesse rocks from Matawai Group covering strata over large areas, at least to the west of the Moutohora Faull
- east of Moutohora Fault, soft sediment slump features and intraformational olistostrome-breccias in Urutawan-Moluan (Albian) time represent a period of instabilily
- some possible Torlesse rocks at Hawai River contain the same Korangan stage (Aptian) indicator fossil as the oldest Matawai Group covering strata

Figure 15 On the south bank of Koranga Stream (X17/912967) vertical sandstone and mudstone of the Torlesse composite terrane are unconformably overlain by gently dipping, fossiliferous conglomerate and sandstone of the Te Wera Formation, Matawai Group. The scale is given by the figure on the far bank. *Photo CN42254119: D.L. Homer*

of the Koranga-Matawai area (*Aucellina* cf. *radiatostriara)*

- zircon fission track and SHRfMP UlPb ages suggest some Torlesse rocks are younger than the oldest Matawai Group strata.

Stratigraphic and structural analysis led Mazengarb & Harris (1994) to conclude that subduction-driven deformation and thrust faulting continued through Early Cretaceous lime until about 85 million years ago; their model is in part supponed by the fission track thermochronology work of Kamp (1999).

IN-PLACE CRETACEOUS TO OLIGOCENE ROCKS

This section deals only with the in-place (autochthonous) Cretaceous to Oligocene rocks which underlie either the East Coast Allochthon thrust sheets (northeast) or the Early Miocene unconformity (southwest), i.e. those rocks which have not been displaced tectonically from where they were originally deposited.

Early and Late Cretaceous rocks of the Matawai Group

Raukumara Peninsula has some of the best preserved Early and Late Cretaceous sequences in New Zealand (Wellman 1959; Spedcn 1975; Crampton *el al. 1995).* The Matawai Group is a unit of moderately indurated, in-place sedimentary formations of late Early Cretaceous to Late Cretaceous age, outcropping along the southeastern flank of the Raukumara Range. The stratigraphy varies considerably within the mapped area.]n the west, four unconformity-based transgressive sequences are recognised. Lateral facies changes suggest a west to east transition from shelf to bathyal sequences.

The oldest 'cover' formation (Koranga Formation, Kmk) rests with angular unconformity on Torlesse rocks (Fig. 14) and is known with celtainty only over a strike length of 25 km in the Koranga-Matawai area. It has not been recognised east of the Moutohora Fault. It consists of up to 150 m of indurated, fossiliferous sandstone, conglomerate, intraformational breccia and minor mudstone. Igneous clasts are mostly of silick tuff, breccia, rhyolite, dacite or granitoid. with minor basalt and andesite (Isaac 1977; Mortimer 1992). Koranga Formation sandstones include abundant fresh volcaniclastic material and they are petrographically indistinguishable from sandstones of the underlying Waioeka petrofacies of the Torlesse composite terrane (Isaac 1977).

Te Wera Formation (Kmt) is present over a similar area, unconformably overlying both Waioeka terrane (Fig. 15) and Koranga Formation. It comprises moderately indurated. well bedded conglomerate, breccia. and coarse- to fine-grained sandstone, with thin intercalated mudstones, and is locally up to 250 m thick (Speden 1975; Isaac 1977). Macrofossils are relatively C0l111110n and indicate an Albian (Urutawan) age (Speden 1975). The depositional environments of the Koranga and Te Wera formations have been interpreted as shallow marine inshore shelf (Speden 1975; Isaac 1977) or alternatively, deep marine (Laird & Bradshaw 1996). Te Wera sandstones are pelfographicalJy distinct from those of the underlying Waioeka petrofacies and Koranga Formation, for they are texturally and compositionally morc mature.

Oponae Melange (Kmo), present locally in the extreme west of the mapped area, was originally mapped within the Torlesse rocks (e.g. Feary 1979), but is now considered to be a part of the Matawai Group, since it apparently overlies Torlesse rocks unconformably, and is itself conformably overlain by Karekare Formation. It is considered to be a basal olistostromal unit, as originally proposed by Speden (l972b), and consists of angular blocks and rounded pebbles of sandstone, mudstone, coal, bedded chert, marble, basalt and other igneous pebbles enclosed in a sheared and folded mudstone to very fine-grained sandstone matrix. Rare macrofossils (W16/864188; just west of the map boundary) and stratigraphic constraints indicate 3nA lbian (Motuan) age. Chert blocks incorporated within the melange are Early Jurassic (Feary & Pessagno 1980).

These relatively thin late Early Cretaceous basal conglomerate, breccia and sandstone units are conformably overlain by a thick l1udslOne-dominated sequence of late Early CreIaceous to Late Cretaceous age (Karekare Formation, KOla; Figs. 16, 17). It includes intervals of thinly bedded sandstone and mudstone, and in places, rare Lhick sandstone, tuff beds, conglomerate, and illlercalations of red and green mudstone (Fig. 18). Karekare Formation is characterised by relatively abundant fossils, mainly the large mussel-like inoceramid bivalves which are commonly present as shell beds (Fig. 17; Crampton 1996). Karekare sandstones are more quartzose and less lithic than Te Wera sandstones i.e. the younger the Matawai Group sandstone the higher the textural and compositional maturity (Isaac 1977).

West of the Moutohora Fault Karekare Fonnation overlies and partly inLerfingers with Te Wera Formation, and ranges in age from Albian Lo Turonian (Urutawall-Mangaotanean). The Karekare FormaLion in this area is up to 1220 m thick (Speden 1975); it consists mainly or mudstone, with intercalations of thinly bedded sandstone and mudstone, and rarely, sandstones up to several metres thick. ALKoranga a prominent strike ridge is formed by the Choveaux Sandstone Member, a 16 m thick interval of sandstones with lenses of granule conglomerate and

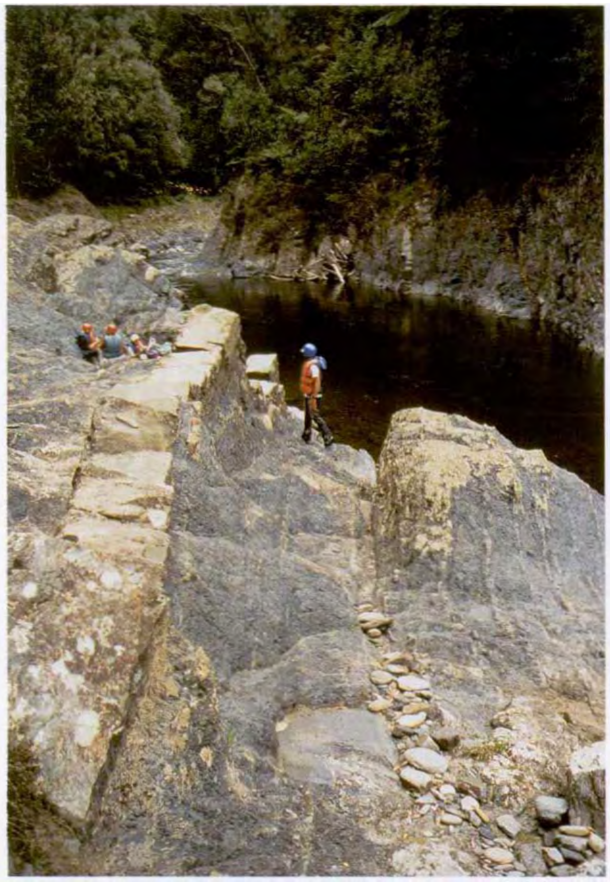

Figure 16 Vertically bedded sandstones (pale) and mudstones (blue-grey) of Earty Cretaceous Karekare Formation in the banks of the Motu River *(X161185279)*. *Photo: J.S. Crampton*

breccia (Speden 1975). The Raukumara Series Karekare rocks here are too thin (100m at Koranga Bridge) to differentiate 011 a 1:250000 map.

East of Moulohora Fault, Karekare Formation directly overlies Torlesse rocks (Waioeka terrane) and ranges in age from Albian to Santonian (Urutawall-Piripauan). The basal or near-basal Karekare Formation commonly consists of mudstone with slump folding and otber soft sediment deformation (Pakihi River, X1610 13276) and sedimentary breccia (up to 250 m thick in Kokopumatara Stream, Y16/345329). Six stages of the ew Zealand geological timc scale arc defined from the biostratigraphy of Karekare Formation strata exposed in the MoLu River near Motu Falls (Clarence Series; Urutawan, Motuan, Ngaterian), and Mangaotane Stream (Raukumara Series; Arowhanan, Mangaotanean, Teratan) (Wellman 1959). In the reference section at Te Waka Stream, near Motu, the Karekare Formation is 2650 m thick (base not exposed and top eroded), mainly mudstone, but including 5 discrete intercaJations of thinly bedded sandstone and mudstone which range in thickness from 60 to 190 m (Isaac 1977). The thinly bedded units are useful markers in that Lhey can be traced southwest and nOl1heast for at least 10-15 km. East of Kirk's Clearing (X16/210240) the otherwise monotonous blue-grey mudstone typical of the Karekare Formation includes several bedding-parallel intervals of red mudstone and minor green mudstone, commonly 5-10 m thick (Fig. 18). The red and green mudstones and blue-grey mudstone immediately overlying them are typically devoid of fossils, i.e. they represent barren zones in an otherwise fossiliferous sequence. The barren zones define the range zones of individual inoceramid species; below the coloured mudstone shown in Figure 18 the key fossil is

Figure 17 In places Karekare Formation blue-grey mudstones contain shellbeds - in this case of the giant mussel-like bivalve *Magadiceramus? rangatira rangatira,* the index fossil of the Arowhanan stage (Mangaotane Stream, *X1612793 12). Photo:* J. S. *Crampton*

Figure 18 A prominent red mudstone bed within Late Cretaceous Karekare Formation at Mangaotane Stream (*X 161 291300*). Above the red mudstone the more typical blue-grey mudstone contains inoceramid fossils indicative of the Mangaotanean Stage; below it the fossils are Arowhanan. *Photo: J.S. Crampton*

the very large *Magadiceramlls? rOf/gafira rallgafira,* but above it the key fossil is *Cremnoceramus bicorrugatus fl/afwllutlS* (Crampton 1996). The origin of the red mudstones and their influence on the fossils are poorly understood.

In Kokopumatara Stream the lower part of the Karekare Formation includes mudstone, breccia and sandstone lithologies showing evidence of soft sediment slumping; the lowermost 90 m may be a single slump breccia. Breccia clasts are intraformational and include blocks of fine-grained sandstone up to 10m thick, calcareous concretions and clasts of granule conglomerate to coarse-grained sandstone, enclosed in a mudstone matrix. Inoceramid prisms are common. Prominent intercalations of thinly bedded sandstone and mudstone present higher in the sequence include thin lenses of fossiliferous conglomerate, rip-up clasts and abundant plant material. They match the Waitahaia Formation as mapped further east (see below), suggesting that locally the two formations interfinger. Near Arowhana and to the east, Karekare Formation of Late Cretaceous age unconformably overlies and onlaps Waitahaia Fonnation; the overlying Karekare Formation ranges in age from Cenomanian to Coniacian (Ngaterian-Teratan). In the easternmost outcrops (e.g. Puketoro Stream, Y 15/ 55 14 10), the Karekare Formation consists of thinly bedded sandstone and mudstone passing gradationally upward into bedded mudstone.

East of Arowhana, Karekare Formation is unconformably underlain by centimetre- to decimetre-thick, well bedded alternating sandstone and mudstone, with minor conglomerate, pebbly mudstone and tuff (Waitahaia Formation, Kmh). Rarely, individual sandstone beds are as thick as 14 m. In places bedding is disrupted by intervals of intrafonnational slumping up to 20 m thick. The formation has a known maximum thickness of 1400 m and the known age range is Albian to Cenomanian (Motuan-Ngalerian). Waitahaia sandstones are apparently less feldspathic than Karekare sandstones (Kenny 1984a; her Hikurangi Beds), perhaps because they were derived mainly from Omaio petrofacies rocks.

Moanui Formation (Kmm) has a very restricted distribution; it covers a small area between the Koranga and Kotepato faults which is mainly west of the Raukumara map area. It consists of fossiliferous, moderately indurated mudstone to very fine-grained sandstone with lenses and beds of conglomerate, breccia, pebbly sandstone and pebbly siltstone (Moore 1978). It is up to 500 m thick and the known age range is Cenomanian to Coniacian (Arowhanan-Teratan). Moanui Fonnation is a lateral correlative of Karekare Formation, deposited as a transgressive sequence in an inner shelf environment.

Early and Late Cretaceous rocks of Ihe Rualoria Group

An area of Late Cretaceous, centimeLre- to metre-bedded, fine-grained sandstone and mudstone at lower Mata River, previously mapped as Tikihore and Tapuwaeroa formations of the East Coast Allochthon (Moore *et al.* 1989), is now thought to lie structurally below the basal thrust, i.e. the beds are apparently in-place (Rait 1992). This requires some revision of stratigraphic nomenclature, since:

Black's (1980) definition of Tikihore Formation was for slructuraUy complex areas now recognised to

- be within the East Coast Allochthon (Mazengarb *el al*. 1991a; Field, Uruski *el al.* 1997)
- he suggested no group name
- no type section was nominated, but the reference sections are both within the East Coast Allochthon
- Mazengarb *el al.* (199 Ia) included Tikihore and Tapuwaeroa formations in their RU3toria Group
- according to their definition, "Ruatoria Group encompasses all primarily sedimentary allochthonous formations underlying the allochthonous part of the Tinui Group..."
- the intent was thal Ruatoria Group was to apply 10 the allochthonous units, but not to the autochthonous units.

Ruatoria Group is therefore expanded to include allochthonous Tikihore and Tapuwaeroa rocks, and also the apparently autochthonous equivalents_ It is lherefore analogous to Tinui Group which has components (e.g. Whangai Formation) in both the autochthon and the East Coast Allochthon.

There is near-continuous exposure of 1060 m of Tikihore Formation (Kri) and Tapuwaeroa Formation (Krp) in the lower Mata River area (Y 15/648473), in a structurally simple setting. Inoceramid fossils indicate the sequence has an age range of Cenomanian to Santonian (Arowhanan-Piripauan).

The Tikihore Formation is mainly centimetre- to metre-bedded, alternating, fine-grained sandstone and mudstone. Sandstones typically show normal grading, with common sole structures, trace fossils and incomplete Bouma sequences; deposition is inferred to have been from turbidity currents. Five sedimentary cycles are recognised, each starting with a thick (up to 20 m) slump horizon which is overlain by thick (up to 3 m) lenticular sandstones, followed by the more typical alternating sandstone and mudstone (Laird *el al.* 1998a, 1998b). Bioturbated horizons and intervals are common within mudstone and there are zones of abundant inoceramid fossils, some up to I m across, and apparently litlle transported from growth position. It has been argued that inoceramids in growth position indicate Tikihore Formation accumulated at relatively shallow depths, but the use of life position alone as an indicator of paleobathymelry is now known 10 be unreliable (Crampton 1996). The extent of the formation, its great thickness. monotonous facies and sedimentary structures suggest Tikihore Formation accumulated as a submarine fan or fans. in deep marine (slope to bathyal) environments (Mazengarb 1993).

