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HOLOCENE SHORELINE DEPOSITIONAL PROCESSES AT POVERTY BAY, A TECTONICALLY ACTIVE AREA, NORTHEASTERN NORTH ISLAND, NEW ZEALAND

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Holocene depositional processes at Poverty Bay have been affected by: (1) tectonism; (2) sea level response to climate change; (3) fluvial processes responding to: (1) and (2), severe storms and volcanic eruptions. The height distribution of radiocarbon dated beach and estuarine shells and wood, show that during the Holocene relative uplift of the land has occurred at the northeastern margin of the Poverty Bay flats, while subsidence has occurred at the southwestern margin. Three Holocene tectonic subregions are distinguished at the Poverty Bay flats coast; a northern (Gisborne–Wainui) uplift area, a central (Makaraka–Awapuni) static pivotal area and a southern (Patutahi–Muriwai) downdrop area. Periods of significant fluvial upstream degradation into gravel terrace deposits and downstream gravel aggradation are dated at ca. late last glaciation, 12,000–9000 and 7000–5000 BP. The 12,000–9000 BP gravel deposits show tilting to the southwest. Major erosion and infilling events also occurred at ca. 1700 and 300 BP. Holocene marine transgression and progradation shoreline locations are mapped and the coastal processes are reviewed in terms of the tectonic, fluvial and eustatic sea level influences.

INTRODUCTION

New Zealand is situated in the southwest Pacific along the boundary zone of the Australian and Pacific lithospheric plates. Studies of active tectonism along the east coast of North Island, New Zealand show uplift predominating throughout Neogene time to the present. The average Holocene rate of uplift varies from 0.2 to 4 m/ka at northeastern North Island and locally there are reversals to the uplift trend (Ota *et al.*, 1988). Poverty Bay flats is an area of late Quaternary subsidence occupied by the floodplain of the Waipaoa River.

Lithologic descriptions and samples of the strata underlying the Poverty Bay flats have been obtained from water wells and groundwater exploration wells to depths of 200 m. These provide evidence of changing depositional paleoenvironments during the late Quaternary. At the coast fluctuating sea levels produced transgression and regression. Local tectonic events produced uplift or subsidence. Other influences on coastal processes are severe storms which periodically affect the Waipaoa River catchment hydrological and erosional processes to produce floods and rapid fluvial deposition on the Poverty Bay flats. Volcanic eruptions in the central North Island lead to the deposition of significant ash thicknesses in the Waipaoa River catchment and on the Poverty Bay flats, and may also have affected erosional and downstream depositional processes by killing the vegetation cover. Radiocarbon dates from organic material enclosed within the sediments indicate the rate and time of occurrence of the Holocene processes that formed Poverty Bay flats.

POVERTY BAY AND POVERTY BAY FLATS

Poverty Bay is a sheltered semi-circular oceanic embayment, 63 km^2 in area on the northeastern coast of North Island, New Zealand (Fig. 1). Gisborne city is situated at the northern side of the bay. The Poverty Bay coast is prograding with sediment transported by the north-flowing coastal current and sediment derived from the catchment of the Waipaoa River. Coastal processes at Poverty Bay have formed a sand beach backed by sand dunes enclosing estuaries and lagoons. The Poverty Bay flats (Fig. 2) of about 20,000 hectares comprise the coastal alluvial floodplain of the Waipaoa River and extend inland for about 20 km to an altitude of about 20 m a.m.s.l.

The Poverty Bay flats have been called a structural depression (Waipaoa Depression) by Kingma (1964) and a syncline by Stoneley (1962). Northeast trending faults dislocating the Tertiary age rocks on the hills adjacent to the Poverty Bay flats (Fig. 3) have been mapped principally by Kingma, Stoneley, Ridd (1964) and Neef (1992) but the detailed structure of the area is poorly understood.

The Waipaoa River has a catchment of about 2000 km^2 mainly in soft Cenozoic mudstone and siltstone. Downstream deposition by the Waipaoa River results in late Quaternary fluvial silt predominating beneath the Poverty Bay flats. However, indurated sandstone of Cretaceous age in the western extremity of the Waipaoa catchment (Fig. 1), has periodically contributed significant amounts of stronger clasts for transport and deposition downstream. Gravel and sand derived from this rock source underlie a series of terraces adjacent to the Waipaoa River valley and floodplain. Also derived from this Cretaceous sandstone are late Quaternary and Holocene buried gravel river channels forming confined aquifers underlying the Poverty Bay flats.

SEDIMENTARY INFILL OF THE POVERTY BAY FLATS BASIN

The 'basement' rock beneath the Poverty Bay flats is Miocene mudstone, siltstone and sandstone (Brown, 1984).

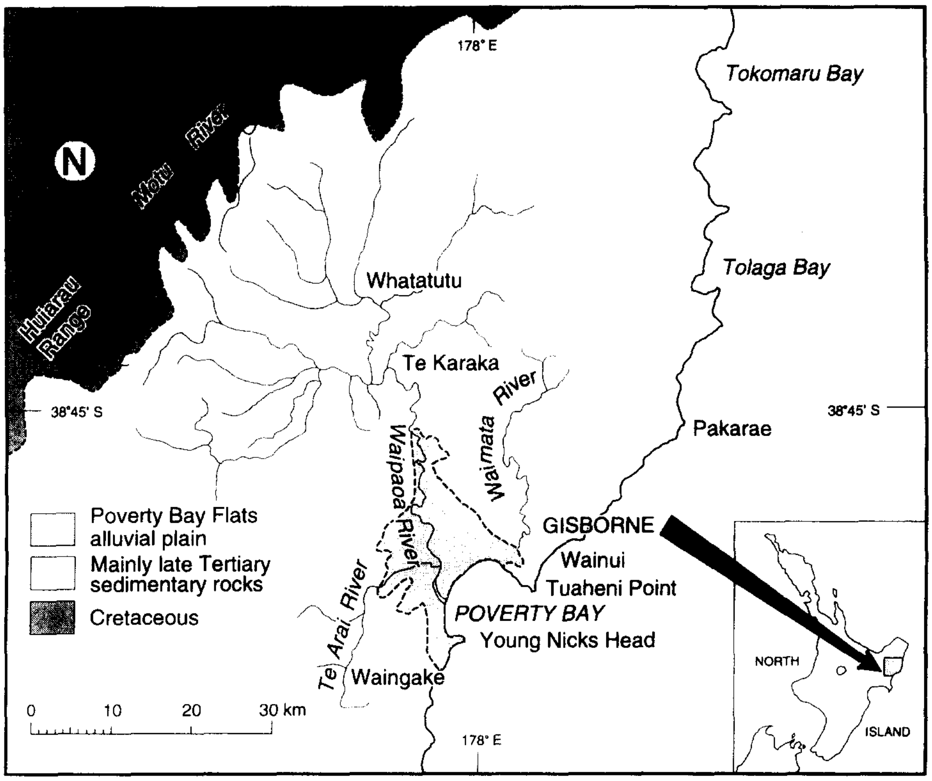

FIG. 1. Map showing Poverty Bay and Waipaoa River catchment.

Structural contours of the thickness of overlying late Quaternary fluvial and marine sediments based on testbores and water well logs and Poverty Bay bathymetry, suggest a basin structure with a maximum depth to basement of at least 200 m b.m.s.l. beneath the King Road (Waiohika–Hexton area) (Figs 2 and 3). Wells have provided organic material for radiocarbon dating (Table 1) and macrofauna and microflora assemblages for paleoenvironment determinations. Beneath the Poverty Bay flats Holocene beach, estuarine, lagoonal, swamp and fluvial channel and overbank sediments overlie last glaciation fluvial and swamp sediments. In the deeper parts of the basin (generally at more than 100 m) last glaciation sediments are underlain by marine and swamp deposits. These do not contain age diagnostic fossil species but a temperate climate is indicated by pollen assemblages (D.C. Mildenhall, *pers. commun.*). Reworking of dinoflagellates, pollen and spores from Mesozoic (Cretaceous)–Cenozoic sediments, and of shell fauna from Cenozoic sediments is common.

