THE LATE QUATERNARY GEOMORPHOLOGY OF THE LOWER MANAWATU

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by

PATRICK ALAN HESP

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ABSTRACT

The geomorphology of the present Lower Manawatu floodplain and the valleys that exit at the margin of the floodplain, is presented. An introduction to the geology and geomorphology of the study area is given, and previous studies are reported where relevant.

Two types of tributary valleys have been recognised in the study area. These valleys have been cut into the Tokomaru Marine Terrace. The first type recognised are predominantly gravel-floored, box-shaped valleys with headwaters in the Tararua Ranges. The second and major type recognised are box-shaped valleys without gravel floors. The first type have been formed by normal fluvial processes, while the second type were originally V-shaped, and have been infilled by estuarine sedimentation processes. The latter occurred as a direct result of the Flandrian Transgression.

The morphology of the Tokomaru Marine Terrace margin is examined, and it is concluded that the margin is predominantly river-cut. The Manawatu floodplain was originally an estuary. As the Flandrian Transgression began the lower reaches of the Manawatu and eventually the Oroua Rivers were drowned. As the Transgression progressed, the Lower Manawatu became an estuary. It appears that the Himatangi Anticline and Poroutawhao High acted as effective barriers to direct marine incursion in the study area.

The degree of warping and compaction of Aranuian sediments could not be ascertained. The degree of regional uplift has probably been greater than any localised anticlinal uplift which has been negligeable in the last 6000 years.

An examination of fossiliferous estuarine beds near Shannon illustrates that typical estuarine processes were prevalent. A higher Post-glacial sea level than present is disputed for the study area. Finally, a brief geomorphological history of the study area is presented.

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1. INTRODUCTION

1.1 Introduction

No detailed geomorphological investigations have been previously carried out in the Lower Manawatu. Consequently the geological and geomorphological history of the area has tended in part to be generalised from studies predominantly carried out in areas to the north and south of the study area.

During field reconaissance in the Manawatu area in 1974, the writer briefly examined the morphology of the floodplain and its tributary valleys. The existence of many box-shaped valleys, as opposed to v-shaped, inspired the writer to examine more closely their origin.

Initial study of the box-shaped valleys led to the tentative conclusion that their formation may have been related, either directly or indirectly to the Flandrian transgression. The study was then expanded to include an examination of the geomorphology of the present Manawatu floodplain.

The primary aim of this thesis is therefore to detail the geomorphology of those landforms produced by, or related to the Flandrian transgression.

1.2 Location

The area selected for study, here termed the Lower Manawatu, forms a portion of the coastal lowland of

Western Wellington Province (Figure 1 A). The margin of the Tararua Range to the east, and the coastline to the west form natural boundaries to the area. The southern boundary became apparent after field investigation; it lies approximately northwest along Highway 1, west of Levin. The northern boundary was chosen arbitarily and was taken as a line joining Himatangi Beach to the City of Palmerston North.

1.3 Terminology

In recent years the varying use of certain terms in geographical studies has led to some confusion. The terms Holocene, Flandrian, Post-glacial, Recent, and Last Glaciation, in particular fall into this category. The use of these terms in this study is here defined.

The present writer uses the term 'Flandrian transgression' for the world-wide rise of sea level that resulted from the melting of the ice of the last major glaciation, c. 18,000 to 16,000 years B.P. (Hopkins 1975). The New Zealand term 'Aranuian stage' as defined by Suggate and West (1967), is used in a local sense only, to embrace deposits of less than c. 14,000 - 15,000 years, i.e. deposits laid down since the retreat of the glaciers of the Last Glaciation in New Zealand. The deposits are therefore part of the Flandrian stage. Accordingly, the term "Flandrian' is used where deposits are thought to be younger than c. 18,000 years, but it is not known

LOCATION

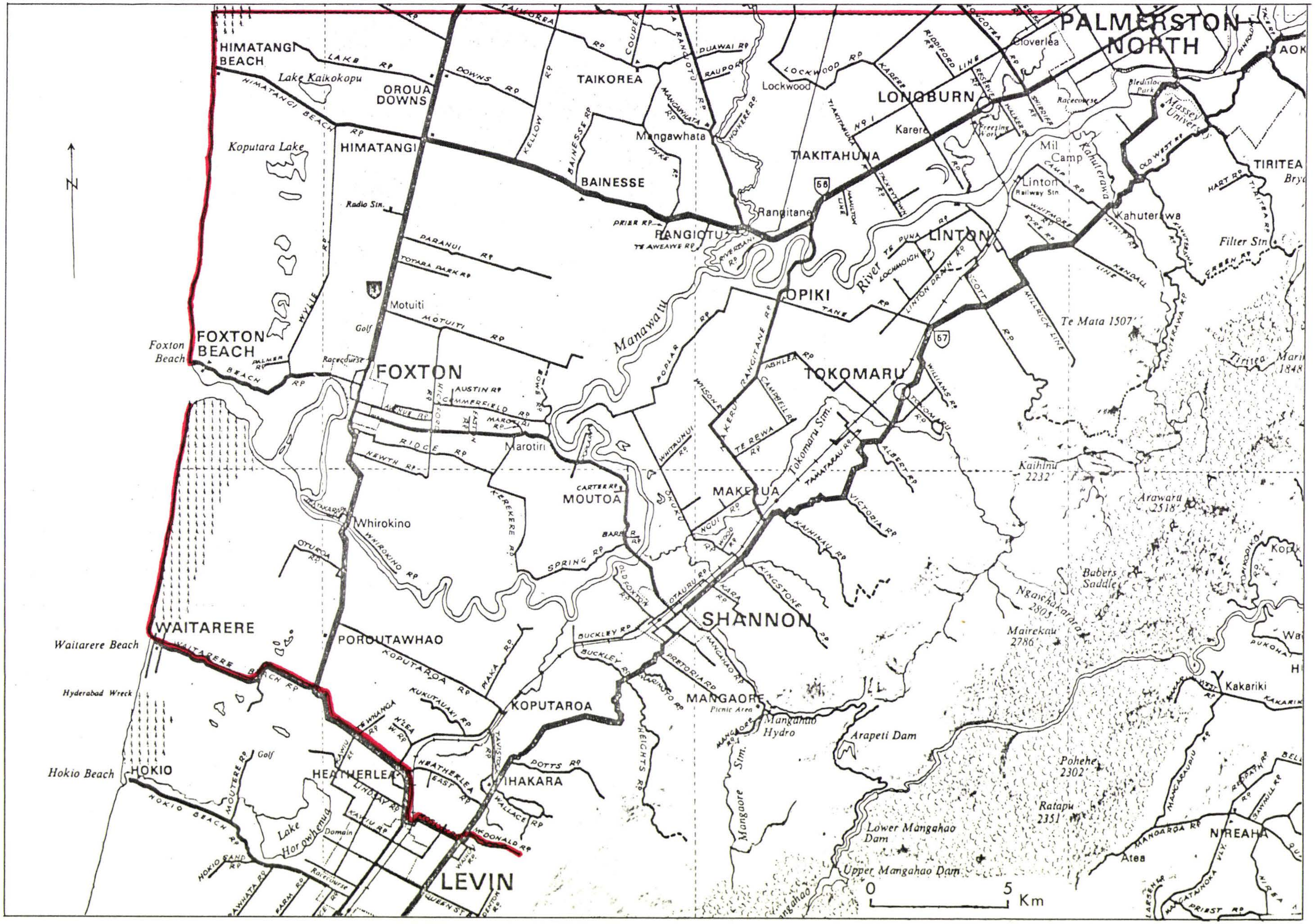


Figure 1A

if they are younger than 15,000 years.

The term 'Post-glacial' is used in this thesis to refer to the period of time equivalent to the Aranuian stage.

The term 'Holocene' is used in the text. It is taken as referring to the last 10,000 years, and therefore deposits of 'Holocene' age are also members of the Flandrian 'stage'. The term 'Recent' is synonomous with 'Holocene'.

The use of the term 'Last Glaciation' in a New Zealand context is difficult, as the Otiran Glacial Stage is correlated on the basis of carbon dating with upper Wisconsin (= upper Weichsellian), but there is no evidence that the Otira began at the same time as the Wisconsin or Weichsel (Te Punga, pers. comm.). However the term 'Otiran Glacial Stage' is generally used in reference to the 'Last Glaciation', and this usage has been followed here.

The New Zealand term 'Oturian' has been used in a similar sense for the Interglacial stage prior to the Otira Glaciation.

1.4 Chapter Format

Chapter one is concerned with familiarising the reader with the setting, geology, geomorphology and structure of the study area, and the surrounding regions. A literature review per se is not given. Rather the work of authors who have studied certain landforms with which this thesis is concerned, is included with a general description of that landform. Such landform descriptions follow a chronological order from oldest to youngest.

A description of the climate of the study area, and of the previous and present vegetation is given. A table of tidal ranges is also included.

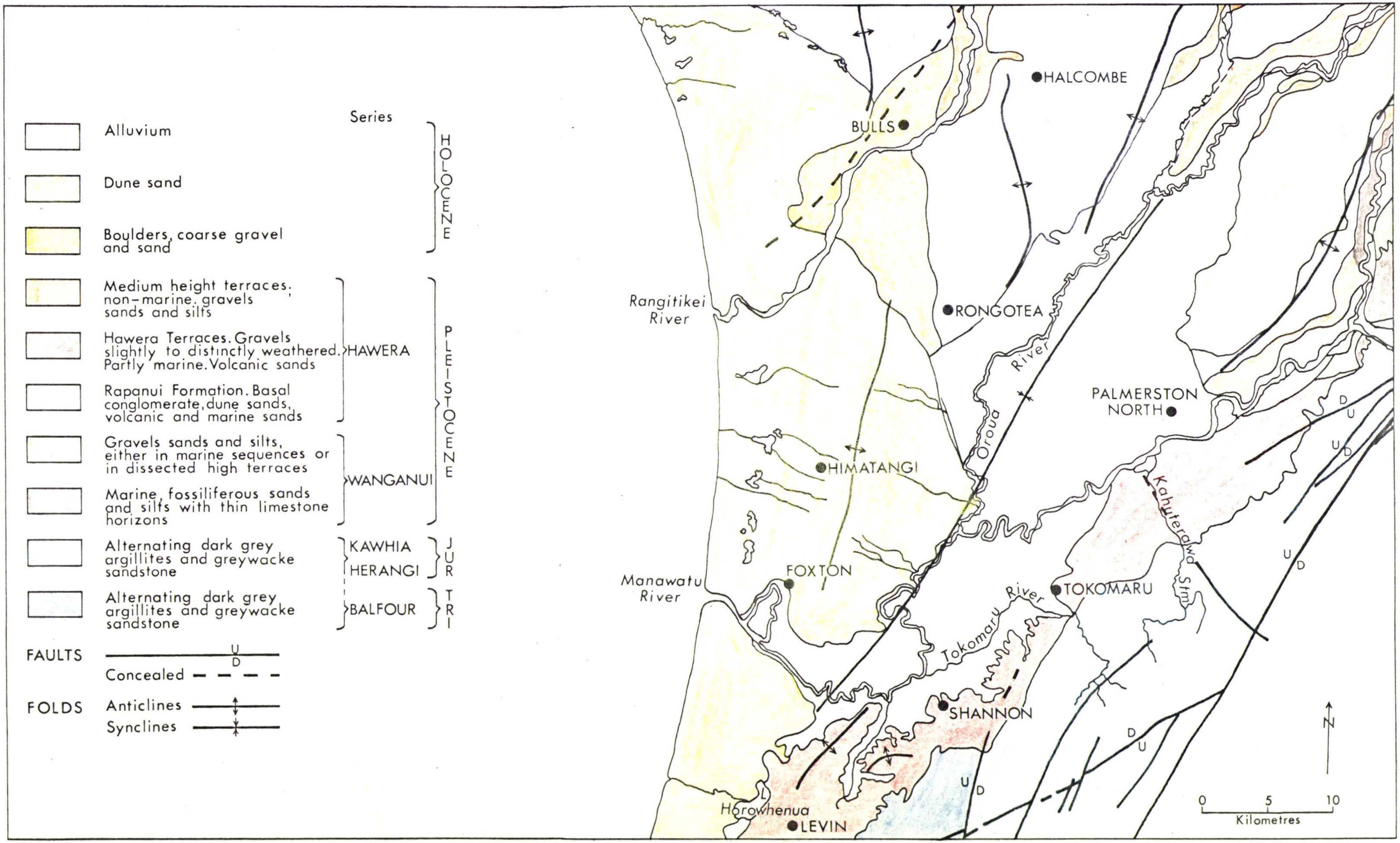
1.5 Geology

1.51 Introduction

The study area forms a portion of the Wanganui Basin, one of the largest of the sedimentary basins in New Zealand[1]. Most of the Basin is covered by Plio-Pleistocene sediment; older Tertiary rocks crop out only towards its northern margin. The Basin is bounded to the east and northeast by the pre-Tertiary Kaimanawa and Ruahine-Tararua Ranges, and extends westward into Cook Strait (Figure 1 B).

1.52 Triassic - Jurassic

Underlying the entire Manawatu area, and outcropping in the Tararua and Ruahine Ranges are the basement greywackes. This undermass consists predominantly of strongly deformed sedimentary strata, (alternating sandstones (greywackes), and



Series
Alluvium
Dune sand
Boulders, coarse gravel and sand
HOLOCENE
Medium height terraces. non-marine gravels sands and silts
Hawera Terraces. Gravels slightly to distinctly weathered. Partly marine. Volcanic sands
HAWERA
Rapanui Formation. Basal conglomerate, dune sands, volcanic and marine sands
Gravels sands and silts, either in marine sequences or in dissected high terraces
Marine, fossiliferous sands and silts with thin limestone horizons
WANGANUI
PLEISTOCENE
Alternating dark grey argillites and greywacke sandstone
KAWHIA
HERANGI
JUR
Alternating dark grey argillites and greywacke sandstone
BALFOUR
TRI
FAULTS
U
D
Concealed
FOLDS
Anticlines
Synclines
HALCOMBE
BULLS
RONGOTEA
Rangitikei River
Oroua River
PALMERSTON NORTH
HIMATANGI
Kahuterawa Stm
FOXTON
Manawatu River
TOKOMARU
Tokomaru River
SHANNON
Horowhenua
LEVIN
N
0 5 10
Kilometres

and siltstones (argillite), with occasional bands of red volcanics), of Mesozoic age, much of it shattered and crushed.

The New Zealand geosyncline emerged as a geanticline during the Cretaceous and continuous erosion produced a peneplained crest. Submergence during the Pliocene, allowed deposition of marine sediments on the crest. The geosyncline re-emerged during the Kaikoura Orogeny to form the present axial ranges. Downwarping of the adjacent land caused a deep syncline, the Wanganui Basin, to form the west of the axis.

1.53 Pliocene - Lower Pleistocene (Wanganui Series)

Cope and Reed (1967, fig. 9) have divided the Wanganui Basin into three major divisions, the Taranaki, North Wanganui and the South Wanganui Basins. The South Wanganui Basin, east of the Taranaki Fault and south of the Pipiriki High, "contains a thick sedimentary fill, of exclusively Plio-Pleistocene age which on seismic evidence reaches 5100 meters in the 'Turakina Syncline' (Katz 1968; Fleming 1953, p. 297).

Pliocene sediments at least 4500 meters thick have been measured in the Rangitikei Valley by Superior Oil Co. geologists (Feldmayer et. al. 1943; Fleming 1953), on top of which another few thousand meters of Lower to Middle Pleistocene beds are found, still partly marine (Katz 1968, p. 1095).

Fleming (1953) states that "the formation of the Wanganui Series followed one another without great unconformity in a subsiding basin. After their deposition, diastrophic movements (tilting and faulting) reached a climax". The depth to basement, in the Basin, differs considerably and abruptly suggesting that the basement has a block faulted nature (Lensen 1959).

1.54 Upper Pleistocene (Hawera Series)

In the study area, material deposited during the last interglacial, (N.Z. Oturi - probably occurring within the period 70,000 to 120,000 years B.P.) forms an extensive terrace, whose inner margin abuts the greywacke range[2]. Following the deposition of the predominantly marine sediments, secular uplift, orogenic in character (Adkin 1951), plus regression of the sea during the succeeding Glacial (N.Z. Otira) produced above sea level, a seaward sloping, extensive marine plain.

Oliver (1948), who named the marine beds "Otaki formation" considered that most of the sandstone exposed today was deposited during the seas withdrawal. Adkin (1910) considered the Otaki formation, a "double" formation, partly formed during the advance of the sea, and partly during the retreat.

Rich (1959) proposed a division of the marine formation into Tiritea formation (strata lying north of Kahuterawa Stream), Oliver's Otaki formation (equivalent beds south of Kahuterawa Stream).

The beds of the Tiritea formation according to Rich differ lithologically from rocks of equivalent age to the north and south. "Strata of the Tiritea formation are composed of poorly consolidated greywacke conglomerate, loose, coarse bedded sands, and massive to thinly bedded siltstones (Rich 1959, p. 77). Southwestwards from Aokautere to Kahuterawa Stream sand becomes increasingly important". Rich cites evidence indicative of beach or intertidal deposition and also aeolian deposition.

From Kahuterawa Stream to the southern limits of the study area "Hawera sediments consist of compact, well stratified sand with scattered minor bands and lenses of gravel". These strata, commonly known as 'Otaki sandstone', "contain a higher proportion of ferromagnesium minerals than equivalent sands to the north...have widespread lamination consisting of light and dark mineral grains, and gently inclined cross bedding", and are thus consistent with the marine origin ascribed to them by Oliver (Rich 1959, p. 83).

Kingma (1962, 1967) indicates that the Tiritea and Otaki Formations of Rich (1959) and Oliver (1948) are part Castlecliffian, part Hawera in age. However, the above Formations as mapped by Rich and Oliver extend from north of Palmerston North to Paekakariki.

There is very little definitive marine fossil evidence to indicate a Castlecliffian, or early to middle Hawera age, for beds that underlie the "surface" termed Tiritea and Otaki by Rich and Oliver. Te Punga (pers comm) comments that Kingma, as a compiler, was forced to make arbitrary decisions concerning the lower beds of the Tiritea and Otaki formations. As the topographic surface of the formations is continuous, this study recognises the incorporation of the two into a single unit, which is locally known as the Tokomaru Marine Terrace Formation. The relationship between this formation and the topographic surface, the Tokomaru Marine Terrace, is not certain. The marine terrace itself is considered to be of Oturi age, but the age of the formation hinges on whether or not the rocks and the topographic surface are conformable. Several authors assume this to be so and therefore place at least the upper beds of the formation in the Oturian stage (e.g. Fleming 1971).

The term Tokomaru Marine Terrace was first used by Cowie (1961) and was retained by Fair (1968). The term "marine terrace" is used more loosely than by Cotton, who defined a marine terrace as a shelf consisting of marine sediments, which has subsequently been uplifted and cliffed by modern marine erosion (Cotton 1958, p. 418).

It is not known if older beds, e.g. Waimean gravels, underlie the Oturi beds and overlie the greywacke undermass. Furthermore it is unknown if successively older Hawera sediments and Castlecliffian sediments underlie the Tokomaru Marine Terrace Formation and the Aranuian sediments.

Cowie (1963) described four distinct dune building phases in the Manawatu. The oldest, the Koputaroa phase, is late Pleistocene in age as the Aokautere Ash (c. 20,000 years old) occurs within it. A peat horizon in the dunes, analysed in Cowie (1963), has been dated as 35,000 $\pm$ 1700 years B.P. (N.Z. 522) (Fleming 1971). Koputaroa dunes were not distinguished from the underlying Otaki sandstone by Oliver (1948). As the formation of the Koputaroa dunes preceded the Flandrian Transgression, box-shaped valleys and marginal cliffing are present where the dunes border the floodplain. For this reason the Koputaroa dunes are included as part of the Tokomaru Marine Terrace in this thesis.

Angular solifluction gravels forming Otiran periglacial fans mantle the western margin of the Tararua Ranges, and overlie the Tokomaru Marine Terrace. A date from carbonaceous silt in the Lindale section near Paraparaumu indicates that fan formation was well advanced before 19,200 years B.P. (Fleming 1970).

Loess deposits cover terraces in the study area. Most of the loess is considered to have been blown from the river beds by the prevailing northwesterly winds during the Otiran Glacial Stage (Cowie 1964a). A volcanic ash, the Aokautere Ash (= Oruanui Ash, Vucetich and Pullar 1969), approximately 20,000 years old, is present within the loess, providing a datum plane in the Manawatu area (Cowie 1964b).

1.55 Recent Series

Generally speaking, the surficial alluvium of the Manawatu floodplain consists of fine sand, silt and clay, although locally swamp deposits contain carbonaceous and peaty material. In the Manawatu River deposition of gravel sized material appears to cease about 4.8 kilometers east of Rangiotu, and in the Oroua River this limit is about eleven kilometers north of Rangiotu.

The sand dunes have been built and are being built by sediments derived from three main sources (Gibbard 1972): (a) greywacke from the axial ranges; (b) siltstones and mudstones flanking (a); (c) volcanic material from the Taranaki and Tongariro districts. "In general these deposits have been mixed into a variety of mineral suites in the littoral zone, which in turn has become a second order source of dune material" (Gibbard 1972).

1.6 Tectonism

There are six elongated anticlinal structures in the Manawatu area, namely: Mount Stewart - Halcombe, Pohangina, Oroua, Feilding, Himatangi and Levin anticlines. A seventh appears to be present near Shannon; it will be discussed in a later chapter.

Of the anticlines known, the Levin and Himatangi are the only two directly affecting the study area. The Levin anticline trends north-east and "can be traced as a geomorphic feature for about 6.4 kilometers between Levin and the Manawatu River", the anticlinal crest is only 48.76 meters above sea level, and the sediments that have been folded are beds of the Otaki Formation (Te Punga, 1957).

The Himatangi anticline lies between the Manawatu River and the coast. "The crest trends slightly east of north for approximately 21 kilometers from Foxton to Rongotea, and the...coastal plain is only very gently warped (Rich, 1959).

The anticlines are 'drape folds', the folded beds being "draped" over upfaulted blocks of greywacke basement (Te Punga, 1957).

Rich (1959), believes that a downwarp extends through the centre of the floodplain, a feature he termed the 'Kairanga trough'. "Topographically it is expressed as an elongate alluvial plain which extends for 48 kilometers from Feilding to Lake Horowhenua" (p. 136). The trough is bounded by the Mount Stewart - Halcombe and Himatangi anticlines, and the Levin and Pohangina anticlines on the west and east respectively.

The Tokomaru Marine Terrace displays noticeable variations in height on the surface. Some of this undulation is probably due to gentle warping of the sediments since they were deposited. Some of it may be due to the occurrence of beach and aeolian marine deposits which were later overlaid and smoothed by loess deposition.

In some localities the Tokomaru Marine Terrace rises upwards to the margin of the Tararua Ranges. This may have resulted from a number of processes. Tectonic movement along the greywacke margin may have resulted in the soft sediments being dragged upwards; winds may have blown sand into dunes which piled up against the foothills as the Oturi sea retreated, or a second transgression following the first regression may have resulted in the formation of a lower surface. A combination of these factors is not unlikely.

Te Punga (1957), has identified a few minor faults with displacement of a few centimeters in beds of the Tokomaru Marine Terrace Formation between Shannon and Levin. Such faults, according to Rich (1959) "may result from post-depositional compaction and settling of the sediments, or from mild tectonic activity along the flank of the Tararua Range in post-Hawera time".

Te Punga (1957), and Rich (1959), consider that the folding described above is superimposed on regional epeirogenic uplift, which has been greatest in the north and nearest the axial ranges.

1.7 Geomorphology

1.71 Tararua Ranges

The Tararua Ranges form the eastern boundary of the study area. These rugged, extensively forested ranges, with peaks over 1500 meters high run in a north-easterly direction and are intersected by, and separated from one another by, a number of more or less parallel faults. There has been no movement along many of the faults since Tertiary times, but some are still very active, the Wellington Fault being a notable example.

1.72 The Tokomaru Marine Terrace

The Tiritea Formation (Rich 1959), Otaki Formation (Oliver 1948), and the Koputaroa Dunes (Cowie 1963), comprise the topographic feature known as the Tokomaru Marine Terrace (see Figure 1 c).

The terrace is characterised by flat to undulating, generally undissected surfaces. Adkin (1910) considered that this "inclined plain of marine deposit" is "an extensive series of raised beaches" (p. 507), and in 1919 reaffirmed this statement in reply to Cotton (1918) who proposed that the Otaki formation was of aeolian origin. Oliver (1948) accepted in the main Adkin's (1910) sequence of events, but stated more firmly that conglomerates, dune sands, beach sands, lagoonal deposits, and swamp deposits were all present within the Otaki formation.

Cotton (1918) noted the characteristic steep-sided stream gullies present within the Tokomaru Marine Terrace, which have wide flat floors, and often very small streams running in them. These valleys Cotton described as "box-shaped" a term here retained as a useful description of the morphology of such valleys.

Between Palmerston North and Linton,and between Tokomaru and Levin the margin of the Tokomaru Marine Formation is cliffed. Oliver (1948) considered that the cliffs were cut by the action of the Manawatu River. Cotton (1918), Adkin (1919), Te Punga (1962), Fair (1968) and Heerdegen (1972), considered that the cliff has been cut by marine agencies; Rich (1959) considered the cliff was cut by lagoonal processes.

1.73 Terraces of the Manawatu River

Fair (1968) studied the terraces of the Manawatu River, between the Manawatu Gorge and Palmerston North. The "aggradation terraces of the river have been linked to deglaciation in the Tararua-Ruahine Range during the late Pleistocene" (p. 82). Four terraces have been recognised. These terraces which are successively younger and lower in relation to one another, have been named the Forest Hill terrace,the Milson terrace, the Ashhurst terrace, and the Raukawa terrace.

1.74 The Manawatu Floodplain

Between the Tokomaru Marine Terrace and the coastal sand country lies an extensive floodplain, over which the Manawatu River meanders, joined by the Oroua River near Rangiotu, and into which many smaller tributary streams flow. The floodplain is characterised by its low elevation (less than 15 meters), its relatively level topography and its composition of gravels, sands, muds and silts.

Edwards (1921) termed the floodplain "a great deltaic flat", and mentioned also the existence at that time of two extensive swamps, the Makerua and Ohotuiti, the latter covering a drowned forest about 1.8 meters below the surface of the water. Adkin (1948) states that along "its lower reaches the Manawatu River pursues a well-developed meandering course consequent on a very low gradiant, the channel being tidal for many miles

Figure 1C General view of the floodplain (1), Tokomaru Marine Terrace (2), and the Tararua Ranges (3) near Tokomaru.

upstream from its mouth" (p. 266). Under conditions of normal flow the river is confined between silt banks which form natural levees.

1.75 The Coastal Sand Dunes

The sand dunes cover 312 square kilometers in the coastal Manawatu district, and extend as far as 19 kilometers inland north of the Manawatu River.

Three dune building phases, the Foxton, (about 4500 to 2000 years old), Motuiti (1000 to 500 years old), and Waitarere (started about 100 years ago), have been studied by Cowie (1963). They form belts parallel to the coast, the oldest belt,the Foxton, being the furtherest inland.

Heerdegen (1972) considered that when sea level dropped slightly following the Flandrian transgression, "considerable quantities of fine estuarine muds and sands" were available for production of a large dune building phase.

Adkin (1910) suggested that sand dunes may have blocked the Ohau River towards the termination of the Pleistocene period and so formed Lake Horowhenua. Several other dune lakes occur in the study area, their origin apparently due to the accumulation of sand dunes blocking the streams and impeding drainage (Oliver, 1948).

1.8 Climate

The Descriptive Atlas of New Zealand describes the Manawatu Climatic District thus: West to northwest winds prevail with relatively frequent gales. Mean annual rainfall 89-101 centimeters. Rainfall reliable and evenly distributed throughout the year. Warm summers, mild winters (Robertson, 1959).

The Köppen Climatic classification is Cfh, temperate rainy climate with warm summers but no marked dry season.

Coulter (1966) states that "New Zealand lies within the middle latitude belt of predominantly westerly winds, where the weather is dominated by a series of moving pressure systems. The overall effect of these systems is to produce a changeable climate, with variable surface winds and irregular periods of rain and sunshine" (p. 41).

Coulter states that in the free air over New Zealand above about 2100 meters the wind is predominantly from a westerly direction,while near the surface, directions are more variable. "At Shannon...westerlies predominate strongly. There are many calms and light winds, and the average speed is relatively low (9 km.p.h.)". The region is fully exposed to the northwest and many of the winds blowing across the Tararua Mountains, bring cloudy weather and showers, particularly between 600 and 1500 meters.

Apart from this, "there is a general increase in cloudiness and rainfall, and a decrease in sunshine, from the coast towards the hills" (Coulter, 1966).

The average annual rainfall is about 83 centimeters on the coast, about 99 centimeters at Palmerston North, and about 508 centimeters on the tops of the Ranges. Rain is evenly spread through the year with a winter maximum and a summer minimum.

The area receiving the greatest amount of sunshine is near Foxton which has averaged about 1880 hours and Palmerston North about ~~1510~~ 1810 hours per year.

Saunders (1964) describes mean temperatures in the Manawatu as being moderate, with only slight differences existing between coastal and inland situations, (e.g. Ohakea 55.6 degrees Fahrenheit, Palmerston North 54.9 degrees Fahrenheit) and between the lowland and the hill country.

1.9 Sea levels

Table I shows mean heights of three stations on the coastline. The first is a standard Port (Taranaki), the latter two secondary Ports. The tidal range at the mouth of the Manawatu River is 0.2 to 2.4 meters LWS-HWS.

TABLE I : Standard Port, and Secondary Ports : Time Differences and Heights

	Position		Time Differences		Mean Heights (Meters)				M.S.L.
	Latitude	Longitude	MHW	MLW	HSW	HWN	LWN	LWS	
Port Taranaki	39 04	174 02			3.4	2.7	1.0	0.3	1.9
Manawatu River Entrance	40 28	175 13	-0020	-0020	2.4	1.8	0.9	0.2	1.3
Wanganui River Entrance	39 57	174 49	+0035	+0035	2.7	2.0	0.8	0.3	1.6

1.10 Vegetation : Past and Present

1.101 Previous Vegetation[3]

1.1011 Tararua - Ruahine Ranges

Evidence remains of a pre-fire cover of the northern rata, Halls totara, kamahi, rimu and miro on the Tararua Ranges. At about 720 meters leather wood girdled the few tops projecting above this level. The area between Shannon and Levin carried a northern rata - rimu forest up to around 600 meters, with kamahi and Hall's totara in the upper levels which extended into the silver beech zone above. A scrub zone dominated by leather wood separated the silver beech forest from the tussock above it.

1.1012 Manawatu - Oroua Lowland

Except for small scrubby clearings and swamps the Manawatu Oroua lowland carried heavy stands of timber. Forests dominated by kahikatea and pukatea girdled swamps and followed the more sluggish streams. Totara forests, often with matai, occupied the free draining strips along river margins.

1.1013 Rolling Country

A similar diversity of species occurred on the forested rolling areas. The forest margin ran from Awahuri almost due west for several miles and then skirted northwards through the Sanson district.

1.1014 Terraces

The forests of the terraces were very much older than those of the river flats. This is evident from the greater quantities of northern rata associated with the podocarps and from the increasing proportion of broad leaved species, particularly tawa and hinau, with black maire forming a subcanopy beneath the podocarp crowns.

1.1015 Dunes

Before the introduction of marram grass by Europeans, the only plants withstanding the wind, salt spray and moving sand on the toe of the foredune were pingao and spinifex. On the lee of the foredune the shrubs,pimelea, sand coprosma, and cottonwood, maintained a hold and became more abundant further inland until replaced by manuka and bracken. The inter-dune flats carried a varied flora - mainly of low plants near the coast but with shrubs, flax and cabbage tree where the soil was stable, wet and fertile.

1.1016 Swamps

Around the margins of swamps the full range of soil moisture regimes from free surface water to seasonal low moisture levels brought about zonation of vegetation. Ringing the lagoons and standing in a foot or more of water was the swamp sedge on tall pedestals formed by its own root mass. Outside, raupo flourished in the shallower water, but was replaced on its outer margin by flax and toetoe growing above water level. On higher ground a zone of swamp scrub gave way to semi-swamp forest dominated by Kahikatea and pukatea. The width of each zone depended on the extent of soils in each moisture regime.

1.102 Present Vegetation

Most of the land within the study area is devoted to pasture or crops. The former applies for most of the lower slopes of the Ranges, and some of the "Terrace" country, the floodplain and the sand dune country. Both original cover and second growth forests remain on the steeper and higher areas of the Ranges.

Those areas of dunes not fixed by pasture are either non-vegetated dunes bordering the coastline, or dunes that have been planted with marram,lupins,and trees (predominantly pines). Small swamps still remain and vegetation is similar to the original swamp communities previously described. Small stands of native bush occur in isolated patches on the floodplain.

Notes

1 The geological introduction and subsection 1.52 (Triassic - Jurassic), have been compiled from these references: Katz (1968); Harris (1968); Fleming (1953); Te Punga (1953a); Fleming (1962); Turner (1944); Rich (1959); Lensen (1959); Kingma (1962); Kingma (1967).

2 Opinion is divided as to the sea level height of the Oturi sea. Fairbridge's (1961) sea level curve indicates a sea level approximately 18 meters (60 feet) higher than the present during the Oturi interglacial. Evidence from many areas discussed by Guilcher (1969) points to a lower shoreline (Lower Normannian) 4 - 5 meters above the present highest water mark, and a higher shoreline (Upper Normannian) 12 - 18 meters above H.W.M., during the Eemian (Last) Interglacial of northern Europe.

American evidence (Hoyt et. al. 1964) points to a sea level 6 - 7.6 meters (20 - 25 feet) above the present level, during late-Pleistocene (Middle and late Sangamon Interglacial stage) time. Recent studies on the east coast of Australia M.J. Shepherd, pers. comm.) indicate that sea level during the late Oturian interglacial stage was about 2 - 4 meters above the present level. Bloom et. al. (1974) states that sea level was at the present 120,000 years B.P.

3 All the information on the previous vegetation of the study area is from Esler (1964).

2. VALLEYS OF THE TOKOMARU MARINE TERRACE

2.1 Introduction

The tributary valleys of the Manawatu floodplain described in this chapter cross the Tokomaru Marine Terrace and exit at its margin. These valleys are thus marginal to the floodplain. Two types of valley have been recognised in the study area. (1) Box-shaped, gravel floored valleys originating in the Tararua Ranges; and (2) V-shaped and box-shaped valleys without gravel floors. The term box-shaped is described in the text. Those valleys without gravel floors are predominantly developed within the Tokomaru Marine Terrace; some, however, do have streams originating in the Tararua Range foothills.

Three distinct morphological areas have been recognised in the study area, on the basis of differences in valley morphology (this chapter), and differences in the morphological characteristics of the outer margin of the Tokomaru Marine Terrace (Chapter 3).

2.2 Gravel-floored, Box-shaped Valleys With Headwaters in the Tararua Ranges

2.21 Introduction

Within the three morphological areas described in the introduction to this Chapter, there are several valleys which basically differ from the majority of marginal valleys described .

The differing valleys all have headwaters within the Tararua Ranges and are at least partly gravel floored. These valleys are from north to south: Tiritea Stream, West Stream[1], Kahuterawa Stream, (Area 1); Nguturoa Stream, Scotts Stream[2], (Area 2); Tokomaru River, Waterfall Creek, Mukara Stream[3], Mangapuketea Stream, Kara Stream, Mangaore Stream, Otauru Stream, and Waoku Stream, (Area 3). The valleys may be located on Map 1.

The above valleys were not studied in detail, although certain observations can be detailed concerning their morphology and stratigraphy.

2.22 Morphology

The valleys in general are box-shaped (Figure 2A). In comparison to most other box-shaped valleys in the study area, except Koputaroa Stream valley, the width is much larger. Valley widths are up to half a kilometer across, and the width of the valley floors remains constant for almost the total length of some of the valleys.

2.221 Stream Origins

In every case the streams have headwaters in the Tararua Ranges. Basin areas are generally greater than those of the majority of marginal valleys in the study area, the streams

Figure 2A The large box-shaped valley of Scotts Stream. Note the incised stream, and the slightly hummocky floor of the valley. The visible riser to the left has probably been cut by stream meandering.

of which have been predominantly initiated on the Tokomaru Marine Terrace. Basin areas of the gravel-floored box-shaped valleys in general are between 2.59 and 1.29 square kilometers; some basin areas are greater. Basin areas of the majority of box-shaped valleys in the study area in general average less than 1.29 square kilometers. Because of this both discharge and load are far greater in the gravel floored valleys than in the majority of marginal valleys. Loads are far greater because the Tararua Range greywackes can supply coarse detritus to the streams, whereas most marginal valleys are only supplied with loess and sandstone beds of the Tokomaru Marine Terrace. Most streams in these gravel floored valleys are slightly incised. This could be the result of adjustment to grade, or response to a small amount of uplift in the Tararua Ranges.

2.222 Terraces

The Tiritea and Kahuterawa Streams, and the Tokomaru River have well developed terraces. The terraces, where exposures are present, appear to be cut surfaces with a capping of gravels and loess. The thickness of the cap varies between terraces.

There are four terraces of the Kahuterawa Stream, for example, near Linton Camp. A terrace (No. 1), 0.6 kilometers wide and 0.9 to 1.2 meters below the Tokomaru Marine Terrace, gives way to a lower terrace, 0.2 kilometers wide, (No. 2), with a riser of 1.2 to 2.4 meters. A smaller lower terrace (No. 3) has a riser of 6 to 9 meters and the terrace below that (No. 4) has a riser of approximately 3 to 3.6 meters.

Terraces of the Manawatu River have been named Forest Hill, Milson, Ashhurst and Raukawa, and can be distinguished on the basis of covering deposits (Fair 1968). Terraces of Kahuterawa Stream, Tiritea Stream, and Tokomaru River, may be tentatively correlated with the Manawatu River terraces on the basis of cover deposits. As the highest Kahuterawa terrace (No. 1) below the Tokomaru Marine Terrace appears to have a thin covering of loess it may have been formed at the same time as the Ashhurst. The successively lower terraces may be 'slip-off' terraces, or may have been formed during later stages.

Fair (1968) terms the Manawatu River terraces aggradational, and considers they were formed during the Otira glacial/ late glacial. Fair linked the building of the terraces to deglaciation in the Tararua - Ruahine Range; periods of degradation were related to the phase of advancing ice at the onset of glaciation. As the Kahuterawa terraces are cut surfaces with gravel caps they are only in part aggradational. A detailed study of the terraces was not carried out, and therefore the period in which they were built cannot be stated.

Lower terraces of limited height and extent may be Holocene in age. The major terraces of the Kahuterawa, Tiritea and Tokomaru Valleys appear to dip beneath the floodplain, if terrace profiles are extended. These terraces are thus not solely related to a rising Flandrian base level, but to an increase or decrease in load/discharge ratios produced by climatic change during the Otira glaciation. The lower terraces which may be Holocene in age, could well be related to a few feet of uplift along the Tararua Ranges.

Less well preserved terraces are present in West Stream, Nguturoa Stream, Waterfall Creek, Mangapuketea Stream, Kara Stream, Mangaore Stream, Otauru Stream, and Waoku Stream. Scotts Stream and Mukara Stream have no terraces. Because of the state of preservation and the distance and differences in terrace heights between these valleys, it is unknown if the terraces are correlatives of the Manawatu River terraces, or are of Holocene age.

