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Te Horo beach groundwater investigation bores

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Te Horo Beach Groundwater Investigation Bores

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1.1 Introduction

In 1983 the Manawatu Catchment Board (MCB) commissioned the drilling of a bore to investigate the occurrence of groundwater aquifers at Te Horo Beach and to provide hydrogeological data relevant to the aquifer-aquiclude sequence penetrated by wells in Kapiti - Horowhenua district. The bore was part of the Horowhenua Regional Groundwater Investigation (HRGI) project. This project had begun in February 1982 following landowner concerns about the capacity of the groundwater resource to supply domestic, farm and stock water supply as a result of the drilling of wells for irrigation water for the rapidly expanding area of berry fruit (especially kiwifruit) production in the Hautere plains area. Several deep irrigation wells (to a maximum depth of 128 m) had recently been drilled. At the time local opinion was that the groundwater resource should be reserved for the “traditional” water use requirements and that irrigation water should be sourced from surface water sources such as the Otaki River.

Because central Government funding contributed to the HRGI, a Technical Advisory Group (TAG) was established to “steer” the investigation. Personnel from the MCB, New Zealand Geological Survey (Department of Scientific and Industrial Research) and Water and Soil Division, Ministry of Works and Development lent their expertise in groundwater and water resources to the project. The TAG’s first meeting was on 4 August 1982. One of the TAG’s first decisions was that a groundwater investigation bore be drilled. Keith Caldwell, the MCB engineer in charge of the HRGI supervised and co-ordinated the drilling and NZGS geologists logged the bores and collected strata and water samples for analyses.

The results of the drilling and the hydrogeological interpretations and their application to the groundwater resource are summarized in Kampman and Caldwell (1985). The detailed logging of the drilling and the results of the various determinations, analyses and tests carried out on the water and strata samples collected during the drilling operation have never been published. This report details the bore logging of NZGS geologists and presents the results of the examinations and analyses of the strata and water samples by DSIR scientists. This information is relevant to the present Wellington Regional Council investigations into the possibility of using groundwater from the aquifers underlying the Otaki River floodplain as a source of water supply for the Kapiti Coast to the south for the urban population of Waikanae and Paraparaumu.

1.2 Background

1.2.1 Geological setting

Te Horo Beach is coastwards of the Hautere Plain last glaciation surface and the postglacial marine transgression sea cliff terrace of the Otaki River floodplain. The present day floodplain landform and the sequence of the underlying strata is a product of geological processes during the last 400 000 years of the late Quaternary Period. During this time the main influence on late

Quaternary geological processes has been the climate change cycles that produced alternating cold glacial and temperate climatic conditions. Superimposed on the climate cycles are tectonic events. These events include uplift in the east in association with the isostatic uplift of the mountains of the Tararua Range and subsidence at the coast at the southeast margin of the Wanganui Basin (Anderton 1981).

During cold glacial periods there was increased erosion of the Tararua Range, in response to the lower altitude of the vegetation cover on the mountains and the exposure of the greywacke to weathering agents including ice and snow. The Otaki River transported and deposited the erosion debris as outwash fan deposits where its course emerged from the mountain valley at the Otaki Gorge. In temperate interglacial periods, vegetation re-established to higher altitudes and the river carried less eroded debris. Also, sea level rose and the sea transgressed over the coastal sector of the plain land surface. The Otaki River responded to the reduced sediment load by entrenching into the glacial outwash deposits at the inner margin of the floodplain and reworking gravel, sand and silt for deposition down stream.

1.2.2 Summary details

Wellington Regional Council well number: R25/8540049 (Deep or North); R25/0003 (Shallow or South).

Grid Reference: NZMS 260: R25/863444

Reduced Level Site: 8.2 m above ground surface.

Drilling Contractor: Richardson Drilling Company Limited, Palmerston North.

Drilling Methods: Cable tool using Bucyrus Erie 22W rig to 107.3 m;

Combination Rotary/Cable tool to EOH at 165.4 m.

Drillers: Graham Butler (cable tool) and Russel Gardiner (combination).

Drilling: 5 July 1983 – 23 September 1983 (cable tool); 25 October 1984 – 27 November 1984 (combination).

Logging: Len Brown assisted by Neville Smith, David Heron and Merrill Gray

1.2.3 Drilling site

The testbore is located at Te Horo Beach on the road reserve on the right-hand side of Sims Road going north about 50 m north of the bridge over the Mangaone Stream. The site was chosen because:

- it would provide information about the aquifer-aquiclude occurrence in an area where there were no deep wells;
- the coastal location enhanced the possibility of the testbore intersecting recognisable and datable “marker beds” such as peat, vegetation and shells in the interglacial and glacial sediments penetrated. These marker beds would allow correlation with the established regional geological history and stratigraphy;
- the testbore would provide water level, water quality and water yield data from the various aquifers encountered during drilling;

- the location was appropriate for the establishment of a permanent water level and water quality monitoring site;
- the coastal location also provided the opportunity to monitor groundwater chemistry for the possibility of seawater intrusion into the aquifers.

1.2.4 Construction

Drilling began on 5 July 1983 using a cable-tool percussion drilling rig. The drilling technique provided the most cost efficient method of obtaining relatively undisturbed samples of the strata penetrated. The casing diameter was 150 mm.

The drilling procedure varied depending on the compactness, sorting and water bearing properties of the strata. In “loose” strata conditions the casing was driven into the stratum and the sediments bailed from inside the casing using the sand pump. When the stratum was hard, as would occur when boulder size gravel deposits were being drilled, the chisel shaped bit would be used to break the cobbles and boulders into pieces that could be bailed by the sand pump. This work would be done below the bottom of the casing and a cavity would be formed. The casing was then driven and the broken and loosened sediment would be bailed from inside the casing and sometimes from the cavity at the base of the casing. Logging consisted of collecting and examining the sediment samples as they were emptied from the sand pump. The samples were only slightly disturbed and mixed by the drilling process except for “tight” strata where the sediments were reduced to a slurry by the drill bit. Drilling water was added as required as drilling proceeded. The cable tool drilling method facilitated precise logging of the sediments in terms of lithology and depth. The drilling method also provided an intimate contact with the strata in terms of the contained groundwater, so that the presence of aquifers and variations of water bearing properties within aquifers was instantly indicated to the driller.

At a depth of 60.5 m when 0.7 m into a “brown gravel poorly sorted up to 150 mm subrounded to subangular with some rust staining and a few black stained and light brown soft silty gritty sand” it became apparent that the casing was buckling and bending and drilling could not proceed. The decision was made to abandon the testbore and start again. The casing was left in the ground and the well would later be screened and developed and utilised as a monitoring well for the aquifer at 60 m depth. This well is known as the Sims Road south bore (well number R25/0003). The second testbore was located 2 m north of the original testbore and a larger 200 mm diameter casing was used to allow more robust drilling and driving of the large and “tight” gravel encountered. The second testbore was drilled to a depth of 107.3 m by 23 September 1983. Drilling stopped while the decision to fund deeper drilling was debated.

On 25 October 1984 drilling resumed using the same cable-tool percussion rig. At a depth of 109 m a “grey gravel poorly sorted up to boulder size (300 mm) angular to subangular with some brown staining and poorly sorted tight coarse to fine sand, yellow-brown silt and clay” was encountered. It soon became apparent that this strata was too ‘tight’ for the cable tool drilling method to achieve reasonable progress. The drilling rig was changed to a rotary-cable tool

percussion combination rig and drilling continued with rotary drilling out in front of the casing to loosen the strata and provide a cavity for driving the casing. The rotary drilled fragments and chips were bailed from the casing with the sand pump. At 118 m the strata became looser and this drilling method achieved good progress. At a depth of 165.4 m rotary drilling was stopped in a water bearing gravel at the base of what is thought to be marine interglacial strata. The testbore was continued into the water bearing gravel to a depth of 172 m using the cable tool drilling method. The well was screened and developed and is known as the Sims Road north bore (well number R25/8540049).

1.2.5 Well log

The detailed well log as logged during drilling is given in Appendix 1. Lithology descriptions and nomenclature is as recommended in Brown (1990). In the log lithology descriptions the dominant lithology is given first and secondary and other lithology component descriptions follow.

Samples Collected

Lithologic samples

Table 1: List of lithological samples collected

Sample no. = FR no.	Depth (m)	Material	Sent to
R25/f2	5.0 – 5.4	Peat	
3	17.5	Shell	Macrofauna/Radiocarbon
4	18.5	Shell	Macrofauna/Radiocarbon
5	19.5	Shell	Macrofauna
6	20.5	Shell	Macrofauna
7	24.5	Shell	Macrofauna
8	25.5	Shell	Macrofauna
9	27.5	Shell	Macrofauna
10	28.5	Shell	Macrofauna
11	29.5	Shell	Macrofauna
12	30.5	Shell	Macrofauna
13	31.5	Shell	Macrofauna
14	32.2	Shell	Macrofauna
15	32.5	Shell	Macrofauna
16	33.0	Shell	Macrofauna/Radiocarbon
17	33.5	Shell	Macrofauna/Radiocarbon
18	17.5	Shell	Macrofauna
19	18.0	Shell	Macrofauna
20	18.5	Shell	Macrofauna
21	19.0	Shell	Macrofauna
22	19.5	Shell	Macrofauna
23	20.0	Shell	Macrofauna
24	20.5	Shell	Macrofauna
25	21.0	Shell	Macrofauna
26	21.5	Shell	Macrofauna
27	22.0	Shell	Macrofauna

28	22.5	Shell	Macrofauna
29	23.0	Shell	Macrofauna
30	23.5	Shell	Macrofauna
31	24.0	Shell	Macrofauna
32	24.5	Shell	Macrofauna
33	25.0	Shell	Macrofauna
34	25.5	Shell	Macrofauna
35	26.0	Shell	Macrofauna
36	26.5	Shell	Macrofauna
37	27.0	Shell	Macrofauna
38	27.5	Shell	Macrofauna
39	28.0	Shell	Macrofauna
40	28.5	Shell	Macrofauna
41	29.0	Shell/peat	Macrofauna/Microflora
42	29.5	Shell	Macrofauna
43	30.0	Shell	Macrofauna
44	30.5	Shell	Macrofauna
45	31.0	Shell	Macrofauna
46	31.5	Shell	Macrofauna
47	32.0	Shell	Macrofauna
48	32.5	Shell	Macrofauna
49	33.0	Shell	Macrofauna
50	33.5	Shell	Macrofauna
51	34.0	Shell	Macrofauna
52	34.5	Shell	Macrofauna
53	74.0 - 75.0	Carbonaceous	Microflora/Radiocarbon
54	99.5	Shell	Macrofauna
55	100.0	Shell	Macrofauna/Radiocarbon

56	100.5	Shell	Macrofauna
57	101.0	Shell	Macrofauna
58	101.3	Shell	Macrofauna
59	101.5	Shell	Macrofauna
60	101.8	Shell	Macrofauna
61	102.2	Shell	Macrofauna
62	102.5	Shell	Macrofauna
63	102.8	Shell	Macrofauna
64	103.2	Shell	Macrofauna
65	103.5	Shell	Macrofauna
66	104.0	Shell	Macrofauna
67	104.5	Shell	Macrofauna
68	105.0	Shell	Macrofauna
69	105.6	Shell	Macrofauna
70	106.6	Shell	Macrofauna
71	107.3	Shell	Macrofauna
72	160.0	Shell	Macrofauna
73	108.0	Shell	Macrofauna

1.2.6 Lithostratigraphic units

Various workers have recognised, mapped and defined a wide range of lithostratigraphic units for the Quaternary age strata forming and underlying the Manawatu, Horowhenua and Kapiti coastal plains. These units range from deposits related to specific geologic events: Taupo (Pumice) Dunesand (Fleming 1972) to the Otaki Sandstone (Oliver 1948), encompassing the last interglacial period. Most of these units are summarised by Fleming (1970 and 1972). Water wells also penetrate lithostratigraphic units that have not been described locally but can be correlated with the late Quaternary climate stages of Suggate (1985) and the interglacial Wanganui units of Pillans (1990). These correlations are established by shell deposits that are indicative of high sea level interglacial periods and palynology that provides information on the climate at the time of deposition. Gravel strata are generally devoid of material that contains fossils and is mainly assumed to have been deposited during low sea level glacial periods.

During the process of logging and sampling strata penetrated by the Te Horo Beach groundwater exploration bores, additional information has been acquired that is relevant to the lithostratigraphy and hydrogeology of the Horowhenua – Kapiti districts. This information is also incorporated in the identified lithostratigraphic units for the Te Horo Beach exploration bore. These are as follows:

Postglacial Deposits (Aranuian Stage)

These sediments accumulated during the last 14 000 years when the world climate became warmer at the end of the last glaciation. As ocean ice sheets and land ice caps melted, and glaciers receded, sea level rose and the sea transgressed over the former land surface. About 6 500 years ago sea level stabilised at close to present level having risen over 140 m in 7 500 years (Gibb 1986). From Te Horo north to the Otaki River, and immediately to the west of State Highway 1, a prominent sea cliff cut into the last glaciation gravel deposits marks the maximum inland extent of the postglacial sea. During the next 6 500 years of relatively stable sea level the coast built out, or prograded, as sand dunes and interdunal swamps and beach sand deposits accumulated. By about 4 000 years before present the coastline had reached its current location.

The location of the coastline is dependant on the delicate balance between coastal progradation and erosion. This balance is affected by several factors: earthquake activity producing tectonic uplift or subsidence and tsunami; removal of vegetation cover on the coastal sand dunes can initiate wind and wave erosion; natural (volcanic eruption) and man-induced (forest clearing) activities in the catchments of local and distant rivers such as the Otaki, Manawatu, Rangitikei and Wanganui rivers, can affect the sediment load carried to the coast and influence coastal progradation and erosion processes.

The Te Horo Beach testbore penetrated postglacial deposits to 34.5 m depth. From ground level to 16.5 m these are beach, sand dune and interdune or coastal swamp deposits. Gravel clasts are interspersed throughout these deposits and are probably derived from high flows and major floods of the Otaki River. These sediments would include Waitarere Dunesand attributed to dune activity following European settlement (Cowie 1963), Motuiti Dunesand attributed to dune activity following Polynesian settlement (Cowie 1963), Taupo Dunesand (Fleming 1972) containing pumice derived from the Taupo eruption about 1860 years BP (140 years AD), Paraparamu Peat (Fleming 1970) and the postglacial progradational Foxton Dunesand (Cowie 1963).

From 16.5 to 34.5 m postglacial marine deposits were penetrated. These deposits comprise the postglacial progradational marine Paripari Formation (Fleming 1972) and the postglacial transgressional marine Kenakena Formation (Fleming 1972). A total of 48 samples were collected from these formations during the drilling of the Te Horo Beach testbore. Depositional paleoenvironments and radiocarbon dates were obtained (see Appendices). Dr Alan Beu's determinations identify deposition in shallow water to a maximum depth of 20 m off an open ocean sandy beach. Radiocarbon dates show deposition occurred from about 7000 to 4000 years BP with only progradational Paripari Formation deposits represented. The lack of Kenakena

Formation sediments suggests that the high energy open beach depositional environment resulted in the transgression marine deposits being eroded before the progradational marine deposits accumulated.

During the postglacial period the Otaki River depositional processes would be predominantly downcutting and entrenchment into the last glaciation floodplain as the river adjusted to the rising sea level and shortening of its course. Once sea level stabilised and the coast prograded, river processes changed to aggradation and overbank flooding within the relatively narrow confines of the terraces bounding the present day river bed. On the south bank of the Otaki River inland of the postglacial sea cliff, the undulating surface of the last glaciation floodplain strewn with gravel up to boulder size, was probably formed by flood channels from the Otaki River originating down stream of the Otaki Gorge in early postglacial time. These temporary channels periodically downcut into the floodplain surface until the main river channel became sufficiently entrenched to prevent overbank flooding.

Last Glaciation Deposits (Otiran Stage)

These deposits accumulated about 70 000 – 14 000 years ago during the predominantly cold climate of the last glaciation when sea level was up to 120 m below present sea level and the North and South Islands were connected by an isthmus between D’Urville Island (western Marlborough Sounds) and the Kapiti-Horowhenua area (Te Punga 1953). The sediments are mainly poorly sorted river gravel, sand and silt deposited by the Otaki River with a catchment in the Tararua Ranges and local creeks and streams derived from the western slopes of the ranges. Gravel derived from more distant sources including South Island igneous and schistose rock types (Te Punga 1953) and the catchments of other rivers flowing into the Wanganui Bight (Wanganui, Rangitikei and Manawatu rivers) could also be present. Interbedded sediments including carbonaceous material, possibly associated with warmer climate intervals (interstadials) within the glacial period, and wind blown fine silt (loess) are identified.

Fleming (1972) records several lithostratigraphic units encompassing the last glaciation – Te Waka Dunesand, Judgeford Loess, Parata Gravels, Matenga Fanglomerate, Tini Loess and Waimahoe Lignite. The ages of these units are loosely constrained by radiocarbon dates and only the carbonaceous Waimahoe Lignite can be recognised in the sediments penetrated by water wells in the Kapiti – Horowhenua area. The Waimahoe Lignite probably accumulated during a period of warmer climate (interstadial) about 30 – 40 000 years ago. A similar extensive last glaciation interstadial carbonaceous deposit has been identified from well logs and well samples beneath the Hutt Valley (Brown & Jones 2000) and Wainuiomata Valley (Begg et al. 1993). A sample of carbonaceous material from a depth of 74.5 m in the testbore was submitted to Dr D.C. Mildenhall, NZ Geological Survey for microflora examination. The sample contained pollen and spores that were too poorly preserved to permit identification and palaeoenvironment determination. Wood from this same sample was radiocarbon dated at 36 900 years (NZ 6574) (see Appendix 4).

In this report, last glaciation gravel deposits penetrated by the testbore overlying the Waimahoe Lignite are correlated with the Parata Gravels and are the equivalent of the Ohakean terrace and alluvium deposits originally mapped by Te Punga (1952) in the Rangitikei Valley and now mapped throughout the Wanganui – Manawatu region (Begg & Johnston 2000). The gravels underlying the Waimahoe Lignite are correlated with the Rangitikei Valley Rata terrace and alluvium deposits of Te Punga (1952).

Last Interglacial Deposits (Kaihinuan Stage)

In the Horowhenua district, marine sediments deposited during the high sea levels associated with the last interglacial period are correlated with the Otaki Formation of Oliver (1948). The Otaki Formation is mainly beach and dune sand and forms a surface outcrop deposit composed predominantly of sand (Otaki Sandstone). Its occurrence and preservation is a result of tectonic uplift. Further north along the western margin of the Tararua Range this surface is known as the Tokomaru marine surface (Sewell 1991, Taylor et al. 2001). It is an undulating surface cut by past and present streams, underlain by a brown-weathered sandstone up to 45 m thick (McLarin et al. 1999).

The test bore penetrated sand of the Otaki Formation at 89.5 to 107.3 m. From 99.5 m, the sediments were grey silty sand with shells and wood fragments. These deposits accumulated about 70 000-125 000 years ago. The shell assemblages (Appendix 2) show a transition of depositional palaeoenvironment from shallow sand beach to offshore (10-30 m depth) sandy beach and back to shallow open ocean sandy beach. During the last interglacial Kapiti Island and another offshore island at Poroutawhao just north of Levin, would have provided some protection for the mainland coast from marine erosion processes (Sewell 1991). The latter island (Levin anticline of Te Punga (1956)) is now buried beneath postglacial dune, lagoon and beach sand deposits. A water well drilled in 1984 on the property of Peter Bartholomew, Waitarere Beach Road near trig Piha (S25/006678), encountered greywacke at 17 m below ground level (about 3 m above sea level) and possibly is the highest point of the now buried island.

