STRUCTURAL, TECTONIC AND CLIMATIC CONTROL
OF THE FLUVIAL GEOMORPHOLOGY OF THE MANAWATU RIVER
WEST OF THE MANAWATU GORGE

A Thesis Presented in Partial Fulfilment of the
Requirements for the Degree
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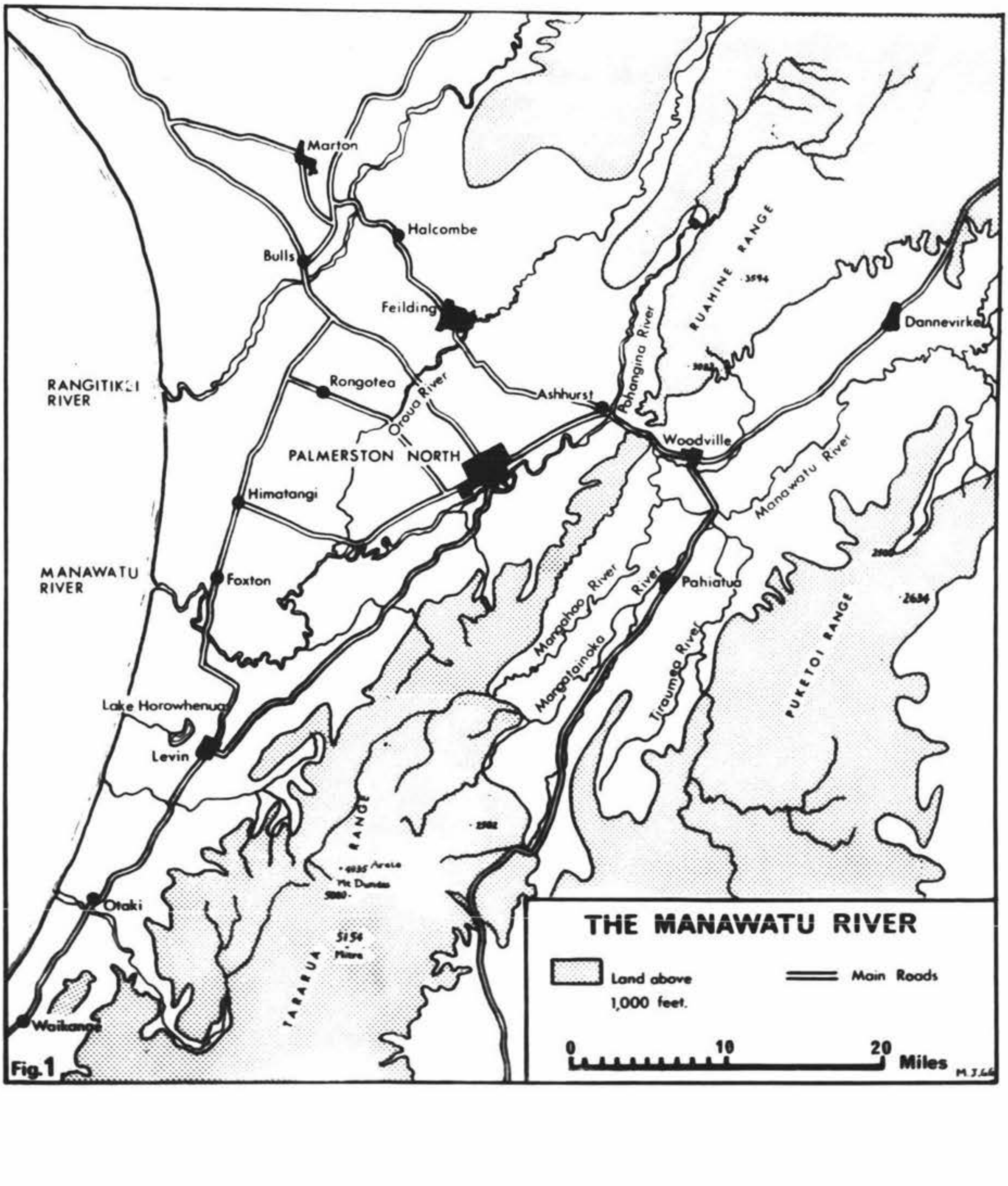
I. INTRODUCTION

LOCATION

The Manawatu River is one of the major rivers of the North Island of New Zealand, draining a catchment of 2,296 square miles. The river is over 120 miles long and is one of the few rivers in the world to rise on one side on an axial mountain range, flow through the range and enter the sea on the opposite side. (See Fig.1.) The Manawatu River, rising on the eastern flanks of the Ruahine Range flows south to the 'Dannevirke Depression' (Lillie, 1953, 89) where it joins the northeastwards-flowing Mangahao, Mangatainoka and Tiraumea Rivers. These rivers with catchments on the eastern side of the Tararua-Ruahine Range, drain an elongated basin which extends from north of Dannevirke to south of Eketahuna. They join the Manawatu River in the Dannevirke Depression then flow westwards across the Tararua-Ruahine Range in the Manawatu Gorge to the Kairanga alluvial plain. Although only one-third of the river's catchment lies to the west of the axial range, the river here has an attenuated course of 63 miles, a little more than half its total length.

Between February and April 1967 the writer completed a preliminary study of the terraces along the Manawatu River, between the Manawatu Gorge and the river mouth at Foxton. Investigations revealed that the best terrace development existed on the ten miles between the Gorge and Palmerston North whereas, in the lower reaches, terrace development is limited by prevalence of flooding, the swampy nature of the


Marton
Halcombe
Bulls
Feilding
Rongotea
Oroua River
Ashhurst
Pohangina River
RUAHINE RANGE
3594
Dannevirke
RANGITIKEI RIVER
PALMERSTON NORTH
Woodville
Himatangi
Manawatu River
MANAWATU RIVER
Foxton
Pahiatua
Mangahao River
Mangatainoka River
Tiraumea River
PUKETOI RANGE
2634
Lake Horowhenua
Levin
RANGE
TARARUA
5154 Mitre
Otaki
Waikanae
THE MANAWATU RIVER
Land above 1,000 feet.
Main Roads
0
10
20
Miles
Fig.1

terrain and the progradation of the coastline. The unstable sand dunes of the coastal belt have also masked most of the terrace series in the lower reaches of the river.

The specific research area chosen lies between the Ashhurst Road Bridge, N.149/240412, and the Fitzherbert Bridge, N.149/115329 (Palmerston North City Bridge). This area has total map coverage by the N.Z.M.S.1, New Zealand Topographical Map 1:63360, Palmerston North Sheet N.149, and all grid references included in the text refer to this map. Aerial photographs taken in 1957 and 1964 were supplementary to the map and were an invaluable aid to field work, even though the latter series do not cover the area east of the river between Aokautere (N.149/151335) and the Manawatu Gorge.

PREVIOUS RESEARCH

The most extensive research previously pursued in the Manawatu area was initiated by Rich in 1959 and was mainly concerned with the faulting on the Tararua Range. Rich also carried out a survey of the terraces of the Manawatu River and named the terrace series occurring on both sides of the river without attempting correlation across the river. Cowie (1961, 1964a and b) has conducted research on the loess deposits on the river terraces and older formations and the distribution of the Aokautere ash band[1] within these loess deposits.

The origin of the Manawatu Gorge has been the topic of many papers and the best known of these hypotheses includes works by Cotton (1922), Adkin (1930), Ongley (1935) and Lillie (1953). The Superior Oil Company (Ower, 1943) in their search for oil carried out detailed geological mapping in this area. Te Punga (1954a, 1957) has also carried out extensive research in the Manawatu area and Oliver's (1948) study of the Otaki Sandstone deals with Hawera deposits which lie just to the south of the study area.

METHODS OF RESEARCH

Base maps covering the Manawatu River from the Manawatu Gorge to the sea were drawn at a scale of four inches to the mile. These base maps were drawn from the New Zealand Topographical Maps 1:63360, sheets N.149, 148, 152 and 153. The finer detail (e.g. the scarp edges of the terraces) was obtained by using aerial photographs, mosaics and stereoscopic pairs. The scarp edges of the terraces and their positions were then carefully checked in field studies.

Spot heights were recorded in the main research area between the Ashhurst and Fitzherbert Bridges with a System Paulin aneroid barometer which was calibrated in five feet intervals. In a series of tests with this barometer it was discovered that the instrument could be read to an accuracy of ± 10 feet. This degree of accuracy was maintained in the field with synchronised atmospheric pressure readings at Milson Airport (every two hours) and Massey University (every half hour). At the beginning of each day's field work the aneroid barometer was calibrated to a known spot height on the Massey University campus. In the field a time check was taken with each reading. This enabled corrections to be made for any barometric fluctuations that occurred.

The accuracy of the aneroid is also influenced by temperature and this parameter was recorded with each altitudinal reading and corrections were applied for all temperature fluctuations. The normal field procedure was to take two complete sets of readings, one along the transect and the other set at the same points on the return. These cross-checks were utilised in correcting for fluctuations in temperature, atmospheric pressure, instrument sensitivity and human error. Appendix A shows the collection of the data from a typical day's field work.

Field work with the aneroid barometer was limited to periods when slow moving high pressure systems prevailed, so that in fact most of the measurements were not complicated by pressure fluctuations. The most satisfactory measurements were obtained when there was only a small temperature range over the observation period. Consequently, most of the field work was undertaken in short periods of three or four hours, particularly in the low sun seasons when temperature fluctuations between 1030 hours and 1530 hours are quite negligible.

Wind also causes significant inaccuracies with aneroid measurements (Sparks, 1953) and readings were only attempted on calm days. The dependence on favourable meteorological parameters restricted most of the field operations to the stable, calm autumns of 1967 and 1968.

AIMS OF RESEARCH

The main aim of the research programme was to examine the terrace series in the Manawatu River valley and to correlate them across the river valley. It was originally considered that in such a structurally unstable area tectonic control could have been the most important controlling factor in the evolution of the geomorphology of the Manawatu River. The course of the Manawatu River lies between an upfaulted mountain range and a series of tectonically active anticlines[2] (Te Punga, 1957), which appear on cursory evidence to exert greater influence on the river than climatic control. It was therefore decided to determine the validity in the Manawatu River valley of King's hypothesis that "rivers may be studied to throw light on past climatic oscillations and variations in the other factors that control their character" (1966, 61). Research was therefore undertaken to study the denudational chronology of the Manawatu River valley with particular emphasis on the influence of structural and climatic control upon its fluvial geomorphology.

REFERENCES

1. The Aokautere ash band is interbedded in the loess on most of the older surfaces in the Manawatu area and is a useful marker band for terrace correlation and dating. It is discussed in more detail on p.71.

2. Anticlines in the Wanganui Basin are blocks of upfaulted basement greywacke (Te Punga, 1957). The uplift of these blocks also involves the folding of the Plio-Pleistocene marine sedimentary cover. They are discussed in greater detail in the following section on p.26.

II. ELEMENTS OF GEOLOGY AND STRUCTURE

MAIN STRUCTURAL ELEMENTS

The Manawatu River valley lies on the eastern edge of the Wanganui Basin,[1] a large sedimentary syncline. This basin is flanked on its eastern side by the Tararua-Ruahine axial range. The Manawatu River has corraded into the marine sediments of the Wanganui Basin and its valley is now entrenched within flights of its own terraces. The geology of the Manawatu region, although seemingly consisting of two main rock formations, is in fact complex due to the tectonic and structural instability of the area.

In the Manawatu there are two basic types of rock formation, Mesozoic greywacke and Plio-Pleistocene sedimentary rocks. Greywacke, the oldest rock type, forms the Tararua-Ruahine Range and the basement of the extensive Wanganui Basin. This basement greywacke consists of well indurated and deformed rocks of the early Mesozoic and perhaps late Palaeozoic age which are separated by a major unconformity from the younger marine sediments of the basin. The large synclinal Wanganui Basin has been filled with Plio-Pleistocene marine sediments and Recent alluvium, which now form the coastal lowland and terrace country.

The undermass of the Tararua-Ruahine Range consists of an unknown thickness of unfossiliferous greywacke, argillite and spilite, complexly folded and faulted. These rocks, usually referred to as undifferentiated greywackes or Alpine facies (Wellman, 1952), will here be termed the

Rimutaka sequence after Rich (1959, 22) who mapped them in this area. The age of this complex sequence is uncertain and may range from Permian to Jurassic. It is thought, however, to be mainly of Triassic age as indicated by the recent discovery of the Upper Triassic shell Monotis Richmondiana, from the headwaters of the Otaki River. (Shaw and Stevens, 1966, 789.)

THE NEW ZEALAND GEOSYNCLINE

The greywacke of the Rimutaka sequence was laid down in the New Zealand Geosyncline in which an enormous thickness of sedimentary and volcanic rocks accumulated. "The oldest fossils so far discovered in the rocks of the New Zealand Geosyncline are Permian, although it is likely that it was in existence in the Carboniferous. Stratigraphically there occurs beneath the proven Permian strata tens of thousands of feet of basic volcanic lavas, agglomerates, breccias and tuffs." (Shaw and Stevens, 177.) The Mesozoic rocks consist of greywackes and argillites (indurated sandstones and siltstones) and occasional intrusive beds of red and green volcanic rocks. It is thought that the land from which these thick deposits of sediments were derived lay to the west and south of the present landmass, mainly because the west marginal facies are better stratified than those on the east. (Shaw and Stevens, 778.)

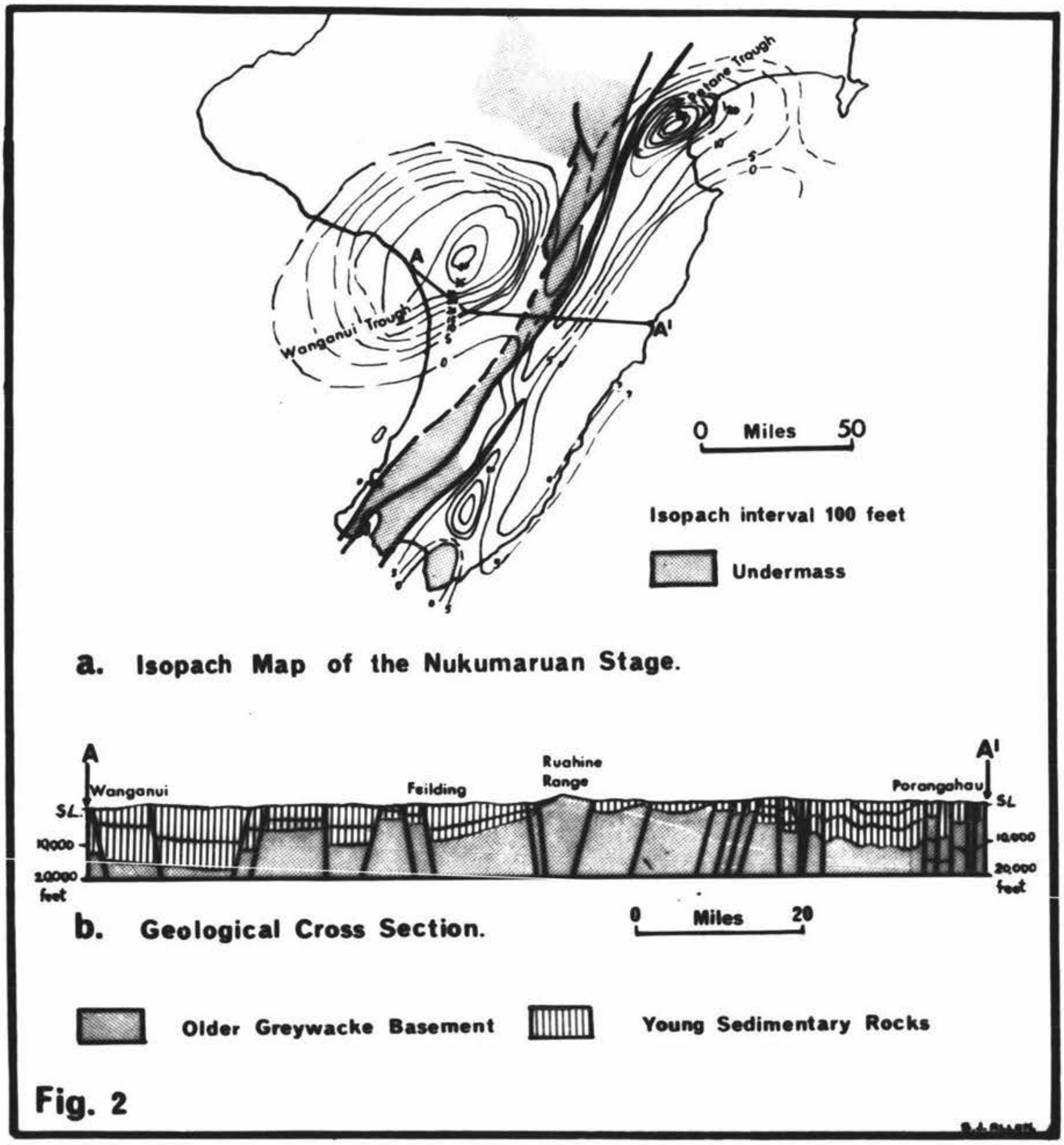
The North Island Geosyncline began to rise as a geanticline in the Cretaceous emerging in the lower Eocene and continuing to rise until the Miocene. The geanticlinal crest was eroded continuously during its uplift and it is possible that no extensive mountain ranges were formed. (Kingma, 1957a, 497.) It was then submerged during the Pliocene when marine sediments were deposited on its pene-plained crest, and re-emerged rapidly in the lower Pleistocene to form the axial range of the southern portion of the North Island.

This rise of the North Island geanticline was presumably accompanied by anticlinorial folding of its strata. The strata deposited across the geanticlinal crest during the Pliocene transgression, according to Kingma (1957a, 498), "do not show warping that would be attributed to tightening of the anticlinorial folds; thus prior to the main phase of the orogeny the folds were already 'frozen' and geanticlinal folding was so far advanced that no further compression of the strata took place. Thus the maximum stage of anticlinorial folding was reached in the pre-Pliocene time." In the Pleistocene further orogenic movement took place, rapidly uplifting the greywacke mass and its Pliocene cover. This final and rapid rise of the axial range was a horst-like uplift.

THE TARARUA-RUAHINE HORST AND SYNCLINAL BASINS

The Tararua-Ruahine Range is tectonically a horst (Kingma, 1957a and b, 1959) in which the Mesozoic greywacke (Rimutaka Sequence) comes to the surface. This horst is only a small segment of the basement greywacke of the geanticline which in the North Island had a crest over a hundred miles wide. The position of the horst on the eastern flank of the geanticline is, from a tectonic point of view, rather unusual. Kingma (1959, 11) assumes that the narrow horst "was forced up as an enormous piercement body. The faults bordering the horst on the west are all of the reverse type and dip 70° to 80° east, while those on the eastern side are mainly vertical. If these fault planes extend to any depth maintaining the same dip ... then the horst has the shape of a large assymetrical wedge, with an apex probably terminating in a crushzone approximately five to ten miles deep." The existence of the horst as a piercement body is substantiated by a bouguer gravity survey (Robertson and Reilly, 1958, 562) which shows the 'Rangitikei-Waiopu gravity anomaly' intersecting the axial ranges of the North Island, thus indicating a crustal downwarp which is not in isostatic equilibrium. This evidence strengthens the assumption that the base of the horst has no real roots but culminates in a single crushzone.

Deep, marine sedimentary basins were formed in the faulted downthrown greywacke basement on the eastern and western sides of the Tararua-Ruahine Range. During the Plio-Pleistocene eras, large quantities of sediment accumulated in these geosynclinal basins. The Petane Trough (Kingma, 1959, 16) developed on the east of the Ruahine Range and, although the geosynclinal axis of the trough extends from Napier south into Wairarapa, the greatest accumulation of sediment occurred just to the northwest of Napier. (See Fig.2a.) On the west



a. Isopach Map of the Nukumaruan Stage.

b. Geological Cross Section.