The towns of Tokomaru and Shannon appear to be sited on erosional terraces of the Tokomaru River, and Mangaore-Otuaru Streams respectively. It appears that the terraces have been cut into the Tokomaru Marine Terrace; the marine terrace has however retained its seaward slope. A sample collected from below loess beds on one of the Tokomaru terraces was remarkably similar to sandstone beds exposed at the Tokomaru Dump (grid ref. N152/000189). It is unclear why no gravels cap the surface. Small streams have since incised the terraces.

2.223 Fossil landscapes

Some of the valleys with headwaters in the Tararua Ranges are tentatively regarded as fossilised. That is, the former morphology has been buried. The middle and upper valleys of Nguturoa Stream, Mangapuketea Stream, Kara Stream and Waoku Stream fall into this category. West Stream valley may be less certainly regarded as fossilised. In all these valleys, the landscape has been partially resurrected or exhumed.

Kara Stream valley serves as an example. At some time Kara Stream perhaps aided by Mangapuketea Stream, eroded a large valley and formed terraces. At a later stage much of the topography was buried; it appears predominantly by loess. The valley risers are still apparent, but only one terrace remnant is distinguishable on the northern side of the valley. The effect of burial has been to produce smoothed or rounded forms. Sharp breaks of slope are rarely seen.

Kara Stream and its northern tributaries are youthful and are flowing on top of what is probably a former terrace; the surface here is partially exhumed. Mangapuketea Stream once flowed in the Kara Stream valley, but at some stage deserted that course and either by eroding a new valley or occupying a smaller westward flowing tributary valley, incised below Kara Stream valley.

The age of fossilisation of valley morphology is unknown. Cowie (1964a) states that loess was probably accumulating rapdily when the Aokautere Ash was erupted (c. 20,000 years B.P.) and continued accumulating until shortly after the formation of the Ohakea Terrace (= Ashhurst Terrace, Cowie 1961). A minimum age for the Ohakea Terrace is c. 10,000 years B.P. (Cowie and Wellman 1962). The age of fossilisation is greater than c. 10,000 years, and is likely to be related to glacial/late glacial processes.

Mapping of the fossilised valleys was extremely difficult as risers were obscured and hard to locate (See Map 1).

2.224 Valley size

Several of the valleys are large in comparison to most of the marginal valleys in the study area. The widths of valley floors has already been mentioned, as has the box-shaped nature. This large box-shape appears to be due to normal fluvial processes. Waterfall Creek is instructive as an example.

Waterfall Creek flows from a small basin within the Tararua Range foothills. It falls as a waterfall southeast of Tokomaru and flows in a box-shaped valley to the floodplain where the stream is artifically channelled. The valley is box-shaped from head to mouth and the valley riser is typically indented. The stream meanders the full length of the valley. The box-shaped form of the valley is thus due to lateral erosion by meandering. It would appear that for these valleys the greater the stream discharge, the greater the meandering and the larger the valley size. Valley-size meander scars are present in many of the valleys named, giving weight to this interpretation. No lower beds were exposed so that the former valley shape (box-shape or V-shape) could not be exactly determined. It is likely that the form of these valleys is the result of lateral erosion.

2.23 Stratigraphy

The generalised stratigraphy of Scotts Stream is presented in Figure 2 B. Although the stratigraphy is not identical to all the valleys it is similar to that of Tiritea, Nguturoa, Mangapuketea, Kara and Waoku Streams.

Figure 2 B illustrates that floodplain sediments infill the downstream section of Scotts Stream valley and wedge over the upstream sediments without any morphological break, to give a continuous topographic surface. The floodplain sediments extend only one and a half kilometers up Scotts Stream valley, where they give way to gravels, clays and loess. The top of the uppermost gravel deposit is irregular; the overlying loess provides a filling cover which smooths the surface. Occasionally, small peat layers overlie the gravel and underlie clay. These deposits filling the valley have a gradual inclination upstream, and dip beneath floodplain deposits downstream.

Upstream, stratigraphically lower beds are exposed and blue clay underlies the uppermost gravels and overlies more gravel.

It appears that in the case of Scotts Stream valley and the other similar valleys mentioned, the uppermost infilling gravel deposits described are possibly aggradational deposits. The uppermost gravels may have been deposited as the streams aggraded in response to a rising base level during the latter stages of the Holocene. The clay lying between the gravels may be indicative of a post-glacial climatic change. Successively

SCHEMATIC GENERALISED STRATIGRAPHY OF PART OF SCOTTS STREAM ALLUVIUM

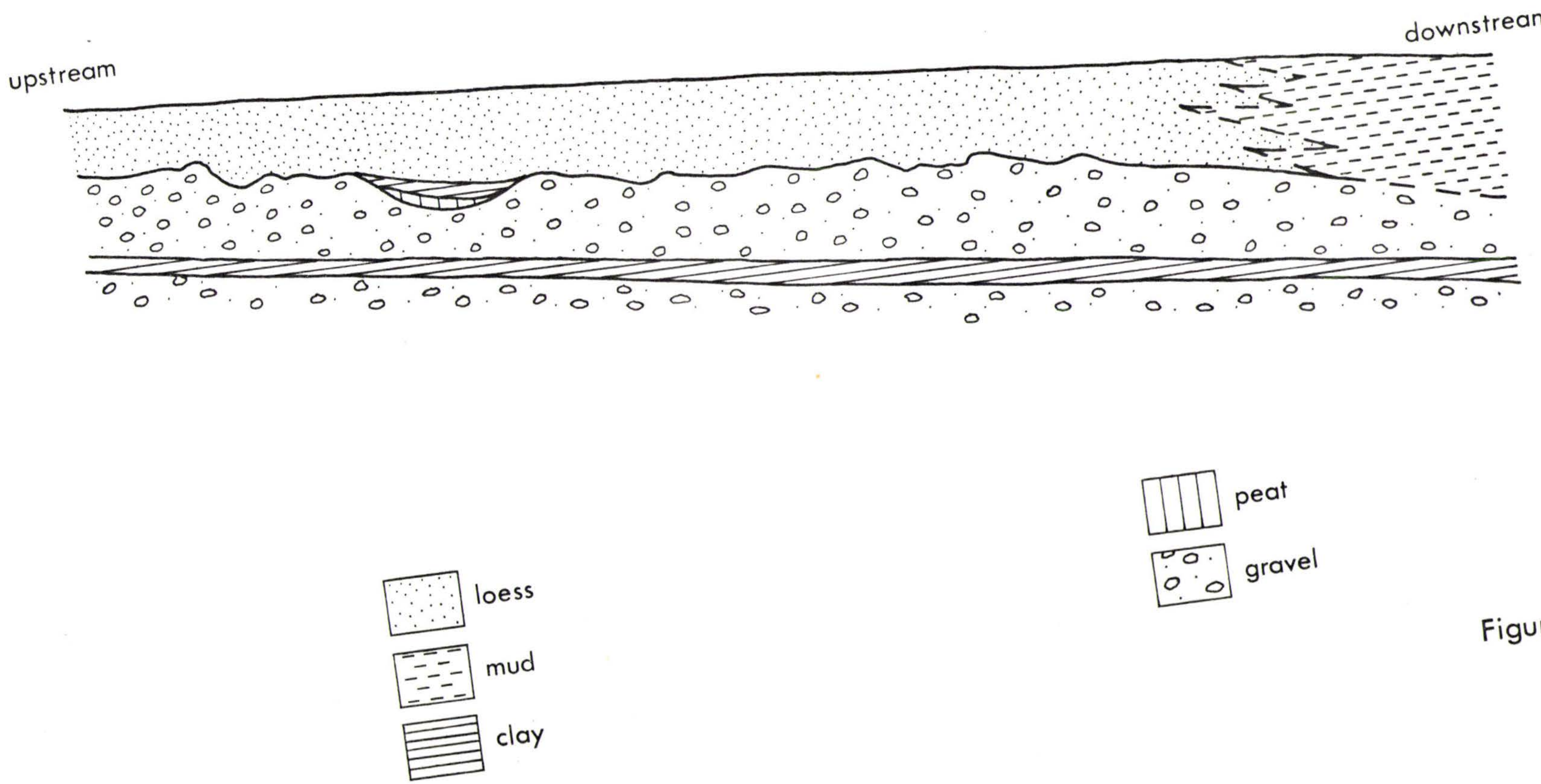


Figure 2B

lower beds (not exposed) are likely to be related to late glacial processes.

In general the valleys of streams with headwaters in the Tararua Ranges are predominantly composed of gravels with varying amounts of floodplain sediments in the valley mouths.

2.24 Summary

Several valleys differ from the majority of marginal valleys in the study area, because they have their headwaters within the Tararua Ranges, and are primarily composed of gravels. Basin areas are larger and corresponding discharges are greater. All of the valleys are box-shaped and generally large. Some are terraced and the valleys which do not have major terraces have gravel floors. Some of the valleys are fossil valleys which have been partially exhumed.

2.3 Valleys Without Gravel Floors

2.31 Introduction

The majority of valleys in the study area do not have gravel floors. Many of these valleys are developed wholly within the Tokomaru Marine Terrace. These valleys are described and are divided into three morphological areas. Valleys with gravel floors in the three areas discussed in the previous section, are omitted from the following discussion.

2.32 Area 1

Area 1 extends from Massey University to one kilometer north of Linton village (Figure 2 C). In this area consequent streams, flowing in parallel V-shaped valleys, drain the Tokomaru Marine Terrace. The streams flow in tight meanders over the floors of the valleys. The valleys are not strictly V-shaped as the slopes of the top of the 'V' are slightly convex (Figure 2 D). This form has probably been produced by creep and terracetting of the covering loess deposits. Most streams flow intermittantly. Between Massey University and Kahuterawa Stream the valleys are deeply incised at their mouths. Here the streams have cut down through the cliffed margin of the Tokomaru Marine Terrace until they have reached the level of the Manawatu floodplain. Figure 2 C illustrates the straight parallel nature of the valleys and the short gorge-like features at their mouths.

From Kahuterawa Stream to one kilometer north of Linton village, the streams and their valleys are similar, except for the fact that their mouths are not deeply incised. The streams flow with a gentle gradient to their confluence with the Manawatu River. The number of streams crossing the Tokomaru Marine Terrace is less here.

GEOMORPHOLOGICAL MAP OF AREA ONE

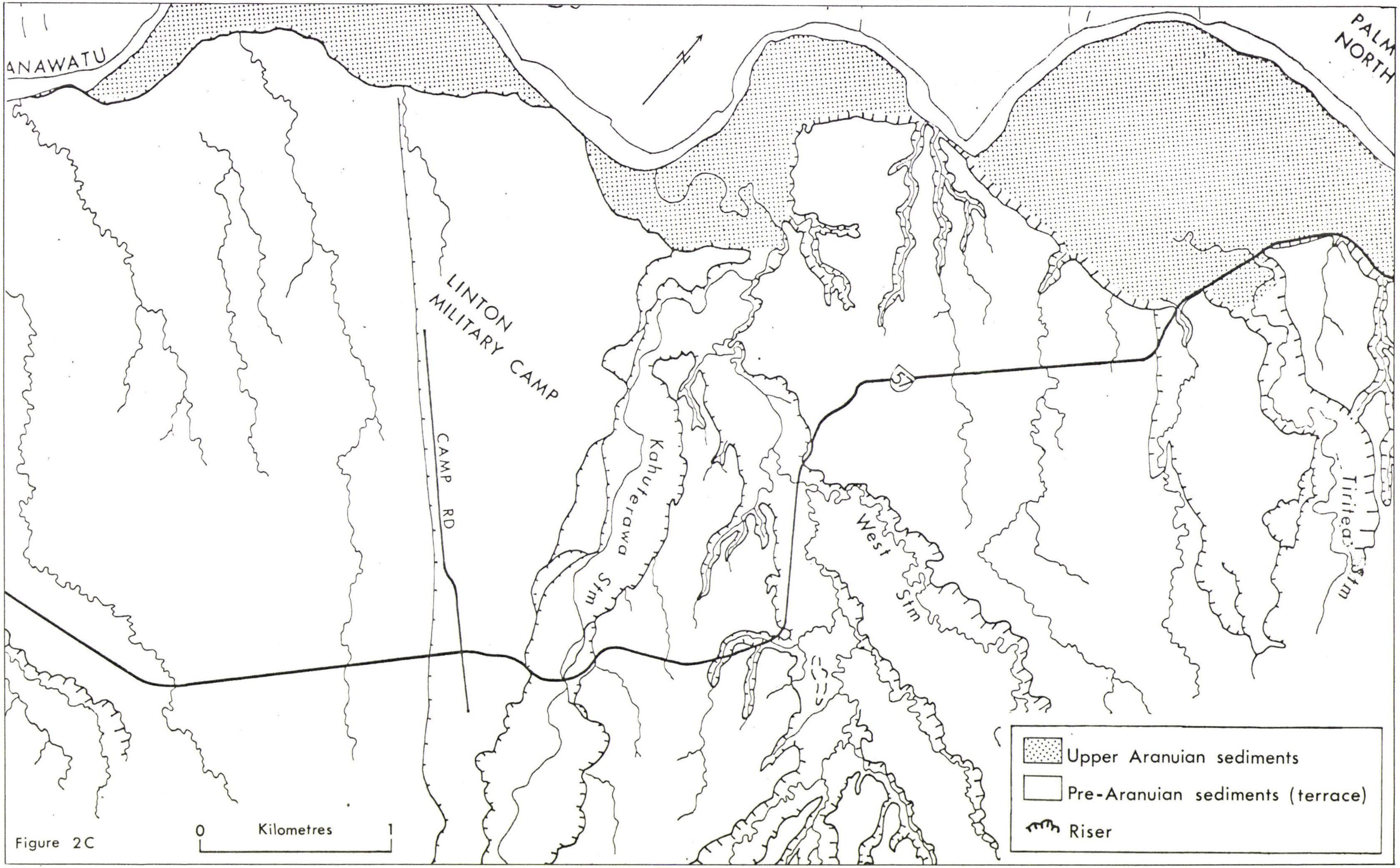


Figure 2C

Figure 2D   A small v-shaped valley south of Massey University (Area I) showing typical convex valley-side slopes.

2.33 Area 2

From one kilometer north of Linton Village to Tokomaru (Figure 2 E) several of the consequent streams are V-shaped almost to their valley mouths. The morphology of these valleys is similar to Area 1 except that the valleys are deeper and the valley mouths differ. At, and within the mouths of several of the valleys, are small peaty swamps which are surrounded by the sloping edge of the Tokomaru Marine Terrace (Figure 2 F). It appears that the wider the valley floor the greater the area of peat swamp, and the further the swamp extends up the valley (See Figure 2 E). Where some of the valleys are large enough they may be described as box-shaped, the swamp providing a flat floor to the valley.

Most streams in the valleys are intermittant and drainage is poor. In both Areas 1 and 2, there is often no definite stream channel. In the summer months grass usually grows in the bottom of many of the valleys.

2.34 Area 3

Area 3 extends from Tokomaru to just north of Lake Horowhenua near Levin (Figure 2 G). The majority of valleys in Area 3 are box-shaped in form. Cotton (1918) distinguished such valleys from V-shaped valleys. Cotton noted the steepness of the valley sides "which remains practically constant as the

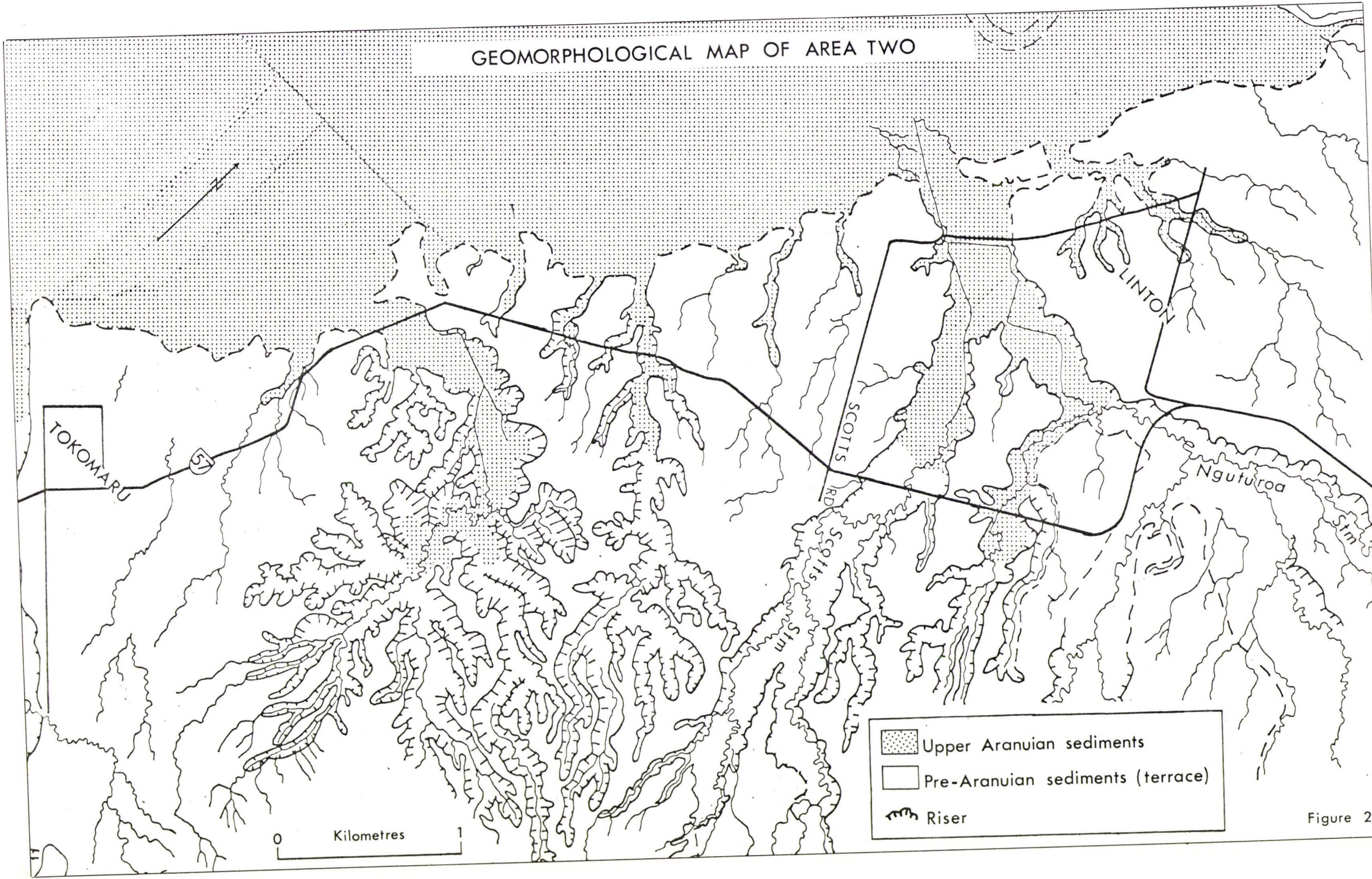

GEOMORPHOLOGICAL MAP OF AREA TWO
N
TOKOMARU
57
SCOTTS
RD
Scotts
Stm
LINTON
Nguturoa
Stm
Upper Aranuian sediments
Pre-Aranuian sediments (terrace)
Riser
0
Kilometres
1

Figure 2 E

Figure 2F The gently sloping Tokomaru Marine Terrace (Area 2) showing the ill-defined junction between the Terrace and the floodplain, and the swampy valley mouths.

width of the floor increases" (p. 220). Valley floors are in general fairly flat and do not exhibit a marked increase in height proceeding up the valley (Figure 2 H). Many of the box-shaped valleys are deep having risers of nine to twenty five meters.

Some box-shaped valleys grade into a V-shaped form upstream and may be deeply incised with steep sides (up to 30 degrees). Where V-shaped valleys form the upper part of box-shaped valleys, they sometimes have headwaters at the Tararua Range margin. However discharge is slight and gravels are not normally carried by the streams. Others are box-shaped to their heads, which can be likened to the form of an amphitheatre (Figure 2 I). A notable feature of the box-shaped valleys in the study area is the small size of streams compared with valley size. The box-shaped valley form is best developed in the Shannon district.

2.35 Area's 1, 2 and 3 : Summary

The marginal valleys described are often developed wholly within the Tokomaru Marine Terrace. They have incised both minor and large valleys and are either box-shaped or V-shaped or a combination. They are not terraced, are not composed of gravels, streams have little or no discharge and are usually artifically channelled. None of the valleys are fossilised.

LOCATION OF AREA THREE

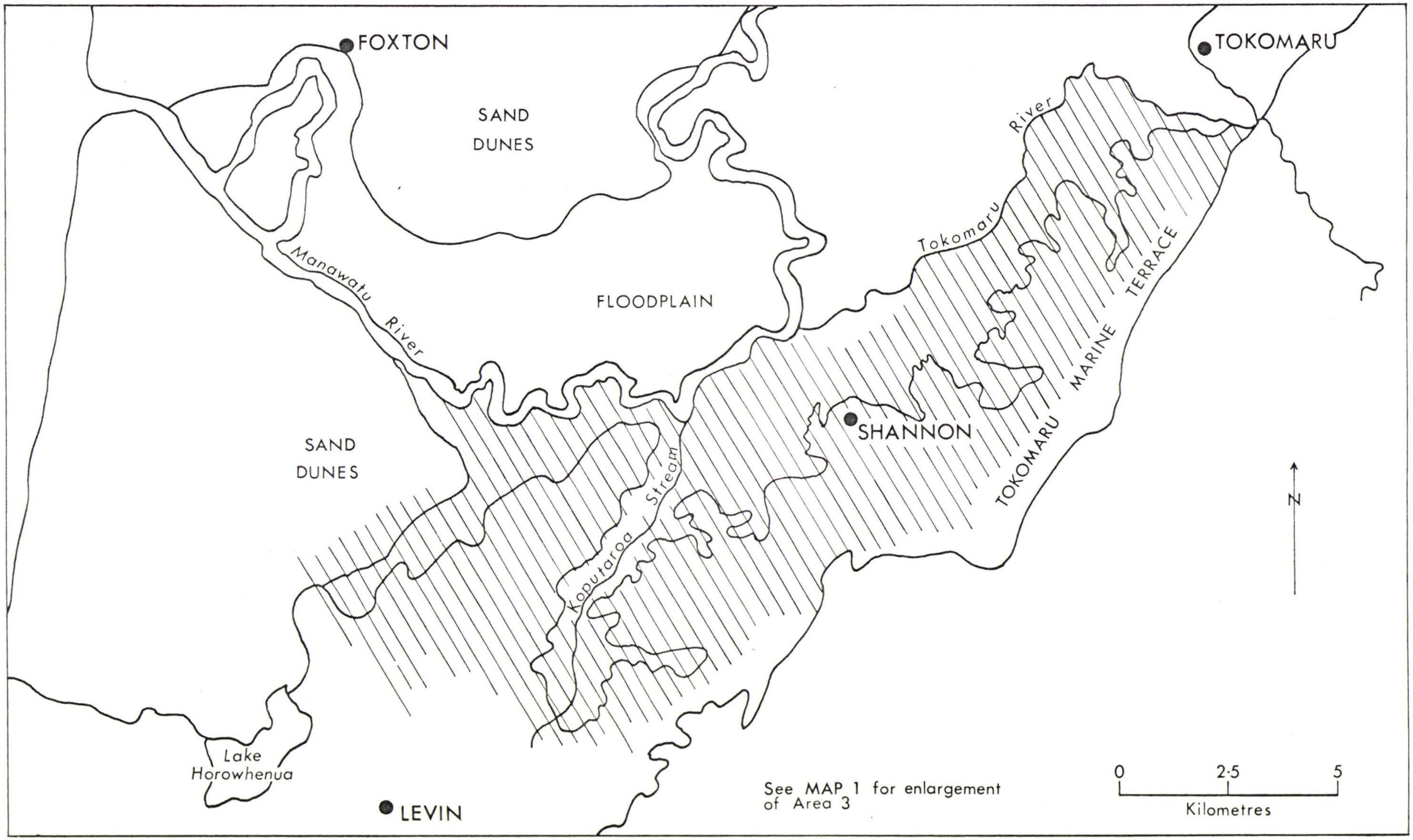


Figure 2 G

Figure 2H A typical flat floored, steep valley side, box-shaped valley near Kaihinau Road.

Figure 21 A valley south of Shannon, showing the "amphitheatre" form developed where the valley is box-shaped to its head.

2.4 Origin of the Box-shaped Valleys

2.41 Previous Work

Cotton (1918) considered that the box-shaped valleys were eroded quite rapidly during a period of retrogradation; progradation followed and swamps, near the border of the Tokomaru Marine Terrace, extended as arms up the floors of the valleys. These valleys, he concludes, are currently "in the process of aggradation with fine silt" (p. 217).

Oliver (1948) considered that the box-shaped valleys are "merely the result of rapid rejuvenation followed by lateral erosion and deposition of alluvium". He stated that "the softness of the sandstone is probably the reason for the erosion of large gullies compared with the size of the streams which have excavated them" (p. 9).

Heerdegen (1972) noted the box-shaped, flat floored valleys within the Tokomaru Marine Terrace and stated that they appeared to be aggrading. According to Heerdegen "this could either reflect a lack of recent regional uplift or an inherited adjustment to the sea level maximum of 5000 years ago" (p. 14).

The above researchers' failed to distinguish between those streams which are box-shaped, gravel floored, and have headwaters in the ranges, and those which are box-shaped but do not have gravel floors and are predominantly developed within the Tokomaru Marine Terrace. The former box-shape appears to be the result of normal fluvial processes, but this cannot be claimed for the majority of marginal box-shaped valleys in the study area.

2.42 Hypothesis for the Origin of Box-shaped Valleys

During the Last or Otiran glacial stage, continental ice sheets extracted a sufficient amount of water from the oceans to account for a world-wide lowering of sea level. The lowest level reached during the maximum of the glacial stage is not exactly known, although several estimates have been made. Pritchard (1974), Hopkins (1973), and Morner (1971) estimate between 90 - 123 meters. Russell (1964), Brannon et. al. (1957), Millman and Emery (1968), Vita-Finzi (1973), and Garrison and McMaster (1966) generally accept about -130 meters as the maximum. The greatest depth recently indicated is -175 meters (Veeh and Veevers 1970).

The present writer proposes that as the glacial sea level fell, strandlines were displaced progressively seawards and the Manawatu and Oroua Rivers and their tributaries cut down in their lower reaches to adjust their profiles to the lowering base level. Upstream of a certain point aggradation probably occurred due to an increase in the load/discharge ratio. River valleys in New South Wales, Australia, for example, the Paramatta, Georges, Hawkesbury and Hunter Rivers, at least 20 kilometers from the glacial coastline, are known to have incised at least 90 meters (Langford-Smith and Thom, 1969).

The Manawatu and Oroua Rivers may have incised to considerable depths below present sea level, in their lower reaches. Tributaries to the east could easily have eroded large V-shaped valleys in the soft predominantly marine sediments of the Tokomaru Marine Terrace.

As the following Flandrain transgression began, shorelines were moved upward and across the present continental shelves. It is proposed that as the sea level rose, the lower reaches of the Manawatu River, and eventually the Oroua River were progressively drowned and became estuaries. As the transgression progressed tributaries of the two main rivers were probably also drowned, and became fingers of the estuary. Estuarine sedimentation processes were then responsible for infilling the former valleys of the Oroua and Manawatu Rivers, and the box-shaped valleys came into existence.

Such buried valleys are known from the Gulf Coast of America (Russell, 1964) and the British Isles, France, Belgium, North Germany, and northeast Canada (Charlesworth 1957).

As the Lower Manawatu was occupied by an estuary throughout the Post-glacial, either a sand bar or barrier or possibly a structural feature prevented direct incursion of the sea into the study area. In many parts of the world sand barriers were built near the present coastlines in response to the transgression, (Zenkovich 1967; Shepherd 1974), and several structural features are known to exist in the study area.

2.5 Evidence for Post-glacial infilling of Box-shaped Valleys

2.51 Morphology

The morphology of the valleys can clearly be seen from figure 2 J. The valley sides are reasonably steep and the floors quite flat. Box-shaped valleys previously described as having gravel floors can easily be mistaken for Post-glacial infilled valleys.

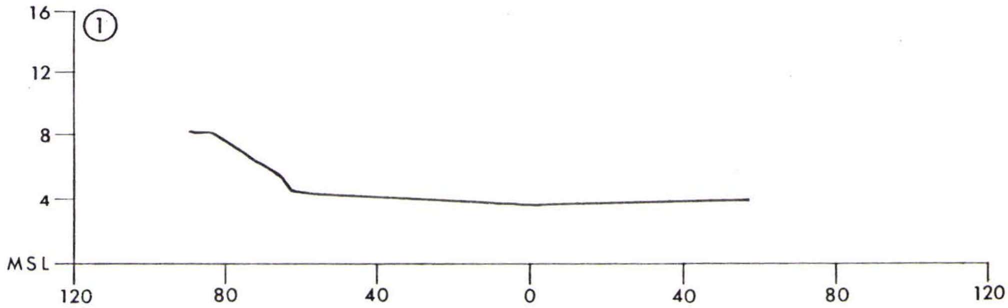
The form of these valleys is immediately recognisable as anomalous. It is difficult to imagine that the small streams draining the box-shaped valleys could have conceivably formed such a valley by lateral erosion. Whereas the gravel floored valleys are produced by normal fluvial processes, the majority of box-shaped valleys in the study area are not.

2.52 Stratigraphy

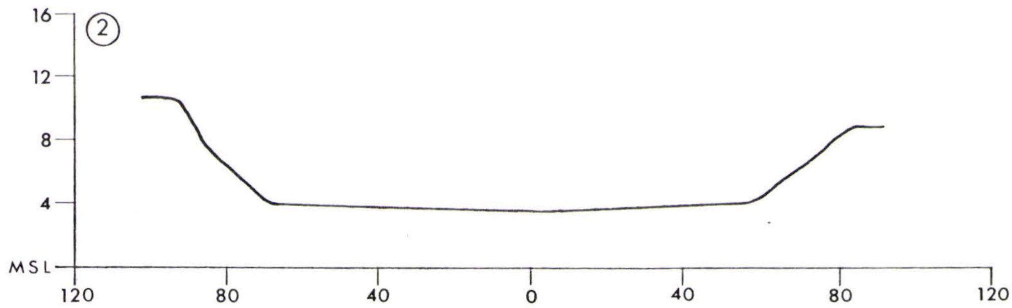
2.521 Sediments

The valley and floodplain in the study area are generally comprised of muds, sands and silts. Figure 2 K illustrates the stratigraphy and height relative to sea level, for several bores drilled in the Shannon district. Figure 2 L shows the position of each of these bores. In the valleys, the cover deposit usually consists of 0 up to .3 meters of topsoil. Depending on the location this can range from free-draining to

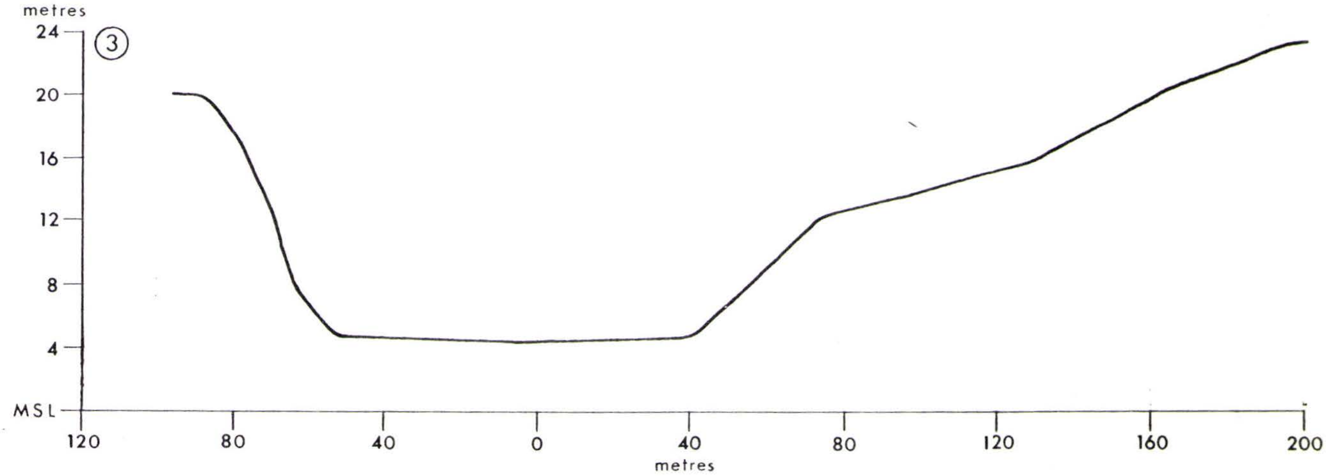
CROSS PROFILES OF A BOX SHAPED VALLEY NEAR SHANNON



V.E. = 4·28



Profile 2 is 58 metres upstream from Profile 1



Profile 3 is 98 metres upstream from Profile 2

Figure 2 J

swampy, this determining the colour and texture of the soil. Soils are often peaty. This grades into a grey or grey/brown mud which often has vegetation and rootlets within it. Lower down in this mud, small peat layers and sandy lenses can be encountered. The mud often becomes slightly sandier with depth, and the colour changes to blue.

In the floodplain the topsoil is similar but is underlain by a brown, often puggy soil/mud (silt?). Between 1.5 and 2.1 meters blue mud is usually encountered. Plant remains are not uncommon. Below this sand or sandy mud is encountered. The sand is sometimes peaty for a centimeter or so.

The sediments above are similar to those described as "floodplain sediments" infilling the lower reaches of box-shaped gravel floored valleys, previously discussed in Section 2.23.

2.522 Shelly Facies

Within the valley blue muds and floodplain muddy sands, shells have been encountered. In 1962, Te Punga discovered marine molluscs (spisula aequilateralis, Dosinia sp.) associated with swamp deposits near Shannon, on the floodplain. (Grid reference, N152/901117).

At a location (grid ref. N152/9000116) very near to the Te Punga reference, a bore hole (H. 26) penetrated 2.134 meters (seven feet) of muds and a further 4 meters of sand. Shells were encountered at a depth of 2.134 meters (1.1 meters above m.s.l.) and were present throughout the remaining 6 meters.

STRATIGRAPHY OF BORES IN THE SHANNON-KOPUTAROA DISTRICT

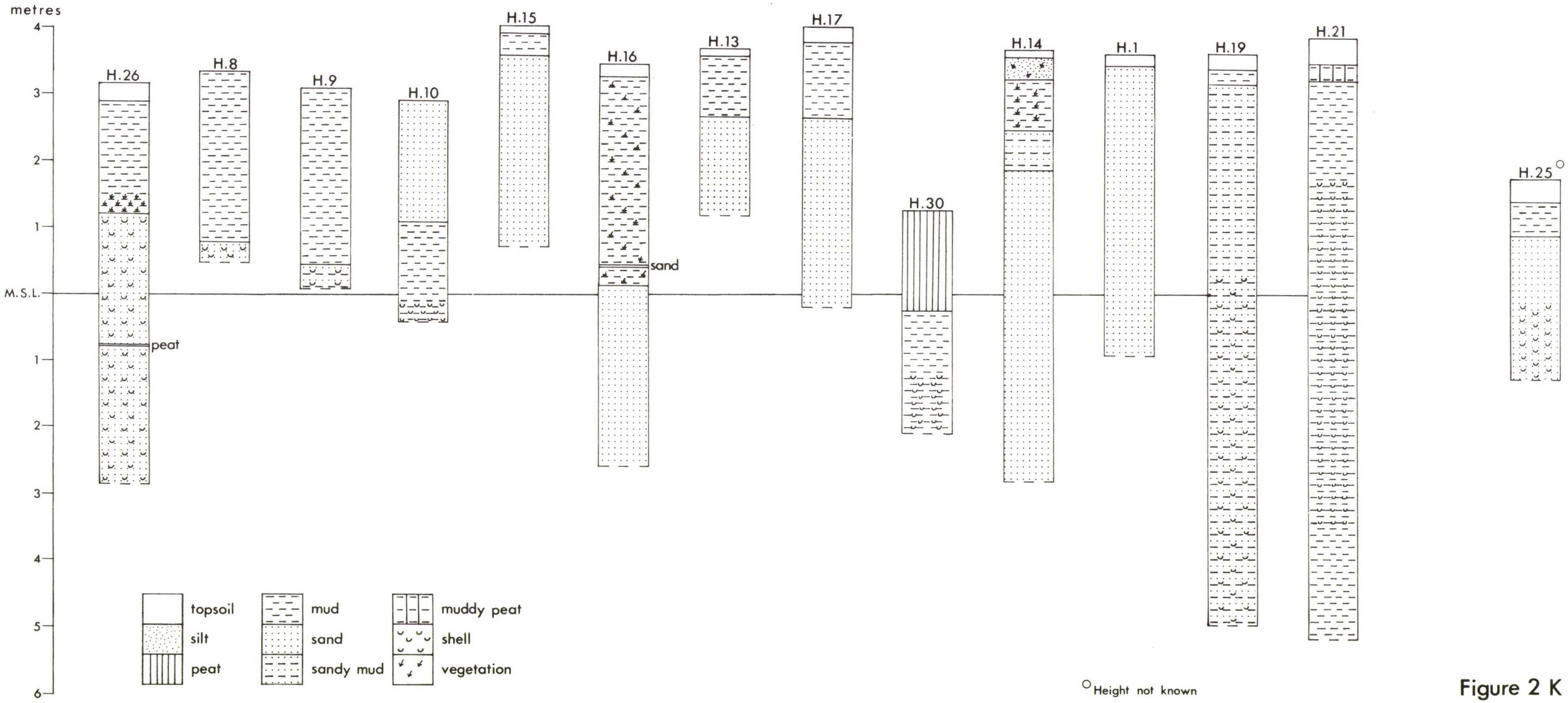


Figure 2 K

LOCATION OF SHANNON-KOPUTAROA BORES

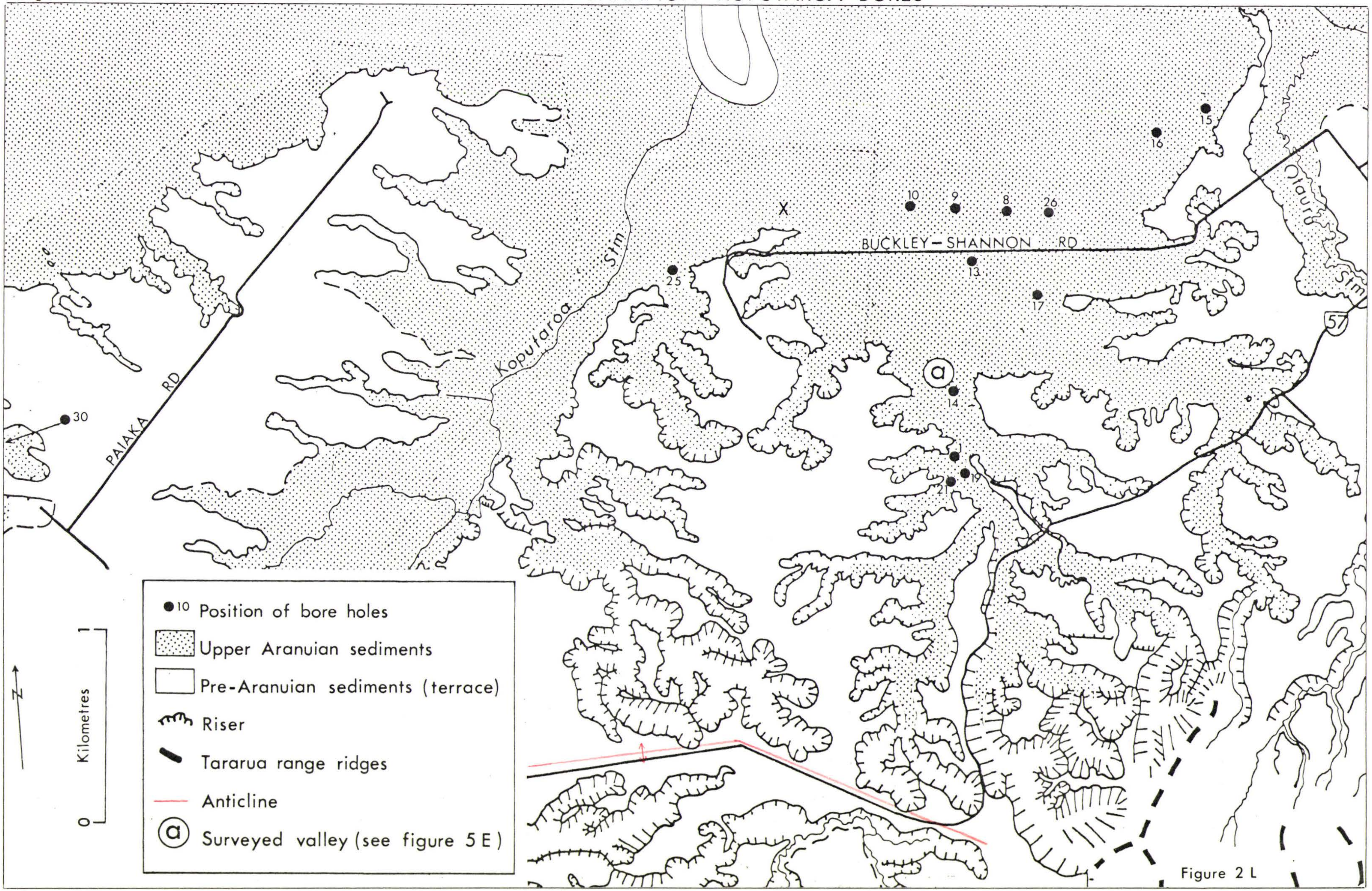


Figure 2 L

Further bore holes, H. 8, H. 9, and H. 10 were drilled along a southerly trending line, to assess the continuity of the stratigraphy encountered in bore hole H. 26. Shelly facies were first encountered at depths of 2.59 meters, 2.66 meters and 3.048 meters respectively. The heights of the top of the shelly horizons lie between 0.9 to 1.2 meters above m.s.l.