Te Punga (1962) describes an interbedded carbonaceous bed within Otaki Sandstone in a section exposed in Waterfall Stream near Otaki. Fleming (1972) designated this bed Awatea Lignite. This layer is the peaty sand bed in the well log (Manawatu Wanganui Regional Council well no. 372009) presented in Figure 3, McLarin et al. (1999) that is incorrectly labeled Waimahoe Lignite. Several peat and vegetation layer samples (Awatea Lignite) from within Otaki Sandstone outcrops and from water wells have been examined for pollen and spore content. The results of these analyses are listed in Appendix 3. Awatea Lignite was not present in the Otaki Formation strata penetrated by the Te Horo Beach test bore.

Penultimate Glaciation Deposits (Waimean Stage)

Gravel deposits forming an alluvial fan remnant and exposed in creek beds to the east of State Highway 1 near Pukehou just north of Otaki, were mapped by Sewell (1991) as penultimate glaciation Waimean Stage and informally named

Pukehou formation. These gravel deposits consist of blue-grey gravel clasts commonly interbedded with carbonaceous peat and wood debris within the sandy silt matrix. Water well logs typically describe a range of lithologies including blue clay, fine blue sand, blue peaty sand, grey clayey silty sand, or fine grey sand. The blue and grey colours are a distinguishing feature of the Pukehou formation. Pukehou formation was penetrated by the Te Horo test bore from 107.3 to 146 m.

Penultimate Interglacial Deposits (Karoroan Stage)

Brown and blue sandy silt and sand with shells, wood fragments and gravel, were penetrated by the Te Horo test bore from 146 to 165.4 m. Because of the rotary drilling method shells were broken beyond recognition and only one sample was submitted for macrofauna palaeoenvironment determination (R25/f72 – Appendix 2). The only identifiable specimen – *Paphies* sp (? Tuatua) – suggested accumulation in a shallow water marine environment off a sandy ocean beach. These strata are tentatively correlated with deposition during the Karoro penultimate interglacial period.

Deeper Strata

From 165.4 to 172m, where drilling stopped, the Te Horo test bore penetrated water bearing brown gravel. Based on the lithostratigraphic subdivision of the overlying strata this brown gravel is tentatively correlated with Waimaungan glacial stage.

Basement rock is greywacke. Well 381161) located in Arcus Road, Te Horo (map reference S25/902425) about 5 km inland of the Te Horo Beach test bore, encountered greywacke rock at 192 m below ground level (Wellington Regional Council 1994). This depth suggests that at the Sims Road site greywacke might be about 220 m below ground level. The 50 m of strata from the bottom of the test bore to basement might include marine deposits associated with the Scandinavian Interglacial (Suggate 1985) penetrated by deep water wells on the Manawatu Plain as far inland as Palmerston North (Taylor et al. 2001).

Hydrogeology

Unfortunately financial constraints for the Te Horo Beach test bore necessitated that the drilling rate be maximised to fit a time schedule. This schedule precluded delaying drilling progress to test the water bearing properties of the aquifers encountered as the wells were drilled. However the test bore provided detailed information on the sequence of strata, aquifers and aquicludes to allow correlation with the New Zealand geologic and climatic stages and the development of a stratigraphic lattice for establishing the regional hydrogeology. This information provided the basis for the conceptual model of the Coastal and Hautere groundwater zones proposed by Kampman and Caldwell (1985) and developed by Wellington Regional Council (1994).

The Coastal groundwater zone extends from the terrace running alongside the Otaki River in the north to Peka Peka and Hadfield Roads in the south and

joins the Hautere groundwater zone in the east. The Hautere groundwater zone includes most of the Hautere Plain. This area is composed of fluvial outwash deposited during the last (Otiran) glaciation. In the north the plain forms a high terrace along the edge of the Otaki River. The Hautere groundwater zone extends east and south to the Tararua Range foothills.

Kampman and Caldwell (1985) and Wellington Regional Council (1994) identify four aquifer systems that can be grouped in terms of lithostratigraphy as follows:

- 1) An unconfined to partially confined aquifer system about 5 – 30 m below ground level and composed of postglacial brown and blue beach sand and gravel westwards of the postglacial marine transgression 6 500 year BP sea cliff and last glaciation brown and blue fluvial gravel inland from the cliff. Groundwater chemistry is characterised by high variability of parameters both spatially and with depth. Localised high nitrate-nitrogen levels may be a result of land use practices. Both local and coastal rain, and higher altitude catchment derived water contribute to groundwater recharge and groundwater flow in relatively rapid compared to deeper aquifers (Appendix 5). Transmissivities are generally less than 100 m²/day in the coastal sector and 100 – 150 m²/day for the fluvial gravel aquifer sector. Piezometric contours presented in Wellington Regional Council (1994) (Figure 24.4) show groundwater movement toward the coast and the Otaki River terraces. The gradient is relatively steep adjacent to the Tararua Range foothills as indicated by closer contours. The contours widen out towards the Otaki River and the postglacial marine transgression sea cliff, indicating reduced gradients and groundwater velocities. Springs occur in the area where the contours widen out as a result of impeded groundwater flow. The average daily discharge from nine identified springs at the foot of the sea cliff ranges from 600 to 7000 m³/day (Cussins 1994).
- 2) A confined, mainly blue and brown fluvial gravel aquifer system 30 - 70 m below ground level. This system is last glaciation gravel (Parata Gravels) that may have undergone reworking and sorting at the time of the warming associated with the interstadial when the Waimahoe Lignite accumulated. High iron and manganese are associated with wells in the 30 – 70 m aquifers. Transmissivities range from 50 – 150 m²/day and tend to decrease inland. Local rain and higher altitude catchment derived water contribute to groundwater recharge. Tritium measurements show a significant proportion of the groundwater in the deeper aquifers (last glaciation and older) has been present in the aquifers for at least 30 years suggesting a slow through flow of groundwater at depth.

Last glaciation water bearing gravels underlying the Waimahoe Lignite form what appears to be a low yielding aquifer on a regional scale, although locally there are a few sporadic higher yielding wells possibly deriving groundwater from reworked gravel channel deposits.

- 3) A confined penultimate glaciation (Waimean) blue and blue-brown gravel and sand aquifer system 60 – 100 m below ground level correlated with the informal Pukehou formation underlies the last interglacial Otaki Sandstone.

Total hardness and conductivity is higher than for the overlying aquifers as a result of higher concentrations of most of the measured range of anions and cations apart from iron and manganese. High levels of boron can cause problems when the groundwater is used for irrigation of crops such as kiwi fruit the foliage of which is sensitive to boron. Limited test pump data gives transmissivities in a range from 50 – 150 m²/day. Local rain and higher altitude catchment derived water contribute to groundwater recharge. Tritium measurements show a significant proportion of the groundwater in the deeper aquifers (last glaciation and older) has been present in the aquifers for at least 30 years suggesting a slow through flow of groundwater at depth.

- 4) A few wells including the deep Te Horo Beach test bore (Sims Road north bore – well no. R25/8540049) tap groundwater in a confined Waimaungan glaciation brown gravel aquifer 110 – 172 m below ground level. Total hardness and conductivity is higher than for the overlying aquifers as a result of higher concentrations of most of the measured range of anions and cations apart from iron and manganese. High boron concentrations are a major constraint for use of groundwater for irrigation. Tidal analyses for well R25/8540049 indicate a transmissivity of 117 m²/day and a storage coefficient of 10⁻⁵ (see Appendix 6) and further inland transmissivities can be higher. Tritium measurements show groundwater has been present in the aquifer for at least 50 years.

The aquifer groups identified in the Te Horo Beach – Hautere district would be expected to extend south beneath the Kapiti Coast district. They are present to the north beneath the Horowhenua district and the Manawatu Plains.

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Gridref: 2686347.6044408

Ground Level Altitude +MSD

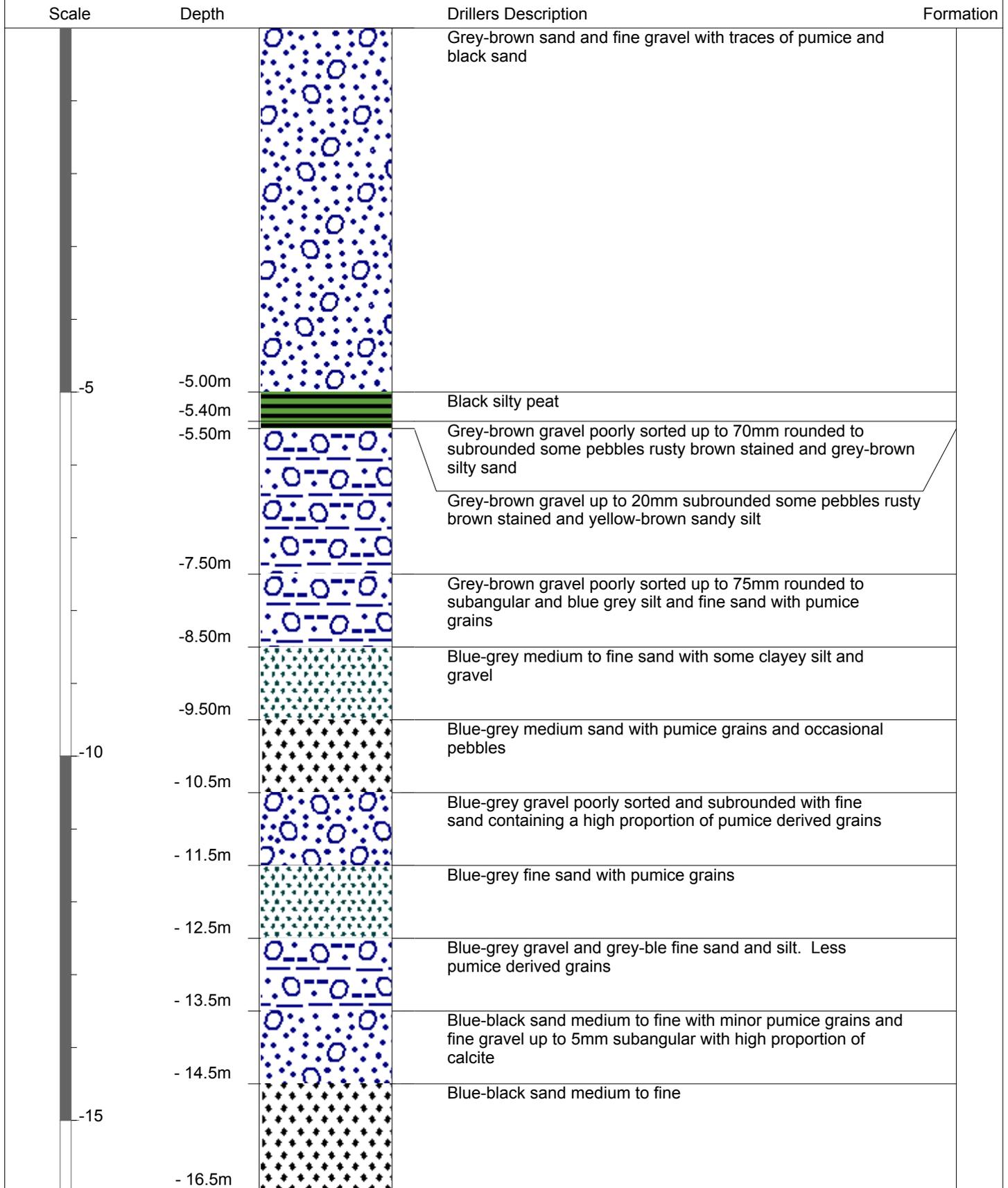
Driller : RICHARDSON DRILLING COMPANY LTD

Drill Method: Cable Tool

Drill Depth : 172m Drill Date : 23/09/1983



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Scale	Depth	Drillers Description	Formation
	- 16.5m	Blue-black sand medium to fine	
	- 17.5m	Blue-black sand medium to fine with small subrounded gravel and shell fragments including "sand dollar"	
	- 18.5m	Blue-black medium to fine with small subrounded gravel and shells either fragments or whole gastropods	
	- 19.5m	Blue-black sand fine with shell fragments	
-20	- 20.5m	Blue-black sand fine sand and silt with minor shell fragments	
	- 23.5m	Blue-black medium to fine sand and sparse shell fragments	
	- 24.5m	Blue-black fine sand and shell fragments	
-25	- 25.5m	Blue-black fine sand and silt with shell fragments	
	- 26.5m	Blue-black fine sand and silt and sparse shell fragments	
	- 27.5m	Blue-black very fine sand and silt with shell fragments	
	- 28.5m	Blue-black medium to fine sand and silt with shell and wood fragments	
	- 29.5m	Blue-black silt and very fine sand with shell and wood fragments	
-30	- 32.2m	Blue-black fine sand and silt with shell and wood fragments	

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Scale	Depth	Drillers Description	Formation
	- 32.2m	Blue-black fine sand and silt with shell and wood fragments	
	- 32.5m	Blue-black medium to fine grained sand and silty clay with shells and wood fragments	
	- 33.0m	Blue-black fine sand, gravel up to 20mm subrounded to angular and silty clay with shell fragments	
	- 33.5m	Blue-black very fine sand, silt and gravel up to 25mm rounded to subrounded with shell fragments	
	- 34.2m	Blue gravel up to 50mm angular to subrounded and blue-black silty fine sand with sparse shell fragments	
	- 34.5m	Blue-brown gravel up to 25mm subrounded to angular with brown staining and some reddy volcanic rock sourced metamorphosed pebbles, coarse gritty sand, shell fragments and clay	
-35	- 35.5m	Blue coarse gritty sand and clay, with gravel up to 80mm subrounded and often brown stained with shell fragments	
	- 36.5m	Brown-grey gravel poorly sorted up to 40mm subrounded to subangular mostly loose some layers brown clay/grit bound	
	- 37.5m	Brown gravel up to 40mm subrounded to subangular and brown clayey grit	
	- 37.7m	Brown gravel poorly sorted up to 70mm and coarse sand and clay	
	- 38.5m	Brown gravel poorly sorted up to 60mm rounded to subangular and gritty clay	
	- 38.6m	Brown-grey gravel poorly sorted up to 70mm subrounded to subangular and some clay	
-40	- 39.5m	Brown-grey gravel poorly sorted up to 60mm subrounded to subangular and gritty clay bound	
	- 39.7m	Brown gravel poorly sorted up to 60mm subrounded to subangular and coarse sand and gritty clay	
	- 41.0m	Brown gravel poorly sorted up to 70mm subrounded to subangular occasional brown stained and some clay	
	- 42.2m	Brown gravel subangular and often rust stained and silty clay and coarse to fine sand	
	- 42.8m	Brown gravel and clayey gritty silt	
	- 43.2m	Brown gravel up to 60mm and gritty silt	
	- 43.5m	Brown gravel up to 40mm rounded with hard gritty clay. Slow drilling	
	- 44.5m	Brown-grey gravel subangular to angular and gritty clay bound	
-45	- 45.5m	Dirty brown gravel angular and coarse sandy clay	
	- 46.5m	Grey-brown gravel up to 70mm subrounded to subangular and gritty silty clay bound	
	- 47.5m	Brown gravel up to 40mm subrounded to subangular and gritty clay bound	
	- 48.5m	Grey-brown gravel gritty clay bound	
	- 48.5m	Brown sand coarse to grit and gravel up to 30mm subangular and slight clay	

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Scale	Depth	Drillers Description	Formation
-48.5m	-48.5m	Brown sand coarse to grit and gravel up to 30mm subangular and slight clay	
	-49.5m	Brown gravel up to 60mm angular to subangular brown coarse to grit sand and slight clay	
-50	-49.5m	Brown gravel up to 60mm angular to subangular and brown coarse to grit sand and clay bound	
	-51.5m	Brown sand medium to coarse to grit with gravel cobbles up to 150mm	
-51.5m	-51.5m	Brown sand medium to coarse to grit with gravel and clay	
	-52.5m	Brown sand medium to coarse to grit with gravel and clay	
-53.5m	-52.5m	Brown sand medium to coarse to grit with gravel and clay	
	-53.5m	Brown gravel poorly sorted up to 150mm angular with some rust staining and gritty clay bound	
-55	-55.5m	Brown gravel up to 40mm rounded with some brown-red staining and brown gritty sand	
	-55.6m	Brown gravel up to 30mm rounded to subangular and sandy clay bound	
-56.5m	-56.5m	Brown gravel up to 30mm rounded to subangular and sandy clay bound	
	-57.0m	Brown gravel up to 20mm subrounded to angular and gritty clay bound	
-57.5m	-57.0m	Brown gravel up to 20mm subrounded to angular and gritty clay bound	
	-57.5m	Brown gravel up to 50mm rounded to subrounded and coarse sand and slight clay	
-58.3m	-57.5m	Brown gravel up to 50mm rounded to subrounded and coarse sand and slight clay	
	-58.3m	Brown gravel coarse rounded to subrounded with rust staining and a few black stained and sandy gritty clay	
-59.5m	-58.3m	Brown gravel coarse rounded to subrounded with rust staining and a few black stained and sandy gritty clay	
	-59.5m	Brown gravel up to 100mm subrounded with rust and black staining and slight gritty soft brown clay	
-60	-59.5m	Brown gravel up to 100mm subrounded with rust and black staining and slight gritty soft brown clay	
	-59.8m	Brown gravel poorly sorted up to 80mm subrounded to subangular with some rust staining and a few black stained and light brown soft silty gritty clay bound	
-60.5m	-59.8m	Brown gravel poorly sorted up to 80mm subrounded to subangular with some rust staining and a few black stained and light brown soft silty gritty clay bound	
	-60.5m	Brown gravel poorly sorted up to 150mm subrounded to subangular with some rust staining and a few black stained and light brown soft silty gritty sand	
-61.0m	-60.5m	Brown gravel poorly sorted up to 150mm subrounded to subangular with some rust staining and a few black stained and light brown soft silty gritty sand	
	-61.0m	Brown gravel up to 40mm angular and gritty clay and slight sand	
-61.5m	-61.0m	Brown gravel up to 40mm angular and gritty clay and slight sand	
	-61.5m	Brown-grey gravel up to 60mm rounded to angular and gritty clay and slight sand	
-62.5m	-61.5m	Brown-grey gravel up to 60mm rounded to angular and gritty clay and slight sand	
	-62.5m	Brown gravel well sorted up to 6mm and light brown gritty clay	
-63.5m	-62.5m	Brown gravel well sorted up to 6mm and light brown gritty clay	
	-63.5m	Brown sandy grit with occasional gravel up to 30mm angular	
-64.5m	-63.5m	Brown sandy grit with occasional gravel up to 30mm angular	
	-64.5m	Brown gravel up to 60mm subrounded to angular and clay bound	