At Mata River the Tikihore Formation passes upward gradationally into the sandstone-dominated Tapuwaeroa Formation; the contact is placed at a Coniacian (Teratan) intraformational breccia unit 22 m thick. Late Cretaceous decimetre- to metre-bedded, sandstone-dominated, alternating sandstone and mudstone beds present locally at Mahia Peninsula (e.g. Webb 1979) are also inferred to be autochthonous Tikihore and Tapuwaeroa formations, for they lie well south of the inferred southern limit of the East Coast Allochthon. In southern Hawke's Bay and Wairarapa similar beds have been mapped as Glenburn Formation (Field, Uruski *et al.* 1997).

Late Cretaceous to Paleocene rocks

From the western map boundary ncar Koranga as far northeasl as Ihungia the Matawai Group is overlain by the mudstone-dominated Tinui Group (Moore *et al.* 1986) of latest Cretaceous to Paleocene (Piripauan-Teurian) age. As the Matawai Group rocks were folded, uplifted and, in some areas, deeply eroded before deposition of the Tinui Group, the contact between the two is a low to moderate angle unconfomlity of regional extent.

Over a distance of about 100 km. from Te Hoe River in the southwest (50 km beyond the Raukumara map boundary) to Moutohora inl-he northeast, the basal Tinui Group beds are massive to well bedded, relatively quartzose fine-grained sandstones, with minor glauconitic siltstone and glauconitised siltstone breccia (Tahora Formation, Kit). Tahora Formation is inferred to have been deposited in beach to mid shelf environments following renewed marine transgression in Piripauan time (Crampton & Moore 1990; Isaac *et al.* 1991). Within the area covered by the Raukumara map the Tahora Formation is typically less than 50 m thick and present over areas too small to differentiate at 1:250 000 scale.

Further east, up to 100m of upward-fining, well bedded sandstone and mudstone (Owhena Formation, Kio) is present in the same stratigraphic position over a geographically restricted area along Waitahaia River (Phillips 1985). The immediately underlying Karekare Formation is intensely burrowed, with abundant calcareous concretions. Owhen3 Formation is interpreted as a deeper water equivalent of Tahora Formation, deposited by sediment gravity flow mechanisms in outer shelf and slope environments.

Tinui Group basal sandstone facies are confonnably and in places gradationally overlain by the Whangai Formation (Kiw), a thick, mudstone-dominated unit widely recognised throughout eastern New Zealand (Northland, Raukumara Peninsula, Hawke's Bay-Wairarapa and Marlborough) and in adjacent areas offshore (Lillie 1953; Moore 1988b; Field, Uruski *el al.* 1997). The Whangai Formation typically consists of 300-500 m of noncalcareous and calcareous shale and mudstone. In western areas the formation is typically siliceous and massive (Western Facies of Moore 1988b), and in eastern areas (including within the East Coast Allochthon) it is more calcareous and better bedded (Eastern Facies).

Several lithologicaJly distinctive members of regional extent have been mapped (Moore J988b) but only one can be differentiated on the map. Kirks Breccia (Kik) is known only from Kirk's Clearing in the middle reaches of the Motu River. It consists or up to 200 m of channel-filling, mau'ix- to clast-supported breccia-conglomerate of angular to subrounded, fine-grained sandstone and mudstone clasts derived from the underlying Karekare Formation. Many clasts contain Late Cretaceous (Motuan or Arowhanan) macrofossils, but microfossils from the breccia matrix indicate a late Piripauan to early Haumurian age. The unit is interpreted as a submarine debris flow deposit, generated by slumping associated with a growing fold (Moore 1989a). The Rakauroa Member (200-300 m thick) is regionally extensive and consists of hard, generally poorly bedded, weakly fissile, noncalcareous mudstone, dark to medium grey in colour when fresh, but weathering to white or very pale grey, often with a rusty appearance. Minor associated lithologies include thin beds of glauconitic sandstone, calcareous concretions, chert and calcareous beds. The commonly overlying Upper Calcareous Member consists of up to 200 m of poorly bedded, medium grey to light blue-grey weathering, slightly to moderately calcareous, micaceous, siliceous mudstone with rare calcareous concretions, pyrite nodules, glauconitic sandstone and breccia beds. In the Waitahaia River area, cenlimetre- to decimetre-bedded sandstone, siliceous mudstone with chert nodules and moderately calcareolls mudstone are mapped as a part of the Porangahau Member (Moore 1988b). The Whangai Formation is inferred to have accumulated in a regionally extensive ocean basin, mainly at bathyal depths (Wilson & Morgans 1989; Leckie el *al.* 1995).

Whangai Formation is conformably and gradationally overlain by the Waipawa Formation (or Waipawa black shale), a distinctive unit of very poorly bedded, dark brown-grey to brown-black, moderately soft to hard, noncalcareous micaceous mudstone of Late Paleocene (mid to late Teurian) age (Moore J988b; Moore 1989b; Leckie *el al.* 1992). Typical samples of the shale have 2-6% TOC (total organic carbon) and the unit has by far the highest hydrocarbon-generating potential of any East Coast source rock (Field, Uruski *el al.* 1997). Waipawa Formation is locally absent and generally less than 20 m thick. Foraminifera indicate deposition was at outer shelf to upper bathyal depths (Field, Uruski *el al. 1997);* paleogeographic and geochemical studies suggest deposition was restricted to environments near the top of the continental sJope (Killops *el al. 1996).*

Eocene and Oligocene rocks

Deposition of mud-rich sediments continued throughout Eocene and Oligocene time over much of what is now the East Coast region, including the area of the Raukumara map (the Mangatu Group; Mooreel *al. 1986).* Ln the southwest of the Raukumara map area the Waipawa Formation is conformably overlain by Wanstead Formation (Egw), which consists of up to 200 m of poorly bedded, bioturbated, green-grey to blue-grey, caJcareous, glauconitic mudstone, with minor alternating glauconitic sandstone and mudstone, and locally, massive muddy greensand. Mudstones contain a high proportion of smectitic clays and are commonly, though wrongly, referred to as bentonites. Wanstead clays accumulated from background sedimentation in a deep ocean basin, while true bentonite clays are derived from alteration of volcanic tephra or tuff (see Fergusson 1985). Landforms developed on these lithologies are typically unstable because of the clays and outcrops are often marked by slumps and earthflows. Southwest of Matawai the overlying Weber Formation (Ogw) rests unconformably on Wanstead Formation, but may overlie it conformably in the east, as in the area of Waerellgaokuri (P.R. Moore & H.E.G. Morgans pers. comm.). It consists of up to 400 m of calcareous, alternating, glauconitic sandstone and mudstone, and light grey bioturbated, calcm'eous massive mudslOne. The Wanstead Formation and Weber formations are of Paleocene to Oligocene age (Joass 1987; Field, Uruski *el at.* 1997); foraminifera suggest deposition was mainly at mid bathyal depths.

THE EAST COAST ALLOCHTHON

Large scale displacements of Cretaceous and Cenozoic rocks were first recognised in Raukumara Peninsula by Stoneley (1968) who identified and mapped a series of 15 gently to moderately dipping thrust structures in the Maungahaumi area, east of Matawai (Fig. 19). Subsequent mapping elsewhere has confirmed that between Matawai and East Cape large areas of Cretaceous to Oligocene rocks are allochthonous, displaced at least tens of kilometres, and possibly hundreds of kilometres, from their original sites of deposition (the East Coast Allochthon; Moore 1988a; Rait 1992; Field, Uruski *el al.* 1997; Rait 2000a). Differentiation of the autochthonous and allochthonous rocks is based mainly on differences in structural style. For example, strata overlying the Te Rata-Waitahaia Thrust are strongly deformed by northwest-trending folds and low angle thrusts, whereas those below are only gently deformed. All pre-Miocene units north of Te Puia are strongly deformed. Age reversals (i.e. old rocks now overlying younger rocks) are also present within the allochthon. The Matakaoa Volcanics, believed to be amongst the oldest rocks of the allochthon, and emplaced in the most distal. oceanic setting. are now at the top and back of the overthrust sequence (Rait 1992; Field, Uruski *el al.* 1997; Rait 2000a). Over large areas the allochthonous rocks have been thrust over the top of the in-place Cretaceous to earliest Miocene sequence.

The thrust sheets identified by Stoneley are believed to be the southwestern margin of the allochthon and equivalent in-place beds are present in the immedimely adjacent area, ncar Matawai. The southeast limit of the allochthon is obscured by the overlying Miocene-Pliocene sequence: it probably extends east from Te Karaka to meet the coast in the area of Whangara. 20 km northeast of Gisborne (Field, Uruski *el al. 1997).*

Discrete. lithology-based units have been differentiated and mapped within the allochthon (e.g. Mazengarb *el al.* 1991a). Many but not all have lateral correlatives within the in-place (autochthonous) sequence to the southwest. The allochthonous units commonly represent deposition at greater depths than equivalents within the in-place sequence (Field, Uruski *el al. 1997).*

Almost all the rocks of the East Coast Allochthon are of late Early Cretaceous to Oligocene age. Detailed mapping, facies analysis, paleontology and structural interpretation indicate that the thrust sheets were emplaced mainly towards the SSW, in Early Miocene time. The range of lithologies, ages of the displaced strata.

Figure 19 Southwestward-directed emplacement of the East Coast Allochthon formed an imbricate stack of thrust slices near Matawai (the hill in the foreground is at *X17/115095;* see Stoneley 1968). The approximate position of thrust faults and folds are shown. The dotted line marks the base of the Miocene sequence which overlies Wanstead Formation unconformably. The high, bush-covered scarp in the left distance is Maungahaumi. The view is towards the southeast. *Photo CN42078110: D.L. Homer*

structural style, direction of emplacement and timing of emplacement of the East Coast Allochthon are all similar or identical to those of the Northland Allochthon (Ballance & Sporli 1979; Brook *et al.* 1988; Isaac *et al.* 1994; Isaac 1996).

Early Cretaceous to Eocene igneous rocks

Early Cretaceous to Eocene submarine basaltic lava, pillow lava, brecciated pillow lava, hyaloclastite breccia and tuff (Malakaoa Volcanics, Kov, Kog, Kos) form two low ranges at the northern tip of the Raukumara Peninsula, namely the Matakaoa massif between Cape Runaway and Marakaoa Point, and the Pukeamaru massif which extends inland southeast of Hicks Bay. A small outlier of similar volcanics is present at Te Kiwikiwi Hill, 9 km south of Te Araroa (Moore & Challis 1985). The volcanic rocks are mainly subalkaline and tholeiitic in composition. In places the eruptive rocks have minor intercalations of sandstone, mudstone, limestone and chert, and they are intruded by dikes and sills of basalt, dolerite and gabbro.

Detailed studies have been carried out in coastal areas where Matakaoa Volcanics are typically well exposed in low cliffs and shore platforms (Gifford 1970; Pirajno 1980; Rutherford 1980). K-Ar dating of lavas from the relatively fresh coastal exposures gave Late Eocene to Early Oligocene ages (Brothers & Delaloye 1982), but these are incompatible with the Early Cretaceous (Albian), Late Cretaceous, and Late Paleocene to Early Eocene ages determined from fossils contained in the intercalated sedimentary rocks (Strong 1976, 1980; Sporli & Aita 1994). It is inferred the lavas are too altered for accurate dating by the K-Ar technique.

Sporli & Aita (1994) suggested the Matakaoa Volcanics are possibly up to 10 km thick. However, it is not yet possible to determine either the present thickness or the original stratigraphic thickness because of the structural complexity, the likelihood of imbrication and lack of marker horizons. Sewell (1992) inferred they accumulated in a marginal basin adjacent to an island arc but Mortimer & Parkinson (1996) suggested they could be an onshore fragment of the large Hikurangi Plateau igneous province. Matakaoa Volcanics are correlatives of the Tangihua Complex rocks present within the Northland Allochthon (Isaac *et al.* 1994).

In the northern Tapuaeroa valley the Early Cretaceous Mokoiwi Formation (see below) includes a somewhat discontinuous stratiform band of mafic lavas, intermediate and silicic tuffs, and tuffaceous sediments informally known as the Rip Volcanics (Krr; Pirajno 1979). The band is up to 600 m thick and can be followed laterally for 11 km. Pirajno termed them a "spilite-keratophyre" association; analyses suggest the basalts are subalkaline, of either mid ocean ridge or back-arc affinity, and similar to the Matakaoa Volcanics (Mortimer 1992; Sewell 1992).

Early and Late Cretaceous sedimentary rocks

The allochthonous equivalent of the in-place Matawai Group consists mainly of centimetre- to decimetre-bedded alternming sandstones and mudstones (the Ruatoria Group; Mazengarb *et al.* 1991a) with intervals of thicker sandstone and mudstone, minor conglomerate, and sedimentary breccia. Several lithologic units are differentiated. The latest Cretaceous and Paleocene sedimentary rocks of the allochthon are included in the Tinui Group.

Alternating centimetre- to decimetre-bedded, fine- to medium-grained mid grey sandstone and dark blue to black mudstone present over a large area in the Tapuaeroa valley are mapped as Mokoiwi Formation (Krm; Speden 1976b; Gibson 1986; Fig. 20). Smaller areas of Mokoiwi Formation are present further south (Mazengarb *et al.* 1991a). Inoceramid fossils are common and in places mudstone beds contain calcareous concretions. The formation is typically highly tectonised and is in many places broken formation. It includes lensoidal sandstone masses mapped as Taitai Sandstone Member (front cover). Taitai sandstone is massive, poorly sorted, dark grey to grey-green and fine- to coarse-grained. Locally it contains conglomerate and breccia bands up to 15 m thick. It forms the mountains of Wharekia and Aorangi, and several other smaller massifs in the vicinity. At Mount Taitai itself (Y15/685553), typical well bedded Mokoiwi sandstone and mudstone is unconfomably overlain by an upward-fining breccia- and sandstone-dominated unit considered by Speden (1976b) to be sufficiently different from Taitai Sandstone to warrant separate formation status (Mangaohewa Formation). Alternatively, the unconformity may represent the scoured base of a submarine channel-fill sequence, as seen in some Taitai Sandstone masses; the unit is here included in Taitai Sandstone. Igneous clasts in the conglomerates include granophyre, rhyolite, rhyodacite, dacite, tuff and vesicular basalt (Mortimer 1992, 1995; Speden 1976b). Small areas of conglomerate in the Waitahaia-Puketoro area (e.g. Y16/540395) are included in the Taitai Sandstone even though they lack significant sandstone.

Mokoiwi Formation is faulted against Torlesse composite terrane basement in the headwaters of the Raukokore River and, elsewhere, is thrust over in-place Matawai and Tinui group strata. All known basal contacts are faulted. The stratigraphic relations with younger units are also uncertain. In the headwaters of the Mangaoporo River

Figure 20 Folded centimetre- to decimetre-bedded sandstones and mudstones typical of the Mokoiwi Formation exposed in the eastern bank of Mangawhairiki Stream, Tapuaeroa valley (Yl51617591). *Photo CN42277/5:* D.L *Homer*

an indurated and deformed mudstone-dominated unit of Albian (Motuan) age, considered to be Mokoiwi Formation, apparently grades conformably into less indurated rocks mapped as Tikihore Formation (see below). The thickness of the Mokoiwi Formation is difficult to estimate because of the unresolved structural complexity. Speden (1976b) estimated a thickness of 900-1200 m.