Recent excavation of drains (June 1975), carried out by the Manawatu Catchment Board in the Shannon district, enabled the writer to view upper beds of mud and shell extending from bore hole H. 10 to a point near the cliff (x on figure 2 L). Bore hole H. 25 confirmed the existence of fossiliferous beds further south. Figure 2 M shows the floodplain below Shannon where fossiliferous beds were encountered.

Bores H. 15 and H. 16 were drilled to depths of 3.3 meters and 6 meters respectively in a northwesterly direction from bore hole H. 26. No fossiliferous beds were encountered. Bore hole H. 17, drilled to a depth of 4.2 meters was nearer to the Tokomaru Marine Terrace and also did not encounter any fossiliferous beds.

Bore hole H. 14 was drilled in a tributary box-shaped valley. Shelly facies were encountered at 5.3 metres, and were continuous to 6.5 metres, the maximum depth attained. The top of the fossiliferous bed was 1.6 meters below m.s.l.

Further up the valley bore holes H. 1, H.19, and H. 21 first encountered shelly facies at depths of 1.52 meters (2.13 meters above m.s.l.), 3.35 meters (.305 meters above m.s.l.)

Figure 2M The Manawatu River, its floodplain, and box-shaped valleys developed within the Tokomaru Marine Terrace. Shannon-Buckley Road can be seen crossing diagonally to Shannon township on the right, with State Highway 57 in the foreground. The arrow indicates the position of dated fossiliferous beds (Bore H.26).

and 2.13 meters (1.52 meters above m.s.l.) respectively (Figure 2 N).

In the Koputaroa district, shelly facies were encountered at 2.8 meters, 1.52 meters below m.s.l. in Bore H 30 (Grid ref. N152/834097). The shelly facies were encased in muds. The stratigraphy of all bores prefixed with 'H' is given in Appendix I.

2.53 Depositional Environment

The fauna was identified by Dr A.G. Beu, New Zealand Geological Survey, Wellington. They are predominantly estuarine species, which lived in an environment where salinity was lower than that of the ocean. The fauna assemblages indicate that estuarine conditions extended from moderate salinity on the floodplain to marginal and brackish conditions up the tributary valleys. The estuarine environments will be dealt with in greater detail in Chapter Six.

2.54 Age of infilling

A Post-glacial origin for the shells has been confirmed by radiocarbon dating. Shells collected from a horizon 1.12 to 0.9 meters above m.s.l. in Bore hole H. 26, Grid reference N152/9001166, were dated at 6330 ± 70 years B.P. (N.Z. 3085 B).

Figure 2N A box-shaped valley (arrowed) adjacent to Buckley Road (near Shannon). This valley was the main one investigated, and positions of bore holes are indicated. The valleys within the Tokomaru Marine Terrace flank the axis of the Levin Anticline. State Highway 57 is in the foreground.

2.6 Source of Sediment

2.61 Introduction

Where fossiliferous beds with identifiable fossils have been found in the valleys and floodplain, sediments encasing the fauna are assumed to be estuarine. Where shelly facies have not been found, the depositional environment of the valleys cannot be definately determined. Several analyses to examine the nature of infill sediments were carried out. The actual procedure for each is stated in Appendix II.

2.62 Possible Sources of Supply

Eefore detailing the analyses, the possible sources of sediment supply are given :

Sources :

(A) Sands and small gravels of the Tokomaru Marine Terrace. The main member of the Tokomaru Marine Terrace formation is the Otaki Sandstone (Oliver 1948).

(B) Loess; according to Cowie (1964a) derived from the glacial/late glacial river beds.

(C) Dune sand; either from an early phase underlying the Foxton phase (2-5000 years old), or, in the southern part of the study area from Koputaroa dunes (late glacial - older than 20,000 years old).

(D) Aokautere Ash (= Oruanui Ash, Vucetich and Pullar 1969) dated at c. 20,000 years old and lying within loess.

(E) An assortment of sediments brought into the area by the Manawatu and Oroua Rivers, and their tributaries.

(F) Shelf and beach sands carried into the study area by estuarine processes (e.g. salt wedge, flood tide). This includes along-shore drift sediments brought from more northerly areas.

2.63 Analysis

Tables II and III show the results of rounding and percentage of opaque minerals of selected sources and samples. Samples 26/10 and 19/6 were selected because they were definately identifiable as estuarine, because shells were present. S/26/10 from a depth of 2.66 meters, and S 19/6 from a depth of 4.1 to 4.3 meters. Sample 15/2 was collected from 3.2 to 3.3 meters, 45 meters west of the Tokomaru Marine Terrace cliff. It is unknown if this sand is estuarine or fluvial, but it was analysed to see if it was derived primarily from the cliff sediments. Sample 23/2 from 3.7 to 3.8 meters was a mixture of estuarine muddy sediment and Otaki sandstone, collected from drilling in the side of a box-shaped valley. Sample 14/4 from 1.98 to 2.28 meters was sand probably from a bar built at the mouth of a valley. The

Sample number, e.g. S 14, refers to the bore hole number.

These can be located on figure 2 L.

TABLE II: Rounding of Sand Grains of Selected Samples

SOURCE AREAS				
Otaki Sandstone	Otaki Beach Sand	Himatangi Beach Sand	Manawatu River Sand	Himatangi Dune Sand
0.332	0.284	0.33	0.31	0.38
SELECTED SAMPLES				
S26/10	S14/4	S15/2	S19/6	S23/2
0.412	0.298	0.407	0.304	0.370

TABLE III Percentage of Opaque Minerals

Himatangi Beach Sand	Otaki Sandstone	S26/10	S14/4	S15/2	S19/6	S23/2
41.3174	37.6344	23.636	57.732	38.4	54.255	43.137

Initial examination of roundness and opaqueness gave little encouragement for further detailed study. For example, S 23/2 should have approximated closely to Otaki sandstone, yet the difference between them is quite significant. The information in the tables is statistically meaningless, and correlation of a source area with a sample area was considered spurious. Analysis of several bore logs drilled north of Shannon was not carried out as the above analyses could not be used as reliable indicators of estuarine or fluvial sedimentation.

Mineral identification of several source samples was carried out in order to discover if a particular source was supplying sediments to a particular area; or if a particular source was providing more sediments than the other sources; or if the minerals could be used in a diagnostic sense to differentiate fluvial and estuarine sediments.

The writer's analysis plus the analysis of Oliver (1948) of source samples taken from various environments (e.g. beds of the Tokomaru Marine Terrace, Dune Sand, Beach sand, River sand, Aokautere Ash) showed that the mineral groups are mainly comprised of quartz grains, a lesser amount of feldspar, together with small lithic fragments, and in some cases volcanic glass. Heavy mineral content varied markedly with river sediment possessing the lowest percentage. In all samples the following heavy minerals were identified and generally constituted more than five percent of the sample: Opaque minerals (probably Fe and Ti oxides), brown hornblende, augite, hypersthene, red hornblende, green hornblende.

A few rare grains of zircon were identified. This analysis agrees in general with Oliver's (1948) work.

There appeared to be no individual heavy mineral types or assemblages which could be used to identify any one particular environment. This is probably due to the polygenetic origin of the source sediments in all cases.

Several samples of estuarine sediments from the valleys and floodplain were analysed. Grains of silt or sand size in the Flandrian sediments were of similar composition. Consequently, it was not possible to identify the source of the Aranuian infill material, and it seems likely that the infill is derived from many different environments. Although Oliver could distinguish beach and dune sand from Otaki sandstone (beds of the Tokomaru Marine Terrace) to the south of the area, by the high proportion of volcanic glass, in all samples examined, including a beach sample, only very occasional grains of volcanic glass were encountered. In Aranuian sediments, volcanic glass may have been derived from Holocene or Pleistocene marine sediments, redeposited by the Manawatu River, from the coast by flood tide currents in an estuary, or from the Aokautere ash bed which mantles the Tokomaru Marine Terrace.

In view of the apparent lack of diagnostic minerals, it was not considered likely that a more detailed mineralogical study, within the scope of this thesis, would prove fruitful. Like the beds of the Tokomaru Marine Terrace, and the beach sands, the Aranuian infilling sediments are most likely polygenetic in origin, and represent a combination of sediments from all sources.

Augite and hornblende percentages of the heavy mineral fraction did appear to be higher in beach and dune sands than in the Manawatu river sand. This may offer opportunities for further investigation.

A pilot study was carried out to determine the percentage of sand present in several samples. It was considered that such an analysis would prove useful in distinguishing between fluvial and estuarine sediments. However the results were inconclusive and further investigation was abandoned.

The most typical deposits of this estuary and most estuaries are fine-grained muds which formed the shoals and tidal flats that emerged at low tide. The presence of these clayey deposits is partly due to the absence of wave action, and partly due, especially in brackish water, to floculation. Also muds carried in at high tide may adhere to the mud surface, and after deposition, high current velocities are needed to resuspend the mud. Deposition of mud is further promoted by the accumulation of suspended matter in turbidity maxima, as the material has an opportunity to settle at slack tide (Postma 1967).

According to Rusnak (1967), high sediment concentrations may come into an estuary from entering rivers. "Estuaries fronting streams with high sediment discharge rates may fill very rapidly by deposition of tractive and suspended loads at their heads, prograding the delta front. Or they may fill relatively more slowly in their basin centres where vertical accretion of suspended sediment occurs" (Rusnak 1967).

Sediments from the Tokomaru Marine Terrace and older beds in the Manawatu district were eroded during the Otiran glacial stage. Previous offshore and shelf deposits were exposed and loess deposition was widespread. As the Flandrian transgression followed, many of these sediments were reworked and redeposited. The complex assortment of sediments were probably carried by estuarine processes into the study area and redeposited. At the same time the Manawatu and Oroua Rivers were probably aggrading and depositing sediments into the northern end of the estuary. Dune sands were probably blown into the estuary. In the majority of tributary valleys it appears that only a small amount of material was brought down by the streams during the Post-glacial. Erosion was dominant in these valleys during late Otiran time but virtually ceased as sea level rose during the following transgression.

2.7 Development of Box-shaped valleys

The total depth of infill for box-shaped valleys in the study area is unknown, as the equipment used for drilling could only penetrate 9 meters of sediment. For each valley, the depth is likely to vary. However, indirect evidence has been utilised to reconstruct an approximation of an original valley profile, for the main box-shaped valley studied. The depth indicated on figure 20 is for a cross-profile approximately 800 meters up-valley from the valley mouth.

Several box-shaped valleys grade into V-shaped valleys in the Shannon area. Some examples are very deep (up to 60 meters) and wide. It seems likely that the marginal streams dissecting the Tokomaru Marine Terrace prior to the Flandrian transgression were also flowing in V-shaped valleys. The Tokomaru Marine sediments are soft and easily eroded, and the small streams could have carried out the work involved.

Figure 2 0 : The box-shaped valley floor and riser was drawn from a surveyed cross profile of the main valley studied near Buckley Road. Two bore holes, numbers H. 22 and H. 23, (see Appendix I), were drilled at the edges of the valley floor and they struck Otaki sandstone at the depths indicated. Angles of the valley-side slopes of a V-shaped valley which grades into the box-shaped valley near Buckley Road, were measured. These were drawn on the profile at the correct angle, and intersecting the two points at which Otaki sandstone was encountered.

It appears from figure 2 0 that this particular valley could have theoretically incised to c. 30 meters below present sea level. The writer considers such a depth of incision quite plausible. Once the estuary reached the mouth of the valley at some time during the Post-glacial, the valley was infilled by estuarine sedimentation processes which continued until c. 4 - 6000 years ago.

THEORETICAL FORMER V SHAPE OF A BOX SHAPED VALLEY NEAR SHANNON

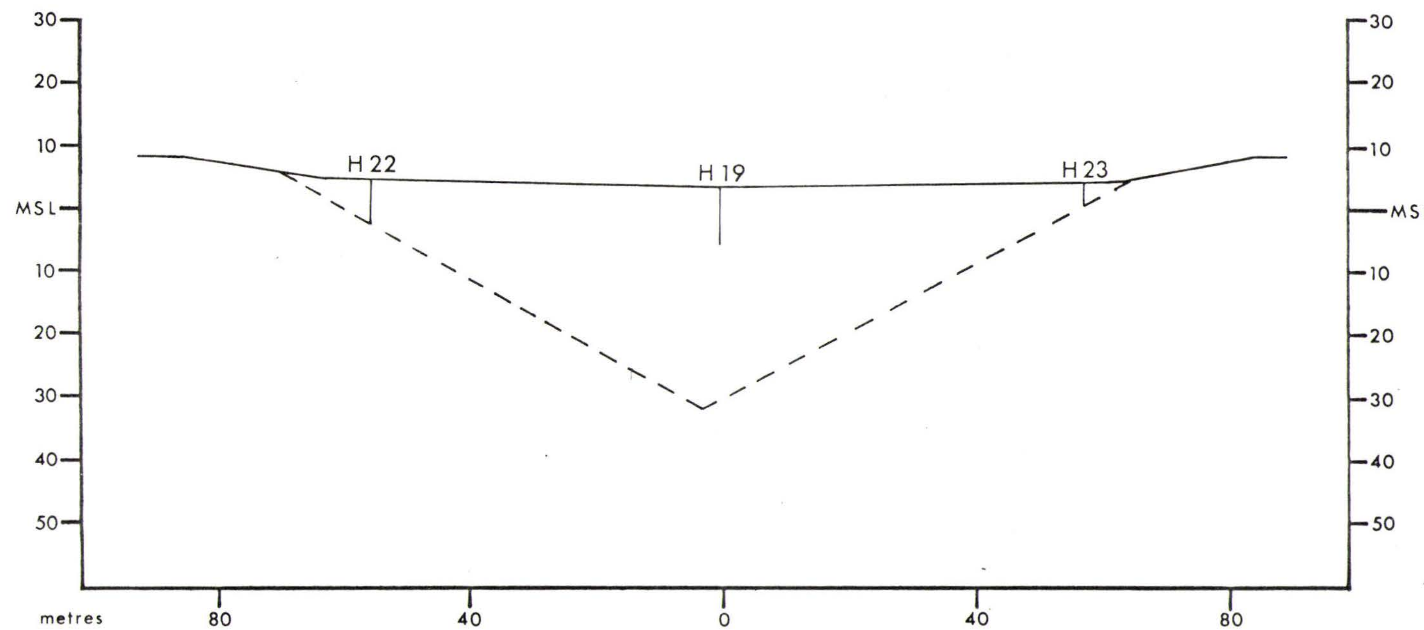


Figure 20

2.8 Summary

Two principle categories of marginal stream valleys have been recognised in the study area. The first category comprises gravel-floored, box-shaped valleys, with headwaters in the Tararua Ranges. These valleys are generally larger than those of the second category, their streams are incised, some of the valleys are terraced and some of the valleys have been fossilised and partially exhumed. The mouths of several of these valleys have been infilled with Aranuian sediments.

The second principle category of valley recognised comprises the majority of valleys in the study area. Valleys of this category are either box-shaped or V-shaped or a combination. Box-shaped valleys have not been formed by normal fluvial processes, i.e. lateral erosion, as the valleys in the first category have. Rather, the former valleys were once v-shaped valleys and during Post-glacial time became arms of an estuary, and were infilled with Aranuian sediments. Examination of the morphology, stratigraphy, shelly facies, depositional environment and the age of infilling confirmed this statement.

Sediment analysis indicates the Aranuian sediments are similar to beds of the Tokomaru Marine Terrace Formation, in that they are polygenetic in origin.

Notes

1. West Stream, named by the writer, after Old West Road and Fitzherbert West, the area from which it flows.

2. Scotts Stream, named by the writer after the road which runs parallel to the stream.

3. Mukara Stream, named by the writer after the settlement adjacent to the stream.

3. GEOMORPHOLOGY OF THE TOKOMARU MARINE TERRACE MARGIN

3.1 Introduction

A knowledge of the morphology of the seaward margin of the Tokomaru Marine Terrace is important for two reasons. Firstly it represents the eastern boundary of Aranuian infilling. Secondly many writers, (Adkin 1919, Cotton 1918, Oliver 1948, Te Punga 1962, Rich 1959, Heerdegen 1972, Fair 1968), have argued that the present form is due to one of two possible processes - either river cutting or sea/lagoon cutting. An understanding of the processes which affected the terrace margin would facilitate any attempt to reconstruct the geomorphological history of the area.

The three fold division of the Tokomaru Marine Terrace has been retained for this section.

3.2 Methodological Discussion

Accurate definition of the margin of the Tokomaru Marine Terrace is in some instances difficult. In places, streams have dissected the outer margin of the Tokomaru Marine Terrace to such an extent that only thin terrace remnants extend seawards leaving the margin ill-defined. Furthermore, the Tokomaru Marine Terrace is not everywhere cliffed, and in places where it is not, the junction between the floodplain and Tokomaru Marine Terrace is sometimes difficult to determine.

In the former case above, aerial photography has facilitated the mapping of the outer margin of dissected portions of the terrace. In the latter case, a dashed line on the large map of the study area, and on smaller diagrams indicates that the margin of the Tokomaru Marine Terrace cannot be mapped with total certainty.

Mapping was implemented from aerial photographs and checked in the field.

3.3 Previous Work

Adkin (1919) considered that cliffs along the margin of the Tokomaru Marine Terrace are sea-cliffs and he states that these are in a good state of preservation notably between Shannon and Tokomaru. He correlates the sea-cliffs in the above district with those at Paekakariki, Otaki and Ohau (p. 109).

In 1918 Cotton proposed a theoretical history for the growth of a coastal lowland. The area discussed extended from Paekakariki into the Manawatu area. Cotton considered that during a period of retrogradation, the Tokomaru Marine Terrace was "cut back to a line of cliffs of growing height" by the action of the sea. At a later stage progradation began and the cliffs along the margin of the Tokomaru Marine Terrace were reduced to gentler slopes by subaerial erosion (p. 217).

Cotton further states (p. 222) that "the Manawatu River at present bends to the southwest after emerging from its gorge across the old land, and at a not very distant date it swung still farther to the south. The toe of the bench formed by the Otaki series, i.e. Tokomaru Marine Terrace, is here cut back to a line of cliffs by the action of the River...". It is unclear whether Cotton means that the river cutting occurred at a later date, or whether Cotton is only referring to river-cutting of the northernmost cliffs in the study area.

Oliver (1948) considers that once the Manawatu River had entrenched itself in the Otaki Formation (Tokomaru Marine Terrace), the River "proceeded to cut laterally to a great extent especially in its lower reaches, where the gradient was very gentle". According to Oliver much of the Tokomaru Marine Terrace was removed by this action, and as a result, a line of cliffs was cut forming the present western margin of the Tokomaru Marine Terrace.

In 1962 Te Punga studied an ancient cliff between the Otaki and Waikanae Rivers. He considered that the cliff was marine cut, and represented part of the thermal maximum shoreline of western Wellington. Te Punga states that this shoreline is continued into the Manawatu area, and that "from Shannon to Linton the thermal maximum shoreline is represented by the almost continuous cliffed seaward margin of the " Tokomaru Marine Terrace.

Te Punga cites the intricate embayed outline of the Tokomaru Marine Terrace, and the discovery of marine molluscs near the foot of the cliff at Shannon as evidence.

Rich (1959) states that "while a shallow lagoon occupied the lower part of the Kairanga plain, slight cliffing of the Hawera sediments (Tokomaru Marine Terrace) took place". The post-Hawera shoreline, according to Rich, can be traced from Lake Horowhenua to Linton village.

Fair (1968) states that the sea cliffed the seaward edge of the Tokomaru Marine Terrace, during a climatic Optimum 7000 to 4000 years B.P., when sea level was about four meters above the present level.

Heerdegen (1972) considered that the Tokomaru Marine Terrace margin was cut by the sea "during the Flandrian transgression some 5000 years ago, or more recently by the Manawatu River" (p. 6).

3.4 Morphology

3.41 Area 1

Area 1 extends from Massey University to one kilometer north of Linton Village (see Figure 2 C). Between Massey University and Kahuterawa Stream the present form of the Tokomaru Marine Terrace margin is a river cut cliff. The cliff is high (approximately 20 - 30 meters) and almost vertical, although terracetting has reduced the angle in places. Vegetation has stabilised the cliff in some localities, while in others blocks of sandstone fall from

Figure 3A The cliffed margin of the Tokomaru Marine Terrace near Massey University. Note the small v-shaped valleys that have incised into the predominantly flat Tokomaru Marine Terrace.

the cliff, maintaining a vertical face (Figure 3 A).

From the south side of Kahuterawa Stream to one kilometer North of Linton Village the margin of the Tokomaru Marine Terrace is low[1]; cliffing is vertical and may be maintained by flooding. In general the cliff line is straight.

3.42 Area 2

Area 2 extends from one kilometer north of Linton village (grid ref. N149/044280) to the secondary road bridge over the main trunk railway line at Tokomaru Village (grid ref. N149/005210) (See Figure 2 E). Within this area the margin of the Tokomaru Marine Terrace is difficult to locate. The terrace margin is a gently sloping surface which meets the floodplain without a distinct morphological break (see Figure 2 F). The slope of the margin varies between three and seven degrees.

3.43 Area 3

Area 3 extends from Tokomaru Village to Lake Horowhenua (see Figure 2 G). Tokomaru Stream has a wide valley mouth bordered by small terraces. On its southern side the stream has cut back the Tokomaru Marine Terrace to an embayed line of high cliffs. These cliffs decrease in height and slope from Tokomaru Dump (Grid ref. N152/000189) to the junction of Tamatarau Road, and the Shannon Highway, No. 57 (see Figure 3 B).

Figure 3B The margin of the Tokomaru Marine Terrace just south of Tokomaru. Tokomaru River is to the left, and State Highway 57 crosses the centre of the photograph.

In the vicinity of the mouths of Waterfall Creek and Mukara Stream the topography appears 'drowned' by Aranuian sediments and the margin of the Tokomaru Marine Terrace is one of low subdued relief. In the locality, two isolated remnants of the Tokomaru Marine Terrace are encountered on the floodplain. These features have been termed 'umlaufbergs', a term proposed for similar features in Germany by Kolb (Te Punga pers comm). The term describes isolated hummocks of older material surrounded by a 'sea' of younger alluvium.

South of Mukara Stream (northwest of Makerua School) slight low cliffing of a subdued nature is the common form; cliffing becomes progressively more pronounced in a southerly direction. Between Opiki turnoff (Shannon Highway No. 57, Grid ref. N152/957159) and the mouth of Mangapuketea Stream, long remnants of the Tokomaru Marine Terrace extend westwards, the terminal slopes of these remnants being the margin of the Terrace (Figure 3 C). Low cliffs border the floodplain here; cliffing becomes more prominent towards Kingston Road and continues southwards.

Shannon township appears to be sited on an erosional terrace of the Tokomaru Marine Terrace which slopes towards the floodplain, and has been drowned along the margins by Aranuian sediments. Otauru Stream has cliffed the Tokomaru Marine Terrace on the southern side of Shannon township. Cliffing extends around the bluff in a broad embayment to Koputaroa Stream. On the south side of Koputaroa Stream, Koputaroa dunesands, formed during the Otiran glacial stage, are present.

Figure 3C Remnants of the Tokomaru Marine Terrace extend westwards between large box-shaped valleys. Note the artificial drainage, and the successively higher levels (eastwards) of the Tokomaru Marine Terrace. Photograph taken 4.8 Km. north of Shannon.

Koputaroa dunesands probably overlie, in part, beds of the Tokomaru Marine Terrace. The presence of the dunesands has acted to subdue the surface expression, and the margin of the Tokomaru Marine Terrace is less pronounced.

Slight low cliffing extends from Koputaroa Stream to the southern boundary of the study area. A few umlaufbergs are also present in the vicinity of Piaka Road. In general the margin of the Tokomaru Marine Terrace in area 3 is more embayed and indented than in the former two areas. The cliff varies more in height and slope also.

3.5 A Proposed Mode of Formation of the Tokomaru Marine Terrace Margin

As sea level fell at the beginning of the Otiran glacial stage, the streams and rivers flowed across the newly exposed marine plain, now known as the Tokomaru Marine Terrace. Eventually with sea level below the present these rivers would have incised into the Tokomaru Marine Terrace and eroded a great deal of it. The position of the Oroua and Manawatu Rivers is such that most of the marine sediments west of the present Tokomaru Marine Terrace margin could have been eroded. Smaller streams carved westward trending valleys and eroded more of the Tokomaru Marine Terrace.

It is suggested here that the Oroua and Manawatu Rivers, combined with the several smaller rivers and streams are almost entirely responsible for the original major eastward cliffing of the Tokomaru Marine Terrace.

The present form of the Tokomaru Marine Terrace margin can be divided into a three-fold division. The northern margin is entirely river cut to Linton Village. From Linton Village to Tokomaru the margin is gently sloping and is nowhere cliffed. From Tokomaru to near Lake Horowhenua the margin is cliffed.

In Area 1 the Manawatu River is structurally controlled to Palmerston North by the Tararua - Ruahine Horst to the east, and the Pohangina anticline on the west. Upon emerging from this synclinal position the river continues flowing southwestwards to Linton. On geomorphological evidence it appears that in Area 2 (Linton to Tokomaru), the Tokomaru Marine Terrace slopes under Aranuian sediments. There is no evidence along the margin of the Tokomaru Marine Terrace here to suggest erosion by lagoon or ocean waves.

Rather, the writer believes that the Tokomaru Marine Terrace in Area 2 has merely been eroded by the river at a lower level and then drowned by Aranuian sediments. The Tokomaru Marine Terrace everywhere displays a gentle seaward slope. After the initial exposure of the Tokomaru Marine Terrace, uplift, greatest along the eastern margin, probably accentuated this seaward slope. The Manawatu River eroded the Tokomaru Marine Terrace between Palmerston North and Linton and continued flowing in a south-westerly direction, cutting away the Tokomaru Marine Terrace to

THE GEOGRAPHIC POSITION OF THE MANAWATU AND TOKOMARU RIVERS IN RELATION TO THE TOKOMARU MARINE TERRAC

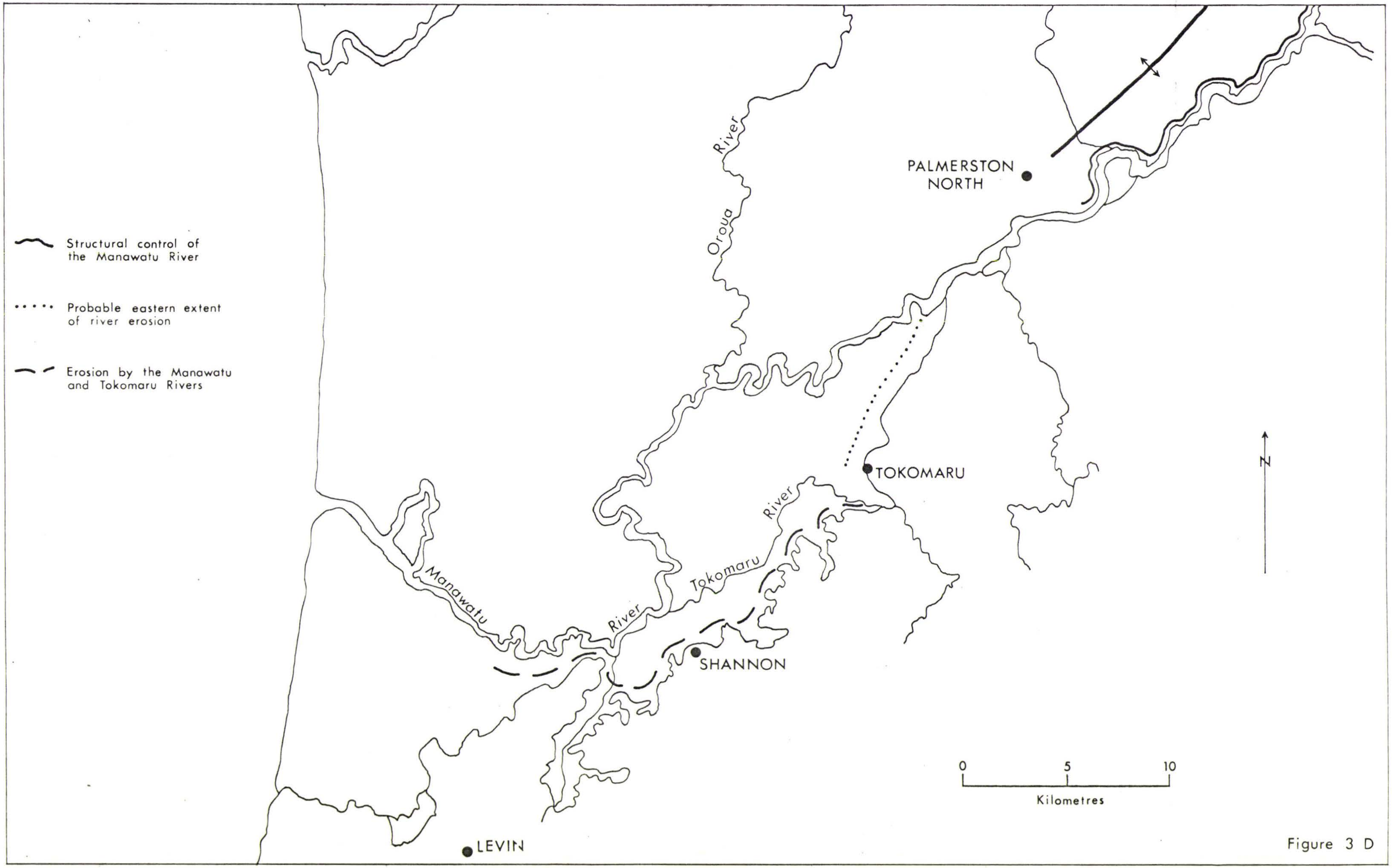


Figure 3 D

the west of Tokomaru and Linton. This erosion would thus have occurred west of the present Marine Terrace margin and is now buried by floodplain sediments. The Tokomaru River appears to have been instrumental in eroding a large part of the Tokomaru Marine Terrace between Tokomaru and Shannon. The Manawatu River was probably responsible for eroding the southern portion of the Tokomaru Marine Terrace in the study area. Much later, estuarine processes may have aided in some small-scale erosion in the latter area (Figure 3 D).

The seaward slope of the Tokomaru Marine Terrace in the Tokomaru - Koputaroa area (Area 3), has been markedly reduced by erosion of the Tokomaru Marine Terrace margin.

3.6 The Tokomaru Marine Terrace Margin : River Cut or Sea Cut?

The most compelling evidence for river cutting is provided by the existence of umlaufbergs in Area 3 - Tokomaru to just north of Lake Horowhenua.

These low round hummocks predominantly comprised of soft sandstones could not have survived in an environment where waves were an erosional agent. Rather, it is suggested they were left as isolated remnants of the Tokomaru Marine Terrace as rivers and streams incised into that Formation. Later during the Post-glacial, sedimentation in an estuary characterised by a low energy environment partially drowned the remnants.

Stream valleys of the three areas discussed in Chapter 2, Section 2.3, differ morphologically. Stream valleys of Area 2 between Linton and Tokomaru are the headward remnants of much longer and larger streams. The greatest amount of incision occurs in the Shannon district where the Tokomaru Marine Terrace had been cut back to a line of cliffs. Incision would be easiest here for streams able to erode the soft sandstone on a steep slope, and proceed by headward erosion. Valleys in Area 2, (Linton to Tokomaru) also probably incised in this way, but lower estuarine and upper alluvial sediments buried the lower and middle reaches of the valleys. The valleys described in Area 2 of Chapter 2 are the remnant upper reaches of much longer valleys.

Shelly facies encountered in bore holes in the Shannon and Koputaroa districts show that an estuary was definately in the southern portion of the study area. Several of the shells were found "in situ". That is, they were found in the position in which they lived, and there had been no post-mortem transport. Morton and Miller (1968) consider that shells found "in situ" indicates quiet waters free from much wave and current action. Furthermore, the predominant sediment types indicates that the high energy environment typical of a littoral environment affected by ocean waves was not present.

In the Shannon - Koputaroa district it is likely that high spring tides or storm waves may have slightly re-eroded the Tokomaru Marine Terrace cliff-line. North of Tokomaru the elevation of the land would have been too high for the cliff to have been wave cut.

Evidence for the age of the Tokomaru Marine Terrace margin and the nature of the estuarine environment will be discussed in more detail in the following chapters.

Notes

1. No explanation is given here for the difference in height between the north and south sides of Kahuterawa Stream. The possible extension of a fault along the northern side of Kahuterawa Stream, and indicated on the Geological Map (Kingma, 1962), may explain this height difference.

4. THE ESTUARY: EXTENT, AGE AND NATURE

4.1 Introduction

D.W. Pritchard (1974) defines an estuary "as a semi enclosed coastal body of water that has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage".

From a geomorphological standpoint there are four primary subdivisions of estuaries: (1) drowned river valleys, (2) fjord type estuaries, (3) bar-built estuaries, and (4) estuaries produced by tectonic processes (Pritchard 1974). A combination of two of these primary subdivisions has been termed a composite estuary.

In the study area, the development of a former estuary has been apparently influenced by the location of the Manawatu river valley, the coastal sand-dunes and the Tokomaru Marine Terrace. The geomorphology of these land forms and their relevance to the estuary is discussed. Boundaries are proposed for the limits of the estuary, the depth of infilling is discussed, and the age of the estuary is examined.

4.2 The Sand Country

4.21 Extent of the Sand-Dunes

The dunes have been formed during three distinct dune-building phases, the Waiterere, Motuiti and Foxton phases (Cowie 1963). "Dunes of the Waiterere Phase form a coastal belt from one quarter to two miles wide, and also occur as small patches where previously stablised sand plains and dunes of the Motuiti Phase have been wind eroded and their sand transported" (p.271). Dunes and sand plains of the Motuiti Phase form a belt up to 9.6 kilometers wide inland of the Waiterere dunes. A line of small lakes marks the contact between the two. Dunes of the Foxton Phase form a 3.2 - 6.4 kilometer wide belt inland of the Motuiti dunes (Cowie 1963), (Figure 4.A).

4.22 Age of the Dunes

The Waiterere dunes are less than 120 years old, and the Motuiti Phase 1,000 to 500 years old (Cowie 1963). Although Cowie originally considered the Foxton Phase to be 4,000 to 2,000 years old, it may be as old as 4,500 years (Cowie pers comm, and reported in Inqua Guide Book Al, 1973). The age of the Foxton phase is based on indirect evidence. The dunes are older than the Taupo eruption dated at 1800 years B.P., as they pre-date the Taupo pumice alluvium; their sands lack pumice; the dunes have a well defined topsoil about 30 centimeters deep and a subsoil deeper and browner than that of the subsequent phase, the Motuiti; and the dunes overlie loess deposits.

The age of upper beds of the estuary in the Shannon district is 6,330 $\pm$ 70 years B.P. The estimated age

EASTERN, SOUTHERN AND POSSIBLE MAXIMUM NORTHERN EXTENT OF THE MANAWATU ESTUARY

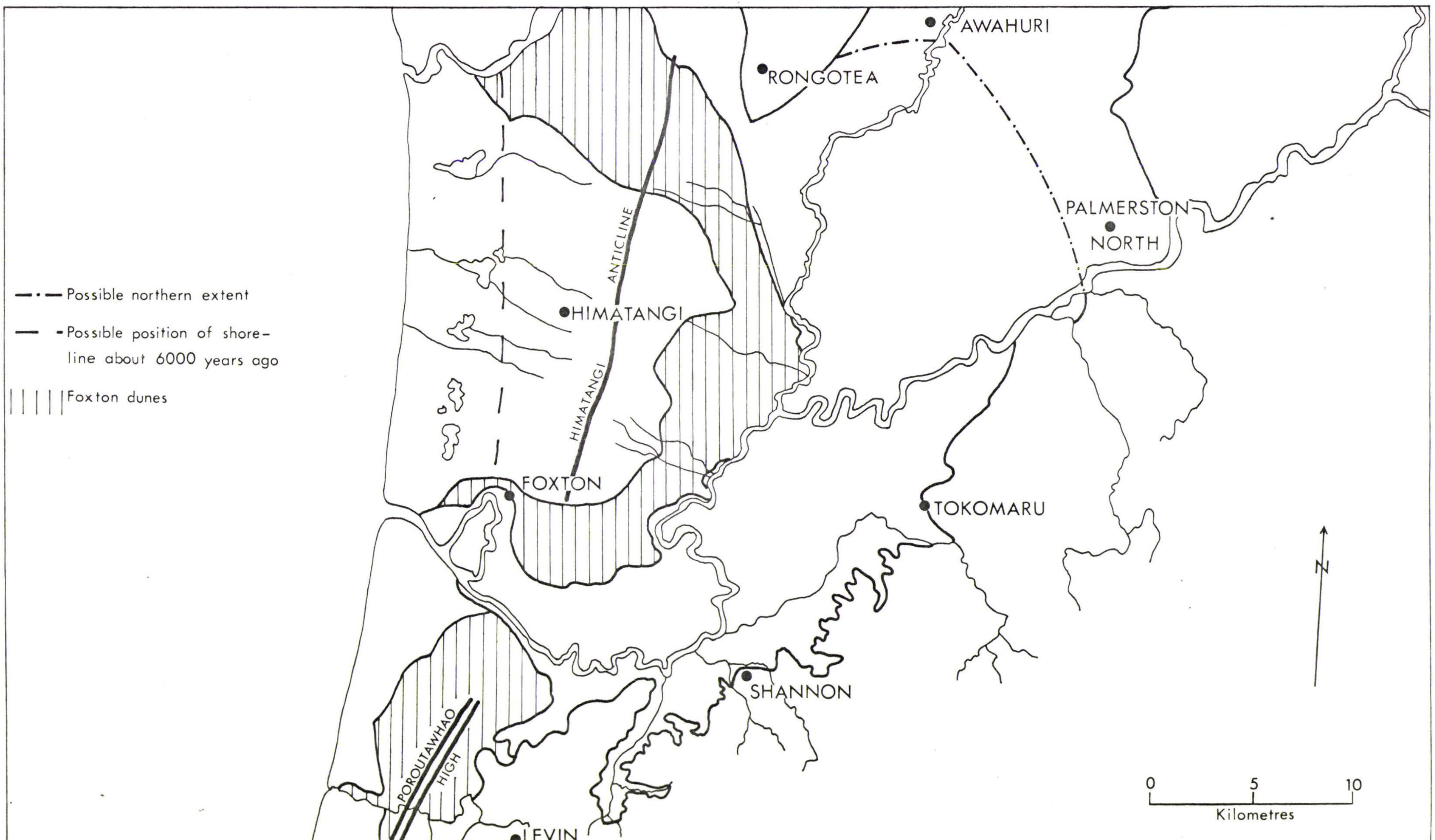


Figure 4 A

of the Foxton phase places it as younger than the Manawatu estuary.

