SOME ASPECTS OF THE CENOZOIC GEOLOGY OF THE MOAWHANGO RIVER REGION, IN THE ARMY TRAINING AREA, WAIOURU, NORTH ISLAND, NEW ZEALAND.

A thesis presented
in partial fulfilment of the requirements
for the degree
of Master of Science in Quaternary Geology at
Massey University

JOHN KIM WILLIAMS

1994

ABSTRACT

Late Tertiary marine strata of the Waiouru Formation were unconformably deposited on a dissected Late Cretaceous peneplain surface of unusually high relief formed on Torlesse Supergroup greywacke at Waiouru, Central North Island, New Zealand. Waiouru is uniquely located on the southern boundary of the Taupo Volcanic Zone and the northern margin of the Wanganui Basin, an infilled Pliocene basin now subject to Plio-Pleistocene uplift.

Two transgressive episodes are identified. The first involved submergence of the peneplain in the Neogene, when Kapitean mudstone was deposited. Then a general marine shallowing occurred around the New Zealand landmass which saw uplift of Waiouru towards the end of the Kapitean Stage, followed by a period of sub-aerial erosion. The second transgressive episode was initiated by subsidence of the Wanganui Basin in the Pliocene, which led to onlap of coarse shallow-water sandstones during the Opoitian Stage.

Basement subsidence tended to result in vertical rather than horizontal migration of the shoreline. No evidence has been found for previously recognised eustatic sealevel cycles, due possibly to masking by strong tidal conditions throughout the Opoitian sequence; Waiouru being located on the northern edge of the Pliocene Kuripapango Strait. Eventually, shallow seas supported a faunal population sufficient to produce widespread carbonate skeletal fragments that formed extensive shell limestone beds at the top of the Waiouru Formation.

Rapid lateral and vertical changes in the facies are interpreted as due to rapidly changing local depositional conditions. These were caused by the submerging basement initially forming a steep coast with at least two offshore islands. Marine infilling occurred within former incised river valleys 3 km wide and over 300 m in depth. Erosion of local greywacke contributed to the Opoitian sedimentation, as did a granitic source, probably in North-west Nelson, with materials transported from this latter source by currents propagating through the Kuripapango Strait.

The presence of abundant granite-derived micas in Opoitian strata, yet their absence in the Kapitean strata provide a limiting age for the arrival of micas in Wanganui Basin strata. As the Wanganui Basin depocentre moved southwards, offlap and emergence occurred with Plio-Pleistocene uplift.

The paleo-Moawhango River established its course in the newly uplifted strata, forming superimposed gorges where it cut into exposed basement. Except for initially deposited basal strata, dips in the Neogene marine strata are almost all uniformly consistent with the regional dip. Mapping of the shell limestone beds has shown post-Opoitian development of a small scale (<2 km wide) anticline and a minor associated fault.

To the south of the study area, the Waipipian age Taihape Mudstone overlies the Waiouru Formation. The contact between the two is interpreted to be the Opoitian-Waipipian boundary and thus the Waiouru Formation was deposited within the Opoitian Stage.

ACKNOWLEDGMENTS

I wish to thank my joint supervisors, Dr Vince Neall and Dr Alan Palmer for their advice and support. Further thanks are due to Dr Alan Beu, Institute of Geological and Nuclear Sciences, for his invaluable help and advice in fossil identification and fossil paleoenvironmental conditions.

My thanks also to Dr C.E Ingham for his notes and geophysical data of the Moawhango Dam area; Andrew Hammond for his ready assistance in field work (as well as providing innumerable cups of coffee) and to the Department of Survey and Land Information for permission to use copyrighted map material from the NZMS 317 map series.

I am indebted to the two officers who have held the position of Commander, Army Training Group Waiouru, during this study, for granting permission to study in the military training area. My thanks to Colonel Clive Sinclair and Colonel Roger Mortlock.

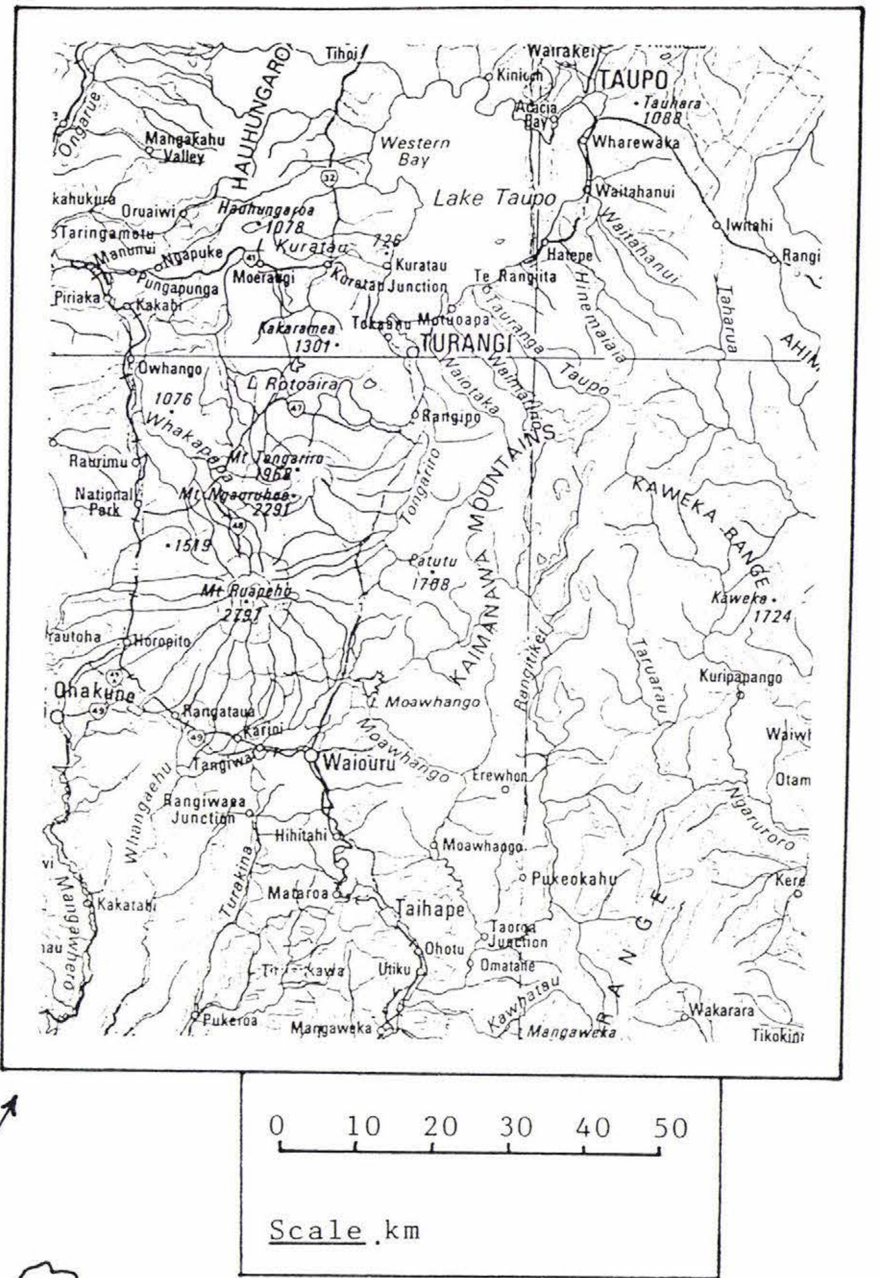
Finally, thanks must go to my wife Pamela for her support and encouragement throughout this study.