Fig. 2

of the axial range the shallower, larger Wanganui Basin developed with a geosynclinal axis centred at Marton. (Fleming, 1953, 298.)

These sedimentary basins, flanking the axial range, have greywacke basements and throughout Tertiary time were accumulation centres for the erosional products of the ranges. The filling of the Petane Trough began in the Cretaceous and was completed by the Miocene; its contents have since been folded and faulted. The filling of the Wanganui Basin commenced in the late Miocene and is still continuing with the aggradation products from many large rivers; the Manawatu, Rangitikei and Wanganui draining the ranges are actively extending the coastline seawards with their loads of silt, sand and shingle.

The Wanganui Basin, due to tectonic movement in both the Pliocene and Pleistocene, has been broken into a series of faulted blocks. (See Fig.2b.) Sediments from all the Pliocene and Pleistocene stages have been measured in drill holes near Marton to a depth of 20,000 feet. (Lehner, 1965, 343.) The lower Pliocene sediments have been deposited directly on the greywacke basement, giving a difference in height of more than 24,000 feet between the greywacke surface of the synclinal basin and the greywacke abrasion surface of the Tararua-Ruahine Range. The Wanganui Basin is not symmetrical and the stratigraphic sequence in the basin becomes thinner as the basement rises to the west. The syncline is centred at Marton, with its axis extending from Taihape in the northeast through Marton to below sea-level southwest of the coast.

When the Tararua-Ruahine Range was flooded by Pliocene and Pleistocene Seas, it was covered by marine sediments. Much of this marine sedimentary cover has been eroded away and now only small remnants remain. Fossiliferous marine beds rest on the greywacke surface of the Tararua Range near the Manawatu Gorge. The base of this marine series is marked by thick pebbly sandstones and conglomerates, often with calcareous concretions yielding good Waitotaran (late Pliocene) fossils. (Lillie and Fleming, 1941, 3.) To the north of the Gorge the Waitotaran stage is represented by a thick bed of rounded and subangular boulders attaining diameters of two to three feet, resting directly on the greywacke surface. The pebbly and bouldery nature of a large part of the beds representing the Waitotaran, Nukumaruan and Castlecliffian stages of the Wanganui Series, indicates marked emergence at these times of this part of the axial range, creating estuarine conditions in the vicinity of the Manawatu Gorge.

These marine beds just to the north of the Manawatu Gorge are underlain by a well defined greywacke erosion surface, thought to correlate with the 'K-Surface', in the Wellington area. (Cotton, 1957, 763. Stevens, 1957a, 316.) A similar surface on the Wakara Range in central Hawkes Bay (Kingma, 1958, 86) is thought to have evolved at the same time as the K-Surface. In the Manawatu this surface extends for about six to eight miles south of the Gorge as the broad crest of the Tararua Range, until it is deformed by warping. If this greywacke erosion surface is the K-Surface then, because it is unconformably overlain by Waitotaran beds, it was evidently formed in pre-Waitotaran Pliocene time.

Intense tectonic activity at the end of the Pliocene and early Pleistocene was responsible for the uplift of the Tararua-Ruahine Range. The faulting that accompanied this tectonic activity cut indifferently into both the soft marine sedimentary cover and the harder, indurated greywacke. The resultant uplift of the axial range led to the formation of the 'Manawatu Strait' (Lillie, 1953, 89), the marine connection across the range between the two sedimentary basins, the Petane Trough on the east and the Wanganui Basin to the west. (See Fig.3.) This strait was later to exert considerable influence upon the course of the Manawatu River across the axial range.

THE DEVELOPMENT OF THE MANAWATU GORGE

The Manawatu River, rising to the northeast of the Ruahine Range, is fed mainly by streams flowing eastward off the range. The river flows in a southwesterly direction until it reaches the Dannevirke Depression where it is joined by the northeastward flowing Mangahao, Mangatainoka and Tiraumea Rivers, which are subsequents in synclinal troughs running parallel to the Tararua Range. In the Dannevirke Depression the Manawatu River makes a right-angled turn, to flow in a northwesterly direction, crossing the axial range at the Manawatu Gorge. (See Fig.1.) The Manawatu River is now incised into the greywacke at the Gorge to a depth of 1,000 feet. The river on leaving the Gorge once again makes an abrupt right-angled turn to flow in a southwesterly direction parallel to the Tararua Range. The Gorge itself is a most imposing and interesting geomorphic feature and its origin has consequently been the subject of many theories.

Early hypotheses to explain the origin of the Gorge range from lake-spillover, earthquake rift and piracy by headwater erosion, to antecedent, anteconsequent or superposed-antecedent; all these theories have been summarised by Adkin (1930) and Ongley (1935). The earlier more colourful theories have now been rejected and more detailed research in the area and the probable processes that could have operated to form the Gorge now seem to favour the Superposed-Antecedent Theory of Adkin (1930, 355) and Lillie's Consequent Theory with its relationship to the early drainage pattern reflecting the structure and certain aspects of Tertiary stratigraphy (1953, 89-90).

At the present time the Manawatu River at the Gorge cuts across a structural high, the lowest part of the axial sag being at the Saddle, a mile and a half to the north, where both crestal elevations and buried undermass are much lower than at the Gorge. A probable explanation for this has been presented by Cotton (1922) who recognises the antecedent appearance of the gorge and accepts either an antecedent or an anteconsequent origin. He has suggested that the river was "guided by the first wrinkles of the surface as it emerged from the sea and maintained the consequent course thus assumed during a continuation of the movements, though in the later, more intensive stage of deformation the slope of the surface changed very considerably and the low gaps do not now coincide with the earliest formed wrinkles". He also noted the "uncommonly low sag in the crest of the range", suggesting that unless this gap at the gorge could be proved to be still the lowest tectonic gap, the river should be classified as anteconsequent.

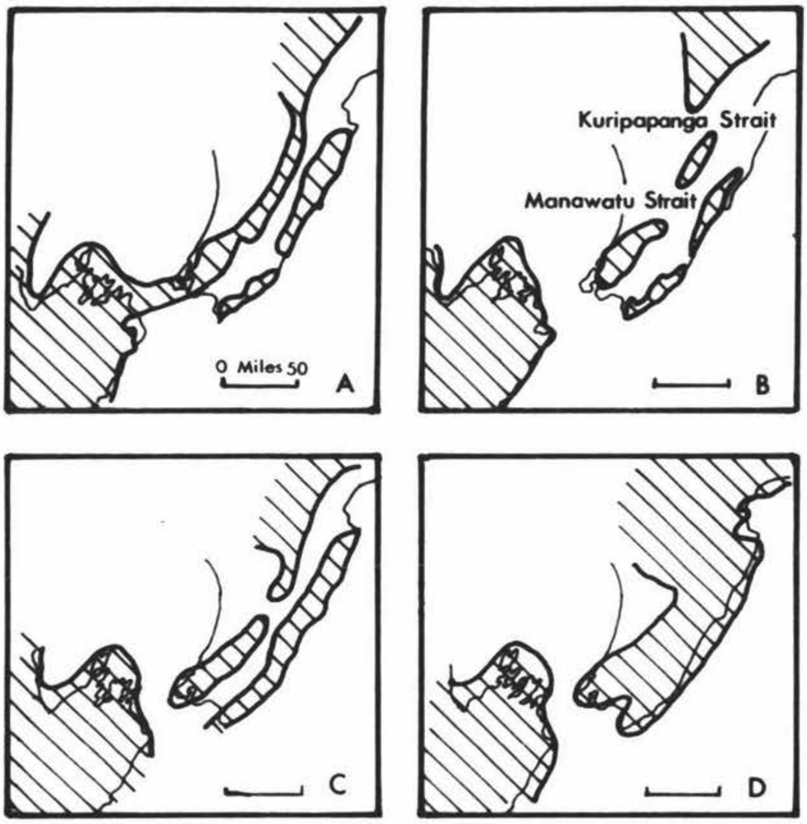
Lillie's (1953) reconstruction of the Manawatu Gorge development, which visualises a close reflection in the early drainage pattern of the structure and the processes that were operating at the end of the Tertiary Period, is accepted here. This in broad detail is similar to the theory advanced by Adkin (1930).

During the late Pliocene (Opoitian and Waitotaran Stages) the main axial range was flooded by the sea and the subsequent deposition indicates "an increase in the depth of water at a rate much greater than the rate of sedimentation". (Grant-Taylor and Hornibrook, 1964, 305.) The Opoitian transgression (see Fig.3a) resulted in the deposition of some 700 feet of limestone, conglomerate and sandstone in the vicinity of the Gorge. (Ower, 1943.) The culmination of the Opoitian transgression in the early Waitotaran (late Pliocene) occurred when Cook Strait, the Manawatu Strait, and further north another strait at Kuripapanga had developed across the axial range. (See Fig.3b.) Once these straits had formed, the tidal currents in them would have been very powerful, cutting down to considerable depths as they now do at Cook Strait. The late Waitotaran marine regression began on the west of the axial range when the sea withdrew from the northern Tararuas and the land further to the east emerged. During Nukumaruan time the sea continued to regress although it probably still penetrated the Manawatu Strait (see Fig.3c) and it was not until late Castlecliffian time, due to further regression, that the sea existed only in the Wanganui Basin, lapping the western entrance to the strait. (See Fig.3d.)

As the land to the east of the Ruahine Range emerged from the sea in early Nukumaruan time, a consequent drainage pattern was initiated. The rivers flowed down a surface which dipped westward as a result of the general tilt of the Tertiary surface. Lillie (1953, 90) has proposed that this westward tilting surface extended from the Waewaepa Range to the Tararua-Ruahine Range (see Fig.1). Thus the consequent rivers from the Waewaepa Range area flowed down the tilting surface and through the lower lying Manawatu Strait area.

Marine deposits still exist on parts of the axial range. To the north of the Gorge on the Ruahine Range Waitotaran beds occur but they have been eroded off the Tararua Range. Deposits resulting from the Nukumaruan transgression still exist near the top of the Tararua-Ruahine Range and the Nukumaruan strand line can be traced for a short distance south of the Gorge. (See Plates 1 and 2.) In Castlecliffian time, although the land to the east of the axial range had emerged, the sea still inundated the Wanganui Basin, lapping the western flanks of the Tararua-Ruahine Range but no longer occupied the Manawatu Strait. On the north-western flank of the Tararua Range between the Gorge and the

THE MANAWATU STRAIT



Lined areas represent land.

PLIOCENE : A. Early Opoitian. B. Early Waitotaran.

PLEISTOCENE: C. Early Nukumaruan. D. Castlecliffian.

Fig. 3

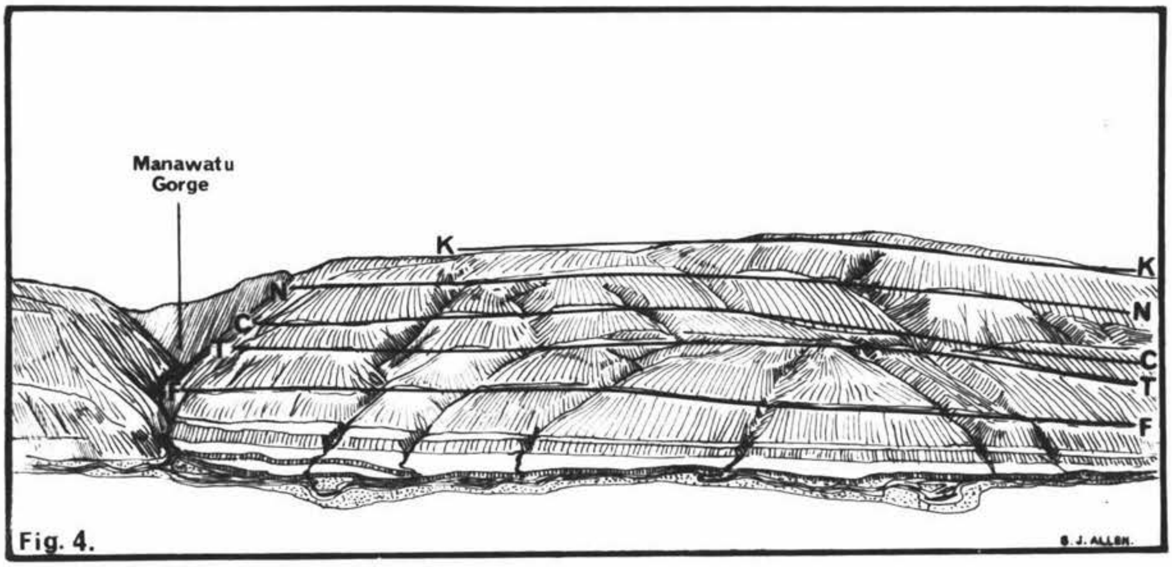


Fig. 4.

Plate 1

The Manawatu Gorge (G) and the marine strand lines on the Tararua Range. The level summit of the range (K) is the K-Surface, below this lies the Nukumaruan (N) strand line, the Castlecliffian (C) strand line, and the Tokomaru Marine Terrace formation (T). Note the gently sloping shoulders of the Manawatu Gorge and lower steeper fluvially eroded section.

Pahiatua Track, relic marine cliffs and benches have been cut into the greywacke. (See Plates 1 and 2, Figs.4 and 5.) It was evidently in Castlecliffian time, therefore, that the Manawatu River originated, flowing across the westward tilting Castlecliffian landmass to the sea on the west of the axial range.

These stepped marine strands on the flanks of the Tararua Range suggest that it was necessary for the sea to downcut into the basement greywacke of the range to maintain its passage in the Manawatu Strait. If in fact this marine erosion did occur it would explain the gently sloping shoulders of the Gorge compared with the lower, steeper, fluvially eroded slopes. (See Plate 1 and Fig.4.) If marine erosion of the basement greywacke did occur in Nukumaruan and early Castlecliffian time, this would then suggest that the Manawatu Strait was in fact more than a "first wrinkle" (Cotton, 1922) on the Castlecliffian surface. It was in fact a trench 300 to 400 feet deep which initially guided the Manawatu River across the axial range. The drainage pattern that evolved therefore was consequent in the Manawatu Strait and the river quickly superposed through any sedimentary cover that may have existed in the strait on to the undermass as postulated by Adkin (1930) and Turner (1944). The course of the river, entrenched in the greywacke undermass, was fixed and antecedent to succeeding uplift of the axial range.

The rate of uplift of the Tararua-Ruahine Range since the Manawatu River set a consequent course through the Manawatu

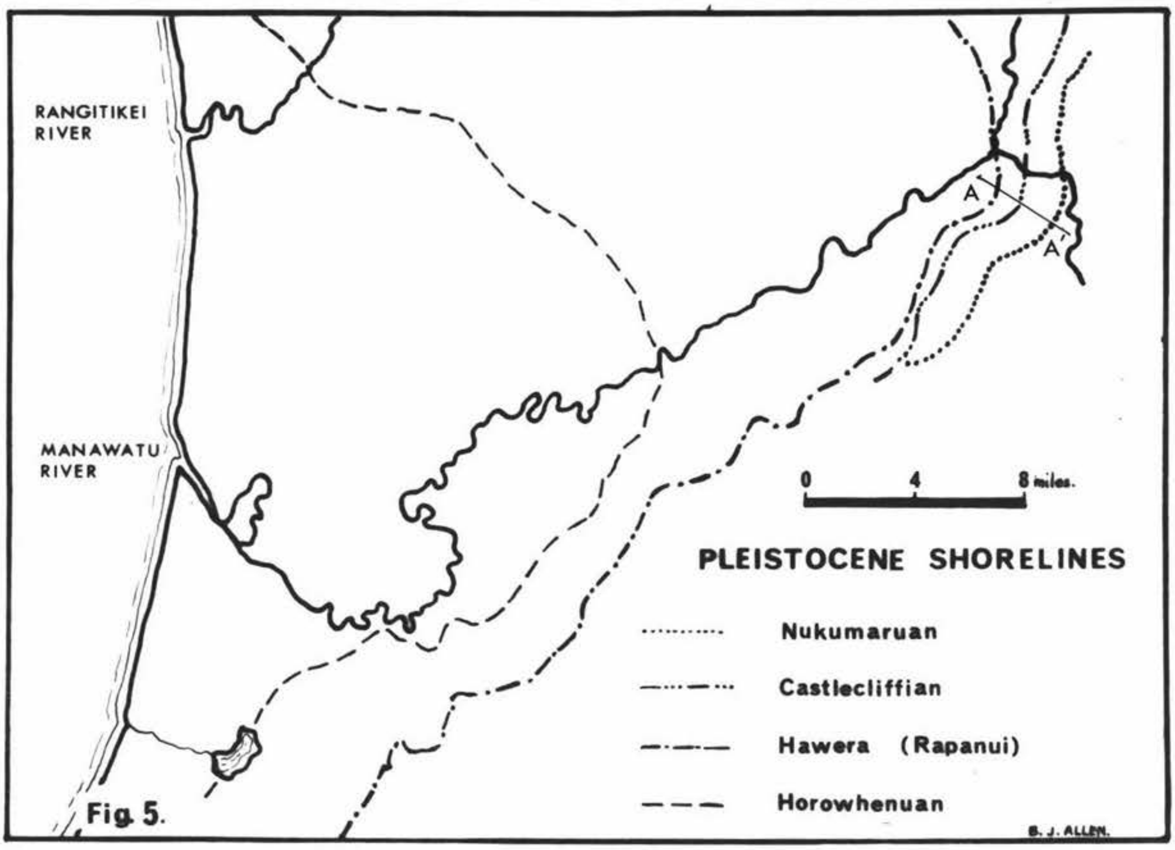


Plate 2

Marine-cut benches and strand lines. Below an old erosion level the K-Surface (K) on section A-A' of Figure 5, lie three strand lines, the Nukumaruan (N), Castlecliffian (C), and Hawera (T). The Hawera strand line is commonly known as the Tokomaru Marine Terrace.

Gorge, has been slow and steady enabling the river to maintain its course in the greywacke. Dextral transcurrent movement which has occurred along the Tararua East-front Fault on the east of the Tararua Range, has not altered the course of the river although near the entrance to the Manawatu Gorge the river does now appear to be fault-guided.

The geomorphological evidence for the existence of the Manawatu River on the western side of the ranges begins only in the late Pleistocene. There is a long time gap between its inception in Castlecliffian time and the oldest river terrace, the Forest Hill Terrace,[2] which is of Hawera age. This lack of evidence may be accounted for by eustatic high sea-levels during interglacial periods, which may have removed all evidence of older fluvial terraces. During the last interglacial, the Oturian, the 'Hawera Sea'[3] lapped the western flanks of the Tararua Range where it deposited the Tokomaru Marine Terrace. This high sea-level would have involved processes of deposition and it is also probable that existing sediments would have been reworked and redeposited by wave action as the sea transgressed the area and again as sea-level dropped.