4.23 Evolution of the Dunes

It is possible that a baymouth bar or barrier predates the Foxton phase, sands of the barrier or bar lying either below or seaward of the Foxton dunes. King (1972) states that where the sea has been rising over a gently sloping former sea bed covered with an abundance of loose sediment, material will be swept forward by wave action. Barriers and bars are formed in this way. During the Flandrian transgression the above conditions were met. Wind action may have formed the dunes known as the Foxton dunes at a later date.

As the salinity of the estuary was lower than that of ocean water some type of barrier, not necessarily a sand barrier, or bar, must have been present prior to the Foxton phase to prevent direct marine incursion into the study area.

4.3 <u>The Himatangi Anticline</u>

In 1959 Rich added the Himatangi anticline to those previously studied by Te Punga (1957). The anticline lies between the Kairanga Trough and the coast, the crest trending slightly east of north for approximately 20.9 kilometers from Foxton to Rongotea.

"Topographic expression is not obvious in as much as the newly emergent coastal plain is only very gently warped and the form of the surface is camouflaged beneath fixed elongate sand dunes. A recognisable drainage pattern .... indicates the approximate dimensions of the anticline. In the Himatangi - Rangiotu vicinity the anticline attains a maximum width of nearly ten miles. Coastal elevations rise from less than 50 feet above sea level near Foxton to approximately 150 feet at the culmination four miles west-southwest of Rongotea, then drop to 30 meters at the northern end" Rich p.133).

It is possible that the Himatangi anticline acted as a barrier to direct incursion of the sea. Rich (1959) considered that the Himatangi anticline may have had geomorphic expression during the Flandrian transgression. He indicates this in his figure 17 by showing the Hawera shoreline encircling the Himatangi anticline.

Although Rich did not have any bore hole information, he did find silt containing a marine microfauna in a pit 7.2 kilometers northeast of Himatangi (grid reference N148/848367). He considered these beds were "probably equivalent in age to the Tiritea formation" (Tokomaru Marine Terrace Formation). He did not find the silt at any other exposures. The present writer visited the site, and found the pit was in a low-lying area located between longitudinal dunes.

The writer has studied several bore logs drilled across the Himatangi anticline. These have been placed on a surveyed profile of the Himatangi anticline, executed during 1922 by the Manawatu Catchment Board (ref. 'Himatangi Cut'). The bore logs are stratigraphically similar (Figure 4.B). All such bore logs are listed in Appendix III.

When the uppermost sandy beds are joined, a general arc is apparent in the underlying beds across the axis of the anticline. From west to east the heights where the underlying beds were encountered, across the middle of the anticline, are 0.3 meters above m.s.1 . (B.L.45) 4.5 meters above m.s.1. (B.L. 162, 163); at m.s.1. (B.L. 164), and 1.5 meters below m.s.1. (B.L. 98), over a distance of 7.2 kilometers. It is not known whether the uppermost sand horizon, which reaches a depth of 25 meters on the axis of the anticline, is all Holocene dune sand, or not. The greatest difficulty with such bore logs is the inability of the writer to distinguish Flandrian from Oturian and older beds. Rich's (1959) marine microfauna exposed a few feet below the surface appears to indicate that Oturian beds are very near the surface.

If the hypothesis that either a sand barrier/bar predating the Foxton phase, or a structural barrier, the Himatangi anticline, (with perhaps some dune sands on top), is correct, a barrier of pre-Flandrian age would have formed the initial oceanic coastline at the height of the transgression.

CROSS PROFILE AND BORES OF THE HIMATANGI ANTICLINE

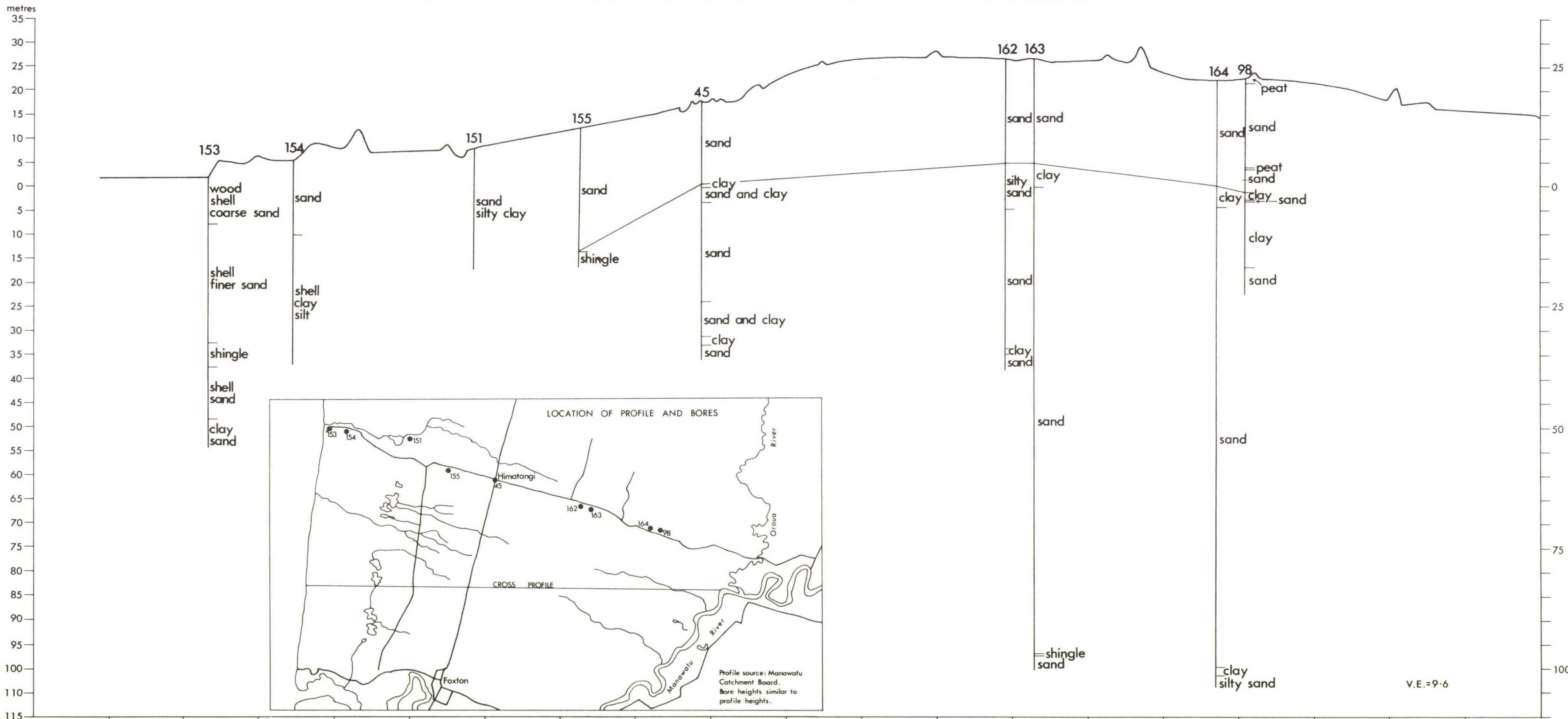


Figure 4B

The strata in bores 155,151, 153, 154, appears to indicate a sedimentary sequence typical of a prograding coastline. If the Himatangi anticline did have geomorphic expression during the Flandrian transgression, the Flandrian shoreline would have been to the west of the anticlinal axis. Shingle, sand and clay would have been deposited as offshore and beach deposits.

It is notable that no gravel beds were encountered in bores on the anticline. Other bores indicate that glacial gravel deposits lie to the east of the anticline. This seems to add weight to the theory that the Himatangi anticline was in existence during glacial/late glacial times as aggrading rivers appear to have been structurally controlled by the anticline.

Although no conclusive evidence is available, the existence of a marine microfauna near the surface of the anticline, the domed strata of the anticline, and the absence of gravels, all indicate that the Himatangi anticline may have been a structural barrier preventing direct marine incursion into the study area during the Flandrian transgression.

4.4 The Poroutawhao 'High'

As the Himatangi anticline does not continue towards Lake Horowhenua, it might be expected that the sea during Flandrian time would have transgressed into the northeast

Levin - Lake Horowhenua area, cliffing the Tokomaru Marine Terrace. Apparently, no such direct marine incursion occurred owing to the presence of the Poroutawhao 'High'.

Te Punga (1953a) detailed the stratigraphy of a bore drilled by Mr S. Richardson in 1939, near Poroutawhao (N152/781102). The bore (see Appendix III) struck 'solid rock' at 24 meters below ground level; this was overlain by dune sands. Te Punga stated that the 'solid rock' was approximately 1.5 meters above sea level, and "is almost certainly greywacke, a diagnosis supported by Dr E.I. Robertson's recent geophysical work, which shows that near Poroutawhao the 'basement' is rising and approaches sea level (pers comm)" (p.189).

Te Punga terms this feature the Poroutawhao greywacke 'high' and considered it "had been of major importance in determining the lower course of the Manawatu River during late Pleistocene time" (p.189).

Mr Neville Webb has kindly supplied logs of bores he has drilled in this area and his findings support the existence of a basement 'high'. Bore hole 134 on the corner of Waiterere Beach Road and Highway 1 (approximately N152/784093) struck blue rock at approximately 100 meters below the surface. Mr Webb reported that approximately 300 meters north of this well, rock is struck at about 40 meters. The height of the surface at both locations is approximately 21 - 24 meters above m.s.l. Further bore logs indicate that the basement 'high' extends southwards past Lake Horowhenua.

Bore 118 struck shattered rock at 15.8 meters near Moutere Road, Levin. A second well drilled nearby (118b) struck 'solid blue rock' at 10.9 meters. The height of the surface above sea level is approximately 15 - 18 meters. Bore hole 119 at Sand Road, Hokio struck blue rock at 32.5 meters. The surface here is 9 - 15 meters above m.s.l.

From the evidence provided in the bores it would appear that the presence of the Poroutawhao 'high' was responsible for preventing any major direct marine incursion into the southern part of the study area. A bedrock barrier, either unbroken or consisting of islands and shoals would have sheltered the lowland to the west and northwest of Levin from direct oceanic influences (Figure 4.A).

4.5 The Eastern & Southern Boundaries

The margin of the Tokomaru Marine Terrace and the formation of that margin has been discussed in Chapter 2. It is apparent that the margin of the Tokomaru Marine Terrace has effectively prevented eastward deposition of Aranuian sediments; only where valleys exit at this margin do Aranuian sediments, infilling the valleys, occur further eastwards.

As illustrated on the accompanying map (Map 1), the margin of the Tokomaru Marine Terrace extends from Koputaroa towards Lake Horowhenua. In fact the margin of the estuary lies approximately along Highway 1 between Te Whanga Road and Waiterere Beach Road. Mapping by Gibbs et. al. (1957) and the present writer illustrates that Koputaroa dune sands and Hawera Beds of the Tokomaru Marine Terrace Formation lie north of Levin bridging the gap between the Tokomaru Marine Terrace and the sand dunes, and hence isolating Lake Horowhenua from a connection with the Lower Manawatu estuary, at least since the end of the Oturian Interglacial Stage.

In the low area, flanked on the west by dunes, and on the east by the Tokomaru Marine Terrace, between Highway 1 (the southern boundary) and the Manawatu River, extensive peat beds overlie estuarine muds and sands (see Chapter 5, section 5.613). Mr N. Webb (Levin well driller, pers comm), reports that west of Te Whanga Road, in the middle of the above area, peat locally reaches a depth of 4.5 - 6 meters and overlies sands (estuarine ?) which he has drilled to 36 meters without penetrating other beds.

4.6 The Northern Extent of the Estuary

4.61 Introduction

Evidence for an estuary in the Lower Manawatu with the exception of the Shannon - Koputaroa district is scarce. What evidence there is, mainly relies on interpretation of bore logs and as no dates and few samples are available the conclusions can only be tentative.

The most detailed bore available is one studied by Te Punga (1954a) at the Awahuri Dairy Factory. Although the location lies to the north of the study area, the bore has been included because of the detail provided, and the significance of the beds encountered.

The evidence for the existence of an estuary in the study area is of two types; (a) several bore holes provide possible evidence of earliest Flandrian estuarine beds at depths of 50 - 100 meters below sea level, (b) shallow estuarine beds have been studied in exposures and by sampling from bore holes drilled by the writer.

Almost all the bore logs were made available to the writer by the Manawatu Catchment Board, and by Mr N. Webb (Levin) and Mr H. Smith (Taikorea), well-drillers. These bore logs are listed in Appendix III.

4.62 Depth of Estuarine Beds: Deep Bore Hole Data

4.621 Awahuri Dairy Factory Bore (Grid. reference N149/033427)

Te Punga (1954a, p.89) states that "the oldest sediments in the Awahuri Well, consisting of 40 feet of poorly fossiliferous sandy gravel (with Chione dominant) were deposited under beach and very shallow-water conditions".

The top of the bed is 90.83 meters below sea level and is overlain by 7.01 meters of clayey beds and then 5.182 meters (78.63 - 83.72 meters below m.s.l.) of fossiliferous sandy beds (with Chione dominant). The latter sandy beds were deposited at or near the shore of an enclosed bay (Te Punga 1954a, p.89).

Some of the beds from 80.16 meters to 37.18 meters yielded a few marine microfossils, and others yielded evidence of a marine influence in the environment of deposition. There was no proof as to whether the deposits in these beds were laid down on the open coast or even in a bay. All the materials noted by Te Punga (p.90) were light and according to him could have been carried a certain distance upstream in an estuary.

A discussion of the evidence for the age of the fossiliferous beds from 78 - 103 meters below m.s.l. at the Awahuri well can be obtained in Te Punga (1954a). At that time Te Punga (1954a) concluded that "the age of the Chione beds at Awahuri may be tentatively considered as late-Pleistocene, probably not older than the Last Interglacial and possibly much younger" (p.89). Te Punga (pers comm., 1975) pointed out that he used the term 'Late- Pleistocene' because the fossils are not definitive. He states that his thoughts at the time (1954) were that the shells at 82.9 - 85 meters below m.s.l. were possibly laid down about the time of the beginning of the Flandrian transgression.

LOCATION OF DEEP BORES DRILLED IN THE MANAWATU

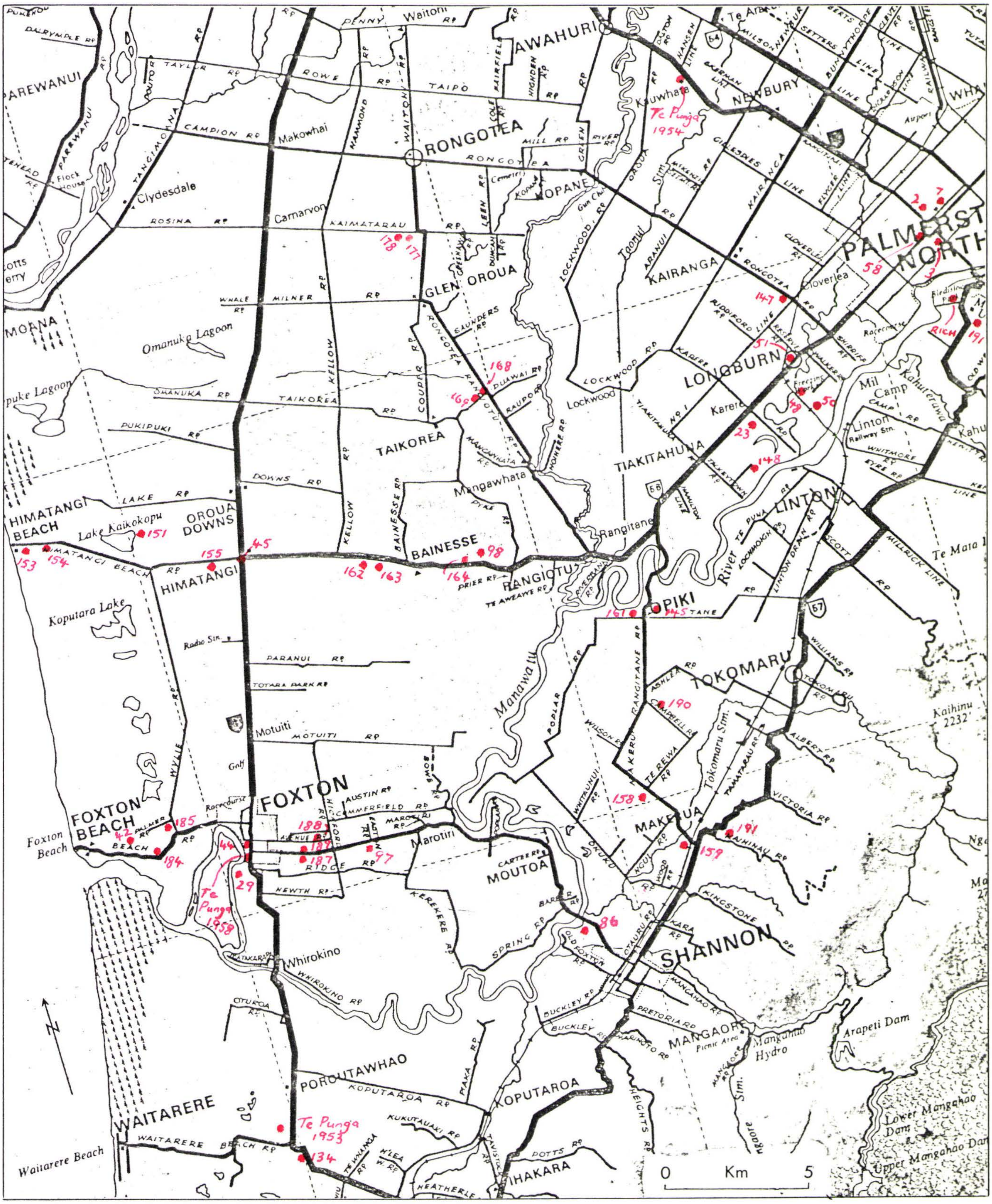


Figure 4C

4.622 Palmerston North City Bore Logs

Several deep bore logs were available for the Palmerston North City area. Five bores, numbers 2, 3, 7, 58 and one recorded by Rich (1959), encountered shells at various depths.

These shells cannot be considered as Flandrian in age. Cowie and Wellman (1962) have shown that the strata above the shells are terrace gravels and are unlikely to be less than 10,000 years old. Aokautere Ash, dated at c. 20,000 B.P. does not occur in cover beds of this terrace, the Ashhurst (=Ohakea), but in beds of the next highest terrace. As the age of the terrace gravels ranges between 10,000 and 20,000 years, the fossiliferous beds lying at greater depths must be regarded as pre-Flandrian.

4.623 Lower Manawatu Bores: Palmerston North to Foxton

The location of all bores is shown on Figure 4.C. Table lV below details the depth and lithology of Flandrian (?) fossiliferous beds and beds indicative of a marine environment encountered in bore holes, from north to south. Bores are separated into two categories; those which are near the Oroua River and those which are near the Manawatu River. The complete logs of all the bores are listed in Appendix III.

TABLE 1V DEPTH AND LITHOLOGY OF FOSSILIFEROUS BEDS, AND BEDS INDICATIVE OF A MARINE ENVIRONMENT

OROUA	MANAWATU
B.L.178:(Near Rongotea) N148/901405 Silty sand, driftwood and shells at 67.05 meters. Height of surface approx. between 15-17 meters below m.s.l. B.L.168:(Taikorea), N148/928340 Shingle with pumice at 90 meters. Height of surface approx. between 40-90 meters above m.s.l.	B.L.147:(Kairanga) unable to locate Fine blue sand and shell, some clay at 71.62 - 77.11 meters below the surface. Height of surface approx. 16 meters above m.s.l. B.L.48:(Longburn)N149/038308 Grey-blue sand, silt, shell at 93.54-102.1 meters. Height of surface 18-19 meters above m.s.l. B.L.23:(Karere)N149/020298 Sand, wood and pumice at 74.37-77.11 meters. Height of surface approx. 13-15 meters above m.s.l. B.L.148:(Tiakitahuna) N149/018284 Sand and shells at approx. 85.34-90 meters. Height of surface approx. 12 meters above m.s.l. B.L.86:(Shannon) N152/909141 Clay, pumice and shell at approx. 140.51-149.96 meters. Height of surface approx. 12-15 meters above m.s.l.

That the fossiliferous beds, and beds with pumice are early Flandrian beds is entirely tentative. No distinction can be made between Flandrian, Oturian and older beds in bore data of the kind provided.

Clay and silty sand are known from strata of the Tokomaru Marine Terrace. In a bore (No. 171) drilled on the Tokomaru Marine Terrace, Mr. H. Smith encountered 59.43 meters of sandstone (most probably Otaki Sandstone), then 29 meters of loose sand, and then 3.6 meters of clay, overlying silty sand. Pumice is also known (bore log 191) to be within beds of the Tokomaru Marine Terrace. It is unknown however, whether beds of the Tokomaru Marine Terrace underlie Flandrian deposits on the floodplain.

Shells in a good state of preservation and retaining a light purple colouration were examined from only one bore hole, Number 148. Several Chione and a few Macomona liliana were identified; these are indicative of an estuarinal environment.

In all the above bores, sand, metal, clay and peat successions overlie the beds described in Table lV (above). The deepest beds indicative of a marine environment are those in B.L. 86 at Shannon. Clay, pumice and shell were encounted at 140.5-149.9 meters, (approximately 125.5 - 134.9 meters below m.s.l.). Overlying this bed was 0.9 meters of clay and sand, and then 40.23 meters of small lenses of peaty clay, wood and seeds.

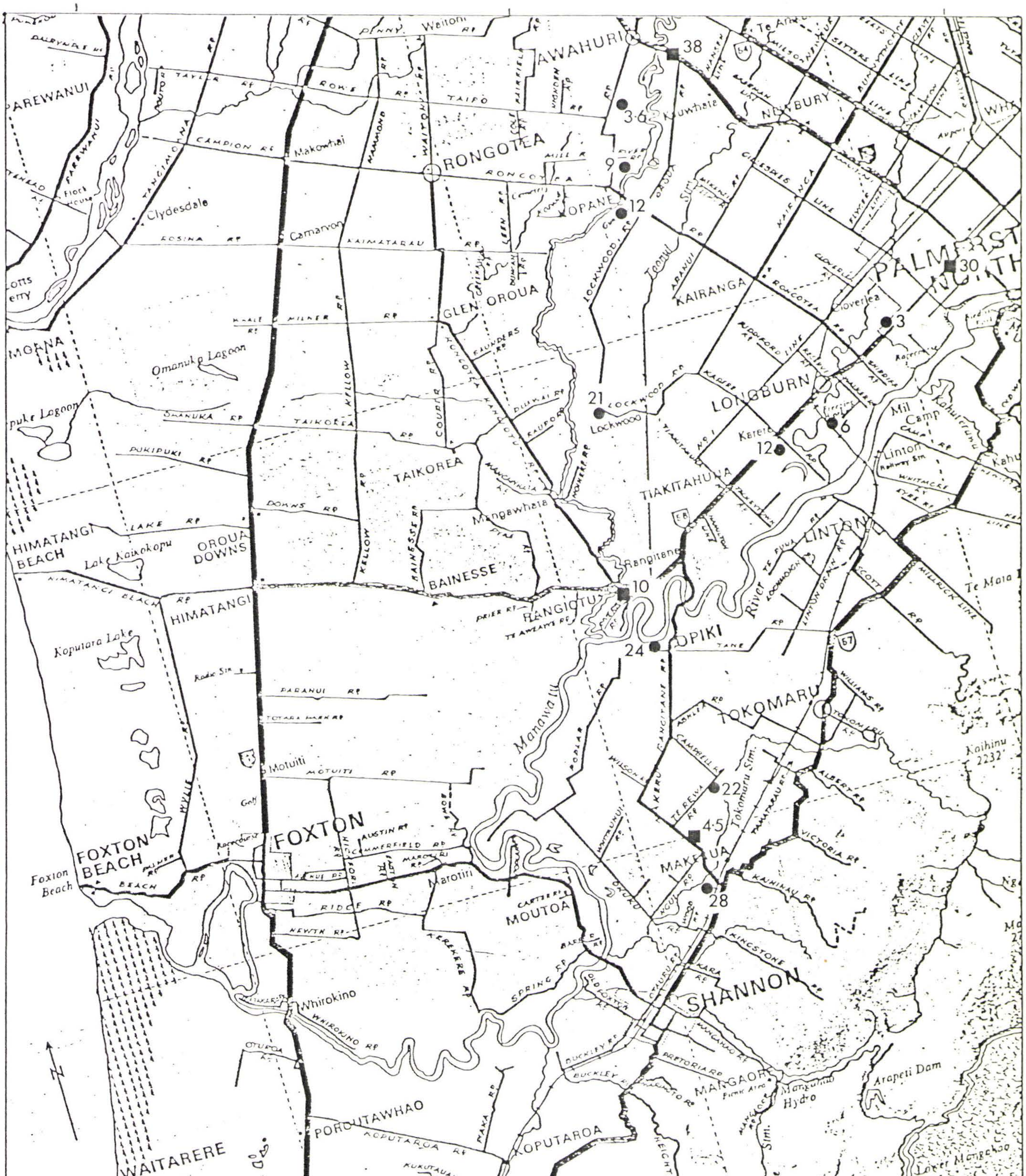
All the deep bores listed in Table lV above, bar one, No. 178, occupy positions quite near to the present courses of the Manawatu and Oroua Rivers. This suggests that the present courses are similar to the former courses during late-glacial earliest-Flandrian time, if the fossiliferous beds described are estuarine and Flandrian in age. The course of the Oroua could have been further west at this stage to theoretically accomodate bore log 178.

Some of the above bores have gravel beds in the stratigraphic column, while others (168, 178) do not.

Several other bore logs (190, 161, 145, 158, 159, 50, 51) indicate that a gravel surface (at least to Shannon) lies beneath the floodplain. This surface decreases in height southwards as is indicated in Figure 4.D. Gravel capped terraces of the Manawatu River in the vicinity of Palmerston North are buried by Aranuian deposits. These glacial-late glacial terraces appear to continue as buried surfaces beneath the floodplain. Figure 4.E illustrates the profile of the last major aggradational terrace of the Manawatu River [1], named by Fair (1968), the Ashhurst terrace. If the profile in Figure 4.E is extended beneath the floodplain at the same angle it indicates that gravel deposits at about Opiki (B.L. 190) for example are in a complementary position.

The writer tentatively suggests that following the last major terrace building phase, the age of which will be discussed later, the Oroua and Manawatu Rivers incised below their terraces. Flowing at a steeper gradient than formerly, the rivers incised deep channels in their lower reaches in response to the low glacial base level. They were able to do this because vegetation began to take hold in the upper reaches of the valleys reducing the load supply, and because the underlying Pleistocene gravels and marine beds consist of unconsolidated sediments which would have offered little resistance to river incision.

MAP SHOWING DEPTH OF PART OF THE GRAVEL SURFACE UNDERLYING THE MANAWATU FLOODPLAIN SURFACE

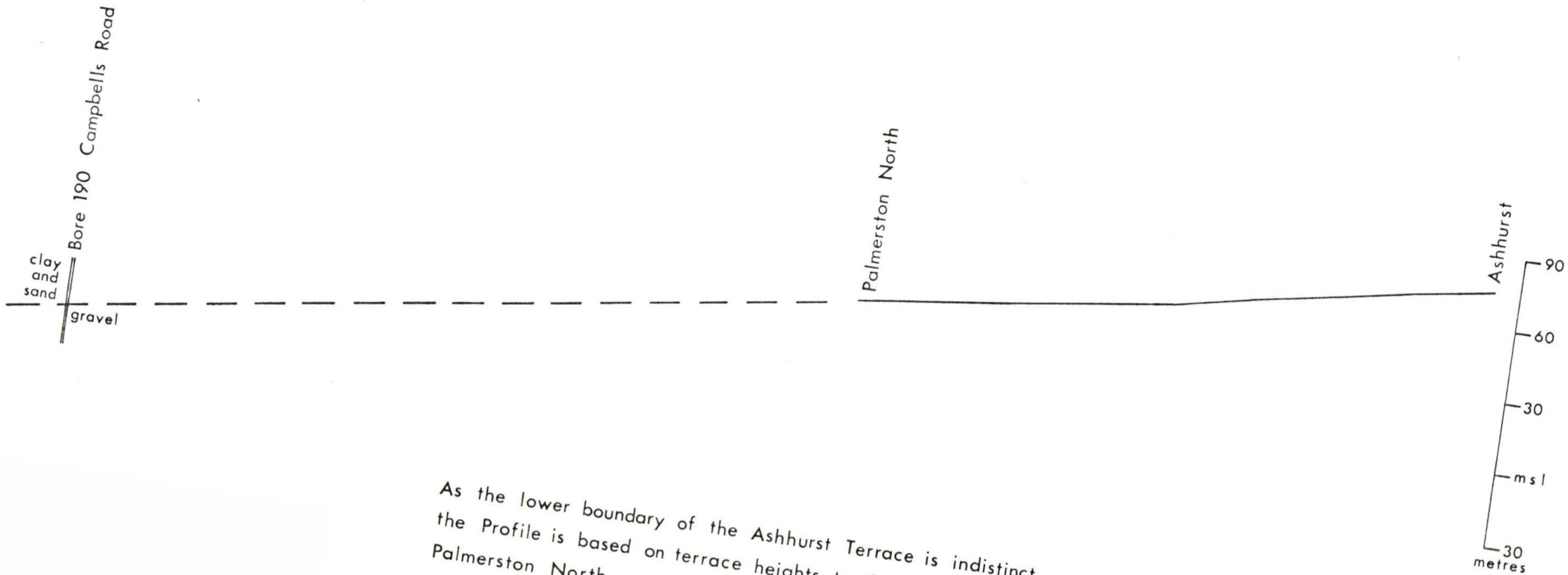


●3 Depth below the surface in metres of the upper boundary of river gravel deposits

■30 Height of surface in metres above m.s.l.

Figure 4 D

LONGITUDINAL PROFILE OF THE ASHHURST TERRACE



As the lower boundary of the Ashhurst Terrace is indistinct, the Profile is based on terrace heights to the northeast of Palmerston North.

Figure 4 E

During the Flandrian transgression an estuary extended up the Manawatu and Oroua river channels. At certain times the conditions were suited to the growth of estuarine fauna. As the transgression proceeded the channels became infilled and the estuary covered the formerly stranded terraces and fans.

The deep bore logs discussed above (Table lV) are tentatively regarded as having penetrated Flandrian beds infilling the Manawatu and Oroua river channels; the several other bores shown on Figure 4.C and listed in Appendix III, have penetrated the gravel terraces and fans. The fossiliferous beds and beds indicative of a marine environment in the deep bore logs in Table lV, plus the Awahuri bore, are tentatively regarded as some of the earliest estuarine beds deposited in the Manawatu and Oroua river valleys.

In the case of bore holes 178 and 168, two further holes were drilled nearby. Bore hole 177 was drilled only 3.6 meters from bore hole 178 and encountered gravel at 30 meters below the surface. This bed was at least 3 meters thick. In comparison bore hole 178 was drilled to 66 meters and did not encounter any gravels. Bore hole 169 was drilled 30 meters away from bore hole 168. No. 169 encountered gravel at 47.24 meters below the surface. In comparison bore hole 168 did not encounter metal until 90 meters below the surface. (The height of the surface is c. 12-27 meters above m.s.l.)

The startling difference in stratigraphy could be attributable to two factors. Either one of the bores in each case has encountered terrace gravels, and the other the infilled former river trench, or, variations in deposition by the river has led to sudden facies changes. In view of the theory proposed above, the former is tentatively accepted.

Fossiliferous beds higher up in the stratigraphic column indicate that later in the transgression, the area surrounding the bore recording those beds, had been drowned by the estuary. Bore log 97 encountered clay bound sand and shells at 46.33 meters. The ground surface is less than 15 meters above m.s.l. (Figure 4F).

4.624 Foxton Deep Bores

At Foxton several deep bores have encountered fossiliferous beds. The beds, which are predominantly clays and sands are considered to be estuarine beds. The position of Foxton at the nose of the Himatangi anticline, and with the Poroutawhao High to the south, indicates that the Manawatu River channel was probably in a similar position to the present river mouth. The estuarine beds are tentatively regarded as Flandrian sediments.

Bore logs 29, 188, and 189 record sands and clays to depths of 60, 48,76 and 22.86 meters respectively. Bore holes 184, 185, 187 all encountered shingle at about 54 - 60 meters beneath alternating clays and sands. In both 184 and 185 shells were present within the shingle. The height of the surface for all these logs is less than 15 meters above m.s.l. Bore logs 42, 43, 44 record sands, clays and gravels at various depths to 60 meters. Shelly beds in logs 42, 43 and 44 are 4.5 - 24 meters, 29.5 - 30.88 meters, 33.18 - 53 meters below m.s.l. in log 42; 5.4 - 10.36 meters and 30.09 - 31.39 meters in log 43; and 10.36 - 32.3 meters below m.s.l. in log 44.

SCHEMATIC SECTION OF THE TOPOGRAPHY AND STRATIGRAPHY OF THE HIMATANGI ANTICLINE, FLOODPLAIN AND MARINE TERRACE

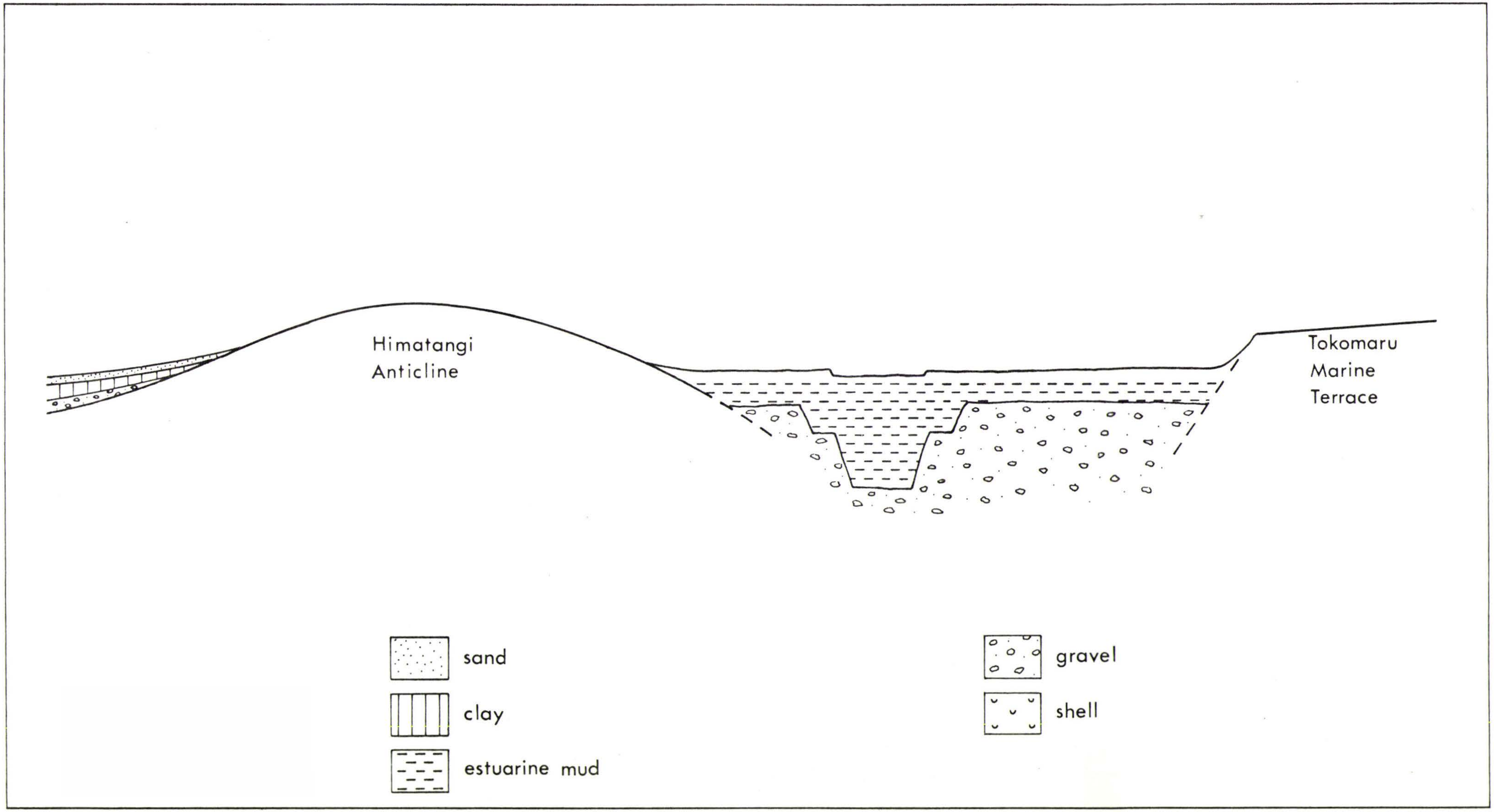


Figure 4 F

4.63 Shallow Bore Data

The stratigraphy for bores drilled by the writer in the Shannon district has been presented in Chapter 2. Estuarine beds, comprising mainly muds and sandy muds have been drilled to a maximum depth of 5.18 meters below m.s.l. in the valleys and 3.04 meters below m.s.l. on the floodplain. Estuarine fossiliferous beds have also been encountered in Koputaroa Stream Valley (B.L. H25).

West of Koputaroa, and west of the axis of the Levin anticline fossiliferous estuarine beds were encountered within a box-shaped valley (B.L. H30). Wellman (1962) has described a section near the Manawatu River mouth, (grid reference N152/770180). He found fossiliferous estuarine clay below M.H.W.M. beneath floodplain deposits and dune sands.

The Manawatu Catchment Board reported finding shells (species unidentified), when clearing channels 3.2 kilometers north of Shannon, at the Okuku Pump House, south of the Ngui Road - Okuku Road junction, (grid. reference N152/918146).