These deposits possibly correlate with temperate climate deposits capping the hills on the northern margin of the Poverty Bay flats adjacent to Gisborne (Fig. 3). These capping strata include remnants of fluvial gravel interbedded with swamp and estuarine deposits of early–mid-Castlecliffian age (1–0.5 Ma) at 290 m a.m.s.l. The age is based on nannofossils extracted from the matrix attached to *Zeacumantus lutulentus* (Town Hill), and the matrix within double valved *Anadara trapezia* (Kaiti Hill) (A.R. Edwards *pers. commun.*). Kaiti Hill (129 m a.m.s.l.) is capped by water-laid tuffaceous sediment overlain by a shell-bed with a fauna dominated by *Anadara*, a rare (in New Zealand) late Pleistocene estuarine temperate climate species. Amino-acid racemization data for *Anadara* shells from Kaiti Hill are consistent with a last interglacial age, probably Isotope Stage 5e (C. Murray-Wallace, *pers. commun.* to B. Pillans). This age implies an average uplift rate of 1 m/ka.

LATE QUATERNARY DEPOSITIONAL ENVIRONMENTS

Radiocarbon-dated organic material (Table 1) provides the time control for Poverty Bay flats Holocene depositional processes. Most of the Poverty Bay dated samples have been collected from groundwater testbores. Drilling was done using the cable tool drilling method and samples obtained by wash bailing from the well casing. The maximum margin of error in the depth of samples is in the order of 3 m. The testbores were cased as drilling proceeded to prevent the collapse of overlying strata. Neither depth nor age errors are shown on the sea level curves constructed from the radiocarbon dates and depth errors have not been included in Table 1, as assessment of the sampling technique and precise site levelling was not available for most samples.

At Poverty Bay the main influences on the Holocene depositional environments have been tectonic processes, coastal processes adjusting to sea level change, and fluvial processes adjusting to base level changes, volcanic eruptions and catchment storm events. These three processes are now discussed in detail.

Tectonic Processes

Regional differential tectonic movement is implied by Kingma's (1964) map showing a fault underlying the Poverty Bay flats with upthrow to the east and downthrow to

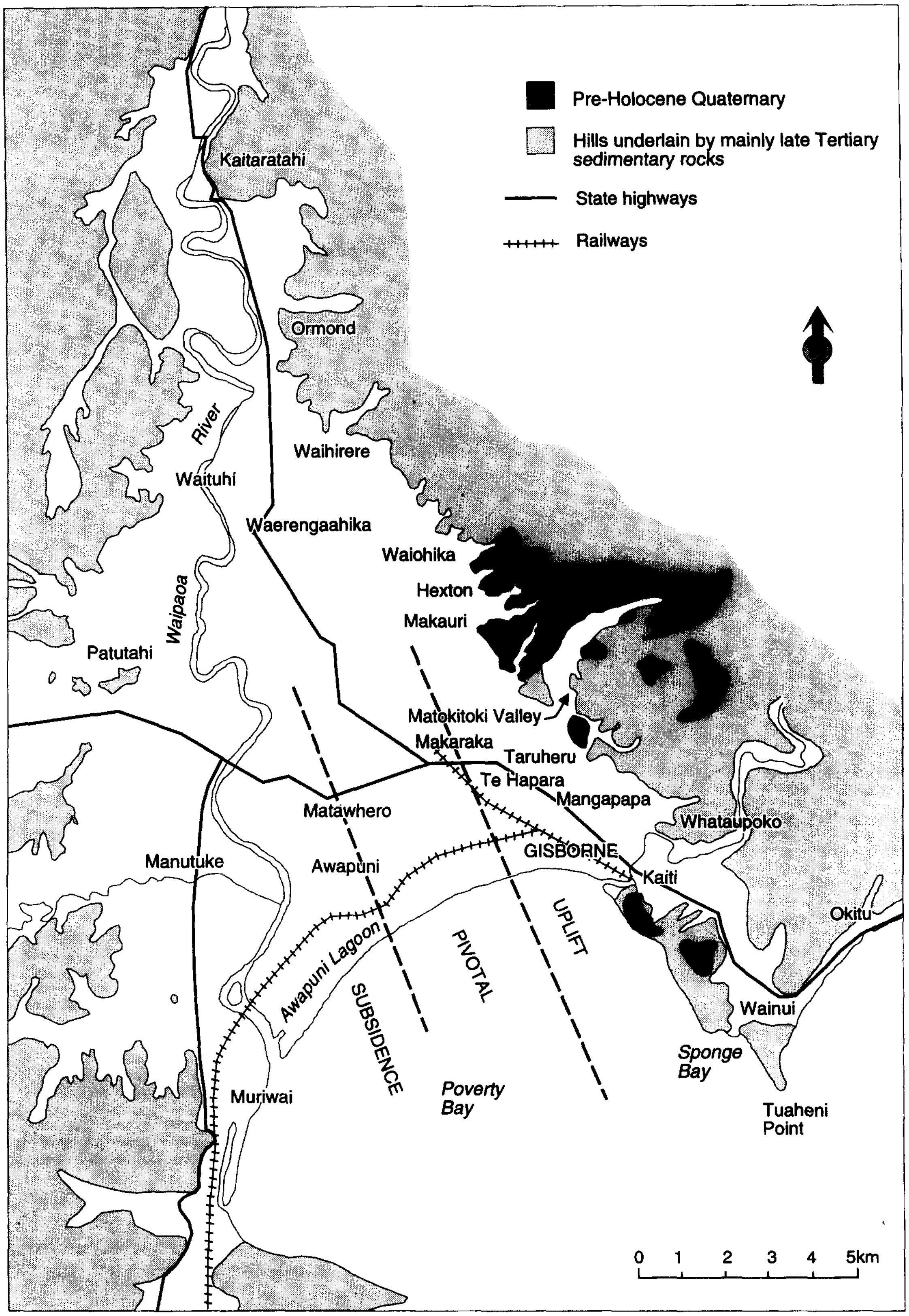

FIG. 2. Poverty Bay flats locality map and Holocene tectonic subregions.

the west. Pullar and Warren (1968) identified tilting in dunes older than 1000 years at the Poverty Bay coast, suggesting that differential tectonic movement is a modern process. Also the surface of Holocene gravel deposits (Makauri gravel — Brown, 1984) underlying the Poverty Bay flats is at a gradient of about 1:200 to the southwest (Fig. 4), compared to the present day gradient of about 1:500 of the Waipaoa River course from Te Karaka to the coast (Pullar, 1962). This is too steep for the Waipaoa River channel immediately adjacent to the coast even at the time of rapidly rising sea level, and suggests postdepositional tilting has occurred.