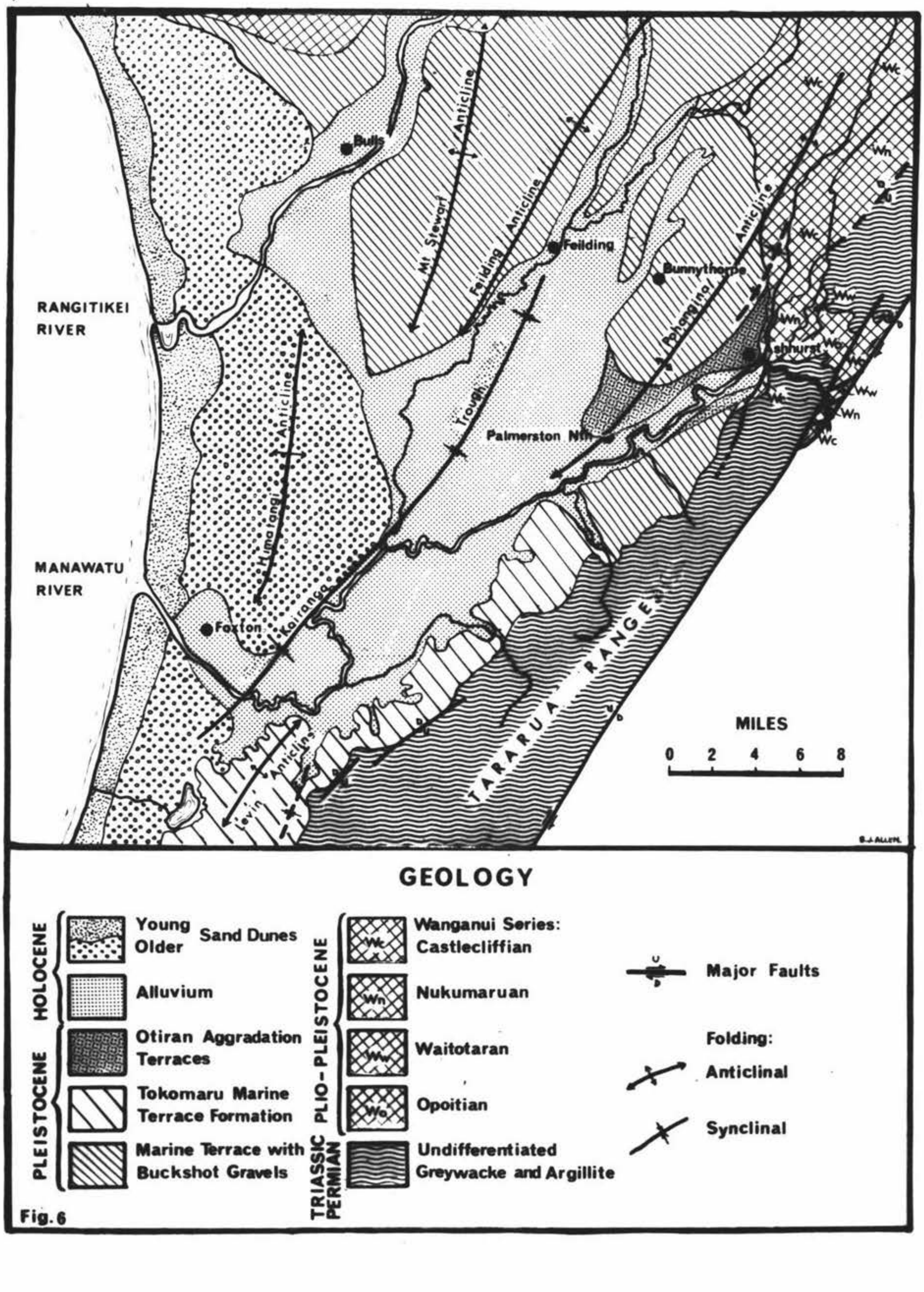
THE TOKOMARU MARINE TERRACE FORMATION

The Hawera Sea deposited sediments over a large area of the southern portion of the North Island; some of these deposits still exist on the northern and eastern edges of the Wanganui Basin. (See Fig.6.) At the height of this marine transgression the sea cliffed the undermass of the Tararua

Range from Levin to the foot of Bryant Hill; the steep cliffing that occurred here seems to be both fault guided and fault reinforced. Throughout most of this distance the Hawera sediments were deposited in water of shallow to moderate depth. (Oliver, 1948.) Northward from Bryant Hill, the cliffing is not so obvious and does not appear to be fault guided. The Hawera marine environment, in response to frequent shifting of both strandline and stream courses along the base of the western flank of the axial ranges, varied from shallow water, to littoral, to a dune foreland environment.

The sea retreated from the flanks of the Tararua Range in late Oturian time, leaving the Hawera surface, here known as the Tokomaru Marine Terrace formation (see p.71), emergent. Much of this formation has since been removed by marine and fluvial erosion although remnants of it occur along the foot of the ranges, and as large doabs to the west of the river. The Manawatu River and the Oroua River further to the west have both corraded away large portions, leaving remnants capping the Pohangina and Mt Stewart-Halcombe anticlines. These marine beds are most extensive between Massey University and Tokomaru but taper out near the Gorge where only a narrow wedge remains. (See Fig.6.)

There is a difference in the lithology of the beds from north to south, the deposits to the north being more gravelly, while in those to the south of the Kahuterawa Stream sand becomes more dominant. The beds consist predominantly of poorly consolidated greywacke detritus, cross-bedded sands and thinly bedded siltstones. Lateral and vertical variation



RANGITIKEI
RIVER
MANAWATU
RIVER
Bulls
Feilding
Bunnythorpe
Ashhurst
Palmerston Nth
Foxton
Mt Stewart Anticline
Feilding Anticline
Pohangina Anticline
Himatangi Anticline
Levin Anticline
Trough
Kairanga
TARARUA RANGE
Wc
Wn
Ww
MILES
0 2 4 6 8
GEOLOGY
HOLOCENE
PLEISTOCENE
Young
Older
Sand Dunes
Alluvium
Otiran Aggradation Terraces
Tokomaru Marine Terrace Formation
Marine Terrace with Buckshot Gravels
PLIO-PLEISTOCENE
TRIASSIC PERMIAN
Wanganui Series: Castlecliffian
Nukumaruan
Waitotaran
Opoitian
Undifferentiated Greywacke and Argillite
Major Faults
Folding:
Anticlinal
Synclinal

Fig. 6

is characteristic and few beds can be traced for more than short distances. Oliver (1948) postulates that the conglomerate layers were originally greywacke gravel fans, extending down from the flanks of the Tararuas on to the flood plain which was exposed in pre-Hawera time. It is also possible that some of the gravels originated as Castlecliffian river and stream terraces which, when transgressed by the Hawera Sea, were reworked and redeposited not once but twice, first when the sea was submerging the land up to the edge of the axial range and secondly as the sea retreated at the end of the Hawera transgression. The sand deposits overlying the conglomerate formations increase in depth to the south. On the Pohangina anticline the sand deposits consist of six to eight feet of sand and siltstone, overlain by six feet of loess (see Plate 3), whereas to the south at Shannon, sand deposits 30 to 50 feet, cap the conglomerates.

The differences in the lithology of the beds from north to south are in part due to the longer emergence of the northern beds; as the sea began to retreat, the northern beds close to the ranges were exposed and the formation is thus progressively younger in a seaward direction. Another factor which indicates that the northern beds have been exposed for a longer interval is the presence in them of 'buckshot gravels'. (Te Punga, 1954a, 2.) In the Manawatu these ferruginous nodules, buckshot gravels, occur in a layer of plastic clay soil (Cowie, 1964a, 75) underlying the loess deposits on the Tokomaru Marine formation, and the Forest Hill Terrace. The degree of chemical weathering necessary to create these iron nodules requires a long period of warm humid climate. The depth of clay in which the buckshot gravels are found also indicates a lengthy period of uninterrupted soil development during warm conditions of the Oturian interglacial. The presence of the buckshot layer in the Manawatu district, extending from Tokomaru to the Manawatu Gorge and to the west in the Marton district, and their absence in beds south of Shannon, may be considered as further evidence that the northern rocks of the Hawera series have been exposed for a longer period than those to the south. The presence of the buckshot on the surface of the Forest Hill Terrace seems to indicate a long period of warm humid climate after the Hawera Sea had retreated from the flanks of the ranges. In this period the Manawatu River had established its course, then become entrenched leaving the flood plain as a terrace surface on which these buckshot gravels formed. This evidence would suggest that the sea retreated from this area some considerable time before the Otiran Glaciation began.

THE ANTICLINES OF THE WANGANUI BASIN

In the Wanganui Basin marine sedimentation of several thousand feet of blue-grey siltstones and sandstone bands continued until the end of the lower Pleistocene. During the Oturian Interglacial the epeirogenic uplift that exposed a large portion of the Hawera coastal plain also revealed that the Hawera surface had been warped into a number of broad gentle folds. These folds, the anticlines, appear to be related to faulted blocks of greywacke.

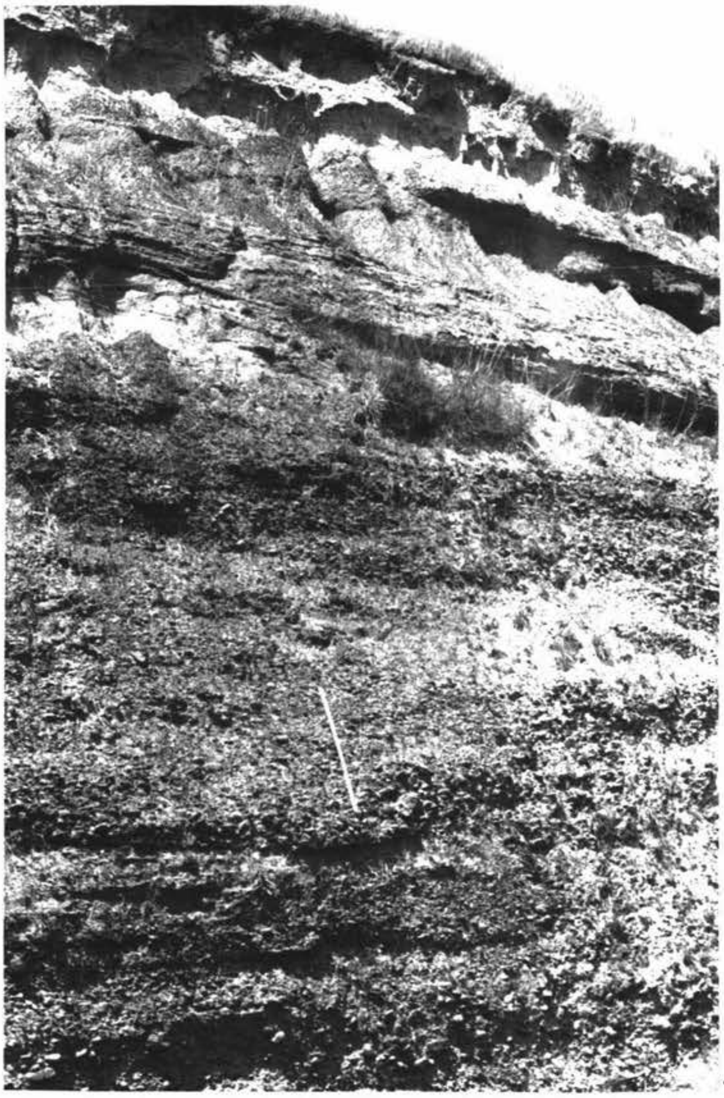


Plate 3

The Tokomaru Marine Terrace formation exposed in a gravel pit on the Pohangina anticline, N.149/168409.

The greywacke basement of the Wanganui Basin appears to have reacted to tension and pressure not by folding but by breaking, cratonisation, into a series of faulted blocks. Some of these blocks have begun to rise and may in fact still be rising, forming a series of upwarped folds on the Hawera marine surface. These upfaulted blocks, the anticlines have distinct geomorphic expression. All are asymmetrical with a sharp eastern scarp and a long gentle western slope. This asymmetry is in turn reflected in a distinct drainage pattern. The anticlines and their accompanying downthrown fault blocks can be substantiated from data collected during seismic and gravity surveys. A portion of the Wanganui Basin was mapped by the Superior Oil Co. (1943) using the reflection seismograph method. Robertson and Reilly (1958) have since compiled a bouguer gravity anomaly map which indicates the general configuration of the undermass forming the floor of the basin, showing that the folds close in the vicinity of the anticlines. Other evidence for the upfaulting of the greywacke blocks forming the anticlines has been obtained from drilling. In a well drilled on the Marton anticline greywacke was encountered at a depth of 6,842 feet, whereas two to three miles to the west seismic reflections from 17,000 feet were obtained. At the Mt Stewart well greywacke was encountered at 3,361 feet and three miles to the east of it seismic reflections showed greywacke at a depth of 14,000 feet. (Lehner, 1965, 344.)

There are seven anticlinal structures in the Manawatu area.[4] Five of these structures occur within the study area and their approximate locations are shown in Fig.6. Three of these anticlines and their accompanying synclines can be considered to be the most important structural elements to have exerted control on the course of the Manawatu River.

REFERENCES

1. Wanganui Basin, a geosynclinal structure, centred on Marton lies on the west of the Axial Range. The Basin is geologically young, post-Miocene (Fleming, 1953, 298) and is discussed more fully on p.12.

2. The Forest Hill Terrace is the oldest terrace surface to be found within the Manawatu River valley west of the Gorge. It is discussed in detail on p.49.

3. The 'Hawera Sea' in this text refers to the high sea-level of the Last Interglacial.

4. All the anticlines have been described either in detail or briefly by the Superior Oil Company, Ower 1943, Turner 1944, Te Punga 1957, and Rich 1959.

III. STRUCTURAL TECTONIC CONTROL

The influence of geologic structure upon surface landforms has long been recognised as an important factor in the understanding of the geomorphology of an area. Thornbury (1954, 17) states as his second fundamental concept of geomorphology that "geologic structure is a dominant control factor in the evolution of landforms and is reflected in them". In the Manawatu where the present topography reflects the underlying structures, this concept applies more especially in the positioning of the Manawatu River valley.

In the Manawatu area indurated Mesozoic greywacke forms the axial range and the basement of the Wanganui Basin. In this basin the basement greywacke has been overlain by poorly consolidated predominantly marine sediments of late Pliocene and Pleistocene age and Recent unconsolidated non-marine superficial deposits. The Manawatu River flows south from the Manawatu Gorge over the Kairanga alluvial plain, on the soft sedimentary rocks of the Wanganui Basin, apparently unhindered by structure and geology. The river here, however, has in fact been greatly influenced by structure. In this tectonically unstable area the basement greywacke of the Wanganui Basin has been faulted into cratons, upfaulted blocks forming anticlines, and downthrown synclines. Three of these anticlines, the Pohangina, Levin and Himatangi Anticlines and two synclines, the Pohangina Syncline and the Kairanga Trough have influenced the course of the Manawatu River.

THE POHANGINA ANTICLINE

The Pohangina Anticline extends for some 20 miles north-northeast from Palmerston North, on the west of the Manawatu River, lying parallel to the axial range. Its crest trends north-northeast in its northern limits but for about four miles at its southern end the trend is northeast. (See Fig.6.) The nose of the anticline extends beyond Longburn; Coupe's (1958) ten foot contour interval survey of the Taonui Basin shows that the contours curve around the nose of the anticline beyond Longburn.

Between the Pohangina Anticline and the axial range lies the Pohangina Syncline (see Fig.6) formed where the covering strata dipping off the western flanks of the ranges are warped up to form the eastern limb of the Pohangina Anticline. The Pohangina Syncline and its accompanying anticline lying at right angles to the path of the river at the Manawatu Gorge, appear to be responsible for the abrupt turn that the Manawatu River makes at the Gorge, forcing the river to flow for about ten miles downstream in the Pohangina synclinal trough.

THE HIMATANGI AND LEVIN ANTICLINES

Both the Himatangi and Levin Anticlines have structurally guided the course of the Manawatu River in its lower reaches. The Himatangi Anticline is thought to be the youngest anticlinal structure in the Manawatu area, lying approximately parallel to the coast with its crest trending slightly east of north for approximately 13 miles from Foxton to Rongotea. (See Fig.6.) The topographic expression of this anticline is not very obvious, as the newly emergent coastal plain is only gently warped and partly masked beneath fixed, elongated sand dunes. The Levin Anticline lies to the south of the Manawatu River near the coast and can be traced for nearly six miles along a north-northeast trend from Levin to the Manawatu River.

Both the Himatangi and Levin Anticlines apparently have risen at right angles across the path of the Manawatu River. (See Fig.6.) If these two anticlines are the youngest in the series as predicted by Te Punga (1957) it then seems that the deformation of this seaward portion of the coastal plain is relatively recent. If Lake Horowhenua is an old cut-off originally formed by the Manawatu River (as it is probable that the river did once flow along a course close to the ranges), then this lake has been formed since the Climatic Optimum high sea-level, here termed the Horowhenua Transgression, when the sea according to Rich (1959, 161) cliffed the Tokomaru Marine Terrace formation from the Kahuterawa Stream to south of Otaki. On this assumption, it would appear that the Levin Anticline has deformed the surface topography only since the sea retreated from the area (approximately 4,000 years B.P.), altering the lower course of the river in the last 3,000 to 3,500 years.

The consequence of basement deformation at the Himatangi and Levin Anticlines has affected the courses of both the Manawatu and Oroua Rivers. (See Fig.6.) The Oroua River most probably once flowed straight out to sea, reaching the coast just to the north of Foxton, while the Manawatu River apparently flowed parallel to the ranges entering the sea just to the west of Lake Horowhenua. The doming of the Himatangi Anticline appears to have forced the Oroua River to the south-east where, in its transposition to join the Manawatu River just to the north of Rangiotu, it has removed a large portion of the Tokomaru Marine Terrace formation. After its confluence with the Oroua River the Manawatu River is guided through the coastal barrier of the Levin and Himatangi Anticlines in the synclinal Kairanga Trough.

THE KAIRANGA TROUGH

In the southern portion of the Wanganui Basin the anticlines or basement highs are centred around a large syncline, the Kairanga Trough. (See Fig.6.) This trough has been described by Rich (1959, 136), who states that "topographically it is expressed as an elongated alluvial plain which extends for 30 miles from Feilding to Lake Horowhenua and attains maximum width of roughly ten miles west of Palmerston North". This trough is bounded on the west by the Feilding, Mt Stewart-Halcombe and Himatangi Anticlines. On the east it is flanked by the Pohangina and Levin Anticlines. Rich considers that a minimum of at least 10,000 feet of sediment occurs at the centre of the trough, which lies about seven miles west-northwest of Palmerston North.

THE STRUCTURAL CONTROL OF THE MANAWATU RIVER

The Pohangina and Mt Stewart-Halcombe Anticlines are both still capped with Hawera marine series strata of the

Tokomaru Marine Terrace formation, which indicates that since the retreat of the Hawera Sea the Manawatu River and the Oroua River to the northwest have not flowed on the summits of the anticlines. This would suggest that both the anticlines were in existence as small mounds when the Hawera Sea first retreated more than 50,000 years ago. The Manawatu River since the Last Interglacial, therefore, has not flowed straight out to sea from the Manawatu Gorge but has always turned southward as a subsequent river in the Pohangina Syncline.

Since the formation of the Himatangi and Levin Anticlines the Manawatu River, in its lower reaches, has been forced to flow in the Kairanga Trough taking a longer course out to sea. The river now flows through a course of 63 miles from the Gorge to the sea, the direct distance being 27 miles. The Manawatu River from its confluence with the Oroua turns southwards to flow for a short distance parallel to the coast, changing course again near the nose of the Levin Anticline, to follow the Kairanga Trough to the sea at Foxton. (See Fig.6.) This longer course of the river, in its lower reaches, is reflected in the gentle profile of the lower river. Between Rangiotu and the coast the river falls only 15 feet in $31\frac{1}{2}$ miles. This gentle gradient of the lower catchment area accounts for its swampy nature and its tendency to flood.

Despite a surface geomorphology which indicates a relatively young river, with the oldest terrace dating from late in the Last Interglacial, the river pattern has nonetheless been controlled by earlier structure. The faulting of the basement greywacke to form the anticlines commenced during the Kaikoura Orogeny, but it was not until post-Hawera time that there was evidence of continued uplift of the older anticlines. The uplift of the older anticlines and the evolution of the younger anticlines have rigidly controlled the path of the Manawatu River so that it is now deeply entrenched in a synclinal course between the steep banks of the older river terraces. Between the Gorge and Longburn the river is restricted to flow in the Pohangina Synclinal trough. South of Palmerston North, on the coastal plain, it is structurally guided by the Kairanga Trough through the seaward barrier imposed by the Himatangi and Levin Anticlines. As a result the whole course of the Manawatu River, from the Manawatu Gorge to the sea, is structurally controlled by the anticlines and synclines of the Wanganui Basin and its position on the Manawatu coastal plain has been determined by the underlying structure of the basement greywacke.