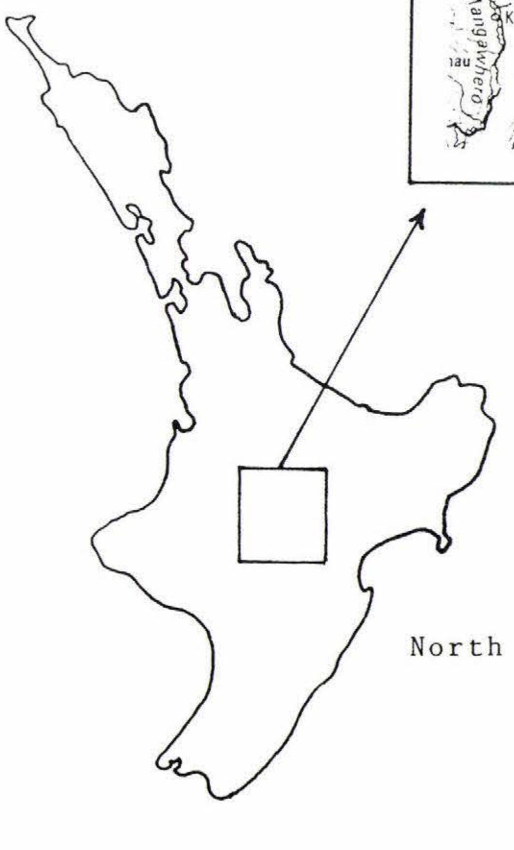
TABLE OF CONTENTS

LIST OF FIGURES

FIG 1.

Location Map





North Island

CHAPTER 1

INTRODUCTION

1.0 GENERAL DESCRIPTION

The Waiouru Formation is a Late Tertiary marine deposit lying unconformably on the Torlesse Supergroup in the vicinity of Waiouru. Unconformable contact of Tertiary sediments onto greywacke exposures of remarkably high local relief was noted and reported by Hector (1870, 1871), Park (1887) and Hill (1889). A more detailed description and mapping of the area to the immediate south of Waiouru was conducted by Feldermeyer et al. (1943) in reports of the Superior Oil Company. Subsequent descriptions by Kingma (1957a) and Suggate (1978), also reported on the high local relief of the greywacke.

As part of the Tongariro Power Project, the Moawhango Dam and Tunnel were constructed within the Army Training Area to the north of Waiouru. Investigations of the geology of the Dam site and along the line of the Moawhango Tunnel, were recorded by the New Zealand Geological Survey (NZGS), and reported by Ingham (1969, 1972); Duder et al. (1977); Hegan (1980) and Beetham and Watters (1985).

These investigations, as well as the NZGS 1:250 000 mapping of Grindley (1960) and the NZGS 1:50 000 sheet by Ker (1991) did not specifically address the conditions that have caused the unusual degree of local relief seen in the greywacke. Basal marine strata were also variously reported to be of Tongaporutuan or Kapitean age.

A personal interest in this area was developed by the author during service with the New Zealand Army, which included two assignments as the military engineer supervising part of the Argo Road construction project. On retirement from the Army, I was determined to investigate the unusual local relief of the greywacke.