Several bores were drilled in box-shaped valleys (Bores H.3, H.4, H.11, H.12 and H.20) and on the floodplain (H.24, H.28, H.29) north of Shannon, but no fossiliferous beds were encountered. One difficulty was that the colour of muds appears to be primarily determined by the presence or absence of water. Muds were normally blue below the water table. Thus colour could not be used to separate estuarine and fluvial clays. Furthermore, the Tokomaru River is artificially channelled, and the downstream sediment types deposited by the river were unknown. Bores H.28 and H.29 drilled relatively near to the unchannelled mouth of Tokomaru River encountered muds, No. H.28 from 0.6 - 4.87 meters, and No. H.29 from 1.82 - 6 meters. The height of the surface is approximately 4.87 meters above m.s.l. for both bores. The muds may be estuarine, but they may have been deposited by the Tokomaru and Manawatu Rivers.

Bores H.11 and H.12 were drilled to 7.62 meters below the surface (reaching to 3.65 meters below m.s.l.). Sediments were analysed (see Section 2.63, Chapter 2) but no definite conclusions could be arrived at.

The Contour Map of part of the study area (Figure 4.G) indicates that estuarine beds, related directly to the level of the sea, will be at greater depths the further north one proceeds. The limitations of the hand auger plus the inevitable uneven distribution of fossiliferous estuarine beds meant that the chances of finding such beds north of Shannon were small. However the Awahuri well shows that an estuarine environment was present a considerable distance up the Oroua River during late post-glacial time.

In general, the writer considers that the younger, stratigraphically highest beds of the estuary were probably covered rapidly in the north of the study area by fluvial muds and sands, deposited by the rivers.

CONTOUR MAP OF PART OF THE LOWER MANAWATU

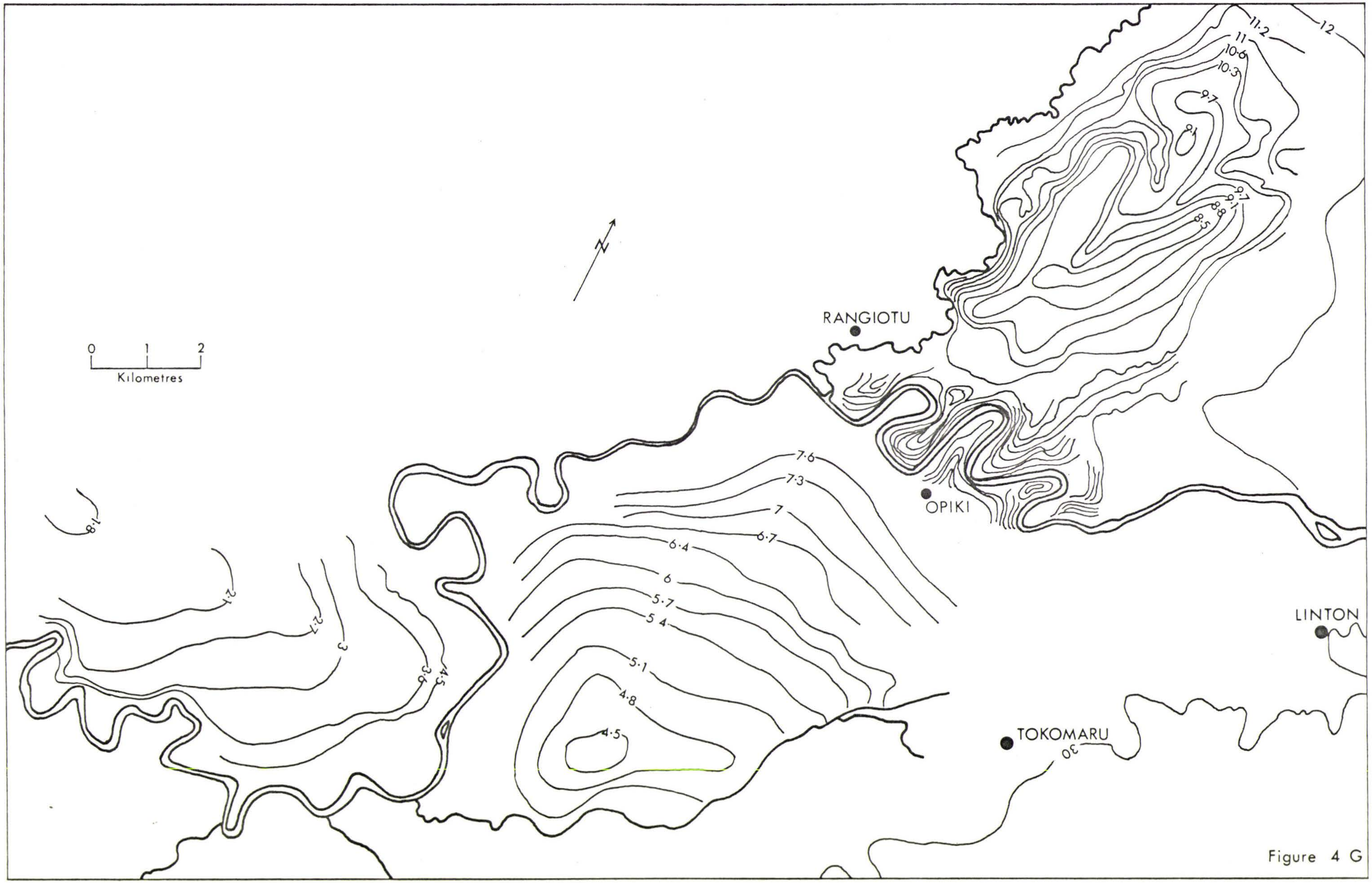


Figure 4 G

Abundant fossils are present in the Shannon - Foxton area at shallow depths, because the estuary probably persisted longest there, the fluvial cover is thin and large parts of the floodplain in that area have not been modified by fluvial erosion.

4.7 Age and Evolution of the Estuary

4.71 Depth of Flandrian Sediment

Evidence provided by deep bore logs, suggests the possibility that the rising Flandrian sea drowned deeply cut river channels of the Manawatu and Oroua Rivers to form an estuary. The greatest depth of sediment of possible Flandrian age is at Shannon, bore log 86; a clay pumice and shell bed at approximately 125 - 134 meters below m.s.l. Before accepting that Flandrian infilling may have occurred to such depths it is necessary to examine evidence from New Zealand and overseas.

4.72 New Zealand's Coastline During the Otiran Glacial Stage

Fleming (1962, p.89) portrayed New Zealand during the Peak of the Otira Glaciation. At the time he stated that during the last glacial stage "the sea withdrew to some 350 feet below present levels" (p.87). Presumably Fleming's map is drawn with this figure in mind. The coastline on Fleming's map is c.50 kilometers west of the present coastline. The map was adapted for the New Zealand Inqua Conference (1973), and the glacial coastline was drawn at c.25 kilometers from the present one. Morgan (1967) states that although evidence is sparse, most rivers seem to have eroded relatively straight valleys directly across the then exposed continental shelf (Le Blanc & Hodgson 1959).

4.73 Overseas Dating of the Last Glacial Maximum Sea Level

Milliman and Emery (1968) indicate that the lowest level the sea reached during the last glacial was 130 meters around 16,000 years B.P. on the U.S. Atlantic Seaboard, or around 19,000 years B.P. in the Texas region. They favour the Atlantic curve rather than the Texas one, because additional data from many other parts of the world appear to be consistent with the Atlantic rather than the Texas sea level curve. Emery and Garrison (1967) quote c.123 meters about 19,000 years ago for data from Texas. Walcott (1972) considers that the Texas data "would appear to be more reliable indicators of the eustatic curve" (p.11). He states that Texas is sufficiently removed from the area of the North America rebound not to be strongly affected by subsidence, and moreover from his calculations no substantial change through elastic deformation of the earth has taken place in the Texas area. Walcott does recognise however "the possibility of a regional vertical movement unrelated to eustatic effects" (p.11).

Russell (1967) states that his evidence "which is based on depths of alluvial fill in valleys and hence is completely independent of volume estimates, indicates a sea stand of about 135 meters below present sea level"(Russell 1964). Fisk and McFarlan (1955) agree with this, but later work by McFarlan (1961) cited evidence for an earlier glacial low at 135 meters around 35,000 B.P. A later glacial low (the last) reached to c. 120 meters below present sea level.

Curray (1961) dated shallow water molluscan species taken from a depth of 112 meters off the coast of Mexico, at 19,000 $\pm$ 300 years B.P.

Veeh and Veevers (1970) obtained radiocarbon and uranium dates for a terrace at -175 meters off the Great Barrier Reef. Because there was a significant difference between the dates the interval 13,600 to 17,000 years B.P. was adopted as the most likely period during which the coral was growing. Jongsma (1970) dated algal rock around -150 meters in the Arafura Sea at 18,000 B.P.

Chappell (1974a) has shown that the variation in the depth of shorelines formed during the last glacial maximum is consistent with theoretical predictions of global hydro-isostatic deformation. Chappell states that Emery and Garrison's (1967) age-depth data "should be corrected for displacement accompanying relaxation of the glacio-isostatic forebulge" (p.419). When this is done "a glacial low value of about -115 meters at 17,000 B.P. relative to the outer margin of the shelf off New York is achieved"(p.421).

Chappell subtracts the elastic effects from the above figure and the figures presented by Veeh and Veevers (1970) and Jongsma (1970) and arrives at a figure around -135 meters for the glacial maximum sea level, relative to outer margins of broad continental shelves.

Bloom et. al. (1974) states that the glacial maximum level "is estimated as between -120 and -135 meters (about 15,000 years ago) on the basis of an extensive submarine delta surface described by Chappell (1974b)".

Vita-Finzi (1973) states that several recent estimates put the magnitude of the regression at 120 - 130 meters.

4.74 Flandrian Sediments?: Discussion

All the above evidence for the lowest stand of sea level during the Otiran Glacial Stage has been selected because it records the greatest known depths. However, although several other writers cite glacial sea levels at lesser depths, most of the above data is very recent and uplift and elastic deformation (Walcott 1972, Chappell 1974a) have been taken into account.

The depths of sediments in deep bore logs tentatively regarded as earliest Flandrian in age, are from north to south; B.L.147, 54.8 - 60.35 meters below m.s.l.; B.L.48, 73.56 - 82.29 meters below m.s.l.; B.L.23, 59.13 - 61.87 meters below m.s.l.; B.L.148, 73.15 - 79.24 meters below m.s.l.; B.L.86, 125.27 - 134.72 meters below m.s.l. The height of the surface at bores 178 and 168 could not be ascertained but as both surfaces are less than 30 meters, a range of values, 15 - 27 meters for 178, 12 - 27 meters for 168, has been accepted. The beds in question lie between 64 - 79 meters below m.s.l. (B.L.168); and 39.62 - 51.81 meters below m.s.l. (B.L.178).

From the depths of the last glacial maximum sea level recorded in various papers above, a level of 130 - 135 meters (approx. 426 - 443 feet) may be taken as representing many recent estimates. In sub-section 4.72 the most recent map of New Zealand during the Otiran Glacial Stage placed the western coastline at 25 kilometers from the present one.

Only indirect evidence is available to suggest the former gradient of the rivers crossing the exposed continental shelf during late-glacial time. The present gradient between Palmerston North and Opiki for example is approximately 2.4 meters per kilometer, and between Opiki and Foxton approximately 0.3 meters per kilometer. During the late glacial the rivers would not have meandered so much, and on the basis of the gradient of the re-drawn Ashhurst terrace profile (approximately 4.8 meters per kilometer) the gradient was likely to be considerably steeper than at present. If the depth of incision was great in the Shannon area, then it would surely have been greater at Foxton, and even more so at the mouth of the river.

It appears that if the glacial coastline was 25 kilometers west of the present one and sea level stood at about 135 meters below the present, the depth of a fossiliferous bed at Shannon (B.L.86) viz. 125 - 134 meters is too deep to be regarded as Flandrian in age.

On the other hand stratigraphically higher fossiliferous beds and beds indicative of marine/estuarine deposition, ranging from 51 - 82 meters below mean sea level could very likely be Flandrian in age. Considering that the late glacial gradients were probably steeper, sea level was c.135 meters below the present, and Palmerston North is sited only 73 kilometers from the glacial coastline, downcutting of at least 50 - 80 meters in the middle reaches of the Manawatu and Oroua rivers is certainly plausible.

The fossiliferous beds in the Awahuri well are tentatively regarded as Flandrian in age by Te Punga (pers comm 1975). However, on the basis of the depth of the lowest fossiliferous beds (90.83 - 103.02 meters), these beds appear to pre-date the Flandrian transgression.

It appears very doubtful that the Oroua River could have incised to 103 meters below present sea level in a geographic position far removed from a coastline at c.135 meters below present sea level. This assumes that the Oroua River was flowing south to join the Manawatu River in the last glacial.

Higher fossiliferous beds in the Awahuri well are probably Flandrian in age. Although examination of such information without being able to determine the age of the beds is highly subjective, Te Punga (1954a) did find marine microfossils in beds from 78.63 - 5.18 meters below m.s.l. which were probably estuarinal.

Only dating of fossils from these positions will enable the above interpretation to be verified. Until this is done, the writer tentatively considers the fossiliferous and marine beds encountered in deep bore holes in the study area, except those in

B.L.86 and the deepest beds in the Awahuri well, are early Flandrian in age. This consideration is based primarily on the depth of the beds in relation to the lowest level of the sea during the Otira glaciation.

4.75 Age of the Estuary

Fair (1968) has linked the aggradational terraces of the Manawatu River to phases of deglaciation in the Tararua-Ruahine Ranges during the late Pleistocene. Periods of degradation were related to the phase of advancing ice at the onset of glaciation. With reference to the former statement, the opposite can also be true. Considering there is no absolute evidence for the age of the terraces, the writer can see no reason why the terraces were not built throughout the cold periods, and not just during the waning stages. Milne (1973a and 1973b) studied the terraces of the Rangitikei River valley and related aggradational gravels to cold climate episodes in a similar way.

Figure 4.H illustrates that if the load/discharge ratio of a river increases, the profile AB is steepened to CD by aggradation. This would often happen during a cold period, but usually in conjunction with a lowered sea level. Whether the constraint is that base level remains the same, or the base level is lowered, the result is the same upstream of 'X'.

Fair (1968) considered the last major terrace in the Manawatu River valley named the Ashhurst terrace, was built

MORPHOLOGICAL AND BEHAVIOURAL CHANGES OF A STREAM IN RESPONSE TO AN INCREASED LOAD/DISCHARGE RATIO AND A LOWERED SEA LEVEL

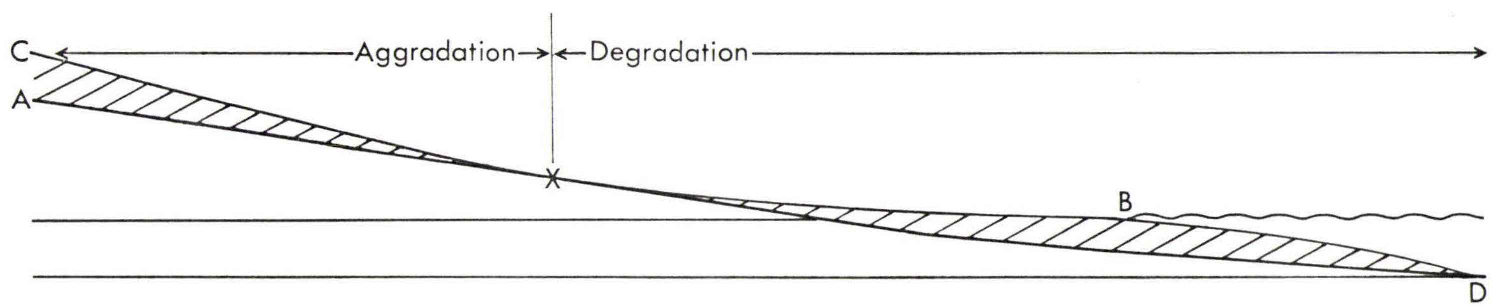


Figure 4 H

"following the glacial retreat at the end of the second Kumara -2 advance, C^{14} dated as occurring between 18,000 and 20,000 years B.P. in the South Island"(Suggate 1965 p. 77). However Suggate (1970) has since revised the chronology of the late Otira glaciation.

The Ohakea terrace of the Rangitikei River valley has been correlated with the Ashhurst terrace on the basis of cover deposits (Cowie 1961). The Ashhurst terrace does not have Aokautere Ash (=Oruanui Ash) which is about 20,000 years old in the covering deposits. According to Suggate's (1970) revised chronology, the Ashhurst terrace could have been aggraded between c.20,000 and c.18,000 years B.P. (Later Kumara -2 advance) or c.17,000 to 16,000 years B.P. (Early Kumara -3 advance). The Later Kumara -3 advance was quite short (c.14,500 - c.14,000 years B.P.) and may have been instrumental in the building of the lower and much smaller Raukawa terrace.

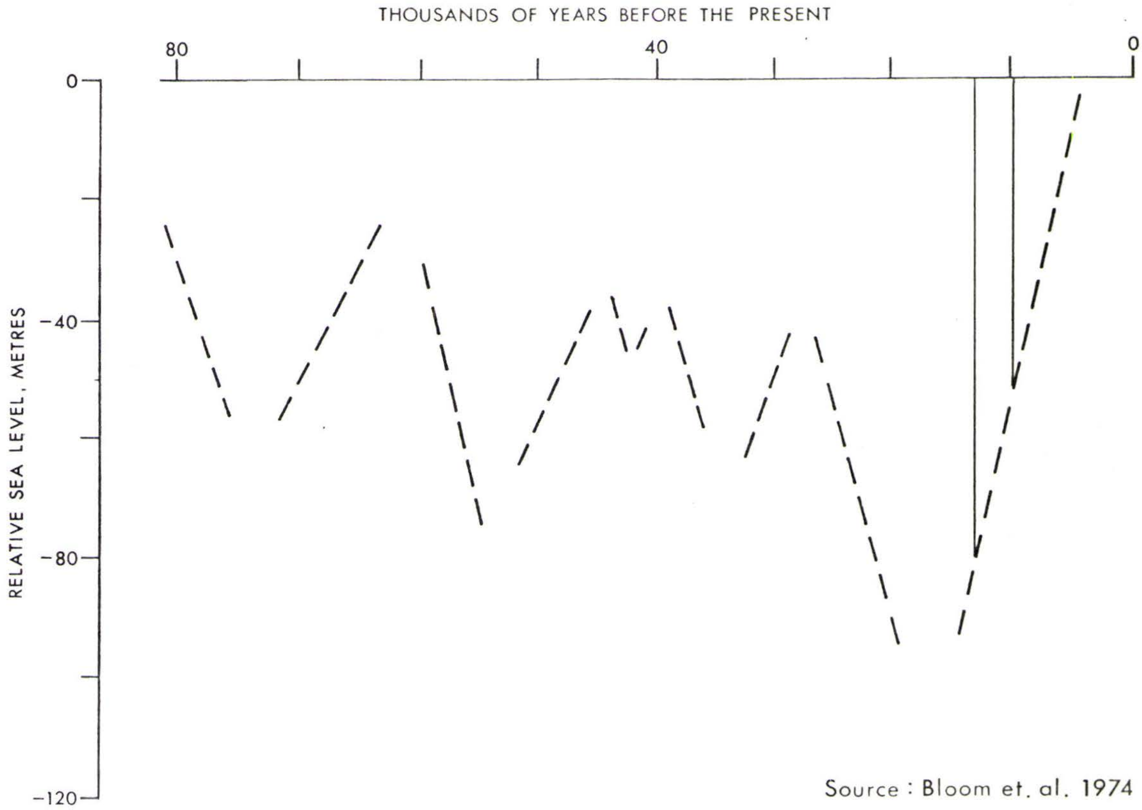
Milne (1973a) has mapped the river terraces in the Rangitikei Basin and has estimated the ages of the terraces. Ages for the Ohakea terraces (comprises three terrace subsets) are based on radiometrically dated deposits that outcrop within the Rangitikei Basin, and on radiometrically dated deposits that have been correlated with deposits within the Rangitikei Basin by Milne. The age of the terraces ranges from 20,000 - 25,000 to 12,000 years. However the middle range is c.20,000 to 14,000 years B.P., which is probably more applicable to the Ashhurst terrace, as only one surface has been recognised.

The age of the lowest stand of sea level during the last glacial, from overseas studies, ranges in age from 19,000 to 15,000 years B.P. According to Suggate (1970) the major retreat of glaciers began in the South Island, New Zealand, about 14,000 years ago.

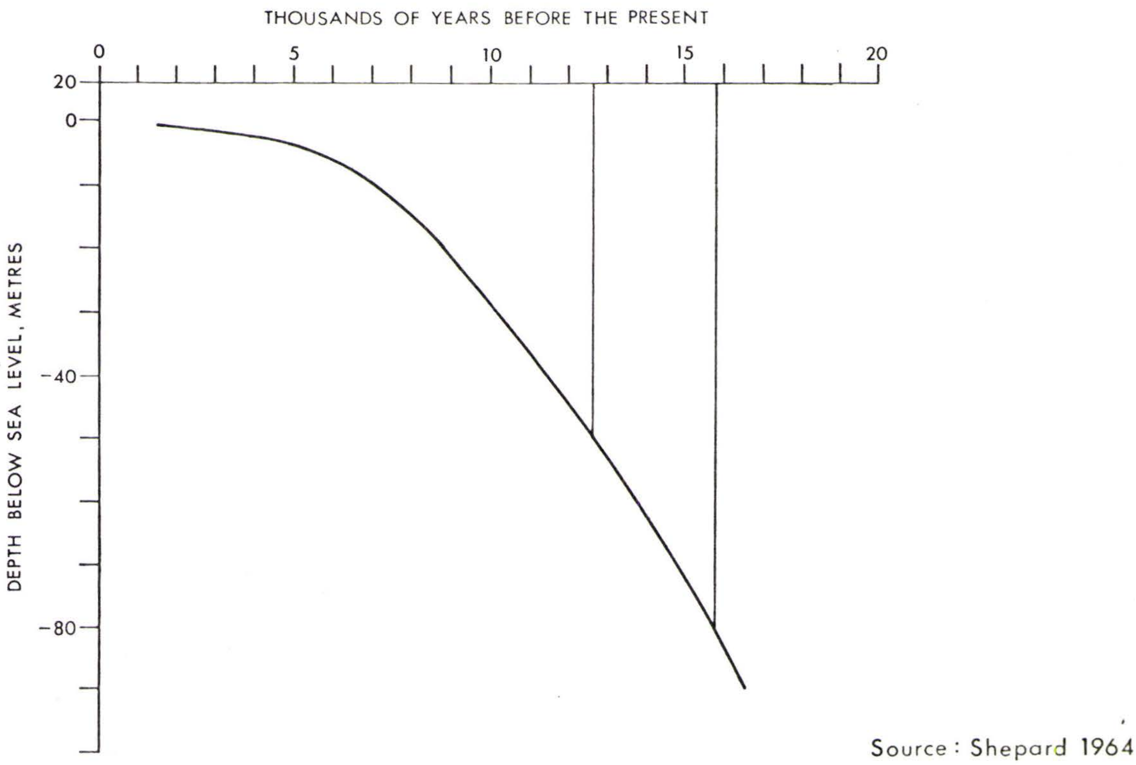
In principle, below a certain point ('X' on Figure 4.H) degradation could be expected to occur in the lower reaches of a river during a colder period. This indicates that the Manawatu and Oroua Rivers could have incised deep channels in their lower courses, during the periods of aggradation upstream. The later Kumara -3 advance, c.14,500 - 14,000 years B.P. may have briefly accentuated this incision. If the Flandrian transgression began to rise prior to 14,000 years B.P., the fossiliferous beds encountered at 50 to 80 meters in the study area are possibly about 15,000 to 11,000 years old. Comparison with a very recent sea level curve (Bloom et. al. 1974) illustrates the likelihood of this age range (Figure 4.I).

Te Punga (1958) dated a log of wood from 45.72 - 46.33 meters (150 - 152 feet) below m.s.l., found in a bore drilled at Foxton (grid ref. N148/796206). Te Punga "tentatively assumed that the log of wood was driftwood probably stranded in the inter tidal zone and later buried beneath estuarine and/or shallow water marine sediments" (p.93). Previous analysis of other Foxton bores supports this interpretation. The log of wood was dated as 9,900 ± 150 years B.P. (N.Z. Fossil No. N148/503).

THE POSITION ON TWO SEA LEVEL CURVES OF FOSSILIFEROUS BEDS ENCOUNTERED AT 50 TO 80 M. IN THE LOWER MANAWATU



Source : Bloom et. al. 1974



Source : Shepard 1964

The gravels surrounding the deep former channels of the Oroua and Manawatu rivers are likely to be of similar age to the Ashhurst and older terrace gravels, as the former gravels are interpreted as glacial terrace or fan extensions beneath Flandrian deposits. A C14 date has been applied for a sample from a log of wood encountered in a bore (No. 190) (grid reference N148/957215) at 35.36 - 36.12 meters below m.s.l. lying within gravels. The date should partially confirm the age of terracing in the Lower Manawatu.

A date for the upper estuarine beds has been determined as 6,330 $\pm$ 70 years B.P. (N.Z. N152/515, N.Z. 3085B; grid reference N152/900116).

4.76 Nature of the Estuary

In the introduction to this chapter four primary subdivisions of estuaries were stated. The two subdivisions which concern this thesis are (1) drowned river valleys and (2) bar built estuaries.

The evidence suggests that the lower reaches of the Oroua and Manawatu Rivers were drowned river valleys, which were eventually infilled. However in order for upper Aranuian beds (and possible lower Flandrian beds) in the study area to be estuarine, direct marine incursion of the sea must have been prevented when sea level was near its present position.

Although the evidence is not conclusive, it appears that the Himatangi anticline had geomorphic expression during the Otira glaciation and Flandrian transgression. There is little evidence to suggest that a sand bar or barrier was formed during late Post-glacial time, but such a bar/barrier may have completed the enclosure of an embayment cut off primarily by the anticline.

Accordingly, the estuary occupying the study area throughout Flandrian time was essentially a composite estuary, a combination of a drowned river valley, and an estuary enclosed by a structural bar.

4.8 Summary

The Lower Manawatu estuary is a composite estuary being partly drowned river valley, and partly barrier-built. It appears most likely that direct marine incursion was prevented by the existence of the Himatangi anticline. Bore log and paleontological evidence support this hypothesis. There is less evidence that a sand bar or barrier was also present during the Flandrian transgression. The Poroutawhao "High" appears to have enclosed the southernmost portion of the study area.

During late-glacial time the Manawatu and Oroua Rivers incised deep channels, deserting their former valleys and terraces. The following Flandrian transgression progressively drowned the river channels, and eventually flooded the Lower

Manawatu area. The environment appears to have been estuarinal throughout the Post-glacial.

The stratigraphy in deep and shallow bore logs, and comparison with New Zealand and overseas data indicates that the above interpretation of Flandrian events is plausible. The age of the oldest (and hence deepest) estuarine beds has been estimated at 15,000 to 11,000 years B.P. Stratigraphically higher beds are progressively younger.

Notes

1 Fair's (1968) terrace profiles were re-drawn from height data. It was found that the Ashhurst terrace profile did not flatten out in the vicinity of Palmerston North, as Fair indicates but rather, it's surface continued at a similar gradient to the upstream surface gradient.

5. TECTONISM

5.1 Introduction

The study area is part of the South Wanganui Basin, which is surrounded by marine and terrestrial terraces on the northern, eastern and southern boundaries, and dips under the Tasman Sea to the west. Several writers (Katz 1968; Fleming 1953; Cope and Reed 1967) consider that the Wanganui Basin is downwarping or sinking; other writers (Te Punga 1953b, 1957, 1953c; Rich 1959; Oliver 1948) consider that uplift is dominant around the margins of the Wanganui Basin. These studies are detailed below.

The relationship of anticlinal and synclinal structures to Flandrian sediments, new evidence for the age of the anticlines, and the discovery of a new anticline are discussed. Compaction of sediments and the affect of tectonic movements is also discussed.

5.2 Regional Tectonism

Few detailed studies and many generalizations have been made of the Wanganui Basin and the Manawatu area specifically. Most of the information available has come from geophysical work and drilling primarily carried out by oil companies (see Feldmayer et. al. 1943).

Katz (1968) states that "in late Jurassic to early Cretaceous time, the Rangitata orogeny (Kingma 1959) concluded the geological history of the New Zealand Geosyncline. Subsequently, the deposition of Cretaceous and Tertiary rocks was largely restricted to basins and troughs (e.g. the Wanganui Basin) of a more local character and limited extent" (p. 1106).

Fleming (1953) states that "Wanganui Basin, Taupo Graben, and White Island Trench are analogous structural depressions situated on the 'back-slope' of the main North Island anticline, in a zone which largely escaped the severe compressional deformation characteristic of the eastern front of the anticline" (p. 30). According to Fleming, the Wanganui sediments in the Wanganui Basin are but gently folded.

Katz (1968) has commented on the general conditions existing in the Wanganui Basin, of which the study area is part. He states that "geophysical work and drilling have revealed two very different areas, separated by the Tongaporutu - Patea basement high with the large Taranaki Fault along its western side" (Lensen 1959; Cope and Reed 1967). West of the Taranaki Fault, basement is downthrown 6,000 - 6,900 meters and covered by an almost complete succession from Eocene to Recent (Cope and Reed 1967). This "'South Wanganui Basin' contains a thick sedimentary fill of exclusively Plio-Pleistocene age, which on seismic evidence reaches 5,000 meters in the 'Turakina Syncline'"(Fleming 1953) (p. 297), (Katz 1968;). Rich (1959), reporting a personal communication with Dr E.I. Robertson, Geophysics Division, states that at least 3,000 meters of sediments are present in the 'Kairanga Trough' (see Figure 5.B).

Katz (1968) using the above seismic evidence, states that "this recent subsidence of the Wanganui Basin in general is marked by a strongly negative gravity anomaly. Fleming (1962) considers the Wanganui Basin to be a "persistently sinking" Quaternary Geosyncline.

Hatherton (1971) places the study area in one of the two regions "which are characterised as active continental margins, and are associated with large gravity anomalies which are equal in amplitude" (p.167).

Eiby (1971) places the study area within the "Main Seismic Region", although shallow earthquakes (1955 - 1965) are conspicuously absent in the study area.

Lensen and Suggate (1973) in defining tectonic zones in New Zealand, characterise the Western North Island (of which the Manawatu region is a part) as a tensional zone. They state that regional extension is dominant, the horizontal component of displacement is not known, graben structures are less conspicuous and subsidence is dominant. According to the authors' rates of vertical deformation in the volcanic and tensional zones vary between -3 to +1 mm per year.

Pavoni (1971) has studied rates of crustal deformation. He states (Table 3, page 9,) that horizontal movement of the Tararua Ranges equals 0.16 centimeters per year. Vertical movement equals 0.049 centimeters per year.

According to Suggate (1973) the Kaikoura Orogeny extended through the Quaternary to the present. "There is no evidence that the rate of tectonic movement has diminished over the country as a whole, although local rates have changed greatly. The main movements appear to have been completed before the Quaternary in the northwest and far northeast, while in some other regions, they may not yet have reached a climax" (Suggate 1973, p.6).

5.3 Local Tectonism: The Study Area

5.31 Uplift

In the study area several anticlinal and synclinal structures have been studied by Te Punga (1957), Rich (1959) and the writer (1975). These structures are of particular importance to this study and will be dealt with in detail in a later section.

Te Punga (1957) who pioneered the work on the anticlines in the Manawatu-Rangitikei regions, considers "there can be little doubt that the local folding" of the anticlines in the above areas, "is superimposed on a more general uplift." The relation of local folding to general uplift is obscure (Te Punga 1957, p.444).

However, Te Punga (1957) utilising evidence from an earlier paper (Te Punga 1953b) states that an average rate of general uplift for 20,000 years may be taken as 0.305 meters in 25 years. He considers that this rate has increased during the last few thousand years.

The evidence from which Te Punga (1953b) derives rates of general uplift has been discounted by Cowie and Wellman (1962). The latter authors found that a C14 date of 3,000 years for the Ohakea Terrace, a terrace of the Rangitikei River Valley, was at least 7,000 years too young. Te Punga's (1953b) rates of uplift above were based on the age of the Ohakea Terrace, which is considered by Cowie and Wellman (1962) to be at least 10,000 years old.

Te Punga (1953c, Figure 18, P.40) proposed that terraces in the Rangitikei Valley are due to regional uplift, the uplift being progressively greater upstream.

Terraces of the Manawatu and Pohangina Rivers (Rich 1959) are not nearly as warped as those of the Rangitikei valley (Figure 5.A). This appears to indicate that uplift is progressively greater to the north and northwest of the study area.

Fleming (1953) agrees with Te Punga in so far that the convergent slopes of terraces of the Wanganui and neighbouring rivers "are the result of discontinuous diastrophic upwarping of the land throughout the period of their formation" (p.76). However Fleming does allow for the succession of Pleistocene climatic fluctuations and eustatic movements of sea level.

Oliver (1948, Figure 38, P.41) presented diagrams of river terraces of the Kahuterawa and Mangaore Streams; these are two of the larger tributary streams in the study area. Oliver's diagrams show convergence downstream due to greater uplift upstream (Figure 5.A).

Rich (1959) agrees with Te Punga (1957) that folding of the anticlines and synclines is superimposed on regional epeirogenic uplift in the study area. Rich states that the effect

PROFILES OF TERRACES IN THE MANAWATU

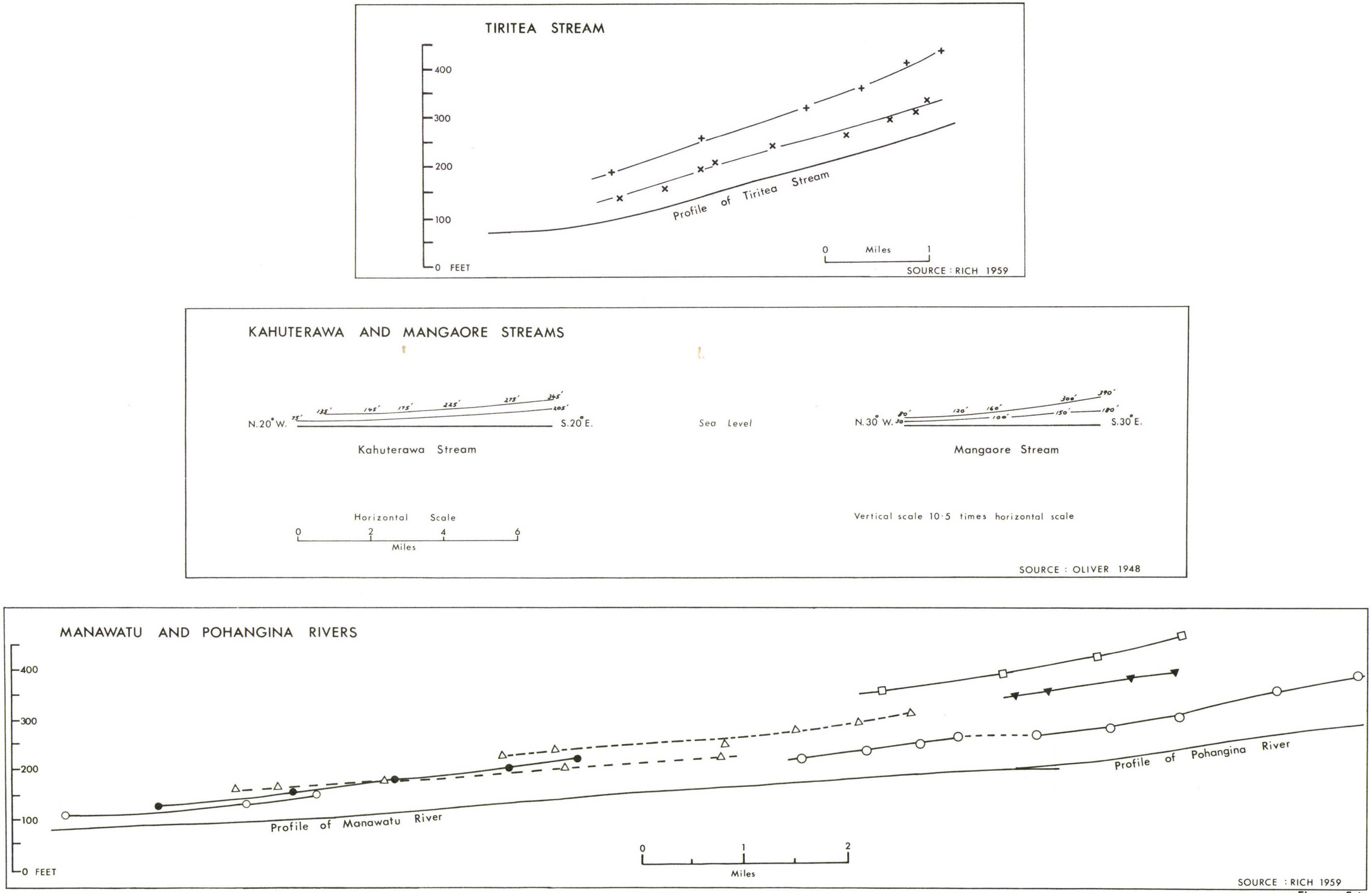


Figure 5A

of this regional uplift has been greatest in the north and nearest the axial ranges. Oliver (1948) has shown (Figure 39, p.41) that the height of the Tokomaru Marine Terrace increases northwards.

5.32 Faulting in the Study Area

5.321 Large Scale

Kingma (1962) and (1967) has mapped only one concealed fault extending from Mangaore across the Tokomaru Marine Terrace to Makerua (Figure 1.B). Turner (1944) mapped several faults extending along the margin of the Tararua Ranges and the Tokomaru Marine Terrace. The mapping of such faults is in keeping with the horst origin of the Tararua Ranges. In the Tararua foothills just south of Shannon there is photographic evidence for three small faults (see Map 1). No doubt others exist.

5.322 Small Scale

Oliver (1948) stated that during the uplift of the Tokomaru Marine Terrace, there was a certain amount of small-scale movement in the sandstone beds, "and faults of a few centimeters throw are present in a number of places". Oliver attributes this movement to "settling down by the beds into a more consolidated condition" (p.40).

Te Punga (1957) found a small fault scarplet in beds of the Mount Stewart - Halcombe anticline (p.444). He considers that the presence of the fault is evidence of active tectonic movement in the vicinity of the anticline. He states that "small faults, with displacements of only a few centimeters, are common in the Levin and Shannon districts and may be interpreted as indications of late tectonic activity" (p.442, Figure 8).

Rich (1959) considered that the minor faults of Te Punga (1957) "may result from post-depositional compaction and settling of the sediments or from mild tectonic activity along the flank of the Tararua Range" since the deposition of beds forming the Tokomaru Marine Terrace Formation (p.125).

The present writer has found one small fault near the northeast end of the previously undiscovered Shannon anticline. The presence of such a fault in sandy beds is indicative of post-depositional compaction at least as much as it indicates mild tectonic activity.

Te Punga (1957) considers that such faults can only be about 100 years old. The present writer considers that there is no reason why the fault traces could not be far older. In the vicinity of Shannon the sandstone is hard and the formation of a fault could be preserved in such beds.

5.33 Discussion

Whether the Flandrian beds encountered in deep bores (Chapter 4) have been uplifted or downwarped cannot be ascertained. Beds of Wanganui age and older appear on geophysical evidence to have been downwarped; whether younger beds have also been downwarped is unknown; Te Punga (1957) believes they have been uplifted. Certainly, the margins of the Wanganui Basin appear to have been uplifting in Middle to Late Pleistocene times. Compaction may have been important.