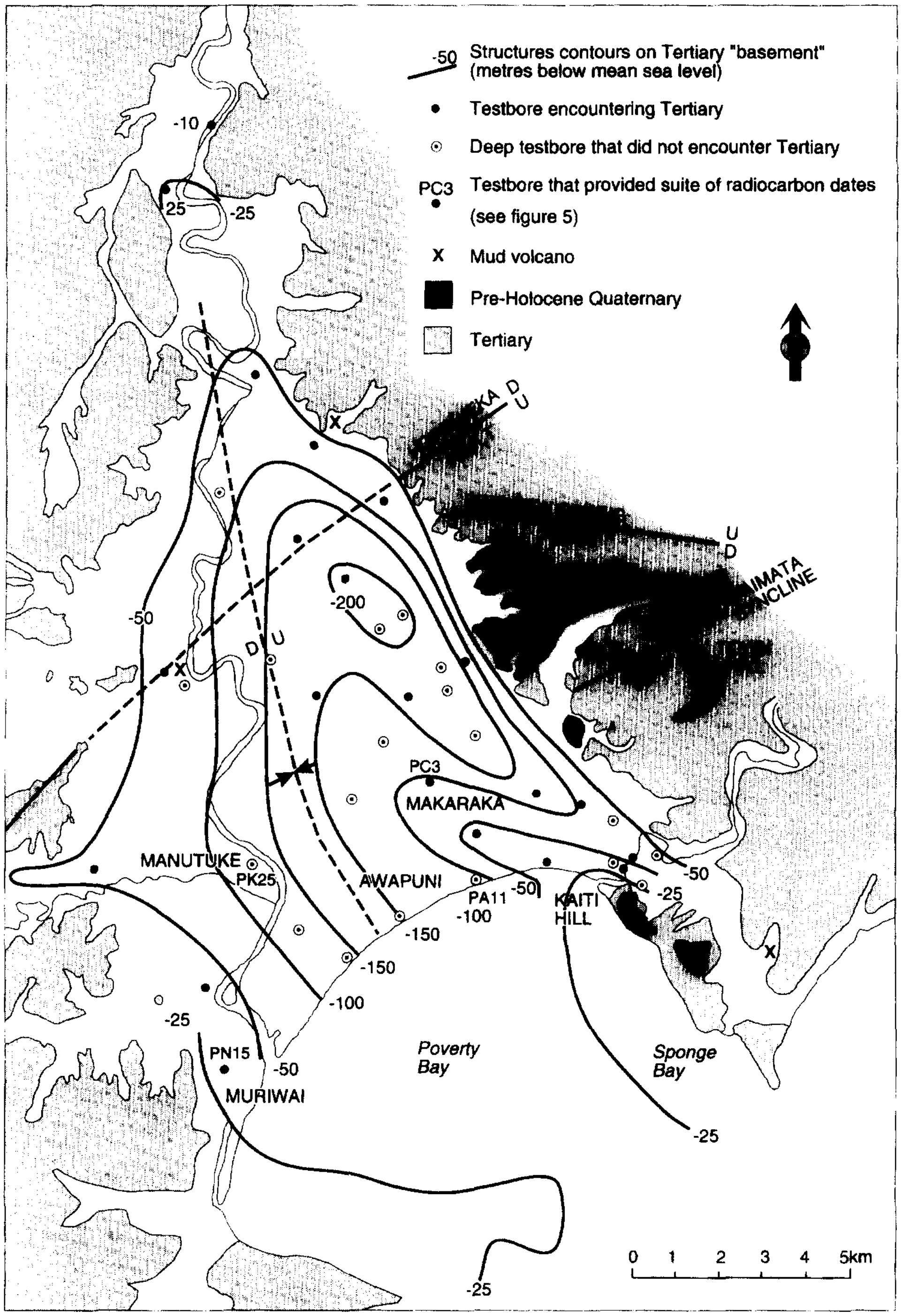

FIG. 3. Structure contours on Tertiary 'basement' beneath Poverty Bay flats and structural features of pre-Quaternary geology.

Local periodicity of major tectonic events is indicated by radiocarbon-dated uplifted marine terraces at the Pakarae River mouth about 20 km northeast of Gisborne (Fig. 1) where at least six coseismic uplift events have occurred in the last 6000 years (Ota *et al.*, 1991). These were at < 600, 1000, 1600, 2500, 3900, and 5500 BP. Prior to 6500 BP sea level was rising rapidly and probably masked tectonic-induced changes. Ages of uplifted terraces vary for different areas of the east coast (e.g. Pakarae River and Mahia Peninsula) implying that local large earthquakes form unique terrace sequences (Berryman *et al.*, 1989). The periodicity of seismicity at Poverty Bay is likely to be similar to that indicated by the terrace sequence at Pakarae.

A plot (Fig. 5) of radiocarbon age versus depth in relation to mean sea level for Poverty Bay postglacial shells and coastal swamp peat deposits, compared with the New Zealand postglacial eustatic sea level curve (Gibb, 1986) shows the influence of tectonism on coastal processes at Poverty Bay. Samples from specific sites (testbores) show abrupt changes of age with depth indicating breaks in deposition and/or erosion. These data can be interpreted to suggest tectonism and subsequent adjustment by fluvial and coastal processes. For example the Makaraka testbore (PC 3)* plot demonstrates a paraconformity between 5 and 8 m b.m.s.l. at ca. 4000 BP. Reworking with redeposition of older organic material has also occurred as shown by reversal of

*Gisborne District Council water well file number.

TABLE 1. Radiocarbon ages of Poverty Bay Flats Holocene samples

Age* (Years BP)	NZ^{14}C No.	NZ Fossil Record no.	Sample	Locality	Grid ref.	Depth from surface (m)	Altitude with ref. to MSL (m)	Site
Zone 1: Gisborne–Wainui (Tectonic Uplift)								
1775 ± 67	7993	Y18/f219	Shells	Kaiti	490684	0.2	+6.9	Excavation
2340 ± 90	6146	Y18/f220	Shells	Kaiti	490684	0.3	+6.8	Excavation
4043 ± 31	6147	Y18/f221	Shells	Mangapapa	463716	2.0	+2.0	River bank
4551 ± 48	8147	Y18/f565	Shells	Mangapapa	468715	1.8	+9.9	Excavation
4798 ± 57	4433	Y18/f1	Shells	Okitu	517683		+7.2	Sea cliff
5831 ± 102	5439	Y18/f146	Shells	Taruheru	444720	3.2	+1.9	PB 39
6356 ± 80	8124	Y18/f226	Shells	Whatataupoko	477703	1.7	+7.8	Excavation
6588 ± 83	6145	Y18/f217	Shells	Sponge Bay	502663		+8.7	Excavation
6808 ± 129	7175	Y18/f356	Shells	Kaiti	484697	11.0	− 0.1	River bank
7253 ± 91	5576	Y18/f159	Wood	Sponge Bay	498658		+3.5	Sea cliff
7395 ± 105	5577	Y18/f160	Wood	Okitu	519687		+5.5	River bank
7517 ± 36	6143	Y18/f213	Shells	Wainui	498658		+3.6	Sea cliff
7668 ± 171	5573	Y18/f155	Shells	Sponge Bay	519687		+1.3	Sea cliff
7703 ± 377	5440	Y18/f147	Shells	Okitu	510663	2.0	+3.0	PA 47
7813 ± 77	6144	Y18/f214	Shells	Sponge Bay	498658		+2	Sea cliff
7832 ± 96	5578	Y18/f161	Wood	Okitu	519687		+3.0	River bank
7907 ± 65	1881		Shells	Okitu	510663		+3.6	Sea cliff
7972 ± 97	5575	Y18/f158	Wood	Sponge Bay	498658		+1.5	Sea cliff
8013 ± 158	5574	Y18/f156	Shells	Sponge Bay	519681		+2.9	Sea cliff
8073 ± 84	8123	Y18/f215	Shells	Sponge Bay	498658	40	+4.0	Sea cliff
8200 ± 87	A1439	Y18/f451	Shells	Sponge Bay	498658		+0.5	Sea cliff
8391 ± 91	7209	Y18/f355	Wood	Kaiti	484697	12.3	− 1.3	River bank
8408 ± 103	5099	Y18/f50	Wood	Okitu	530688		+1.7	Beach
8860 ± 85	6714	Y18/f283	Wood	Taruheru	437723	25.0	− 17.0	PB 102
11423 ± 287	7992	Y18/f148	Shells	Okitu	519681	19.0	−13.9	PA 47
Zone 2: Makaraka–Awapuni (Static Pivotal Tectonic)								
1051 ± 111	5567	Y18/f194	Shells	Awapuni	442691	14.0	−11.2	PA 11
1214 ± 42	5565	Y18/f187	Shells	Awapuni	442691	7.5	−4.7	PA 11
1632 ± 91	6125	Y18/f189	Shells	Awapuni	442691	8.2	−5.4	PA 11
1673 ± 82	6126	Y18/f192	Shells	Awapuni	442691	13.5	−10.7	PA 11
1838 ± 87	6127	Y18/f197	Shells	Awapuni	442691	15.5	− 12.7	PA 11
1852 ± 136	5566	Y18/f190	Shells	Awapuni	442691	9.6	−6.8	PA 11
2118 ± 88	6128	Y18/f200	Shells	Awapuni	442691	17.0	− 14.2	PA 11
2524 ± 140	5564	Y18/f167	Shells	Awapuni	442691	4.5	−1.7	PA 11
2561 ± 119	6129	Y18/f202	Shells	Awapuni	442691	18.0	−15.2	PA 11
3863 ± 272	5436	Y18/f125	Shells	Makaraka	429713	7.7	−4.3	PC 3
3882 ± 78	5431	Y18/f105	Shells	Makaraka	429713	2.0	+1.4	PC 3
3976 ± 84	5433	Y18/f113	Shells	Makaraka	429713	4.4	−1.0	PC 3
4005 ± 80	5434	Y18/f118	Shells	Makaraka	429713	5.6	−2.2	PC 3
4083 ± 38	5432	Y18/f108	Shells	Makaraka	429713	3.5	−0.1	PC 3
4141 ± 80	5435	Y18/f123	Shells	Makaraka	429713	6.8	−3.4	PC 3
5953 ± 851	6124	Y18/f168	Shells	Awapuni	442691	6.0	−3.2	PA 11
7307 ± 150	5437	Y18/f129	Shells	Makaraka	429713	10.4	−7.0	PC 3
8151 ± 72	5438	Y18/f136	Shells	Makaraka	429713	13.0	−9.6	PC 3
8563 ± 245	6131	Y18/f206	Shells	Awapuni	442691	35.0	−32.2	PA 11
8901 ± 297	6130	Y18/f205	Shells	Awapuni	442691	25.0	−22.2	PA 11
9310 ± 110	6252	Y18/f270	Wood	Awapuni	413705	55.0	−51.0	PC 36
9560 ± 155	6309	Y18/f227	Peat	Awapuni	442691	30.0	−27.2	PA 11
18120 ± 2880	6132	Y18/f207	Shells	Awapuni	442691	42.4	−39.6	PA 11
Zone 3: Patutahi–Muriwai (Tectonic Subsidence)								
1999 ± 71	5428	Y18/f57	Shells	Muriwai	379646	8.5	−7.5	PN15
2043 ± 64	5304	Y18/f58	Shells	Muriwai	379646	8.7	−7.7	PN15
2652 ± 102	5303	Y18/f52	Shells	Muriwai	379646	6.5	−5.5	PN15
3925 ± 98	5429	Y18/f63	Shells	Muriwai	379646	13.5	−12.5	PN15
4776 ± 77	5305	Y18/f62	Shells	Muriwai	379646	13.0	−12.0	PN15
4948 ± 40	6499	Y18/f235	Shells	Manutuke	389695	10.0	−5.0	PK25
5599 ± 82	6604	Y18/f254	Shells	Manutuke	389695	19.4	−14.4	PK25
5908 ± 75	6498	Y18/f249	Shells	Manutuke	389695	16.0	−11.0	PK25
6380 ± 55	5562	Y18/f162	Shells	Patutahi	373737	58.0	−46.8	PJ40
6800 ± 64	5442	Y18/f152	Shells	Patutahi	373737	20.0	−8.8	PJ40
7026 ± 99	5441	Y18/f151	Shells	Patutahi	373737	18.0	−6.8	PJ40
7150 ± 133	6122	Y18/f153	Shells	Patutahi	373737	24.0	−12.8	PJ40
7176 ± 92	5563	Y18/f165	Shells	Manutuke	345692	61.0	−51.6	PL7
7261 ± 133	6123	Y18/f166	Shells	Manutuke	345692	62.0	−52.6	PL7
8315 ± 104	6605	Y18/f265	Shells	Manutuke	389695	29.0	−24.0	PK25
8442 ± 206	6606	Y18/f267	Shells	Manutuke	389695	36.0	−31.0	PK25
8461 ± 106	6607	Y18/f275	Shells	Manutuke	389695	61.0	−56.0	PK25
9374 ± 97	6689	Y18/f268	Shells	Manutuke	389695	42.9	−37.9	PK25