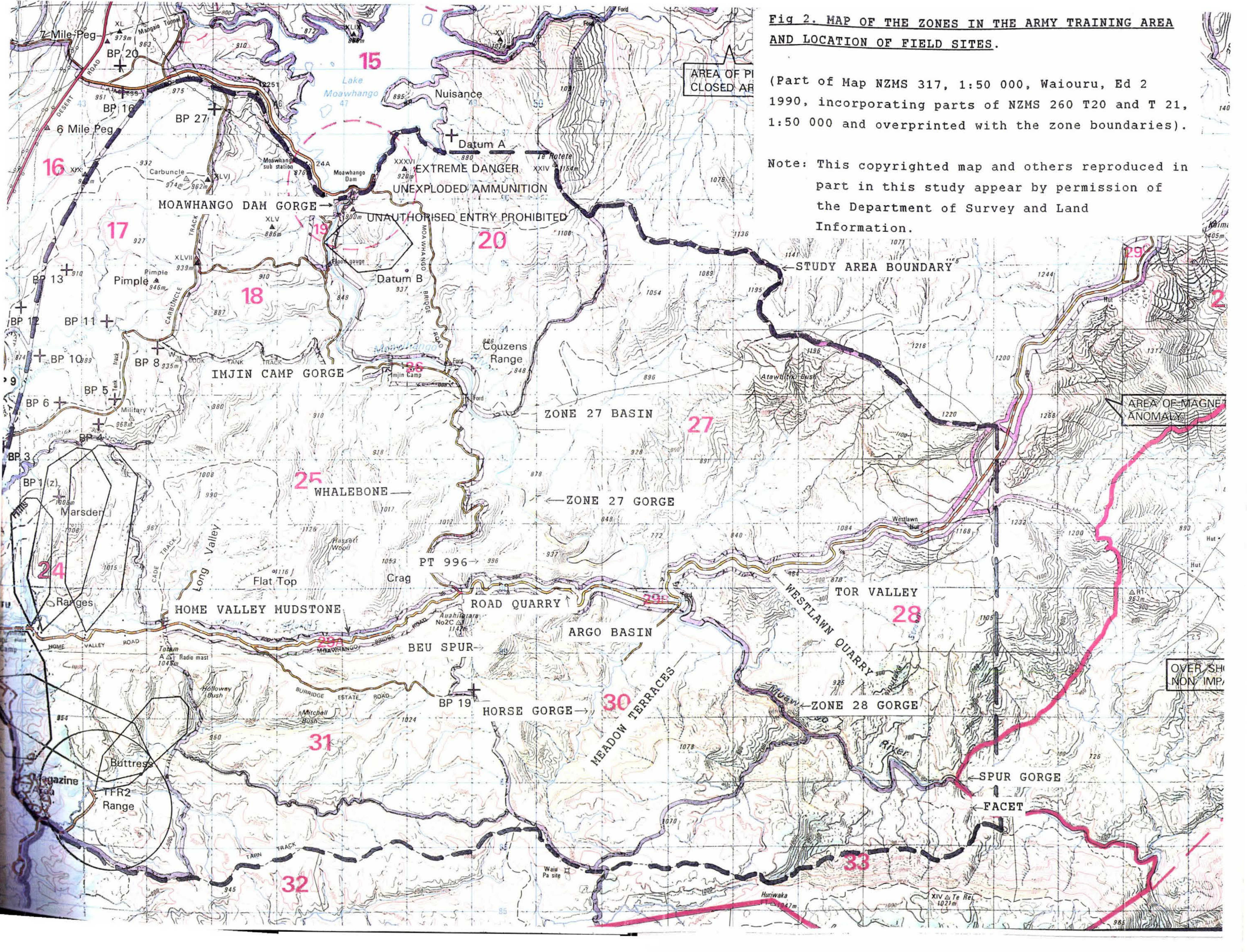


Fig 2. MAP OF THE ZONES IN THE ARMY TRAINING AREA AND LOCATION OF FIELD SITES.

(Part of Map NZMS 317, 1:50 000, Waiouru, Ed 2 1990, incorporating parts of NZMS 260 T20 and T 21, 1:50 000 and overprinted with the zone boundaries).

Note: This copyrighted map and others reproduced in part in this study appear by permission of the Department of Survey and Land Information.

1.1 OBJECTIVE AND SCOPE OF STUDY

The aims of this study were to map and describe the pre-Pliocene relief of the study area; to identify, describe and map the Late Tertiary strata occurring within the study area; and to reconstruct the paleoenvironmental conditions prevalent during the deposition of the Waiouru Formation.

1.2 LOCATION

The study area is in the Central North Island within the Army Training Area at Waiouru (Fig 1). The major settlement is the Army Camp located at Waiouru, with associated housing and a small commercial area serving traffic on State Highway 1 (SH1). The sector of SH1 between Waiouru and Lake Taupo is referred to as the Desert Road.

The use of this area for Army training has seen development of a road network to the east of the Desert Road and has exposed many sections of Late Tertiary strata underlying a cover of Late Quaternary tephra. Due to Army training and safety needs, all access to the area requires a permit from Headquarters, Army Training Group, Waiouru (ATG). The Army has defined internal boundaries within the Training Area delineated as numbered zones. These zones are shown on Fig 2, and are here used as area locations in this text.

Only one zone (Zone 20) is difficult to access, having many unexploded shells. Data in this area has been limited, but being adjacent to the Moawhango Dam, it is balanced by considerable geological data taken from the Dam site during construction.

Within the study area (Fig 2), the Late Tertiary sequence extends from the Moawhango River at an elevation of 520 m, on the southern boundary of the Army Training Area, to further north where isolated remnants of Pliocene marine strata are found on the greywacke basement at an elevation of 1220 m. The bulk of the marine strata in the study area are Pliocene; only one exposure of Kapitean strata having been found in the study area.

The total vertical thickness of Late Tertiary strata is 700 m, but this thickness has to be corrected for post-depositional deformation which has given a dip of approx 3° to the southwest. This is consistent with the North Wanganui Basin regional dip. After this correction, a true stratigraphic thickness of 480 m is preserved for the Late Tertiary strata in the study area.

1.3 METHODS

Exposures of Pliocene-age strata and exposed greywacke were plotted on a 1:25 000 scale map (Appendix A). Pliocene strata were mapped, stratigraphic columns were prepared (Appendix B) and data taken for paleocurrent determinations. One prominent layer of Pliocene strata (Crag reef, Fig 3) was surveyed in detail (Chapter 4) to determine post-depositional deformation. Data collected from seismic investigations during the construction of the Moawhango Dam allowed plotting of some subsurface contours.

Samples were taken for thin-section study where a change in lithology was indicated. Fossils were collected for age and paleoenvironmental determinations.

All map references used in this study are to NZ Infomap 317, Sheet 1 WAIOURU, 1:50 000, Ed 2, 1990. This is a map amalgamating parts of NZMS 260, Sheets T 20 and T 21, and overprinted with the zone boundaries (Fig 2).

1.4 PHYSIOGRAPHY

The study area is located between the Late Quaternary volcaniclastics forming the Mt Ruapheu ringplain and exposed Jurassic greywacke of the Kaimanawa Mountains which forms the regional basement. The distinguishing feature of Pliocene strata in the western part of the study area is the formation of distinctive flat topped hills with accordant summit heights. These are due to gently dipping, near horizontal layers of erosion-resistant calcareous sandstone and shell beds (Fig 4).

The southern toe of the greywacke forming the Kaimanawa Mountains has been mapped as a series of block plateaus (Sporli and Barter 1973), each with a preserved planar surface representing the Late Cretaceous Peneplain of Benson (1935, 1941). The greywacke exposed in the eastern part of the study area forms part of a similar block plateau.