Macrofossils and dinoflagellates suggest an age range of Albian to Cenomanian (Motuan-Ngaterian; Speden I976b; Wilson 1976). Mokoiwi Formation sandstones and mudstones are inferred to have been deposited in a moderately deep water turbidite fan complex. Taitai sandstones represent channel- or canyon-fill deposits within the fan system. The Rip Volcanics were fonned by sea floor volcanism within the oceanic plate on which Mokoiwi Formation was deposited.

Fossiliferous, centimetre- to metre-bedded, alternating fine-grained sandstone and mudstone, typically less indurated and less deformed than Mokoiwi Formation, is present over a large area north of the Tapuaeroa River to the crest of the Raukumara Range and the Kopuapounamu River, and over a large area in the headwaters of the Waipaoa and Mata rivers, Mangatu Forest (Tikihore Formation, Kri; Black 1980; Rait 1992; Mazengarb 1993). Small areas of Tikihore Fonnation are present elsewhere, for example at Orete Point and the mouth of the Raukokore River. Alternating sandstone and mudstone make up by far the greater part of the unit (Fig. 21), but locally either sandstone (as in Mangaoporo River catchment) or mudstone may be dominant. A mudstone-dominated variant ofTeratan age covers a large area north of the Tapuaeroa valley and is differentiated on the map. Minor lithologies include red, green and purple mudstones, slump horizons, conglomerate, breccia and rare flow basalt (Mazengarb *ef al.* 199Ia).

Figure 21 The shore platform at Raukokore *(Y14/413844;* facing west) exposes steeply dipping, Late Cretaceous Tikihore Formation alternating sandstone and mudstone; the direction of younging is to the left. The Tikihore Formation in this area is about 3000 m thick. *Photo CNI2973136: D.L. Homer*

Within the East Coast Allochthon the formation is typically thinner bedded and more monotonous than in the lower Mata River. Inoceramid fossils are common in places, but conspicuous barren zones are present in the coastal sections north of the Raukokore River. At Grete Point the Teratan interval includes 130 m of alternating centimetre-bedded green mudstone (siltstone), red and green muddy sandstone, and grey cross-bedded sandstone, perhaps of similar origin to the coloured mudstones present within the correlative Karekare Formation at Mangaotane.

Tikihore Formation is estimated to be up to 3000 m thick. The base is commonly a fault contact. North oFTapuaeroa River the Tikihore Formation grades upward into the overlying Tapuwaeroa Formation and the two may be, in part, lateral equivalents. Where there is no Tapuwaeroa Formation the Tikihore Formation grades upward into Whangai Formation. The known age range is Cenomanian to Santonian (Ngaterian-Piripauan).

The Tapuwaeroa Formation (Krp; Wellman 1959; Mazengarb 1993) consists of moderately indurated, decimetre- to metre-bedded, sandstone-dominated, alternating sandstone and mudstone, with minor conglomerate, breccia and mudstone. Large areas of Tapuwaeroa Formation are present within the East Coast Allochthon between the Tapuaeroa and Waikura valleys, northern Raukumara Peninsula.

Tapuwaeroa sandstones are more quartzose than those of older Ruatoria Group Formmions and contain more plant fragments and carbonaceous material, glauconite and mica. Individual sandstones are up to 6 m thick; sandstones are typically graded with Bouma sequence sedimentary structures. Piripauan inoceramids (e.g. /. *australis* and /. *pacificLis pacificus*, Crampton 1996) are common in coarse-grained sandstone and pebbly sandstone beds, as is the small oyster *OSfrea lapillicola*, a characteristic Fossil. Tapuwaeroa Formation is 1150 m thick at Waiorongomai River, the type section (Mazengarb 1993), and it ranges in age from Coniacian to Campanian (latest Teratan-Haumurian).

Late Cretaceous to Paleocene sedimentary rocks

Whangai Formation (Kiw) rocks within the East Coast Allochthon are mainly attributed to the Eastern Facies (Fig. 22; Moore 1988b). The rocks consist of poorly bedded, light blue-grey weathering, medium grey, slightly to moderately calcareous, micaceous, siliceous mudstone of the Upper Calcareous Member and well bedded, light grey to white, hard, moderately calcareous mudstone, in places with beds of glauconitic sandstone, of the Porangahau Member. The formation rests conformably on the Tikihore and Tapuwaeroa formations with a gradational contact. The largest single area of allochthonous Whangai Formation covers about 75 km^2 in the headwaters of the Waipaoa River, thrust over younger rocks of the Weber and Wanstead formations, and overlain by Tolaga Group mudstonc of Early Miocene age. Large areas of Whangai Formation are present in the vicinity of the confluence of the Mata and Tapuaeroa rivers, near Ruatoria. Here, Whangai mudstone is thrust over Tapuwaeroa Formation, overthrust by a structurally higher thrust sheet of Early Cretaceous Mokoiwi Formation and unconformably overlain by in-place Miocene-Pliocene sandstone of the Mangaheia Group. Porangahau Member calcareous mudstones are present

Figure 22 Chevron folds in well bedded Whangai Formation mudstones on the bank of Waimatau Stream *(Y I 61382235).* The direction of younging is to the right and the folds are overturned. This style and intensity of folding, involving shallow dipping axial planes, is common within the East Coast Allochthon.

at Wairamaia Stream (near East Cape) and at Mahia (Moore I988b). The Upper Calcareous Member is about 500111 lhick in the reference section at Te Weraroa Stream (Y I6/3 17 197); the total stratigraphic thickness of the Whangai has been estimated to be as great as 900 m (Moore 1988b) but there may be undetected structural repetition.

Whangai Fonnation within the allochthon is conformably overlain by up to 50 m of very poorly bedded, grey to brown-black, moderately soft to hard, noncalcareous mudstone of the Waipawa Formation (Piw). Only one area is large enough to show on the 1:250 000 map: in the upper Waipaoa valley Whangai Formation includes a thrust sliver of Waipawa mudstone which can be traced laterally for c. 5 km (Mazengarb *e1" I.* 199 1a).

Eocene and Oligocene sedimentary rocks

Eocene to Oligocene rocks present within the East Coast Allochthon are similar to equivalent rocks in the in-place sequence and are included in the same lithostratigraphic unit (Mangatu Group). Wanstead Formation (Egw) conformably overlies Waipawa Formation and consists predominantly of pale grey-green calcareous mudstone. in places with intercalated beds of mid to dark green (red-brown when deeply weathered). glauconitic and lithic sandstones. A few sandstones are up to 20 m thick and some are well cemented by calcium carbonate. At Port Awanui (Z *15/89760* I) the formation shows intraformational slump folding. and conglomerate and pebbly mudstone contain clasts of Waipawa Formation up to 3 m across. Coloured (red-browll, white, green-grey) calcareous and noncalcareous. smectitic claystone with thin, fine-grained, glauconitic sandstone beds is a distinctive facies. common in areas of melange within the East Coast Allochthon and in some structurally complex areas of melange and diapirs beyond the allochthon front. Wanstead Formation is apparently lip to 300 111 thick. The known age range is Late Paleocene to Eocene (Teurian-Runangan), as for Wanstead Formation within the in-place sequence.

The conformably overlying Weber Formation (Ogw) consists of up to 900 m of poorly bedded, pale grey calcareous mudstone with thin, glauconitic sandstone beds and muddy limestone. In the Mangatu area limestone is up to 500 m thick. Foraminifera indicate the Weber Formation is mainly of Oligocene (Whaingaroan-Waitakian) age.

MIOCENE AND PLIOCENE ROCKS

Both the Early Cretaceous 10 Oligocene in-place sequence and the East Coast Allochthon are unconformably overlain by a structurally simple sedimentary sequence of Early Miocene to Pliocene age (Stoneley 1968: Moore *el/II.* 1989: Mazengarb *e1 /II.* 1991 a). The unconformity marks a pronounced change in the environment of deposition. The underlying Mangatu Group is mainly clay-rich pelagic mudstone and limestone. whereas the overlying Early Miocene rocks are terrigenous and much thicker, containing sequences of massive blue-grey mudstone. alternating centimetre- to metre-bedded sandstone and mudstone. and massive sandstone, with lesser conglomerate and tuff. Emplacement of the East Coast Allochthon. and the subsequent changes in sedimentation and deformation style, are consequences of a major tectonic event associated with the onset of subduction at an active plate boundary between Northland

and Marlborough (Ballance 1976; Pettinga 1982; Rait el *al.* 199 1). Detailed stratigraphic subdivisions have been established for some local areas (e.g. Kenny 1980; Joass 1987; Savella 1992). However, lateral changes in facies and thickness make it difficult to correlate individual units between such areas. The lithostratigraphy adopted here is based on that of Mazengarb *el al.* (199 1a) who, in the Y16 area, subdivided the Miocene-Pliocene rocks into the Tolaga Group (Early Miocene to Late Miocene; Waitakian to late Tongaporutuan) and the unconformably overlying Mangaheia Group (latest Miocene to Early Pliocene; late Tongaporutuan to Opoitian).

Early Miocene

Ln northernmost Raukumara Peninsula the Matakaoa Volcanics are overlain unconformably by the Whakai Formation (Chapman-Smith & Grant-Mackie 197 1), the basal beds of which are limestone-cemented breccia with intercalated, naggy, oyster-rich limestone (Fig. 23, Mlb). Most of the Whakai Formation consists of well bedded, alternating sandstone and mudstone, massive mudstone (Fig. 24, Mlm) and metre-bedded lensoidal bodies of igneous pebble conglomerate (MIc) of Early Miocene (Otaian-Altonian) age. In the Tauwhareparae area units of Late Oligocene to Early Miocene (Waitakian-Otaian) tuffaceous sandstone-mudstone and breccia-conglomerate were formerly included in the Mangatu Group (Mazengarb *e1 al.* 199 1a) but are now recognised as part of the Tolaga Group (Mlb & Mlv). The breccia includes large blocks of Taitai Sandstone and Whangai Formation, and rounded cobbles and pebbles of basalt and gabbro. At Huiarua, near the headwaters of the Mata River (y *16/420308),* sandy and muddy limestone with basal breccia-conglomerate and intercalations of breccia (Mil) rest unconformably on Tikihore Formation. These breccia-bearing units are considered to be synorogenic, deposited in "piggy-back" basins during and immediately following emplacement of the East Coast Allochthon. The wide range of lithologies present in some breccias indicates East Coast Allochthon units were being uplifted and eroded during the thrust sheet emplacement.

The bulk of the Tolaga Group (MI) comprises massive and thinly bedded mudstones. The typical massive mudstone is moderately soft to moderately hard, medium grey in colour and slightly calcareous, with scattered calcareous nodules and concretions, intercalated beds of fine-grained sandstone and tuff, and rare macrofossils (small bivalves and gastropods). Microfossils, soch as foraminifera, are common throughout and are the principal means of dating the rocks. Centimetre-bedded and millimetre-laminated mudstones are similar lithologically and are a transitional facies into alternating centimetrc- to metre-bedded sandstone and mudstone. In the area of the Raukumara map the Tolaga Group is up to 1000 m thiCK; there is considerable local variation in both thickness and facies.

Igneous pebble conglomerate (MIc; the thungia igneoos conglomerate of McKay 1887) is common at or near the base of the Tolaga Group from Oweka Stream in the nDlth *(Y l4/647875),* Tarndale in the west (Y I613 111 21) and as rar east as Puketiti Station (Kenny 1984b; Mazengarb *ef al.* 199Ia). The southernmost known Ihungia conglomerate is at Whatatutu (Y 17/30403 1) although coarse-grained sandstone present as far southwest as Otoko (X I7/178927) is a probable distal eqoivalent. Locally, the conglomerate is present over an area extensive enough to show on the 1:250 000 map. Conglomerate beds are channelised and range up to about 10m thick. They are commonly interbedded with dark grey, fine- to coarse-grained sandstone and intercalated with mudstone or alternating sandstone and mudstone facies. Clasts are typically well rounded pebbles and cobbles of igneous lithologies, but there are also well rounded boulders (as at Tarndale Road, Y 16/3 1I 121). Igneous and metamorphic clast types include hornblende-rich gneiss, gabbro, hornblende gabbro, quartz-rich tonalite, hornblende hornfels transitional to hornblende schist, quartz diorite and granodiorite (W.A. Watters *in* Mazengarb *ef al.* 199 1a). Sedimentary clasts include concretions, grey chen, reworked macrofossils and, locally, rafts of intraformational siltstone up to 2.5 m across. Some of the igneous clasts are derived from Matakaoa Volcanics but the other sources are still unknown.

Sedimentary breccia/conglomerate beds (both rounded and angular clasts) are present throughout the Tolaga Group (differentiated locally, Mlb), but are most common in the lower part (Mazengarb *el al.* 1991 a). The thickest and coarsest are northeast of Paraeroa Stream (Y *16/567357);* finer grained equivalents are present near the Waikohu River (X 17/198978) and in a fault sliver in Hihiroa Stream (X 17/1909 12). Individual breccial conglomerate beds are up to 30 m thick. Clasts are derived mainly from the sedimentary rocks of the East Coast Allochthon. Clasts over a metre across are rare, lhough the largest known is a 40 m x 7 m block of Whangai mudstone (Mazengarb *el al.* 1991 b).