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Ground Level Altitude +MSD

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Scale	Depth	Drillers Description	Formation
	- 64.5m	Brown gravel up to 60mm subrounded to angular and clay bound	
	- 65.0m	Brown gravel up to 100mm subrounded with rust and black staining and slight sandy silt	
	- 65.5m	Brown gravel up to 160mm rounded and medium to coarse gritty sand and slight clay	
	- 66.5m	Grey-brown gravel up to 60mm rounded and fine to medium sandy grit and clay	
	- 66.8m	Brown gravel fine to medium and silty clay bound	
	- 67.5m	Brown gravel up to 40mm and gritty silty clay	
	- 68.5m	Brown gravel fine and gritty sandy clay silt	
	- 69.5m	Brown gravel up to 40mm rounded with some black staining and silty clay	
	- 70.5m	Rusty brown gravel up to 60mm subangular and slightly clay bound	
	- 71.5m	Brown gravel well sorted up to 40mm angular and brown silty clay bound	
	- 72.5m	Brown gravel well sorted small up to 40mm and silty clay	
	- 73.5m	Brown-grey gravel up to 60mm with rust and black staining and sand	
	- 73.8m	Blue-grey well sorted gravel up to 50mm rounded and sand and clay	
	- 74.0m	Blue-grey silty clay and small gravel and wood fragments	
	- 74.5m	Grey silty clay tight and peat	
	- 75.5m	Grey-brown gravel up to 80mm rounded with rust staining and grey clayey silt	
	- 76.5m	Brown gravel up to 50mm with rust staining and sandy clay bound	
	- 77.5m	Brown sand and a few gravels up to 40mm and slight clay	
	- 78.5m	Brown gravel with black and rust staining and sandy gritty clay	
	- 79.5m	Brown-grey gravel up to 100mm mostly 10 - 20mm rounded and brown clay bound	
- 80.5m	Brown-grey gravel up to 100mm mostly 10 - 20mm rounded and brown silty clay bound		

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Ground Level Altitude +MSD

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Drill Method: Cable Tool

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Scale	Depth	Drillers Description	Formation
-85	- 80.5m	Brown-grey gravel up to 100mm mostly 10 - 20mm rounded and brown silty clay bound	
		Brown gravel and sand and slight clay	
	- 81.5m		
		Brown gravel silty clay bound	
	- 82.5m		
		Brown gravel up to 80mm several quartz pebbles and clayey silt bound	
	- 83.5m		
		Brown-grey gravel up to 100mm and brown gritty clay	
	- 84.5m		
		Brown gravel up to 70mm rounded and clayey silt	
	- 85.5m		
		Brown gravel well sorted mainly 20 - 40mm and up to 60mm subrounded and slightly silty clay bound	
	- 86.5m		
		Brown gravel medium to coarse and tight silty clay bound	
- 87.5m			
	Brown gravel up to 150mm with rust and black staining and tight rusty brown silty clay bound		
- 88.1m			
- 88.5m			
	Grey-brown gravel up to 50mm subrounded and light-brown siltstone (?loess) showing bedding with grey-brown streaks and bands of small gravels		
- 89.5m			
	Grey-brown gravel up to 60mm subrounded and sand		
- 90.5m			
	Grey-brown sand medium to fine with occasional small rounded gravel		
- 90.5m			
	Grey-brown sand dune sand texture		
- 94.5m			
	Grey-brown sand fine		
- 95.5m			
	Grey sand fine		
- 96.5m			

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Scale	Depth	Drillers Description	Formation
	- 96.5m	Grey sand fine	
	- 97.5m	Grey sand and rare small pieces of wood	
	- 98.5m	Grey sand fine	
	- 99.5m	Grey sand fine with shell and wood fragments and grey clay	
	- 100.1m	Grey silty sand with many shells and some wood fragments	
-100	- 100.5m	Grey silty sand with many shells and some wood fragments and gravel rounded sandstone	
	- 101.3m	Grey silty sand with many shells and some wood fragments and sandstone (cemented sand) with carbonaceous streaks and a barnacle colony	
	- 101.5m	Grey sand with a few shells and sandstone pebbles and clay	
		Grey sand with shells and clay	
	- 107.3m	Blue-grey gravel poorly sorted up to cobble size (60mm) angular to subangular with some brown staining and poorly sorted coarse to fine sand, yellow-brown silt and clay with shells and fragments of wood	
	- 109.0m	Grey gravel poorly sorted up to boulder size (300mm) angular to subangular with some brown staining and poorly sorted tight coarse to fine sand, yellow-brown silt and clay	
-110	- 118.0m		

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Scale	Depth	Drillers Description	Formation
		Grey gravel poorly sorted up to boulder size (300mm) angular to subangular with some brown staining and poorly sorted tight coarse to fine sand, yellow-brown silt and clay	
	- 118.0m	Grey gravel poorly sorted up to 300mm subangular to rounded with some brown staining and poorly sorted coarse to fine sand, yellow-brown-grey silt and clay possibly in layers	
	- 125.0m	Grey gravel poorly sorted up to 300mm subangular to rounded with some brown staining and yellow-grey clayey silt and sand	
	- 127.0m	Grey gravel poorly sorted up to 60mm subrounded to subangular with some brown staining and slight yellow silt and clay	
	- 129.5m		

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Scale	Depth	Drillers Description	Formation
		Grey gravel poorly sorted up to 60mm subrounded to subangular with some brown staining and slight yellow silt and clay	
	- 129.5m	Grey gravel poorly sorted up to 20mm subrounded to subangular with some brown staining and firm yellow-brown silty clay	
	- 130.7m	Yellow silty clay stiff and gravel up to 20mm	
	- 131.0m	Brown-grey fine sand with brown gravel up to 20mm including a few pumice pebbles and yellow silty clay to grey-brown-black clay	
	- 132.0m	Brown fine sand with brown gravel up to 20mm subrounded to rounded and some pumice granules	
	- 135.0m	Brown fine sand with small gravel	
	- 137.0m	Brown fine sand with a few small pea (3mm) gravel granules	
	- 144.0m		

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Ground Level Altitude +MSD

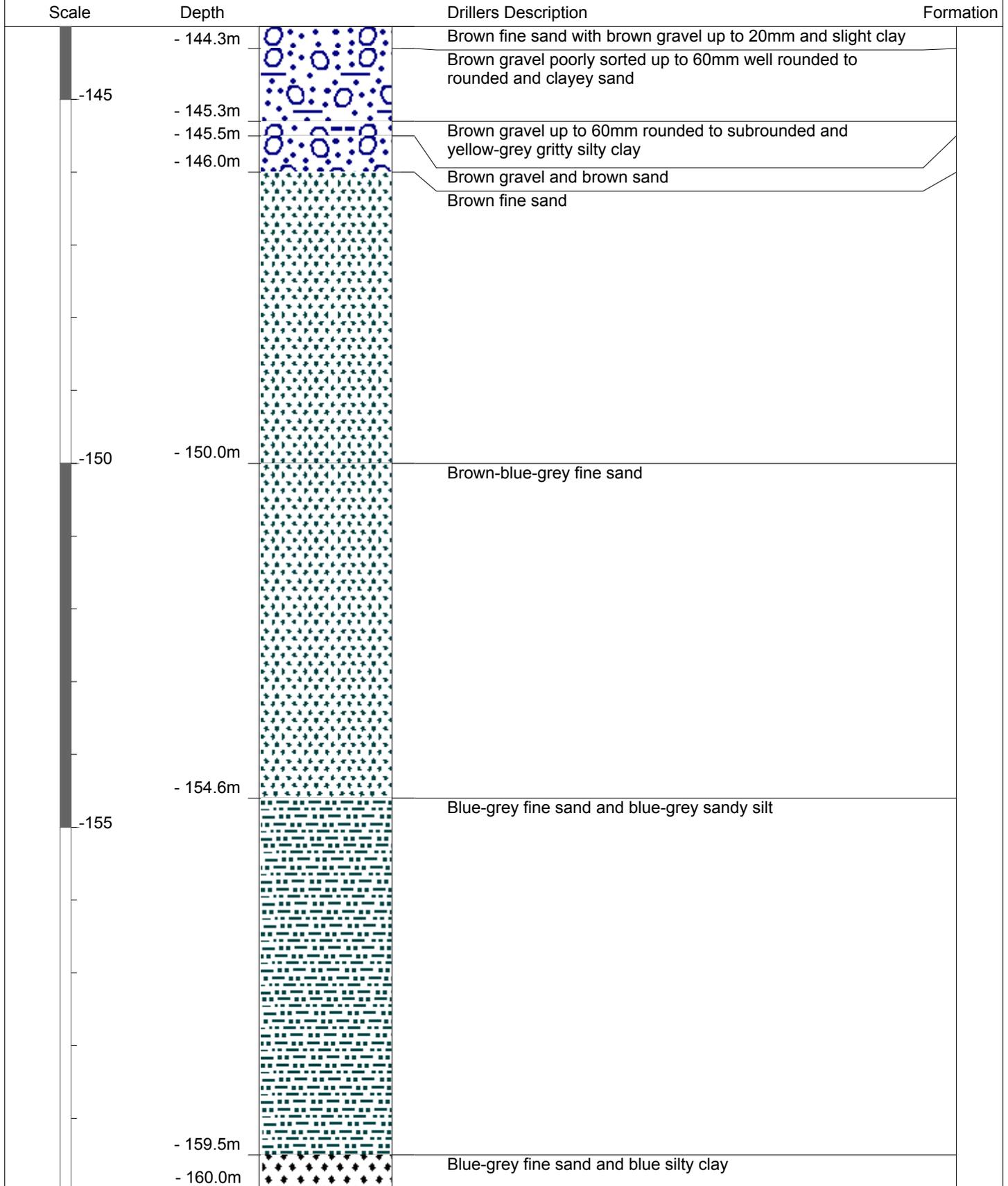
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Drill Method: Cable Tool

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Ground Level Altitude +MSD

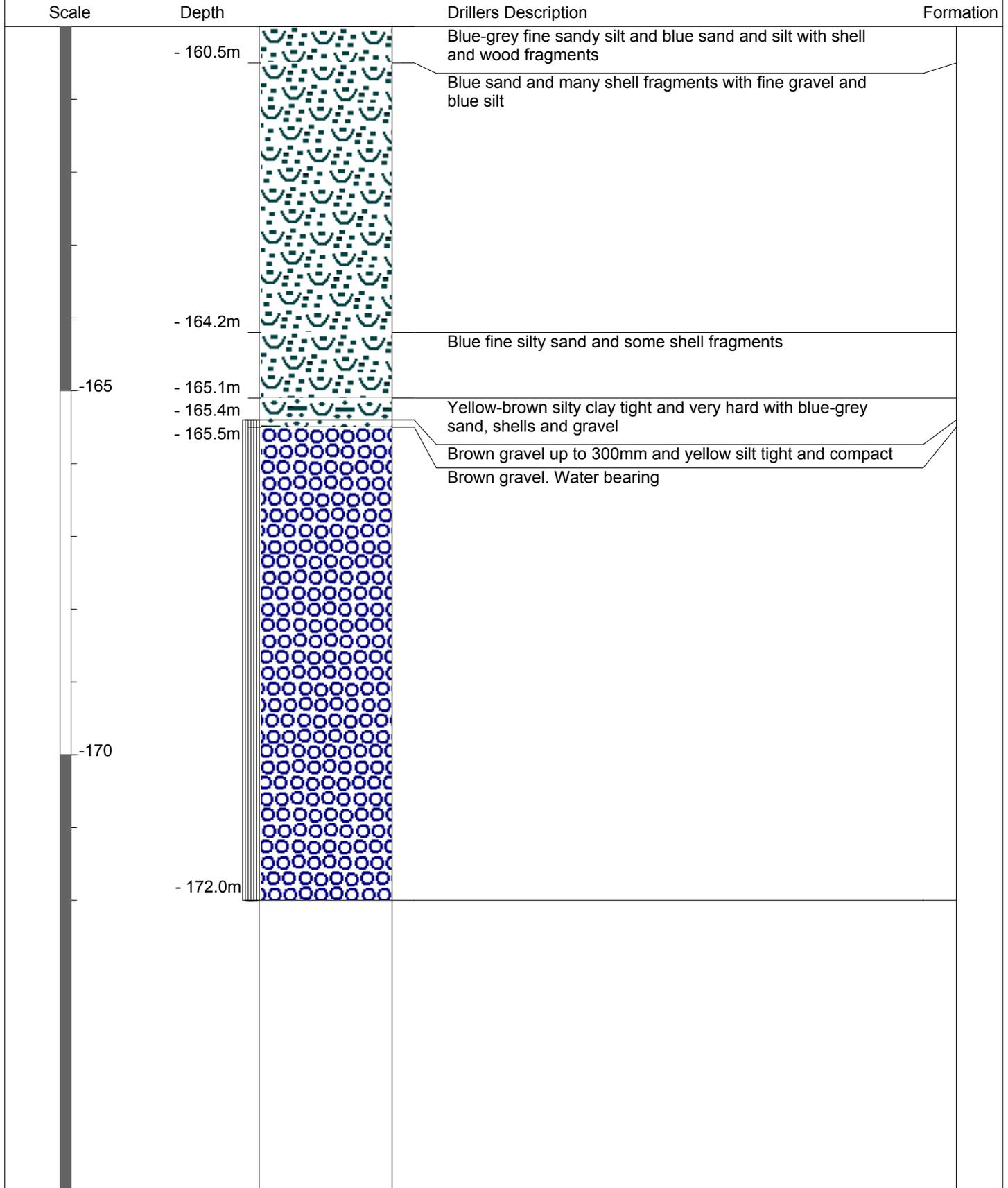
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Appendix 2:

Shell Identification and Palaeoenvironment Determinations for Te Horo Beach Testbore Samples

Fossil Record No. R25/f3; sample from depth of 17.3 m;

Bivalvia: Mactracea, indeterminable fragments.

Echinoidea: *Fellaster zelandiae*, extremely abundant fragments.

Ecology: *Fellaster* is the flat, circular “biscuit urchin” of 1 - 2 m water depth off sandy ocean beaches; restricted to this environment.

Fossil Record No. R25/f4; sample from depth of 18.5 m;

Bivalvia: *Venericardia purpurata*, few fragments.

Macra discors, common juvenile valves + fragments.

Zenatia acinaces, 1 fragment.

Dosinia (Phacosoma) subrosea, fragments.

“*Angulus*” sp., common fragments.

Caryocorbula zelandica, 1 valve, fresh

Gastropoda: *Antisolarium egenum*, 1

Amalda (Baryspira) depressa, 1 + fragments.

Amphibola crenata, 1 large fragment.

Echinoidea: *Fellaster zelandiae*, abundant fragments.

Ecology: The fauna of shallow water (ca. 2 - 5 m) off an open sandy beach.

Fossil Record No. R25/f5; sample from depth of 19.5 m;

Bivalvia: *Macra* sp., fragments + few small hinges.

? “*Angulus*” sp., thin shelled tellinid fragments common + 1 hinge.

Echinoidea: *Fellaster zelandiae*, common small abraded fragments.

Ecology: Shallow water off an open ocean sandy beach.

Fossil Record No. R25/f6; sample from depth of 20.5 m;

Bivalvia: Indeterminable fragments.

Echinoidea: *Fellaster zelandiae*, few small fragments.

Ecology: Shallow water (2 - 3 m ?) off an open ocean sandy beach.

Fossil Record No. R25/f7; sample from depth of 24.5 m;

Bivalvia: *Chlamys* sp., 1 small fragment.
Nucula sp., 1 fragment.
Tiostrea lutaria (common oyster), 1 fresh stained valve.
Venericardia purpurata, 1 fragment.
Gari sp., fragments + hinge.
? "*Angulus*" sp., thin fragments.
Tawera sp., fragment.
Scalpomactra scalpellum, few small.
Myadora sp., fragment.

Gastropoda: *Antisolarium egenum*, 1 good + fragments.
Austrofuscus glans, few small fragments.
Amalda sp., fragment.
Neoguraleus sp., 1 fresh.

Echinoidea: *Fellaster zelandiae*, fragments common.

Ecology: Shallow water (1 - 5 m ?) off an open ocean sand beach.

Fossil Record No. R25/f8; sample from depth of 25.5 m;

Bivalvia: ? Mactracea, few indeterminable fragments.
Resania lanceolata, 1 large fragment.
Gari sp., fragments.
Dosinia (Phacosoma) subrosea, several fresh juvenile valves.
Myadora sp., fragments.
Myllitella sp., fragments.

Gastropoda: *Antisolarium egenum*, 1 fresh.
? *Tanea zelandica*, fragment.
Amalda sp., fragments + juvenile.
Pervicacia tristis, 1 fresh.

Echinoidea: *Fellaster zelandiae*, several large fragments.

Ecology: Shallow water (1 - 5 m ?) off an open ocean sand beach.

Fossil Record No. R25/f9; sample from depth of 27.5 m;

Bivalvia: *Nucula nitidula*, A. Adams, fragments.
Chlamys gemmulata (Reeve), fragments.
Nemocardium (Pratulium) pulchellum, few fragments.
"*Angulus*" sp., small fragments and hinges.
Dosinia (Phacosoma) subrosea, fragments.
Myllitella vivens, few fresh valves.
Caryocorbula zelandica, 1 small valve.
Myadora novaezelandica, few fresh valves.
Spisula aequilaturalis, fragments.

Gastropoda: *Antisolarium egenum*, 1 fresh.
Zegalems tenuis, several.
Austrofuscus glans, few fragments.

Echinoidea: *Fellaster zelandiae*, few fragments.
? *Echinocardium*, spatangoid or similar fragments more common than *Fellaster*.

Also barnacle plates, fish scales, polychaete tubes, 1 small crab claw and bryozoans.

Ecology: A diverse fauna suggesting a significantly deeper deposition site than R25/f3 - 8. This probably inner shelf off a sandy ocean beach in about 10 - 20 m depth of water.

Fossil Record No. R25/f10; sample from depth of 28.5 m;

Bivalvia: "*Tellina*" *huttoni*, 1 broken valve.
? *Gari* sp., 1 fragment.
? *Tawera* sp., 1 fragment.
Nucula nitidula, several broken.
Resania lanceolata, juvenile hinge.
Nemocardium pulchellum, few fragments.
Chlamys gemmulata, few fragments.
Modiolus sp., umbo juvenile.
Myadora sp., few fragments.
? *Soletellina* sp., umbo.
Caryocorbula zelandica, 1 valve.

Gastropoda: ? *Micrelenchus* sp., fragment.
Antisolarium egenum, several.
Zeacolpus (stiracolpus) blacki, 1 fragment.
Sigapatella novaezelandiae, 1 large.
Zegalems tenuis, few small.
Crepidula monoxyla, 1 large.
Austrofuscus glans, small fragments.
Amalda (baryspira) sp., juvenile.
Pervicacia tristis, 2 broken.

Echinoidea: *Fellaster zelandiae*, few fragments.
? *Echinocardium*, spatangoid like fragments.

Also barnacle plates and bryozoans.

Ecology: Diverse fauna from about 10 m water depth or maybe slightly more, on a near flat soft substrate, presumably off a sandy ocean beach.

Fossil Record No. R25/f11; sample from depth of 29.5 m;

Bivalvia: *Nucula nitidula*, few fragments.
Dosinia sp., 1 small juvenile valve.
Myadora boltoni, 1 valve + fragments.

? "*Tellina*" *buttoni*, several small fragments of posterior ends of a small pink tellinid.
+ some small indeterminable fragments.

Gastropoda: *Antisolarium egenum*, several good.

Echinoidea: *Fellaster zelandiae*, very few small fragments.

? *Echinocardium*, several larger fragments of a spatangoid like echinoid.

Also crustacean leg, many bryozoans and 1 worm tube.

Ecology: Depth hard to judge from this small fauna; 'shallow' water about 3 - 10 m or maybe more off sandy ocean beach.

Fossil Record No. R25/f12; sample from depth of 30.5 m;

Bivalvia: *Nucula nitidula*, several valves.

Gari sp., pieces common.

? *Soletellina* sp., pieces several.

"*Tellina*" *huttoni*, several valves.

"*Tellinella*", several fragments.

Dosinia sp., small juvenile valves.

Nemocardium (Pratulum) pulchellum, few fragments.

Hiatella arctica, 1 small.

Myllitella vivens, 1 broken valve.

Gastropoda: *Antisolarium egenum*, several.