IV. CLIMATIC CONTROL

CLIMATIC CONTROL ON PLEISTOCENE LANDFORMS

It is now realised that climate, and especially late Pleistocene climate, is an important controlling factor in the processes of deposition and erosion and the resultant evolution of landforms. In the early part of this century many geomorphologists, especially in America, studied landforms primarily as indicators and measures of diastrophism, despite the fact that Penck (1905) had already hypothesised that landform differences were primarily the result of climatic differences and that, because of climatic fluctuations, landform characteristics could be inherited from the past. Due to subsequent work of such geomorphologists as Cotton (1945b) and Peltier (1950) it has since become accepted that climate is an important factor in the formation of landforms. The climate of the Last Interglacial and glacial periods of the late Pleistocene has been an especially significant controlling factor in the evolution of present day landforms.

A number of conflicting theories and hypotheses have been put forward, however, as to the occurrence of periods of erosion and aggradation within the glacial cycle. All these proposed hypothetical relationships for periods of alluviation, in areas lying beyond the ice fields of glaciated regions, have been summarised by Frye (1961, 600) as (i) terrace deposits of both glacial and interglacial age separated by erosion during earliest and latest glacial time; (ii) terrace deposits of glacial age separated by interglacial erosion; (iii) terrace deposits of late interglacial and early glacial age separated by late glacial and early interglacial erosion; (iv) terrace deposits of late glacial and interglacial age separated by early glacial erosion; (v) minor terrace deposits of early glacial age and major terrace deposits of late glacial age separated by very early glacial and mid-glacial erosion; and (vi) terrace deposits of late glacial to very early interglacial age followed by interglacial equilibrium and separated by early glacial erosion.

Frye supports the sixth hypothesis, that alluvial deposition beyond the glacial limits began and was greatest during glacial retreat, terminating early in the succeeding interval, primarily on the basis of stratigraphical evidence from Texas to the Mississippi River valley as well as from theoretical considerations. During the time of accumulation and advance of glaciers, rates of precipitation must have been relatively high. Such a condition, he states, is conducive to valley incision because the increase of precipitation at and beyond the glacial margins is available for runoff and the advancing glacier immobilises more source sediment than it makes available. Frye also suggests that available evidence indicates that the retreat of glaciers is characterised by increased air temperatures, decreased precipitation, rising sea-level and a progressively increasing source of readily available clastic material for stream transport, although it is possible during the early stages of glacial retreat that meltwaters from the retreating glaciers compensate for, or even exceed the loss of, precipitation. The net effect of these factors during glacier retreat is to decrease the competency of streams and cause valley alluviation.

The Pleistocene era, although short in geological time, is usually considered as lasting approximately one million years, although some geologists now think that it may have been much longer (Shotton, 1966). It was an epoch of large climatic changes which resulted in several advances and retreats of ice sheets. The erosional and depositional phenomena associated with each advance and withdrawal of the ice profoundly affected the landscape and in many areas these were the primary determinants of present day topography.

During periods of glaciation the ice sheets which prevailed in many mid-latitude regions were surrounded by extensive periglacial zones. The periglacial zone has been defined by Zeuner (1959, 81) as the "zone surrounding an ice-sheet in which the cooling effect of the ice produced a frost climate" and (1958, 119) the zone in which "climate favoured permanently frozen subsoil". A periglacial climate produces intense frost action which in turn involves accelerated mechanical weathering, growth of ground ice, volume changes in superficial deposits and mass movement of detritus on slopes. Butzer (1965, 113) agrees with Tricart that rapid erosion occurs at the end of a glacial period because the colloidal structure of silts and clays is broken by freezing, so that these lose their cohesion when the thaw begins. The thawing material has a high water capacity and the abundance of seepage water provides a lubricated ooze capable of mass movement on even gentle slopes.

In a periglacial zone the interaction of accelerated mechanical weathering from intense frost action and the rapid mass movement of the congelifractate even on gentle slopes results in solifluction. These products of solifluction are injected into streams greatly increasing their load. Reduced evaporation, stronger seasonal concentration of runoff in late spring or early summer and non-percolation of water into the frozen sub-soil are factors which increase the vigour of seasonal stream discharge. Aggradation of gravels and sands is greatly accelerated and many mid-latitude stream terraces can be attributed to periglacial alluviation. As ice sheets began to retreat the congelifractate material was no longer ice-bound and great masses of frost weathered debris and solifual materials were washed down-slope to be deposited on extensive flood plains. This, then, is the period of greatest periglacial alluviation.

In the transition to a glacial climate, with the advance of the ice sheets in the mid-latitude regions, the forest zone was forced to migrate beyond the periglacial zone. Subalpine tussock, mosses and dwarfed shrubs surrounded the periglacial zone. This forced migration of plants from large areas contiguous to the ice sheets facilitated erosion of the slopes both by solifluction and by running water during short periods of spring and summer thaws.

Interglacial times presented a climate conducive to extensive development of protective vegetation. Vegetation exercises control on a slope through its root systems intermeshing and holding the soil, by its influence on the force and availability of water at the surface and through its effect on chemical and physical weathering. Plants, with the return of warmer temperatures, invaded the former taiga and tundra zones, stabilizing slopes and slowing down erosion caused by slope-wash and down-slope movement of soil, water and ice.

Sea-level, after an initial rise due to the melting of glaciers, remained essentially stable during interglacial times allowing rivers to grade to a constant base-level. Rivers therefore, during an interglacial, were in a state of approximate equilibrium in relation to transport, deposition and base-level within their regimens.

Loess,[1] another important by-product of periglacial conditions, is the result of deflation and deposition of fine silt by wind. Deflation by wind is limited to dry, loose, fine-grained sediments not protected by plant cover. Particles of silt or fine and medium-size sand (under 0.2 mm) are carried in suspension over long distances by strong winds. Loess deflated from outwash deposits and from river beds and flood plains is also significant for stratigraphical purposes as it is a general indicator of glacial phases. Raeside (1964) has studied the loess deposits on the eastern and southern downlands of the South Island of New Zealand, where he has distinguished at least six layers of loess. He assumes that periods of loess accumulation correspond to glacial stadia and has assigned three of the loess layers to the Last Glaciation and three to the Penultimate Glaciation. Young (1964) also has found the Otago loesses a useful stratigraphic tool for interpreting the record of events since the

Penultimate Glaciation.

Since the last retreat of the ice at the end of the Last Glaciation, climatic changes of smaller amplitude than previously have continued to take place. The present period in the Pleistocene,[2] is considered by Willett, H.C. (1949) to be "probably two-thirds of the way from a period of maximum glacial coldness to a period of maximum interglacial warmth. According to estimates of most geologists, world climate at a time of maximum glaciation averages some 7 - 8°C colder and during a time of interglacial mildness some 3 - 4°C warmer than at present." The lower Holocene boundary dated as occurring at 10,000 years B.P. is accepted as the conventional boundary between glacial cold and interglacial warmth, although the ice sheets had begun to retreat some several thousand years earlier.

The warmer temperatures at the beginning of the Holocene melted the permafrost enabling the forest zone to return to the formerly periglaciated regions. The stabilisation of the slopes with grasses, shrubs and trees followed, resulting in a considerable reduction of gravitational and slope-wash processes. The decreased supply of water from the slopes produced a lessening of the volume and loads of the rivers. According to Flint (1957, 217) the linkage through which climatic change is felt by a stream or river consists of a "change in the ratio of load to discharge. By altering either of these factors a changing climate is thought to be capable of inducing net trenching or net deposition in a stream previously in approximate equilibrium".

The interaction of the geomorphological processes in operation during the Pleistocene, briefly described above, were controlling factors acting on deposition and erosion during glacial and interglacial periods. This interaction led Frye (1961, 603) to suggest that the alluvial deposits that mark the dissected surfaces of the succession of Pleistocene terraces "are genetically related to the retreatal phase of their appropriate glacial phase". Later in the study this hypothesis of Frye will be used to correlate the aggradation terraces of the Manawatu River to the glacial advances and retreats of the late Pleistocene ice fields on the summits of both the Tararua and Ruahine Ranges, where the headwaters of the Manawatu River and its many tributaries rise. Although many New Zealand geologists postulate that aggradation occurs during the ice advance, this view does not seem to be consistent with the periods of aggradation in the Manawatu area.

LATE PLEISTOCENE CONDITIONS IN THE MANAWATU

During the Last Glaciation (the Otiran Glaciation) ice fields developed on the summits of the Tararua and Ruahine Ranges. (Willett, R.W., 1950.) Actual glaciers[3] were restricted to small areas near the summit of the Tararua Range during this glaciation and possibly during the Penultimate Glaciation. (Adkin, 1912.) Solifluction deposits occur over much of the axial range area of the southern part of the North Island of New Zealand. (Cotton and Te Punga 1955, Stevens 1957b, and Rich 1959.) In the northern Tararua Range

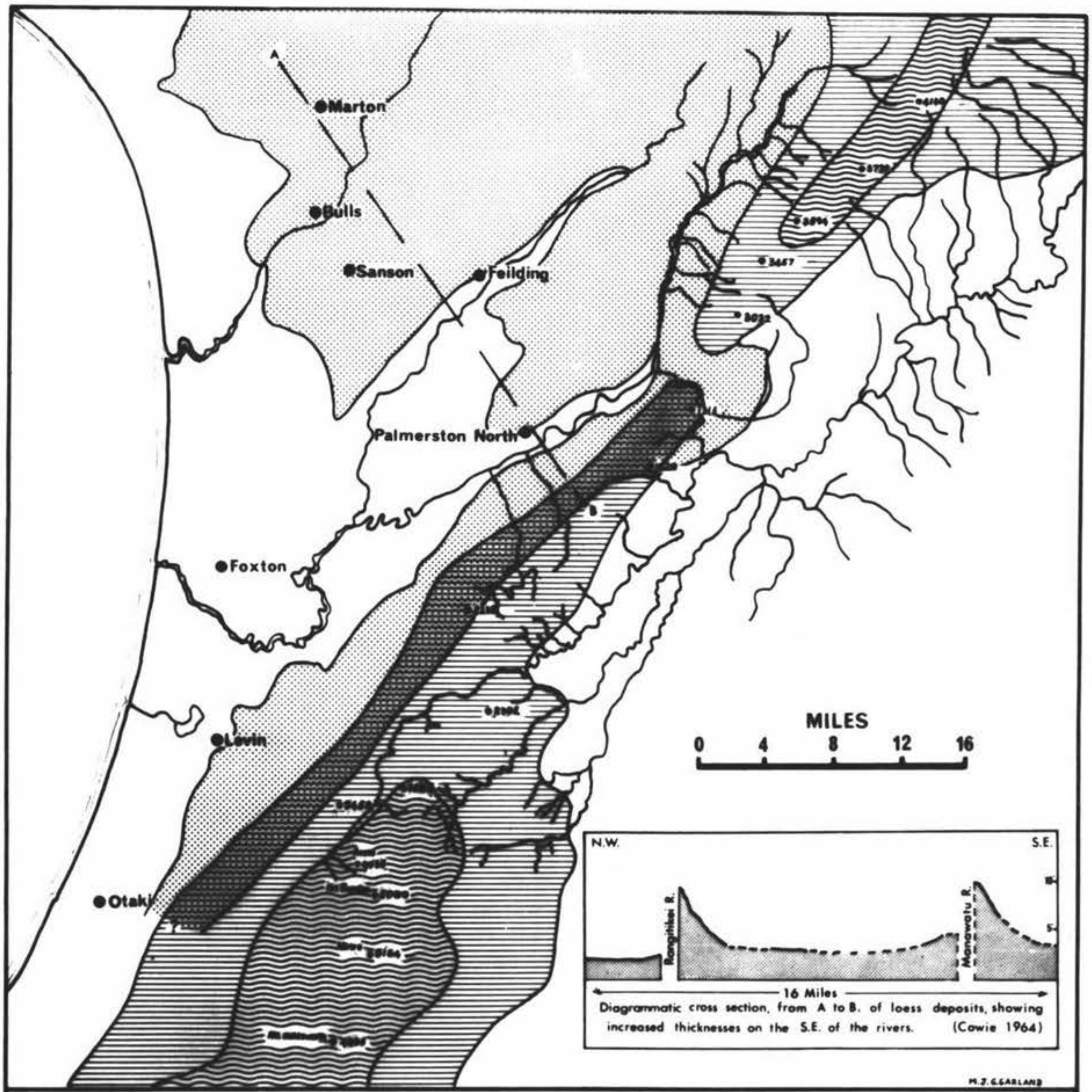
Rich found deposits of greywacke congelifractate on slopes at elevations exceeding 600 feet, where "on open slopes the thicknesses of solifluction deposits ranged from three feet to ten feet, with a thickening of deposits downslope.... At scattered localities the rubble fills steep-sided, V-shaped gullies to depths exceeding 20 feet." (1959, 94.)

Willett, R.W. assumed that glaciation on the Tararua Range could be produced by a uniform reduction of 6°C in temperature throughout the year. This would produce an approximate average snow-line depression of about 3,500 feet below the present day level. The result of this lowering of the snow-line would be bare rock devoid of vegetation down to 2,000 feet, below which sub-alpine tussock vegetation would extend to sea-level, and the forest of the temperate zone, which now occupies the lower part of the range, being absent from the area.

It is normal for cold-climate pollen assemblages to contain grass and Compositae pollens,[4] with few if any tree-pollens. Cold-climate pollen assemblages with no traces of tree pollens at all have been found as far north as Taranaki. (Fleming, 1962.) Sub-alpine Astelia linearis left abundant seeds near present sea-level, in cold-climate deposits near Porirua 20,800 years B.P. Fleming suggests that this evidence, with other plant fossils now available, indicates that conditions during the ice ages could have been more frigid than Willett, R.W. predicted on theoretical grounds and than biologists from knowledge of the present biota usually hypothesise.

The area of glacial ice near the summits of both the Tararua Range and northern Ruahine Range would have been surrounded by an extensive zone of 'periglacial conditions'. (See Fig.7.) Willett, R.W. accepted that the 'periglacial' conditions as defined by Zeuner implied that a severe frost climate affected all areas adjacent to Pleistocene glaciers. Willett therefore, by assuming that temperatures during a glacial period were then uniformly lower by an average of 6°C, delineated the New Zealand 'periglacial zone' as occurring between the margins of the maximum ice advance and the 10°C midsummer isotherm. Gage (1965), however, doubts whether a severe frost climate affected all areas marginal to Pleistocene ice sheets or if permafrost necessarily occurred in New Zealand. He suggests that Soons' use of 'periglacial' (1962, 74) in the sense of Tricart as "a climatic regime in which erosion by running water is replaced by frost action and ... the processes of denudation and resulting landforms associated with such a climate", is especially applicable to New Zealand periglacial conditions.

Willett stated that a lowering of temperature by 7° - 8°C would be sufficient to produce the Pleistocene glacial environments which have left geological and biological effects on the New Zealand landscape. Black (1954), however, suggests that permafrost conditions require ground temperatures to remain below 0°C continuously for at least a number of years and mean air temperatures below zero for still longer periods. The main constructional features of New Zealand's glaciated areas are the extensive fluvio-glacial accumulations and not



DISTRIBUTION OF OTIRAN GLACIATION ICEFIELDS SOLIFLUCTION AND LOESS DEPOSITS

ICE FIELDS (after Willett)

SOLIFLUCTION DEPOSITS (after Cotton - Te Punga 1955 Rich 1959)

LOESS DEPOSITS (Cowie 1964)

Fig. 7

the moraines as in continental glaciated areas. It seems likely therefore that in New Zealand, although average temperatures were lower than at present, the glacial periods were not unbroken seasons of frost, but were diversified by periods of above freezing temperatures in which running water was an active agent. These climatic conditions Gage (1965, 17) considers "would be consistent also with intense gelifraction and solifluction but not with permafrost". The use of the term 'cryergic' might therefore be more apt than 'periglacial' when referring to the conditions of frost, congelifraction and solifluction which surrounded the ice sheets in the southern part of the North Island.

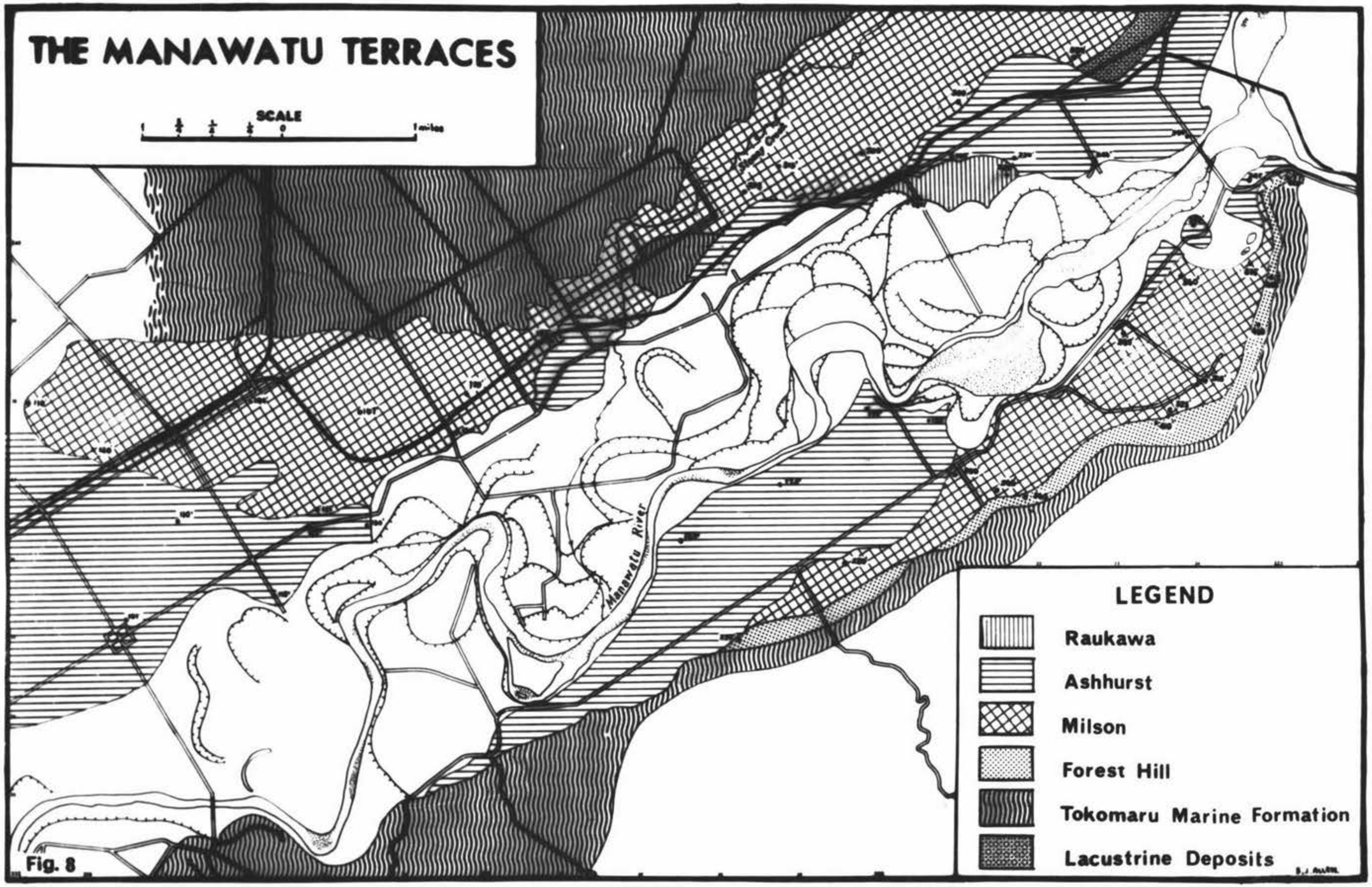
The cryergic zone on the Tararua-Ruahine Range during the Last Glaciation (see Fig.7) was an area of bare rock devoid of vegetation and scree covered, where frost action, namely freezing and thawing, was intense during the summer months resulting in the accumulation of large screes of greywacke detritus.[5] This abundant supply of greywacke debris injected into streams rising in the cryergic zone produced widespread aggradation and terracing during glacial retreatal phases.