Glauconitic sandstone (Whangara Sandstone, Mlw; Neef & Boltrill 1992) at the base of the Early Miocene is here incorporated in Tolaga Group. The unit has been differentiated only in some areas (e.g. near Whangara, Y *18/660790).* It comprises up to 20 m of medium- to coarse-grained, highly glauconilic sandstone. Several small areas of limestone are mapped separately (Mlk). In the upper Waipaoa valley the Moonlight Limestone consists of up to 150 m of moderately to well cemented, poorly bedded, locally naggy, coarse- to very coarse-

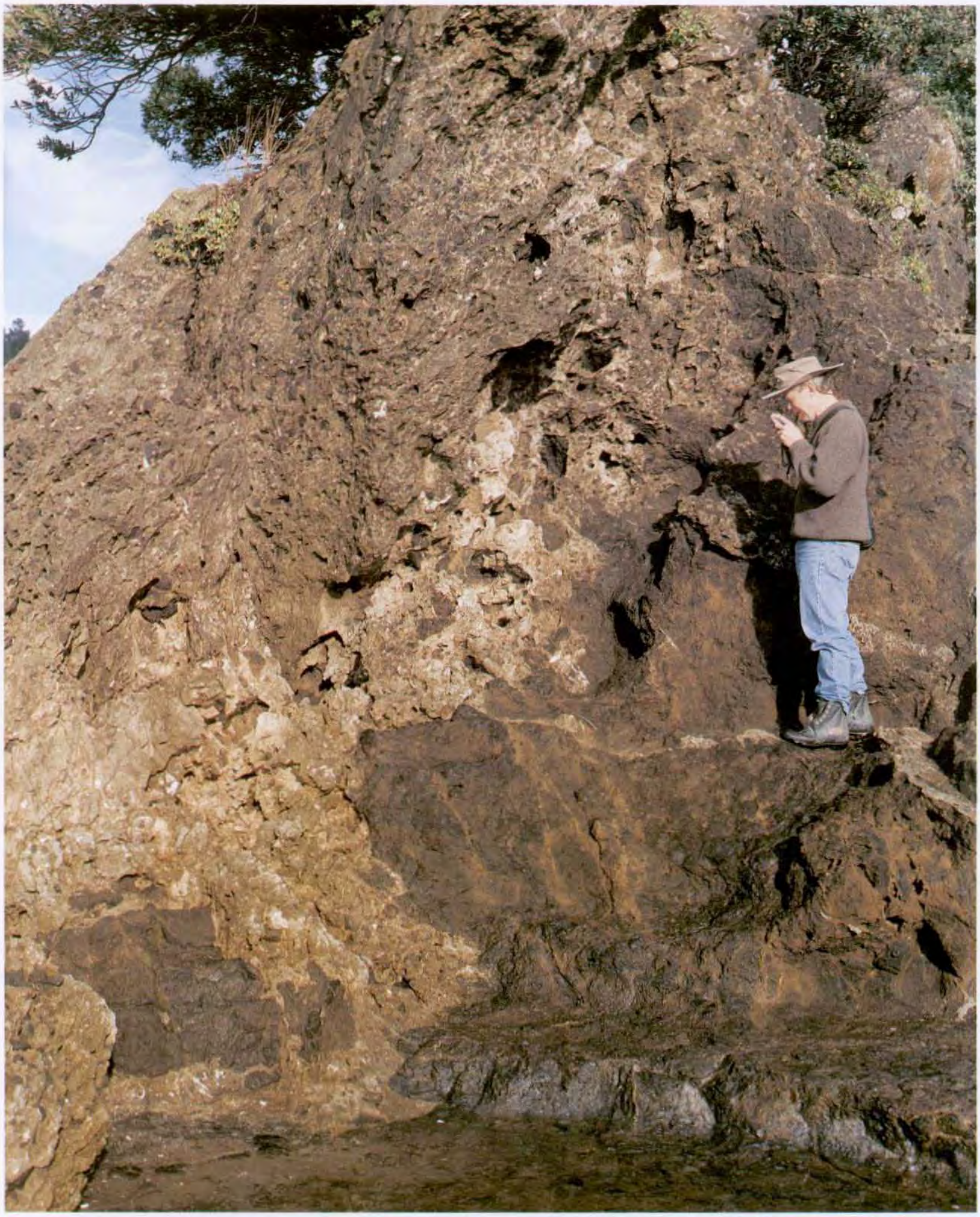

Figure 23 On the point separating Hicks Bay from Onepoto Bay (Z14/772875) the Matakaoa Volcanics (dark beds on right) are unconformably overlain by Early Miocene breccia and limestone of the Whakai Formation, Tolaga Group. The contact is irregular and large blocks of Matakaoa basalt are present as clasts (e.g. bottom left). The Talaga Group rocks were deposited in shallow water and have subsequently been uplifted and tilted to the southeast (left). *Photo CN42422/9: D.L. Homer*

Figure 24 Gently dipping mudstone of the Early Miocene Whakai Formation beside State Highway 35 near Hicks Bay *(214f778874)* is the prevalent lithology within the Tolaga Group. The thin, brown-stained sandstone beds define bedding and show that the fractured appearance of the mudstone is a surface effect resulting from wetting and drying cycles. A small fault dips toward the person.
Photo CN42200119: D.L. Homer

grained, bioclastic limestone interbedded with calcareous sandstones. Large oyster shells are common. The Kouetumarae Limestone is an equivalent present locally between the lower Mata River and Ihungia River; it consists of up to 20 m of poorly bedded, flaggy, bryozoan coquina limestone and shelly, bryozoan-rich sandstone. The limestones are shallow marine deposits, inferred to have accumulated at shelf depths (Kenny 1984b; Mazengarb *et al.* 1991a; Field, Uruski *et al.* 1997).

Southwest of Rakauroa and Te Karaka the Tolaga Group rocks form bluffs and spectacular southeast-facing dip slopes along the northwestern margin of Miocene outcrop. At Hangaroa River and Mutuera Stream the basal sediments include a thin conglomerate, cross-bedded, shelly, pebbly sandstone (Joass 1987) and muddy fossiliferous sandstone of late Early Miocene (Altonian) age (M.ls). The more typical facies are bedded calcareous mudstone, minor sandstone, and intervals of alternating well bedded sandstone and mudstone (Ml). Alternating sandstone and mudstone units are locally distinguished (Mia). Near Wharekopae, Savella (1992) mapped two (informal) units of centimetre- to decimetre-bedded, fine- to medium-grained sandstone and mudstone, namely his Cocos flysch (which includes fossil coconuts; Ballance *et al.* 1981) and Rere sandstone. In the vicinity of the Mokonuiorangi Range the Cocos flysch and overlying mudstone pinch out westward beneath the overlying Rere sandstone.

Middle and Late Miocene

Near Raukokore Torlesse composite terrane basement and rocks of the East Coast Allochthon are overlain unconformably by Middle Miocene Tolaga Group conglomerate, sandstone, mudstone and limestone (Mlh;

Moore 1957). carTe Puia Middle Miocene sedimentary rocks unconformably overlie Tikihore and Whangai formations of the East Coast Allochthon (i.e. Early Miocene beds are absent). In these areas the Middle Miocene beds are generally less than 100 mthick. Much thicker Middle Miocene beds are present further south. South ofTe Puia they are mainly mudstone, locally with intercalations of metre-bedded sedimentary breccia and lenses of Bexhaven Limestone up to 10 m thick and 400 m long (Mazengarb *el "l.* 1991a). The Bexhaven Limestone is a micritic, sulphurous and fossiliferous limestone considered to have famled around cold water seepson the sea floor, simiJar to the modern seeps known offshore (Lewis & Marshall 1996; Campbell *el "f. 1999)*. Locally, however, the Middle Miocene beds are mainly alternating, centimetre- to decimetre-bedded, fine-grained sandstone and mudstone, with minor pebble conglomerate. Southwest of Rakauroa-Makarori one such unit, the Thnanni Formation (MIn). is up to 2000 m thick (Field, Uruski *el "l.* 1997). In northern Hawke's Bay slightly younger units of similar alternating sandstone and mudstone have been mapped informally as Makaretu sandstone or Rerepe sandstone (Mia; Francis 1993b; Field, Uruski *el* "I. 1997) of late Middle Miocene (Waiauan) age.

Between Te Puia and Wairoa Middle Miocene rocks are typically overlain conformably by similar beds of Late Miocene age, although locally the relationship is unconformable. Mudstone is the dominant lithology (MI) with intercalations of well bedded alternating sandstone and mudstone (Mia; Fig. 25), and shelly muddy sandstone (MIz). Late Miocene sandstone-dominated alternating sandstone and mudstone units present between Gisborne and Wairoa have been mapped as Makaretu sandstone (e.g. Davies *el (Il.* 1998). Beyond the Raukumara map boundary Makaretu sandstone is up to 400 m thick: it is interpreted as a base-or-slope sequence comprising four principal turbidite lobes (Davies *el (Il.* 1998; Fig. 26). Some of the Late Miocene sequences include abundant

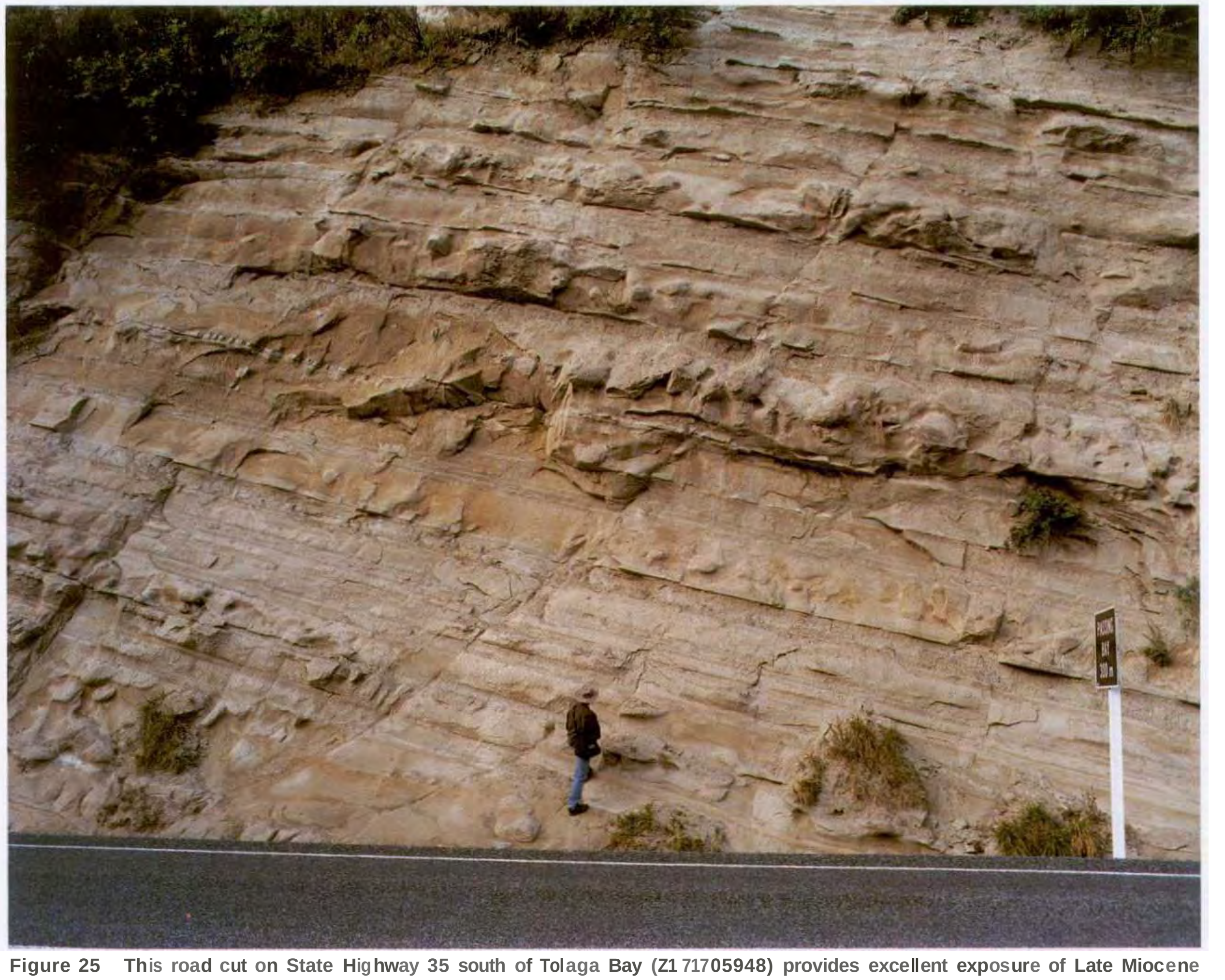

Figure 25 This road cut on State Highway 35 south of Tolaga Bay (Z1 71705948) provides excellent exposure of Late Miocene Tolaga Group sandstones which are offset by several smali laults. *Photo CN42197/13: DL Homer*

volcanic tuff (MJv) derived from rhyolitic eruptions in the Coromandel Peninsula area *(Shane et al.* 1998). There are excellent exposures of sandstones rich in volcanic delritus at Mahia and at Gable End Foreland (Fig. 27; also back cover). Decimetre- to metre-bedded, fine-grained, fossiliferous sandstones which form a prominent tableland in Mangatu Forest (Areoma Sandstone, Mlr) unconformably overlie Middle Miocene rocks (Mazengarb *et al.* 1991 a). A ridge·forming unit of Late Miocene fossiliferous sandy mudstone is present along the north coast ofTolaga Bay. Near Patutahi discontinuous outcrops of shelly limestone 10-20 m thick (patutahi Limestone, Mlp; Beu 1995; Fig. 28) are present within mudstone and the basal contact may be partly or wholly unconformable. Shelly limestone (Mil) present over a small area aLTirihaua Station (Y 18/586275) is similar to the slightly older Bexhaven Limestone and a similar origin is inferred.

Latest Miocene and Pliocene

The latest Miocene to Pliocene Mangahcia Group (Mazengarb *er al.* 1991 a) consists of up Lo 2000 10 of shelly sandstone, sandstone and mudstone. It covers large areas south of Whangaparaoa and in the vicinity of East Cape, and is present between Tauwhareparae and Te Karaka (mainly in broad synclines). within the Wairoa Syncline and in the western part of Mahia Peninsula.

Figure 26 Late Miocene Makaretu Sandstone forms prominent bluffs and spectacular dip slopes; it has potential as a hydrocarbon reservoir lithology in the Wairoa area. Pliocene limestone forms a scarp on the horizon at the extreme right (Whakapunake). The hummocky surface on the dip slope results from slumping. The view is towards the south. *Photo CN42107/19: 0.L. Homer*

In northern Raukumara Peninsula the East Coast Allochthon and Tolaga Group units are unconformably overlain by a shallow marine sequence of tuffaceous, fossiliferous sandstone, calcareous mudsLOne and minor limestone (Te Kahika Formation of Chapman-Smith & Grant-Mackie 1971). Near East Cape the rocks comprise an upwards-coarsening and shallowing sequence deposited at depths between upper bathyal to shelf (Ballance *el al.* 1984). Between Te Puia and Tolaga Bay the Tolaga Group beds are unconformably overlain by bluff-forming shelly sandstone and muddy sandstone of the Tokomaru Sandstone (Mmk) which is locally up to 500 m thick (B10m 1982, 1984; Mazengarb *el al.* 1991a). The overlying Ramanui Formation (Pmz) consists mainly of alternating sandstone and mudstone, with lesser sandstone, mudstone, tuff and limestone (Mazengarb *et al.* 1991a; Field, Uruski *el al.* 1997). The basal contact is conformable in the Tauwhareparae area but unconformable inland from Gisborne. In places massive sandstone units are differentiated (Pms). The Ormond Limestone (Pmm) is known from near Gisborne, at Waihirere. Waerengaokuri and in the low hills between there and Poverty Bay (Beu 1995; Field, Uruski *el al.* 1997).

South of Gisbome Early Pliocene Mangaheia Group rocks are mainly sandstones, some of which are tuffaceous (Pms), and mudstone (Pmz). Several unconformity-

Figure 27 Near-vertical, Late Miocene Tolaga Group alternating sandstones (white beds) and mudstones are well exposed in the sea cliffs at Gable End Foreland *(Z17n 13836)*, so named by Captain James Cook because of the prominent white gable-shaped bed. The sandstones contain abundant volcanic ash probably derived from contemporaneous volcanic eruptions in the Coromandel Peninsula area. The view is towards the southeast. *Photo CN12914A: D.L. Homer*

based, discontinuous, shelly limestones have been differentiated (Opoiti Limestone, Pmo and Whakapunake Limestone, Pmw; Beu 1995). The Opoiti Limestone grades laterally into sandstone on both limbs of the Wairoa Syncline (Beu 1995). The unconformably overlying Late Pliocene shelly limestone (Tahaenui Limestone, Pmt; Beu 1995) is conformably and gradationally overlain by thick sandstone, mudstone and mjnor limestone. The Pliocene sequence shows marked lithofacies and thickness variation laterally, with considerable onlap against pre-existing structures (see cross sections).

Melange

Areas of severely crushed, mixed lithologies are mapped as melange (mel). Typically, fragments and blocks of Whangai Formation and Mangatu Group liLhologies are present in a sheared, smectitic mudstone matrix. The melange is associated with rocks of the East Coast Allochthon and is also present in the cores of diapiric structures bounded by Neogene rocks, i.e. it has apparently been formed by at least two different mechanisms in two main periods. The presence of melange is commonly indicated by areas of slumping.