Thoristella sp., 1 good small.

Calliostoma waikanae, small fragments.

Calliostoma punctulatum, small fragments.

Sigapatella novaezelandiae, 1 small.

? *Struthiolaria* sp., fragments.

Austrofusus glans, fragments.

Amalda (Gracilispira) novaezelandiae, 1 good.

Neoguralens sp., 1 broken.

Scaphopoda: *Dentalium nanum*, 2 fragments.

Echinoidea: *Fellaster zelandiae*, few small fragments.

? *Echinocardium*, several fragments of spatangoid like echinoid.

Ecology: Inner shelf soft bottom fauna, from about 10 - 20 m depth off a sandy ocean beach.

Fossil Record No. R25/f13; sample from depth of 31.5 m;

Bivalvia: *Nucula nitidula*, big valves.

Saccella bellula, few fragments.

Chlamys gemmulata, many fragments.

? *Paphies* sp., 1 large fragment.

Nemocardium (Pratulum) pulchellum, fragments.

Scalpomactra scalpellum, many.
Maorimactra ordinaria, several.
"Tellina" *huttoni*, common.
Gari sp., fragments common.
? *Tawera* sp., hinge.
Hiatella arctica, few valves.
Myadora stratiata, few valves.
Myadora boltoni, few valves.
Myadora novaezealandiae, few valves.
Neolepton antipodium, common.
Myllitella vivens, several.
"Tellinella" sp., fragments.
? *Arthritica* sp., several valves.
Dosinia sp., fragment.

Gastropoda: *Calliostoma pellucidum*, large fragment.
Calliostoma, 2 (?) other species, fragment.
Antisolarium egenum, common.
Maoricolpus roseas, fragments.
Struthiolaria papulosa, fragments.
Austrofusus glans, fragments.
Semicassis pyrum, 1 large piece.
Pervicacia tristis, several.
Neoguraleus sp., few broken.

Scaphopoda: *Dentalium nanum*, few pieces.

Polyplacophosa: *Chiton (Rhyssoplax) canaliculatus*, 2 fragments.

Echinoidea: *Echinocardium cordatum*, large fragments common.
Fellaster zelandiae, very few small fragments.

Also crab carapace and bryozoans.

Ecology: An *Echinocardium* - *Scalpomactra* community; common around New Zealand today on the shelf in about 10 - 50 m of water or more, but this sample towards the shallow part of the range (10 - 20 m ?) on gently sloping soft bottom.

Fossil Record No. R25/f14; sample from depth of 32.2 m;

Bivalvia: *Nucula nitidula*, common.
? *Barbatia novaezelandiae*, large bored fragment.
Chlamys gemmulata, fragments.
Chlamys ? *zelandiae*, fragments.
Pecten novaezelandiae, fragments.
Modiolus aereolatus, large fragment.
Atrina pectinata zelandica, small fragments.
Divaricella (Divalucina) huttoniana, several.
"Tellina" *huttoni*, common.
Dosinia (Phacosoma) subrosea, juveniles.
Tawera spissa, juveniles.
? *Arthritica* sp., common.
Myadora boltoni, few.
Nemocardium (Pratulium) pulchellum, fragments.
Hiatella arctica, several.
Gari, sp., fragments.
Leptomya retiaria, large fragment.
? *Venericardia* sp., juvenile.
Macridae, large indeterminate fragments.
Caryocorbula zelandica, 1 valve.
Maorimacra ordinaria, few.

Gastropoda: *Antisolarium egenum*, several.
Zeacolpus (Stiracolpus) blacki, 1 small.
Tanea zelandica, few large fragments.
Austrofuscus glans, common fragments.
Amalda (Gracilispira) novaezelandiae, several.
Pervicacia tristis, several.
Aoteadrillia wanganuiensis, 1 broken.

Scaphopoda: *Dentalium nanum*, few.

Polyplacophosa: *Lorica haurakiensis*, 2 large pieces (of 1 valve ?) - a rare chiton.

Echinoidea: *Fellaster zelandiae*, few fragments.
Echinocardium cordatum, many fragments.

Ecology: An *Echinocardium* - *Scalpomacra* community; common around New Zealand today on the shelf in about 10 - 50 m of water or more, but this sample towards the shallow part of the range (10 - 20 m ?) on gently sloping soft bottom.

Fossil Record No. R25/f15; sample from depth of 32.5 m;

Bivalvia: *Saccula bellula*, few fragments.
Nucula nitidula, common.
Paphies sp. (“*tuatua*”), stained umbonal fragment.
Divanella (Divalucina) huttoniana, common, some large pieces.
Barbatia novaezealandiae, large fragments.
Chlamys gemmulata, few fragments.
Atrina pectinata zelandica, few fragments.
Modiolarca impacta, 1 fragment.
Arthritica sp., several valves.
Maorimacra ordinaria, several.
Scalpomacra scalpellum, several.
“*Tellina*” *huttoni*, common.
Tawera spissa, few juvenile valves.
Modiolus areolatus, few fragments.
Myadosa novaezealandiae, few fragments.
? *Monia zelandica*, 1 fragment.
Gari sp., many fragments.
Leptomya retiaria, few fragments.

Gastropoda: *Antisolarium egenum*, fresh shells common.
Astrea heliotropium, 1 fragment.
Zeacolpus (Stiracolpus) blacki, 1 good.
Austrofusus glans, many fragments.
Amalda (Gracilispira) novaezealandiae, several.
Amalda (Baryspira) sp., few large fragments.
Pervicacia tristis, several.
? *Cavolinia*, 2 large pieces of pteropods (oceanic pelagic gastropods).

Scaphoda: *Dentalium manum*, few pieces.

Polyplacophosa: *Chiton (Rhyasoplax) canaliculatus*, half a plate.

Echinoidea: *Fellaster zelandiae*, few abraded fragments.
Echinocardium cordatum, many fragments.

Also fish scales and bryozoans.

Ecology: Classic example of the Echinocardium - Scalpomatra community that is so widespread on the New Zealand inner-mid shelf at present in about 10 - 50 m of water or more, but this sample towards the shallow part of the range (10 - 20 m ?) on gently sloping soft bottom. Samples from this well seem to be fairly clear change from about 10 - 20 m up to R25/f9 then about 1 - 5 m above that dominated by *Fellaster*.

Fossil Record No. R25/f16; sample from depth of 33.0 m;

Bivalvia: *Nucula nitidula*, common large.
Atrina pectinata zelandica, umbones common.
Chlamys gemmulata, 1 fragment.
Tiostrea lutaria, few small.
Scalpomactra scalpellum, abundant.
Macra or *Spisula* sp., few juvenile + large pieces.
Gari lineolata or *hodgei*, few whole valves.
"Tellina" *huttoni*, several still pink.
"Tellinella" *eugonia*, few fragments.
Leptomya retiana, few fragments.
"Diplodonta" *striatula*, one good valve.
Tawera sp., few juvenile.
Dosinia (*Austrodosinia*) *anus*, small valves.
D. (*Phacosoma*) *subrosea*, few pieces.
Divanicella huttoniana, few small fragments.
Kellia suborbicularis, few fresh valves.
Myadora striata, common broken.
Caryocorbula zelandica, 1 valve.

Gastropoda: *Notoacmea helmsi*, 1 fresh.
Antisolarium egenum, abundant.
Cantharidella tesellata, one.
Astrea heliotropium, 2 largish pieces.
Zegalerus tenuis, few.
Crepidula monoxyla, several.
Calliostoma sp., few fragments.
Semicassis pyrdum, few small fragments.
Austrofuscus glans, fragments + juvenile common.
Sigapatella novaezelandiae, few.
Maoricolpus roseus, few fragments.
Zeacolpus (*Striacolpus*) *blacki*, few fresh shells.
Amalda (*Baryspira*) *depressa*, one.
Amalda (*Baryspira*) *mucronata*, few pieces.
Amalda (*Gracilispira*) *novaezelandiae*, several.
Alcithoe fusus, 1 large piece.
Tomopleura (*Maoritomella*) *albula*, 1 good.
Pervicacia tristis, several fresh.
Siphonaria sp., intertidal limpet - 1 fresh.

Scaphopoda: *Dentalium nanum*, 3 extra large.

Echinoidea: *Fellaster zelandiae*, fragments common.
Echinocardium, few fragments.

Anthropoda, Cinipedia: Large barnacle plates (*Balanidae*) fairly common.
Whale barnacle (*Coronula* ?), 1 small fresh valve - a rare fossil.

Also a few small bryozoans.

Ecology: Appears to be a fauna that lived in 10 - 20 m on the inner shelf, in soft sediments, in a quiet situation, with a nearby sand beach contributing species such as *Dosinia anus*; a few shells are from intertidal rocks (the limpets *Notoacmea* cf. *Siphonaria*). Slightly more diverse than R25/f17, but no significant differences.

Fossil Record No. R25/f17; sample from depth of 33.5 m;

Bivalvia: *Tawera* sp., juvenile, rare.

Nemocardium pulchellum, few pieces.

Nucula nitidula, large common.

Pecten novaezelandiae, pieces fairly common including 2 large pieces.

Rochefortia reniformis, fragment.

Scalpomactra scalpellum, common fresh and stained whole valves.

Tiostrea lutaria, few juvenile.

Atrina pectinata zelandica, small fragments.

"*Tellina*" *huttoni*, several whole valves still pink.

Leptomya rteiaria, few fragments.

Gari sp., fragments.

Spisula aequilateralis, several thick fragments from large shells + juveniles.

Dosinia (Austrodosinia) anus, fragments + small valves fairly common.

Perna canaliculus, rare umbones.

Notocallista (Striacallista) multistriata, few fragments, fresh.

Myadora striata, common.

Caryscorbula zelandica, 1 valve.

Bassina yatei, 1 piece of a juvenile.

Gastropoda: *Antisolarium egenum*, fresh whole shells abundant.

Calliostoma sp., few fragments.

Cantharidella tessellata, rare.

Astraea heliotropium, 1 fragment.

Crepidula monoxyla, 1 small.

Maoriculpus roseus, few pieces.

Zeacolpus vittatus, few pieces.

Zeacolpus (stiracolpus) blacki, few fresh.

Tanea zelandica, 1 operculum.

Semicassis pyrum, few pieces from near apex.

Austrofuscus glans, fragments common.

Zegalems tenuis, few.

Struthiolaria papulosa, 1 apex.

Pervicacia tristis, several fresh.

Scaphopoda: *Dentalium nanum*, 1 large.

Echinoidea: *Fellaster zelandiae*, pieces common and most rather braded.

Also a few large barnacle plates.

Ecology: Elements of both sandy ocean beach (ca. 1 - 5 m) and inner - mid shelf
Scalpomactra - Nemocardium communities are both common in this sample, suggesting

deposition in rather shallow water (10 - 20 m ?) off a sandy ocean beach, where beach shells could be contributed to the deposition site.

Fossil Record No. R25/f18; sample from depth of 17.5 m;

Mollusca: 2 - 3 unidentifiable very grounded fragments.

Echinoidea: *Fellaster zelandiae*, small and very rounded fragments make up most of the very small sample.

Ecology: Probably deposited in very shallow water (0 - 5 m) off an open ocean sand beach.

Fossil Record No. R25/f19; sample from depth of 18.0 m;

Echinoidea: 100% small angular fragments of *Fellaster zelandiae* broken by drill.

Ecology: Probably deposited in very shallow water (0 - 5 m) off an open ocean sand beach.

Fossil Record No. R25/f20; sample from depth of 18.5 m:

Bivalvia: *Dosinia* sp., one umboral fragment.

? *Paphies* sp. few large thick pieces - most bivalve pieces are highly chalky (leached).

Echinoidea: *Fellaster zelandiae* angular fragments make up >90% of sample.

Ecology: Probably deposited in very shallow water (0 - 5 m) off an open ocean sand beach.

Fossil Record No. R25/f21; sample from depth of 19.0 m:

Bivalvia: *Dosinia* sp., one umboral fragment.

? *Paphies* sp. few large thick pieces - most bivalve pieces are highly chalky (leached).

Echinoidea: *Fellaster zelandiae* angular fragments make up >90% of sample.

Ecology: Probably deposited in very shallow water (0 - 5 m) off an open ocean sand beach.

Fossil Record No. R25/f22; sample from depth of 19.5 m:

Bivalvia: *Tellinidae* indeterminable few large leached pieces.

? *Dosinia* sp., leached pieces.

Gastropoda: *Amalda (Baryspira)* sp., 2 large leached species.

Many other leached molluscan fragments (mostly of bivalves) are unidentifiable.

Echinoidea: *Fellaster zelandiae* rounded and angular fragments make up about 50% of sample.

Ecology: Probably deposited in very shallow water (0 - 5 m) off an open ocean sand beach. This sequence shows a fairly regular increase in proportion of molluscan fragments, perhaps merely reflecting increasing depth and progressively decreasing leaching effects.

Fossil Record No. R25/f23; sample from depth of 20.0 m:

Bivalvia: *Nucula* sp., large fragment.

Gari sp., (aff. *lineolata*) several small and very thin fragments.

Dosinia sp. umboral fragment.

Myadora striata one fragment.

Also many pieces unidentifiable.

Gastropoda: *Neogacraeus* sp., 1 quite good.

Zeacolpus (stiracolpus) sp., 1 piece and a few fragments.

Echinoidea: *Fellaster zelandiae*, rounded and angular fragments make up about 30% of sample.

Ecology: Probably deposited in very shallow water (0 - 5 m) off an open ocean sand beach.

Fossil Record Nos R25/f24 -f38. Depth range from 20.5 - 27.5 m:

These are essentially the same and similar to the preceding R25/f20 - f23. Dominated by *Fellaster zelandiae* fragments but with some bivalve fragments and a few gastropoda in some of the samples.

Myadora striata (an obligate sand beach dweller) is present in many of the samples; large pieces of *Fellaster* are particularly obvious in R25/f31. A few small fragments of *Echinocardium* ("heart urchin") occur in some samples.

Ecology: Top R25/f18 - f20, greatly *Fellaster* dominated; R25/f21 - 38, *Fellaster* common, molluscs reasonable to abundant apparently deposited in about 5 - 10 m off a sandy ocean beach; R25/f38 - f52 slightly more offshore, perhaps 10 - 20 m of water, still off an open ocean sand beach. Note that all changes are very gradual, not abrupt.

Fossil Record Nos R25/f39 - f48. Depth range 28.0 - 32.5:

These are the same sort of fauna with common *Fellaster zelandiae* fragments, *Nucula nitidula*, *Antisolarium egenum*, *Pervicacia tristis*, and fairly consistent but less common *Myadora striata*, *Zeacolpus (Stiracolpus) blacki*, *Amalda* sp., *Dosinia* sp., fragments, *Chlamys zelandiae* fragments, *Caryocorbula zelandiae*, and *Neoguraleus* sp. Slightly more offshore taxa such as *Scalpomactra* or *Dentalium* in R25/f46.

Ecology: R25/f38 - 52 slightly more offshore, perhaps 10 - 20 m of water, still off an open ocean sand beach. Note that all changes are very gradual, not abrupt.

Fossil Record No. R25/f49; sample from depth of 33.0 m:

Bivalvia: *Nucula nitidula* (A. Adams), several.
Divaricella luttoniana (Vanatta), few.
"Tellina" *huttoni* (Suter), few large Tellinidae indeterminate fragments.
Gari sp., fragments.
Scalpomactra scalpellum (Rearc), common.
Dosinia (*Phacosoma*) *subrosea* (Q& G), a few pieces.
Atrina pectinata zelandica (Gray), few pieces.
Caryocorbula zelandica, few whole.
Cuspidaria sp., few pieces.
Chlamys zelandiae, few pieces.
Pecten novaezelandiae, few pieces.

Gastropoda: *Antisdarium egenum*, whole fresh shells common.
? *Modelia* sp., fragment.
Maoricolpus roseus, many fragments.
Zeacolpus (*stiracolpus*) *blacki*, few whole and fragments.
Austrofuscus glans, apices and fragments common.
Penion sulcatus (Lamarck), few large pieces.
Amalda (*Gracilispira*) *novaezelandiae*, one spire.
Pervicacia tristis, common.
Neoguraleus sp., 1 nice.

Scaphopoda: *Dentalium nanum*, several pieces.

Echinoidea: *Fellaster zelandiae*, fragments common.
Echinocardium cordatum, fragments common.

Also a few bryozoan fragments, fish scales and barnacle plates.

Ecology: The presence of *Cuspidaria* and *Dentalium*, the lack of intertidal species shows that this fauna lived on a sand substrate in shallow water (about 10 - 20 m), off an open ocean beach; *Fellaster* may have been transported from slightly shallower water.

Fossil Record No. R25/f50; sample from depth of 33.5 m:

Bivalvia: *Nucula nitidula*, common.
Scalpomactra scalpellum, common.
"Tellina" *huttoni*, several.
Gari lineolata, 1 large valve and fragments.
Monia zelandica, fragments.
Ostre lutaria, few small.
Mactra sp., few pieces.
Dosina (*Phacosoma*) *subrosea*, few pieces.
Chlamys zelandiae, few pieces.
Myadora bolteni, few.
Myadora striata, several fresh.
Dosinia (*Asa*) *lambata*, few pieces.

Venericardia purpurata, 1 fragment.

Gastropoda: *Antisolarium egenum*, common.
Astrea heliotropium, several apices and large spires.
Crepidula monoxyla, several.
Maoricolpus roseus, fragments common.
Zeacolpus (Stiracolpus) blacki, few.
Semicassis pyrum, 1 large piece.
Austrofuscus glans, apices and pieces common.
Buccinulum sp., large piece.
Amalda (Baryspira) depressa, few small whole.
Amalda sp., few large pieces.
Alicithoe fusus, 1 large piece.
Pervicacia tristis, quite common whole and fresh.

Scaphopoda: *Dentalium nanum*, several large.

Crustacea/Brachyura: Crab claw and a few barnacle plates.

Echinoidea: *Fellaster zelandiae*, fragments common.
Echinocardium cordatum, fragments common.

Ecology: This appears to be samples of the *Echinocardium* community (molluscs dominated by *Nucula nitidula*, *Scalpomactra*, and *Antisolarium*) which occurs commonly on sand or muddy sand all around New Zealand on the inner continental shelf in about 10 - 30 m of water. The occurrence of common *Fellaster* fragments shows they were deposited towards the shallower end of the range off an open ocean sand beach.

Fossil Record No. R25/f51; sample from depth of 34.0 m:

Bivalvia: *Ostrea lutaria*
Divaricella huttoniana
Gari lineolata
"Tellina" *huttoni*
Fragments of larger Tellinidae.
Chlamys zelandiae
Barbatia novae zelandiae
Dosinia sp., fragments.
Scalpomactra fragments.

Gastropoda: *Maoricolpus roseus*
Zeacolpus (Stiracolpus) blacki
Austrofuscus glans, fragments.
Calliostoma sp., fragments.
Trochus sp., fragments.
Amalda (Baryspira) depressa, few small fresh.
Amalda (Gracilispira) novaezelandiae, few small fresh.

Scaphopoda: *Dentalium nanum*, several.

Ecology: The inner continental shelf in about 10 - 30 m of water.

Fossil Record No. R25/f52; sample from depth of 34.5 m:

Bivalvia: *Nucula nitidula*
Scalpomactra scalpellum
Antisolarium egenum
Gari sp.
Dosinia sp.
Myadora sp.
Nemocardium pulchellum

Gastropoda: *Maoricolpus roseus*
Zeacolpus (Stiracolpus) blacki
Pervicacia tristis
Struthiolaria papulosa
Chemnitzia sp.