The regime of the Manawatu River was affected by periods of alluviation resulting from glacial advances and retreats of the ice fields on the Tararua-Ruahine Range. Some of the tributaries of the river, rising in ice fields (see Fig.7), were supplied with abundant waste material, in the form of congelifracted greywacke detritus to be deposited as aggradation terraces as the river made its way to the sea. In the Manawatu River valley there is evidence of three aggradation surfaces which this thesis will attempt to correlate with known ice advances of the Otiran Glaciation in New Zealand.

THE TERRACES OF THE MANAWATU RIVER

The detailed area of study in this thesis is the terrace development on the Manawatu River, from its confluence with the Pohangina River to the Fitzherbert Bridge (Palmerston North City Bridge). (See Fig.8.) Between these two points the length of the valley is ten miles and the width ranges from three to five miles; from the Ashhurst road bridge to the Fitzherbert Bridge the river follows an attenuated course of 14 miles, falling some 78 feet in that distance. Apart from Stoney Creek and Raukawa Creek flowing into the river from the west bank, only small streams flow into the river from both banks. There has, therefore, been little interference to the older terrace surfaces from dissection and deposition by the tributary streams.

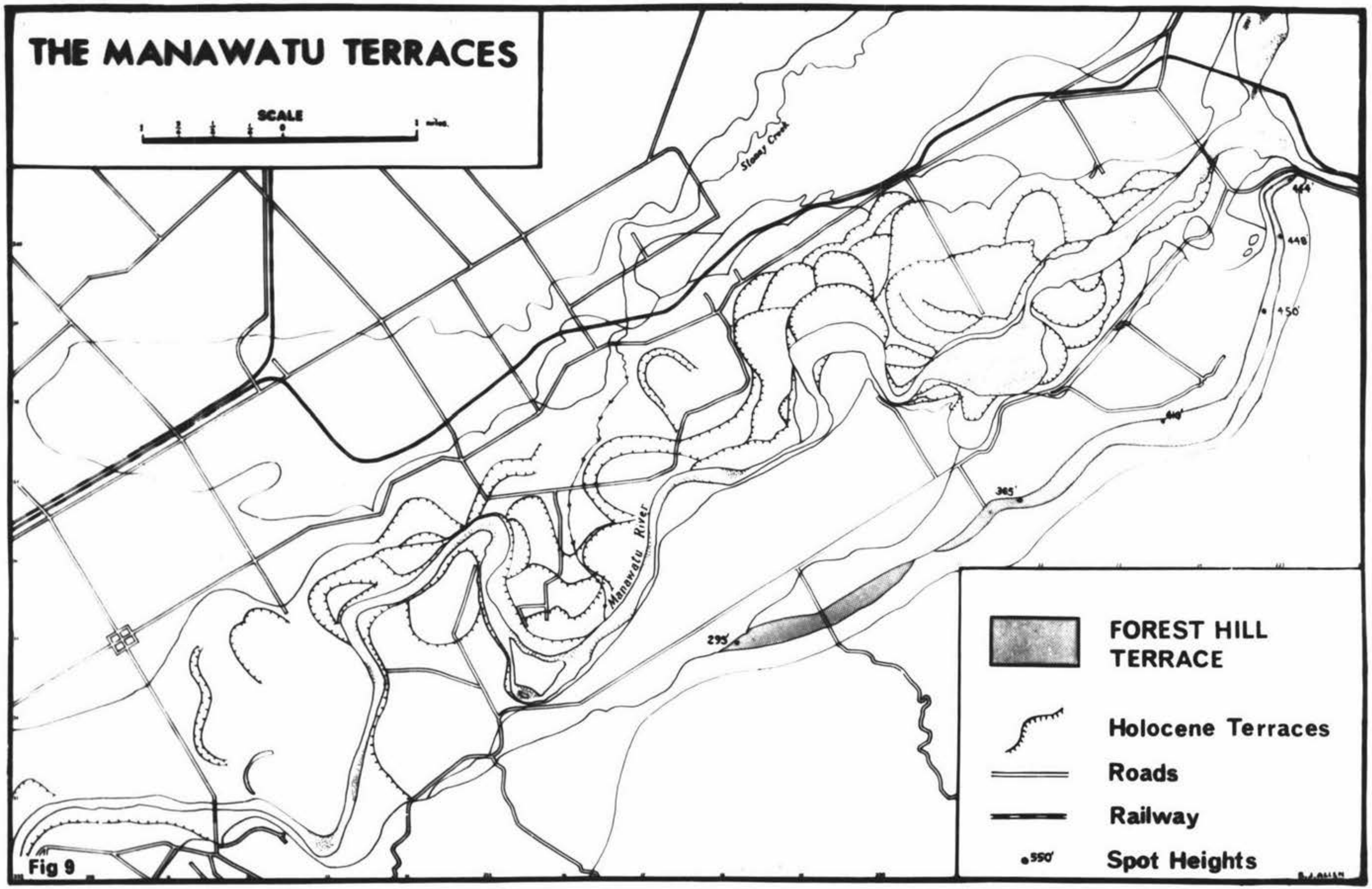
No previous detailed studies have been made of the Manawatu River terraces, although Rich (1959) named a series of terraces on both sides of the river without attempting cross river correlation. Cowie (1961) mentions the older terrace surfaces in conjunction with his work on the Aokautere Ash shower and has since done a soil survey of the three youngest terraces. (Cowie, in press.) These three Holocene terraces are not discussed in this study as they are not related to the major climatic fluctuations which produced the older aggradation surfaces.


THE MANAWATU TERRACES
SCALE
LEGEND
Raukawa
Ashhurst
Milson
Forest Hill
Tokomaru Marine Formation
Lacustrine Deposits
Manawatu River
Fig. 8

The Forest Hill Terrace. The oldest and highest terrace found in the Manawatu River valley exists only on the eastern side of the river and occurs only between the Gorge and Aokautere. (See Fig.9 and Plate 4.) All evidence of this terrace on the west bank has been removed by river erosion. The writer has named this terrace the Forest Hill Terrace from a type locality N.149/192355 where the Forest Hill Road cuts through the terrace formation. Here the formation is 310 feet above sea-level and at its northern extent near the Gorge, four and a half miles away, it is 440 feet above sea-level with a gradient of 28.8 feet per mile.

There is only one exposure of terrace gravels; this is where a section of the terrace has been cut through by the Forest Hill Road. At this type locality only the top two feet of gravels are visible. The terrace deposits consist of poorly sorted subangular to subrounded greywacke gravels showing rust staining, which are scattered through an abundant matrix of fine fawn-coloured silt. The size of the gravels ranges from a quarter of an inch to four inches, while the most common size ranges from one to two inches. Overlying the top of the terrace is a 'buckshot gravel' layer (see p.25) and over twenty feet of loess deposits. Interbedded within the loess deposits is the Aokautere Ash layer. (See Fig.13, p.65.)

The Milson Terrace. The Milson Terrace, named by Cowie as the terrace on which the suburb of Milson is situated, also called the Milson, Grove and Centre Terraces by Rich, is the oldest aggradation surface to be found along this stretch



THE MANAWATU TERRACES
SCALE
Stoney Creek
Manawatu River
464'
448'
450'
385'
295'
FOREST HILL TERRACE
Holocene Terraces
Roads
Railway
550'
Spot Heights
Fig 9

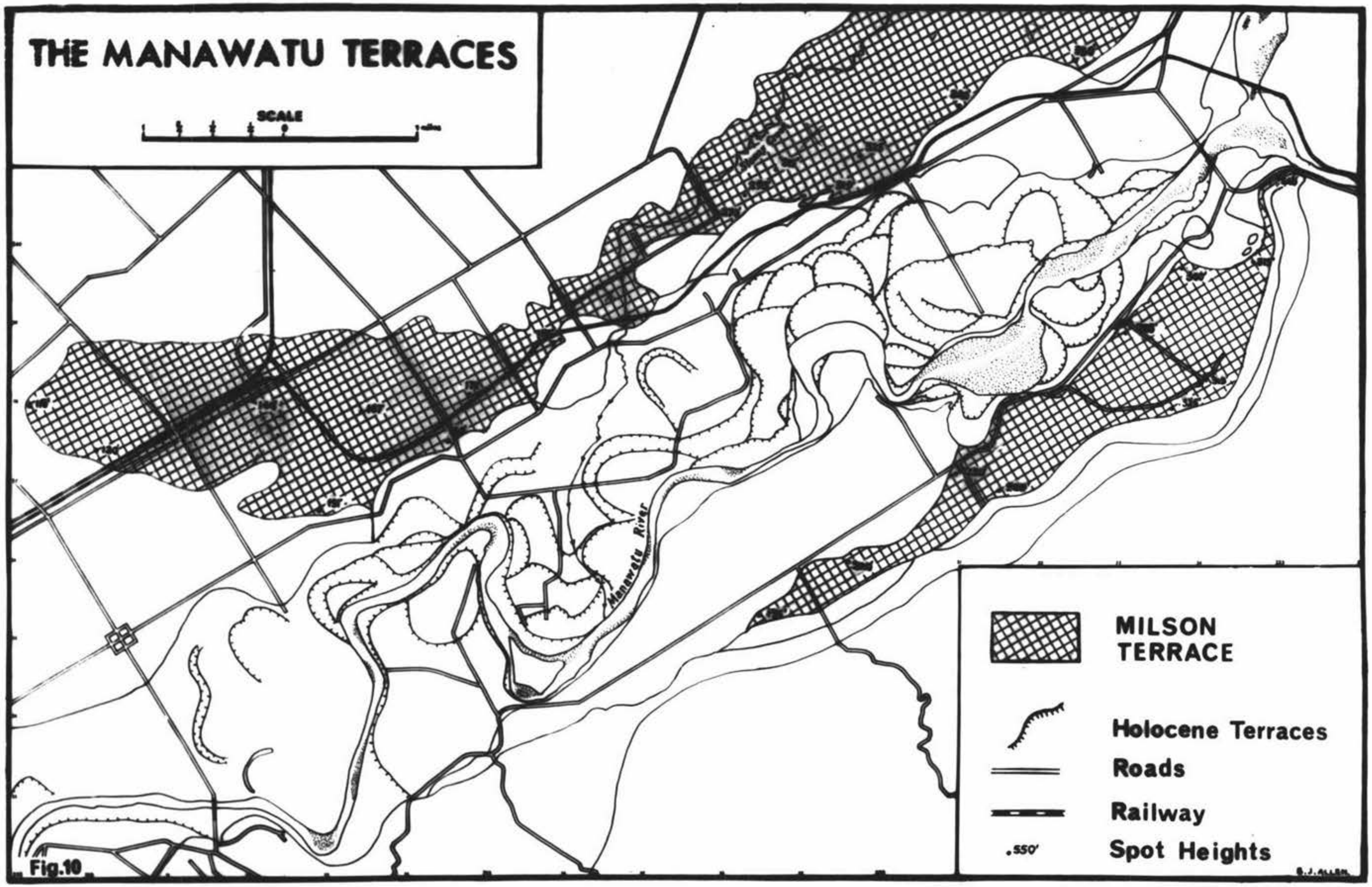
Plate 4

The Forest Hill Terrace (F) looking south along the scarp edge of the terrace.

of the river. Its best development is on the city side of the river extending from Ashhurst through to Palmerston North itself. (See Fig.10.) On the east bank it extends for only five and a half miles south from the Gorge. It has a tread of up to a mile at Centre Road and narrows further south due to later fluvial erosion.

The type locality chosen for the Milson Terrace on the western bank is a quarry on Roberts Line, N.149/135337, where the gravels are clearly exposed. (See Plate 5.) An exposure on the east bank at Centre Road, N.149/232391, was also studied. (See Plate 6.) The terrace deposits consist of compacted, rust-stained, subrounded to subangular greywacke gravels. The predominant size of the greywacke cobbles in a matrix of fine fawn-coloured silt is within the range from four to six inches. The deposits of the Milson Terrace show very little sorting and there is a distinct break between the top of the terrace and the overlying loess, in which the Aokautere Ash band is also interbedded. (See Fig.13 and Plates 5 and 6.) At the type locality the top of the terrace is about 43 feet above the river and 160 feet above mean sea-level. At the northern limit of the study area, near the Ashhurst-Bunnythorpe Road, the east bank is 350 feet above sea-level, falling to 118 feet in eight miles at the south-west of Milson, with a gradient of 29 feet per mile. This terrace is probably the same age as the St John's Terrace in Wanganui (Fleming 1953, 71) and the Rata Terrace on the Rangitikei River (Te Punga, 1952, 38).

The Ashhurst Terrace. The following aggradational


THE MANAWATU TERRACES
SCALE
Manawatu River
MILSON TERRACE
Holocene Terraces
Roads
Railway
.550'
Spot Heights
Fig.10

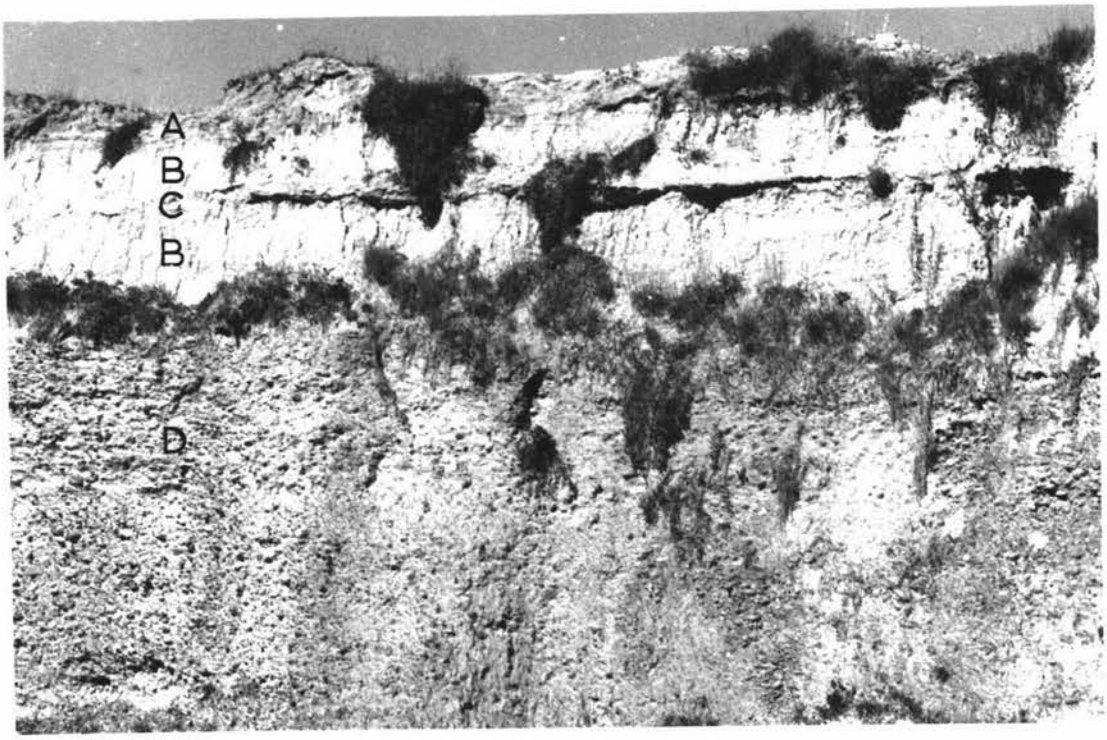


Plate 5

The Milson Terrace on the west of the river in the quarry on Roberts Line, N.149/135337, showing 14 feet of slightly compacted greywacke gravels (D) overlain by seven feet of loess (B). Interbedded in the loess is a six inch band of Aokautere Ash (C) which is overlain by three feet of loess and 6-8 inches of topsoil (A).

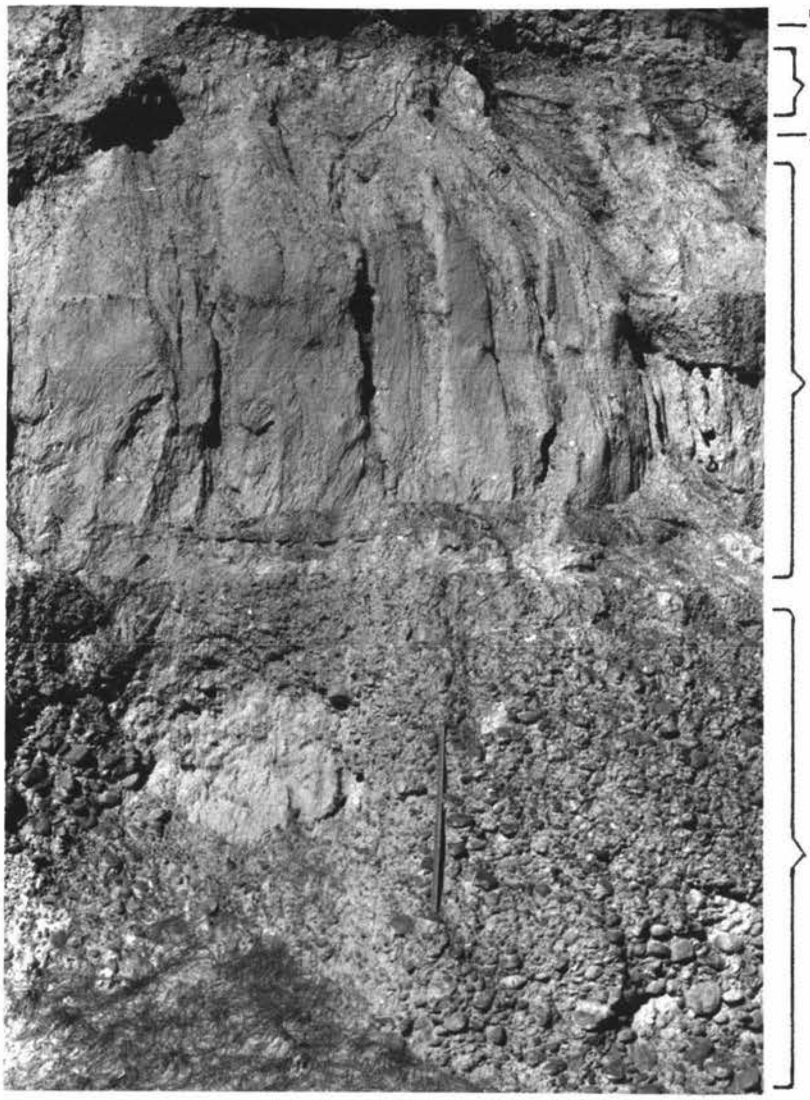


Plate 6

The Milson Terrace on the east bank of the river on Centre Road, N.149/232391. The marker is a three foot measure. Gravel bands in the loess have been deposited by a near-by tributary stream.

phase produced a surface here termed the Ashhurst Terrace (see Fig.11) previously referred to by Rich as the Ashhurst, Terrace End and Aokautere Terraces. Cowie (1961) suggests that this surface might be correlated with the Ohakea Terrace (Te Punga, 1957) on the Rangitikei River. The type locality chosen for the best exposure is a road cutting on the west bank leading away from the Ashhurst bridge, N.149/237416. The road exposure is about 40 feet in height showing a massive bed of unsorted, subrounded to subangular greywacke pebbles of a common size in the four to six inch range. (See Plate 7.) Two other exposures further downstream were also studied; downstream on the west bank on James Line, N.149/156380, and across the river two miles due south of Ashhurst at N.149/234396. In both exposures only about eight feet of the terrace sediments are visible. The top three feet of the gravels deposited, however, showed considerable variation in particle size, ranging from pebbles of two to three inches to nine to twelve inch subangular boulders. (See Plates 8 and 9.) In comparison with the northern exposure where the pebbles were a common size and showed a degree of compaction in a very fine but sparse matrix, the two exposures further downstream showed very little compaction and the pebbles and cobbles were set in an abundant fine silt matrix.