The central portion of the study area is divided by the east-west aligned Home Valley, flanked to the north and south by a moderately dissected landscape of Pliocene sandstones and mudstones (Fig 5). The Home Valley is occupied by the underfit Waiouru Stream, which drains into the Hautapu River, with the saddle at the eastern end of the Home Valley marking the watershed boundary between the catchments of the Hautapu and Moawhango Rivers. Comparison of the Home Valley with its undersized occupying stream strongly suggests that the headwaters of the Waiouru Stream have been captured by the Moawhango River.

Within the catchment of the Moawhango River in the study area, are a series of narrow river gorges cut into the greywacke basement. Between these gorges are two major basins (Zone 27 and Argo basin) where softer Pliocene strata have been preferentially eroded. The approximate eastern rim of the Zone 27 and Argo basins is delineated by the greywacke of the Kaimanawa Mountains.

1.5 CLIMATE

Climatic records for the period 1960-1989, were recorded by the NZ Army-operated Waiouru Weather Station. These climatic records are included in this study by kind permission of Headquarters ATG.

Located at an altitude of 823 m, the climate of Waiouru is strongly influenced by the altitude, with an average annual rainfall of 1140 mm, and a annual daily mean temperature of 9.2° C, (annual mean maximum is 24.5° C and the mean minimum is -6.5° C). Ground frosts are recorded for 27% of the year. The natural treeline is at 1440 m.

Wind directions, as percentages of annual measurement are:

north	10.4	southeast	2.4	west	23.3
northeast	9.9	south	5.4	northwest	11.2
east	11.4	southwest	2.6	calm	23.5

1.6 GENERAL GEOLOGY

The Army Training Area straddles the area of onlap of marine Pliocene strata onto a dissected and tilted greywacke plateau marking the southern exposure of the Kaimanawa Mountains. To the east of the study area (Fig 1), the Kuripapango Strait was open during the Pliocene (Stevens 1974), thus making the Waiouru area the southern coast of the proto-North Island during the Pliocene.

The Pliocene strata in the Waiouru area have been described as,

> "... overlapping onto an unweathered and highly irregular surface of Kaimanawa Greywacke (Gregg 1960). Locally, sandy blue-grey mud, sand and grit are draped over stacks of greywacke or cover a subsurface landscape of deep valleys and islands. " (Suggate 1978).

The dissected nature of the Late Tertiary greywacke surface in the study area, was first reported by Hector (1870). Kingma (1957a) and Cotton (1957) were the first to mention the pre-Pliocene dissection of the greywacke basement as a "fiord topography", implying a degree of dissection similar to the spectacular glacier-cut valleys and sounds of present day Fiordland.

Tectonic activity is evident at the southern boundary of the study area where the Snowgrass Fault is the most prominent of a group of faults striking northeast/southwest with Pliocene strata downthrown 150 m to the northwest (Feldermayer et al. 1943). Drag folding by the Snowgrass Fault has also formed a dome structure, the Snowgrass Dome, in the Pliocene strata covering the basement.

Fig 3 . Shell limestone layer referred to as Crag Reef on the south side of the Home Valley at GR T21/475889. Crag Reef (arrowed), is approx 7 m thick and underlain by a distinctive layer of calcareous concretions, enabling correlation and mapping over a wide area (Chapter 4).

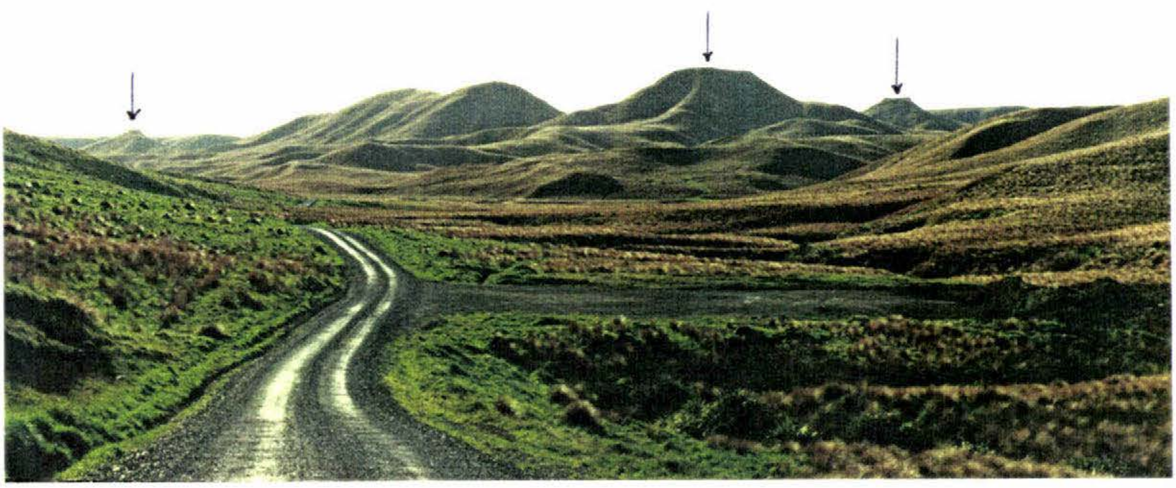


Fig 4 . Looking west towards Waiouru along Home Valley. The hills shown in the background on the north side of Home Valley are of Pliocene strata and comprised of dominantly mudstone and sandstones. Arrows indicate where erosion has removed the softer mudstone and sandstones above the hard shell limestone layer of Crag Reef to give a distinctive flat top to each hill. The incised bed of the Waiouru Stream is in the right foreground.

<u>Fig 5</u>. At GR T21/425897 in Home Valley, looking east away from Waiouru. The Home Valley has been formed in Pliocene sandstones and mudstones of mainly Opoitian age. One exposure of Kapitean age mudstones has been found on the floor of the Home Valley. Crag Reef is visible as an outcrop (arrowed), on the valley sides above the debris mantle covering the lower slopes. The incised bed of the Waiouru Stream is at the right foreground. Flat Top, Auahitotara and Totem are indicated.