Ecology: The inner continental shelf in about 10 - 30 m of water.

Fossil Record No. R25/f54; sample from depth of 99.5 m:

Bivalvia: *Nucula nitidula*, several.
? *Arthritica* sp., common small.
Kellia suborbicularis, few.
Gari sp., fragments.
"*Tellina*" *huttoni*, several whole valves.
Dosinia (Phacosoma) subrosea, several juveniles and pieces.
Scalpomactra scalpellum, few.
Myadora boltoni, several.
Myadora striata, few small.

Gastropoda: *Calliostoma* sp., fragments.
Antisolarium egenum, common.
Austrofuscus glans, few pieces.
Amalda (Gracilispira) novaezelandiae, few pieces.
Pervicacia tristis, several.
Aoteadrillia wanganuiensis, several.

Echinoidea: *Fellaster zelandiae*, several quite large pieces.

Also several barnacle plates.

Ecology: Faunas that lived in about 3 - 20 m of water off a sand beach in a quiet situation on a soft substrate.

Fossil Record No. R25/f55; sample from depth of 100.0 m:

Bivalvia: *Nucula nitidula*, several.

Pleuromeris zelandiae, several.
Divancilla buttoniana, few.
Zenatia acinaces, several big pieces.
Mactra discors, several big pieces.
Bassina yatei, few pieces.
Gari lineolata, several pieces.
Dosinia (Phacosoma) subrosea, big pieces common.
Myadora striata, few small.
Angulus sp., fragment.
Caryocorbula zelandica, few.

Gastropoda: *Antisolarium egenum*, abundant.
Zeacolpus (Stiracolpus) blacki, several.
Tanea zelandica, several.
Xymene gouldi, 1 nice.
Pemon sulcatus, large apex.
Austrofuscus glans, few pieces.
Amalda (Baryspira) mucronata, several pieces.
Amalda (Baryspira) depressa, few whole.
Amalda (Gracilispira) novaezelandiae, few pieces.
Phenatoma sp., 1 very small.
Neoguraleus sp., several common.
Pervicacia tristis, abundant some very large.several.
Aoteadrillia wanganuiensis, one.
Odostomia sp., 1 small polished.

Echinoidea: *Fellaster zelandiae*, small pieces common.

Also common barnacle plates and a few crab "fingers".

Ecology: Deposited in about 3 - 10 m of water off a sandy ocean beach.

Fossil Record No. R25/f56; sample from depth of 100.5 m:

Bivalvia: *Nucula nitidula*, several.
Pleuromeris zealandica, few.
Gari sp., several pieces.
Cosa sp., 1 broken valve.
Dosinia (Asa) lambata, 1 broken in concretion.
Dosinia (Phacosoma) subrosea, few pieces.
Scalpomactra scalpellum, several.
Notocallista multistriata, few large pieces.
Nemocardia (Pratulum) pulchellum, few pieces.
Panopea zealandica, large pieces.
Caryocorbula zelandica, few valves.
Many bivalve fragments indeterminable.

Gastropoda: *Calliostoma* sp., fragments.
Antisolarium egenum, abundant.
Maoricolpus roseus, few small.

Zeacolpus (Stiracolpus) blacki, common.
Tanea zelandica, few small.
Uttleya sp., spire.
Austrofuscus glans, several apices and juveniles.
Amalda (Baryspira) mucronata, many large pieces, apices, etc.
Amalda (Gracilispira) novaezelandiae, common.
Phenatoma rosea, 1 nice.
Phenatoma novaezelandiae, 1 fragment.
Aoteadrilla wanganuiensis, several.
Neoguraleus sp., common.
Pervicacia tristis, abundant.

Echinoidea: *Fellaster zelandiae*, small pieces common and common plates.

Ecology: Faunas that lived in about 5 - 20 m of water off a sand beach in a quiet situation on a soft substrate.

Fossil Record No. R25/f57; sample from depth of 101.0 m:

Bivalvia: *Nucula nitidula*, few pieces.
Divaricella buttoniana, 1 valve.
Gari lineolata, few large pieces.
Dosinia (Phacosoma) subrosea, 1 large hinge and fragments.
Scalpomactra scalpellum, few.
Musculus impactus, few pieces.
Myadora boltoni, few valves.
Panopea zelandica, several large pieces.

Gastropoda: *Antisolarium egenum*, common.
Maoricolpus roseus, several pieces.
Zeacolpus (Stiracolpus) blacki, 1 large.
Tanea zelandica, 1 small.
Uttleya sp., 1 large smooth spire.
Austrofuscus glans, fragments common.
Amalda (Gracilispira) novaezelandiae, several big pieces.
Pervicacia tristis, several.

Echinoidea: *Fellaster zelandiae*, few small pieces.

Arthropoda, Cirripedia: 1 large balanomorph barnacle in a concretion.

Ecology: Faunas that lived in about 3 - 20 m of water off a sandy ocean beach.

Fossil Record No. R25/f58; sample from depth of 101.3 m:

Bivalvia: *Tiostrata chitensis lutaria*, few small pieces.
Nucula nitidula, several large.
Mastridae, indeterminable juvenile.
Zenatia acinaces, few valves.
Gari lineolata, fragments.

Bassina yatie, several large pieces.
Dosinia (Phacosoma) subrosea, many pieces and 1 large umbo.
? *Paphies*, many thick shelled pieces.
Notocallistra multistriata, 1 juvenile.
Myadora boltoni, several few valves.
Panopea zealandica, many large fresh pieces; hinge etc. looks like as if at least one large valve was broken by the drill.
Caryocorbula zelandica, few pieces.

Gastropoda: *Antisolarium egenum*, abundant.
Maoricolpus roseus, few pieces.
Zeacolpus (Stiracolpus) blacki, 1 small.
Crepidula costata, 1 juvenile.
Uttleya sp., 1 spire.
Austrofuscus (Baryspira) depressa, one.
Neoguraleus sp., 1 small.
Pervicacia tristis, 1 small.

Echinoidea: *Fellaster zelandiae*, few pieces.

Ecology: Faunas that lived in about 3 - 10 m of water off a sandy ocean beach.

Fossil Record No. R25/f59; sample from depth of 101.5 m:

Bivalvia: *Nucula nitidula*, fragments.
Gari lineolata, sp., fragments.
? *Macta* sp., fragments.
Paphies sp., many small fragments not determinable.
Myadora striata, several.

Gastropoda: *Emarginula striatula*, 1 small.
Antisolarium egenum, several fresh.
? *Austrofuscus*, fragment.

Echinoidea: *Fellaster zelandiae*, few fragments.

Ecology: Deposited in a few metres (up to 5 m) off a sandy ocean beach.

Fossil Record No. R25/f60; sample from depth of 101.8 m:

Bivalvia: *Nucula nitidula*, common.
Barbatia novaezealandiae, pieces common.
Ostreidae, indeterminate 1 juvenile.
Tawera spissa
Dosinia (Asa) lambata
Dosinia (Phacosoma) subrosea
Leptomya retiaria
Spisula (Crassula) aequilatealis, 1 large crushed valve broken by drill.
? *Gari* sp., fragments.
Chlamys geminulata, common pieces.

Maorimactra ordinaria, 1 small.
Musculus impactus, 1 fragment.
Myadora striata, common.
Divaricella huttoniana, few fragments.

Gastropoda: *Antisolarium egenum*, common.
Emarginula striata, one.
Sigapatella novaezelandiae, few.
Zeglenus tenuis, few.
Maoricolpus roseus, fragments.
Zeacolpus (Stiracolpus) blacki, common.
Tanea zelandica, fragments.
Austrofusus glans, fragments and apices common.
Trochus sp., fragments.
Amalda (Gracilispira) novaezelandiae, several.
Crepidula costata, 1 juvenile - indicates warmer than present as lives only in northeast New Zealand today.
Duplicaria tristis, few.
Turbonilla sp., 1 broken.

Echinoidea: ? *Echinocardium*, plates and spires of a small irregular echinoid.

Ecology: Diverse fauna from well offshore on the inner-middle shelf on a soft substrate probably in the *Scalpomactra-Echinocardium* association of 20 - 50 metre depth.

Fossil Record No. R25/f61; sample from depth of 102.2 m:

Bivalvia: *Nucula nitidula*, common.
Barbatia novaezelandiae, fragments.
Chlamys geminulata, few including 1 large valve.
Tawera spissa, small common.
Dosinia (Asa) lambata, few large pieces.
Dosinia (Uereia) greyi, few small pieces.
Leptomya retiaria, few.
Scalpomactra scalpellum, common.
Gari lineolata, few pieces.
"Tellina" *huttoni*, few.
"Tellina" *edgari*, few large pieces.
Notocallista multistriata, few small valves.
Zenatia acinaces, few pieces.
Myadora striata, common.
? *Paphies* sp., ("tuatua"), few thick pieces.
Neilo australis, few small fragments.
Caryocorbula zelandica, 1 piece.

Gastropoda: *Emarginula striata*, one.
Antisolarium egenum, abundant.
Sigapatella novaezelandiae, few.
Calliostoma, ? new species, very tall with narrow spire.*
Astrea heliotropium, 1 fragment.

Maoricolpus roseus, pieces common.
Zeacolpus (Stiracolpus) delli, common, quite strongly angled whorls.
Tanea zelandica, 1 operculum.
Austrofuscus glans, common.
Amalda (Gracilispira) novaezelandiae, common.
Neoguraleus, 2 species, 1 of each.
Phenatoma novaezelandiae, 1 small.
Aoteadrillia wanganuiensis, 2 nice.
Antimelatoma budianani, 1 fragment.
Duplicaria tristis, several good.

Scaphopoda: *Dentalium nanum*, several good.

Echinoidea: *Echinocardium*, few pieces.

Ecology: Diverse fauna from well offshore on the inner-middle shelf on a soft substrate probably in the *Scalpomactra-Echinocardium* association of 20 - 50 metre depth.

*The *Calliostoma* appears to be similar to one seen in a Teer Creek, Cascade last interglacial collection.

Fossil Record No. R25/f62; sample from depth of 102.5 m:

Bivalvia: *Nucula nitidula*, abundant.
Barbatia novaezelandiae, pieces and juvenile valves common.
Chlamys geminulata, common.
Tiostrea chilensis lutaria, several to 25 mm.
Limatula strangei maoria, 1 piece.
Atrina pectinata zelandica, few pieces.
Musculus impactus, several pieces.
Kellia suborbicularia, 1 valve.
Taras (Zemysia) zelandica, 1 valve.
Divaricella huttoniana, several.
Leptomysa retiaria, several.
Gari lineolata, several large.
Maorimactra ordinaria, few.
Scalpomactra scalpellum, common.
"Tellina" *huttoni*, several.
"Tellina" *edgari*, common.
Dosinia (Asa) lambata, few pieces.
Dosinia (Kereia) greyi, several pieces.
Tawera spissa, common.
Dosina zelandica, few pieces.
Notocallista multistriata, several.
Panopea sp., large pieces (1 valve).
Myadora striata, several.
Caryocorbula zelandica, common.

Gastropoda: *Antisolarium egenum*, abundant.
Trochus tiaratus, few fragments.

Sigapatella novaezelandiae, large common.
Calliostoma, sp., few fragments.
Astrea heliotropium, 1 piece.
Crepidula monoxyia, 2.
Maoricolpus roseus, fragments common.
Zeacolpus (Stiracolpus) delli, several.
Tanea zelandica, few small.
Austrofuscus glans, several large + many apices and fragments.
Trichosirius sp., 1 small.
? *Cominella* sp., 1 columella.
Amalda (Gracilispira) novaezelandiae, several.
Amalda (Baryspira) mucronata, fragments.
Phenatoma rosea, 1 small.
Aoteadrillia wanganuiensis, several.
Duplicaria tristis, several.

Scaphopoda: *Dentalium nanum*, several.

Polypiophora: *Lorica haurakiensis*, 1 plate.

Echinoidea: *Echinocardium cordatum*, several large pieces.
Fellaster zelandiae, 1 small fragment.

Also barnacle plates.

Ecology: Diverse fauna from the inner-middle shelf on a soft substrate in the *Echinocardium* association of 20 - 50 metre depth. Some species (notably *Fellaster*) have come down from shallow water.

Fossil Record No. R25/f63; sample from depth of 102.8 m:

Bivalvia: *Nucula nitidula*, common.
Barbatia novaezelandiae, large pieces several.
Tiostrea chilensis lutaria, several small.
Chlamys geminulata, common pieces.
Limatula strangei maoria, 1 large piece.
Atrina pectinata zelandica, few pieces.
Musculus impactus, few pieces.
Leptomya retiaria, several.
"Tellina" *edgari*, several and fragments.
Tawera spissa, several and fragments.
Dosina zelandica, fragments.
Gari lineolata, fragments.
Notocallista multistriata, several small.
Panopea sp., ? *P. smithae*, several large fragments.
Myadora striata, few small.
Caryocorbula zelandica, several.

Gastropoda: *Antisolarium egenum*, common fresh.
Trochus sp., fragments.

Sigapatella novaezelandiae, few.
Zegalems tenuis, few.
Maoricolpus roseus, fragments common.
Zeacolpus (Stiracolpus) delli, few.
Austrofusus glans, pieces common.
Trichosirius sp., 1 small.
Amalda (Gracilispira) novaezelandiae, few broken.
Amalda (Baryspira) sp., fragments.
Alcithoe arabica, 1 juvenile.
Duplicaria tristis, several.

Scaphopoda: *Dentalium nanum*, few.

Polyplacophora: *Lorica haurakiensis*, 1 valve.

Echinoidea: *Echinocardium cordatum*, few large pieces.

Also barnacle plates.

Ecology: Diverse fauna from well offshore on the inner-middle shelf on a soft substrate probably in the *Echinocardium* association of 20 - 30 metre depth.

Fossil Record No. R25/f64; sample from depth of 103.2 m:

Bivalvia: *Nucula nitidula*, common.
Barbatia novaezelandiae, pieces common.
Tiostrea chilensis lutaria, few pieces.
Chlamys geminulata, many black pieces + some coloured whole shells.
Modiolus aereolatus, few pieces.
Tawera spissa, pieces common.
Dosina zelandica, pieces common.
Notocallista multistriata, few pieces.
Scalpomactra scalpellum, few whole valves.
Zenatia acinaces, few pieces.
Tellinidae indeterminate, several big thin pieces.
Panopea sp., few fragments.
Caryocorbula zelandica, common.
Myadora striata, few valves.

Gastropoda: *Antisolarium egenum*, fresh several.
Calliostoma sp., few fragments.
Sigapatella novaezelandiae, several.
Struthiolaria papulosa, few pieces.
Maoricolpus roseus, pieces common.
Zeacolpus (Stiracolpus) delli, several.
Tanea zelandica, few pieces.
Austrofusus glans, common.
Amalda (Baryspira) mucronata, 1 large crushed.
Amalda (Baryspira) depressa, 1.
Amalda (Gracilispira) novaezelandiae, several.

Alcithoe sp., columella.
Aoteadrillia wanganuiensis, several.
Duplicaria tristis, several.

Scaphopoda: *Dentalium nanum*, several.

Polyplacophora: *Lorica haurakiensis*, 1 plate.

Echinoidea: *Echinocardium cordatum*, several large pieces.

Also barnacle plates.

Ecology: Diverse fauna from well offshore on the inner-middle shelf on a soft substrate probably in the *Echinocardium* association of 20 - 30 metre depth.

Fossil Record No. R25/f65; sample from depth of 103.5 m:

Bivalvia: *Nucula nitidula*, several.
Chlamys geminulata, small black fragments.
Tawera spissa, few pieces.
Dosina or *Dosinia* sp., several fragments.
Caryocorbula zelandica, few pieces.

Gastropoda: *Antisolarium egenum*, several fresh.
Sigapatella novaezelandiae, few small.
Maoricolpus roseus, fragments.
Tanea zelandica, several fragments from a large shell.
Austrofuscus glans, common.
Trichosirius sp., 1 piece.
Buccinulum sp., 1 spire.
Amalda (Gracilispira) novaezelandiae, several.
Alcithoe sp., columella only.

Scaphopoda: *Dentalium nanum*, several.

Also barnacle plates.

Ecology: Fauna from 20 - 30 m on the inner-middle shelf on a soft substrate. This is a little more diverse than the other samples.

Fossil Record No. R25/f66; sample from depth of 104.0 m:

Bivalvia: *Nucula nitidula*, few.
Barbatia novaezelandiae, few pieces.
Chlamys geminulata, fragments.
Cardita aoteana, few pieces.
Mytilus edulis aoteanus, 1 piece.
Tawera spissa, many small pieces.
Dosinia or *Dosina* sp., several moderately large fragments.
Caryocorbula zelandica, several pieces.

Tellinidae indeterminate, several pieces.

Gastropoda: *Antisolarium egenum*, several fresh.

Trochidae indeterminate, 1 fragment.

Maoricolpus roseus, several fragments.

Zeacolpus (Stiracolpus) delli, few.

Tanea zelandica, 2.

Austrofuscus glans, several quite large and whole.

Amalda (Gracilispira) novaezelandiae, several indeterminate one very large whole..

Amalda (Baryspira) australia, 1 worn fairly large.

Alcithoe fusus, 1 large spie missing.

Duplicaria tristis, several.

Scaphopoda: *Dentalium nanum*, several.

Polyplacophora: ?*Lorica haurakiensis*, 1 piece of head valve.

Brachiopoda: *Tegulorhynchia nigricans*, few pieces.

Ecology: Fauna from 20 - 30 m on a soft substrate on the inner shelf, probably the *Echinocardium* community.

Fossil Record No. R25/f67; sample from depth of 104.5 m:

Bivalvia: *Nucula nitidula*, few.

Chlamys geminulata, fragments.

Tawera spissa, few fragments.

Leptomya retiaria, few fragments.

Notocallista multistriata, few fragments.

Tellinidae indeterminate fragments.

Dosinia sp., few thick fragments.

Barbatia novaezelandiae, few fragments.

+ many indeterminate bivalve fragments.

Gastropoda: *Antisolarium egenum*, several.

Sigapatella novaezelandiae, few small.

Maoricolpus roseus, pieces.

Zeacolpus (Stiracolpus) delli, 1 - 2 large.

Austrofuscus glans, few pieces.

Amalda (Gracilispira) novaezelandiae, 1 fragment.

?*Odostomia* sp., 1 small.

Scaphopoda: *Dentalium nanum*, several.

Polyplacophora: *Rhyssoplax canaliculata*, 2 plates.

Ecology: 20 - 30 m of water on a soft substrate on the inner shelf, probably the *Echinocardium* association.

Fossil Record No. R25/f68; sample from depth of 105.0 m:

Bivalvia: *Nucula nitidula*, several.
Chlamys geminulata, fragments.
Nemocardium pulchellum, a few fragments.
Tawera spissa, few small.
Notocallista multistriata, few fragments.
Spisula aequilateralis, few small fragments.
Tellinidae indeterminate, several large thin pieces.
Dosinia (Austrodosinia) anus, few small pieces.
Barbatia novaezelandiae, few small pieces.
Caryocorbula zelandica, several.

Gastropoda: *Antisolarium egenum*, several fresh.
Trochus sp., fragment.
Micrelenehus sp., 1 nice.
Maoricolpus roseus, pieces common.
Sigapatella novaezelandiae, few fragments.
Zeacolpus (Stiracolpus) delli, several.
Naticidae indeterminate, few fragments.
Austrofuscus glans, apices and pieces common.
Amalda (Gracilispira) novaezelandiae, several.
Amalda (Baryspira) sp., few large pieces.
Aoteadrillia wanganuiensis, 2 fresh.
Duplicaria tristis, few.