Continued

TABLE 1. Continued

Age* (Years BP)	NZ¹⁴C No.	NZ Fossil Record no.	Sample	Locality	Grid ref.	Depth from surface (m)	Altitude with ref. to MSL (m)	Site
Samples not related to coastal processes								
510 ± 59	6763	Y18/f286	Wood	Waerengaahika	383773	10.2	+3.6	PE42
1230 ± 60	6316	Y17/f31	Wood	Ormond	Y17/385813	8.5	+11.5	PG13
4702 ± 61	6764	Y18/f288	Wood	Waerengaahika	383773	17.7	-3.9	PE42
5175 ± 174	5430	Y18/f86	Wood	Waiohika	417776	15.5	+4.9	PF56
6092 ± 88	6785	Y18/f291	Wood	Warengaahika	383773	21.2	-7.4	PE42
6161 ± 84	6315	Y17/f30	Wood	Kaitaratahi	Y17/367853	19.6	+5.0	PH14
7139 ± 96	6622	Y17/f42	Wood	Ormond	Y17/386813	27.3	-7.6	PG60
7255 ± 97	6621	Y17/f39	Wood	Ormond	Y17/386813	21.0	-1.3	PG60
7265 ± 74	6723	Y17/f43	Wood	Ormond	Y17/386813	29.0	-9.3	PG60
7924 ± 95	6829	Y18/f296	Wood	Waerengaahika	383773	36.0	-22.2	PE42
8845 ± 129	6739	Y17/f46	Wood	Ormond	Y17f386813	37.7	-18.0	PG60
9147 ± 133	7403	Y18/f369	Wood	Waituhi	368773	41.0	-28.0	PI25
9533 ± 56	6832	Y18/f299	Wood	Waerengaahika	368773	50.0	-36.2	PE42
9535 ± 139	7404	Y18/f370	Wood	Waituhi	368773	58.0	-45.0	PI25

*Conventional radiocarbon age.

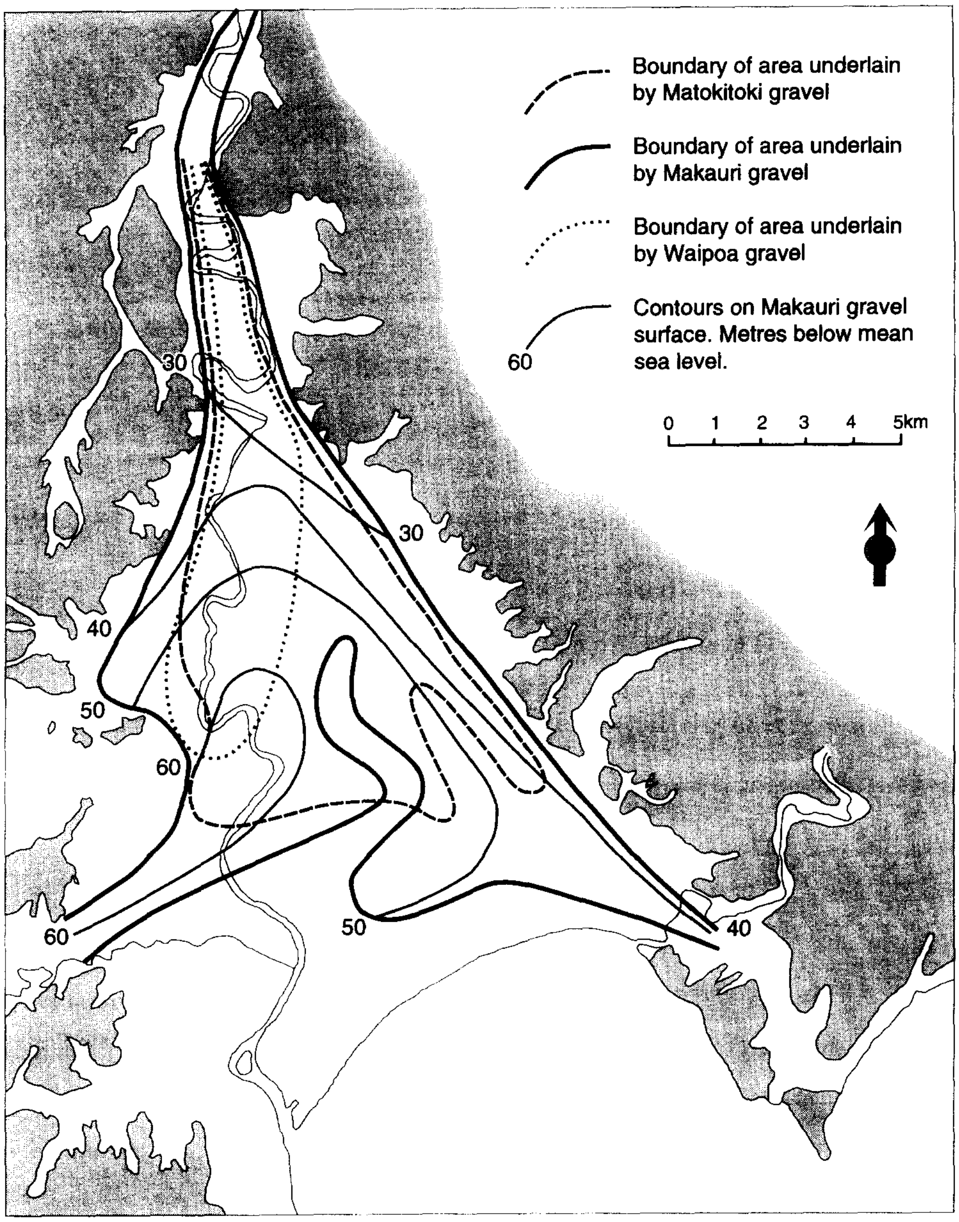

FIG. 4. Fluvial gravel channel deposits underlying Poverty Bay flats and contours on Makauri gravel surface showing tilting to the southwest.