Figure 28 Late Miocene Tolaga Group Patutahi Limestone (upper, mainly dark layer) is a valuable source of aggregate near Gisborne. This outcrop (X18/223679) near the Waerengaokuri Quarry shows the limestone resting with angular unconformity on well bedded sandstone and mudstone (Middle Miocene Tolaga Group). The limestone face is about 10 m high. *Photo CN4219312: D.L. Homer*

QUATER ARY SEDIMENTS

Sediments deposited in Quaternary time (within the last 1.8 million years) are present in onshore coastal plains, alluvial plains, swamps, alluvial fans and landslides, They are described according to their lithology, origins. known or inferred age and, for some. their geographic location. Ages are given in terms of the oxygen isotope time scale (Imbrie *et al.* 1984; Crampton *et al.* 1995), except that some deposits (e.g. the Mangatuna Formation) cover a wide age range and are mapped as undifferentiated Quaternary sediments.

Pleistocene sediments of the Waipaoa catchment

Up to 150 m of Pleistocene sediments are present in the Waipaoa River catchment between What3tutu and Gisbome. and in outliers at Tirihaua, Waim3ta valley and Pouawa (Mangatuna Formation, eQa: eef *et al.*, *1996*; Coleman 1999a, 1999b). The sequences unconformably overlie Talaga and Mangaheia groups and have a wide range of lithologies. Mangmuna Fom13tion is structurally simple, generally dipping at less than 5° over large areas, although close to some faults Mangatuna Formation dips at up to 20°.

NOlth of Ormond the Mangatuna Formation includes fine-grained sand, laminated mud, peat, tephra and diatomite at elevations of up 10 150 m above the Waipaoa River (Figs. 29,30). The muds are fossiliferous and include bivalves (e.g. *Hyridel/fl*, a fresh water mussel), gastropods, fish skeletons. moa bones and impressions of feathers and leaves (Hill 1889: Oliver 1928).

The three members differentiated in the Gisborne-Waihirere area (Neef *et al.* 1996) cannot be shown separately on a map of this scale. Stratigraphic relationships are more complex than outlined by Neef

Figure 29 Flat-topped hills adjacent to the Waipaoa River at Kaitaratahi (middle ground, Y17/374867) are formed of Mangatuna Formation lake deposits about 100 m thick. The lake in which they accumulated occupied a large area in the middle and lower part of the Waipaoa catchment in Early Pleistocene time. The base of the formation is exposed on the river bank at the left. The view is towards the east; the distant hills are mainly of Pliocene Mangaheia Group rocks. *Photo CN42318/8: D.L. Homer*

Figure 30 Alternating, well bedded, very fine sand and clay of Mangatuna Formation lake deposits at Aangatira Station, Te Karaka *(Y171 326950)*. Clay beds infill ripples preserved at the tops of sands. The red and white divisions on the scale are each 10 centimetres long.

(Coleman 1999b). The Calhome Member comprises mainly weakly indurated mudstone with intercalated tephras, ignimbrite. paleosols and minor gravels. A basal lignite 3 In thick is present near Mangatuna Station (Y 18/482750). The MalOkitoki Member is mainly iron-stained, matrix-supported, cross-bedded, polymict gravel with intercalated lenses of sand which locally, as at Hitchens Quarry (Y 18/455748), contains abundant nonmarine fossils. Clasts are derived from a variety of Cretaceous and Tertiary rocks, with a large component from Torlesse composite terrane basement (Neef *et al.* 1996), and igneous clasts identical to those in Early Miocene Talaga Group conglomerate, indicating the sources were 1101111 of Whataltllll. The Town Hill Member includes grey and blue-grey clays, pebbly sandslOnes, fossil-rich horizons up to 1.5 111 thick and thin tephras. The fossils (e.g. *Austrovenl/s stllfchburyi)* indicate deposition in estuarine environments.

Mangatuna Formation contains a number of pumiceous tephras and/or distal ignimbrites, the products of large scale volcanic eruptions in the Taupo Volcanic Zone, 150 km to the west. A 3 111 thick tephra near the base of the Mangatun3 Formation in the area of Gisborne city is correlated with the I Ma old PoLaka Ignimbrite (synonymous with Potaka tephra, Coleman I999a, 1999b; Shane 1994). A near-basal. 8 m thick tephra at Te Karaka has been dated by the fission track method at 620000 ± 6000 years B.P. (B.Y. Alloway pers. comm. 1999). A poorly known estuarine facies present at Kaiti Hill contains the subtropical bivalve *Alladara trapezia* and is. apparently, significantly younger (120 000 years B.P.; Brown 1995).

Shallow marine sediments near Cape Runaway

Shallow marine, fossiliferous, pumiceous, sandy mudstone and sandstone (Q9m) present between Cape Runaway and Te Araroa were previously correlated with what is now known as Mangatuna Formation at Gisborne (see Adams 1910; Chapman-Smith & Grant-Mackie 1971). Fission track daLing of intercalated tephras (D. Seward ill Sumosusastro 1983; Beu *et at.* 1990) indicated an age of about 220 000 years B.P. However, early generation fission track ages have been found to be too young (Seward 1979) and an age of Oxygen Isotope Stage 9 (c. 320000 years B.P.) is considered more likely (L.J. Brown pel's. camm.). The older age is consistent with the greater deformation of the unit (as expressed by elevation changes outlined below) compared with the adjacent Q7b marine terrace at Malakaoa Point.

The Te Piki Member outcrops between 27 m and 60 m above sea level at Te Piki 3 km ESE of Whangaparaoa. It is up to 35 m thick and contains a rich and diverse molluscan fauna indicative of shallow marine deposition in conditions slightly warmer than the present day. The Maddox Member is an estuarine equivalent present over a small area at YI4/658877, 12 km ESE of Te Piki. It could mark the inland extent of the marine incursion, or alternatively, a seaway may have connected Whangaparaoa and Hicks Bay. It is present at up to 210 m above sea level, indicating differential uplift (Chapman-Smith & Grant-Mackie 1971).

Marine terraces

Elevated marine terraces (Qlh, Q3b, QSb, Q6b, Q7b, Q9b, Qllb) are common in many coastal areas, notably along the Bay of Plenty coast between Opotiki and East Cape, and at Mahia Peninsula (Fig. 9). The terraces represent erosion surfaces cut in bedrock by marine processes and subsequently raised by tectonic uplift to as much as 300 m above present sea level. The terraces are commonly overlain by thin deposits of gravel and sand, in places containing shallow marine fossils. Terraces and terrace deposits may be capped by younger tephras and loess (Fig. 31), and by other younger nonmarine deposits (Berryman 1993a, I993b). Near Opotiki terrace remnants al 20 10 100 m above sea level are c. 400 000 years old (QIIb; Manning 1996). At Te Araroa a terrace surface 300 m above present day sea level (Q5b) is c. 125 000 years old (Yoshikawa 1988).

Coastal plain deposits

Coastal plain deposits cover a minor part of the mapped area. Much of Gisborne City is built on the Te Hapara Sands, a unit of beach and minor dune sands (Q1b) present as a series of ridges and swales (troughs). They are as old as c. 9000 years B.P. and lie up to 12 m above present sea level (Pullar & Penhale 1970; Pullar & Warren 1968). Comemporaneous uplift of the eastern side of Poverty Bay is responsible for the progressive decrease in elevation from the oldest dunes to the coast. Estuarine and swamp deposits (Qla) are present behind the modern beach ridge and foredunes, and in the swales of older beach ridges. They are typically present near the mouths of rivers and streams and are well developed on the Poverty Bay flats. In contrast to the sand-dominated Poverty Bay system, the beach ridges at Te Araroa are mainly gravel (Garrick 1979), reflecting the nature of the sediment supplied by the adjacent Karakatuwhero River.

In Holocene time (overthe last 10000 years) beach dunes and sands about 20 m thick have accumulated to form a tombolo between bedrock highs at Opoutama and Mahia (Cameron 1999). Sand dunes and gravel beach ridges between Wairoa and uhaka are present as a continuous strip about 23 km long and up to I kill wide. The gravel has a high proportion of Torlesse composite terrane clasts which were probably transported down the Wairoa and Mohaka rivcrs before coastal processes transported them to their present position. These deposits are a partial barrier to drainage of local streams into the sea and control the presence of several shallow lakes and lagoons (e.g. Whakaki Lagoon). and the accumulation of estuarine and fluvial deposits (Fig. 8; Ota *et at.* 1989).

Rates of coastal accretion or erosion vary widely within the mapped area (Gibb 1981). Ota *et at.* (1989) demonstrated that the Wairoa-Nuhaka coastal plain formed over the last 9000 years, prior to which the shoreline was c. 2 km landward of the presenl position. Brown (1995) estimated that at about 7500-5500 years B.P. the Holocene shoreline in Poverty Bay lay 15 km inland. The associated marine and nearshore deposits have subsequently been buried by alluvium from the Waipaoa River.

Alluvial terrace and floodplain deposits

Alluvial gravels, muds and minor sand deposits (Qla, Q2a, Q3a, Q4a, QSa) are widespread in all the major catchments. Alluvial terraces (Figs. 6, 32) represent remnants of former river levels and, typically, are mantled by tephras derived from eruptions in the Taupo Volcanic Zone. Those older than about 20 000 years may also have a thin covering of loess. Alluvial terraces occur up to 300 m above the adjacent modern river beds (as in the headwaters of Mata River at Y16/486256). In most areas they are poorly dated (OIa *et a/.* 1985; Yoshikawa *et a/.* 1988; Mazengarb *et al.* 1991a; Berryman *el at.* 2000). The main exception is the sequence of lerraces in the middle reaches of the Waipaoa River between Kaitaratahi

Figure 31 Thick tephras present in the upper part of the sea cliff at Awaawakino Bay *(X15/993497)* are the products of eruptions in the Taupo Volcanic Zone; here they are as old as 300 000 years. The lower part of the exposure is of older, undated fluvial (river or stream) deposits. *Photo CN4228613: D.L. Homer*

and Whatatutu. Here, the highest of the four terrace sets is 120 m above the adjacent river level (Fig. 6) and 90000 - I 10000 years old. The terraces are aggradation surfaces formed during periods of cool climate when retreat of the tree line facilitated higher rates of erosion in the headwaters of the catchment. During warm periods protective forest cover was re-established and the river continued downcutting in response to tectonic uplift (Berryman *e1 al.* 2(00).

The Poverty Bay flats are the most extensive and best studied alluvial noodplains in the mapped area (Pullar 1962; Pullar & Penhale 1970; Brown 1995). They are underiain by up to 200 m of mainly nuvial silLS with minor interbedded gravel layers which, locally, include up to 60 m of estuarine or shallow marine sand and mud present near the top of the sequence. Gravel-filled channels up to 15 m thick were deposited 9000 - 12 000 years ago (e.g. the Makauri gravel; Brown 1995).

Alluvial fans

Alluvial fans present at the mouths of some steep, rapidly eroding gullies lypically consist of pooriy soned angular gravel (Q1a. Q3a. Q5a): some are mantled with tephra and loess. During "normal" climate regimes water flow is confined to incised channels, but during rainstorms these are overwhelmed and material is deposited over a wide area, as at Tarndale gully (Fig. 33). The fan at the mouth of the Tarndale gully tributary periodically blocks the Te Weraroa Stream during intense rainstorms, creating a temporary lake behind the fan debris.

Landslides

Landslides are discussed in more detail in the section on Geological Hazards. For some landslides only the head scarps are shown, but for others an overprint pattern is llsed to show the area involved. Where displacement

Figure 32 Wharekia (1 106 m, Y151588566), on the south side of the Tapuaeroa valley, is one of several spectacular sandstone peaks in this catchment. Wharekia, and the adjacent mountains Aorangi and Taitai, are formed of erosion-resistant sandstone bodies surrounded by Mokoiwi Formation. Two terrace surfaces at 400 m and 300 m elevation (arrowed), and approximately 30 000 and 20 000 years old respectively, illustrate the speed at which downcutting (and erosion) is occurring in this valley (approximately 8 mm/year). Gully erosion in the Mokoiwi Formation (left middle ground) is contributing to the rapid aggradation of the Tapuaeroa River bed (left foreground). The river bed here is about 150 m above sea level. *Photo CN42280/11: D.L. Homer*

is significant, and there is substantial modification of the bedrock, the landslide deposits are mapped separately (Ql1). The largest of the onland landslides is the 18 km' Tiniroto Landslide (Fig. 34) formed c. 6 500 years ago (Howorth & Ross 1981). Small lakes and ponds are present on some landslide surfaces (as at Tiniroto). Undifferentiated lake deposits of the Waerengaokuri area (e.g. Bishop 1968b) may have been deposited behind landslide-formed dams across the Hangaroa River.

Te Puia sinter

At Te Puia Springs (Z16/754357, Fig. 35) calcareous sinter (Qcs) deposited from hot mineralised water cooling at or near the ground surface has formed an elongate mass rising up to 30 m above the local relief (Macpherson 1945). The sinter covers an area 600 m long and up to 20 m wide that is restricted mainly to an east-west oriented fissure, possibly formed by movement on the Te Puia Landslide. The age of the upstanding sinter mass is unknown, whereas sinter deposits are currently forming nearby at the hot springs (see below). The elevated position of the sinter is a result of erosion of the surrounding (and softer) bedrock.