Scaphopoda: *Dentalium nanum*, several.

Polyplacophora: *Rhyssoplax canaliculata*, 1 plate.

Echinoidea: *Fellaster zelandiae*, 1 small fragment (possibly transported).

Ecology: Much like all the others, but some indication of nearby boulders in *Micrelenehus*; *Fellaster* lives in very shallow water off open-ocean sand beaches, but the rest look like a 20 - 30 m deep inner shelf fauna from a soft substrate, probably the *Echinocardium* association, so perhaps the *Fellaster* is transported.

Fossil Record No. R25/f69; sample from depth of 105.6 m:

Bivalvia: *Nucula nitidula*.
Barbatia novaezelandiae.
Chlamys geminulata.
Rochfortuia cf. *reniformis*, few good.
Tellinidae, broken indeterminate many fragments.
Tawera spissa, few fragments.
Cardita sp., juvenile.
Hiatella actica, 1 fragment.

Gastropoda: *Antisolarium egenum*, common.
Maoricolpus roseus.

Zeacolpus (Stiracolpus) delli.
Micrelenchus aff. *dilatatus*, 1 nice.
Trochus sp., fragment.
Zegalems tenuis.
Austrofuscus glans, common.
?Tanea zelandica, juvenile.
Zemitrella sp., 1.
Alcithoe sp., small fragments.
Duplicaria tristis, few.

Scaphopoda: *Dentalium nanum*, several.

Polyplacophora: *Acanthochitona zelandica*, 1 tail plate.
Rhysoplax canalicuta, few plates.

Echinoidea: *?Echinocardium* sp., few plates.

Ecology: Offshore on soft substrate (in *Echinocardium* association) as for R25/f62, but likely to have been boulders (or other hard substrate) around at time of deposition of R25/f69, as *Rochefortuia*, *Micrelenchus* and *Acanthochitona* are hard substrate or macroalgae taxa.

Fossil Record No. R25/f70; sample from depth of 106.6 m:

Bivalvia: *Nucula nitidula*, very common.
Barbatia novaezelandiae, few pieces.
Tiostrea chilensis lutaria, few large pieces.
Chlamys geminulata, common.
Pecten novaezelandae, 2 pieces.
Tellinidae indeterminate, many large thin pieces.
Limatula strangei maoria, 1 piece.
Tawera spissa, few small.
Dosinia greyi, many small fragments, strong comarginal lamellae.
Caryocorbula zelandica, several good.
A very large proportion of the sample is corroded, rounded black bivalve fragments.

Gastropoda: *Antisolarium egenum*, common.
Trochus sp., fragments.
Maoricolpus roseus.
Zeacolpus (Stiracolpus) delli delli, several.
Sigapatella novaezelandiae.
Zegalerus tenuis.
Austrofuscus glans, common bits.
Amalda (Gracilispira) novaezelandiae, common.
Duplicaria tristis, several.
Zemitrella sp., 1 small.

Scaphopoda: *Dentalium nanum*, large common.

Echinoidea: *?Echinocardium cordatum*, plates and spires.

Also barnacle plates.

Ecology: Diverse fauna from well offshore on the inner-middle shelf on a soft substrate probably in the *Scalpomactra-Echinocardium* association of 20 - 50 metre depth.

Fossil Record No. R25/f71; sample from depth of 107.3 m:

Bivalvia: *Myadora striata*, 1 large piece.

Nucula nitidula.

Chlamys gemmulata, small fragments.

Tawera sp., small fragments.

Dosinia anus, small fragments.

Other indeterminate bivalve fragments.

Gastropoda: *Antisolarium egenum*, small fragments.

Turritellidae indeterminate, small fragments.

Austrofuscus glans, small fragments and apices.

Amalda sp., few small fragments.

Scaphopoda: *Dentalium nanum*, several small pieces.

Echinoidea: Small pieces of spatangoids, probably *Echinocardium* + spires.

Ecology: The fauna from a soft substrate in about 10 - 50 m on the inner continental shelf - apparently from the *Echinocardium* community so common around New Zealand today.

Fossil Record No. R25/f72; sample from depth of 160.0 m:

Bivalvia: Indeterminate - an elongate bivalve, not identifiable with certainty; hinge appears most like *Paphies* sp., ("tuatua"), not *P. australis*.

Ecology: Shallow marine, probably from shallow water off a sandy beach.

Fossil Record No. R25/f73; sample from depth of 108.0 m:

Bivalvia: *Nucula nitidula*, several valves.

Leptomya retiaria, fragments.

Caryocorbula zelandica, few.

Barbatia novaezelandiae, several fragments.

Dosinia (Phacosoma) subrosea, fragments.

Chlamys geminulata, fragments.

Tellinidae, indeterminate fragments.

?*Dosina zelandica*, fragments.

Myadora boltoni, few whole valves.

Myadora sp., fragments.

?*Gari* sp., fragments.

Atrina pectinata zelandica, fragments.

Scalpomactra scalpellum, few pieces.

A large proportion of indeterminable bivalve fragments.

Gastropoda: *Antisolarium egenum*, common whole.

Zeacolpus sp., pieces.

Maoricolpus roseus, few fresh colourful pieces.

Sigapatella novaezelandiae, several fragments.

Zegalenus fenuis, few whole.

Trochus (*Thorista*) *viridis*, 1 fragment worn.

Tanea zelandica, several fragments.

Austrofuscus glans, juvenile shells and large fragments are common.

Amalda (*Gracilispira*) *novaezelandiae*, 1 whole and pieces.

Amalda (*Baryspira*) *depressa*, few pieces.

Neoguraleus sp., 1 fresh shell.

Duplicaria tristis, few fresh small.

Scaphopoda: *Dentalium nanum*, few small pieces.

Crustacea: A few crab "fingers". I think these are really a callianassid similar to *Ctenocheles*.

Echinoidea: *Fellaster zelandiae*, pieces common.

Also worn barnacle plates are common.

Ecology: A shallow water fauna from ca. 5 - 10 m off a sandy ocean beach, with many beach taxa (notably *Dosinia*, *Fellaster*) and a few fragments from rocky shores (*Barbatia*, *Trochus viridis*). But most are normal soft substrate infauna and epifauna. *Dentalium nanum* rarely occurs shallower than about 10 m.

Appendix 3:

Pollen and Spore Identifications and Palaeoenvironment Determinations Relevant to the Te Horo Beach Testbore.

These microflora analyses are from samples collected in the Manawatu – Horowhenua district by L.J.Brown and examined by either Dr Neville Moar or Dr Dallas Mildenhall.

Fossil Record No. R25/f53; sample from depth of 74.0 m in Te Horo Testbore ;

The sample is swamped by *Cyathea* and monolete spores. Sample is water sorted and preservation of all grains is poor. (DMC).

Pollen Analysis of samples from the Otaki Sandstone:

Samples collected from a farm track cutting beside State Highway 57 just south of Tokomaru Stream. Grid Reference S24/223766. Samples about 17 m below the top of the Otaki Sandstone. These samples were collected by Alan Sewell and are reported in Sewell (1991). The original results as reported in Mildenhall (1990) are reproduced as follows -

Fossil Record No. S24/f44.

Sample S24/f44 contains abundant well preserved plant material but relatively sparse spores and pollen representative of derivation from an acid peat flax swamp with beech/podocarp forest nearby. There were relatively few taxa identified and it was not possible to determine whether the climate was warm or cold although the lack of distinctive cold climate pollen types would seem to indicate an interglacial peat.

The palynoflora is dominated by monolete spores (35% of the total spores plus pollen assemblage) with the total pollen represented by Cyperaceae (possibly including *Gahnia*) (31%), *Coprosma* (15%), *Nothofagus fusca* group (11%), *Phormium tenax* (9%), Gramineae (8%), Restionaceae (5%), Compositae (Tubuliflora) (5%), *Podocarpus/Prumnopitys* (5%), and *Myrsine* (3%). Some of the pollen grains, especially the beeches, were darker in colour than the others and may be recycled. The presence of the spore *Polypodiisporites radiatus* Pocknall & Mildenhall, may indicate a Castlecliffian age. Pollen from trees formed 18% and herbs 54% of the total pollen flora from a total count of only 102 grains.

Fossil Record No. S24/f45.

Sample S24/f45, from immediately above S24/f44, is very similar to S24/f44 and the environment is also an acid flax swamp, except that it contains many more taxa and many more grains in total. A count of 260 grains was made. The presence in this sample of *Dactylanthus taylori* would indicate an interglacial palynoflora. *D. taylori* is a root parasite which only occurs in the North Island down to Kaitoke near Wellington. This would suggest that the climate was at least as equitable as the present day.

The palynoflora is dominated by the following taxa :- undifferentiated monolete spores (15% of the total palynoflora), *Cyathea* (5% of the total palynoflora), and with percentages based only on the total pollen, Cyperaceae (37%), *Nothofagus fusca* group (18%), *Coprosma* (11%), *Phormium tenax* (7%), Compositae (Tubuliflorae) (4.5%), *Podocarpus/Prumnopitys* (4%), Gramineae (3.5%), and *Nothofagus menziesii* (2.5%). A number of pollen grains could not be identified as they occurred as “ghosts”, possibly as a result of transport to the site of deposition; other grains of darker colour may have been recycled. *Polypodiisporites radiatus* was also present in this sample which could be as old as Castlcliffian. Pollen from trees form 33% of the total pollen, and herbs 50% indicating encroachment onto the site of the surrounding forest and a possible drying out of the swamp. However, abundant available flowing water was still present to allow for the growth of flax (*Phormium tenax*), *Myriophyllum*, *Haloragis* and Restionaceae.

Pollen Analyses of samples from wells near Palmerston North.

S24/f4	S24/f5	S25/f2	T23/f4
Linton	Linton	Ohau	Ashhurst
S24/267848	S24/267848	S25/997574	T23/434003
Depth 26 m	Depth 80 m	Depth 60 m	Depth 60 m

Nothofagus and Tree Conifers

<i>Dacrycarpus dacrydioides</i>	2	1		
<i>Dacrydium cupressinum</i>	23	6	tr	+
<i>Libocedrus</i>		1		
<i>Nothofagus fusca</i> type	7	43	17	+
<i>Nothofagus menziesii</i>	1	3	4	
<i>Podocarpus</i>	26	8	5	+

Other Woody Plants

<i>Ascarina</i>	9	5		
Compositae		+	40	
<i>Coprosma</i>	5	3	11	
<i>Dacrydium bidwillii</i>			1	
<i>Elaeocarpus</i>	1			
Fuchsia		1		
<i>Griselinia</i>	2			
Hebe	1		tr	
Hoheria			1	
<i>Knightia</i>		2		
<i>Leptospermum</i>	13	7	8	+
<i>Metrosideros</i>	3	5	tr	
<i>Myrsine</i>	2	3	6	
Myrtaceae			2	
<i>Nestegis</i>			4	
<i>Parsonsia</i>	1			
<i>Phyllocladus</i>	1	1	tr	
<i>Plagianthus betulinus</i>	1	1	tr	
<i>Pseudopanax</i>	2	5		

<i>Pseudowintera</i>	1	+		
<i>Quintinia</i>	1	5		
<i>Weinmannia</i>	1			

Herbs

<i>Astelia</i>		2		+
<i>Cotula</i>			tr	
<i>Cyperaceae</i>	2	3	7	+
<i>Empodisma</i>			2	+
<i>Gramineae</i>	4	5	24	
<i>Gunnera</i>			1	
<i>Haloragus</i>			tr	
<i>Phormium</i>		1		
<i>Rosaceae</i>			tr	
<i>Taraxacum</i>		1		
<i>Umbelliferae</i>	1		tr	

Aquatics

<i>Myriophyllum</i>	1			
<i>Potamogeton</i>		1	1	

Spores

<i>Dicksonia squarrosa</i>	1	1	tr	
<i>Monolete</i>	13	14	7	
<i>Gleichenia</i>			49	
<i>Lycopodium</i>	+			
<i>Lycopodium varium</i>		+		
<i>Trilete</i>	83	47	2	+

Results: Apart from T23/f4 for which pollen were very scarce these samples produced good pollen counts. All of these samples suggest interglacial conditions. (Dr Neville Moar, Botany Division, Department of Scientific and Industrial Research, Lincoln – 13 April 1981.

Fossil Record No. S25/f5 from well at Centrepont Horticultural Complex, Te Horo.

Blue clay and peat sample from a depth of 42 m in an irrigation water well drilled at the Centrepont Horticultural Complex, Te Horo (GR S25/904426). The stratum was thought to be Waimahoe Lignite (Fleming 1972). Pollen identification and palaeoenvironment determination by Dr Dallas Mildenhall, New Zealand Geological Survey, Lower Hutt - 19 June 1985.

Assemblage: *Cyathea* (39%), undifferentiated monolete spores (21%) of total spores and pollen.

Total pollen – *Nothofagus fusca* group (49%), *Coprosma* (10%), *Dacrydium cupressinum* (10%), *Podocarpus* (7%) and *Cyperaceae* (4%).

Environment: Coastal beech forest close to dune sands with coastal scrub.

Climate: Warm moist, possibly even warmer than the present day.

Correlation: While I can not exclude the possibility of this sample being Waimahoe Lignite I must say that it is somewhat different from the Waikanae beds. For instance *Lygodium articulatum* (a warm climate indicator) has not been recorded from the Waimahoe Lignite. No *Knightia excelsa* was recorded (common in Waimahoe Lignite). However I must say that sequences from the Waimahoe Lignite appear to be very different from different localities. (DCM)

Appendix 4:

Radiocarbon Dates Relevant to the Te Horo Beach Testbore

Samples from the Te Horo Beach testbore

NZ C14 No. 6602 – Fossil Record File No. R25/f4

Collector: L.J.Brown and N.H.Smith

Location: Kapiti Coast, Te Horo Beach. Water well for Manawatu Catchment Board, Sims Road. Sample 18.5 m below ground level (10.3 m below sea level). GR R25/863444.

Sample: Shells (shallow water off an open ocean sand beach).

Age: 3900 +- 80 years – with respect to old T $\frac{1}{2}$ (5568 years).

4010 +- 90 years – with respect to new T $\frac{1}{2}$ (5730 +- 40 years).

4380 +- 140 years – corrected for secular effects.

Significance: Sample will provide an age for the rate of postglacial marine deposition before the coast prograded westward to the present day Te Horo Beach.

NZ C14 No. 6603 – Fossil Record File No. R25/f16

Collector: L.J.Brown and N.H.Smith

Location: Kapiti Coast, Te Horo Beach. Water well for Manawatu Catchment Board, Sims Road. Sample 33.0 m below ground level (25 m below sea level). GR R25/863444.

Sample: Shells (from 10 – 20 m on the inner shelf in soft sediments).

Age: 6190 +- 160 years – with respect to old T $\frac{1}{2}$ (5568 years).

6370 +- 170 years – with respect to new T $\frac{1}{2}$ (5730 +- 40 years).

7040 +- 170 years – corrected for secular effects.

Significance: This sample is from near the base of the postglacial marine deposits at Te Horo Beach and age provides a date for the onset of the marine transgression at present day coast.

NZ C14 No. 6574 – R25/53

Collector: L.J.Brown and N.H.Smith

Location: Kapiti Coast, Te Horo Beach. Water well for Manawatu Catchment Board, Sims Road. Sample 75.0 m below ground level (67 m below sea level). GR R25/863444.

Sample: Peat and wood.

Age: 35 800 + 2150 – 1750 years – with respect to old T $\frac{1}{2}$ (5568 years).

36 900 + 2300 – 1750 years – with respect to new T $\frac{1}{2}$ (5730 +- 40 years).

Significance: Possible correlative of Waimahoe Lignite of Fleming (1972).

NZ C14 No. 6612 – Fossil Record File No. R25/f55

Collector: L.J.Brown and N.H.Smith

Location: Kapiti Coast, Te Horo Beach. Water well for Manawatu Catchment Board, Sims Road. Sample 100 m below ground level. GR R25/863444.

Sample: Shells

Age: 41 200 + 2450 – 1950 years – with respect to old T $\frac{1}{2}$ (5568 years).

42 400 + 2500 – 2000 years – with respect to new T $\frac{1}{2}$ (5730 +- 40 years).

Significance: This sample is most likely beyond radiocarbon dating. The age obtained would be a product of a minute amount of contamination of the *in situ* sample by radiocarbon present in groundwater (LJB – collector).

Other Horowhenua – Manawatu Radiocarbon Ages

The following radiocarbon dates from the Horowhenua – Manawatu districts were compiled as part of a joint New Zealand Geological Survey – Manawatu Catchment Board project in 1985. Kapiti Coast radiocarbon dates and post-1985 radiocarbon dates have not been compiled.

NZ C14 No. 293

Collector: J.D.Cowie

Location: Manawatu, Taikora. 10 km from the coast. GR S24/107902.

Sample: Wood

Age: 855 +- 50 years.

Significance: Tree trunk, rooted in place beneath 3 m of wind blown Himatangi sand (Motuiti dune sand). See Cowie (1963).

NZ C14 No. 3085

Collector: P.A.Hesp

Location: Manawatu, Shannon. SW of township near the Buckley – Shannon roads intersection. Below and west of Tokomaru marine terrace formation. 0.9 – 1.2 m above mean sea level. GR S24/126702.

Sample: Shells – marine bivalves.

Age: 6150 +- 60 years.

6330 +- 70 years.

Significance: The occurrence of shell at this location is considered to be evidence of a coastal lagoon in the lower Manawatu Valley at the end of the Holocene transgression. A date for these shells should provide useful information for continuing research on Holocene sea levels, possible Holocene tectonism in this area, and the origin of certain geomorphological features such as box shaped valleys and relict cliffs. See Hesp and Shepherd (1978).

NZ C14 No. 3186

Collector: J.D.G.Milne

Location: Manawatu, Clydesdale. On bank of Rangitikei River exposed in cliffs 1.5 km W. of Mt Alexander Trig station. GR S23/071025.

Sample: Wood

Age: 4170 +- 60 years – with respect to old T $\frac{1}{2}$ (5568 years).

4290 +- 60 years – with respect to new T $\frac{1}{2}$ (5730 +- 40 years).

4850 +- 120 years – corrected for secular effects.

Significance: Small tree trunk buried by advance of the oldest Foxton dune sands at this locality. Should date advance of oldest dune sand.

NZ C14 No. 3187

Collector: J.D.G.Milne

Location: Manawatu, Clydesdale. On bank of Rangitikei River exposed in cliffs 1.5 km W. of Mt Alexander Trig station. GR S23/071025.

Sample: Wood

Age: 3470 +- 60 years – with respect to old T½ (5568 years).

3570 +- 60 years – with respect to new T½ (5730 +- 40 years).

3840 +- 70 years – corrected for secular effects.

Significance: Wood from small trees growing on the oldest Foxton dune sands at this locality and buried by later advance of Foxton dune sand.

NZ C14 No. 4606

Collector: M.J.Shepherd

Location: Manawatu. 2 km S. of Tangimoana and 2 km inland from coast from gravel pit in ancient beach ridge deposits. GR S24/011968.

Sample: Shell

Age: 5480 +- 60 years– with respect to old T½ (5568 years).

5640 +- 70 years– with respect to new T½ (5730 +- 40 years).

Significance: Shell sample from within massive beach gravels 1.2 m below surface extending down to at least 1.6 m below the surface. Date indicates progradation rates since mid-Holocene for the north Manawatu have averaged c. 0.38 m/ year and uplift rates averaged c. 0.35 m / 1000 years (assuming eustatic sea levels have remained constant since the ridges were deposited).