Late Tertiary marine strata (mostly of Pliocene age), near Waiouru were previously described as *The Reef Bearing Sands* (Feldermayer et al. 1943); *Waiouru (Reef-Bearing) Sandstone* (Fleming 1959); *Waiouru Sandstone* (Suggate 1978) and as *Waiouru Formation* (Ker 1991). Waiouru Formation is here used in this study to refer to all Late Tertiary strata within the study area.

The marine strata mapped and described by Feldermayer et al. (1943) were identified as Pliocene strata, although later study (Suggate 1978), located older strata of Kapitean age at one location. The Waiouru Formation thus covers from Kapitean to Opoitian time (6-3.6 ma), using stage boundaries as defined by Beu et al. (1990). Bedding of the Opoitian strata is almost undisturbed and measured dips generally conform to the Wanganui Basin regional dip of 3-5° to the southwest. Some very localized areas do show steeper dips, but with the exception of an anticlinal structure identified in this study, these are identified as deposition on initially steeper basement relief.

Pliocene strata in the study area are mainly sandstones and mudstones with layers of hard calcareous sands showing varying amounts of shells and coquina limestone. Here, coquina is defined as porous, friable, coarse-grained, detrital limestone composed wholly or chiefly of broken calcareous fossils (Beu et al. 1980). For this study, both the coquina and calcareous sand layers are jointly referred to as shell limestone beds.

Shell limestone layers appear as marker beds within the study area (Morgan 1919), with one particular shell limestone layer having distinctive field characteristics which allow correlation over a wide area (Chapter 4).

CHAPTER 2

BASEMENT GEOLOGY

2.0 TORLESSE SUPERGROUP

The basement rocks of the study area are the folded and faulted greywacke strata of the Torlesse Supergroup (Grindley 1960; Kingma 1962; and Suggate 1978). Details of the structure of greywacke in this region have been elucidated by Fleming (1953), Gregg (1960), Sporli (1987) and Sporli and Barter (1973).

Grindley (1960) and Gregg (1960) also reported some metamorphosed zones of low grade pelitic schist and schistose conglomerate mapped as Kaimanawa Schist, crossing the Kaimanawa Mountains in a northerly direction and flanked by complexly folded sub-schistose greywackes.

More recent detailed study of the Torlesse greywacke was promoted by the opportunity of site investigations for the Tongariro Power Project during the construction of the Moawhango Dam and Intake Tunnel. Results from these investigations were published by Beetham and Watters (1985), Hegan (1980), and Duder et al. (1977). Further, the petrology and origin of the greywacke is reported in Staveley-Parker (1978), Browne (1981), and Beetham and Watters (1985).

Beetham and Watters (1985) suggest that basement lithologies in this region are,

" a great melange in which some units of normally interbedded sandstone/siltstone and argillite may be very large irregular discoid bodies, (phacoids), in a megabreccia. Complexly intermixed units, involving sandstone, argillite and chert, approach typical melange. All Kaimanawa Range rocks show pervasive recrystallization and in fabric, most range from textural zone 1 to 2A, (of Bishop 1972). Siltstone and sandstone of textural zone 2B cover only comparatively small areas.

They are characterized by steeply dipping lineation and poorly developed schistosity and are classed as semischist. Fissility is marked in associated argillites. The formation of the melange and associated features recorded is probably the result of severe shearing and imbrication during the Rangitata Orogeny."

The lithology of the greywacke encountered during excavation of the Moawhango Intake Tunnel was investigated by Hegan (1980), who reported little or no schistosity in the greywacke, although the Tunnel passed through the area mapped as Kaimanawa Schist by Grindley (1960). No samples showed a preferred orientation of mica (Hegan 1980), and thus all samples were classified as belonging to Zone 1 of Bishop (1972), (see footnote).

Hegan (1980) described three dominant lithologies from the Moawhango Dam and Intake Tunnel sites. These were,

" 1. Greywacke sandstone, an extremely hard, grey, muddy fine- to medium-grained quartzofeldspathic sandstone,

2. Grey/black argillite, a hard mudstone which commonly has a marked fissility sub-parallel to its bedding; and

3. An 'interbedded' unit of hard rock in which one lithology, usually the sandstone, forms thin discontinuous beds or narrow lens-shaped bodies, (the autoclastic breccias of Hancox 1975), within the other."

These three lithologies are exposed in the study area, best exposed in the walls of the gorges of the Moawhango River.

Footnote: The Schist Zones are based on a division into four zones based on the progressive metamorphism of greywacke. Zone 2 is the appearance of semischists in which clastic structure has been partly obliterated, the grain size reduced by shearing and a definite schistosity developed (Bishop 1972).

Hegan (1980) also reported that Potassium/Argon dating of argillite from the western Kaimanawa Mountains gave an age range of 142-127 myr (Late Jurassic to Early Cretaceous), and this suggested that these dates may mark the end of low-grade metamorphism and recrystallization at the time of cooling and uplift during the Rangitata Orogeny.

Sporli and Barter (1973) in a study located 20 km to the north of Waiouru, noted north-northwest-trending faults as the dominant set within the basement greywacke, with a secondary set striking east-northeast.

The characteristics of the basement in the area south of the Moawhango Dam and Intake Tunnel are not well known. This is due to the deep cover of Pliocene sediments burying the basement to the south of Waiouru, in contrast to the widespread basement exposures in the Kaimanawa Mountains. The only known major structure in the basement of this region is a trough which extends north-east from Taihape to Erewhon, near GR T21/655838, (Hunt 1980).

Immediately to the south of the study area, the Snowgrass Dome (Fig 6), mapped by Feldermayer et al. (1943), was interpreted by Ker (1991) to be a southwest-plunging anticlinal structure formed by the buried southern toe of the Kaimanawa Mountains, over which the Opoitian marine sediments have been draped. This study has reinterpreted the Snowgrass Dome to be formed by post-Opoitian deformation of the basement by faulting, and not by the simple draping of sediments over a pre-Opoitian basement structure.