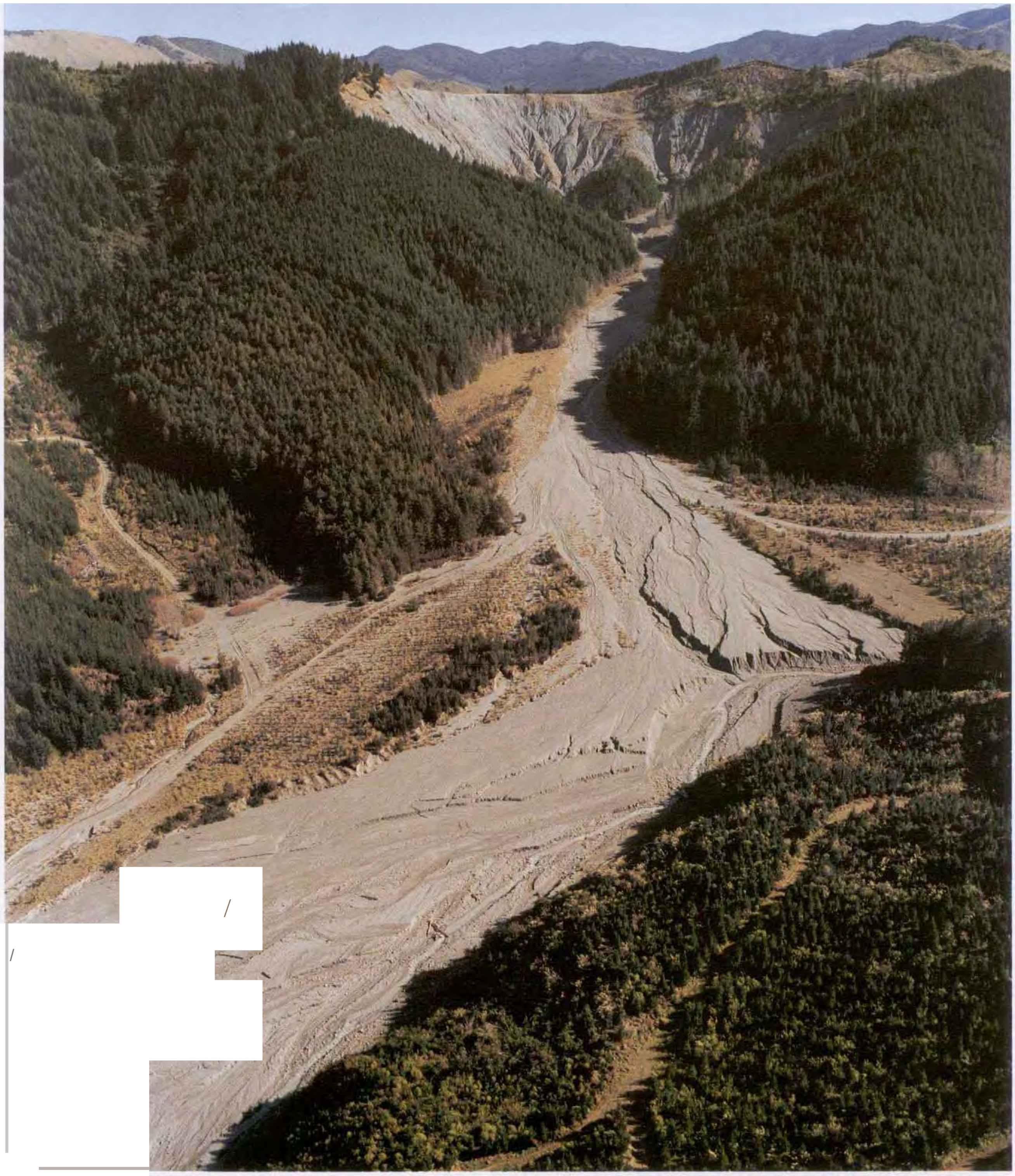

Figure 33 This view is towards the northwest across Te Weraroa Stream to the Tarndale slip, Mangatu Forest (foreground, Y16/302172). During heavy rainfalls, debris (Whangai Formation) from the slip and gully is transported downstream to be deposited as an alluvial fan at the junction with the Te Weraroa; occasionally the stream is blocked temporarily. This gully is insignificant in terms of the area of the Waipaoa catchment yet it generates 2-3% of the current annual sediment load of the Waipaoa River (DeRose *et al.* 1998). The pine plantation has slowed the growth of the gully and is serving to protect other steep gullies from eroding in this manner.
Photo CN42414115: D. L. Homer

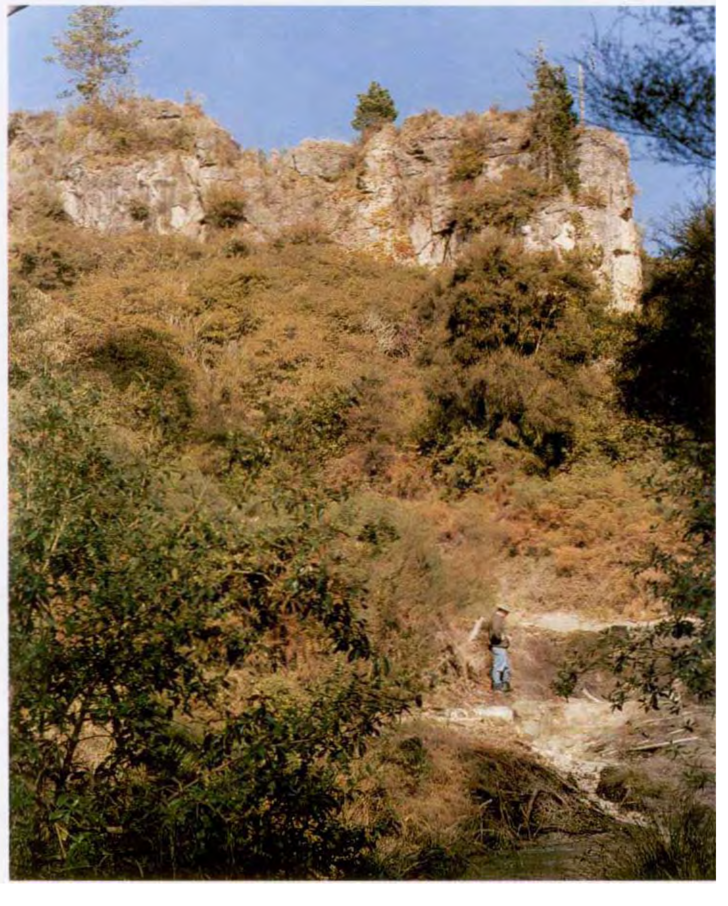

Figure 34 The Tiniroto Landslide (outlined, X18/040600) formed within mudstone of Pliocene age on a gently dipping bedding plane inclined towards the Hangaroa River. The initial failure and subsequent movements may have been triggered by earthquakes, but the downcu«ing action of the river serves to continually destabilise the toe of the landslide. The bush-covered dip slope and scarp at top right are formed by the Whakapunake and Tahaenui limestones. The view is towards the southeast.
Photo CN41 020111: D.L. Homer

Figure 35 At Te Puia an ancient sinter (hot spring deposit) towers over modern hot springs. Newly formed sinter is present beside the person.
Photo CN42 168/25: D.L. Homer

Early and Late Cretaceous

The Torlesse composite terrane and other Eastern Province terranes are considered to have been juxtaposed at a convergent continental margin on the edge of the Gondwana supercontinent before the end of the Early Cretaceous (Bishop *et al.* 1985; Adams & Kelley 1998). In western Raukumara Peninsula the Torlesse rocks were lithified, deformed, uplifted, eroded and then buried beneath transgressive marine sediments (Matawai Group) in Early Cretaceous time. Matawai Group sediments were deposited mainly in outer shelf or slope environments, but the easternmost Matawai Group unit (Waitahaia Formation) accumulated in a deep marine turbidite fan. In Raukumara Peninsula, and perhaps elsewhere, subduction-related deformation (including thrust faulting) may have continued throughout Early Cretaceous time and into the Late Cretaceous (Mazengarb & Harris 1994).

Mid and Late Cretaceous sedimentary rocks now present within the East Coast Allochthon represent deeper water facies than those of the correlative in-place rocks and are inferred to have originally accumulated in more distal (oceanic) settings. The Matakaoa Volcanics are inferred to have accumulated in a distant, oceanic setting, as part of an oceanic plateau associated with a mid-ocean ridge (Mortimer & Parkinson 1996).

Late Cretaceous to Oligocene

Folding, faulting, uplift and erosion in Late Cretaceous time was followed by renewed marine transgression during which the basal sandstone units of the Tinui Group were deposited. Late Cretaceous and Paleogene sedimentary rocks of both the in-place and allochthonous sequences are mainly fine-grained and mudstone-dominated, with intercalated units of deep sea, turbidite sandstones (the Tinui and Mangatu groups). They indicate relative tectonic quiescence and low rates of sedimentation, suggesting that during Late Cretaceous and Paleogene time the New Zealand area was a passive continental margin.

Miocene to Recent

Emplacement of the East Coast Allochthon thrust sheets and deposition of thick clastic sequences in localised basins in Early Miocene time represent a major change in tectonic setting, believed to result from the reactivation and propagation of a plate boundary through the region. The changes in sedimentation rates, depositional settings, sediment type and tectonic style observed at Raukumara Peninsula match those described from Northland (e.g. Isaac *et al.* 1994; Isaac 1996; Rait 2000b). In both areas they are inferred to have resulted from southwest- to SSW-directed subduction of the oceanic (Pacific) plate beneath the continental margin (Australian Plate). The Late Cretaceous to Oligocene passive margin sequence, which had accumulated east and north of Raukumara Peninsula, was dismembered into a series of thrust sheets and emplaced sequentially over the in-place equivalent sequences. In places the rocks of the allochthon have been sheared and mixed together, forming broken formation and melange. Obduction of the East Coast and Northland allochthons has juxtaposed rocks which were originally deposited far apart from each other. In some areas older, distal rocks (such as the Matakaoa Volcanics and the correlative Tangihua Complex) have been thrust over younger beds (Isaac *et al.* 1994; Rait 2000a).

Most of the thrust faults dip north to northeast and indicate SSW-directed emplacement, but in some areas they dip southwest and north. Near the mouth of the Raukokore River Torlesse rocks are thrust over younger Tikihore Formation along the southwest-dipping Raukokore Thrust (Fig. 5). South- to north-directed imbrication of Tikihore Formation is also recognised at Orete Point. Torlesse rocks forming the summit of Hikurangi are considered to be a klippe, or outlier, thrust over the underlying and younger Waitahaia Formation (a partial return to the Taitai Overthrust hypothesis of Washburne 1926). The northeast- to north-directed thrusting is interpreted as backthrusting, perhaps related to reactivation of pre-existing thrust faults of Cretaceous age (Rait 1992).

Thick, Early Miocene clastic-dominated sequences (Tolaga Group) unconformably overlie the thrust sheets of the East Coast Allochthon, indicating that the SSW-directed obduction ceased in Early Miocene time. Patterns of onlap and shifts in the position of maximum sediment accumulation indicate differential uplift and submergence, presumed to reflect deformation associated with ongoing subduction during Middle and Late Miocene time; local unconformities are common. Middle and Late Miocene beds include many tuff beds the source of which was probably subduction-related volcanism in the area of what is now Coromandel Peninsula.

Between Tolaga Bay and Gisborne a series of folds and faulted antiformal structures developed in Late Miocene time. The antiforms are diapiric (Stoneley 1962; Mazengarb 1998) with cores of Whangai and Wanstead formation mudstones. Some antiforms have cores of melange. At Huanui Station (Y17/5 18080) the diapiric structure predates deposition of unconformably overlying Early Pliocene rocks. Diapir emplacement is associated with the development of a network of normal faults and associated folds, commonly with downthrow to the east or south. One such fault is a detachment at the base of the Tolaga Group between Mangatu Forest and Te Puia

(Whakoau Fault of Mazengarb *el al.* 1991a; Fig. 7). This late stage normal faulting may be related to gravity collapse associated with post-Miocene regional uplifL

In Middle to Late Miocene time differential uplift formed a structurally high area about what is now the Mahia Peninsula. This high limited the eastern extent of the adjacent subsiding WaiToa Basin in which a thick sequence of sediments was deposited. Elsewhere, by latest Miocene (Kapitcan) time. shallow marine sediments were being deposited in many areas and much of the Raukumara area has probably been emergent since Middle Pliocene time. Within the last million years a structural high has developed in the area immediately offshore from Mahia Peninsula (the Lachlan Ridge) with consequent coseismic uplift and WNW tilting of marine terraces (Berryman 1993b). Uplifl rates at Mahia have been variable during Ihe last 180000 years. in the range 1-3 mm/year (Berryman 1993b). Elsewhere. dating of terrace deposits has shown that Late Pleistocene and Holocene uplift rates were as high as 4 mm/year (Ota *el al.* 1992). Yoshikawa (1988) suggested Raukumara Peninsula is being upwarped a"ymmetrically as a growing anticlinal structure. Uplift rates are higher in the centre orthe range and where the axis of the structure intersects the coast, near Te Araroa.

Differential subsidence is indicated by the thick Quaternary sequences present in the lower Waipaoa valley (Brown 1995). while no vertical movement is recognised in the coastal rcgion near the mouth of the Wairoa River (Ota *el al.* 1989). Al Gisbome weslward tilling of Ihe Mangatuna Formation demonstrates local differential uplift (to the east) and subsidence (Poveny Bay nats) exceeding 300 m within the last million years.

Palcomagnctic studies show that different parts of eastern New Zealand have been rotated by differcl1l amounts during Neogcnc time. Two paleomagnetic domains have been recognised within the Raukumara area (Wright 1986; Wrighl & Walcott 1986; Mumme *e1 al. 1989;* Thornley 1996). The Raukumara domain (approximately north of Whangara) shows no rotation with respect to the Australian Plate, but the Wairoa domain to the south has apparently been rotaled clockwise by approximately 50°. Rotation of thc Wairoa domain may have occurred because it was locked to the Pacific Plate, whereas the Raukumara domain is decouplcd and more rigidly attached to Ihe Australian Plate (Reyners & McGinty 1999). The exact position and nature of the boundary between the domains are still unknown; the boundary is not well expressed in the surface geology.

Aclive faulls and folds

An active fault is oneon which movcment has takcn placc wilhin Ihe last 125000 years. Active faullS are recognised from landforms such as surface traces, fault scarps and sag ponds (Fig. 36) which are produced when a faull rupturcs the ground surface (in association with a large earthquake). Such features are quickly modified and destroyed by erosion. In the Rallkllmara area the rates of uplift and erosion are high and hence few active traces are prcserved. There are almost certainly far more active faulls Ihan the few identified on the map. The known active traces are typically short segmenrs, some of which arc associated with major faults (for example, the Fernside and Pakarae faults). Only Ihe Pakarae Faull has been studied in detail. It has moved a total of 16 m vertically in three separate events within the last 5500 years (Berryman *el al.* 1992). The effects of aClive faulting on drainage are evident in several places in the Raukumara Range (e.g. near MOIU, X16/120368). Downstream from the Pakuratahi Fault the Motu and Pakuratahi rivers are deeply incised but, in comrast, the area upstream is characterised by extensive river terraces, with small remnants of lake beds. At times fault movement may have temporarily dammed the rivers.

The Mangaone Anlicline (X19/165370) may be a growing fold. II deforms middle Pliocene Slrata and is apparenlly associated with an area of antecedent drainage in the upper Mangaone Stream (i.e. the growing fold is forming a barrier to the natural flow of the stream). At least one active fault trace on the same trend is present nearby.