NZ C14 No. 4719

Collector: M.J.Shepherd

Location: Manawatu. 4 km N. of Tangimoana and 1.2 km from the coast from gravel pit in ancient beach ridge deposits. GR S23/700100.

Sample: Shell (*Paphies subtriangulata*).

Age: 5770 +- 50 years – with respect to old T½ (5568 years).

5940 +- 60 years – with respect to new T½ (5730 +- 40 years).

6600 +- 200 years – corrected for secular effects.

Significance: Shell within beach gravels. Gravel ridge about 2 m above the height of the present beach berm; an uplift rate of about 0.33 m / 1000 years is indicated (assuming a stable eustatic sea level since the ridges were deposited).

NZ C14 No. 4820

Collector: M.J.Shepherd

Location: Manawatu. 1 km SW of Rangiotu where a meander of the Oroua River has undercut a Foxton Phase sand dune, where dunes reach maximum inland extent. GR S24/164836.

Sample: Wood (*Leptospermum scoparium*).

Age: 1800 +- 65 years – with respect to old T½ (5568 years).

1855 +/- 70 years – with respect to new T½ (5730 +/- 40 years).

1785 +/- 70 years – corrected for secular effects.

Significance: River alluvium overlain by 1.6 m of dune sand, which is overlain by a layer 0.5 m in thickness containing peat, clay and macro plant remains. Date provides maximum age for dune migration associated with Foxton Dune Phase (Cowie 1963). Layer A includes small trees and flax, overlain by further 0.3 m of sand and a thin peat layer.

NZ C14 No. 5215

Collector: M.J.Shepherd

Location: Manawatu. 1 km SW of Rangiotu where a meander of the Oroua River has undercut a Foxton Phase sand dune, where dunes reach maximum inland extent. GR S24/164836.

Sample: Leaves, twigs and peat.

Age: 1595 +/- 65 years – with respect to old T½ (5568 years).

1645 +/- 70 years – with respect to new T½ (5730 +/- 40 years).

Significance: Date of layer B gives an approximate age for main encroachment of Foxton Phase dunes in this area, and time interval between deposition of layers A and B.

NZ C14 No. 5216

Collector: M.J.Shepherd

Location: Manawatu. 1 km SW of Rangiotu where a meander of the Oroua River has undercut a Foxton Phase sand dune, where dunes reach maximum inland extent. GR S24/164836.

Sample: Peat

Age: 1950 +/- 65 years – with respect to old T½ (5568 years).

2010 +/- 70 years – with respect to new T½ (5730 +/- 40 years).

1945 +/- 85 years – corrected for secular effects.

Significance: Date for layer A to give maximum age for encroachment of the Foxton Dune Phase in this area.

NZ C14 No. 5217

Collector: M.J.Shepherd

Location: Manawatu. 1 km SW of Rangiotu where a meander of the Oroua River has undercut a Foxton Phase sand dune, where dunes reach maximum inland extent. GR S24/164836.

Sample: Peat

Age: 1775 +/- 65 years – with respect to old T½ (5568 years).

1825 +/- 65 years – with respect to new T½ (5730 +/- 40 years).

1765 +/- 65 years – corrected for secular effects.

Significance: River alluvium overlain by 1.6 m of dune sand, which is overlain by a layer 0.5 m in thickness containing peat, clay and macro plant remains. Date provides maximum age for dune migration associated with Foxton Dune Phase (Cowie 1963). Layer A includes small trees and flax, overlain by further 0.3 m of sand and a thin peat layer.

NZ C14 No. 5218

Collector: M.J.Shepherd

Location: Manawatu. Floodplain of Manawatu River about 4 km SW of Opiki.

Borehole on farm of G.K.Murray. S24/147802.

Sample: Shells (*Austrovenus stutchburyi*).

locality. Should date advance of oldest dune sand.

Age: 6280 +- 220 years – with respect to old T½ (5568 years).

6460 +- 230 years – with respect to new T½ (5730 +- 40 years).

7110 +- 230 years – corrected for secular effects.

Significance: Shells from thinly interlayered beds of estuarine muds and sands which underlie nearly 10 m of river alluvium. Date together with faunal evidence indicates that at the end of the postglacial marine transgression, the Manawatu estuary extended inland to the vicinity of Opiki. See also NZ 3085 near Shannon used by Gibb (1986).

NZ C14 No. 5219

Collector: M.J.Shepherd

Location: Manawatu. 4.5 km SW of Rangiotu on riverbank of Manawatu River where base of dunes is exposed. GR S24/147814.

Sample: Wood (*Podocarpus spicatus*).

Age: 3410 +- 80 years – with respect to old T½ (5568 years).

3510 +- 80 years – with respect to new T½ (5730 +- 40 years).

3730 +- 100 years - corrected for secular effects.

Significance: Wood from 2 m beneath the surface of a layer of blue-grey river alluvium of silt-clay grade which underlies Foxton dune sand. Age of period of floodplain alluvial deposition prior to encroachment.

NZ C14 No. 5220

Collector: M.J.Shepherd

Location: Manawatu. 4.5 km SW of Rangiotu on riverbank of Manawatu River where base of dunes is exposed. GR S24/147814.

Sample: Wood

Age: 2270 +- 60 years – with respect to old T½ (5568 years).

2340 +- 60 years – with respect to new T½ (5730 +- 40 years).

2380 +- 110 years - corrected for secular effects.

Significance: Wood in growing position rooted in palaeosol (layer D), which lies above river alluvium and is overlain by the narrow horizons E and F approximate 14 m of Foxton Dune sand. Maximum age for Holocene dune encroachment and minimum age for underlying alluvial surface.

NZ C14 No. 5221

Collector: M.J.Shepherd

Location: Manawatu. 4.5 km SW of Rangiotu on riverbank of Manawatu River where base of dunes is exposed. GR S24/147814.

Sample: Wood

Age: 1875 +- 65 years – with respect to old T½ (5568 years).

1930 +- 65 years – with respect to new T½ (5730 +- 40 years).

1860 +/- 65 years - corrected for secular effects.

Significance: Wood from horizon F, which lies at the base of a sand dune. Provides an age for the encroachment of the Foxton Dune sand phase in this area.

NZ C14 No. 5222

Collector: M.J.Shepherd

Location: Manawatu. 2 km SW from Tangimoana and 3 km from shoreline. Borehole T1 of drilling project. Core depth 5.4 – 5.8 m. GR S24/023967.

Sample: Shells (*Macra murchisoni*).

Age: 4400 +/- 70 years – with respect to old T½ (5568 years).

4530 +/- 70 years – with respect to new T½ (5730 +/- 40 years).

5110 +/- 80 years - corrected for secular effects.

Significance: Shell from upper part of a gravelly regressive facies of the Holocene marine “wedge” about 1 km seaward from innermost (oldest) Holocene shoreline. Gravels overlain by approximately 3 m of dune sand.

NZ C14 No. 5223

Collector: M.J.Shepherd

Location: Manawatu. 2 km SW from Tangimoana and 3 km from shoreline. Borehole T1 of drilling project. Core depth 11.3 – 11.9 m. GR S24/023967.

Sample: Shell (*Mesodesma subtriangulatum*)

Age: 4570 +/- 70 years – with respect to old T½ (5568 years).

4700 +/- 80 years – with respect to new T½ (5730 +/- 40 years).

5310 +/- 90 years - corrected for secular effects.

Significance: Shell from lower margin of a gravelly regressive facies of the Holocene marine “wedge” about 1 km seaward from the innermost (oldest) Holocene shoreline.

NZ C14 No. 5224

Collector: M.J.Shepherd

Location: Manawatu. 3 km SW of Tangimoana and 3 km inland from the present shoreline. Borehole T3 of drilling project. Core depth 6.7 – 8.5 m. GR S24/029961.

Sample: Shell

Age: 12 500 +/- 150 years – with respect to old T½ (5568 years).

12 850 +/- 150 years – with respect to new T½ (5730 +/- 40 years).

Significance: Shell from Holocene beach gravels surface which lies at the same level as the present high tide swash mark. Gravels overlain by 6.75 m of dune sand. Likely to be reworked shell fragments derived from lower Pleistocene shorelines and transported eastwards by transgressing sea.

NZ C14 No. 5225

Collector: M.J.Shepherd

Location: Manawatu. 2 Km SSW of Tangimoana and 1.5 km inland from the present shoreline. Borehole T4 of drilling project. Core depth 6.0 – 6.9 m. GR S24/005967.

Sample: Shell (*Mesodesma subtriangulatum*).

Age: Modern

Significance: Shell from upper part of a shelly gravel facies overlain by sandy marine sediment. Probably from an offshore environment very close to the beach. As the site is located more than 1 km inland, the modern age is surprising and can only be explained by postulating that the Rangitikei River swung much further southwards before entering the sea at some period during the past 250 years. However, historical maps provide no evidence for such an occurrence during the past 100 years.

NZ C14 No. 5226

Collector: M.J.Shepherd

Location: Manawatu. 2 Km SSW of Tangimoana and 1.5 km inland from the present shoreline. Borehole T4 of drilling project. Core depth 10.8 m. GR S24/005967.

Sample: Shell (*Spisula aequilateralis*).

Age: 2540 +- 80 years – with respect to old T½ (5568 years).

2620 +- 80 years – with respect to new T½ (5730 +- 40 years).

Significance: Shell from lower part of a shelly gravel facies overlain by sandy marine sediment. Probably from an offshore environment very close to the beach.

NZ C14 No. 5228

Collector: M.J.Shepherd

Location: Manawatu. 2 Km SSW of Tangimoana and 1.5 km inland from the present shoreline. Borehole T4 of drilling project. Core depth 26.0 m. GR S24/005967.

Sample: Shell (*Spisula aequilateralis*).

Age: 4590 +- 80 years – with respect to old T½ (5568 years).

4730 +- 80 years – with respect to new T½ (5730 +- 40 years).

5350 +- 80 years - corrected for secular effects.

Significance: Shell from lower part of a shelly gravel facies overlain by sandy marine sediment. Probably from an offshore environment very close to the beach.

NZ C14 No.5229

Collector: M.J.Shepherd

Location: Manawatu. 2 km SW from Tangimoana and 2.5 km inland from the present shoreline. Borehole T5 of drilling project. Core depth 2.5 – 3.1 m. GR S24/016967.

Sample: Shell (*Mesodesma subtriangulatum*).

Age: 3780 +- 90 years – with respect to old T½ (5568 years).

3890 +- 100 years – with respect to new T½ (5730 +- 40 years).

4230 +- 110 years - corrected for secular effects.

Significance: Shell from Holocene beach gravels 2.5 km inland from coast. Surface of beach gravels about 1 m above the present high-tide swash mark. Will determine age of Holocene “wedge” in this area. Also see sample NZ C14 No. 5230.

NZ C14 No.5230

Collector: M.J.Shepherd

Location: Manawatu. 2 km SW from Tangimoana and 2.5 km inland from the present shoreline. Borehole T5 of drilling project. Core depth 2.5 – 3.1 m. GR S24/016967.

Sample: Shell (*Glycymeris Mactra*).

Age: 9850 +- 130 years – with respect to old T½ (5568 years).

10 150 +/- 150 years – with respect to new T $\frac{1}{2}$ (5730 +/- 40 years).
Significance: Shell from Holocene beach gravels 2.5 km inland from coast. Surface of beach gravels about 1 m above the high-tide swash mark. The laboratory considers that of the two dates obtained for this sample, the older is more likely to be correct. If this is so, the shell fragments which were well rounded must have been reworked.

NZ C14 No. 81

Collector: M.Te Punga

Location: Foxton, Manawatu Plain. Water well located adjacent to water tower. Sample 47 m below ground level (48 m below sea level). GR S24/033787).

Sample: Wood

Age: 9900 +/- 150 years – with respect to old T $\frac{1}{2}$ (5568 years).

Significance: Sample provides an age for the onset of the Postglacial marine transgression of the present day coast of the Manawatu Plain. See Te Punga (1958).

NZ C14 No. 5243 – Fossil Record File No. S24/f3

Collector: L.J.Brown

Location: Palmerston North. Water well for General Foods Corporation. Sample 44 m below sea level (26 m below sea level). GR S24/308920.

Sample: Wood (*Leptospermum ericoides*).

Age: > 33 200 years – with respect to old T $\frac{1}{2}$ (5568 years).

> 34 200 years – with respect to new T $\frac{1}{2}$ (5730 +/- 40 years).

Significance: Beyond radiocarbon and most likely shell from the last interglacial (Kaihinuan) Tokomaru Marine Surface.

NZ C14 No. 80

Collector: M.Te Punga

Location: Manawatu, Awahuri. Water well (M-WRC well no. 325203) for former Awahuri Dairy Company. Sample 71 m below ground level.

Sample: Shell

Age: > 45 000 years.

Significance: See Te Punga (1954).

NZ C14 No. 522

Collector: C.A.Fleming and T.L.Grant-Taylor

Location: Horowhenua. Levin – Koputaroa Road. Peat 1.6 m below base of Aokautere Ash in Koputaroa Dune sand. GR S25/064668.

Sample: Silty peat.

Age: 35 000 +/- 1700 years.

Significance: Dates a phase of cooler climate. See McIntyre (1963) in Cowie (1963).

NZ C14 No. 3938

Collector: P.A.Hesp and M.J.Shepherd

Location: Tokomaru. About 4 km N. of Tokomaru 100 m N. of Campbell Road. GR S24/180791.

Sample: Wood (Totara).

Age: 41 500 +7450 –2800 years – with respect to old T¹/₂ (5568 years).

42 700 + 7650 – 3950 years – with respect to new T¹/₂ (5730 +- 40 years).

Significance: Many borelogs indicate that the lower Manawatu floodplain is underlain by a horizon of river gravels commonly occurring at a depth of 20 – 30 m. Date confirms that Manawatu terraces formed during the Otiran Glacial Stage continue beneath the lower Manawatu floodplain. The terrace gravels dated, probably correlate with the Milson Terrace of the Manawatu Valley, and the Rata Terrace of the Rangitikei Valley and were deposited during the penultimate major phase of aggradation during the Otira Glacial.

NZ C14 No. 5262 – Fossil Record File No. S25/f1

Collector: L.J.Brown

Location: Horowhenua – SH 1, Ohau. Water well for Mr K.Young. Sample 68 m below ground level (41 m below sea level). GR S25/997574.

Sample: Shell (*Austrovenus stutchburyi*).

Age: > 35 700 years – with respect to old T¹/₂ (5568 years).

> 36 700 years – with respect to new T¹/₂ (5730 +- 40 years).

Significance: Last interglacial marine deposits correlated with Otaki Sandstone. This shell bed may prove to provide a “marker bed” for subsurface correlation of late Quaternary deposits in the Horowhenua – Manawatu region.

NZ C14 No. 5262 – Fossil Record File No. S25/f2

Collector: L.J.Brown

Location: Horowhenua – SH 1, Ohau. Water well for Mr K.Young. Sample 60 m below ground level (33 m below sea level). GR S25/997574.

Sample: Peat.

Age: > 36 300 years – with respect to old T¹/₂ (5568 years).

> 37 400 years – with respect to new T¹/₂ (5730 +- 40 years).

Significance: Last interglacial marine deposits correlated with Otaki Sandstone. This shell bed may prove to provide a “marker bed” for subsurface correlation of late Quaternary deposits in the Horowhenua – Manawatu region.

Appendix 5:

Water Isotope Analyses Relevant to the Te Horo Beach Testbore

Groundwater and surface water samples have been collected from wells, springs, rivers and streams in the Horowhenua – Kapiti districts and analysed for tritium, oxygen 18/deuterium isotopes at the Institute of Nuclear Sciences, Department of Scientific and Industrial Research, Lower Hutt. Dr Mike Stewart (oxygen18/deuterium) and Dr Claude Taylor (tritium) have carried out the analyses and their interpretation. The following list makes no claim to include all groundwater isotope analyses for samples from the Horowhenua – Kapiti districts. It only lists those samples where New Zealand Geological Survey (and later Institute of Geological and Nuclear Sciences) was involved in sample collection.

The concentrations of the hydrogen isotope tritium in groundwater provide valuable clues in distinguishing the old (pre-1953) and modern (post-1953) groundwaters. The concentration of the isotope oxygen 18 provide clues as to the origin and sources of the groundwater. Deuterium concentration complements the oxygen 18 analyses result.

Tritium concentrations are expressed as Tritium Ratios (TR) + 1 standard measurement error at the date of sample collection. TR = 1 corresponds to a T/H ratio 10^{-18} . Oxygen 18 concentrations are expressed as the conventional d- values, where d ^{18}O is the difference between the $^{18}\text{O}/^{16}\text{O}$ ratio of the water sample and that of the Vienna Standard Mean Ocean Water (V-SMOW); the experimental precision is about 0.1 in these units.

Isotope Analyses Samples

Well numbers are as listed in WRC (1994) and include some obvious errors and duplications – Table 23.3 (WRC 1994).

NZGS Sample H 1/83

Well 371681 owned by Gavin Sims, Swamp Road, Te Horo. Grid reference R25/878454. Total depth 24 m. Sampled 25 May 1983.

INS No. HNI 124 – $d^{18}\text{O}\text{‰}$ –5.9

NZGS Sample H 2/83

Well 371681 owned by Downs Bros., Pukenuamu Road, Te Horo Beach. Grid reference R25/864426. Total depth 27 m. Sampled 25 May 1983.

INS No. HNI 125 – $d^{18}\text{O}\text{‰}$ –6.0

NZGS Sample H 3/83

Well 370051 owned by Bruce Davis, Sims Road, Te Horo Beach. Grid reference R25/866450. Total depth 37 m. Sampled 25 May 1983.

INS No. HNI 126 – d₁₈O‰ –5.6

NZGS Sample H 4/83

Well 380001 owned by Mike Campion, Main Road, Peka Peka. Grid reference S25/858391. Total depth 76 m. Sampled 25 May 1983.

INS No. HNI 127 – d₁₈O‰ –5.9

NZGS Sample H 5/83

Well 381025 owned by Paul Faith, Te Horo – Hautere Cross Road, Te Horo. Grid reference R25/883425. Total depth 9 m. Sampled 25 May 1983.

INS No. HNI 128 – d₁₈O‰ –5.6

NZGS Sample H 6/83

Well 371581 owned by de Berry, Hogg and Shaw, Main Road, Te Horo. Grid reference R25/892432. Total depth 95 m. Sampled 25 May 1983.

INS No. HNI 129 – d₁₈O‰ –5.7

NZGS Sample H 7/83

Spring on property of Jim Spiers, Te Horo Beach Road, Te Horo. Grid reference R25/887437. Sampled 25 May 1983.

INS No. HNI 130 – d₁₈O‰ –5.8

NZGS Sample H 8/83

Mangaone Stream at Main Road bridge, Te Horo. Grid reference R25/892432. Sampled 25 May 1983.

INS No. HNI 131 – d₁₈O‰ –5.2

NZGS Sample H 9/83

Otaki River, 8 km upstream of Main Road at end of Rainui Road, Otaki Gorge. Grid reference S25/953420. Sampled 25 May 1983.

INS No. HNI 132 – d₁₈O‰ –5.4

NZGS Sample H 10/83

Well 381171 owned by Centrepont, Te Horo – Hautere Cross Road, Te Horo. Grid reference S25/990424. Total depth 128 m. Sampled 25 May 1983.

INS No. HNI 133 – d₁₈O‰ –5.5; TR 0.20 +- 1.13

NZGS Sample H 11/83

Well 381031 owned by Bob Blackburn, Te Horo – Hautere Cross Road, Te Horo. Grid reference S25/381031. Total depth 52 m. Sampled 25 May 1983.