<u>Fig 6</u>. Snowgrass Dome. Photo taken from Zone 33 looking southwest to the dome (centre). Horizontal lineations seen on the sides of the Dome are steeply dipping outcrops of shell limestone beds. This study has re-interpreted the Snowgrass Dome to be a fault bounded upwarping of the basement.

2.1 THE WESTLAWN SURFACE

During the Cretaceous, erosion of the New Zealand landmass gradually reduced the landscape to a plain of limited relief and gentle slopes which was named " The Late Cretaceous Peneplain" (Benson 1935, 1941). Gage (1980) has subsequently noted that the New Zealand landmass in the Cretaceous more probably exhibited a full range of erosional forms, but the peneplain was the major landscape feature. This terminology is adopted here.

Much of the Peneplain surface survives, but under covering strata which still conceal this surface in many areas. Where erosion has removed the covering strata it often appears as an exhumed fossil land surface.

The accordant summit heights and gently rounded ridges of greywacke in the Waiouru area are consistent with the Peneplain hypothesis. To the immediate north and northwest of the study area several small block plateau surfaces are identified as part of the remnant Peneplain surface (Sporli and Barter 1973).

A similar surface is found within the study area. Within Zone 28 there is a strikingly planar surface that is here considered to be a Cretaceous Peneplain remnant. It is here referred to as the Westlawn Surface, named from the Westlawn Hut located at GR T20/559909, (Figs 7 & 8).

The Westlawn Surface has been used in this study to indicate any post-Cretaceous deformation. While the surface displays a gentle relief and has thin (1-5 m thick), cover beds of Late Quaternary tephras overlying the greywacke, any fault lineations indicating significant vertical displacement should be visible on the surface. Linear features would be detectable from preferential erosion along zones of weakness, such as stream and river bed alignments, a criterion which was used in prediction of faults in the Moawhango Tunnel (Hegan 1980, Beetham and Watters 1985).

Several traverses of the Westlawn Surface were made to investigate possible fault lines. Many exposures showing Pliocene strata overlying greywacke were found showing evidence of considerable crushing and faulting within the greywacke, but this did not extend into the overlying strata, and showed no offset of the Peneplain surface; thus this faulting pre-dates the Late Cretaceous.

With the exception of the Snowgrass Fault (Feldermayer et al. 1943) at the southern boundary of the study area, and a newly discovered minor fault along the Home Valley, no evidence of post-Cretaceous faulting could be found. This is consistent with the investigations of the Moawhango Dam site (Ingham 1969, 1972 and Duder et al. 1977) which found no rejuvenation of any faults or fault zones in the Moawhango Dam gorge.

Ingham (1972) suggested that there is an intrusion in the basement within the study area. This was based on gravity anomalies found during the Moawhango Dam surveys and stream patterns in the Paradise Valley area. A further possible indication of an intrusion is an," *Area of Magnetic Anomaly*", delineated in red on NZMS 317 Sheet 1, (Fig 2). This marks an area where the Army has observed unreliable readings from magnetic compasses. A detailed magnetic survey would have to be carried out over this area to confirm the anomaly or any intrusion.

2.2 LATE TERTIARY BASEMENT TOPOGRAPHY

Exposures of greywacke in the study area and data from the Moawhango Dam site were used to derive a map of the Late Tertiary landscape (Fig 9 and Appendix A). With the exception of the superimposed gorges cut by the Moawhango River and its tributaries, there is no evidence of modern erosion sufficient to have significantly altered the contours of the greywacke surface exhumed from beneath the cover of marine strata. Thus, the present contours on the greywacke are assumed to represent subsequent erosion and deformation of the Late Cretaceous Peneplain prior to the Late Tertiary transgression.

Duder et al. (1977) reported the contact of marine Pliocene strata with the greywacke at the Moawhango Dam site as an eroded greywacke basement unconformably overlain by marine Pliocene sands and pebble conglomerates. The presence of the Pliocene/greywacke contact at the proposed Dam site meant possible leakage paths on the contact from Lake Moawhango behind the Dam. This possibility required extensive seismic investigations to determine the shape of the greywacke sub-surface, especially any deep valleys in the basement that may have been filled with permeable material (C.E.Ingham, pers. comm. 1993).

Data from the seismic investigations at the Dam site were correlated with information from boreholes, thus allowing a considerable degree of control on seismic interpretations. Inferred sub-surface contours around the Dam site were published by Ingham (1969) and show the basement sloping gently to the west of the Dam site under the Pliocene strata, while to the east, the greywacke surface dips steeply under the marine Pliocene strata to form one side of a buried valley (Fig 10). The eastern side of the buried valley is formed by the greywacke exposure along Te Rotete ridge at GR T20/502965 (Fig 2). Projections of valley slopes indicate that the buried valley is filled with at least 300 m of Pliocene strata (Fig 11).

Later seismic investigations by Ingham (1971, 1972) and Sissons and Dibble (1981), further to the west of the Dam site, show that Pliocene strata cover a gently undulating basement of greywacke. This basement has been displaced by the Desert Road Fault which is aligned generally north-northeast, and is downthrown 150 m to the west (Sissons and Dibble 1983). Over 300 m of Pliocene strata overly the basement at the 7 mile peg on the Desert Rd at GR T20/434985 (Sissons and Dibble 1981).

The oldest Late Tertiary strata found in the study area are marine mudstones containing a Kapitean fauna (T21/f12 at GR 473893). This gives a minimum age for the Westlawn Surface peneplain and its fiord-like embayments at the southern margin of the Kaimanawa Mountains.

Fig 7 . On the Westlawn Surface at the eastern boundary of the study area. Greywacke of the Westlawn Surface is here thinly covered by up to 5-10 m of Late Quaternary tephra. Looking northeast, the Argo Road climbs gently to a road cutting (centre), at T20/570920.

Fig 8 . The Westlawn Surface, a remnant of the Late Cretaceous Peneplain, viewed from the west side of Zone 27 gorge. The Argo Road is seen in the centre, extending from the Moawhango River ford (right), up the prominent spur at centre to the Westlawn Hut (left, arrowed). Greywacke basement is exposed in the Zone 27 gorge (foreground), beyond which are Pliocene sediments filling the Argo Basin.