These three terraces can be correlated by the fact that they are all overlain by loess deposits in which no Aokautere Ash band occurs (see Fig.13) and also by their height relationships or profiles. (See Fig.15a, p.72.) The

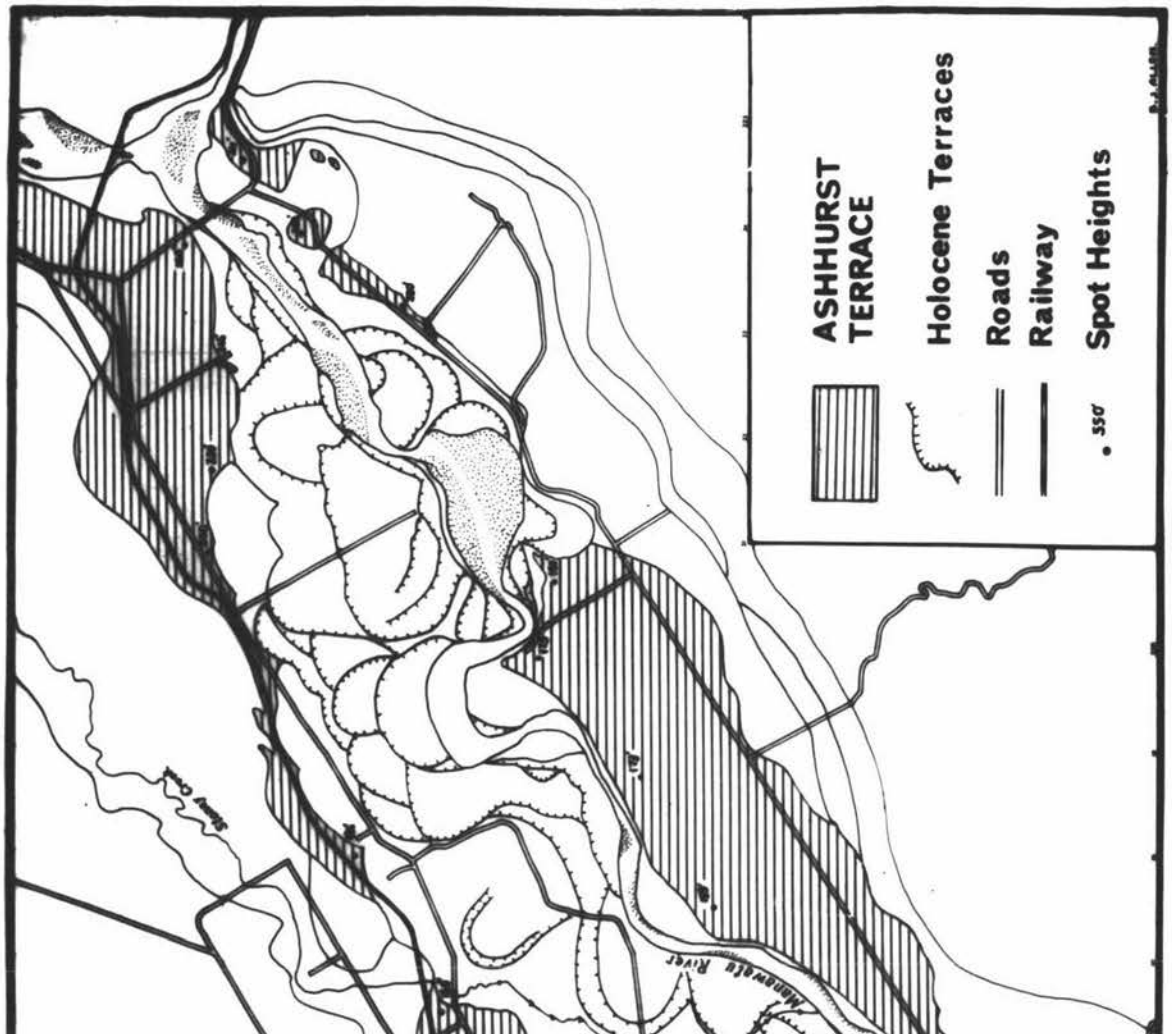

THE MANAWATU TERRACES
SCALE
1 mile
Stoney Creek
Manawatu River
ASHHURST TERRACE
Holocene Terraces
Roads
Railway
Spot Heights
350

Fig.11

Plate 7

The Ashhurst Terrace exposed in a road cutting on the west side of the river near the Ashhurst Road Bridge (N.149/237416). The loess deposits overlying the terrace gravels are only a few inches thick. The marker is a three foot measure.

Plate 8

The Ashhurst Terrace on James Line, N.149/156380, on the west of the river. The terrace deposits consist of greywacke cobbles set in a matrix of gravelly sand. The loess deposits here have accumulated to a depth of only 8-12 inches. This accumulation may be compared with that on the east bank of the Manawatu River. (See Plate 9.) The marker is a three foot measure.

Plate 9

The Ashhurst terrace deposits at N.149/238241, on the eastern bank of the Manawatu River, showing a silt lense occurring within the gravels. The loess accumulation of two feet has been much greater than at the other two areas studied. (See Plates 7 and 8.)

loess deposits on the three terraces vary in thickness. Near the Gorge the loess is three to four inches deep, while further downstream it has thickened to about eight inches and on the eastern side of the river the loess deposit is over two feet in thickness. (See Plates 7, 8 and 9.)

The Ashhurst Terrace extends on the west bank as dissected remnants from the Gorge to Palmerston North while on the east bank it has been cliffed and eroded away south of Aokautere. (See Fig.11.) The most extensive area of tread, over a mile and a quarter wide, is on the east bank near Orr's Road. The gradient of the terrace on the east bank falls from 250 feet at the Gorge to 135 feet just south of Aokautere, 115 feet in seven and a half miles with a gradient of 15.3 feet per mile. On the western bank the terrace stands at 250 feet above mean sea-level at its type locality, dropping to 100 feet near the Square (Palmerston North City), N.149/214348, a drop of 150 feet in eight miles, a gradient of 18.7 feet per mile.

<u>The Raukawa Terrace</u>. The lowest and youngest aggradation surface found along the Manawatu River is much smaller in extent than the older terraces; a remnant of it exists only within two and a half miles of the Gorge. Its type locality is taken from a cutting on the Raukawa Road, N.149/204406, and hence will be referred to as the Raukawa Terrace. (See Fig.12.) This terrace is the only aggradation terrace to show a slight degree of stratification of the gravels. (See Plate 10.) This stratification, occurring near the top of the terrace deposits, may be indicative of climatic variations

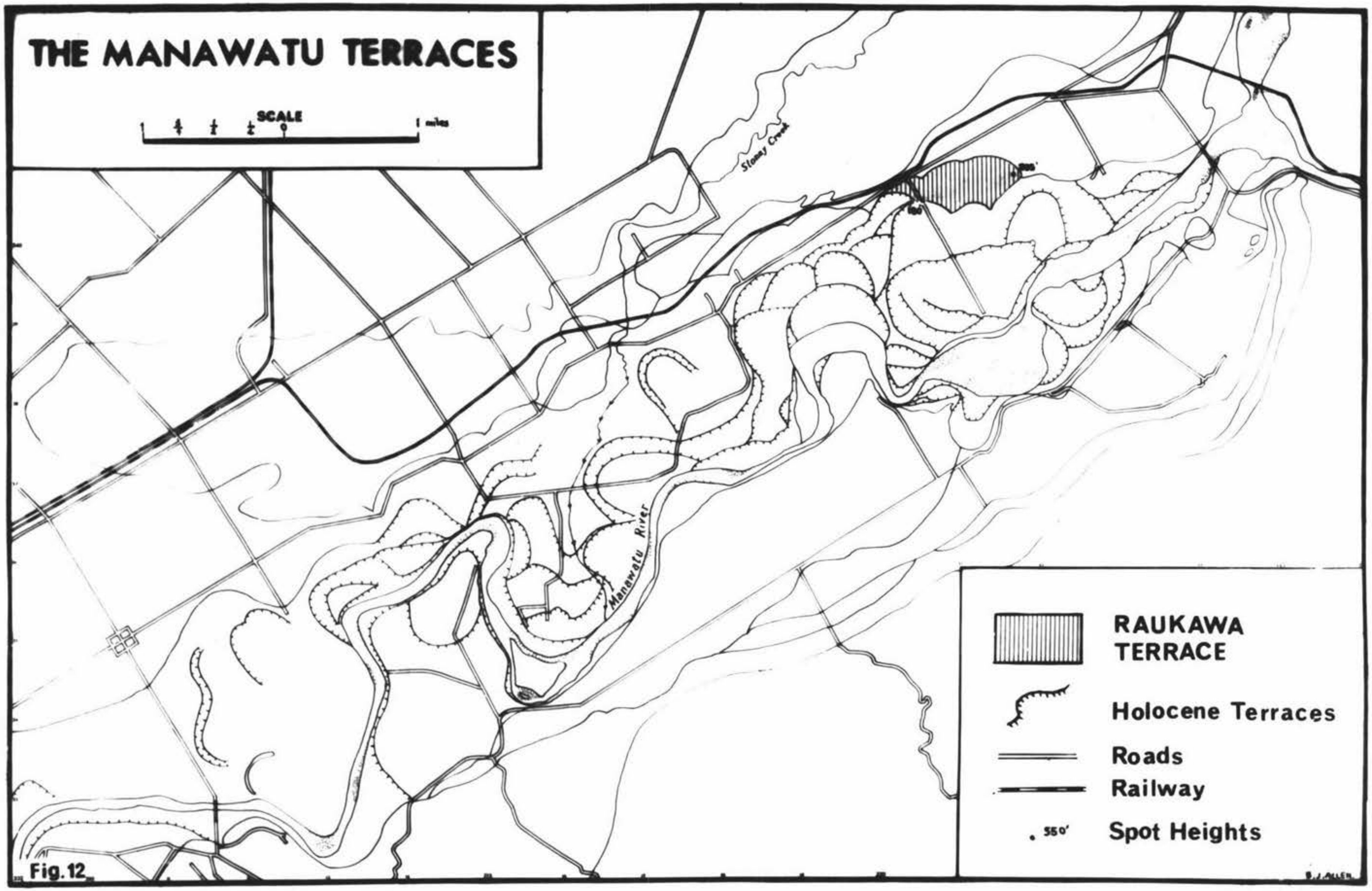

THE MANAWATU TERRACES
SCALE
1 miles
Stoney Creek
Manawatu River
RAUKAWA TERRACE
Holocene Terraces
Roads
Railway
550'
Spot Heights

Fig. 12

Plate 10

The Raukawa Terrace at the exposure on Raukawa Road, N.149/204406, this is the youngest aggradation surface in the Manawatu River valley. The gravels overlain by three feet of loess show a slight degree of stratification. The marker is a three foot measure.

reflecting load and volume differences that occurred as glacial conditions were receding. The subrounded and subangular greywacke gravels range in size from pebble bands one to two inches in length, to strata of ten to twelve inch boulders. The matrix of yellow-brown sandy silt in which little compaction has occurred, is relatively abundant. At the top of this terrace a distinct break again occurs where loess deposition takes place and over three feet of loess overlies the terrace. (See Fig.13 and Plate 10.)

Terrace Deposits. The terrace deposits consist predominantly of greywacke gravels with very minor amounts of red chert fragments. The coarser greywacke debris has been derived from the greywackes of the Rimutaka Sequence of the Axial Range. The greywacke detritus in all the terraces shows no great marked contrast in the size of the cobbles, which range from quarter of an inch to twelve inches, with cobbles in the two to four inch range being the most common. Rich (1959, 99) considers that, as similar-sized cobbles appear in the streams and rivers, this small size range is apparently dependent upon a more-or-less restricted initial size range of the greywacke fragments, controlled by the closely spaced fracturing of the undermass, resulting in few large, joint-free blocks being delivered to the streams. The intense congelifraction that occurred during the glacial periods no doubt also played a part in this surface fracturing of the greywacke. The finer material of the matrix has been derived from the erosion products of the softer covering strata, mainly Tertiary in age, which were deposited on the older,

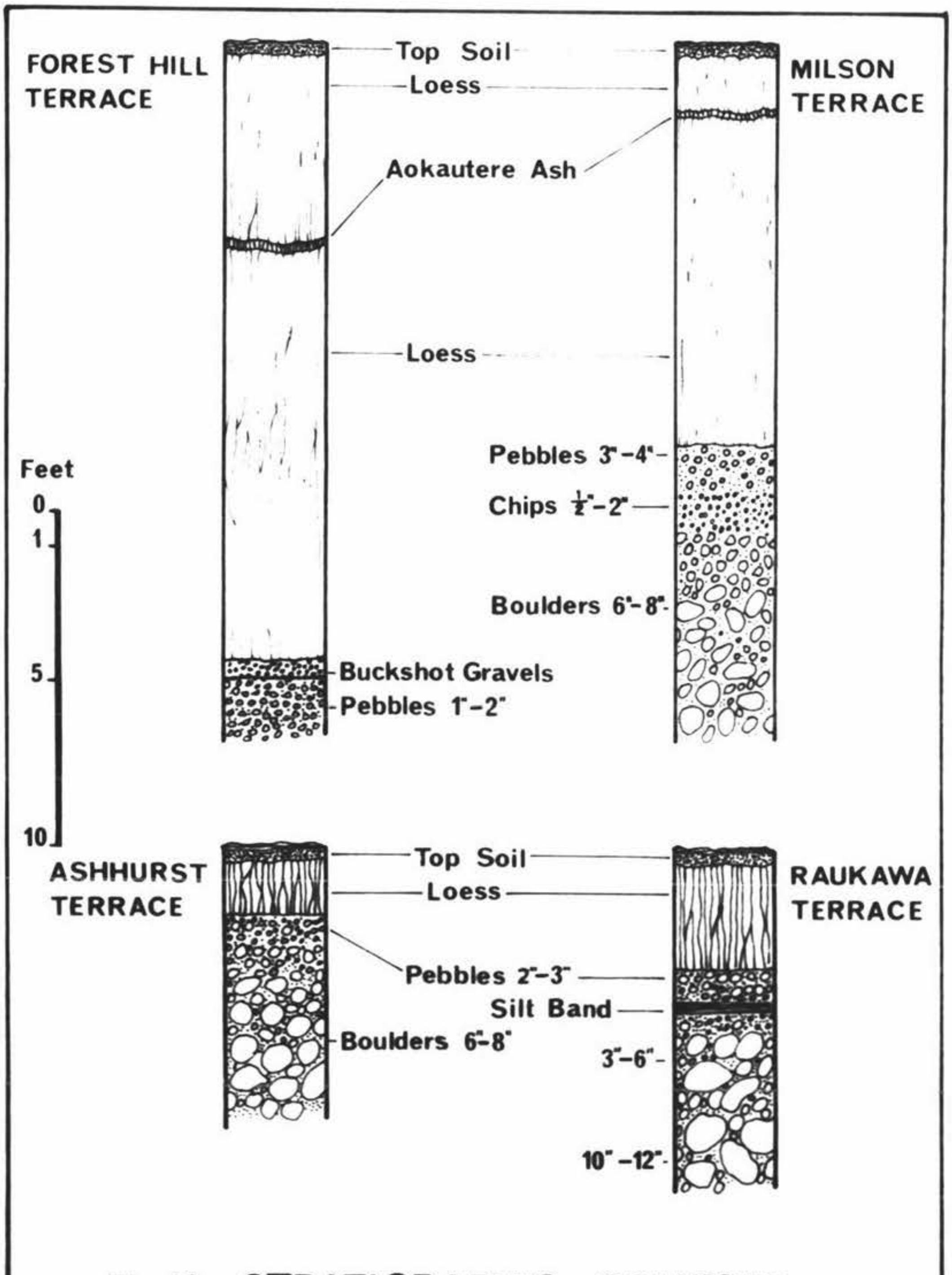


Fig. 13 STRATIGRAPHIC COLUMNS.

indurated greywacke of the axial range.

A small range is evident in the degree of compaction of the sediments. The youngest terrace, the Raukawa, with its fine silty matrix shows no compaction whereas on the older Milson Terrace the gravel beds show a small degree of compaction. A similar sequence also occurs in the rust-coloured iron-staining of the sediments; the Raukawa sediments show no rust colouring, the Ashhurst a dull dark brown colour, the Milson Terrace a rusty brown and on the Forest Hill Terrace rust stains are bright orange. It appears, then, that the degree of rust staining and compaction both increase with age.

Loess Deposits. Loess deposits blanket all the aggradational terraces within the study area. The thickness of these deposits varies, ranging from six inches on the west bank of the Manawatu River to over twenty feet on the east bank. (See Plates 5, 6, 8 and 9.) This differential deposition of loess on all the aggradation terraces and older formations means that the surface deposits are much younger than the fluviatile and marine deposits they overlie. The loess results in a ubiquitous soil type on all the terraces so that soil development and soil types could not be used as a supplementary study in dating the terraces.

The term loess is used here to include sediments formed from wind blown dust and not, as is common with the European loess sediments, based on calcium carbonate content and narrow size range. The loess deposits in the Manawatu show no characteristic bedding and lensing of water deposited sediments. The uniform deposition above the sub-aerial

Aokatuere Ash and the presence of numerous yellowish-brown stained pores "thought to represent the root channels of the plants that grew while the loess accumulated" penetrating it, all indicate a loessial origin. (Cowie, 1964b, 71.)

The loess on the Manawatu River Terrace surfaces is thought to be derived from dust blown mainly from river sediments. (Cowie, 1964b.) This deflation by wind is limited to dry, loose, fine-grained sediments not protected by a plant cover. Conditions necessary for the deflation of the loess would have existed during periods of glaciation when cryergic conditions in the surrounding hill country prevailed down to elevations of 600 to 1,000 feet above sea-level. If vegetation did exist in the Manawatu district during the glacial periods, it would probably have been predominantly sub-alpine grasses and dwarfed shrubs providing only a scant vegetation cover. The wide braided flood plain of the Manawatu River, together with other rivers to the west, would have exposed extensive areas of silt and sand for deflation, providing a bountiful source area for the loess. The almost non-existent fine sand matrix in some parts of the terrace sediments is probably due to the wind deflating this material from the flood plain of the braided river and depositing it as loess on the older surfaces. This probably accounts for the sharp transition noted between the gravels of the terraces and the loess deposits capping them. (See Plates 4 to 9.)

It seems reasonable to assume that during the glacial periods the winds were predominantly from a north-westerly direction as they are today. Evidence for this is found in the greater accumulation of loess on the south-east bank of the rivers in the Wanganui Basin. (Cowie, 1964b.) The greater deposition of loess to the south-east of the Manawatu River was further augmented by the axial range, acting as a barrier to the further dispersal of loess by the north-west wind. This differential deposition of loess on the terraces has led to problems concerning both the validity of terrace profiles and the degree of accuracy of the profiles drawn.