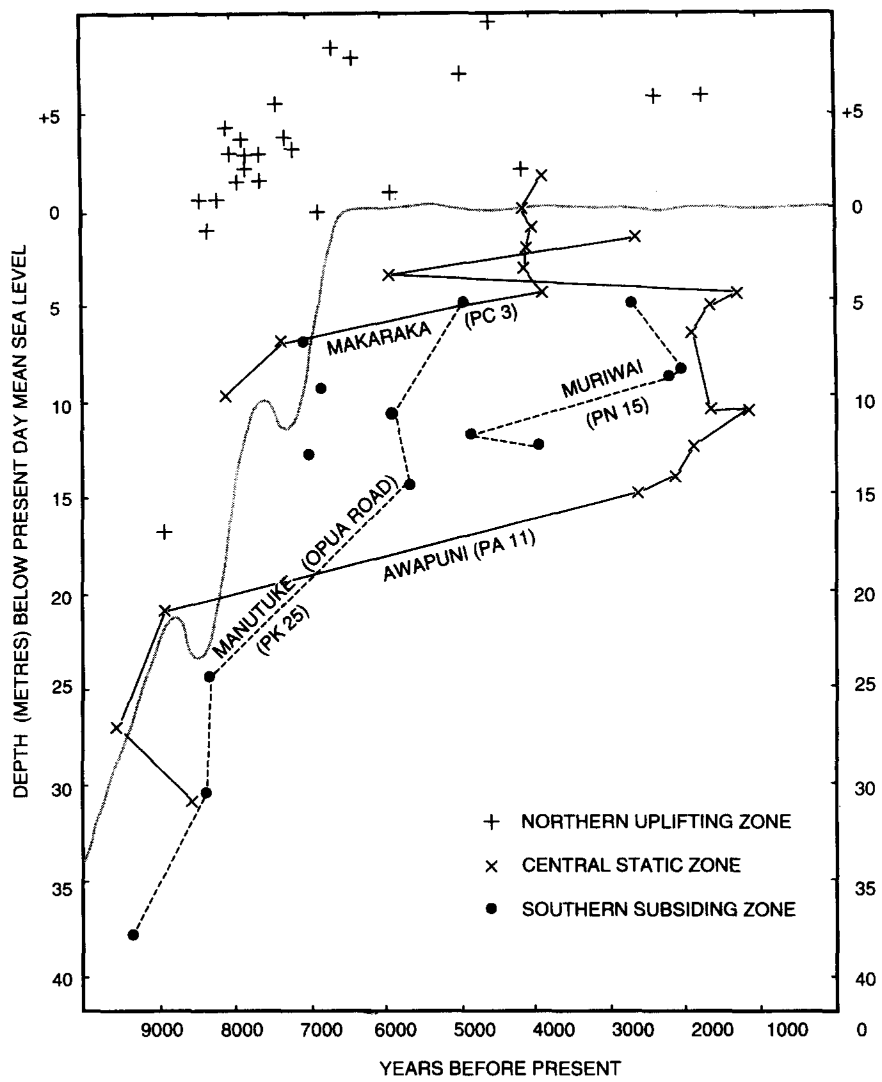

FIG. 5. Poverty Bay flats marine Holocene radiocarbon dates compared with New Zealand eustatic sea level curve.

age with depth down testbores. The Awapuni testbore (PA 11) plot shows reworking at 2.5 m b.m.s.l.

Ota *et al.* (1988) distinguished 11 tectonic subregions at the North Island east coast from East Cape to Cape Palliser based on the average uplift rate of Holocene marine transgressive deposits. Poverty Bay flats was one of two subregions where net subsidence had occurred. The height distribution of radiocarbon-dated beach and estuarine shells and wood show that during the Holocene relative uplift of the land has occurred at the northeastern margin of the Poverty Bay flats, while 12 km away at the southwestern margin subsidence has occurred. For convenience for discussing data, this study divides the coastal Poverty Bay flats into three tectonic zones where differing tectonic influences have affected Poverty Bay Holocene coastal processes over the last 6500 years (Fig. 2).

The Poverty Bay tectonic zones are:

(i) A northern zone where shell and organic material from excavations, exposures in river banks and sea cliffs, and wells, show tectonic uplift has been significant during the Holocene (Table 1). This zone is identified from the northern Gisborne suburb of Mangapapa east to Wainui at the Pacific Ocean coast (Fig. 2). Uplifted pre-6500 BP estuarine sediments predominate and are typically exposed in a beach cliff section at Sponge Bay (Fig. 7). Further east in the Mangapapa suburb of Gisborne, McGlone *et al.* (1984) describe a section where 2 m of Holocene beach sands unconformably overlie last glaciation silt deposits at 7 m a.m.s.l. In the Mangapapa–Kaiti area a 1–3 m layer of post-6500 BP fluvial and/or coastal marine sediments accumulated in an embayment-estuary environment at the mouth of the Turanganui–Waimata River, as the river adjusted to the uplift by downcutting. This marine environment persisted in the Kaiti area until 1775 ± 67 BP (NZ7993)† (Table 1) when uplift exceeded river downcutting capacity.

Average Holocene uplift rates vary over short distances

†All radiocarbon dates are Conventional Radiocarbon Age as defined by Stuiver and Polach (1977) in years BP (1950 A.D.).

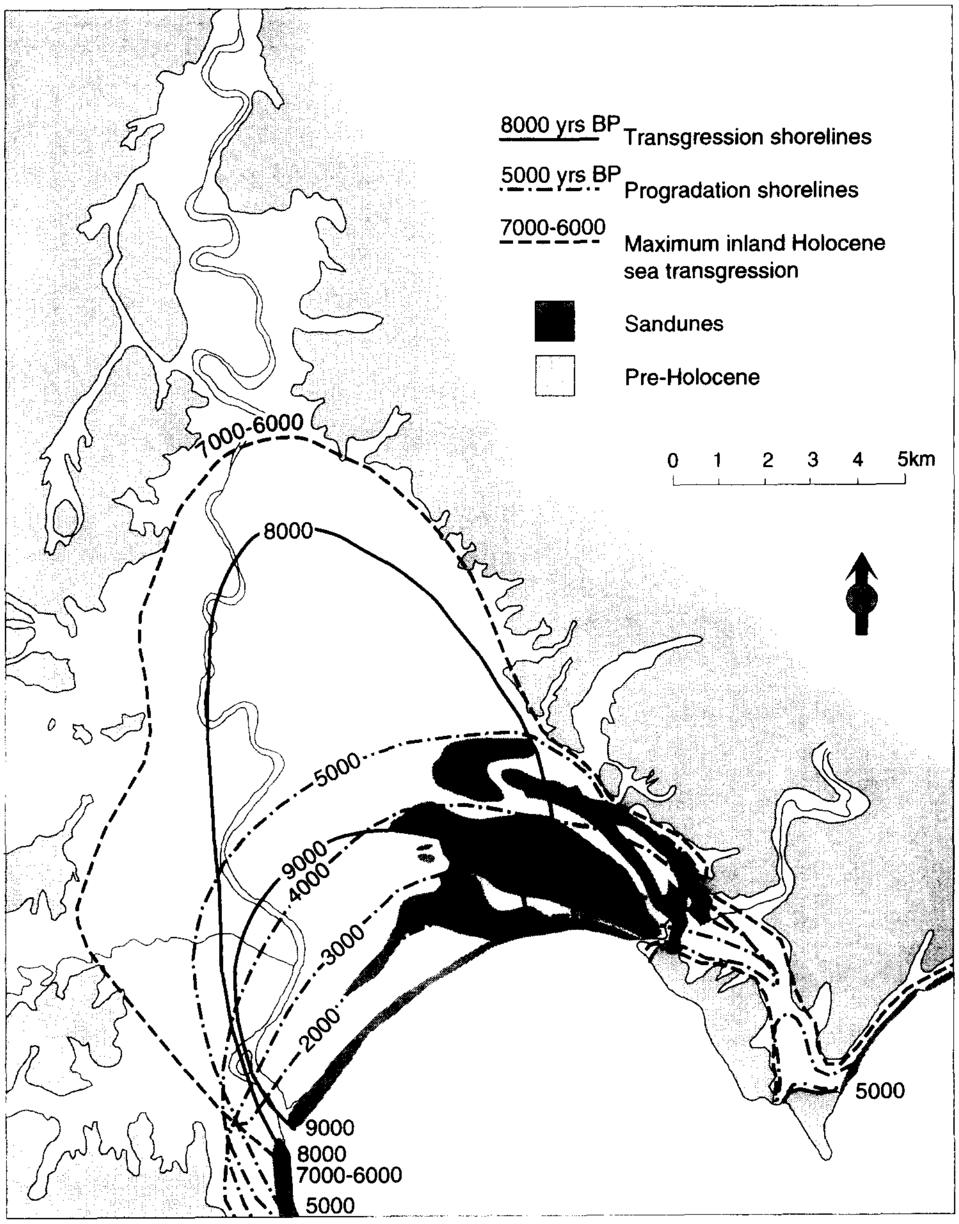

FIG. 6. Poverty Bay flats Holocene marine transgression and progradation shorelines.