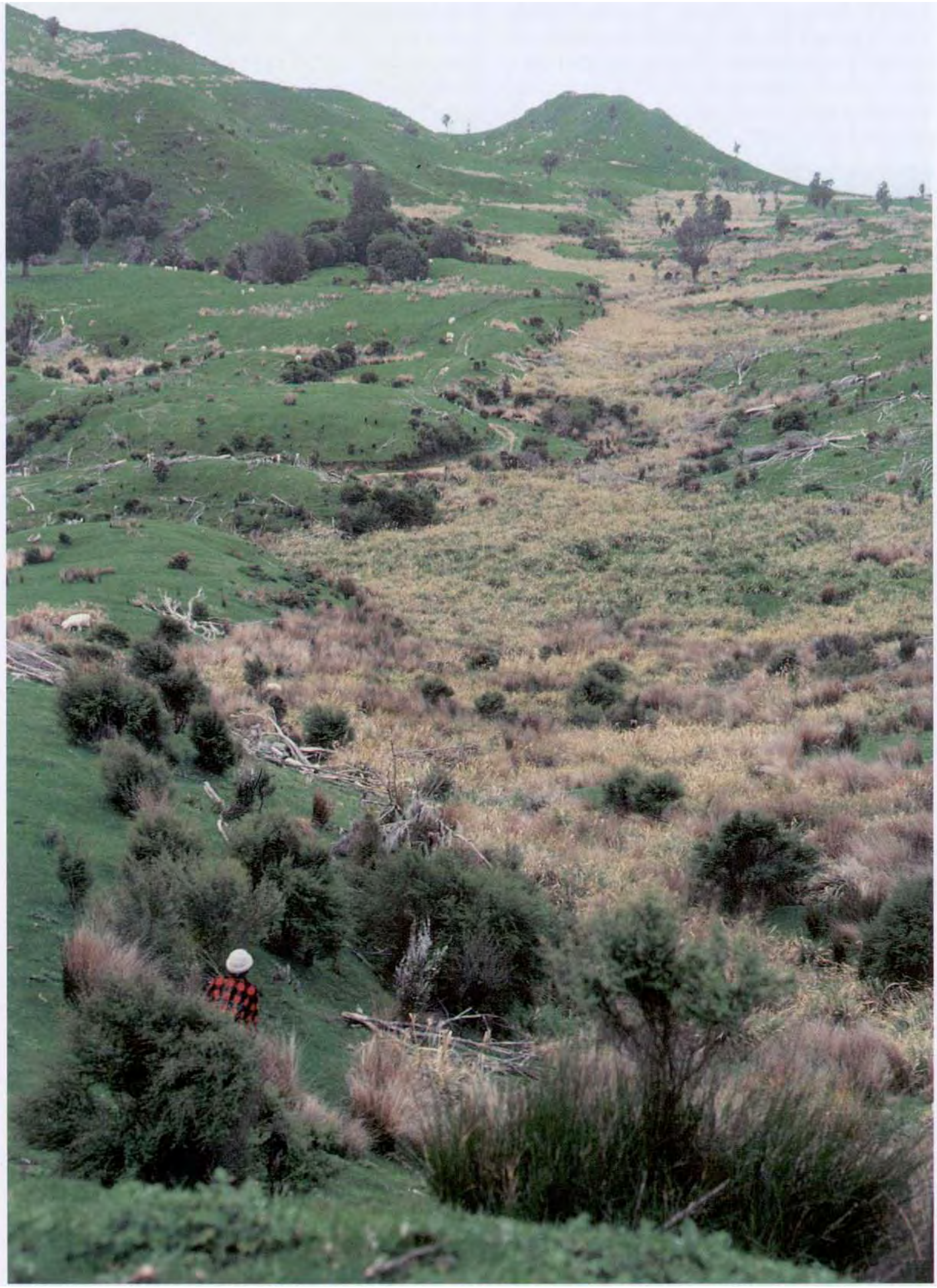

Figure 36 North of Tolaga Bay differential movement of the active Marau Beach Fault *(Z1617601 13)* has ponded the natural drainage forming a swamp along the downlhrown side. View is 10 the easl and the person in the foreground gives scale.

Only the northern pan of the area is covered by a publicalion based on the Geological Resource Map (GERM) database (Francis *et 0/.* 1991). Data for lhe southern part of the area arc compiled but not published. The Raukumara area has few known occurrences of metallic minerals: Brathwaite & Pirajno (1993) give details, but a summary is included here. A full assessment of the oil and gas prospecls has recently been published by Field. Uruski *et 01 (1997).*

Aggregate

In the northwest good quality aggregates are quarried from Torlesse sandstones (e.g. Moulohora Quarry, X 16/032 157) or extracted from Torlesse-derived river and beach gravels. Koranga Formation sandstone is quarried for aggregale near Malawai (X 17/007035). Matakaoa Volcanics rocks are a source of moderate quality aggregate in the Cape Runaway - Hicks Bay area. but may contain abundant zeolite minerals which cause them to break down readily on weathering. Away from the main ranges there are limited sources of rock suitable for aggregate. Near Gisborne the Late Miocene Patulahi Limestone (e.g. X 18/224679) and the Late Crelaceous-Paleocene Whangai Formation are quarried, although the latter produces only poor quality material. Pleistocene gravel is also quarried for aggregate near Gisborne (Y 18/455747). as are lerrace gravel deposils near Wairoa (Y 19/927346). Holocene river gravels (Torlesse-derived) and dunes near uhaka (e.g. Y1 7/17 1284) are quarried for aggregate and sand.

Groundwater

Groundwater is a valuable resource, particularly because the East Coast of New Zealand is drought-prone. Large volumes are extracted from confined Quaternary gravel aquifers in Poverty Bay and Wairoa, mainly to sustain intensive cropping. horticulture and vineyards. Detailed studies have been published only for the Poverty Bay flats (Brown 1984; Brown & Elmsly 1987; Taylor 1994) where Lhere are three recognised confined gravel aquifers (Malokitoki, Makauri & Waipaoa) and the unconfined Te Hapara sand aquifer. Groundwater quality is poor and treatment is often necessary before it is suitable for domestic use or irrigation. In Lhe Wairoa River valley groundwater is extracted mainly from two confined gravel aquifers (Cameron 1999). Groundwater from limestone aquifers has yet lo be exploiled.

Hot springs

Hot saline springs al Morere (X 19/254354) and Te Puia Springs (Z 16n53357) have insufficient flow rale and heal (45°C & 65°C respeclively; Hill 1895; Macpherson 1945) for purposes other than bathing. The origin of the waters differs from those of the Taupo-Rotorua area in that they are not derived from, or heated by, volcanic sources. The chemistry suggests the hot water has been expelled from sedimentary rocks present at depths of probably greater lhan 3 km. heated by the Earth's geolhermal gradienl (approximalely 25"C/km: Stewart *e, al.* 1990). At Morere the springs lie on the crest of a dome structure and it is likely that the water has migrated to the surface lhrough permeable rocks (e.g. sandstones) and along faults.

Limestone

Limestone quarried in the Raukumara area is used almost entirely for aggregate, but in the past has also been exploited for agricultural lime (Moore & Halton 1985; Francis *el al.* 1991). The major quarries are near Gisborne at Huanui (Early Miocene), and al Palulahi and Waerengaokuri (Late Miocene). Pliocene limestone in lhe Wairoa-Mahia area was quarried prior to 1970. Small farm quarries have worked Weber limestone in the Mangatu area. The Late Miocene Patutahi Limestone is a suitable source of rip-rap for the protection of river banks and foreshores.

Smectite

Smectite clay is extracted from a small quarry in Wanstead Formation (Eocene) at Parehaka Station near Te Karaka (Y 17/486054). A large quantity is available for use if needed (Ker 1969; Gregg & Carlson 1971). Smectite was once quarried near Whatatutu and unworked areas of smectite are known elsewhere (for example at Ruatoria. thungin, Whangara, Waitangi Hill, Nuhaka and Mahia).

Metallic minerals

Over an area of about 1.5 km^2 near Te Kumi, in a tributary of Mangahaupapa Stream (Y 15/497684). poorly bedded and intensely sheared sandstones contain pods of pyrite and chalcopyrite, layers of maroon-coloured tuff and red chert. Small quantities of copper ore were mined in the 1920s. Pirajno (1979) mapped the h0Sl rocks as Mokoiwi Formation, but they are now recognised as Torlesse composite terrane basement. Minor pyrite and chalcopyrite mineralisation is present in Matakaoa Volcanics near Lottin Point (Pirajno 1980; Rutherford 1980) and at Mangatulu Stream, Pukemnarll Range (Cody & Grammer 1981). No mineralisation of economic inlerest has been found (Pirajno 1979. 1980; Brathwaite & Pirajno 1993).

Oil and gas

The relatively common oil and gas seeps of eastern Raukumara Peninsula attracted the attention of early explorers (Figs. 37, 38). Belween 1872 and 1913 pils and

Figure 37 Active mud volcanoes and seeps in the Waimata Valley *(Y17/508894)* discharge mud, brine and natural gas. The lack of vegetation is typical, presumably because of the high salinity of the fluids.

Figure 38 At Waitangi Station *(Y17/383016)* there are a number of aligned, oil-filled ponds and seeps which for over a century have inspired the search for oil. The oil is warm to touch and may have leaked from a breached reservoir within the Tolaga Group.

shallow wells were dug in and near the seeps at Rotokautuku. Waitangi andTotangi, and the Waingaromia borehole reputedly produced 20-50 barrels of oil a day before the derrick was deslroyed by lire in 1887. Histories of early oil and gas exploration have been given by McLemon (1972, 1976, 1992) and Francis (1993c, 1994, 1995). It proved difficult to drill through the smectitic clays of the Wanstead Formation, which caused major delays, cost overruns and abandonments. There waSalso inadequate understanding of the geology; only a few of the early wells were drilied on slruClure. The 1962-1972 wells ROlokautuku-1. Te Horo-I andTe Puia-I were sited on apparent surface anticline features which on drilling were shown 10 pass inlo probable Ihrusl nappes al depth (Field, Uruski *el 01. 1997).*

The widespread Whangai and Waipawa formations are regarded as the best source rocks in the Raukumara area (Field, Uruski *el 01.* 1997; Rogers *el 01.* 1999). Though the Whangai has less total organic carbon than the Waipawa Formmion it is much thicker and is capable of generating greater quantities of hydrocarbons. Some Cretaceous sandstones have fair reservoir pOlential (Te Wera Formation, Tahora Formation and, perhaps, the Tikihore and Tapuwaeroa formations) and these have been the targets of several wells (e.g. Rere-I). Fracture porosity is present in parts of Whangai Formation. Assessment of Cretaceous targets is hampered by the present poor understanding of the distribution and thickness of reservoir unils. In 1985-86 Rere-I drilled 4352 m of Miocene to Cretaceous strata and was still in Early Cretaceous Karekare Formalion al tOlal deplh. The primary target reservoir (Tahora Fonnation) was absent. In some areas exploration is further hampered by difficulties in determining deep structure beneath the East Coast Allochthon, by a poor understanding of the origin of diapiric structures and by the difficulty in obtaining high quality seismic reflection data.

Some Middle and Late Miocene shelf and deep water turbidite sandstones have good reservoir potential (e.g. Lhe Areoma Sandstone, Tokomaru Sandstone, Tunanui Formation and Makaretu Sandstone). Prospects defined by surface mapping and seismic surveys have been driJled in the Wairoa-Mahia area and in 1998 the first commercial discovery of hydrocarbons in the East Coast region was made in the Kauhauroa-I well, 10 km nonheasl ofWairoa. The discovery well nowed gas al up to I1.5 MMSCF a day (Minislry of Commerce 1998); anolher polential commercial discovery followed (Tuhara-I, drilled 10 km eaSI of Wairoa; Frederick *el 01* 2(00). In the area of the discoveries the target reservoir lithologies are Kauhauroa Limestone, an Early Miocene bryozoan-dominated bioclastic limestone known only from the drillholes, and a Middle Miocene turbidite complex (the Tunanui Sandstone of Frederick *el al. 2000).*

The Raukumara area is considered to have considerable potential for future discoveries (Field. Uruski *el 01. 1997;* Frederick *el 01* 2(00); there is aClive exploralion bolh onshore and offshore. a wells have yet been drilled in the offshore area covered by the Raukulllara map; Hawke Bay-I was drilled just outside the map boundary.

The designers of engineered structures in the region face many challenges because of the properties of local rock types and the potential impact of natural processes and events such as earthquakes, landslides, tsunamis. floods, erosion and volcanic eruptions. This section, and the one following, provide a brief overview of rock properties and significant geological hazards in the area Ia help engineers, architects and planners recognise vulnerability and minimise risk. More detailed information appropriate to specific sites can be obtained from local territorial authorities and GNS. The background information given here is not a substitute for proper site investigations or detailed hazard assessments.

Basement rocks

Torlesse composite terrane rocks are strong and variably jointed, and hard to very hard when unweathered. Unweathered rock will stand in steep faces (e.g. the massive sandstone forming the gorge in the Motu River at X *16/022350* was a proposed dam site) but rock strength is decreased with increased weathering and/or jointing. The contact between sandstones and mudstones is a significant rock defect and some road cuttings in the Waioeka Gorge shed mllch loose material, particularly where the strata dip at moderate angles towards the road.

Cretaceous to Oligocene sedimentary rocks

These rocks show great lithologic variation and, correspondingly, a wide range of rock properties. Wanstead Formation and some other units with a high clay contelll, including most of the units mapped as melange, are prone to failure by earth now mechanisms. Other formations (e.g. Whangai and Mokoiwi) are typically moderately hard to hard and of moderate strength, but susceptible to gully erosion and slumping, especially where the rocks are fractured or crushed as is common within the East Coast Allochthon.

Matakaoa Volcanics

The gabbro, dolerite, basalt and breccia are variably sheared, closely to moderately jointed, hard to very hard rocks which stand well in steep faces when fresh or slightly weathered. Where resistant Matakaoa rocks overlie weaker materials erosion can undermine the steep natural faces at the margins of the Matakaoa massifs, resulting in landslides.

Miocene and Pliocene rocks

Miocene and Pliocene rocks range froJ11moderately hard to moderately soft depending on lithology, bedding type, cementation and degree of weathering. Sandstones, where unweathered, form steep natural faces (as at Y *16/403165)* and they stand well in steep road cuts (e.g. the Tolaga Bay "gorge", ZI71705946). However, bedding plane slippage is a recognised failure mechanism where dip slopes are underclit. Mudstone-dominated lithologies are generally more prone to slipping than sandstones. Slumping and bedding failures are common. Limestone is generally a competent rock type, forming bluffs and dip slopes. However, large bedding plane failures are associated with some undercut limestone dip slopes and rockfalls occur in the vicinity of bluffs.

Quaternary sediments

Quaternary sediments are loose, weak rocks (or soils, in engineering terms). tn places they include soft peats and mud, unconsolidated to poorly consolidated sands and gravels, and layers of volcanic ash. Because of the range of materials, their generally unconsolidated nature and variable topographic settings, site-specific studies are necessary before any major engineering works are undel1aken.

Volcanic activity

The Raukumara area is adjacent to the active Taupo Volcanic Zone (TVZ) where there have been many eruptions before and since human occupation. Volcan.ic ash from TVZ eruptions has raUen over the Raukumara area in the past, and will do so again. The thickness of ash-fall at a particular site is influenced by factors such as the volume of material ejected from the volcano, the force of the eruption, the prevalent wind direction and the distance from the volcano. The last major ignimbritic eruption in ew Zealand was from the Lake Taupo area approximately 1860 years ago; it deposited a maximum of SOO mm of ash near Ruakituri, and 100 mm of ash further east near Whangara (Healy *el al.* 1964). Eruptions of this size have an expecled frequency of 2S00-S000 years (SCOll 1997). Smaller eruptions from Ruapehu, Egmonl, Taupo, Okataina or White Island are much morc frequent.

The area of the Raukumara map is likely to receive minor falls of volcanic ash every 20-S0 years (Scott 1997). The impact will vary depending on the thickness. Even small eruptions could have significant effects. Falling ash is not toxic but it acts as an irritant, affecting eyes and throats. Casualties can result from secondary effects such as roof collapses. Services and facilities likely to be affected are electricity supply, telecommunications, water supply, waste-water, buildings and transportation (air, road. rail, sea). Pastoral farming, cropping and horticulture will also be affected to varying degrees.