Loess deposits are generally regarded as accumulating during the glacial periods when cryergic conditions existed in the watersheds of the main rivers. It would appear that loess accumulation was in progress in the Manawatu area during the aggradation of the terraces, continuing in the interstadials, while cryergic conditions still existed on the axial range. The loess deposited on the steeper slopes of the axial range has since been moved downward by mass wasting and has accumulated at the base of the slopes as colluvium. In other places colluvium has also masked the height relationships between adjacent terraces and has also smoothed the scarp faces of the older terraces. (See Fig.14.) The Milson Terrace between Aokautere and Forest Hill Road, for example, has undergone a degree of masking due to downslope movement of colluvium. Here the difference in height between the Milson and the Ashhurst Terraces is 25 feet, whereas, diagonally across the river, it is over 30 feet where the scarp edge is much sharper. This masking of the terraces at Aokautere can be seen quite clearly in Plate 11.

The uniformity of the loess and lack of soil layers on the terraces seems to indicate that the climate during the interstadials of the Last Glaciation did not ameliorate enough for soil forming processes to occur. The advance of the ice and the accompanying cryergic conditions pushed sub-alpine shrubs and grasses down to sea-level. Recolonisation by plants was from the north. As noted earlier, Fleming (1962) found cold climate pollen assemblages with no tree pollens present as far north as Taranaki. Consequently, plant recolonisation was hindered by distance from a seeding area and the slow return to warmer conditions during the interstadials. Plant recolonisation also would be inhibited if the summer maximum temperatures were hovering only a few degrees above freezing point; this does not necessarily imply extremely cold conditions throughout the whole year. From the uniform deposition of the loess in the Manawatu, it appears that throughout most of the Otiran Glaciation climatic conditions favoured the slow accumulation of loess. Further evidence for a slow return to warmer conditions and the slow reinvasion of the area by plants is the three feet of loess deposited on the Raukawa Terrace. The Raukawa Terrace was aggraded during the final retreat of glacial conditions about 14,000 years B.P. and as Cowie (pers comm) considers that a foot of loess could take over a thousand years to accumulate, loess accumulation probably did not end until about 10,000-11,000 years B.P.

<u>The Aokautere Ash Band</u>. In the Manawatu district a volcanic ash band, the Aokautere Ash, occurs in most of the older loess deposits. Cowie (1964a) studied this ash layer

Plate 11

The Milson Terrace just north of Aokautere, N.149/194365, showing masking of the edge by colluvium. The surface in the foreground is the Ashhurst Terrace behind which is the gentle scarp of the Milson Terrace. The broken line indicates the remnants of the Forest Hill Terrace and above this is the Tokomaru Marine surface (T).

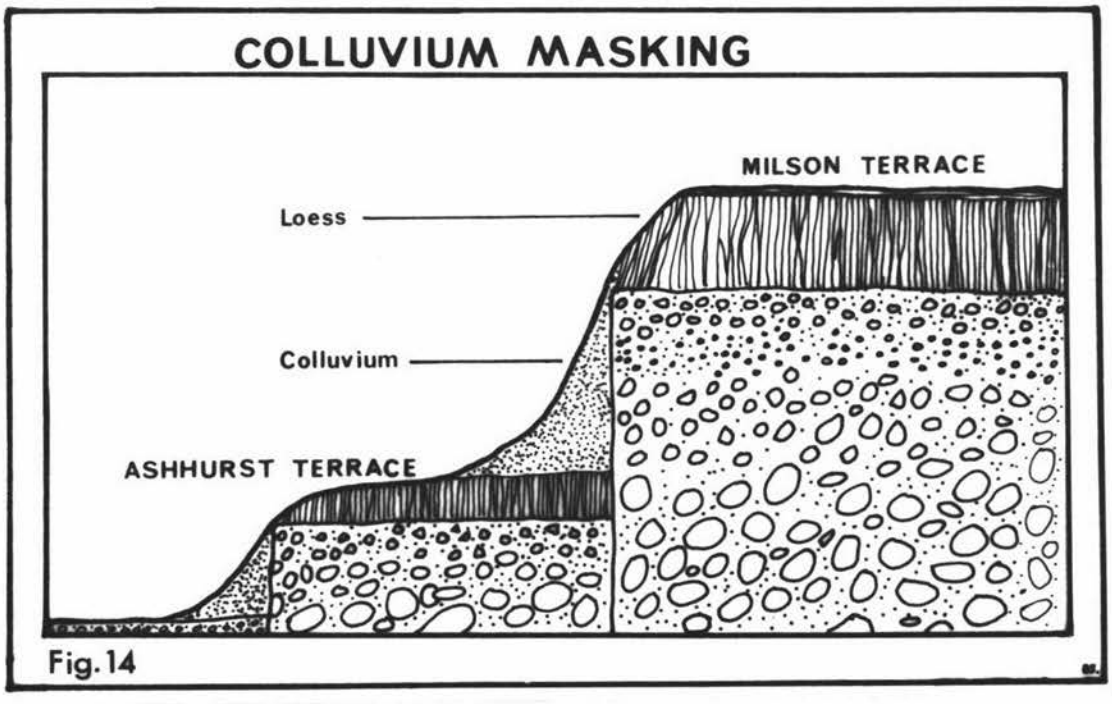


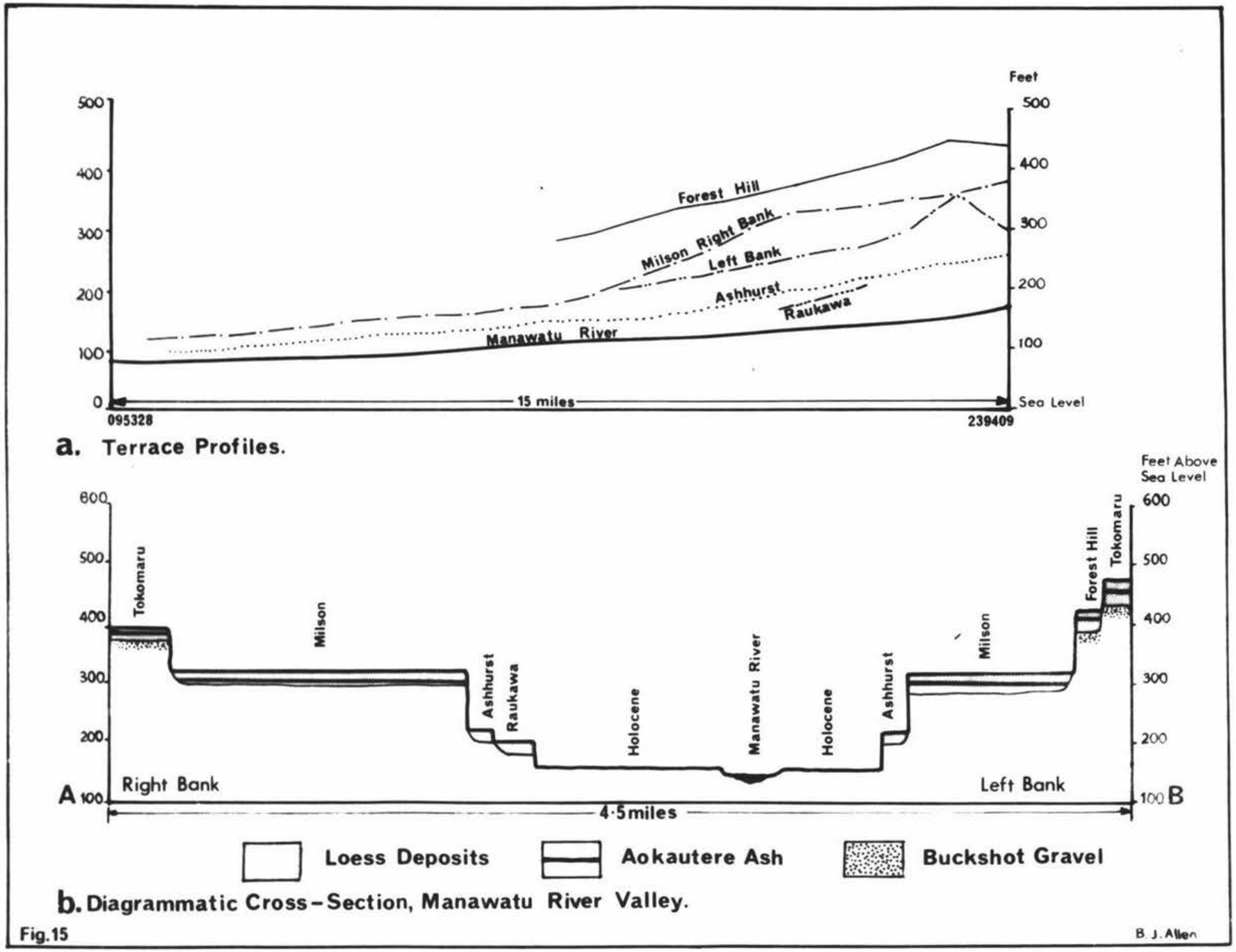
Fig.14. Schematic cross section of the Milson and Ashhurst Terraces, showing the masking of the true scarp edge by downslope movement of colluvium.

in a type locality, N.149/132313, one and three quarter miles southwest of Aokautere. This ash was erupted from a source area north of Taupo. Loess was accumulating when the ash was deposited, and for several thousand years after, rapidly burying and protecting it from erosion and soil forming processes.

The Aokautere Ash band, the only marker bed in the study area, has been dated as 21,000 years B.P. ± 500 years, by Cowie and Vucetich. (In Press.) This ash band is interbedded with loess on all surfaces older than the Ashhurst Terrace (see Figs. 13 and 15b), including the gently rolling tops of the Tararua Range. Both the Forest Hill and the Milson Terraces must be older than 21,000 years, and the Ashhurst and Raukawa aggradation surfaces must therefore be younger.

CONDITIONS OF TERRACE FORMATION

The fluvial deposits of the Manawatu River are all younger than a Hawera marine formation of late Oturian age, which has been named the Otaki Sandstone (Oliver, 1948), the Tiritea Formation (Rich, 1959), and the Tokomaru Marine Terrace (Cowie, 1961), known here as the Tokomaru Marine Terrace formation. At Waikanae a lignite band lies ten feet below the surface of this Hawera marine formation. Te Punga (1962) has C^{14} dated a sample of this lignite as being older than 45,000 years B.P. As all the fluvial terraces of the Manawatu River are younger than this formation they were therefore formed less than 45,000 years B.P.



a. Terrace Profiles.

b. Diagrammatic Cross-Section, Manawatu River Valley.

Fig. 15

The retreat of the Hawera Sea which left the Tokomaru Marine formation emergent seems, on the following evidence, to have been tectonic rather than eustatic in origin. It appears that when the land was uplifted the Manawatu River first cut into the marine formation followed by aggradation during a period of base-level stability. (See Fig.16a and b.) This period of aggradation was followed by a lowering of base-level and entrenchment, leaving the previous floodplain as a terrace here named the Forest Hill Terrace. (See Fig.16c.) It was on this terrace surface that a soil profile developed during a period of climatic and tectonic stability. This soil layer is also present on the Tokomaru Marine Terrace formation. (See Fig.15b.) A later development in this soil profile was the leaching of the iron salts to form a 'buckshot gravel' layer. (Te Punga, 1954.) The degree of chemical weathering necessary for the formation of these iron nodules and the depth of the clay in which they have developed indicate a lengthy period of uninterrupted soil formation and a warm humid climate. This suggests that the Hawera sediments of the Tokomaru Marine Terrace and the Forest Hill Terrace were emergent for quite a considerable time at the end of the Last Interglacial. Another fact which indicates that these terrace surfaces are Oturian in age is the fact that loess deposits occur only above this soil layer, whereas on the three aggradation surfaces no soil development has occurred and the loess is deposited straight on to the terrace gravels.

The first advance of the Otiran Glaciation ice caps in the North Island absorbed large volumes of water as ice,

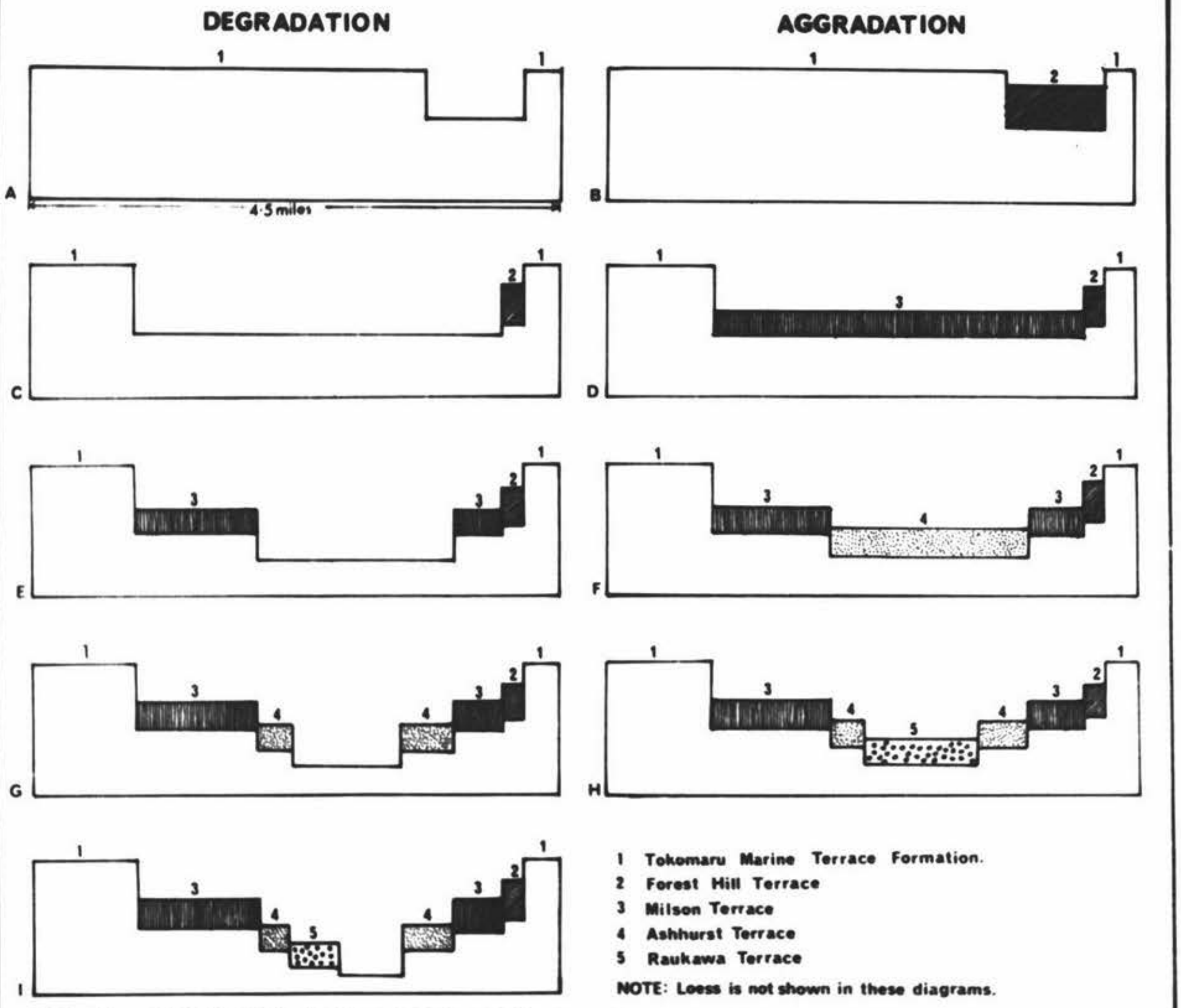


FIG. 16. HYPOTHETICAL CROSS SECTION OF THE TERRACES.

and as this was probably a world wide advance of glacial conditions, a corresponding lowering of sea-level took place. The lower sea-level forced the Manawatu River to degrade, cutting through the terrace gravels into the Tokomaru Marine Terrace formation. This downcutting removed all evidence of the Forest Hill Terrace on the west bank and excavated the Tokomaru Marine Terrace on both banks. (See Fig.16c.) With the return of warmer conditions during an interstadial the Manawatu River and its tributary streams were supercharged with greywacke detritus. The rising sea-level and the increased load of the river resulted in the aggradation of the Milson Terrace, a typical cut and fill terrace. (See Fig. 16d.)

The aggradational phase of the Milson Terrace appears to be linked to the retreatal phase of the Kumara-2 first advance (Suggate, 1965), dated by Brodie (1957, 638) as occurring in the Wellington area about 37,000 years B.P. Terrace aggradation probably was greatest between 32-35,000 years B.P. It seems that at this stage of its history the Manawatu river was flowing over a wide flood-plain, leaving a perched meander including a marine formation remnant at N.149/179394.[6]

A portion of another formation is situated in the north of the study area. (The southern-most portion of this formation is at N.149/226422 and it extends in a northerly direction.) (See Figs. 8 and 17.) This formation was first thought to be a terrace (see Plate 12), but closer inspection in a quarry at the southern end (N.149/228423),

Plate 12

The terrace like lacustrine deposits intersected by the road are an intermediate formation between the Milson Terrace, with its smooth scarp edge on the left of the photograph, and the younger Ashhurst Terrace in the foreground.

where road construction was in progress, revealed lacustrine deposits. In the quarry a stratigraphic column of over twenty feet was exposed. (See Plate 13.) The lowest bed visible was four feet of lamella, cross-bedded, fine, grey, soft sandstone, showing very little compaction. The break in sedimentation between this soft sand and the overlying six feet of pale grey 'papa'-like mudstone is marked by a thin iron-stained band. Another iron-stained band separates the mudstone from the overlying loess. The Aokautere Ash band occurs in the upper layer of the loess, so that at some time since the glacial retreat of the Kumara-2 first advance, 32,000 - 35,000 years B.P., and before the deposition of the Aokautere Ash layer at 21,000 years B.P. it appears that the Manawatu and Pohangina Rivers have been ponded to form a lake in the vicinity of the Gorge. (See Appendix B.)

The second Kumara-2 glacial advance and its consequent lowering of sea-level, caused the Manawatu River to corrode all the lacustrine deposits on the range side of the river. During this degradational phase the river also removed all vestiges of the Milson Terrace on the east bank north of Aokautere undercutting the Forest Hill Terrace which it has left as a 'hanging terrace'. (See Plate 14.) This aggradational phase, following the glacial retreat at the end of the second Kumara-2 advance, C^{14} dated as occurring between 18,000 and 21,000 years B.P. in the South Island of New Zealand (Suggate, 1965, 84), produced the Ashhurst Terrace in the Manawatu. (See Fig.16f and g.) The loess deposits on this terrace do not contain the Aokautere Ash band, therefore

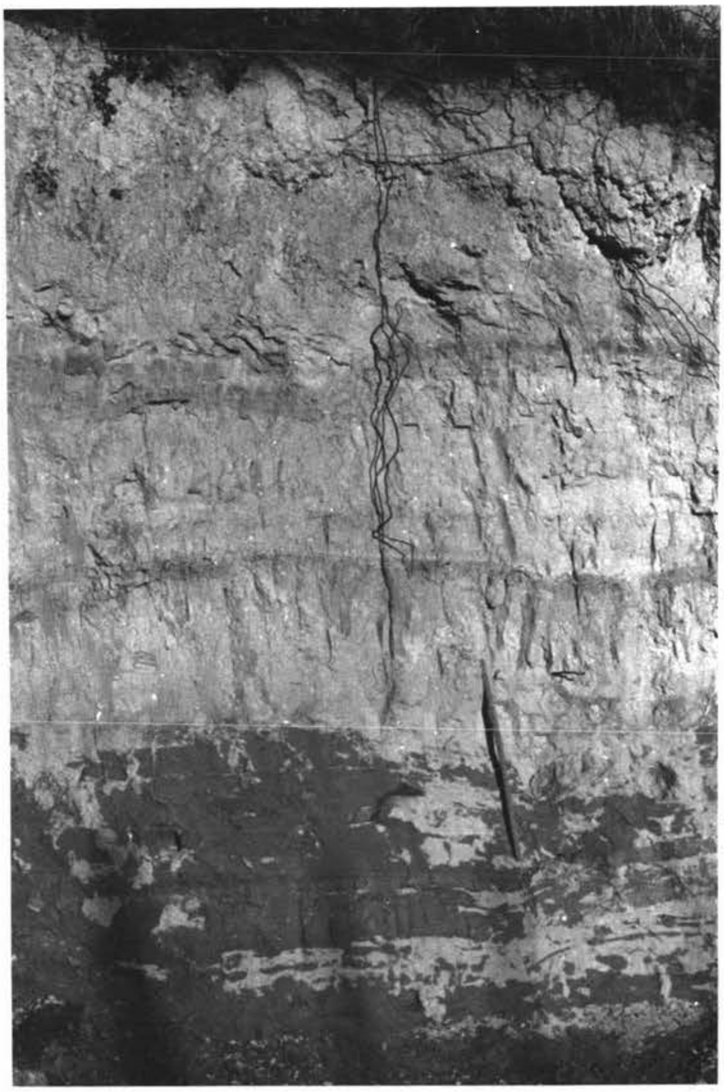


Plate 13

The lacustrine deposits exposed in a road cutting at N.149/228423. The marker is a three foot measure.