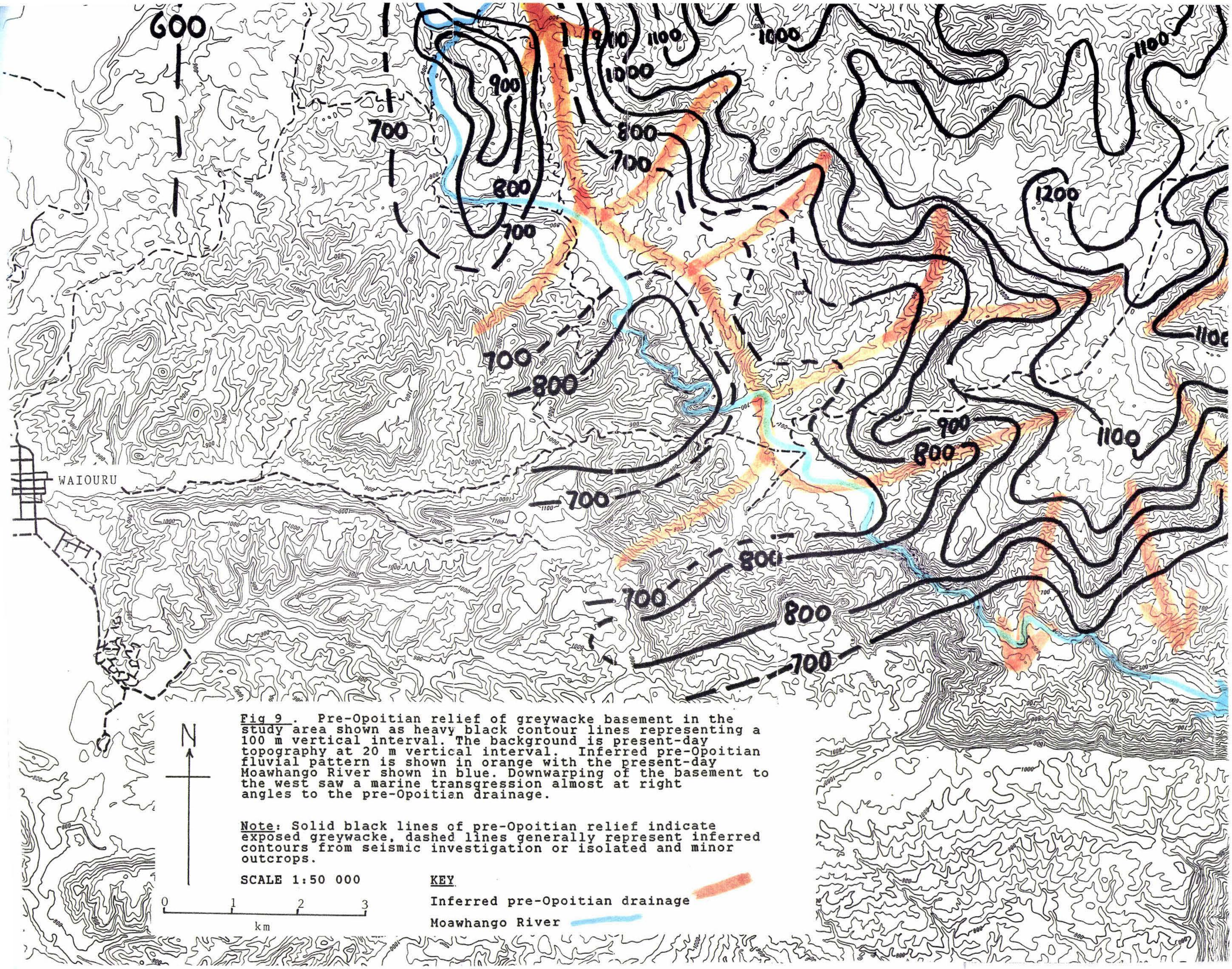


Fig 9 . Pre-Opoitian relief of greywacke basement in the study area shown as heavy black contour lines representing a 100 m vertical interval. The background is present-day topography at 20 m vertical interval. Inferred pre-Opoitian fluvial pattern is shown in orange with the present-day Moawhango River shown in blue. Downwarping of the basement to the west saw a marine transgression almost at right angles to the pre-Opoitian drainage.

Note: Solid black lines of pre-Opoitian relief indicate exposed greywacke, dashed lines generally represent inferred contours from seismic investigation or isolated and minor outcrops.