INS No. HNI 134 – d₁₈O‰ –5.5; TR 0.15 +- 0.13

NZGS Sample H 12/83

Well 381131 owned by Ted Cobb, Te Horo – Hautere Cross Road, Hautere. Grid reference S25/927422. Total depth 70 m. Sampled 25 May 1983.

INS No. HNI 135 – d₁₈O‰ –5.9

NZGS Sample H 13/83

Well no. ? owned by Tom Empson, Old Hautere Road, Te Horo. Grid reference S25/919439.

Total depth 31 m. Sampled 25 May 1983.

INS No. HNI 136 – d₁₈O‰ –5.9; TR 4.60 +- 0.24

NZGS Sample H14/83

Well no. ? owned by Roper, Lang, Burke and Cleland, Otaki Gorge Road, Otaki. Grid reference S25/915457. Total depth 15 m.

INS No. HNI 137 – d₁₈O‰ –5.1; TR 6.08 +- 0.29

NZGS Sample H 15/83

Well no. ? owned by Ron Monk, Mill Road, Otaki. Grid reference S25/911485. Total depth 10 m. Sampled 25 May 1983.

INS No. HNI 138 – d₁₈O‰ –5.7

NZGS Sample H 16/83

Well 371171 owned by Alister Pain, Te Horo. Grid reference R25/896443. Total depth 14 m. Sampled 25 May 1983.

INS No. HNI 139 – d₁₈O‰ –5.3

NZGS Sample H 1/84

Well 371331 owned by Bill Hunt, Otaki. Grid reference S25/696877. Total depth 60 m. Sampled 8 May 1984.

INS No. ? TR –0.7 +- 0.09

NZGS Sample H 2/84

Well 381171 owned by Centrepoint, Te Horo – Hautere Cross Road, Te Horo. Grid reference S25/990424. Total depth 128 m. Sampled 8 May 1984.

INS No. ? TR -0.03 ± 0.09

NZGS Sample H 3/84

Spring, Te Horo. Grid reference R25/886432. Sampled 8 May 1984.

INS No. ? TR 4.39 ± 0.29

NZGS Sample H 4/84

Otaki River, Otaki. Grid reference S25/912462. Sampled 9 May 1984.

INS No. ? TR 3.32 ± 0.23

Results

The $\delta^{18}\text{O}$ measurements show a range of -5.1 to -6.0‰ which is considerably larger than the measurement error. The Otaki River is likely to have a more negative average $\delta^{18}\text{O}$ value than rainfall on the coastal plain, but it would also have a seasonal variation with less negative values in late summer. The results are inconclusive for assigning the derivation of the groundwater to a particular source. Both local and coastal rain and higher altitude catchment derived water contribute to groundwater recharge (M.K.Stewart pers. comm. 1985).

The tritium measurements show a significant proportion of the groundwater in the deeper aquifers (last glaciation and older) has been present in the aquifers for at least 30 years suggesting a low through flow of groundwater at depth.

WRC Testbores – Kapiti Coast

A series of groundwater testbores were drilled for the Wellington Regional Council and the Kapiti District Council in 1994 - 1995 as part of an extensive investigation of the groundwater resources in the Kapiti Coast region (WRC 1994). Groundwater in two of these investigation wells was sampled for oxygen 18 and tritium analyses.

Samples from well at El Rancho Christian Holiday Camp, Waikanae

Well number 380205, Grid reference R26/807349. Water sample from aquifer at a depth of 19 m. Sampled 26 November 1993.

INS No. ? $\delta^{18}\text{O}\text{‰} -5.78$; TR 3.09 ± 0.08

Well number 380205, Grid reference R26/807349. Water sample from aquifer at a depth of 72 m. Sampled 6 January 1994

INS No. ? $\delta^{18}\text{O}\text{‰}$ -5.94; TR 0.048 +- 0.016

Results

The tritium results show the age of the groundwater in the deep aquifer is at least 50 years old while the shallow groundwater is recent recharge. The shallow groundwater is local rainfall sourced groundwater while that from the deep aquifer may include higher altitude derived groundwater (C.B.Taylor pers. comm. 24 May 1994).

KCDC Depot, Waikanae

Well number KCDC TW1/26, KCDC depot, Waikanae. GR ?. Water sample from ? depth. Sampled ? 19 January 1995.

INS No. ? $\delta^{18}\text{O}\text{‰}$ -5.60; $\delta^2\text{H}$ -32.8‰.

Results

This sample was analysed after concern that sea water might be intruding into the aquifer as a result of high groundwater abstraction and low recharge.

This is typical average result for rainfall sourced groundwater on the Kapiti Coast and shows no input of sea water (M.K.Stewart pers. comm. 24 May 1995).

Appendix 6:

Aquifer Characteristics

Sims Road: Te Horo

**Hydrological Services Group
Wellington Regional Council
February 1993**

1. Abstract

The specific storage and hydraulic conductivity in two confined gravel aquifers near Te Horo Beach on the Kapiti Coast are calculated in this report. The method used has been described by Sinclair (1990). The method involves the measurement of lag and amplitude decay for the response of ground water inland to fluctuations in the sea tide.

2. Introduction

Tidally affected continuous ground water level data is analysed to determine specific storage and hydraulic conductivity in two confined gravel aquifers. Continuous time series data of ground water level fluctuations is collected at two sites near the Te Horo Beach foreshore. Data is collected at 15 minute intervals and store on-site on a paper tape recorder. Leopold and Stevens records are used with a float and counterweight.

Site Name	Tideda Site No.	Depth (m)	Map Reference (NZMS260)	Lithology
Sims Road North	370031	172	R25:866449	Gravel
Sims Road North	370003	60	R25:866449	Gravel

Table One (above) Ground water sites

The two sites used are described in Table One (above). Both sites are approximately 400m from the Te Horo Beach foreshore.

The data is analysed using the tidal response method described in Sinclair (1990). This report uses the same symbols and terminology. Sensitivity analyses are shown assuming changes in porosity and distance of the wells from the shoreline.

The aquifer transmissivity (T) and storage coefficient (S) are calculated using the hydraulic conductivity and specific storage (S_s) determined from this method. Pumping test data is available from the shallower aquifer. T and S values calculated from this test compare favourably with those calculated using the tidal response method.

3. Method

The tidal effect was estimated using hourly tidal data from Port Taranaki. High tide at Port Taranaki occurs 20 minutes after high tide at Te Horo. The data was modified accordingly. Ground water level response data was available for two bores located in Sims Road,

Te Horo. (See Table One). The Sims Road North well records level data from a confined gravel aquifer 172 m below ground. The Sims Road South well is finished in a gravel aquifer 60m below ground level.

The tidal response method is described in Sinclair (1990).

Data from each site; tidal response, north well, and south well, were transformed so that the mean amplitude was zero. Data from the two well sites was originally collected and stored with reference to an arbitrary datum. The tidal data was originally stores as height above chart datum at Port Taranaki. Figure One (below) shows the groundwater and tidal responses before the data was transformed to a common zero datum.

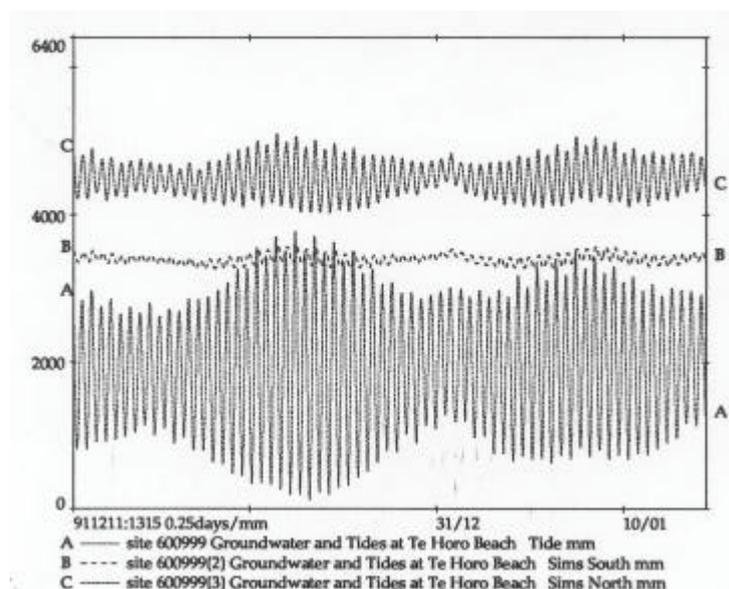


Figure 1: Ground water and tidal response at Te Horo Beach

Response diagrams were plotted using data collected on 12 December 1991. Figure Two (below), shows the water level response at each site. The tidal data has been lagged by 20 minutes. Figures Three and Four show the tidal response on the horizontal axis and ground water level response on the vertical axis for Sims Road South and Sims Road North, respectively.

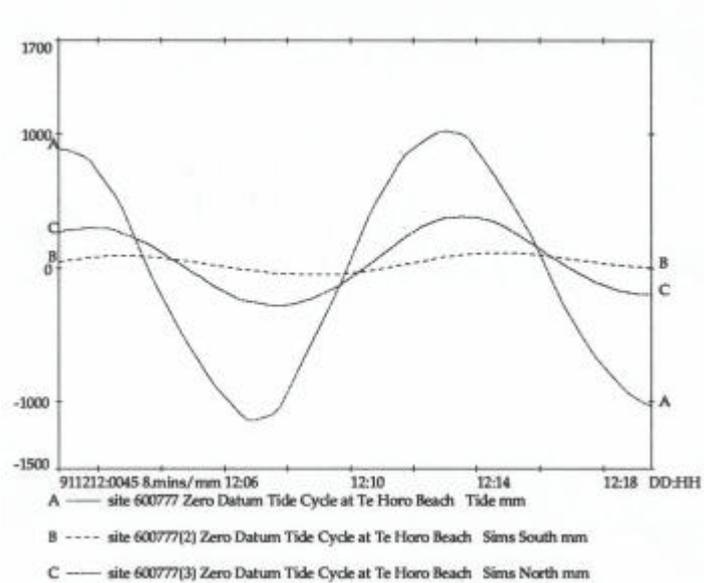


Figure 2: Water level response at each site for 12 December 1991

The slope of the major axis of the response diagrams is used to calculate the remote efficiency (η_r) of the aquifer. The angular lag was calculated using the tidal ratio in the horizontal plane. Specific storage and hydraulic conductivity were calculated once the angular lag and tidal efficiency were determined.

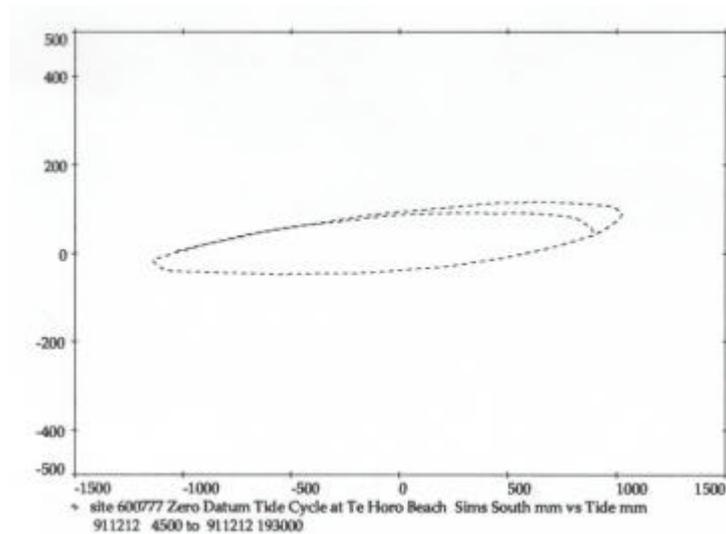


Figure 3: Response diagram for Sims Road South

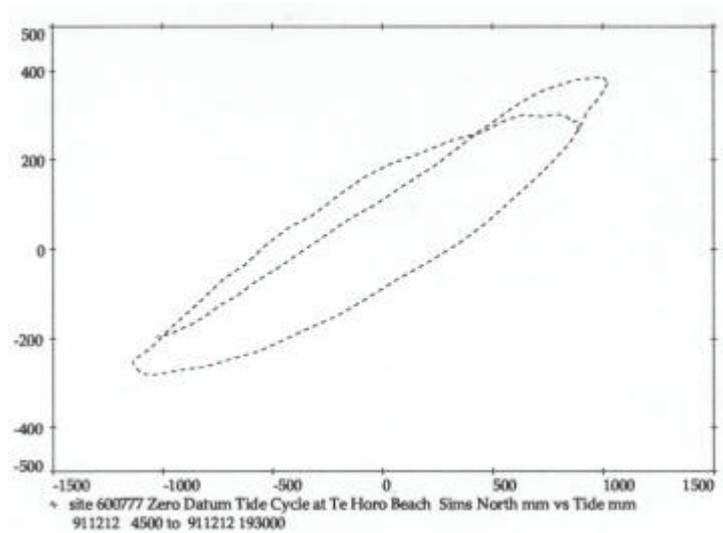


Figure 4: Response diagram for Sims Road North

4. Results

Tidal period $t_0 = 745$ minutes
 $= 0.517$ days

Specific weight of water at 15°C $\gamma_w = \text{N/m}^3$
 Compressibility of water at 15°C $C_w = 4.67 \times 10^{-10} \text{ m}^2/\text{N}$

For calculations of transmissivity and storage coefficient it is assumed that the aquifer thickness (b) is 5m. The initial calculation for hydraulic conductivity assumes that the distance to the shore (x) is 500 m. The initial calculation for specific storage assumes that the porosity (n) is 0.3.

4.1 Sims Road North (370031) 172m Deep

(1) Remote efficiency (η_x)

$$\eta_x = \frac{B'B'}{A'A'}$$

$$= \frac{387 - 281}{1027 - 1138}$$

$$= 0.309$$

(2) **Angular lag (?)**

$$\sin ? = \frac{AA}{A'A'}$$

$$= \frac{860}{2163}$$

$$= 0.398$$

$$? = 0.409 \text{ radians}$$

(3) **Lag (t_l)**

$$\text{Lag (t}_l) = \frac{t_o ?}{2p}$$

$$= \frac{0.517 \times 0.409}{2p}$$

$$= 0.034 \text{ days}$$

$$= 48 \text{ minutes}$$

(4) **Tidal Efficiency (?_o)**

$$\begin{aligned} ?_o &= ?_x e^? \\ &= 0.309 e^{0.409} \\ &= 0.465 \end{aligned}$$

(5) **Specific Storage (S_s)**

$$\frac{nC_w ?_w}{1 - ?_o}$$

$$1 - ?_o$$

$$= \frac{0.3 \times 4.67 \times 10^{-10} \times 9798}{1 - 0.465}$$

$$1 - 0.465$$

$$= 2.57 \times 10^{-6} / \text{m}$$

(6) **Hydraulic Conductivity (K)**

$$K = \frac{p S_s ?^2}{t_o ?^2}$$

$$t_o ?^2$$

$$\frac{px2.57x10^{-8}x(500)^2}{0.517X(.409)^2}$$

$$= 23.3 \text{ m/day}$$

4.1.2 Sensitivity Analyses for Sims Road North

Porosity	S _s	K (m/day)	S	T (m ² /day)
0.1	8.55 x 10 ⁻⁷	7.8	4 x 10 ⁻⁶	39
0.2	1.71 x 10 ⁻⁶	15.5	9 x 10 ⁻⁶	78
0.3	2.57 x 10 ⁻⁶	23.3	1 x 10 ⁻⁵	117
0.4	3.42 x 10 ⁻⁶	31.1	2 x 10 ⁻⁵	155

Table Two : Variation of transmissivity and storage coefficient values with changes in porosity

Distance from Shore (m)	Hydraulic Conductivity (m/day)	Transmissivity (m ² /day)
300	8.4	72
400	14.9	75
500	23.3	117
600	33.6	168
700	45.7	229

Table Three : Variation of transmissivity with distance of well from foreshore

4.2.1 Sims Road South (370003) 60 m deep

(1) **Remote Efficiency (?_x)**

$$?_x = \frac{B'B'}{A'A'}$$

$$= \frac{116 - 47}{1027 - 1136}$$

$$= 0.0754$$

(2) **Angular Lag (?)**

$$\text{Sin } ? = \frac{AA'}{A'A'}$$

$$= \frac{1640}{2163}$$

$$= 0.758$$

$$? = 0.861$$

(3) **Lag (t_l)**

$$t_l = \frac{?t_o}{2p}$$
$$= \frac{0.861 \times 0.517}{2p}$$

= 0.071 days

= 102 minutes

(4) **Tidal Efficiency (?_o)**

$$?_o = ?_x e^?$$
$$= 0.0754 e^{0.861}$$
$$= 0.178$$

(5) **Specific Storage (S_s)**

$$S_s = \frac{n C w^2 w}{1 - ?_o}$$
$$= \frac{0.3 \times 4.67 \times 10^{-10} \times 9798}{(1 - 0.178)}$$
$$= 1.67 \times 10^{-6} / m$$

(6) **Hydraulic Conductivity (k)**

$$K = \frac{p S_s x^2}{t_o ?^2}$$
$$\frac{p \times 1.67 \times 10^{-6} \times (500)^2}{0.517 \times (0.861)^2}$$
$$= 3.4 \text{ m/day}$$

4.2.2 **Sensitivity Analysis for Sims Road South**

Porosity	S_s	K (m/day)	S	T (m²/day)
0.1	5.567x 10 ⁻⁷	1.1	3 x 10 ⁻⁶	6
0.2	1.116x 10 ⁻⁷	2.3	6 x 10 ⁻⁶	12
0.3	1.676x 10 ⁻⁷	3.4	8 x 10 ⁻⁶	17
0.4	2.226x 10 ⁻⁷	4.5	1 x 10 ⁻⁵	23

Table Four : Variation of transmissivity and storage coefficient values with changes in porosity

Distance from Shore (m)	Hydraulic Conductivity (m/day)	Transmissivity (m ² /day)
300	1.23	6
400	2.19	11
500	3.42	17
600	4.92	25
700	6.71	34

Table Five : Variation of transmissivity with distance of well from foreshore

5. Discussion

Transmissivity and storage coefficient estimates for both aquifers are available from a Wellington Regional Council report (1992). They are shown in Table Six, with the representative value calculated by the tidal response method.

Site	Transmissivity (m ² /day)		Storage Coefficient	
	Estimate	Tidal Method	Estimate	Tidal Method
Sims Road North	150	117	3 x 10 ⁻⁴	1 x 10 ⁻⁵
Sims Road South	10	17	1 x 10 ⁻⁴	8 x 10 ⁻⁶

Table Six : Calculated results

A pump test on the 60 metre layer in 1983 shows a transmissivity range of 11-15 (m²/day). The storage coefficients differ by 1-2 orders of magnitude. This suggests that other factors affect the storage coefficient determined from pumping tests.

The tidal response diagrams also exhibit deviation from “ideal” behaviour. Sea tide fluctuations do not follow an ideal sinusoidal fluctuation. Ground water fluctuations are also affected by ground water pumping. Hence actual tidal response diagrams look more like hysteresis curves than ellipses.

6. Conclusions

The tidal response method shows good agreement with transmissivities calculated from pumping tests. Storage coefficient estimates appear to differ by 1-2 orders of magnitude. The deep aquifer (172 m) at Sims Road has a transmissivity of about 120 m²/day while the shallow aquifer (60 m) has a transmissivity of about 20 m²/day.

References

Sinclair T.J.E. (1990)

Tidal Response Method for Aquifer Characteristics in Proceedings New Zealand Geomechanical Society Vol. 16 Issue 1 (G).

Wellington Regional Council (1992)

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