Erosion

Raukumara Peninsula is rising in response to deformation associated with subduction processes at the boundary between the Australian and Pacific plates; the rate of uplift is variable, ranging up to about 4 mm/year (ata *el at.* 1992). The uplift is counterbalanced by natural erosion processes as streams and rivers remove a vast amount of detritus to the sea. However, the influence of man has accelerated erosion processes; for example, the removal or substantial modification of the native vegetation cover has created major land use problems. Erosion is recognised as a key problem facing the East Coast region (e.g. Taylor 1970). The Mangatu area in the headwaters of the Waipaoa River provided a textbook case study of rapid hillside erosion, gullying and stream aggradation following the conversion of native forest to pasture (Fig. 33; Cumberland 1947; Allsop 1973; Hicks & Campbell 1998; DeRose *et al.* 1998). Similar problems are present elsewhere (e.g. the Tapuaeroa and Waikura valleys). Though the most obvious effects of erosion are in the headwaters (the "critical headwaters" of the Taylor Report) accelerated erosion also poses problems for those living lower in the catchment on the gently sloping floodplains, because the vast amount of gravel. sand and mud added to the drainage systems increases the risk and height of tlood events. Low-lying terrace land of high value for agriculture can be inundated by gravel, sand and mud, as occurred during Cyclone Bola in 1988 (Fig. 6; Singleton *el al.* 1989a, I989b; Page *el al. 1999).*

Major influences on the susceptibility of land to erosion include the extent and type of vegetation cover, rainfall characteristics and slope angle. Geological factors such as rock type (O'Byrne 1967), tectonic uplift and earthquake shaking are also very important. Rock properties with a major influence on erosion susceptibility include:

- grain size - sandstone is generally stronger than mudstone
- degree of cementation - rocks with high amounts of calcium carbonate (e.g. limestone) or silica are relatively erosion-resistant (see Pearce *el at.* 1981)
- induration - older rocks are generally harder than younger rocks
- clay mineral content - many mudstones contain smectite clays and break down readily during wetting and drying cycles
- fractures - fractured rock has lower strength than unfractured rock
- crushing - crushed rock associated with major faults and thrusts has low strength
- orientation of bedding surfaces to the land surface
- weathering - degree and thickness of the zone of weathering.

Mudstones oflhe Mangatu Group, Mangatuna Formation and, to a lesser extent, Whangai Formation are the most erosion-prone geological units in the area. Most rocks of the East Coast Allochthon are also eroding rapidly, the major exception being the resistant Matakaoa Volcanics. Miocene and Pliocene mudstones are extensively eroded in some catchments. Protective planting of exotic forests started al Mangatu in 1960 (Gage & Black 1979) and was later extended to cover other rapidly eroding areas. Reafforestation has substantially reduced the rates of erosion and stream aggradation (DeRose 1996).

Slope instability and landslides

Slope instability, often resulting in landslides. earth tlows and surface creep, is a major problem for roads. railways. buildings and other structures, particularly in areas of weak or closely fractured rock. Rocks susceptible to slope failure underlie much of the hill country southeast of the crest of the Raukumara Range. from Cape Runaway to Wairoa. The extent and type of erosion and slope failure are highly variable, as is soil development. Shallow-seated soil slips are common on steep topography and in stream headwaters (Fig. 39), as are rockfalls from escarpments of limestone and sandstone. Soil slips are mainly triggered by heavy rainfall events such as Cyclone Bola in 1988 (Phillips 1988, 1989). Large rotational slumps and bedding plane failures are common in areas of significant stream incision and along coastal headlands (e.g. Gibb 198 1), p",ticularly where bedding planes or other forms of rock defect dip down slope. Earth !lows and slumps are common in areas where the rocks contain high proportions of clay minerals. as in Mangatu Forest, where Zhang *el al.* (1993) demonstrated that earthflow velocities were significantly lower under forest cover than in pasture.

The Tiniroto Landslide (Fig. 34) is one of several landslides on the banks of the Hangaroa River that have formed following downcutting and subsequent failure along bedding planes. The initial failure may have been triggered by an earthquake. Movement toward the Hangaroa River about 6500 years ago created the distinctive hummocky LOpography and the TiniroLO lakes (Howorth & Ross 1981). Continuing downcutting and erosion of the landslide toe destabilises 'he slide leading to the likelihood of future failures.

The Te Puia Springs settlement is located on an active landslide, measured as moving 011 average at 55 mm/year towards the coast (Gibb 1981). The landslide consis's mainly of Late Cretaceous bedrock sliding as large blocks on a slip plane which may bc lubricatcd by water from the adjacent springs. Towards the toe the landslide transforms into an eanhtlow.

In many instances it is impossible to prevcnt landslides from moving. Long term planning should aim to identify areas of potential hazard and minimise the risk, for example by preventing development on or near unstable slopes. Only the largest landslides call be shown on this I :250 000 map. More detailed information is available from the Large Landslides Inventory, a GIS-compatible database held by the Institute of Geological & Nuclear Sciences.

Figure 39 Not all erosion in the Raukumara area is related to deep-seated failure of bedrock. This hillside north of State Highway 2 near Nuhaka (X19/133300) suffered extensive surficial erosion (soil slips) during a recent rainstorm. The steepness of the hillside, limited vegetation cover and intensity of rainfall were important contributing factors. The pale slip scars expose bedrock of Pliocene sandy mudstone.

Seismoleclonic hazard *(by M. Stirlillg & C. Mazellgarb)*

Seismicity in the Raukumara area is an expression of the subduction of the Pacific Plate beneath the Australian Plale along the Hikurallgi margin. Earthquakes recorded by the New Zealand National Seismograph Network (e.g. Anderson & Webb 1994) are distributed over a wide depth range and area. However. the vast majority are in a westward-dipping zone which defines the downgoing slab of the Pacific Plate (e.g. Reyners & McGinty 1999). The zone is at about 30 km depth beneath the east coast. deepening to about 60 km beneath the Bay of Plenty coast. Further west, beneath the Bay of Plenty, the slab zone dips more steeply and reaches 300 km depth. The focal mechanisms of the earthquakes in the slab zone lend to indicate normal faulting and are, therefore, consistent with tensional strain in the downgoing slab ("slab pull"; Reyncrs & McGinty 1999)

Shallow crustal seismicity in the Raukumara area is morc widely scattered than the deeper seismicity with some significant differences in seismicity rates parallel to and perpendicular to the plate boundary. Specifically, the number of thrust events at the plale interface increases to the northeast. This is probably due to a decrease in the degree of coupling at the plale interface in that direction (Reyners & McGinty 1999). Focal mechanisms for earthquakes in the uppermost part of the AustraJian Plate show extensional strain oriented towards the Hikurangi Trough. This is probably due to extension and gravitational failure of surficial rocks uplifted to form the Raukumara Range (see cross-section C).

The historical record shows that many moderate to large earthquakes have occurred in the region. The Richter scale (M) is a measure of the energy released at the earthquake source; 30 events of Richter magnitude M>5 have occurred in the period 1940-97 and 5 events of M>6.5 in the period 1840-1997 (including onc M>7 event in 1995).

The Modified Mercalli scale (MM) is a measure of the felt intensity at the ground surface. For a given earthquake the felt effect at the surface will vary depending on Richter magnitude, focal depth and distance lo epicentre. Because seismic waves are attenuated through the Eal1h, deep and distal earthquakes will generally have a much lower MM value than shallow local earthquakes of the same magnitude. At least 19 felt earthquakes with MM felt intensities (see Table I) of 5 or grealer have occurred since 1840 (Downes 1995). The largest felt earthquake was the October 6. 1914 East Cape-I earthquake with MM intensities up to 9. The 1966 Gisborne earthquake caused slight damage to the city (Hamilton *er al. 1969).*

The intensity of shaking is also affected by the local geology. Areas underlain by "soft" sediments, such as the Quaternary deposits underlying the lower Waipaoa valley. are capable of amplifying seismic waves by up to two MM intensities compared with adjacent areas situated on more solid ("sliff') material (i.e. pre-Quaternary bedrock). In addition. if seismic shaking is strong (>MM 6) areas containing saturated fine-grained sands may liqucfy. creating local sand boils. ground fissuring. subsidence and lateral spreading. Sediments prone to liquefaction are typically found in coastal areas and valleys underlain by Quaternary deposits. Strong MM intensities can also trigger landslides (including in offshore areas) and tsunamis (see below). Surface rupture on faults will damage and displace structures built over them.

The level of seismicity over Raukumara Peninsula is typical for an area of New Zealand adjacent to the Australian-Pacific plate boundary and considerably higher than the seismicity levels for areas located away from the plate boundary (e.g. Southland and Northland). Large earthquakes will certainly occur in the future with consequent casualties and damage to structures in areas subject to strong ground motion. The mean return time for a MM 7 event has been estimated as 59 years for Gisborne, and for a MM 8 event 180 years (Smith 1995; Dellow *et al. 1997).*

Tsunami

In historic times at least seven tsunami have affected coastal areas of the Raukumara map area (de Lange & Healy 1986; Mazengarb *er al.* 1997). Typically the tsunami have been associated with earthquakes though in the past some have been attributed to submarine slumping and submarine mud volcanism (Eiby 1982). In 1947 two tsunami with wave heights locally up to 10 m high inundated a part of the coast near Gisbome. A bridge was damaged and buildings flooded. including the fonner Tatapouri Hotel. These tsunami were probably generated by earthquakes in the adjacent area offshore (Downes *el al.* 2(00). Locally generated tsunami are cause for greatest concern as warning times may be very shorl or nonexistent. Their wave heights can be greater than tsunami generated by more distant events. Tsunami generated by distant events take many hours to reach New Zealand and an international tsunami monitoring system is in place to provide warnings.

Table 1 Modified Mercalli Intensity scale (MM) (in part; summarised from Downes 1995).

MM2	Felt by persons at rest, on upper floors or favourably placed.
MM 3	Felt indoors; hanging objects may swing, vibration similar to passing of light trucks.
MM4	Generally noticed indoors buf nof oufside. Light sleepers may be awakened. Vibration may be likened to passing of heavy traffic. **Doors and windows rattle.** Walls and frames of bUildings may be heard to creak.
MM S	Generally felt outside, and by aimost everyone indoors. Most sleepers awakened. A few people alarmed. **Some glassware and crockery may be broken.** Open doors may swing.
MM6	Felt by all. People and animals alarmed. Many run outside. Objects fall from sheives. Glassware and crockery broken. **Unstable furniture overturned.** Slight damage to some fypes of buildings. A few cases of chimney damage. Loose material may be dislodged from sloping ground.
MM7	**General alarm.** **Furniture moves on smooth floors.** **Unreinforced stone and brick walls crack.** Some pre-earthquake code buildings damaged. Roof tiles may be dislodged. Many domestic chimneys broken. Small slides such as falls of sand and gravel banks. Some fine cracks appear in sloping ground. A few instances of liquefaction.
MM8	Alarm may approach panic. Steering of cars greafly affecfed. Some serious damage fa pre-earthquake code masonry buildings. Mosf unreinforced domestic chimneys damaged, many brought down. **Monuments and elevated tanks twisted or brought down.** Some post-1980 brick veneer dwellings damaged. **Houses not secured to foundations may move.** Cracks appear on steep slopes and in wet ground. **Slides in roadside cuttings and unsupported excavations.** **Small earthquake fountains and other instances of liquefaction.**
MM9	Very poor quality unreinforced masonry desfroyed. Pre-earthquake code masonry buildings heavily damaged, some collapsing. Damage or distortion to some post-1980 buildings and bridges. Houses not secured to foundations shifted off. Brick veneers fall and expose framing. Conspicuous cracking of flat and sloping ground. General iandsliding on sfeep slopes. Liquefaction effects intensified, with large earthquake fountains and sand craters.
MM 10	**Most unreinforced masonry structure destroyed.** Many pre-earthquake code buildings destroyed. Many pre-1980 buildings and bridges seriously damaged. Many post-1980 bUildings and bridges moderately damaged or permanently distorted. Widespread cracking of flat and sloping ground. Widespread and severe landsliding on sloping ground. Widespread and severe liquefaction effects.

AVAILABILITY OF QMAP DATA

The geological map accompanying lhis book is derived from information slored in the geographic information system (GIS) database mailllained by the InslilUte of Geological & Nuclear Sciences and from olher GIS-compatible digital databases. The data shown on the map are a subset of the available information. Customised single-factor and multifaClar maps can be generated from the GIS and integrated with other data sets to produce, for example. maps showing fossil or mineral localities in relation to specific rock types. or maps showing rock types in relation to the road network. Data can be presented for user-defined specific areas, for irregular areas such as local authority territories, or in the form of strip maps showing information within a specified distance of linear features such as roads or the coastline. The information can be made available at any required scale bearing in mind the scale of data capture and the generalisation involved in digiLising. Maps produced at greater than 1:50 000 scale will not show accurate, detailed geological information unless they are based on point data (e.g. structural infomlation). If required the QMAP series maps can also be made available in digital fonn using standard data interchange formats.

The digital data have been captured from data record maps compiled on standard 1:50000 NZMS 260 topographic maps. These record maps are filed in GNS offices in Dunedin and Lower HUll (Gracefield) and, although unpublished, are available for consultation. They are stored on transparent film and copies can be made. The legend and mapping philosophy used for the detailed maps are based on lithostratigraphy and may differ from those used on QMAP.

For new or additional information, for prints of this map at other scaJes, for selected data or combinations of data sets or for derivative or single-factor maps based on QMAP dara, please contact:

QMAP Leader
InSlilUle of Geological & uclear Sciences Ltd.
P. O. Box 30 368
Lower HUll

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This full colour, large format geological map illustrates the geology of Raukumara Peninsula and northern Hawke's Bay (eastern North Island, New Zealand) at a scale of 1:250 000. The map is panof a series initiated in 1996 which will cover the whole country.

Onshore geology, offshore bathymetry and geology are shown, derived from published and unpublished mapping by the Institute of Geological & Nuclear Sciences, the National Institute for Water & Atmospheric Research, university staff and students, and exploration company geologists. All geological map data are held in a geographic information system, are available in digital form, and as **thematic maps at various scales. The accompanying illustrated text summarises the regional geology** and tectonic development, the economic and engineering geology, and the potential geological hazards.

The Raukumara Range is formed of Torlesse composite terrane indurated sandstone and mudstone, of **Late Jurassic to Early Cretaceous age. In western Raukumara Peninsula Torlesse basement is** unconformably overlain by an Early Cretaceous cover sequence, but in the east the nature of the **contact is still disputed. Late Cretaceous to Oligocene sandstone, mudstone and minor limestone were** deposited in a passive margin setting. The boundary between the Australian and Pacific plates propagated through the region in Early Miocene time with emplacement of a series of thrust sheets (the East Coast Allochthon) and deposition of thick Miocene to Pliocene clastic sequences.

Rapid uplift and changes in sea level during the Quaternary have resulted in extensive alluvial terraces, floodplain deposits and uplifted marine terraces. Erosion and landsliding are widespread. Seismicity levels are typical for an area at the Australian-Pacific plate boundary, and further damaging earthquakes can be expected in the future. Oil and gas seeps are common and the first commercial discovery of hydrocarbons was made near Wairoa in 1998.

The shore platform at Auroa Point, Mahia (y19/388232), exposes gently dipping, Late Miocene tuffaceous sandstones of the Tolaga Group, interpreted as turbidite deposits from a deep marine environment. The beds are cut by an orthogonal joint pattern.

Photo CN42J72: D.L. Homer

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