(see Table 1). An uplift rate of 2.3 m/ka for a 7972 ± 97 BP (NZ5575) tree trunk at Sponge Bay (Fig. 7) has been determined by Ota *et al.* (1988). NZ7993 from Kaiti 2 km west of Sponge Bay implies an uplift rate of 3.9 m/ka.

Further evidence of uplift is provided by historical events and surveying. On 17 February 1931 the 'Sponge Bay uplift' resulted in 2 m average uplift of about 2 hectares of coastal platform on Tertiary mudstone and siltstone offshore of Sponge Bay (Strong, 1933). No specific accompanying earthquake was felt, but at the time of the occurrence, frequent aftershocks of the Hawkes Bay earthquake were still taking place (Eiby, 1982). On 4 March 1966 a magnitude 6.2 shallow earthquake with an epicentre 25 km northwest of Gisborne produced a maximum intensity of shaking of VII–VIII at Gisborne (Hamilton *et al.*, 1969). Following the earthquake a check of the level of benchmarks in the Gisborne city area showed some variation in level since the previous check in 1924. The level changes suggested that in 42 years Whataupoko (a northern suburb) had settled a maximum of 37 mm and Kaiti had risen a maximum of 24 mm with respect to the central commercial area of Gisborne.

On Kaiti Hill last interglacial estuarine deposits are at 129 m a.m.s.l. (C. Murray-Wallace, *pers. commun.* to B.H. Pillans) and ? older interglacial deposits to 290 m a.m.s.l. at Town Hill and other localities adjacent to Gisborne (Fig. 3) indicate that uplift is an ongoing late Quaternary process at Poverty Bay.

(ii) A central zone in the Makaraka–Awapuni area where no *in situ* 7300 to 4140 BP marine deposits (shells) underlie the Poverty Bay flats. This suggests a zone where coastal erosion processes were operative during this period in the

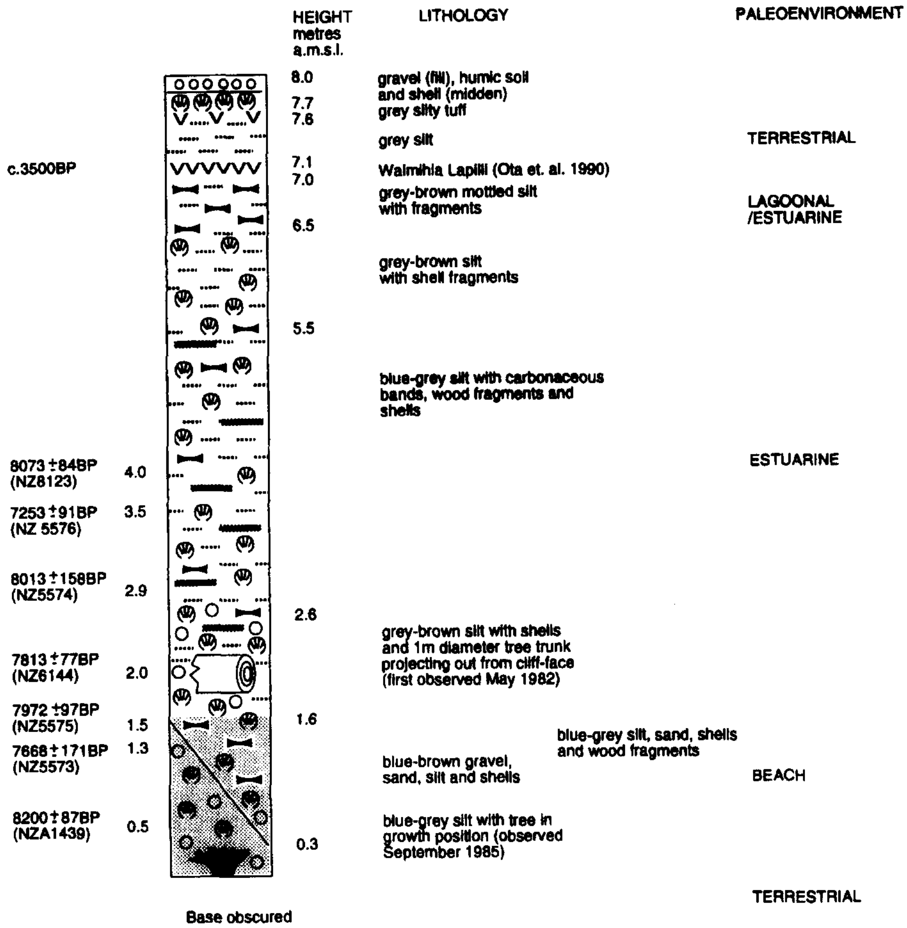

FIG. 7. Sponge Bay beach cliff section (after Ota *et al.*, 1990).

near-shore embayment environment. Pre-7000 BP transgressive marine samples from this area are close to the New Zealand eustatic curve, suggesting minimal tectonic dislocation since deposition. During the last 4000 years the embayment has filled with marine and estuarine sediments as the coast prograded.

This sequence of coastal changes has been established from the lithological logs and samples from the Makaraka testbore (PC3) to the west of Gisborne city and the Awapuni testbore (PA 11) located at the coast (Fig. 8). The Makaraka testbore radiocarbon data have no samples in the 7300 to 4140 BP time range. Radiocarbon dates from the Awapuni testbore show an even longer paraconformity — 8901 BP at –22.2 m b.m.s.l. for a transgressive estuarine sample (*Austrovenus stutchburyi*) to 2561 BP at –15.2 m b.m.s.l. for a pre-progradation offshore sheltered sandy beach sample (*Maorimactra ordinaria*). The paraconformity in these two testbores occurs for a period when the testbore sites would have been offshore, suggesting a zone of near-shore erosion and subsequent infilling associated with coastal progradation. There is no direct evidence of tectonic displacement.

(iii) A southern zone from Manutuke to Young Nicks Head of Holocene tectonic subsidence.

The plot of radiocarbon dates of shells (Table 1) from testbores at Patutahi (PJ 40), Manutuke (Papatu (PL 7) and Opou Roads (PK 25)) and Muriwai (PN 15) (Figs 3 and 9) on the southern Poverty Bay flats, shows subsidence has been the predominant Holocene tectonic trend. For the Muriwai testbore (Fig. 9), the furthest south of the testbores, radiocarbon dates suggest that at Muriwai the land subsided beneath the sea about 4000 years ago. A subsidence rate of ca. 4 m/ka is indicated at Muriwai compared with 7 m/ka at Patutahi and Manutuke (Papatu Road) for the last 7000 years. Despite this subsidence Young Nicks Head has always been part of the mainland in the Holocene.

The effect of subsidence is shown by the Holocene shorelines established by radiocarbon dates (Fig. 6). In the Muriwai area these young to the south as a result of the sea transgressing over the subsiding Holocene fluvial deposits immediately overlying Miocene 'basement' siltstone. Although sea level has been similar to that of the present day for the last 6500 years progradation has only exceeded the effects of subsidence in the last 2000 years.