5.4 Folding

5.41 Introduction

The age of folding in the Manawatu area is considered very young by Te Punga (1957). Post-glacial sediments in the study area may thus have been deformed by this folding. Te Punga (1957) has described the process by which such anticlines derive their present form. He states that the anticlines are not folds of the decollement type, but rather each anticline "is related fundamentally to the highest edge of an upfaulted block of greywack basement". The anticlines are thus 'drape folds', the folded beds are merely draped over the edges of basement 'scarps' at depth (Te Punga, p.446).

Te Punga (1957) has identified several such structures in the Manawatu region. These are the Marton, Mount Stewart - Halcombe, Feilding, Oroua, Pohangina and Levin anticlines; Mangaone Stream, (flowing between the Mount Stewart - Halcombe and Feilding anticlines), Pohangina River, partly the Manawatu River (for about 9.6 kilometers downstream from the Ashhurst end of the Manawatu Gorge), Oroua River and Koputaroa Stream occupy synclinal positions. Rich (1959) added another anticline, the Himatangi anticline, and an "elongate depression" (p.76). the Kairanga trough. The present writer has discovered an anticline, (see Figure 5.B) here termed the Shannon anticline, in the vicinity of Shannon township. The Himatangi, Levin and Shannon anticlines, the associated synclines and the Kairanga trough are the only structural features of direct concern to this thesis (Figure 5.B).

5.42 The Levin Anticline

The Levin anticline, which trends northeast can be traced as a geomorphic feature for about 6.4 kilometers between Levin and the Manawatu River. "The anticlinal crest which is only 160 feet above sea level at its highest point, slopes gently in a northeasterly direction from the junction of Heatherlea Road with the Levin - Foxton highway about three miles north of Levin. The northwest flank slopes down at one to two degrees; on the southeast flank the nature and amount of dissection indicates that the initial slope was slightly steeper but it cannot be measured accurately as doabs are few and small" (Te Punga 1957, p.441).

In the Marton, Mount Stewart - Halcombe, Feilding, Oroua and Pohangina anticlines strata of both the Wanganui and Hawera series are involved in the folding. In the case of the Levin anticline, Te Punga (1957) considered that beds of the Hawera series rest directly on the basement greywack. Evidence for this is partially provided by the existence of the Poroutawhao High to the west where there is greywack at 1.5m above m.s.l.

LOCATION OF ANTICLINES AND SYNCLINES IN THE STUDY AREA

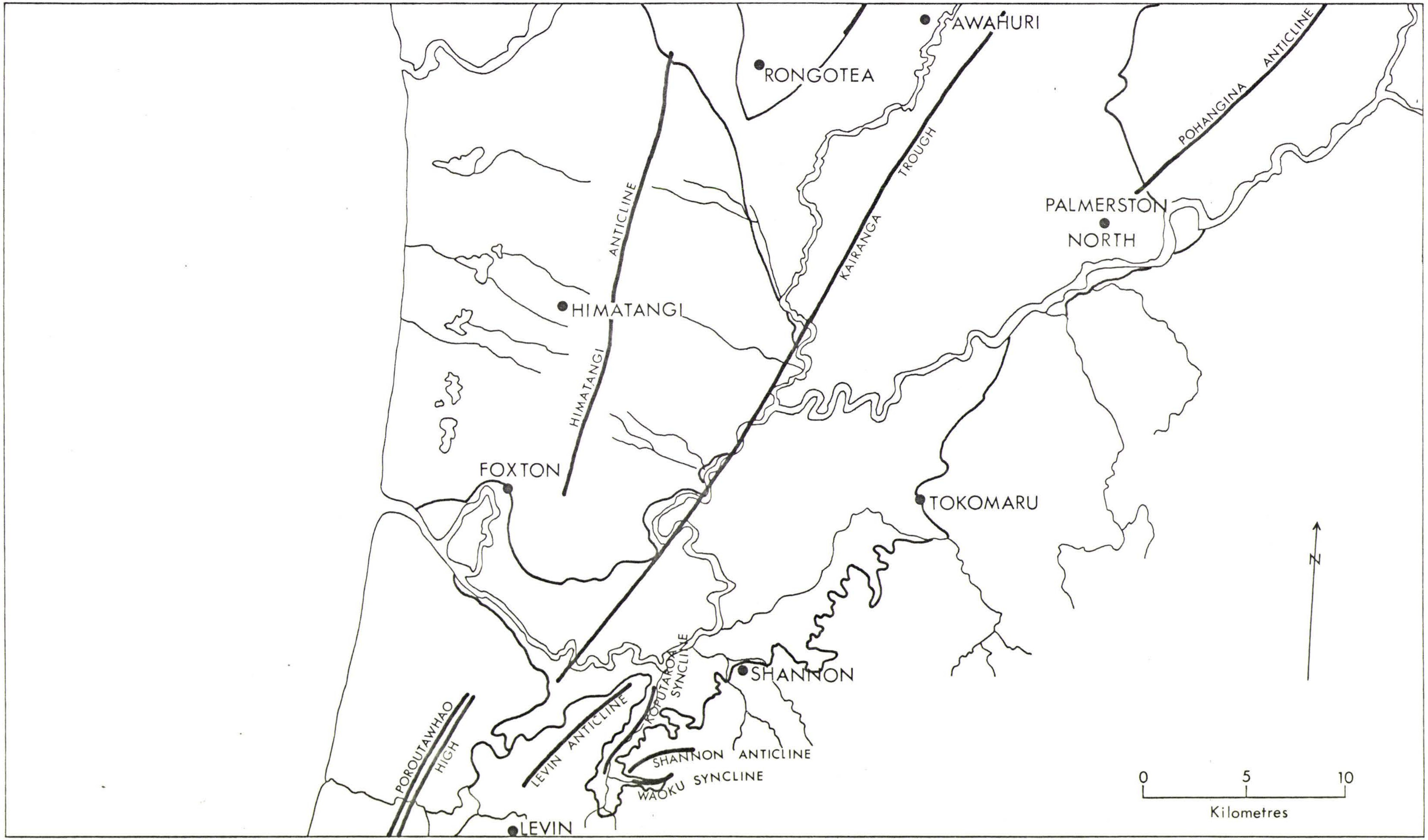


Figure 5B

(Figure 5.B), and by the proximity (4.8 kilometers east) of the greywacke Tararua Range.

Koputaroa Stream flowing north, on the eastern flank of the Levin anticline is a synclinal primary consequent for at least six kilometers upstream from its confluence with the Manawatu River (Te Punga 1957). The syncline is "a shallow poorly defined fold with a length and trend similar to those of the Levin anticline" (Rich 1959, p.138).

Rich (1959) stated that the available gravity data did not show a close relationship of the Levin anticline and Koputaroa syncline to basement structure.

5.43 The Himatangi Anticline

"The Himatangi anticline lies between the Kairanga trough and the coast, and the crest trends slightly east of north for approximately 13 miles from Foxton to Rongotea" (Rich 1959, p.133). Topographic expression is not obvious, (see discussion in Chapter 4) as the coastal plain is only gently warped, and the form of the surface is camouflaged beneath fixed elongate sand dunes.

Rich, quoting the seismic survey of the Superior Oil Company (Turner 1944) states that a structural 'high' located 1.2 kms. north-northeast of Himatangi, was revealed in the Wanganui strata. From this Rich infers that strata of similar age to those of the Mount Stewart - Halcombe anticline, i.e. Waitotaran sediments, occur at depth in the Himatangi anticline.

5.44 The Kairanga Trough

The Kairanga trough is topographically expressed "as an elongate alluvial plain which extends for 30 miles from Feilding to Lake Horowhenua attaining a maximum width of 10 miles west of Palmerston North" (Rich 1959, p.136). The Gravity Survey of the Superior Oil Company outlined the locus of maximum downwarping in the study area. This is an elongate depression. "The centre of the trough lies about 7 miles north-northwest of Palmerston North at the locus of a strong local negative anomaly" (Rich, p.136).

5.45 The Shannon Anticline

The Shannon anticline is approximately 4 kilometers long, and extends from a point 4 kilometers S/E of Shannon (approximate grid reference N152/900080) in an arc to the vicinity of Potts Hill (Figure 5.C). Potts Hill is a local name for the section of Highway 57 which climbs up the southern nose of the anticline, just north of the Potts Road - Highway 57 junction. The northeast end of the Shannon anticline rises to meet the Tararua Ranges; the southern end appears to plunge in the vicinity of Potts Road. From the bedding exposed near this location, Waoku Stream has probably eroded the true nose of the anticline leaving a bluff which continues in a northwest direction forming the eastern riser of Koputaroa Stream Valley.

Figure 5C Part of the Shannon Anticline. The anticlinal axis lies just to the west (seaward) of State Highway 57.

Dissection of the Shannon anticline is roughly radial; i.e. as the northeast end of the anticline rises to the Tararua Ranges, drainage is deflected north and south. Consequent streams draining the flanks of the anticline are deep (generally 30 meters and up to 60 meters) and V-shaped in the upper sections (Figure 5.D). Streams on the western flank grade into box-shaped valleys which have been discussed previously. On the southern nose and on the eastern flanks of the anticline, streams, occupying deep V-shaped valleys, flow into the box-shaped valley of Waoku Stream. The width of some of the valleys, particularly on the northwest flank of the anticline,is at least 150 meters.

Apart from Koputaroa and Waoku Streams, most of the valleys have insignificant discharges except after heavy rain.

Geomorphic evidence indicates that the drainage pattern developed initially on flat topography. This was followed by uplift which led to the development of the present erratic and disordered nature of dissection. Streams have eroded large short valleys in all possible directions leaving isolated remnants of the Tokomaru Marine Terrace remaining (see Map 1.). Furthermore, uplift appears to have been greatest in the north and least in the south. Valleys tend to be deeper in the middle and northern sections than on the south or southwest.

The anticline is asymmetrical. West of the anticlinal axis the surface slopes at one to two degrees. East of the axis much of the Tokomaru Marine Terrace has been eroded by Waoku Stream.

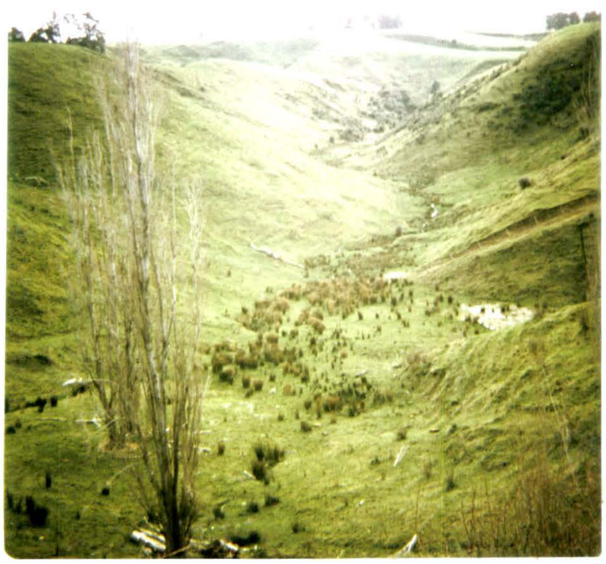


Figure 5D A large v-shaped valley which flanks the axis of the Shannon anticline.

The easternmost tributaries of Waoku Stream, draining the flanks of the Tararuas, flow in an easterly direction and all then turn south. Presumably this is a result of uplift of the anticline. Waoku Stream occupies a synclinal position between the Tararua Horst and the Shannon anticline. Koputaroa Stream is 'doubly' synclinal, flowing between the Levin and Shannon anticlines.

The Shannon anticline rises from below 15 meters above m.s.l. at the southern nose to 75 meters at the northeast end. Streams flowing north from the northeast end of the anticline are interpreted as primary consequent streams; their tributaries are secondary consequent streams which flow east to join them. Mapping just north of the anticline is misleading. It appears that a further fold exists, the axis of this fold lying between streams flowing west and those flowing east. However field observation shows that the Tokomaru Marine Terrace in this district has a general seaward slope and folding just north of the Shannon anticline is discounted. Rather as above, primary streams have eroded valleys in a northerly direction and tributary streams flowing east have enlarged their valleys by headward erosion.

Near the middle and southern nose of the anticline a gentle trough exists on the eastern side of the anticlinal axis. The trough runs parallel to Highway 57 and is part of the Shannon anticline. The trough is not interpreted as an expression of complex subsurface folding but as a relict coastal landform. The origin of the upper beds of the Tokomaru Marine Terrace, excluding the overlying loess, is probably similar to that of the Rapanui formation of the Wanganui district (Te Punga, pers. comm.).

Dune sands, beach sands, lagoon, swamp and shallow offshore deposits are all probably represented in the upper beds of the Tokomaru Marine Terrace. The trough could thus represent any number of coastal features; e.g. a tidal stream channel, or a back-dune depression. Trig 15261 (grid reference N152/867086) west of the anticlinal axis appears to be sited on a former dune. The feature is a rounded hummock which is present on a generally seaward sloping surface.

The surface east of the trough described above appears to gradually slope upwards towards the Tararua Ranges. This may be partly a coastal landform, and may partly indicate that uplift has been greater and more prolonged along the Tararua axis, since the folding of the Shannon beds.

One small fault was found by the writer in a new exposure on private property near the northeastern end of the anticline. The fault is only 3 meters long and beds of the Tokomaru Marine Terrace have been displaced one centimeter. The fault trace is well preserved, and is thought to be due to post-depositional compaction.

No beds other than Oturian beds (Otaki sandstone) were seen in any of the exposures on the Shannon anticline. As the Shannon anticline is even closer to the Tararua horst than the Levin anticline it might be expected that Hawera beds rest directly on the basement greywacke. This can only be verified by deep drilling.

5.5 Age and Nature of Folding

5.51 Introduction

In the Mount Stewart - Halcombe, Feidling, Pohangina, Oroua, Marton (Te Punga 1957) and Himatangi (Rich 1959) anticlines, beds of Waitotaran age are either known, or assumed on geophysical evidence to be involved in the folding. Folding must post-date the youngest beds involved in the folding, although conceivably, early folding may have been contemporaneous with deposition. An estimate of the age of folding has been made (Te Punga 1953b, 1957; Rich (1959). In the light of new evidence these estimates are discussed.

It should be noted that as Te Punga (1957) states, beds of the Hawera series, the upper beds of which comprise the Tokomaru Marine Terrace Formation (New Zealand Oturi), vary in age from place to place in the study area. Rich (1959) states that the topmost beds of the Tokomaru Marine Terrace decrease in age from the Ranges toward the sea, and from north to south. This is the result of regression and uplift.

5.52 Previous Work

Te Punga (1953a) estimated the age of the beds of the crest of the Mount Stewart - Halcombe anticline, as somewhat less than 20,000 years old (Te Punga 1957), utilising evidence from the ages of Rangitikei River terraces (Te Punga 1953b). However overseas radiocarbon dating and more recent New Zealand geological work has shown that the beds of the crest of the Mount Stewart - Halcombe anticline are part of the Rapanui Formation of the Oturian Interglacial stage.

Te Punga (1957) states that "in the case of the Mount Stewart - Halcombe anticline folding cannot have began until after withdrawal of the sea to the extent that its margin lay west of the present position of the crest of the fold" (p.433).

Te Punga (1957) states that the folding of the other anticlines has been similar to that outlined for the Mount Stewart - Halcombe anticline. Furthermore, from the distribution and nature of 'buckshot gravels' in soil profiles (Te Punga 1954b) he consideres it probable that the "Pohangina anticline is older than the Mount Stewart - Halcombe anticline, and that the latter is older than the extremely youthful Levin anticline" (p.445).

Rich (1959) stated that "the relative rates of deformation of the various folds are not known, but no evidence was observed to indicate that the rates have differed markedly from one fold to another" (p.139). Furthermore he states that geomorphic and structural evidence supports Te Punga's age sequence. In the light of this Rich contends that the Himatangi anticline is probably younger than the Levin anticline (Rich 1959).

It appears that Rich (1959) considered that upper beds of the Tokomaru Marine Terrace were exposed near the surface of the Himatangi anticline (see discussion in Chapter 4). It is unknown if Rich considered that these beds are the youngest involved in the folding of the anticline.

Rich in discussing the Kairanga trough, states that deposition during Wanganui and Hawera time, is considered to have been thickest and most continuous in the Kairanga trough. Dr E.I. Robertson, Director of the Geophysics Division at the time, considered that a maximum of at least 3,000 meters of sediment occurs at the centre of the downfold. Due to compaction, the gravity survey may not have truly represented the thickness of sediment, and there could be over 4,200 meters of sediment present (Rich footnote, p. 136). The thickness of sediments "supports the inference that the Kairanga trough has been an active downwarp since early Wanganui times" (Rich 1959, p.144).

Rich states that river terraces of the Manawatu River, Tiritea, Kahuterawa and Mangaore Streams, all converge toward the axis of the Kairanga trough. According to Rich, this is evidence that the Kairanga trough has recently downwarped. He states that the relative age of the trough remains uncertain (p.141).

Te Punga (1957) considers that all folds are still active.

5.53 New Evidence For the Age and Nature of Folding

5.531 Introduction

The primary concern of this thesis is with Flandrian stratigraphy. Thus the degree of warping of Flandrian sediments needs to be examined. In order to establish the relative position of fossiliferous estuarine beds in the study area, levelling was carried out in valleys flanking the Levin and Shannon anticlines.

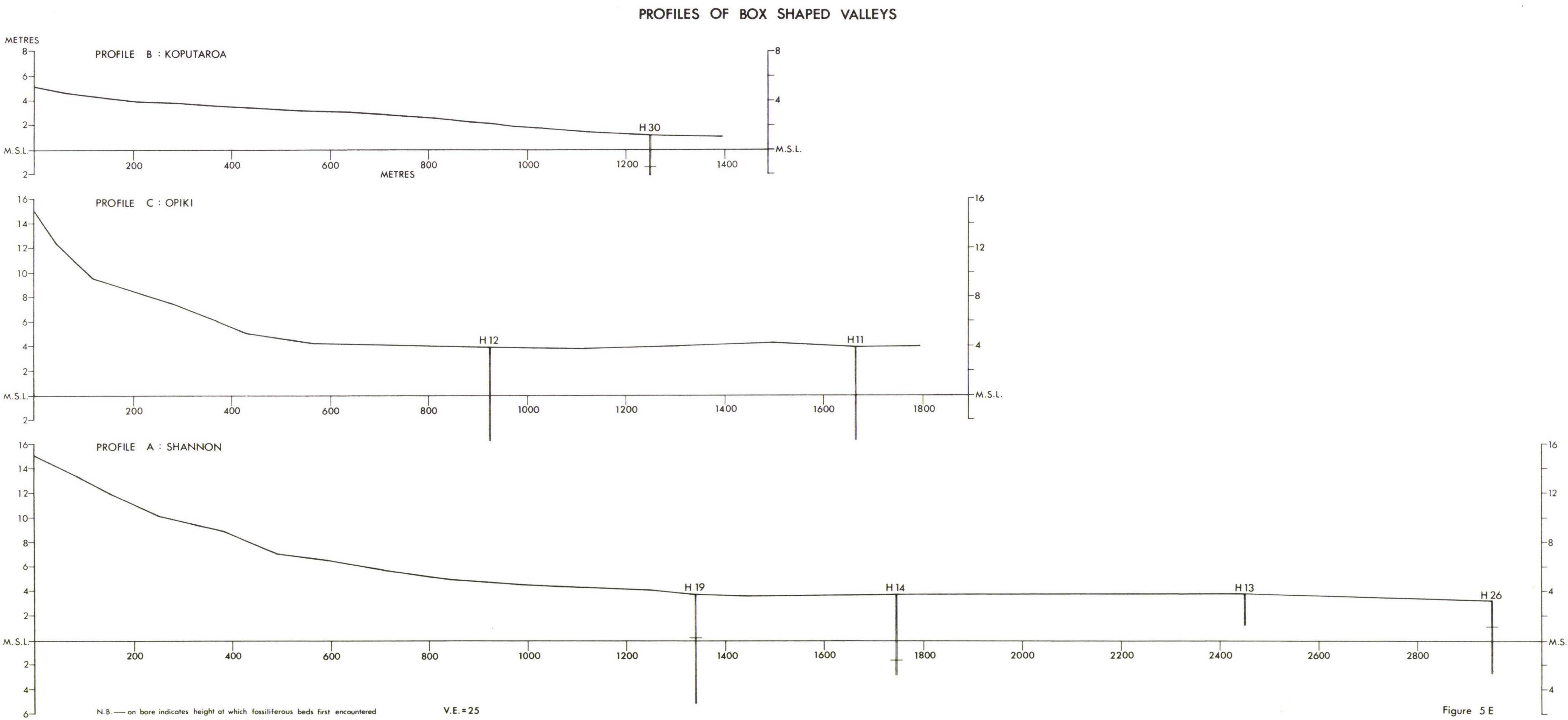
Drilling was also carried out in conjunction with the levelling. The information obtained provides new evidence for the age and nature of folding in the study area.

5.532 Geomorphological Evidence: The Infilled Box-Shaped Valleys

Many of the valleys on the flanks of the Levin and Shannon anticlines are infilled box-shaped valleys. In many cases the box-shaped valleys grade into V-shaped valleys upstream. There are exceptions though, and a few valleys are box-shaped right to their heads. Uppermost estuarine sediments in the valleys are c. 6,000 years old. If anticlinal folding is still active it might be expected that estuarine beds will have been progressively uplifted towards the crest of the fold.

A box-shaped valley near Shannon which grades into a V-shaped valley (see Figure 5.E) was surveyed and drilled. The valley is box-shaped for approximately 1.6 kilometers. A profile, (a), Figure 5.E, was drawn from the survey and the location and partial stratigraphy of bores is shown. The survey line extends from the floodplain, up the box-shaped portion of the valley and a short distance into the V, which drains from the axis of the Shannon anticline.

A surveyed valley west of Koputaroa, on the flank of the Levin anticline is wholly box-shaped; the valley is infilled to its head. The profile is illustrated in Figure 5.E (b). Profile (c) is of a box-shaped valley just south of the Opiki turnoff (Highway 57). This valley was surveyed for comparative purposes.


PROFILES OF BOX SHAPED VALLEYS
METRES
PROFILE B : KOPUTAROA
H 30
M.S.L.
METRES
PROFILE C : OPIKI
H 12
H 11
PROFILE A : SHANNON
H 19
H 14
H 13
H 26
N.B. — on bore indicates height at which fossiliferous beds first encountered
V.E. = 25
Figure 5 E

There is no known localised folding of the Tokomaru Marine Terrace in this area.

Profile (a) is remarkably similar to (c) and seems to indicate that little uplift has taken place since the infilling of the valley. Further evidence is available. Shells found 'in situ' on the floodplain in bore log H.26 were first encountered at 2.134 meters below the surface, 1.12 meters above m.s.l. The present tidal range at the Manawatu River mouth is 0.2 - 2.4 meters (LWS-HWS). The shells are within the present tidal range and have been dated at 6,330 $\pm$ 70 years, B.P. (N.Z.3085B). Up the valley 1.6 kilometers east of bore log H.26, bore log H.19 encountered shelly facies, which are in a similar stratigraphic position in another bore (H.21) nearby, 3.473 meters below the surface, 0.235 meters above m.s.l.

The position of the shells indicates that anticlinal uplift has not taken place in the effects of compaction are ignored.

Profile (b) has a gradient of only three meters per kilometer, from the valley head to the valley mouth. Considering this wholly box-shaped, infilled valley flanks the axis of the Levin anticline, the gradient is very gentle. The uppermost estuarine beds of the valley are probably within the range 6,000 - 6,300 years B.P. on the basis of the abovementioned C14 date. Lower estuarine beds increase in age with depth.

Both the Shannon and Koputaroa valley upper estuarine fossiliferous sediments do not appear to have been warped. This implies that in the last 6,000 years there has been little or no anticlinal uplift. Gradients of the box-shaped valley when compared with a valley where no known uplift has taken place also indicates this. Furthermore, alluvial sediments covering the estuarine beds could have produced a greater surface slope, particularly at the heads of the valleys; for example, by rain wash, and downslope movement, of the terrace covering loess.

The Shannon box-shaped valley described above (Profile (a)) grades into a V-shaped valley. V-shaped valleys are well developed in the Shannon district. Profile (a) illustrates that the gradient is steeper than that for the box-shaped valley. Yet in the lower reaches of several V-shaped valleys studied, drainage is poor and swampy conditions are prevalent. This is probably the result of infilling of the lower reaches of the valley so that in the upper reaches, streams with low discharges and loads are unable to adjust their profiles.

However, if uplift of the anticline had occurred, the streams draining the upper reaches of the valleys could have incised into the lower box-shaped portion. No such incision occurs. Often valleys are artificially drained from the mouth of the 'V', through the box-shaped portion, to the floodplain.

It is to be expected that uplift would be greatest at the head of the valley. Yet in the Koputaroa box-shaped valley (Profile (b)), there is no stream channel, and a drainage ditch is present from the head of the valley to the mouth. The head of the valley is only 190 - 390 meters west of the axis of the Levin anticline.

5.533 Age of Hawera Sediments

It is clear from the discussion on rates of general uplift (p.5) that the age of terraces and the associated rates of uplift proposed by Te Punga (1953b) are incorrect. The age of beds on the crests of the anticlines are also too young (Te Punga 1957).

Beds of the Tokomaru Marine Terrace and those of the northern anticlines (mapped as Rapanui; Kingma 1962; Lensen 1959) were deposited during the Oturian Interglacial stage. Fleming (1971) states that the Tokomaru Marine Terrace "is attributed to the last Interglacial age which from isotope datings overseas is thought to be about 80,000 - 120,000 years old" (p.64). Bloom et. al. (1974) sea level curve suggest "that the transition period from the last interglacial (120,000 years B.P.) to the last glacial is somewhere within a series of sea level oscillations, superimposed on a general decline of sea level to the full-glacial minimum only about 15,000 years ago" (p.204).

Chappell (1975) utilising the above curve adopts the hypothesis that the cutting of the Ngarino Terrace (a terrace just above the Rapanui Terrace in the Wanganui District) terminated at 120,000 years B.P. The marine Rapanui and the surface of the Tokomaru Marine Terrace are both likely to have been exposed for 100,000 years or so judging by this evidence.

Te Punga (1957) states that "in the case of the Mount Stewart - Halcombe anticline, folding cannot have begun until after withdrawal of the sea" to the west of the crest (p.443). However, the present writer can see no reason why folding cannot have commenced while the Oturi sea still covered the Hawera beds. Beds formed later by beach and wind processes could still have been incorporated in the folding.

Te Punga (1957) considered on the basis of the development of buckshot gravels in soil profiles (1954b), that the Levin anticline was the youngest anticline. However, time is not the only factor in the development of buckshot gravels. Although the Oturi climate may have favoured buckshot formation in beds exposed earliest, other factors are mineral composition of the soil and soil moisture conditions. Te Punga is thus making many assumptions when he bases the age of the anticlines on the presence or absence of buckshot gravels.

5.54 Rates of Uplift

Te Punga (1957) has estimated the average rate of general uplift for 20,000 years at about 0.3 meters in 25 years. However, his calculation is based on a C14 date for the Ohakea terrace (Te Punga 1953b), and must be considered incorrect.

The surface of the Shannon anticline rises from 42 meters near the southern nose to 75 meters at the northern end. If it is assumed that the marine beds were deposited slightly above present sea level (see Note 2, Chapter 1; also Guilcher 1969; Hoyt et. al. 1964; Bloom 1974) 100,000 years ago, the rate of general uplift for beds at 60 meters above m.s.l. is 0.3 meters in 500 years. The rate for beds at 30 meters above m.s.l. is 0.3 meters in 1,000 years.

The surface of the Tokomaru Marine Terrace increases in height from south to north so that near Palmerston North the rate may be greater than 0.3 meters per 500 years. However, apart from the Levin anticline, the outer and middle surface of the Tokomaru

Marine Terrace in general lies between 30 and 60 meters above m.s.l.

The sea level curves of Shepard (1963), Jelgersma (1961) and Bloom et. al. (1974) all indicate that 6,000 years ago sea level was about four to six meters below the present level. If the dated estuarine beds near Shannon were deposited in the intertidal zone, as seems likely, it would appear that they have been uplifted by about four meters to their present level during the last 6,000 years, a rate which compares exactly with the rate computed above (0.3 meters in 500 years). Alternatively, sea level may have reached the present level 6,000 years ago, with no tectonic movement having taken place since. Uplift at the rate postulated by Te Punga (1957) cannot be substantiated by the evidence from this area.

Uplift along the axis of the anticlines has been greater at some time than the rate of general uplift; this localised uplift has produced the domed surfaces.

Te Punga (pers. comm. 1975) believes that the Awahuri well, sited between the Mount Stewart and Feilding anticlines, is probably being uplifted only very slowly relative to the crests of the anticlines.

Rich (1959) has stated that river terraces in the study area converge toward the axis of the Kairanga trough; according to him this indicates that the Kairanga trough has recently downwarped. In fact terrace profiles of Kahuterawa and Mangarore Streams flatten out as they reach the floodplain (Figure 5.A), and if the profiles of the Manawatu are extended they dip beneath the floodplain.

The terraces have merely been drowned by Flandrian and recent fluvial infilling sediments. Downwarping need not be proposed for the present morphology.

There is no available evidence to indicate whether the Kairanga trough has downwarped during Post-glacial time, and it is more likely that compaction has occurred. The compaction may be superimposed on regional uplift.

It is possible that the rate of general uplift for the period between 100,000 years ago and the last late-glacial has been between 0.3 meters per 500 years and 0.3 meters per 1,000 years. Whether this rate applies to the Post-glacial period is unknown, although on the basis of the height of estuarine beds dated at 6,300 years, compared with some sea level estimates, it may do.

5.6 Compaction and Recent Tectonism

5.61 Compaction

Aranuian sediments cover the major part of the study area, and Flandrian sediments may exist at depth. As these sediments are composed of clay, sand, peat and gravel, it is necessary to discuss the possibility of compaction.

5.611 Field Conditions

The study area suffers from poor drainage, and flooding occurs after heavy rainfall. Field conditions vary seasonally but can also vary locally from week to week depending on the amount of rainfall. Consequently in most bore logs sediments were very wet, at least to the maximum depth drilled (9 meters).

5.612 Practical Considerations

Compaction is affected by increasing load, and changing hydrological conditions. It varies with the type of sediment, being high in clay and peat and low in sand. (King 1972). Twenhofel (1961) states that compaction is important in clays; it is produced by closer spacing of particles and expulsion of water, and the decrease in volume may rarely exceed 75% and commonly exceeds 40% - 50% (p.774). Bloom (1964) reports that a sedge peat at Clinton, Connecticut, which is overlain by a maximum of 10.668 meters of Post-glacial estuarine mud, has been compressed in 7,000 years to between 13% and 44% of its original thickness.

5.613 Sediments Of The Study Area

In the study area it is generally true to say that peats are underlain by muds or sands or a combination of both. The thickest peat succession known to the author is in the low lying swampy area between Te Whanga Road and the sand-dunes (north Levin - southwest Koputaroa district). Here the peat locally reaches a depth of six meters. In the remainder of the study area the floodplain peats are more silty, the valley peats less so. Compaction of peats has been mainly caused by artificial drainage. Such drainage has only been carried out in the last 50 to 70 years, and has been concentrated in the Makerua and

and Moutoa (formerly swamp) areas. Three successive forests have come to the surface in the Makerua area, providing evidence of sinking and compaction of upper beds at least.

However, peat beds are the most recent beds in the study area and are likely to be less than 5,000 years old[1].

Little can be said about compaction in estuarine muds and sands in the study area, except that beds penetrated to a depth of nine meters were very wet. Sandy lenses were common in the muddy estuarine sediments and sandy beds were more common in the Shannon floodplain area. These sands may have provided a partial control on the amount of compaction.

The deeper the infill the greater the possible amount of compaction and the greater the lowering of the surface. As sand and gravel beds alternate with clay and peat beds, the former would reduce the overall amount of compaction.

5.62 Recent Tectonism: Faulting

The majority of faults mapped in the study area are either within the Tararua Ranges or lie close to the western margin of the ranges. From geomorphic evidence it is apparent that movement of these faults has a limited effect on the nearest surrounding land form, the Tokomaru Marine Terrace, and has no effect on features more distant.

Only one fault, a concealed fault mapped by Kingma (1967) extending from Mangaore to Makerua is present within the Tokomaru

Marine Terrace. The surface expression here is such that the Tokomaru Marine Terrace is lower on the eastern side of the fault and higher on the western side. Local variations in the height of the Tokomaru Marine Terrace are not unusual, however, and without more definite evidence a fault-origin need not be accepted.

5.7 Summary

The study area is part of the Wanganui Basin. Geophysical evidence indicates that the basin has downwarped since early times. There is little evidence available to confirm this in the study area, and hence the degree of warping of sediments encountered in deep bores cannot be ascertained.

There is evidence available that suggests that the margins of the basin have been uplifted, and may still be doing so. There appears to have been no localised folding of the Shannon and Levin anticlines, during the last 6,000 years, as indicated by the position of fossiliferous beds, valley profiles, and the nature of stream dissection, in valleys flanking the anticlines. The age of folding of the anticlines is older than that previously estimated.

Uppermost Aranuian estuarine sediments were either deposited when sea level was at about the present position 6,000 years B.P., or sea level was about four to six meters lower 6,000 years B.P. and the sediments have been uplifted. In the latter case a rate of general uplift of 0.3 meters in 500 years, which would apply to the whole study area, is estimated.

Compaction of Aranuian sediments has probably occurred, the amount increasing with depth.

Notes

1 It appears that the Lower Manawatu peats began forming when the Manawatu River formed natural levees and ponded drainage in the Makerua (Linton - Shannon) and Moutoa (Shannon - Foxton) areas.

6. THE ESTUARY AT SHANNON, AND POST-GLACIAL SEA LEVEL

6.1 Introduction

In a box-shaped valley southwest of Shannon, and on the floodplain adjacent to the valley, several bore holes encountered fossiliferous beds which were indicative of an estuarine environment. Several samples were collected by the writer and identified by Dr A.G. Beu of the New Zealand Geological Survey. The species are listed in Appendix 1V. The species present may be used to tentatively reconstruct the environment at the time they were living.

6.2 The Estuarine Environment

Table V lists the samples and environments suggested by the species in those samples. Figure 6.A shows the location of the samples. The upper fossiliferous beds on the floodplain are muddy; this usually grades into a sandy mud or sand. In the valleys mud predominates.

Species in the three samples from bore log H.26 indicate a rise in the level of the estuary water surface; stratigraphically higher beds have species present which are indicative of a progressive increase in the depth of the estuary at that position.

Samples one to four were dominated by Chione, and in samples three and four, several Chione were found 'in situ', that is, there had been no post-mortem transport.

All the box-shaped valley samples (five to eight) suggest deposition near the high-tidal zone of an estuary. No

SAMPLE LOCATIONS OF FOSSILIFEROUS BEDS

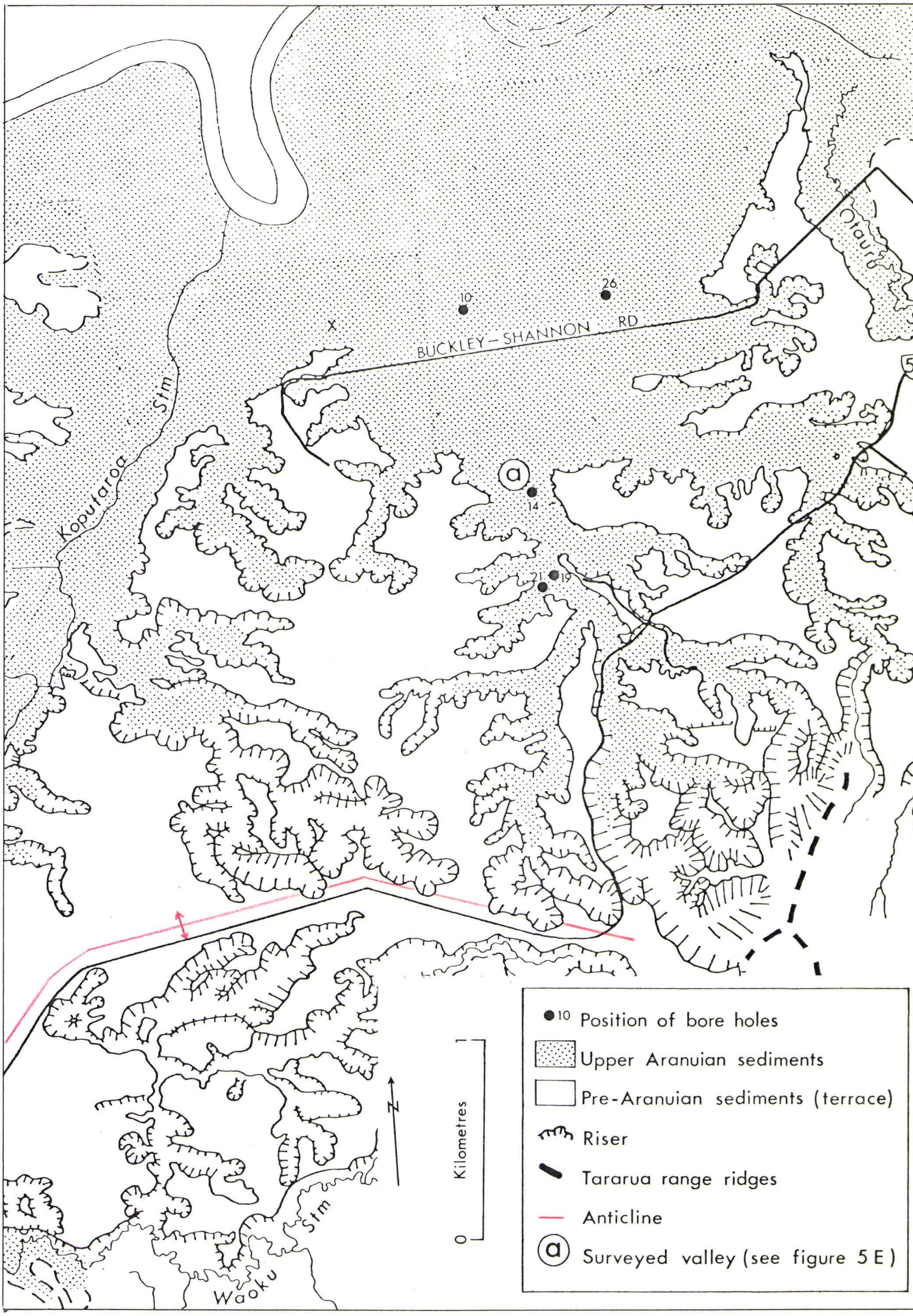


Figure 6 A

TABLE V : Environments Indicated and Sample Locations of Shannon Fauna.

Sample	Bore Log No.	Location	Depth	Environment Indicated
Sample 1	Bore H. 26	N152/900116	+0.914 to +0.57 m.	All species restricted to estuarine mud and sand flat. Salinity not extremely reduced.
Sample 2	Bore H. 26	____________	+0.57 to +0.085 m.	Deposition in an estuary, nearer to the shore than Sample 1.
Sample 3	Bore H. 26	____________	+0.085 to -0.097 m.	Deposition in a site very near the high-tidal fringe.
Sample 4	Bore H. 10	N152/888116	-0.274 to -0.366 m.	This fauna could occur at the mouth of a gently flowing stream with brackish tidal influence.
Sample 5	Bore H. 14	N152/895104	-1.59 to -1.9 m.	Similar to Sample 2.
Sample 6	Bore H. 19	N152/897098	+0.24 to +0.118 m.	Deposition near the high tidal zone of an estuarine mud flat, possibly where a fresh-water stream flowed across the flat when the tide was out.