Plate 14

Remnants of the Forest Hill Terrace. Lateral corrasion by the Manawatu River has removed the Milson Terrace and left the Forest Hill Terrace as a 'hanging terrace' above the much younger Ashhurst Terrace.

this terrace was formed either before 21,000 years B.P. or it was being deposited when the ash shower occurred, hence the ash is mixed in with the gravels and does not remain as a distinct layer. The Ashhurst Terrace appears to correlate with the Takapu Stadial on the Wellington Peninsula, which is C^{14} dated to have occurred from 20,000 to 23,000 years B.P. (Brodie, 1957, 638.) The second Kumara-2 Glaciation (the Takapu Stadial) was the maximum glacial advance of the Otiran Glaciation. The bulk of the ice on the ice fields of the Tararua and Ruahine Ranges had probably melted by about 16,500 years B.P. and cryergic conditions would have existed only at high altitudes.

A short return to glacial conditions at the end of the Otiran Glaciation occurred when the ice caps advanced for a short time about 14,800 ± 230 years B.P. with most of the aggradation having ceased by 14,100 ± 220 years B.P. (Suggate, 84.) The Raukawa Terrace is the result of this short glacial advance and retreat. (See Figs.12 and 16.1.) A slow return to warmer conditions is indicated by a three foot layer of loess overlying the gravels of this terrace. The loess would probably have taken well over 3,000 years to accumulate (see p.69), and since the Raukawa Terrace lies on the west side of the river where maximum accumulation would not be expected, this three feet of loess suggests that cryergic conditions may have continued for a considerable period after the aggradation of the Raukawa Terrace. It seems probable from this thick deposit of loess that, at the end of the last glacial retreat, there was a slow return to warm conditions lasting for 3,000 to 4,000 years, until approximately 10,000 years B.P. which is accepted as the close of the Otiran Glaciation.

At the commencement of the Holocene 10,000 years B.P., climatic conditions ameliorated to a much warmer climate and most of the ice caps melted. This warmer climate aided the processes of slope stabilisation through soil-formation followed by the recolonisation of the area with vegetation, firstly by grasses, succeeded later by manuka scrub, then podocarp and nothofagus forest assemblages.

The steady warming of the climate in the last 10,000 years reached a peak at the Climatic Optimum of 7,000 to 4,000 years B.P. It has been postulated that at this time a marine transgression, here termed the Horowhenuan Transgression, occurred when sea-level rose about 15 feet above present sea-level; this hypothesis is not, however, accepted by all geologists and geomorphologists. Evidence in the Wanganui Basin points to a marine transgression occurring at this time cliffing the seaward edge of the Tokomaru Marine Terrace. (Te Punga 1962, Rich 1957, and Wellman 1962.) This transgression perhaps occurred for only a relatively short time and this could account for lack of evidence in areas of the world where the transgression would have occurred over hard crystalline rocks, which would not have eroded easily. Whether this transgression in the Wanganui Basin was eustatic or tectonic will not be argued here.

This Horowhenuan Transgression, which covered the easily eroded soft sediments of the Wanganui Basin, probably accounts for the absence of aggradation surfaces on the river between Palmerston North and the sea. Fleming (1962, 88) has postulated that the rivers of the Wanganui Basin, the west coast of the Wellington peninsula and the Marlborough Sounds area, would have built out extensive flood-plains during the lower sea-levels of the Last Glaciation of the Pleistocene, linking the North and South Islands of New Zealand across Cook Strait. Theoretically, the aggradation terraces of the Manawatu River would have extended much further coastward than at present. Since the Climatic Optimum of 7,000 to 4,000 years ago and the associated Horowhenuan Transgression, there has been no major terrace development along the Manawatu River. Three Holocene terraces have been formed and there is very little difference in height between them. Cowie (in press) has classified them by soil types.

The denudational chronology of the Manawatu River is summarised in the accompanying table. The aggradational terraces of the river have been linked to deglaciation in the Tararua-Ruahine Range during the Late Pleistocene. Conversely the periods of degradation have been related to the phase of advancing ice at the onset of glaciation.

In the Manawatu River valley the formation of the terraces has been sensitive to both the subtle and major pulses in climatic change. The major terrace development in this valley can be related to the glacial advances and retreats of the ice sheets and cryergic conditions that existed on the Tararua-Ruahine Range during the Otiran Glaciation. Climate has not only directly affected the formation of the terraces themselves but has also been important in

SUMMARISED CHRONOLOGY OF LATE PLEISTOCENE EVENTS IN THE MANAWATU RIVER VALLEY

AGE Years before the present	CLIMATE	GLACIAL AND INTER-GLACIAL CONDITIONS	FLUVIAL PROCESSES	GEOLOGICAL PROCESSES	LANDFORM
>45,000	Warm	OTURIAN INTERGLACIAL	Degradation	Retreat of Hawera Sea	Tokomaru Marine Terrace formation Forest Hill Terrace
>45,000-37,000	Warmer and wetter than the present		Aggradation and Degradation	Soil formation and leaching	Formation of fossil soil and 'buck shot gravels'
37,000-35,000	Cold	OTIRAN GLACIATION Kumara-2 First Advance	Degradation		Loess Deposition
35,000-32,000	Cool	Kumara-2 First Retreat	Aggradation		Milson Terrace
32,000-27,000	Warm but not as warm as the present	Interstadial		Tectonic down-warping of Pohangina Syncline	Manawatu and Pohangina Rivers ponded up to form a lake near the Gorge
27,000-23,000	Cool				
23,000-21,000	Cold	Kumara-2 Second Advance (Takapu Stadial)	Degradation		Loess deposits
21,000±500	Cold			Aokautere Ash Shower	Aokautere Ash Band
21,000-18,000	Cool	Kumara-2 Second Retreat	Aggradation		Ashhurst Terrace
18,000-14,800	Warm but not as warm as the present	Takapu Interstadial			Loess deposits
14,800-14,400	Cold	Kumara-3 Advance	Degradation		
14,400-14,100	Cool	Kumara-3 Retreat	Aggradation		Raukawa Terrace
14,100-10,000	Warm but not as warm as the present				Loess deposits
10,000-0 HOLOCENE	Warm	INTERGLACIAL			
7,000-4,000	Warmer than present	Climatic Optimum		Horowhenuan Marine Transgression	Cliffing of Tokomaru Marine Terrace formation

the development of the loess deposits which overlie the three aggradation surfaces and older formations, giving them all a smooth even topography.

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1. Loess is a pale yellowish or brownish unstratified silty sand, rich in vertical capillary structures. Loess embraces all aeolian deposits where transport has been primarily by suspension and deflation by wind. Not all loess has been derived from glacial sources. In some areas loess consists of material derived from arid regions by deflation.

2. Pleistocene is used in this sense as still occurring, although this thesis will also use the term Holocene as denoting this present interglacial period.

3. Glacial conditions prevailed on the Tararua Range during the Otiran Glaciation. There is evidence, U-shaped valleys and glacial cirques, on the slopes of the Mitre and Arete Peak that glacial ice filled five river valleys. (Adkin, 1912, 308.)

4. Compositae, the family of daisies, dandelions and thistles, is the largest, most widely scattered and most successful of all the families of flowering plants in the world. There are over 260 species in New Zealand.

5. The alpine greywackes of the South Island alpine chain at present produce large volumes of scree, especially in the foothills, where cryergic conditions prevail. A topography similar to the scree slopes and wide braided river flood plains of the Canterbury Plains would have been a characteristic feature of the late Pleistocene topography in the Manawatu area.

6. In a study of the morphology of the Manawatu District, conducted by Geography Masterate students in 1966, the reverse drainage pattern, which occurs around this perched meander forcing the drainage away from the river at this point, was noted. No further field work, however, was conducted into finding why the drainage at this point should slope away from the river.

V. CONCLUSION

This thesis which is basically a denudational chronology of the Manawatu River valley has also investigated the more important aspects of structural, tectonic and climatic controls upon the evolution of the river valley. As the Manawatu area is structurally unstable, it was originally considered that tectonic control could have been a major controlling factor in the evolution of the Manawatu River terrace development. Another aim of the research, therefore, was testing the validity of King's hypothesis that "rivers may be studied to throw light on past climatic oscillation and variations in the other factors that control their character". (1966, 61.) The result of this research now indicates that climatic and not tectonic control has been of the greater importance in the evolution of the fluvial geomorphology of the Manawatu River valley.

The Otiran Glaciation ice-fields and their associated cryergic zones on the Tararua and Ruahine Ranges produced large volumes of frost-shattered greywacke scree and soliflual material. During periods of glacial retreat large amounts of this material, no longer ice-bound, moved down-slope and was injected into the tributary streams of the Manawatu River. This abundant supply of frost weathered soliflual debris greatly increased the load of the river. This factor, together with a reduced flow because of decreased precipitation which Frye (1961) has suggested also characterises the retreat of glaciers, plus a rising sea-level, caused alluviation in the Manawatu River valley.

The major terracing on the Manawatu River, the Milson, Ashhurst and Raukawa Terraces, can be related to the three major glacial retreats of the ice fields on the Tararua-Ruahine Range during the Otiran Glaciation. The first retreatal phase of approximately 35,000 to 32,000 years B.P. produced the Milson Terrace, the second following the longest ice advance, the Kumara-2 second advance (the Takapu Stadial), of the Otiran Glaciation resulted in the aggradation of the Ashhurst Terrace between 20,000 and 18,000 years B.P. The final Kumara-3 advance and its associated retreat 14,400 to 14,100 years B.P. produced the Raukawa Terrace. These three terrace formations within the Manawatu River valley owe their origins primarily to the climatic oscillations of the Otiran Glaciation.

Large amounts of the world's water was frozen in the great ice caps during the glacial advances and sea-levels were correspondingly much lower. Emiliani (1955) and Fairbridge (1961) have suggested that sea-levels during the Last Glaciation were as low as 100 metres below present sea-level. The thawing and melting of all the ice caps would, according to Fairbridge, produce a rise in sea-level of only 50 metres above the present datum. These eustatic changes in sea-level which have determined the base level of the Manawatu River have in turn affected the longitudinal slope of the terraces. The longitudinal profiles of the three aggradation terraces of the Manawatu River indicate that the base level (sea-level) of the river differed with each aggradational phase. (See p.72,

Fig.15a.) The Raukawa Terrace, with its extrapolated surface descending steeply below present sea-level, appears to have been formed when sea-level was considerably lower than it is at present. Consequently this terrace surface has been either eroded away or masked by Holocene river terraces further down river.

Climate, directly or indirectly, has controlled the aggradation of the terraces and the longitudinal gradients of these terraces within the Manawatu River valley. The formation of the loess deposits which overlie the three aggradation surfaces and the older surfaces in the Manawatu area, owe their origin to climate. Cryergic conditions evidently existed down to low levels on the axial range during the Otiran Glaciation, forcing the forest zone to migrate down to sea-level, leaving the Manawatu River valley with a sparse vegetation cover of sub-alpine tussock grassland. The flood plains of rivers on the eastern margins of the Wanganui Basin and the Manawatu alluvial lowlands with their sparse vegetation cover acted as a bountiful source area for these extensive loess deposits which were laid down during the Last Glaciation.

The positioning of the Manawatu River valley on the eastern edge of the Wanganui Basin has been largely controlled by structure. The basement greywacke of the Wanganui Basin is being subjected to great pressure from the west and, instead of folding, is breaking up into blocks or cratons. Some of these blocks are uplifted to form the anticlines and others the downthrown synclines. The Pohangina, Levin and

Himatangi Anticlines and their associated synclines, the Pohangina Syncline and the Kairanga Trough, are the important factors in the structural control of the Manawatu River. The anticlines rise at right-angles across what would appear to be the logical course of the river. The Manawatu River on leaving the Manawatu Gorge is forced by the Pohangina Anticline lying parallel to the Gorge to make a right-angled turn into the Pohangina Syncline, while further south the Levin and Himatangi Anticlines lying parallel to the coastline appear to act as a barrier to the river entering the sea. The Manawatu River, throughout its course from the Manawatu Gorge to the sea, flows as a subsequent river in the synclines associated with these anticlines. On leaving the Gorge it flows in the Pohangina Syncline then further south its course across the Kairanga alluvial plain is controlled by the Kairanga Trough which then guides it out to sea through the coastal barrier of the Himatangi and Levin Anticlines.

The anticlines and the synclines together have exerted considerable control in the positioning of the river. The Manawatu River, originating in late Oturian time, appears throughout its history to have been structurally guided as a subsequent river in the synclines. Since the Hawera Sea left the flanks of the axial range the river between the Gorge and Palmerston North has maintained its present course in the Pohangina Syncline. The relatively narrow river valley is bounded on either side by the Tokomaru Marine formation providing evidence that since this marine transgression the Manawatu River has not flowed straight out to sea across the

Pohangina Anticline.

Tectonically the Manawatu area has been particularly active during the Pleistocene resulting in the uplift of the axial range. This uplift is apparently still occurring for, since the Last Interglacial, the Oturian surface (i.e. the Tokomaru Marine Terrace formation) now lies some 440 feet above the present sea-level. At the Manawatu Gorge this formation is over 500 feet above sea-level; this uplift then has occurred in a period somewhat longer than 50,000 years. Some of the relative displacement can be attributed to eustatic sea-level change; most, however, is the result of tectonic uplift.

A period of intense tectonic activity appears to have occurred after the formation of the Milson Terrace. The two older terraces, the Forest Hill and the Milson, together with the Tokomaru Marine Terrace formation, all show evidence of warping within two and a half miles south of the Gorge on the left bank of the river. In the vicinity of Centre Road a number of faults converge (Rich, 1959) and it is here that doming occurs. (See Plate 15.) The older terrace profiles show this doming at Centre Road dropping down toward the Gorge. (See Fig.15a.) Across the river the Milson and Tokomaru Marine Terraces show no evidence of this faulting. This tectonic movement may in fact be related to a downward movement on the Pohangina Syncline as there does appear to be a relationship with the faulting causing the break in the terrace profiles and the lake that formed in this vicinity after the Milson Terrace was formed, especially as the Ashhurst Terrace

Plate 15

The northernmost part of the Tararua Range where the older surfaces, (N) Nukumaruan, (C) Castlecliffian, (T) Tokomaru Marine Terrace and (M) the Milson Terrace are domed and downwarped towards the Manawatu Gorge on the left.

shows no evidence of this faulting. (See Appendix B.)

This denudational chronology of the Manawatu River has revealed that the river originated in Castlecliffian time as a consequent flowing from the vicinity of the Waewaepa Range on the westward tilting Castlecliffian landmass. It established itself in the Manawatu Strait and has since been able to maintain its course through the axial range where it is now entrenched at the Gorge, into the greywacke to a depth of 1,000 feet. On the west of the Manawatu Gorge there appears to be a considerable time gap between the river's inception in Castlecliffian time and the oldest terrace which is of late Oturian age. Since the retreat of the Hawera Sea the Manawatu River has become entrenched in the Pohangina Syncline in a narrow course between the Tararua Range and the Pohangina Anticline, and even on the broad Kairanga alluvial plain its course is now structurally influenced by the Kairanga Trough and the Himatangi and Levin Anticlines.

The research carried out in the Manawatu River valley has also indicated that King's hypothesis is valid when applied to the Manawatu River. The climatic oscillations of the Otiran Glaciation have produced the major terrace developments in the river valley. Structural and tectonic controls have also played important roles in the positioning of the river but climate, however, appears to have been the most influential and most obvious control in the evolution of the fluvial geomorphology of the valley.

APPENDIX A

Data collected from an afternoon's field work, April 1967.

PLACE	TIME hours	TEMPERATURE in °F.	BAROMETER READING in feet	TIME hours	TEMPERATURE in °F.	BAROMETER READING in feet	MEAN ALTITUDE at 68 F.
Centre Road turnoff	14.40	68	180	15.48	65	174	180
Milson Terrace	14.47	68	285	15.42	64	277	285
Forest Hill Terrace	15.05	68	410	15.38	64	403	410
Gates on farm track	15.13	67	495	15.33	65	491	497
Tokomaru Marine Terrace	15.17	66	545	15.31	64	541	549
Marine strand (Castlecliffian)	15.26	64	695	15.28	64	695	703

APPENDIX B

The Kaikoura Orogeny which produced the younger mountain ranges of New Zealand including the Tararua-Ruahine Range, is probably still in progress. The Manawatu area is usually regarded as tectonically mobile and although there is little apparent surface trace of movements along the faults separating the axial ranges from the Wanganui Basin, the six live anticlines (Te Punga, 1954) are considered to be slowly and steadily rising. Accompanying this upward movement of some of the cratonised blocks in this eastern portion of the Wanganui Basin is the associated downward movement of the synclines, the Kairanga Trough and the Pohangina and Levin Synclines. (See p.30.) The tectonic instability of this area may in part account for the development of the lake on the Pohangina and Manawatu Rivers, in the north of the study area.

Tectonic activity appears to have been more intense in the period between the formation of the Milson and Ashhurst Terraces and it was during this period 21,000 years to 32,000 years B.P. that the lake was formed. The profiles of the Milson and Forest Hill Terraces on the left bank of the river are downwarped between Centre Road and the Gorge. (See Fig.15a.) This downwarping which occurred before the formation of the Ashhurst Terrace, is also evident on the Tokomaru and Castlecliffian marine formations. The down-warping of these surfaces in this portion of the river valley appears to be related to a downward movement of the Pohangina

Syncline as there is no corresponding downwarping of the terrace profiles across the valley on the Pohangina Anticline. The basement block of greywacke forming the northern end of the Pohangina Syncline apparently sank in relation to the Ruahine Range, the Pohangina Anticline and the river valley. This downwarping of the syncline, which may have been a very rapid drop or a steady slow sinking, caused the Pohangina and Manawatu Rivers to aggrade. While aggradation was occurring these rivers apparently formed a large lake in this synclinal depression. This lake would have remained until movement on the synclinal block had ceased and/or aggradation in the lake area had restored grade within the river valley.

The lacustrine deposits which lie at the northern part of the study area seem on cursory examination to extend up river for three to four miles, forming a lake of approximately 20 square miles. Further research, however, is necessary before the definite area of this lake can be postulated with any degree of accuracy.

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STRUCTURAL, TECTONIC AND CLIMATIC CONTROL OF THE FLUVIAL GEOMORPHOLOGY OF THE MANAWATU RIVER WEST OF THE GORGE

EILEEN E. FAIR
Massey University
1968

Figure 17


THE MANAWATU TERRACES
SCALE
1 ¾ ½ ¼ 0 1 mile
Stoney Creek
Manawatu River
TOKOMARU MARINE TERRACE
FOREST HILL TERRACE
MILSON TERRACE
ASHHURST TERRACE
RAUKAWA TERRACE
LACUSTRINE DEPOSIT