Coastal Processes

Radiocarbon dates for estuarine shells (mainly *Austrovenus stutchburyi*), peat and wood, and paleoenvironmental determinations of fauna and flora show that about ca. 9500 BP the rising postglacial sea began to transgress over the Poverty Bay flats. Shell assemblages are dominated by estuarine and lagoonal species with influxes of sandy beach and rocky shore species (A.G. Beu, *pers. commun.*). Silty peat samples contain pollen indicating

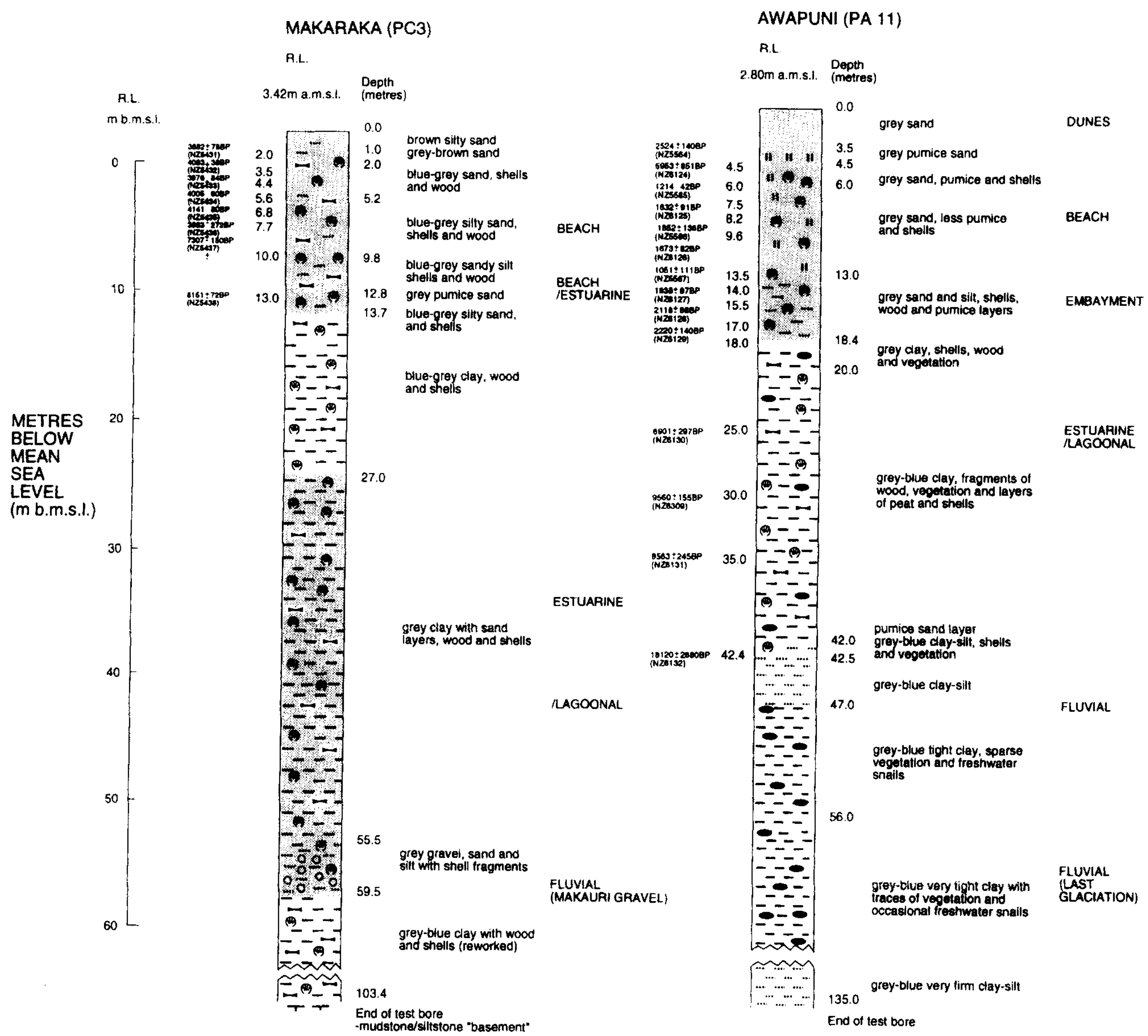

FIG. 8. Lithologic logs, radiocarbon dates and paleoenvironments of Makaraka and Awapuni testbores.

deposition in coastal swamp and brackish water environments. The presence of pollen grains of mangrove (*Avicennia marina*) from ca. 10,000–7000 BP provides evidence of a period of climate stability and average temperature higher than the present (Mildenhall and Brown, 1988; Mildenhall, 1994). Mangroves do not now grow at Poverty Bay.

A New Zealand eustatic sea level curve compiled by Gibb (1986), shows New Zealand postglacial sea level stabilizing at a level similar to that of the present at about 6500 BP (Fig. 5). Ota *et al.* (1988) observed that at the tectonically active east coast North Island, for sites with a high average Holocene uplift rate (> 1 m/ka) the postglacial transgression culminated ca. 7100–6800 BP, and for sites where there is subsidence or very low uplift the culmination occurred ca. 6300–5500 BP. At Poverty Bay, shorelines for the period 7500–5500 BP are difficult to define because local erosion and reworking of postglacial marine deposits has occurred probably in response to the differing tectonic influences. During this 2000 year period, the postglacial marine transgression reached its maximum inland extent near Waiherere (Fig. 5) 15 km from the present coast and then prograded about 8 km southeast to the 5000 BP shoreline. A minimum average rate of progradation of at least 3 m/year is indicated. This is significantly greater than the 0.2–0.8 m/year calculated by Pullar and Penhale (1970) for shoreline advance at Poverty Bay for the last 2000 years; a period that includes accelerated erosion and coastal progradation of 2.7 m/year (Pullar and Penhale, 1970) following forest clearing in the Waipaoa River catchment since 1932 (Pullar, 1967). Local storm and tectonic events may have been a significant factor contributing to accelerated erosion during the 7500–5500 BP period.

Progradation shorelines of the Poverty Bay coast from 5000 BP to the present are indicated by sand ridges, sand dunes and swales (Pullar and Warren, 1968) (Fig. 6). Dunes reach their maximum inland extent (5 km) in the western Gisborne suburb of Taruheru. The older inland dunes and ridges are up to 12 m a.m.s.l. and are aligned in a northwesterly direction over about 7 km from Taruheru to Kaiti. The more recent dunes are parallel to the present southwesterly oriented coastline from Young Nicks Head