TABLE V : (Continued)

Sample	Bore Log No.	Location	Depth	Environment Indicated
Sample 7	Bore H. 19	N152/897098	-0.918 to -1.04 m.	Deposition in the high-tidal zone of an estuary.
Sample 8	Bore H. 21	N152/895097	-3.098 to -3.19 m.	Estuarine, near the high-tidal zone.

NOTE: All heights in terms of m.s.l.

Chione were recognised in any of the samples from the box-shaped valley.

Estuaries normally display a zonation of species; this zonation is intricately tied to the tidal flow and ebb at any one time. The sample heights of sample two and sample six are similar. Their species indicate that at the time of growth the floodplain was covered by the incoming tide; this tide barely reached the sample six position up the valley.

The clearest evidence of freshwater influence is in sample four, with the brackish mussel *Xenostrobus securis*. However the interpretation of environment in Table V may be incorrect. *Chione* was the dominant species in this sample and several were found 'in situ'. It is likely, therefore, that the fragments of *Xenostrobus* were transported to the site by tidal or freshwater influences, and sample four (bore log H.10) is more indicative of deposition near the high-tidal zone.

Samples one to four all have common *Chione* and all but sample two lack *Cyclomactra*, whereas samples five to eight have common *Cyclomacta* and lack *Chione*. Beu (pers. comm.) states "it appears that *Potamopyrgus* and *Amphilbola* are more common and more consistently present in samples five to eight than in one to four, suggesting shallower water, but this does not explain how five to eight can contain *Cyclomactra* without any trace of *Chione*." He suggests that there may be "a sedimentary control, such as a sandy mud substrate, able to be burrowed by *Chione* but too firm for *Cyclomactra*, in samples one to four, and a finer mud substrate more suitable for *Cyclomactra* in five to eight." Certainly from drilling, mud is more prevalent in the valleys (samples five to eight), and sand and sandy mud is more prevalent in the floodplain (samples one to four).

Pettijohn et. al. (1972) states that the "ratio of sand to mud in an estuary is controlled by the relative strength of wave-generated, tidal, and river currents, and availability of mud verses sand." (p.474). Reineck (1967) states that in modern estuaries "on the tidal flat surface, finer sediments lie on the shore near the high water line and the coarser sandy sediments lie at the low water level." Postma (1967) states That the presence of fine-grained muds is partly due to the absence of wave action, and the fact that in brackish water, mud deposition is supported by flocculation.

According to Reineck (1967) "the current is greater on the lower part of the tidal flat than at the upper regions, and greater current velocity is found in the tidal channels than on the open tidal flat itself. Both waves and currents are stronger at the lower part of the tidal flat; therefore the coarser sediments are distributed near the lower part of its surface and the finer sediments above."

The vertical zonation of sediment encountered in the bores tends to follow the above pattern. The beds in bore H.26, and other similar bores not mentioned (H.8 and H.9; Appendix 1) on the floodplain, were sandy beds, probably subjected to some current and wave action. Sample four, from bore H.10 was in mud; this may have been a mud bank, or at least in a position removed from direct tidal currents. Bores in the valley indicate that most current action was probably restricted to a single narrow channel.

Figure 6B The cliffed margin of the Tokomaru Marine Terrace just south of Shannon, in the Buckley-Shannon Road area. Fossiliferous beds extend from the flood-plain (foreground) up the main valley studied (arrowed).

In summary, it appears that the fauna of the box-shaped valleys may have lived in strongly estuarine, near high-tidal conditions on a substrate of fine mud, whereas the fauna in the floodplain samples (one to three), lived in water of slightly greater salinity, and slightly greater maximum depth, on a coarser substrate.

6.3 Post-glacial Sea Level

6.31 Introduction

The writer has dated estuarine fossiliferous beds southwest of Shannon (grid reference N152/900116) from 0.9 to 1.12 meters above mean sea level. The shells which are from bore H.26 and close to the uppermost estuarine beds, were lying within the present tidal range. The date for the shells was determined as 6,330 $\pm$ 70 years B.P. (N.Z. 3085B). As the lower shell species present in bore H.26 appear to indicate a rising estuarine surface level, and hence indirectly a rising sea level, the position of the shells may be used to discuss the possibility of a Post-glacial sea level, higher than present.

Te Punga (1962) has argued that the cliffline directly in front of the dated sample (Figure 6.B), was eroded by marine agencies "at the time of the Post-glacial thermal maximum (=climatic optimum) when sea level was higher than present." The likelihood of this is examined.

6.32 The Attitude of the Dated Estuarine Beds Near Shannon

The dated sample was lying within the present tidal range. However, in some estuaries tide heights are magnified by the shape of the estuary, and the position of fauna in the estuary bears no relation to the actual tidal range at the open coast. Twenhofel (1961) states that tidal range tends to be higher due to the funnel-like shape of many estuaries; this also leads to strong tidal currents. However, in the study area, owing to the relatively small size of the estuary, the small tidal range, and the likelihood of a constricted entrance, the writer considers that the tidal range would have been similar, if not slightly less than the tidal range recorded at the coast.

Compaction has been briefly dealt with in Chapter 5. The writer considers that little or no compaction has affected the dated beds; or that compaction may have been compensated for by possible uplift.

The growing position of the dated fauna indicates that the 0.9 to 1.12 meter range is adequate to encompass the two main species present in the sample collected. It was predominantly comprised of Chione which is normally found on the neap tide flat of the lower beach. Chione burrow only an inch or so deep. Macomona, the second most abundant shell in the sample lives in a similar position to Chione, but burrows 20 to 22 centimeters below the surface (Morton and Miller 1968).

6.33 Post-glacial Sea Level

6.331 General Discussion

Opinions on the Flandrian transgression are sharply divided when considering the closing stages of the eustatic rise. Vita-finzi (1973) has summarised the three main schools of thought that have been recognised. "The first maintains that the sea rose to its current level 3,000 to 5,000 years ago and has since fluctuated above and below it; the second that sea level has remained relatively stable since that time, and the third that the rise has been continuous" (p.55).

6.332 New Zealand Evidence For the Flandrian Transgression

In comparison with other countries, New Zealand does not have a large list of dates recording the Flandrian transgression. Those that are available are predominantly for the last 8,000 to 4,000 years B.P.

McKnight (1968) encountered a relict shell assemblage and pebbles 32 kilometers northwest of Cape Farewell at -126 meters. He states that a sea level of approximately 100 to 120 meters below the present sea level is suggested by the present known environmental requirements of the shells.

Van der Linden et. al. (1974) states that "radiocarbon dates and paleoecological considerations provide compelling evidence that sea level in Karamea Bight area was approximately 110 meters below present sea level 16,000 to 17,000 years ago." McDougall and

Brodie (1967) reported in Norris (1972) encountered a submerged shoreline at a depth of 60 to 110 meters. Norris (1972) encountered distinct gravel and shell layers in 20 of 22 cores collected from the continental shelf between Cape Egmont and the Karamea Coast. From composite dates of several samples and estimation of depth of deposition by using Curray's (1965) sea level curve it appears that the shell layers were deposited on the continental shelf, for the most part between depths of 25 and 100 meters, during the late Pleistocene and Holocene transgression.

Brothers (1954) stated that sea level reached a minimum of 58 meters below present datum during the Last Glacial, a figure taken from bore records in Waitemata Harbour. Cullen (1967) has interpreted a relict shoreline as a submerged lagoon and spit at 64 meters in the vicinity of Foveaux Strait approximately estimated from overseas dating at 11,000 years B.P. Te Punga (1958) dated a log at Foxton 45.72 meters below present sea level at 9,900 $\pm$ 150 years B.P.

Suggate (1958, 1968) stated that several radiocarbon ages indicate a rapid rise of sea level from -22.25 meters to -3.658 meters in the period from 9,400 to 6,100 years B.P. A date at 17.67 meters was given as 8,000 years B.P. The -22 and -17 meter dates are both for samples taken from woody peat layers "which may be accepted as having formed at those places;" the samples at -3.6 meters was from shell beds associated with 'blue plug' indicating probable estuarine conditions. Suggate considers that at the above rate of rise, sea level probably reached a maximum at or a little above present sea level about 5,000 years ago.

Cullen (1967) dated peat at 14 meters below present sea level at 9,300 $\pm$ 80 years. When compared with his other date, above, he states that sea level rose 50 meters at an average rate of approximately 30 meters per 1,000 years. "This exceeds the subsequent rate which averaged approximately 1.5 meters per 1,000 years over the last 5,000 years. Amon (1974) states that sea levels older than 7,500 years are 15 meters or more below present sea level. Sea level was three to five meters below the present 6,000 to 7,000 years ago, and levels more recent than 5,500 years approximate the present.

Webby (1964) describes conspicuous remnants of a 3.658 to 4.572 meter bench preserved around Porirua Harbour. He states that "it is likely the bench developed at about 3.048 meters above m.s.l., because the 1855 earthquake caused a regional uplift of 0.914 meters in the Porirua area. This bench probably developed during the Post-glacial thermal maximum period." Stevens (1956a) considers a terrace (the Melling Terrace) "apparently represents a terrace developed to the highest sea level of the Post-glacial thermal maximum period." Uplift of 0.914 meters (1855 earthquake) and 1.2 to 1.5 meters (deduced from geomorphological evidence, Stevens 1956b) has been subtracted from the height of the Melling Terrace. He states the hypothesis that the Melling Terrace was carved during the Post-glacial thermal maximum period is confirmed by radiocarbon dates of 4,350 and 4,275 years B.P. for the Melling fossil forest below the terrace, which was overwhelmed by rapid alluviation caused by a rapid rise of the sea up to the thermal maximum level (1957), and by climate determination from pollen.

Brothers (1954) considered that the recent retreat of the sea from the Post-glacial maximum level was responsible for beaches and benches 2.4 to 3.6 meters above modern m.s.l. in the Kaipara District.

Schofield (1960) has described a chenier plain of the Firth of Thames. He assumes that for one traverse across the cheniers (north of Whakatiwai) that each of the gravel ridges reached storm ridge level, and that these storm ridges were built to levels above high spring tide as high as today's storm ridge. Sea levels for the second traverse (Miranda) are obtained by comparing the past storm ridge, high spring tide, and tidal stream flat levels with their modern counterparts. Seven samples of shells from the ridges were dated to give a sea level curve showing fluctuations of the level. According to Schofield, sea level has fallen from +2 meters 3,900 years ago to its present level about 2,000 years ago, since when there have been minor fluctuations of up to one meter.

Te Punga (1962) described an ancient cliff between Otaki and Waikanae which he considered was marine cut at the time of the Post-glacial thermal maximum, when sea level was about three meters higher than present. He considers the margin of the Tokomaru Marine Terrace in the study area represents the continuation of the thermal maximum shoreline.

6.333 Discussion

Little can be said about the continental shelf deposits of McKnight (1968), Van der Linden et. al. (1974), McDougall and Brodie (1967) and Norris (1972), except that they compare favourably with more detailed overseas studies. Similar comments apply to Brothers (1954) minimum glacial level. Cullen's (1967) submerged lagoon and spit has not been directly dated and could therefore be older than his assumed age. Te Punga (1958) states "that there is no decisive evidence to indicate whether the land (at the well site) has been stable or tectonically elevated or depressed in recent time" (p.93). Yet Godwin et. al. (1958), Norris (1972), Cullen (1967), Suggate (1968) and Schofield (1964) all place the log of wood at 45 meters below m.s.l. on their sea level curves. Godwin et. al. and Suggate both state that Foxton lies in an unstable area.

It is possible that the log of wood sunk to the bed of an estuary in deep water, and the height of the wood bears no relation to the level of the sea at the time of burial.

Jelgersma (1966) states that "the report of the ANZAAS Quaternary Shorelines Committee of the Hobart Congress (1965), mentions that the sea level curve of New Zealand by Schofield is strongly influenced by tectonics." King (1972) states that it seems likely that an area like the Firth of Thames has been liable to tectonic disturbance. Schofield (1960) states that effects of tectonic movement are ruled out unless conditions of a slow regional rise combined with fluctuating sea level have operated. J.R. Hails (1965), suggests that a series of descending beach ridges which are often used as evidence of a falling sea level could be due to a decreasing supply of sediment during the period of progradation. Other possible factors are changes in offshore relief, affecting the refraction pattern, and a variation of littoral currents. Another possibility is that the ridges do indicate a falling sea level, but that this is the result of minor earth movement and not a eustatic fall of sea level" (King 1972 P.199).

The evidence for a Post-glacial sea level higher than present proposed by Webby (1964) and Stevens (1956a) must be considered spurious. Both authors take into account an arbitrary amount of uplift which reduces the heights of the terraces to about three meters above m.s.l. However, the fact that one earthquake, that of 1855, was responsible for 0.9 meters of uplift, suggests to the present writer that the total height of bench (Webby) or terrace (Stevens) could be due to tectonic movements.

The modern beach, beach ridges and cliff just south of the Otaki River were surveyed from the beach to a bench mark (opposite Addington Road) by the writer and others, to determine if the height of the cliff-foot deposits were related to a higher sea level, as Te Punga (1962) stated. As the beach ridges backing the present beach are sand covered, drilling was carried out along the traverse to determine the height of former storm ridges.

The gravel horizon is in no place higher than the present storm beach, and the oldest gravel beach is almost a meter lower. This oldest gravel beach directly in front of the cliff is overlain by 2.134 meters of peat. Te Punga's proposition that the Otaki-Waikanae cliff is marine cut is substantiated, but there is no evidence for Post-glacial sea levels higher than present.

Fleming (1965) dated a sample of wood debris, lying within beach deposits at the foot of the cliff near Paekakariki, at 5,140 $\pm$ 90 years B.P. (N.Z. 519). Normal high tides reach to the top of the bed. This confirms the marine origin of the cliff and indicates that the cliff was cut at about or earlier than 5,140 years B.P.

6.334 Post-glacial Sea Level in the Study Area And Its Implications

In Chapter 5, the dated fossiliferous estuarine beds near Shannon were thought to be either (a) deposited at that level when the sea was at about the present level 6,300 years ago, or (b) they were deposited at about four meters lower when sea level was lower than present. In the latter case regional uplift has lifted the shells to a position lying within the present tidal range.

Surveying and drilling of the Otaki ridges shows that there is no evidence for a higher sea level when the older ridges were formed. The Otaki - Waikanae cliff has been cut by marine agencies when the sea was at about the present level. The former beach ridges indicate that coastal progradation has occurred without a fall in sea level.

The major implication of this in the study area is that the Tokomaru Marine Terrace cliffed margin was not cut when the sea was at a higher level than present. The distribution of estuarine fauna and the environments in which the fauna were living, the fact that the highest fossiliferous estuarine beds on the floodplain are within the present tidal range, and the existence of umlaufbergs in the Tokomaru to Koputaroa area, add weight to the hypothesis presented in Chapter 3, that the cliffed margin of the Tokomaru Marine Terrace has been produced by river cutting during the Otiran Glacial Stage.

In the Shannon - Koputaroa district, storm waves in the estuary may have washed against the cliff and caused some further erosion.

The rise of Post-glacial sea level as indicated by a dated log of wood (9,900 $\pm$ 150 years) at Foxton (Te Punga 1958), lying 45.72 to 46.33 meters below m.s.l., and dated estuarine beds (6,330 $\pm$ 70 years) near Shannon, at 0.9 to 1.12 meters above m.s.l., is 44.60 meters in 3,570 years, if the position of the dated horizons is considered reliable.

Comparison with Shepard's (1964) average curve of sea level (his Figure 2) indicates that the wood at Foxton is too deep by about 15 meters; Bloom et. al. (1974) indicates that the position of the wood is directly comparable to their curve. Suggate's (1958, 1968) date of 6,100 years B.P. for shells at -3.68 meters compares well with the 6,300 years B.P. shells at Shannon if the latter has been uplifted at an estimated rate of 0.3 meters per 500 years. Amon's (1974) levels for 6,000 to 7,000 years are also three to five meters below the present level. Suggate's date of 9,900 years B.P. for a peat at -22.25 meters does not compare with Te Punga's (1958) age of 9,900 years B.P. for -45.72 meters.

Such comparison may, however, be spurious. As the writer has already noted, the Foxton log of wood may have sunk in deep water, and the site since then may have been subjected to uplift and compaction. The shells near Shannon may have been uplifted as much as four meters in 6,000 years. Until far more detailed work has been carried out in this area, with regard to rates of earth movement and changes of sea level, it is spurious to correlate levels in an attempt to provide meaningful results.

7. GEOMORPHOLOGICAL HISTORY OF THE LOWER MANAWATU

7.1 Earlier Pleistocene Landscapes

The Pleistocene in New Zealand comprises the Upper Wanganui series and the Hawera series. Deposits of the Upper Wanganui series overlie the Pliocene sediments in the Wanganui Basin. The first glacial stage, following the Pliocene, is the Hautawan, followed by the Nukumaruan Interglacial. Another glaciation followed, and was succeeded by a second Interglacial represented by the Castlecliffian (=Putikian) Stage.

Seas of the Nukumaruan Interglacial occupied the Manawatu Strait linking the Wanganui and Hawke Bay - Wairarapa basins. During the Castlecliffian, the sea occupied restricted parts of the Wanganui Basin, and only reached the western entrance of the Manawatu Gorge. Earth movements accelerated during Nukumaruan and Castlecliffian time.

Four glacials and four interglacials comprise the main events of the Hawera series. North of the study area in the Wanganui district, coastal terraces were formed during interglacial stages, and alluvial aggradation deposits were formed during the glacial stages. Shore line changes of the Late Pleistocene were mainly, but not entirely, due to eustatic sea level changes. The rise of the Tararua - Ruahine Horst continued.

7.2 Oturian Interglacial Stage

This, the interglacial stage occurring approximately 80,000 to 120,000 years B.P., prior to the last glaciation, deserves special mention. Upper beds of Oturi age form a terrace, termed in this study the Tokomaru Marine Terrace, which was the latest developed, and possibly the only Pleistocene marine coastal plain in the study area. Sea level during the Oturi Interglacial was at about the present level or a little higher, and the Oturi sea lapped the western margin of the Tararua Range (Figure 7A). Marine, estuarine, lagoon and beach deposits were all laid down during the transgression and subsequent regression.

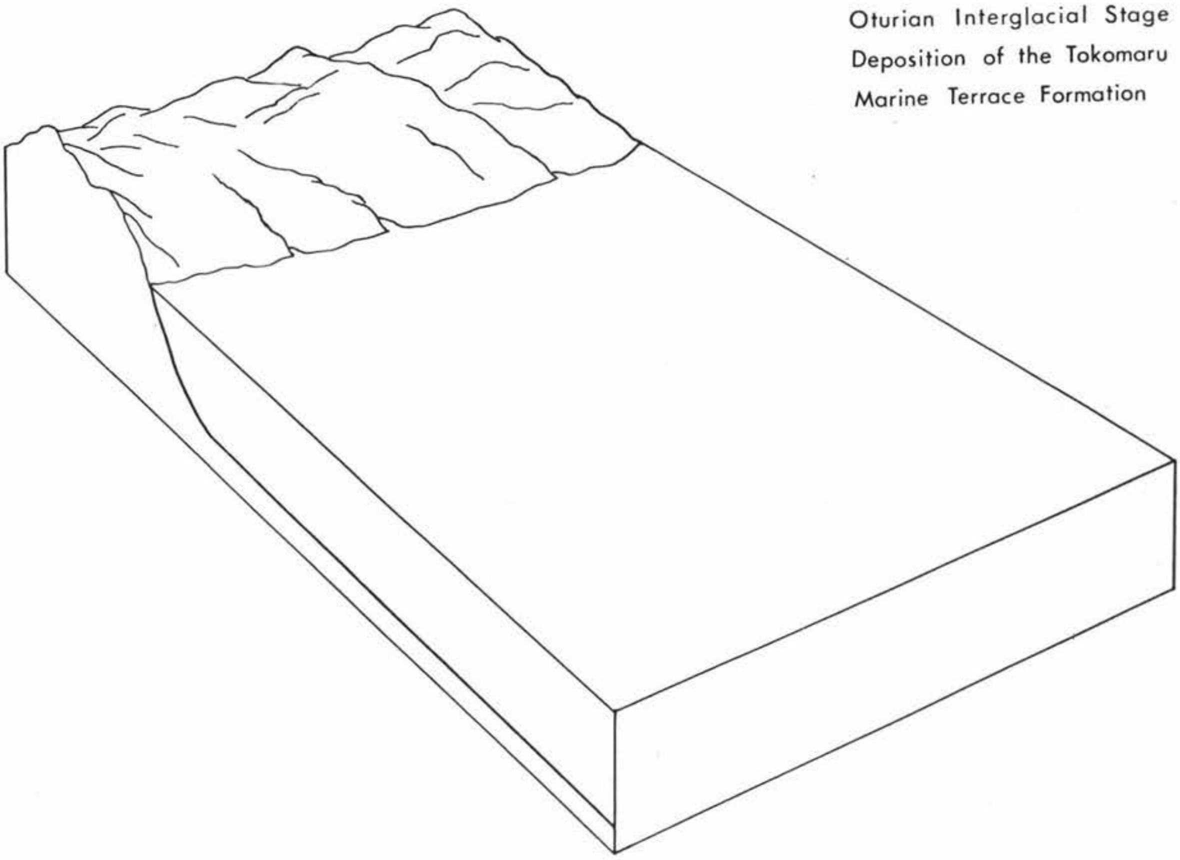
Uplift along the axis of several anticlinal structures in the study area may have preceded the Oturian stage, and certainly immediately postdated it. This uplift produced domed surfaces in the Shannon, Levin and Himatangi - Rongotea districts.

7.3 Otiran Glacial Stage

When the Oturi sea retreated, streams draining the foothills of the Tararua Range flowed across the newly exposed surface, and incised into that surface. Larger rivers such as the Oroua, Manawatu and Tokomaru, eroded much of the formation as the sea regressed and as uplift proceeded. The Tokomaru Marine Terrace margin was cliffed by these larger eastward eroding rivers. Small streams initiated near the margins of the Terrace eroded small westward trending V-shaped valleys.

During episodes of cold climate, the upper limit of vegetation in the ranges was lower than at present, the ranges were being rapidly weathered and eroded and the bedload of rivers was increased. Sets of river terraces, at least in part aggradational,

FORMER AND PRESENT LANDSCAPES



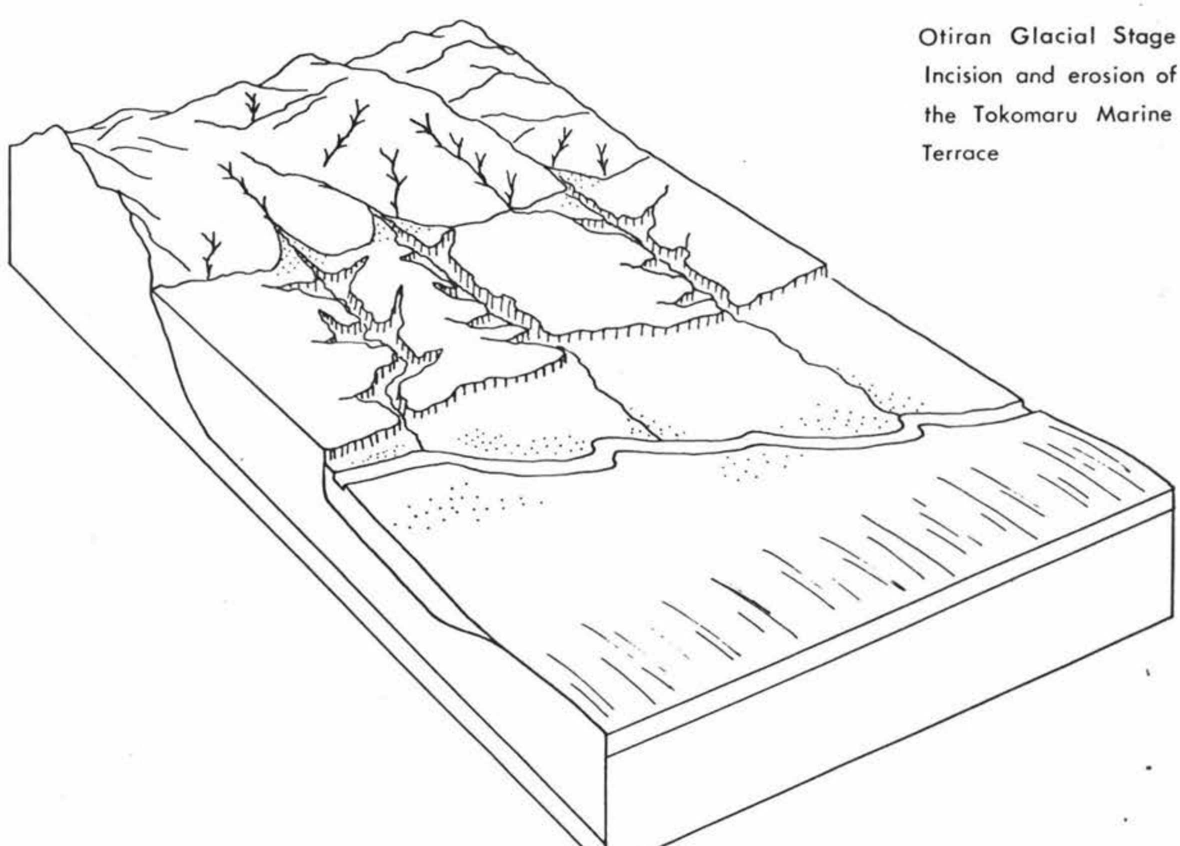
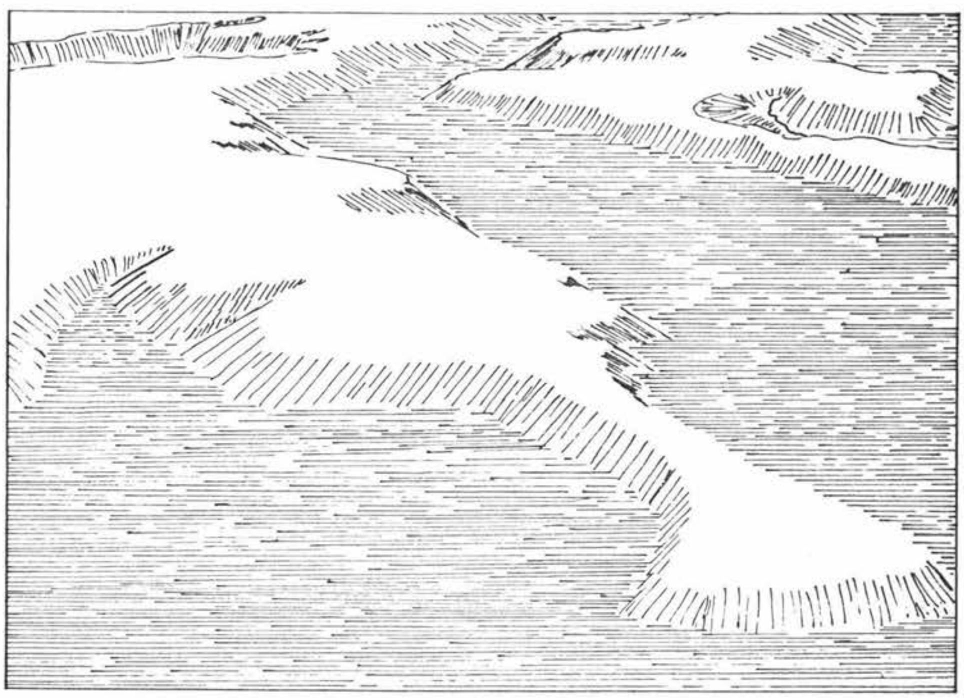


Figure 7 A



Part Of The Present Landscape
The Tokomaru Marine Terrace and infilled box-shaped valleys

were formed in the Manawatu, Oroua, and larger tributary valleys. Periods of loess deposition also occurred. Gravel fans were formed and mantle the Tararua foothills, and overlie the eastern margin of the Tokomaru Marine Terrace. In some localities sand-dunes were formed.

Sand and gravel deposits of the Manawatu and Oroua Rivers probably formed coalescing fans which extended beneath the present floodplain. Information obtained from drilling indicates that these gravels were restricted in their deposition by the presence of the Himatangi anticline.

During the latter part of the Otira glaciation sea level was approximately 135 meters below the present, and the coastline was about 25 kilometers west of the present coastline. The Oroua and Manawatu Rivers incised deep valleys within their former floodplain or fan deposits. Tributary streams, some of which had formed box-shaped valleys by lateral erosion, incised deep V-shaped valleys in the Tokomaru Marine Terrace.

7.4 The Flandrian Transgression

About 15,000 to 17,000 years B.P. sea level began to rise, primarily as a result of melting of the continental ice sheets. As the shoreline moved upward and across the continental shelf, the lower reaches of the Manawatu, and eventually the Oroua river valleys were drowned and became estuaries. Fauna were growing in the estuary at this time about 14,000 to 15,000 years B.P.

As the transgression proceeded the lower reaches of tributary valleys were drowned by the estuary, as were the former gravel floodplains and terraces of the lower reaches of the two main rivers. Estuarine sedimentation predominated, sediment being supplied by the rivers and sea. Estuarine fauna continued to inhabit the tidal flats of the estuary.

An estuarine environment prevailed until at least 6,000 years ago because a barrier prevented direct incursion of the sea into the study area. From geomorphological and bore log evidence it appears that the Himatangi anticline acted as a structural barrier. Development of a sand bar or barrier may have been contemporaneous with the latter part of the transgression, and thus may have aided in preventing direct marine incursion.

On the southern side of the present Manawatu River mouth, the Poroutawhao 'High' prevented direct marine incursion into the west - Koputaroa - northwest - Levin district.

Many former V-shaped valleys in the study area became box-shaped as they were infilled by estuarine sediments. Some of the larger tributary streams flowing in former box-shaped valleys appear to have aggraded their floors with gravels during the transgression.

Infilling of the estuary proper was most rapid in the north where the Oroua and Manawatu Rivers deposited silt, sand and gravel as they became estuarine. Consequently, the estuarine environment persisted longest in the lowest and most southern part of the study area - the Shannon - Koputaroa district.

Sea level either rose to the present level about 6,000 years B.P., or was about four to six meters lower than present 6,000 years ago. The latter statement infers a rate of general uplift of 0.3 meters per 500 years, which can be calculated for the Tokomaru Marine Terrace in the study area. Anticlinal uplift has been negligible in the last 6,000 years.

There is no evidence for sea level having been higher than present, and the majority of the cliffed margin of the Tokomaru Marine Terrace is regarded as river cut. Only in the south Shannon - Koputaroa district is it likely that the estuary eroded the Terrace margin. Even here, the existence of umlaufbergs and clay sediments suggests that such erosion was of limited effectiveness.

7.5 Post Flandrian

Compaction of Aranuian sediments has probably been continuous throughout Post-glacial time, although the degree of such compaction could not be estimated.

The fact that tidal influences extend at least 20 kilometers up the Manawatu River at the present time indicates that the estuary, at least in the Shannon - Koputaroa area, may have persisted for some time after 6,000 years B.P. Silt was, and is deposited during floods on the floodplain and in the valleys at the present time. Peat swamps have developed in many of the box-shaped valleys, due to poor drainage.

The Manawatu River formed natural levees which ponded drainage in the Makerua (Linton to Shannon) and Moutoa (Shannon to

Foxton) areas, causing the formation of large swamps.

7.6 Conclusion

This study has been primarily concerned with Flandrian events, and the order and magnitude of those events. The Lower Manawatu has been characterised by glacio-eustatic changes in sea level and changes in the dynamics of streams and rivers. In an attempt to grasp a basic understanding of these complex events which have directly influenced the morphology of the study area, a description of the geomorphological history of the Lower Manawatu has been presented.

APPENDIX I : Bore Logs (Prefixed 'H') Drilled by the Writer.

Bore log H. 1

N152/897098
Surface : +3.66 m
0 - .3 m. topsoil
.3 - 4.5 mud

H. 3

N152/986173
Surface : +6.8 m
0 - .28 m. topsoil
.28 - 1.5 sandy clay
1.5 - 1.9 muddy sand
1.9 - 3.05 blue mud

H. 4

N152/980182
Surface : +16.6 m
0 - .15 m. topsoil
.15 - 1.52 clay, wood
1.52 - 4.0 blue mud
4.0 - 4.7 brown sandy mud

H. 8

N152/897116
Surface : +3.4 m
0 - 2.58 m grey mud
2.58 - 3.0 sand, shell

H. 9

N152/893116
Surface : +3.05 m
0 - 2.7 m blue/grey sandy mud
2.7 m - " " " "
shell

H. 10

N152/888116
Surface : +3.04 m
0 - 1.8 m grey sand
1.8 - 2.13 mud
at 3.04 " shell

H. 11

N152/954153
Surface : + 3.913 m
0 - 0.61 m topsoil
0.61 - 0.76 clay, wood
0.76 - 1.524 sandy clay
1.524 - 2.28 blue/grey sand
2.28 - 2.43 clay, wood
2.43 - 2.9 peaty clay
2.9 - 7.6 clay, plant fragments

H. 12

N152/963149
Surface : + 3.910 m
0 - 0.305 topsoil
0.305 - 0.7 silt/clay
0.7 - 3.6 clay, plant
3.6 - 3.9 peaty clay
3.9 - 7.6 blue/grey clay

NOTE : All log heights recorded in metres below the surface.

H. 14

N152/895104
Surface : +3.7 m
0 - 0.1 topsoil
0.1 - 0.7 silt
0.7 - 1.8 sandy mud, vegetation
1/8 - 5.28 sand
5.28 - 6.5 " shell

H. 15

N152/908123
Surface : +4.06 m
0 - 0.1 topsoil
0.1 - 0.45 brown mud
0.45 - 3.35 oxidised grey sand

H. 16

N152/903120
Surface : +3.5 m
0 - 0.15 topsoil
0.15 - 3.04 mud, vegetation
3.04 - 3.05 sand
3.05 - 3.5 mud
3.5 - 6.1 bluesand

H. 17

N152/898111
Surface : +4.11 m
0 - 0.17 topsoil
0.17 - 1.36 mud
1.36 - 4.26 sand

H. 19

N152/897098
Surface : +3.7 m
0 - 0.25 topsoil
0.25 - 0.45 grey brown mud
0.45 - 0.9 grey mud, wood
0.9 - 1.9 sandy grey mud, wood sand lenses
1.9 - 5.8 grey/blue sandy mud ditto, shells, wood
5.8 - 6.1 grey blue sandy mud

H. 20

N152/964163
Surface : Unknown
0 - 0.45 m topsoil
0.45 - 1.36 brown mud
1.36 - 4.57 blue mud

H. 21

N152/895097
Surface : +3.96 m
0 - 0.4 topsoil
0.4 - 0.62 muddy peat
0.62 - 2.2 mud
2.2 - 7.3 ditto, shell wood fragments
7.3 - 9.1 mud, wood

H. 22

N152/898098
Surface : +4.24 m
0 - 0.5 topsoil/silt
0.5 - 1.21 brown oxidised mud
1.21 - 1.97 grey mud, rootlets
1.97 - 2.28 dark grey peaty mud
2.28 - 5.48 grey sandy mud, sand lense s
5.48 - 6.09 muddy sand
6.09 - 6.4-1 sand, green mottling (Otaki sandstone)

H. 23

N152/896096
Surface : + 4.26 m
0 - 0.28 topsoil
0.28 - 1.06 grey oxidised mud
1.06 - 1.36 grey peaty mud
1.36 - 1.5 grey mud, roots
1.5 - 2.28 grey peaty mud
2.28 - 2.35 peat
2.35 - 2.58 grey mud
2.58 - 3.9 blue mud
3.9 - 4.2 dry sand, green mottling (Otaki sandstone)

H. 24

N152/964200
Surface : +4.8 m (approx)
0 - 0.76 topsoil
0.76 - 1.2 grey brown clay
1.2 - 2.7 blue grey clay
2.7 - 2.9 grey mud
2.9 - 3.1 peaty mud
3.1 - 3.3 blue mud

H. 25

N152/878109
Surface : Height Unknown
0 - .31 topsoil
0.31 - 0.85 dry grey clay, wood
0.85 - 1.5 muddy sand, grey/brown
1.5 - 3.04 grey/blue muddy sand. Shells began at 1.8 m.

H. 26

N152/960116
Surface : +3.19 m
0 - 0.27 topsoil
0.27 - 2.0 brown mud
2.0 - 2.13 mud, vegetation
2.13 -6.09 sand, shells, sand muddier at times, lenses of fine and coarse grained sand.

H. 28

N148/976207
Surface : + 4.8 m (approx)
0 - 0.55 peaty topsoil
0.55 - 1.6 grey mud, wood
1.6 - 4.9 blue mud

H. 29

N148/978204
Surface : +4.8 (approx)
0 - 0.1 topsoil
0.1 - 1.5 sandy mud
1.5 - 1.6 sand/fine rock fragments
1.6 - 1.7 sandy mud
1.7 - 1.8 peaty mud, wood
1.8 - 6.1 grey plastic mud

H, 30

N152/835097
Surface : +1.32 m
0 - 1.52 peat
1.52 - 3.6 grey/blue mud, roots, shell at 2.7 m

APPENDIX II : Laboratory Procedures

(A) Rounding

The method used was that proposed by Powers (1953). Six roundness classes are given by Powers, and a value is attached to each class. The classes range from very angular (.14) to well-rounded (.84). Photographs of particles which fall very near the geometric means of the six class intervals are provided in Powers.

"In determining the roundness of a sample, each particle is assigned to one of the classes depending on the photograph with which it most nearly compares. Fifty or more grains are thus classified by comparison with the photographs. An average roundness for the sample is determined by multiplying the number of particles in each class by the geometric mean of that class and dividing the sum of the products by the total number of particles counted" (Powers 1953).

(B) Opaqueness of Grains

Several samples of mud were washed through a No.240 BS Test sieve and the retained sand was collected and dried. A sample of the sand was placed on a watch glass and 50 or more grains were counted by microscopic inspection. The number of opaque grains was then counted, and this number was calculated as a percentage of the total.

(C) Sand-Clay Percentage

The procedure for Test 7 (C) Standard method for fine grained soils (pipette method), in the British Standard 1377 was basically followed, except the pipette was not used.

Method : The samples of air-dried mud selected for analysis were placed in an oven and dried over-night at a temperature of 105 degrees F. The samples were then placed in a desiccator to cool. Upon cooling, each sample was weighed to .0000 of a gram, and was assigned a weighing bottle. Each weighing bottle was also weighed.

The samples were placed in beakers and distilled water was added. The samples were then heated for ten minutes, and were stirred continuously throughout the heating. Each sample was then mechanically mixed for fifteen minutes. Sodium hexametaphosphate was added following mixing.

Each sample was then transferred to a No. 240 (63 mm) BS test sieve. The samples were repeatedly washed using distilled water in a wash bottle, until all silt and clay was removed. Each sample was air-dried on the sieve.

Organic matter could be satisfactorily removed by visual inspection once the sample had dried. Each sample was brushed into a collecting tray, and from there into a weighing bottle. The samples were oven dried, then placed in a desiccator, and finally weighed. Those samples containing shell fragments were treated with hydrochloric acid, decanted, oven dried and weighed.

APPENDIX III : Deep bore logs

BORE LOG 2.