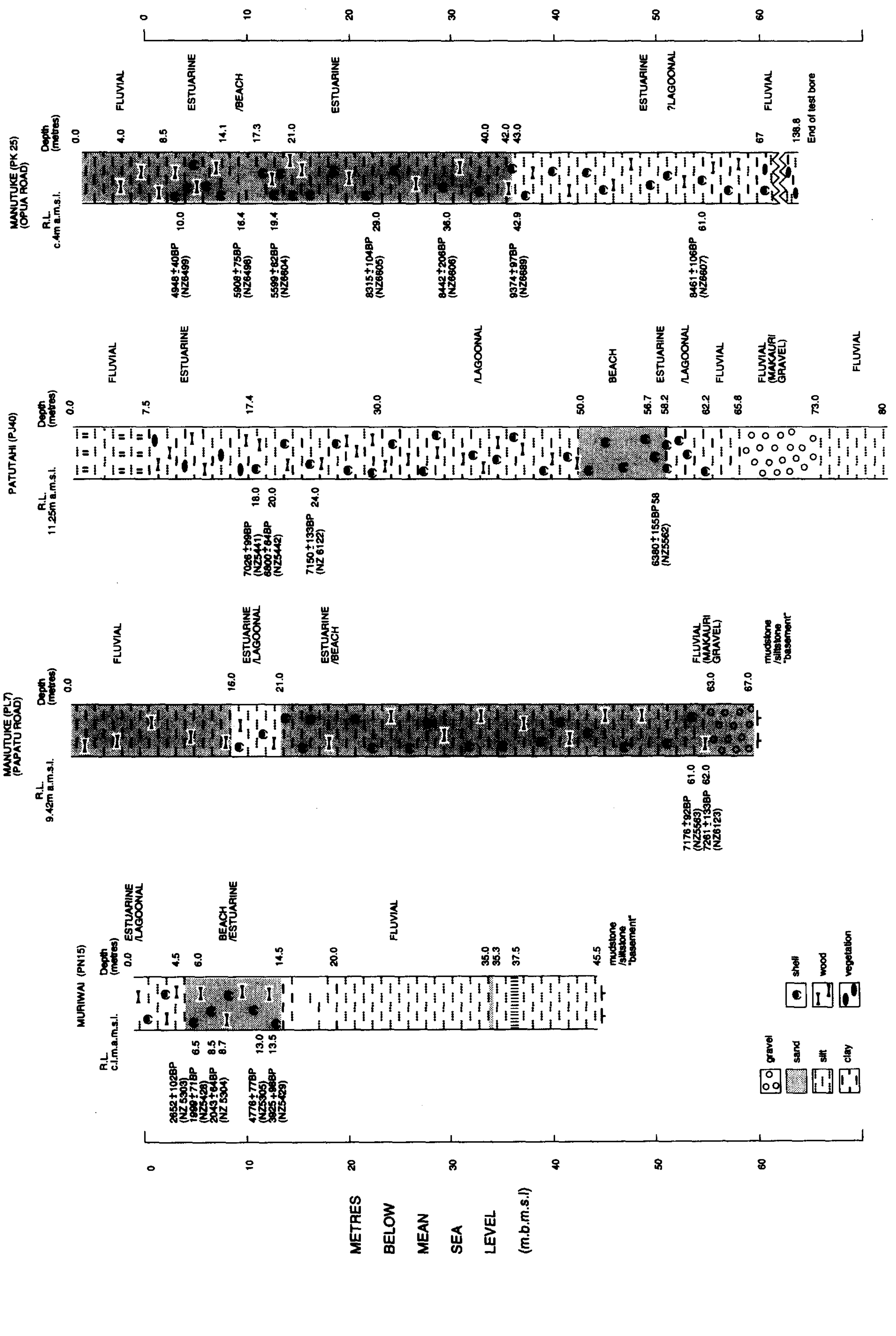

FIG. 9. Lithologic logs, radiocarbon dates and paleoenvironments of Muriwai, Patutahi and Manutuke testbores.

around Poverty Bay to Kaiti Beach and enclose the almost infilled Awapuni Lagoon adjacent to the Waipaoa River mouth.

Fluvial Processes

During the last glaciation (70,000 to 14,000 BP), gravel, sand and silt derived from indurated Cretaceous sandstone and mudstone of the western Raukumara Range (Fig. 1), infilled east coast river valleys. In the Waipaoa River valley subsequent river downcutting into the valley infill sediments and downstream deposition of gravel, has resulted in last glaciation and Holocene gravel river channel deposits underlying the Poverty Bay flats to a depth of ca. 100 m. Deeper gravel deposits interbedded with silt, wood and shell fragments suggesting a marginal marine or beach depositional environment occur to at least 190 m (at Hexton). Brown and Elmsly (1987) informally delineated four zones of distinct gravel river channel deposits underlying the Poverty Bay flats — Matokitoki and Makauri gravels deposited when sea level was lower than that of the present, and Waipaoa gravel and shallow fluvial (Fig. 4) sediments deposited with sea level at that of the present.

The Matokitoki gravel (Brown and Elmsly, 1987) channel deposits at 50–80 m beneath the Poverty Bay flats are probably the product of aggradation by the Waipaoa River during low but rising sea level when the coast was several kilometres east of the present day coast towards the end of the last glaciation.

The Makauri gravel (Brown, 1984) is a series of gravel channel deposits underlying the Poverty Bay flats at depths ranging from 25 m below ground surface at Kaitaratahi to 70 m at Patutahi. Radiocarbon dating of interbedded organic material (wood) suggests that this series of gravel channels was deposited about 12,000 to 9000 BP when the postglacial sea level was rising rapidly in response to climate warming. The Makauri gravel and associated fluvial silt deposits form the base on which the postglacial rising sea level deposits accumulated.

The Waipaoa gravel (Brown and Elmsly, 1987) is a series of gravel, sand and silt, terrace, fan and channel deposits of the Waipaoa River formed during the period of stable sea level and accelerated coastal progradation about 7000–5000 BP. It extends down the Waipaoa River valley from Te Karaka and out onto the Poverty Bay flats to Waerengaahika (Fig. 4) to interfinger with progradational beach, swamp, estuary and lagoon deposits. The Waipaoa gravel infills a meandering river channel cut into fluvial silt, swamp, lagoon and estuarine sediments deposited at the time of the maximum inland extent of the postglacial marine transgression. Waipaoa gravel is about 10–30 m below ground surface.

For the last 5000 years, deposition from the Waipaoa River has been dominantly overbank silt-sized material interbedded with pumice sand beds and gravel, and coarse sand river channel deposits. These fluvial deposits merge into sand dunes and lagoonal–estuarine silt deposits adjacent to the present coast. Maximum thickness is 10 m.

About 2200 BP there was a period of intense sedimentation which buried and killed forest on the Poverty Bay flats (Pullar and Patel, 1972) and coincides with the earthquake triggered landslide (Read *et al.*, 1992) that dammed the 56 km^2 Lake Waikaremoana 70 km west of the Poverty Bay flats (Pullar and Penhale, 1970). About 300 BP there was another period of rapid erosion and infilling on the Poverty Bay flats (Pullar and Penhale, 1970). This coincides with catastrophic storm damage to forest on the Huiarua Range (Grant, 1963) about 80 km west of the Poverty Bay flats. These flood events suggested by the geological record are more severe than any Waipaoa River flood recorded in historic time.

The most severe historic flood was associated with heavy rain from a cyclonic storm on 7 March 1988 when the Waipaoa River carried the largest recorded suspended sediment load for a New Zealand river for one day. A peak flood flow of 5300 m^3/sec (the mean flow for the Waipaoa River is about 38 m^3/sec), resulted in an estimated 16,259,000 m^3 of sediment (mainly silt) being deposited on the Poverty Bay flats or discharged into Poverty Bay (Gisborne District Council, *pers. commun.* 1993). Although as yet no discernible acceleration of Poverty Bay coastal progradation has been detected following the 7 March 1988 flood, there was a temporary build-up of sediment (sand) on the beach at Wainui (Fig. 2) just north of Poverty Bay during 1988 (Gisborne District Council, *pers. commun.* 1993). By 1990 Wainui beach coastal processes had reverted back to a delicate balance between stability and erosion during storms producing heavy seas. This supports the geologic evidence that in order to sustain post-7000 BP Poverty Bay coastal progradation, prehistoric (pre-forest clearing) Waipaoa River floods must have commonly eroded and transported quantities of sediment in excess of that recorded for historic time. The geologic processes contributing to the accelerated erosion would have been local tectonic events and volcanic eruptions in the central North Island, and erosion and deposition as a result of major storm events. The effects of these processes are imposed on the sea level response to Holocene climate change.

CONCLUSIONS

At Poverty Bay the coastal geologic processes over the last 4000 years of relatively stable sea level have been affected by tectonic events, and major storms producing erosion and flooding of the Poverty Bay flats. Some erosion may have been initiated by volcanic eruptions. Radiocarbon dates suggest correlation with tectonic, volcanic and storm events observed in areas adjacent to the Poverty Bay flats.

The testbore data has provided information on geologic processes that have affected coastal deposition at the Poverty Bay flats during the Holocene. Elevations of radiocarbon-dated shells show variations from the New Zealand eustatic sea level curve. These variations can be explained with a tectonic model dividing the Poverty Bay coast into three zones for post-6500 BP geologic processes: (1) a northern zone incorporating most of Gisborne city where tectonic uplift has occurred; (2) a central relatively stable zone where erosion and reworking of the Holocene post-6500 BP sediments occurred until 4000 BP; and (3) a southern zone where subsidence has predominated.

The other influence on coastal processes has been river deposition and the adjustment of fluvial processes to climate change, sea level change, and storm and possibly volcanic events. Tectonism is also likely to have affected fluvial processes. Adjustment by the Waipaoa River resulted in downcutting into gravel terraces and deposition of the gravel on the floodplain as a series of gravel channel deposits. The gravel channels underlie the Poverty Bay flats and form a network of confined aquifers. Three main periods of gravel deposition can be identified: (1) a late last glaciation series of gravel channels informally known as Matokitoki gravel deposited during low but rising sea level; (2) 11,000–9000 BP temperate climate rapidly rising sea level deposited gravel channels called the Makauri gravel; and (3) 7000–4000 BP Waipaoa gravel channels deposited during the rising and following stable sea level as a result of accelerated erosion in the Waipaoa River catchment and valley.

In terms of planning awareness of geologic hazard intensity, the Holocene geology provides a record of recurrent tectonic and flood events affecting the Poverty Bay flats, that exceed the intensity of historic earthquakes and floods. This should be considered for hazard mitigation planning.

This paper provides a case study of how hydrogeological data derived primarily from groundwater investigations can be applied to Quaternary coastal evolution and geologic hazard mitigation studies. This multiple use of data bases is particularly appropriate for countries where earth science research resources are limited.

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