0 – 3 metal
-3·3 clay
-10·3 metal
-11·2 blue metal
-15·2 " clay
-39·1 blue metal
-39·4 clay
-46·1 metal
-47·6 clay
-54·6 sand, metal
-60·3 blue clay
-66·4 metal
-81·9 blue sand
-82·8 grey clay, shell
-94·2 blue sand
-95·1 blue clay
-98·5 metal

BORE LOG 3 (N149·105343)

0 – 0·3 topsoil
-2·1 yellow clay
-3·9 blue "
-7·3 metal
-7·9 peat
-11·5 blue clay
-15·5 sand, metal
-19·2 clay, sand
-19·5 " , metal
-27·4 blue clay
-33·9 metal
-37·9 sand
-41·5 blue clay
-43·4 sand
-44·3 clay, sand
-51·3 metal
-51·4 blue clay
-59·8 sand
-61·8 sand, clay, shell
-72·1 " " "
-74·6 blue clay
-79·2 metal

BORE LOG 29

0 – 0·6 topsoil
-4·8 sand
-5·4 clay
-6·7 sand, clay
-60 " "

BORE LOG 7.

(N149·114366)

0 – 1·5 clay
-12·1 " , gravel
-16·1 gravel, sand
-22·8 " " clay
-25·9 " "
-34·5 " "
-35·7 "
-36·4 clay, sand
-37·6 gravel, " clay.
-41·2 " "
-54·3 " "
-61·5 sand, clay, silt
-63·6 blue sand
-65·1 grey clay
-67 sandy clay
-69·1 gravel, sand
-70·3 sandy clay
-78·8 gravel, sand
-80·1 sand, clay
-87·7 " " silt
-92·7 " " " shell
-94·2 clay, sand
-97 " "
-97·9 blue clay
-102·4 gravel, sand
-102·8 clay
-113·1 sand
-114·3 sand, shell
-118·9 clay, sand, shell
-122·4 " "
-128·2 gravel, sand

BORE LOG 23.

0 – 0·3 topsoil
-2·7 silt
-12·8 clay
-13·4 metal
-14·9 sand
-23·1 metal
-23·4 " , clay
-27·1 "
-27·4 clay
-31·2 metal
-31·8 clay
-34·2 metal
-34·8 metal, wood
-43·1 metal
-49·5 clay, sand
-52·2 "
-62·7 sand
-63·3 peat
-65·4 clay
-67·3 sand
-69·1 clay
-73·4 sand
-76·1 sand, wood pumice
-77·6 sand, clay
-80·1 clay
-81·3 peat
-81·6 clay
-84·6 sand

BORE LOG 45

(N148·827308)

0 – 19·2 sand
-19·8 clay
-22·8 " sand
-28·3 sand
-42·2 "
-49·8 " clay
-50·1 blue clay
-51·6 " "
-54·3 sand

BORE LOG 42

0 – 2·7 sand
-9·1 sand, silt
-28·6 " shell
-33·3 " gravel
-37 " " shell
-37·3 metal
-57·1 sand, shell
-59·8 gravel
-60 blue clay
-64·2 metal

BORE LOG 43

(796210)

0 – 1·5 silt
-7·6 metal, sand
-12·4 " " shell
-21·6 sand
-24·3 " clay
-32·7 sand
-33 " shell
-36·7 clay, sand
-54·6 " "
-65·4 metal

BORE LOG 44

0 – 2·4 blue silt
-6·0 gravel
-9·1 sand
-12·4 " gravel
-13·1 "
-34·5 sand, shell
-39·1 silty clay
-56·8 sandy silt
-57·4 sand
-64·5 metal

BORE LOG 48
(N149·038308)
0-4·2 silty clay
-14 blue "
-28·3 metal
-30 "
-35·4 clay
-49·8 sand, clay
-53·1 clay
-54·6 sand clay
-58·3 blue sand
-84·3 sand, clay
-88 metal
-92·1 sand silt shell
-100·6 clay
-102·1 sand
-106·4 metal
-110·7 clay sand
-117·1 "
-123 sand metal
-125·4 "
-125·7 clay
-148·9 blue sand
-149·8 silty "
-156 sand
-161·2 clay, sand
-162·8 clay
-164·3 sand
-173·4 metal
-173·7 sand

BORE LOG 50
(N149·042302)
0-2·4 loam
-4·8 metal, silt
-24·3 "
-30 clay silt
-50·7 " sand
-51·3 metal
-72·1 clay sand
-72·8 metal
-76·1 sand
-79·5 metal
-88·6 clay sand
-95·1 metal
-136·4 sand
-139·2 sand, clay
-144·3 silty sand
-157·9 sand, clay, metal.

BORE LOG 51
(N149·042321)
0-2·4 silt
-3·9 clay
-5·4 peat
-9·1 gravel
-27·3 "
-34·2 blue clay
-38·5 gravel
-48·2 sandy silt
-50·1 sand
-50·7 wood
-51·3 clay
-52·5 sandy gravel
-53·7 clay
-56·2 gravel
-58·6 " clay
-59·2 "
-69·1 clay sand
-79·2 "
-81·9 gravel sand
-82·5 "
-90·9 clay
-91·5 gravel
-92·4 silt
-102 gravel

BORE LOG 58
(N149·095348)
0-13·1 metal
-16·7 " sand
-17·0 log
-19·8 clay sand
-20·7 " peaty
-31·5 metal
-32·4 " silt clay
-33·6 "
-37·9 silt, clay, veget.
-39·7 sandy metal
-48·2 sand
-48·5 peat, clay metal
-51·3 metal "
-61·2 sand
-65·4 clay
-67·0 sand
-68·5 clay
-70·6 sand
-71·5 clay sand
-74·6 " " metal
-87·4 hard sand, clay
-92·1 shell / sand shell
-102·1 clay "
-102·8 "
-108·2 metal

BORE LOG 86
0-12·8 silt
-18·8 gravel
-37 clay
-40·6 " sand
-44·3 peat
-52·5 peaty sand
-53·1 hard "
-62·7 clay
-65·4 hard sand
-91·5 clay, peat wood
-92·7 log
-94·2 sand
-137·6 clay, peat, sand, seeds
-138·5 clay sand
-148 " shell pumice
-150·6 clay
-153·9 sand
-154·5 clay

BORE LOG 118
0-0·6 topsoil, sand
-1·2 clay, gravel
-1·8 peat
-2·7 clay, gravel
-14·6 sand
-15·2 sand, stones
-15·8 clay, gravel
-15·9 shattered rock

BORE LOG 118b.
0-7·0 sand, clay, peat
-9·1 sand, gravel
-9·4 gravel
-10·6 blue clay, gravel
-10·9 gravel, sand
-11·0 solid blue rock.

BORE LOG 119
0-32·1 sand
32·1— blue rock

BORE LOG 134
0-99·1 sand etc.
99·1 — blue rock

BORE LOG 145
0-1·8 silt
-2·7 silty clay
-3·0 sandy silt
-3·9 silty sand
-5·1 sandy silt
-7·0 silty clay
-8·5 sandy silt
-8·8 silty sand
-10·3 " " veget.
-10·6 silty clay
-10·9 silty sand
-11·8 clay, wood
-14·9 " "
-15·5 silty clay
-15·8 sandy silt
-17·0 silty sand
-17·3 sandy silt
-21·9 "
-22·2 sand, gravel
-28·6 metal

BORE LOG 147

0 - 12·8 silt
- 27·4 sand
- 39·1 metal
- 51·3 clay
- 70·6 sand
- 76·1 sand, shell slight clay
- 94·2 clay
94·2 - metal

BORE LOG 148

84·3 - 96·0
sand and shell at bottom.

BORE LOG 151

0 - 24 alternate layers of sand and silty clay

BORE LOG 153

0 - 9·1 timber, coarse shelly sand
- 36·0 finer sand shells
- 38·2 shingle
- 48·2 sand, shells
- 54·3 clay/sand alternating

BORE LOG 154

0 - 15·2 sand
- 40·6 clay/silt alternating. Shells in silty layers.

BORE LOG 155

0 - 24·3 sand
24·3 - shingle

BORE LOG 158.

0 - 6·0 peat and clay alternating
- 22·8 sand
22·8 - shingle

BORE LOG 159

0 - 1·2 peat
- 28·3 clay
28·3 - sandy shingle

BORE LOG 161

0 - 22·8 clay
- 24·0 silty sand
24·0 - shingle

BORE LOG 162

0 - 21·3 sand
- 30·0 silty sand
- 58·0 sand
- 59·2 papa (mudstone)
59·2 - sand

BORE LOG 163

0 - 21·3 sand
- 25·9 clay (honeycombed)
25·9 - 119·0 sand
- 396·6 shingle
396·6 - sand

BORE LOG 164

0 - 21·3 sand
- 25·9 clay (honeycombed)
- 117·4 sand
- 119·3 clay
119·3 - silty sand

BORE LOG 168

0 - 21.3 sand
-small layers of peat

-25.9 clay

-81.3 sand

-90.0 clay

90.0 - shingle and pumice.

BORE LOG 169

0 - 21.3 sand

-25.9 clay

-46.7 sand

46.7 - shingle

BORE LOG 171

0 - 12.1 loose sand

- 15.2 sandstone

- 28.9 "

-58.9 hard sandstone

-87.4 loose sand

-90.6 clay

90.7 - silty sand

BORE LOG 177

0 - 30 sand

30 - shingle

BORE LOG 178

0 - 21.3 clay

- 60.0 sand

-66.0 clay

220 - silty sand, wood, shells.

BORE LOG 184

0 - 9.1 sand

-30.0 clay/sand alternating

-54.3 sand

-60.0 shingle/silt/clay mixture; lot of shells

60 - heavier shingle

BORE LOG 185

0 - 9 sand

-30 clay/sand

-54 sand

-57.4 "

57.4 - shingle

BORE LOG 187

0 - 27.4 sand, clay alternating

-60 sand

60 - shingle

BORE LOG 188

0 - 36.0 sand, small layers of clay

-48.0 clay

48.0 - sand

BORE LOG 189

0 - 18.2 sand; little clay and peat

-22.8 clay

22.8 - sand

BORE LOG 190

0 - 6.0 layers of peat and clay

-19.8 sand

-43.1 shingle
log of wood

-54.0 sand

-58.9 clay

-59.5 sand

BORE LOG 191

0 - 0·45 loam, gravel
- 2·9 sand "
- 3·9 clay "
- 4·1 silt
- 4·5 clay
- 4·8 silt, some sand
- 9·8 sand, silt lenses
- 10 sandy silt
- 10·6 sand
- 10·8 silt
- 10·9 sandy silt
- 11·2 coarse sand
- 11·3 sand
- 12·2 " , silt lenses
- 12·9 silty sand
- 13·5 sandy silt
- 14·1 sharp white pumice
- 14·2 sandy silt

RICH 1959 BORE
MASSEY COLLEGE DAIRY FACTORY
(N149·104324)

Reliable index fossils are not represented. Shells at 120
36·4 below m.s.l.

TE PUNGA 1953a
(N155·781102)

0 - 24 soft sand
- 54·3 solid rock

TE PUNGA 1958
(N148·796206)

0 - 1·5 silt
- 7·6 sandy gravel
- 12·4 sand, " shell
- 21·6 "
- 24·3 clay, sand
- 33·1 sand
- 33·4 " shell
- 47·1 " clay
- 47·7 log of wood
- 55·3 clay sand
- 66·2 gravel

TE PUNGA 1954a
(AWAHURI N149·033427)

0 - 3·6 clay
- 4·2 sandy clay
- 7·9 clay
- 20·7 sandy gravel
- 22·5 clay
- 28·0 gravel
- 29·5 silty mud, rare pebbles
- 31·6 clay
- 32·2 sand, little silt
- 37·1 gravel
- 38 " , sand, pumice
- 40·7 clay, plant remains, silicaliths
- 43·2 sand, grit, pumice, rare shell fragments
- 44·4 clay
- 46·8 sand, fine gravel; rare pumice, shell frag
- 50·8 clay and peat
- 57·2 layers of fine sandy clay, coarse sand and greywacke grit
- 61 sand, fine grit
- 63·8 sand, some mud and clay
- 66·8 sandy mud, plant frags. Abundant pumice and wood
- 68·7 silty sand, granules, tiny pumice few sponge spicules
- 69·9 sand, greywacke grit and pebbles pumice and wood frags
- 72·0 gravel, some coarse sand Sponge spicules, frags of mollusc shells beach-worn 'pebbles' of wood
- 73·2 gravel, grit, sand, pumice
- 74·8 clay
- 76·3 gravel, pumice
- 77·8 clay
- 80·3 sand
- 80·9 clay, pumice
- 88·2 sand
- 88·8 peaty mud
- 91·8 clay, pumice dust
- 93 sandy mud
- 94·2 peat
- 105·2 sand
- 108·5 pumiceous sand
- 111·4 clay
- 115·5 fossiliferous medium-coarse sand
- 116·8 poorly fossiliferous stiff clay, few sandy layers
- 121 clay
- 121·6 sand
- 122·5 clay
- 133·7 sandy shelly gravel

APPENDIX IV : Shell Species Identified in Samples Collected near Shannon

Sample	Location*	Species Present
Sample 1 (Bore H. 26)	N152/900116 +0.914 to +0.573 m. above m.s.l.	Bivalvia : Macomona liliana (Iredale). Chione (Austrovenus) stutchburyi (Gray). Gastropoda : Zeacumantus lutulentus (Kiener). Cominella glandiformis (Reeve).
Sample 2 (Bore H. 26)	N152/900116 +0.573 to +0.085 m. above m.s.l.	Bivalvia : Macomona liliana (Iredale). Cyclomactra sp. Chione (Austrovenus) stutchburyi (Gray). Gastropoda : Potamopyrgus antipodarum (Gray). Amphibola crenata (Gmelin).
Sample 3 (Bore H. 26)	N152/900116 +0.085 m. above m.s.l. to -0.097 m. below m.s.l.	Bivalvia : Chione (Austrovenus) stutchburyi (Gray). Gastropoda : Potamopyrgus antipodarum (Gray). Neoguraleus sp. Amphibola crenata (Gmelin).
Sample 4 (Bore H. 10)	N152/888116 -0.274 to -0.366 m. below m.s.l.	Bivalvia : Xenostrobus securis (Lamarck). Chione (Austrovenus) stutchburyi (Gray). Gastropoda : Potamopyrgus antipodarum (Gray). Xymene plebeius (Hutton). Neoguraleus sp. Chemnitzia sp. ?Amphibola crenata (Gmelin).
Sample 5 (Bore H. 14)	N152/895104 -1.589 to -1.894	Bivalvia : probably Cyclomactra. Arthritica bifurca (Webster). Gastropoda : Potamopyrgus antipodarum (Gray). Amphibola crenata (Gmelin).

Sample	Location	Species Present
Sample 6 (Bore H. 19)	N152/897098 +0.240 to +0.118 m. above m.s.l.	Bivalvia : Cyclomoctra ovata (Gray). Gastropoda : Potamopyrgus antipodarum (Gray). Amphibola crenata (Gmelin).
Sample 7 (Bore H. 19)	N152/897098 -0.918 to -1.040 m. below m.s.l.	Bivalvia : Arthritica bifurca (Webster). Cyclomactra ovata (Gray). Gastropoda : Potamopyrgus antipodarum. Amphibola crenata (Gmelin).
Sample 8 (Bore H. 21)	N152/895097 -3.098 to -3.190 m. below m.s.l.	Bivalvia : Cyclomactra ovata (Gray). Gastropoda : Amphibola crenata (Gmelin).

* All locations refer to grid references on N.Z. Topographical Map 1:25,000 - Levin Sheet N152.

BIBLIOGRAPHY

Adkin, G.L. 1910: The post-Tertiary geological history of the Ohau River and of the adjacent coastal plain, Horowhenua County, North Island, N.Z. Transactions of the N.Z. Institute, 43, 496-520.

________. 1919: Further notes on the Horowhenua coastal plain and associated physiographic features. Transactions of the N.Z. Institute, 51, 108-118.

________. 1948: On the Occurrence of Natural Artesian Springs in the Horowhenua County. N.Z. Jl. Science and Technology, 29 (5 Section B), 266-272.

________. 1951: Geology of the Paekakariki Area of the Coastal lowland of Western Wellington. Trans. of the Royal Society of N.Z., 79 (2), 157-176.

Amon, J.W. 1974: Late Quaternary shorelines near Lake Ellesmere, Canterbury, N.Z. N.Z. Jl. Geology and Geophysics, 17, 63-73.

Bloom, A.L. 1964: Peat accumulation and compaction in a Connecticut Coastal Marsh. Jl. of Sedimentary Petrology, 34 (3), 599-603.

Bloom, A.L.; Broecker, W.S.; Chappell, J.M.A.; Matthews, R.K.; Mesolella, K.J. 1974: Quaternary Sea Level Fluctuations on a Tectonic Coast : New $^{230}Th/^{234}U$ Dates from the Huon Peninsula, New Guinea. Quaternary Research, 4, 185-205.

Brannon jun., H.R.; Simons, L.H.; Perry, D.; Daughtrey, A.C.; McFarlane jun., E. 1957: Humble Oil Company Radiocarbon Dates II. Science, 125, 919-923.

British Standards 1377, 1967: Methods of Testing Soils for Civil Engineering Purposes. British Standards Institute, London.

Brothers, R.N. 1954: The Relative Pleistocene Chronology of the South Kaipara District,N.Z. Trans. of the Royal Society N.Z., 82 (3), 677-694.

Chappell, J. 1974a: Late Quaternary Glacio- and Hydro-isostasy, on a layered Earth. Quaternary Research, 4, 429-440.

__________. 1974b: Geology of coral terraces, Huon Peninsula, New Guinea : a study of Quaternary tectonic movements and sea level changes. Geological Society of America Bulletin, 85, 553-570.

__________. 1975: Upper Quaternary Warping and uplift rates in the Bay of Plenty and west coast, North Island, N.Z. N.Z. Jl. Geology and Geophysics, 18 (1), 129-155.

Chalesworth, J.K. 1957: The Quaternary Era. Edward Arnold Ltd, London.

Cope, R.N.; Reed, J.J. 1967: The Cretaceous Paleogeology of the Taranaki - Cook Strait Area. Proceedings of the Australian Institute of Mining and Metallurgy, 222, 63-67.

Cotton, C.A. 1918: The geomorphology of the coastal district of South Western Wellington. Transactions of the N.Z. Institute, 50, 212-222.

__________. 1958: Geomorphology. (Revised 7th ed.) Whitcombe and Tombs Ltd., N.Z.

Coulter, J.D. 1966: Climate of the Horowhenua Lowlands. Wellington Botanical Society Bulletin, 33.

Cowie, J.D. 1961: Aokautere Ash in the Manawatu District, N.Z., and its significance to soils and soil formation in the sand country of the Manawatu-Horowhenua District, N.Z. Unpublished M.Sc. thesis, Victoria University of Wellington.

_________. 1963: Dune-Building Phases in the Manawatu District, N.Z. N.Z. Jl. Geology and Geophysics, 6 (2), 268-280.

_________. 1964a: Loess in the Manawatu District, N.Z. N.Z. Jl. Geology and Geophysics, 7, 389-396.

_________. 1964b: Aokautere Ash in the Manawatu District, N.Z. N.Z. Jl. Geology and Geophysics, 7, 67-77.

Cowie, J.D.; Wellman, H.W. 1962: Age of Ohakea Terrace, Rangitikei River. N.Z. Jl. Geology and Geophysics, 5, 617-619.

Cullen, D.J. 1967: Submarine evidence from N.Z. of a rapid rise in sea level about 11,000 years B.P. Paleogeography, Paleoecology, Paleoclimatology, 3, 289-98.

Curray, J.R. 1961: Late Quaternary sea level : a discussion. Geological Society of America Bull., 72, 1707-1712.

_________. 1965: Late Quaternary history, Continental shelves of the U.S., 723-735. IN Wright, H.E. Jr.; Frey, D.G. (Editors): The Quaternary of the United States. Princeton University Press, Princeton, N.J.

Edwards, R. 1921: Notes on Manawatu swamps and district, 106-110. IN Borough of Palm. Nth. Municiple Year Book.

Eiby, G.A. 1971: Seismic Regions of New Zealand, 153-160. IN Collins, B.W.; Fraser, R. (Editors) : Recent Crustal Movements. Royal Society of N.Z. Bulletin, 9.

Emery, K.O.; Garrison, L.E. 1967: Sea levels 7,000 to 20,000 years ago. Science, 157, 684-687.

Esler, A.E. 1964: The vegetation of early Manawatu, IN Saunders, B.G.R.; Anderson, A.G. (Editors) : Introducing Manawatu. Geography Department publication, Massey University.

Fair, E.E. 1968: Structural, Tectonic and Climatic Control of the Fluvial Geomorphology of the Manawatu River West of the Manawatu Gorge. Unpub. M.Sc. Thesis, Massey University.

Fairbridge, R.W. 1961: Eustatic changes in sea level. Physics and Chemistry of the Earth, 4, 99-185.

Feldmayer, A.E.; Jones, B.C.; Firth, C.W.; Knight, J. Superior Oil Company 1943: Geology of the Palmerston - Wanganui Basin, 'West Side', North Island, N.Z. Typescript and Maps filed with N.Z. Geological Survey, Wellington.

Fisk, H.M.; McFarlan, E. 1955: Late Quaternary deltaic deposits of the Mississippi River, 279-302. IN Crust of the Earth, Geological Society of America, Special Paper 62.

Fleming, C.A. 1953: The Geology of Wanganui Subdivision, N.Z. N.Z. Geological Survey Bulletin, n.s. 52.

___________. 1962: N.Z. Biogeography - A Paleontologists Approach. Tuatara, 10 (2), 53-108.

___________. 1965: Radiocarbon dating from a Post-glacial beach in Western Wellington. N.Z. Jl. Geology and Geophysics, 8 (6) 1222-1223.

___________. 1970: Radiocarbon dating and pollen analyses from

Otiran periglacial fans in western Wellington. Transactions of the Royal Society N.Z. (Earth Science), 7 (11), 197-208.

____________. 1971: 14C. Dates in the Quaternary Geology of the 'Golden Coast', Wellington. IN Radio-carbon Users Conference, Wellington, 139-148. D.S.I.R. Publication.

Garrison, L.E.; McMaster, R.L. 1966: Sediments and geomorphology of the Continental shelf off Southern New England. Marine Geology, 4, 273-289.

Gibbard, R.G. 1972: Beach morphology and Sediments of the West Wellington Coast. M.Sc. thesis, Massey University.

Gibbs, H.S.; Harris, C.S.; Cowie, J.D. 1957: Provisional Soil Map of Horowhenua County. Sheet 1. Soil Bureau. D.S.I.R.

Godwin, H.; Suggate, R.P.; Willis, E.H. 1958: Radiocarbon dating of the Eustatic Rise in Ocean Level. Nature, 181, 1518-1519.

Guilcher, A. 1969: Pleistocene and Holocene Sea Level Changes. Earth Science Revue, 5, 69-97.

Hails, J.R. 1965: A critical review of sea level changes in eastern Australia since the last glacial. Australian Geographical Studies, 3 (2), 65-78.

Harris, W.F. 1968: Peat classification by Pedological Methods applied to peats of western Wellington, N.Z. N.Z. D.S.I.R. Bulletin, 189.

Hatherton, T. 1971: The Association of Gravity with Seismicity and Tectonism in N.Z. IN Collins, B.W.; Fraser, R. (Editors): Recent Crustal Movements. Royal Society N.Z. Bulletin, 9.

Heerdegen, R.G. 1972: Landforms of the Manawatu. Miscellaneous papers no. 2, Dept. of Geography, Massey University.

Hopkins, D.M. 1973: Sea level history in Beringia during the Past 250,000 years. Quaternary Research, 3 (4), 520-540.

___________. 1975. Time-Stratigraphic Nomenclature for the Holocene Epoch. Geology, 3 (1), 10, (Geological Society of America).

Hoyt, J.H.; Weimer, R.J.; Henry, V.J. Jr. 1964: Late Pleistocene and Recent Sedimentation, Central Georgia Coast, U.S.A. IN Developments in Sedimentology 1, (Deltaic and Shallow Marine Deposits).

I.N.Q.U.A. Guidebook; 1973: Guidebook for Excursion Al, Western North Island. IX INQUA Congress, Christchurch NZ.

Jelgersma, S. 1961: Holocene sea level changes in the Netherlands. Mededelingen van de Geologische stichting, Series C VI.

___________. 1966: Sea level changes during the last 10,000 years. IN Royal Met. Soc: World Climate from 8000 to 0 B.C. Proc. International Symposium, April.

Jongsma, D. 1970: Eustatic sea level changes in the Arafura Sea. Nature (London), 228, 150-151.

Katz, H.R. 1968: Potential oil formations in N.Z. and their stratigraphic position as related to basin evolution. N.Z. Jl. Geology and Geophysics, 11 (5), 1077-1133.

King, C.A.M. 1972: Beaches and Coasts. Edward Arnold. London.

Kingma, J.T. 1959: The Tectonic setting of the Ruahine-Rimutaka Range. N.Z. Jl. Science and Technology, B 38, 858-861.

__________. 1962: Sheet 11, Dannevirke (1st Edition). Geological Map of N.Z. 1:25,000. D.S.I.R., Wellington.

__________. 1967: Sheet 12, Wellington (1st Edition), Geological Map of N.Z. 1:25,000. D.S.I.R., Wellington.

Langford-Smith, T.; Thom, B.G. 1969: New South Wales Coastal Morphology. IN The Geology of N.S.W., Chapter II. Geological Society of Australia, 16, 572-80.

Le Blanc, R.J.; Hodgson, W.D. 1959: Origin and development of the Texas shoreline, 57-101. Second Coastal Geography Conference, Baton Rouge, Louisiana.

Lensen, G.J. 1959: Sheet 10 Wanganui (1st Edition). Geological Map of N.Z. 1:25,000. D.S.I.R., Wellington.

Lensen, G.J.; Suggate, R.P. 1973: Quaternary deformation in N.Z. Abstracts IX INQUA Conference, Christchurch, N.Z. 206-207.

McDougall, J.C.; Brodie, J.W. 1967: Sediments of the Western Shelf, North Island, N.Z. N.Z.D.S.I.R. Research Bulletin, 179.

McFarlan, E. 1961: Radiocarbon dating of Late Quaternary deposits. Geological Society of America Bulletin, 72, 129-158.

McKnight, D.C. 1968: Recent and relict molluscan faunas off Cape Farewell. N.Z. Jl. Marine and Freshwater Research, 2 (4), 708-711.

Milliman, J.D., Emery, K.O. 1968: Sea levels during the past 35,000 years. Science, 162, 1121-1122.

Milne, J.D.G. 1973a: Maps and Sections of river terraces in the Rangitikei Basin, North Island, N.Z. N.Z. Soil Survey Report 4. N.Z. Soil Bureau.

__________. 1973b: Should read: Cowie, J.D.; Milne, J.D.G. 1973: Explanatory notes to accompany N.Z. Soil Survey Report 6.

N.Z.D.S.I.R.

Morgan, J.P. 1967: Ephemeral estuaries of the Deltaic environment. IN Lauff, G.H. (Editor) : Estuaries. Conference on Estuaries 1964. American Assoc. for the Advancement of Science, Publication no. 83. Washington D.C.

Morner, N.A. 1971: Eustatic changes during the last 20,000 years and a method of separating the isostatic and eustatic factors in an uplifted area. Paleogeography, Paleoclimatology, Paleoecology, 9, 153-181.

Morton, J.E.; Miller, M. 1968: The New Zealand Sea Shore. Collier, London.

New Zealand Nautical Almanac 1975: Nautical Almanac and Tide Tables. Marine Divison, Ministry of Transport, Wellington.

New Zealand Topographical Map 1968: NZMS 1, Sheet N 148, Tangimoana (3rd Edition).

____________________ 1968: NZMS 1, Sheet N 149, Palmerston North (4th Edition).

____________________ 1973: NZMS 1, Sheet N 152, Levin (4th Edition).

Norris, R.M. 1972: Shell and gravel layers, western Continental Shelf, N.Z. N.Z. Jl. Geology and Geophysics, 15 (4) 572-589.

Oliver, R.L. 1948: The Otaki Sandstone and its Geological History. N.Z. Geological Memoir, 7. D.S.I.R.

Pavoni, N. 1971: Recent and Late Cenozoic movements of the Earths Crust. IN Collins, B.W.; Fraser, R. (Editors); Recent Crustal Movements. Royal Society of N.Z. Bulletin, 9, 7-17.

Pettijohn, F.J.; Potter, P.E.; Siever, R. 1972: Sand and Sandstone. Springer - Verlag, New York.

Postma, H. 1967: Sediment transport and Sedimentation in the Estuarine environment. IN Lauff, G.H. (Editor) : Estuaries. Conference on Estuaries 1964. American Assoc. for the Advancement of Science, Publication no. 83. Washington D.C.

Powers, M.C. 1953: A new roundness scale for Sedimentary Particles. Jl. of Sedimentary Petrology, 23 (2), 117-119.

Pritchard, D.W. 1974: Circulation and mixing in coastal regions and estuaries, 389-401. IN Vetter, R.C. (Editor) : Oceanography - The last frontier. Voice of America, Forum Series.

Reineck, H.E. 1967: Layered Sediments of Tidal Flats, Beaches and Shelf Bottoms of the North Sea. IN Lauff, G.H. (Editor) : Estuaries. Conference on Estuaries 1964. American Assoc. for the Advancement of Science, Publication no. 83. Washington D.C.

Rich, C.C. 1959: Late Cenozoic Geology of the Manawatu Valley, N.Z. Ph.D. Thesis. Microfilm held at Massey University.

Robertson, N.G. 1959: The Climate of New Zealand. IN A Descriptive Atlas of N.Z. Government Printer, Wellington.

Rusnak, G.A. 1967: Rates of Sediment Accumulation in Modern Estuaries. IN Lauff, G.H. (Editor) : Estuaries. Conference on Estuaries 1964. American Association for the Advancement of Science, Publication no. 83. Washington D.C.

Russell, R.J. 1964: Techniques of Eustasy Studies. Z. Geomorphol. Hans Mortensen festch, 8 (Sonderhft), 25-42.

____________. 1967: Origins of Estuaries. IN Lauff, G.H. (Editor) : Estuaries. Conference on Estuaries 1964. American Assoc. for the Advancement of Science, Publication no. 83, Washington D.C.

Saunders, B.G.R. 1964: Climate. IN Saunders, B.G.R.; Anderson, A.G.; (Editors): Introducing Manawatu. Geography Dept. Publication, Massey University.

Schofield, J.C. 1960: Sea level Fluctuations during the last 4,000 years as recorded by a Chenier Plain, Firth of Thames, N.Z. N.Z. Jl. Geology and Geophysics, 3, 467-485.

_______________. 1964: Postglacial Sea Levels and Isostatic Uplift. N.Z. Jl. Geology and Geophysics, 7, 359-370.

Shepard, F.P. 1963: Thirty-five thousand years of Sea level, 1-10. IN Essays in Marine Geology in honour of K.O. Emery. University of S. California Press.

____________. 1964: Sea level changes in the past 6000 years : Possible archeological significance. Science, 143, 574-576.

Shepherd, M.J. 1974: Progradation of a Holocene Sand Barrier in N.S.W. Search, 5 (5), 210-11.

Stevens, G.R. 1956a: Stratigraphy of the Hutt Valley, N.Z. N.Z. Jl. Science and Technology, B. 38, 201-235.

________. 1956b: Recent Earth movements in the Wellington Area. N.Z. Geographer, 12 (2), 189-194.

________. 1957: Geomorphology of the Hutt Valley, N.Z. N.Z. Jl. Science and Technology, B. 38, 297-327.

Suggate, R.P. 1958: Late Quaternary deposits of the Christchurch metropolitan area. N.Z. Jl. Geology and Geophysics, 1, 103-122.

________. 1965: Late Pleistocene Geology of the Northern part of the South Island N.Z. N.Z. Geological Survey Bulletin, n.s. 77. N.Z.D.S.I.R.

________. 1968: Post-glacial Sea-Level Rise in the Christchurch Metropolitan area, N.Z. Geologie en Mijnbouw, 47, (4), 291-297.

________. 1970: Revision of the Chronology of the Late Otira Glacial. N.Z. Jl. Geology and Geophysics, 13, 742-746.

________. 1973: The Development of N.Z. in the Quaternary IN The N.Z. Quaternary - an introduction. IX INQUA Conference, Christchurch, N.Z.

________; West, R.G. 1967: The substitution of local stage names for Holocene and Post-glacial. Quaternaria, 9, 245-246.

Te Punga, M.T. 1953a: A Late Pleistocene Land Bridge across Cook Strait, N.Z. N.Z. Jl. Science and Technology, B. 35 161-92.

________. 1953b: Radiocarbon dating of a Rangitikei River Terrace. N.Z. Jl. Science and Technology, B. 35, 45-48.

__________. 1953c: Should read 1952: The Geology of Rangitikei Valley. N.Z. Geological Survey Memoir 8.

__________. 1954a: Fossiliferous Late-Pleistocene beds in a Well At Awahuri, near Palmerston North. N.Z. Jl. Science and Technology, B. 36, 82-92.

__________. 1954b: Late Pleistocene Buckshot gravels from western Wellington. N.Z. Jl. Science and Technology, B. 36, 1-13.

__________. 1957: Live Anticlines in Western Wellington. N.Z. Jl. Science and Technology, B. 38, 433-46.

__________. 1958: Evidence for a Low Sea-Level 9900 years ago. N.Z. Jl. Geology and Geophysics, 1 (1), 92-94.

__________. 1962: Some Geological features of the Otaki-Waikanae District. N.Z. Jl. Geology and Geophysics, 5 (4), 517-30.

Turner, R.E. 1944: Geology of Northern Wellington and South Hawke Bay. Unpublished Report in Victoria University Library, Wellington.

Twenhofel, W.H. 1961: Treatise on Sedimentation. Dover Publications, New York.

van der Linden, W.J.M.; Norris, R.M. 1974: Structure and Quaternary History of Karamea Bight, South Island, N.Z. N.Z. Jl. Geology and Geophysics, 17 (2), 375-388.

Veeh, H.H.; Veevers, J.J. 1970: Sea level at -175 meters off the Great Barrier Reef 13,600 to 17,000 years ago. Nature, 226, 536-537.

Vita-finzi, C. (Editor) 1973: Recent Earth History. Macmillan, London.

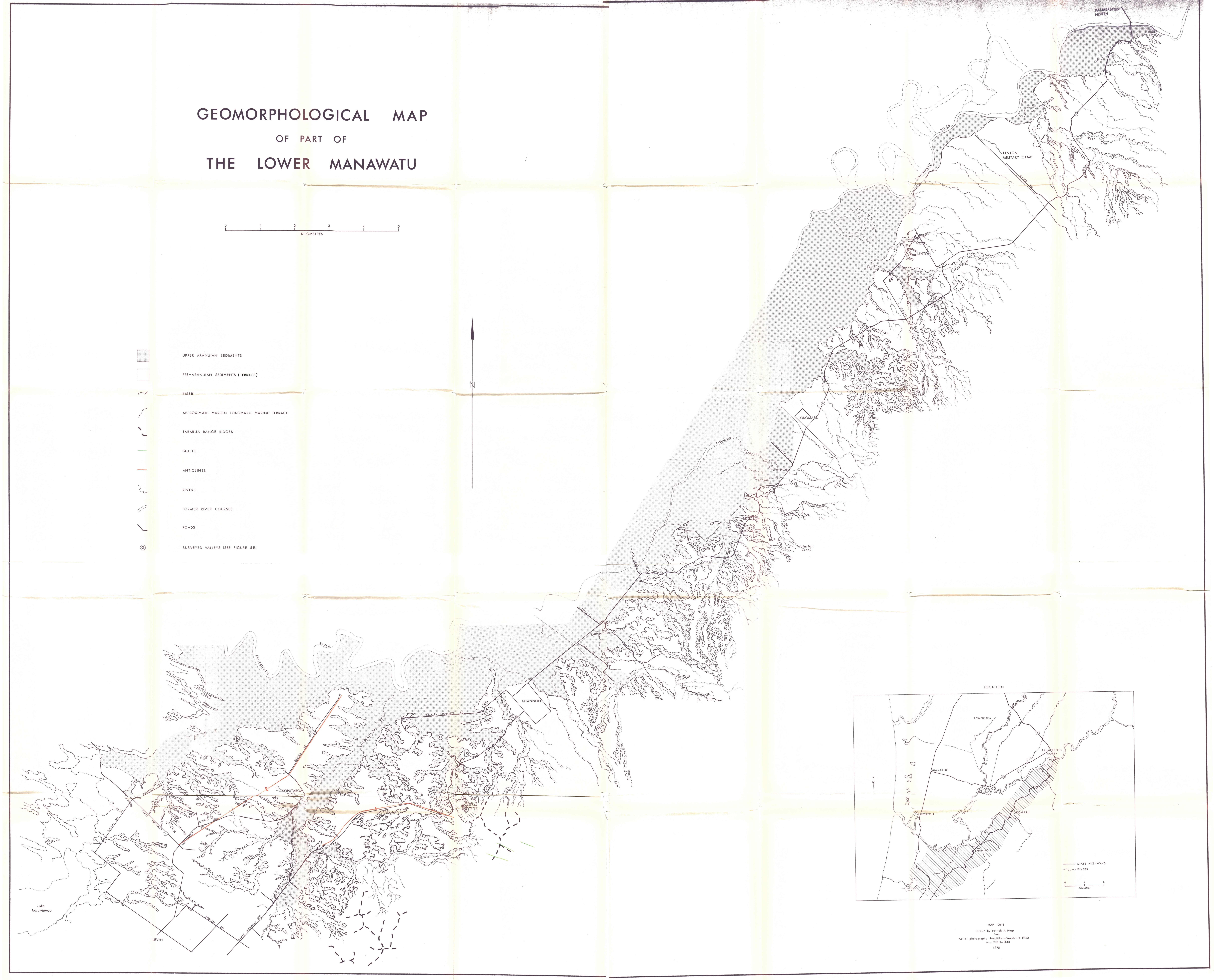
Vucetich, C.G.; Pullar, W.A. 1969: Stratigraphy and Chronology of Late Pleistocene volcanic ash beds in Central North Island, N.Z. N.Z. Jl. Geology and Geophysics, 12, 784-837.

Walcott, R.I. 1972: Past Sea levels, Eustasy and Deformation of the Earth. Quaternary Research 2, 1-14.

Webby, B.D. 1964: Quaternary deposits in the Porirua Area, N.Z. N.Z. Jl. Geology and Geophysics, 7, 371-388.

Wellman, H.W. 1962: Holocene of the North Island of New Zealand: a Coastal Reconnaissance. Transactions of the Royal Society of N.Z., Geology, 1 (5), 29-99.

Zenkovich, V.P. 1967: Processes of Coastal Development. Oliver and Boyd, London.


GEOMORPHOLOGICAL MAP
OF PART OF
THE LOWER MANAWATU
KILOMETRES
N
UPPER ARANUIAN SEDIMENTS
PRE-ARANUIAN SEDIMENTS (TERRACE)
RISER
APPROXIMATE MARGIN TOKOMARU MARINE TERRACE
TARARUA RANGE RIDGES
FAULTS
ANTICLINES
RIVERS
FORMER RIVER COURSES
ROADS
SURVEYED VALLEYS (SEE FIGURE 5E)
PALMERSTON NORTH
MANAWATU RIVER
LINTON MILITARY CAMP
LINTON
TOKOMARU
Waterfall Creek
SHANNON
KOPUTAROA
LEVIN
Lake Horowhenua
LOCATION
PALMERSTON NORTH
TOKOMARU
SHANNON
LEVIN
FOXTON
STATE HIGHWAYS
RIVERS
Kilometres
MAP ONE
Drawn by Patrick A Hesp
from
Aerial photographs, Rangitikei–Woodville 1942
runs 218 to 228
1975