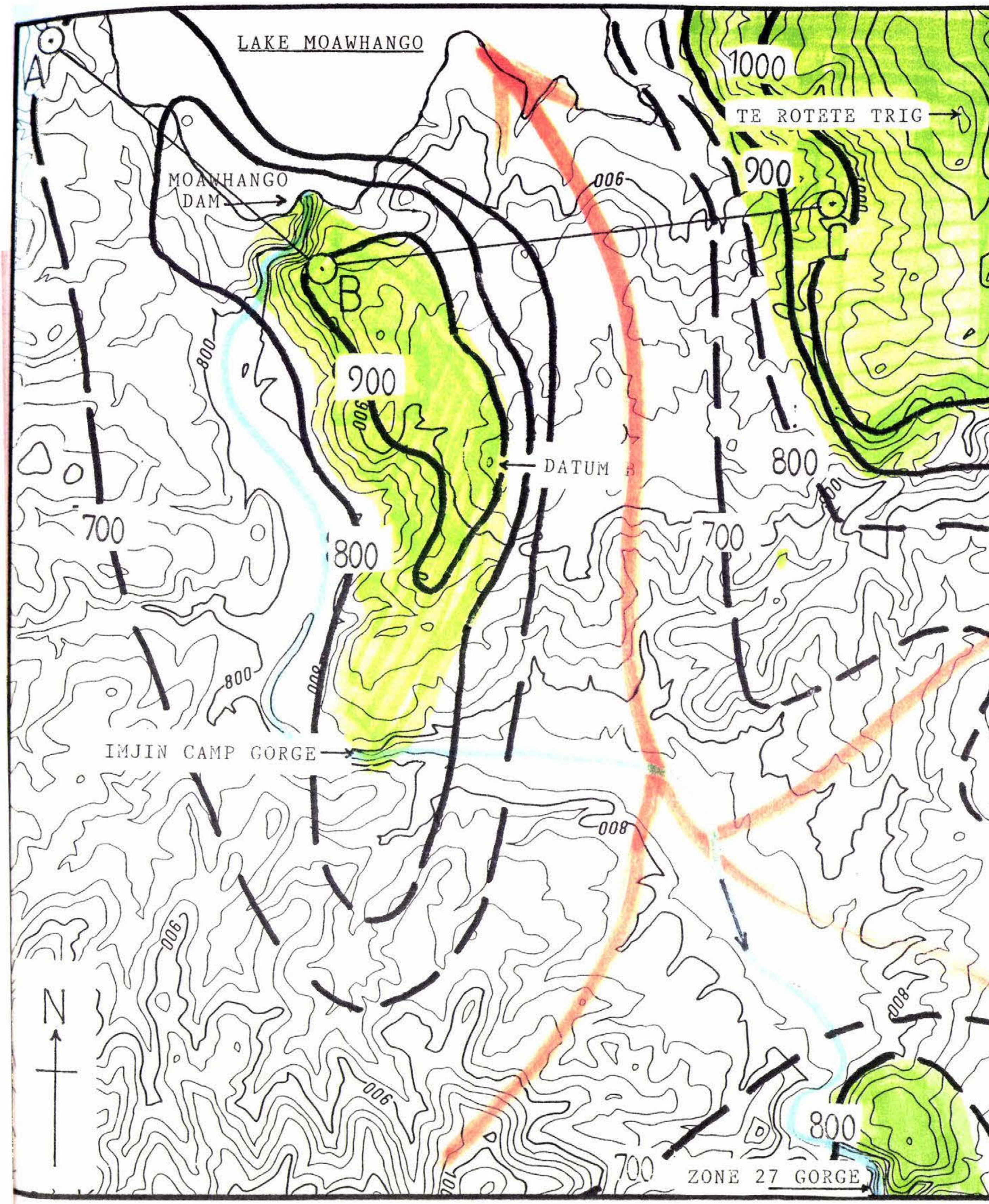


Fig 10 . Basement contours at the Moawhango Dam, Imjin Camp and Zone 27 gorges. Exposed greywacke is here shown in green Heavy black lines represent 100 m vertical contours of the basement. The background is the 20 m vertical interval contours of present day relief. Shown in orange is the inferred pre-Opoitian drainage pattern; contrasting with the present course of the Moawhango river, here outlined in blue. A cross-section on the line A - B - C is shown in Fig 11. Scale is 1:25 000.

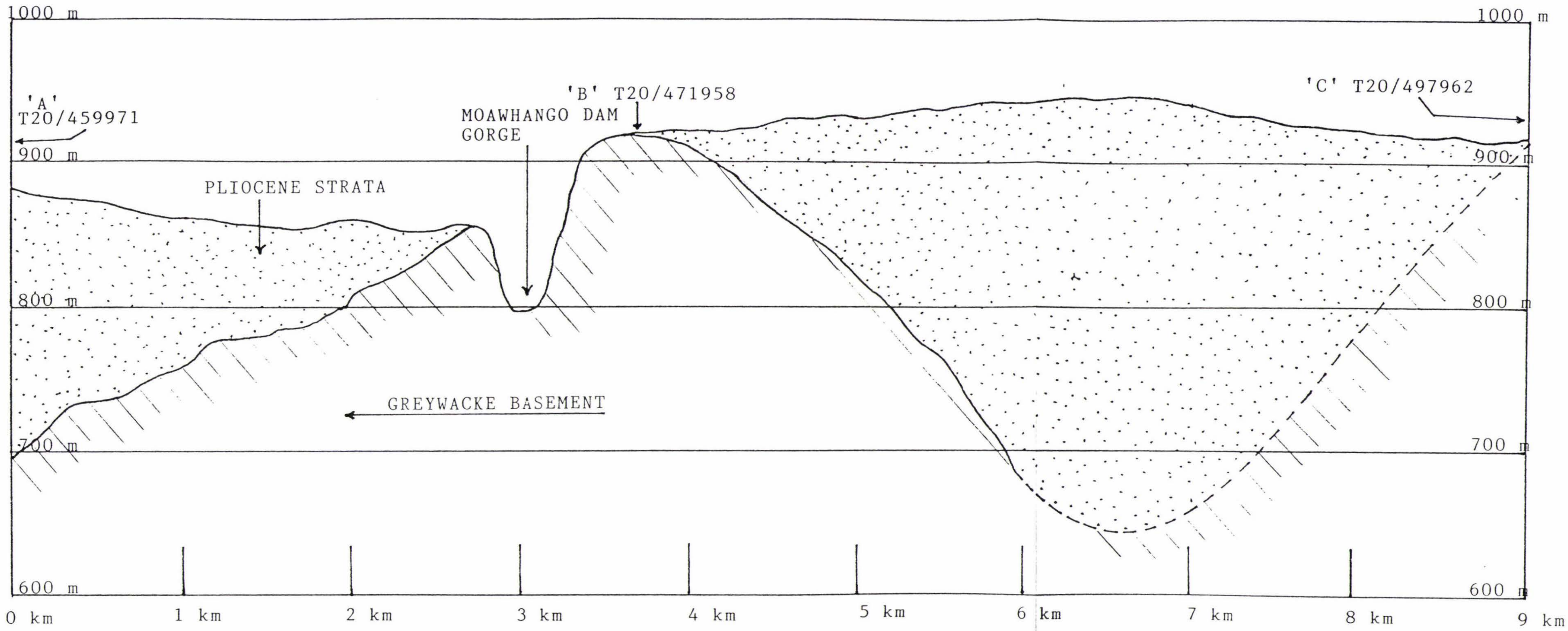


Fig 11 . Sub-surface contour along line A-B-C in Fig 10. Solid line is derived from seismic investigations (Ingham 1971) and dashed line represents that inferred from a extension of the valley slope westwards from Te Rotete Trig.

2.3 SUPERIMPOSED GORGES

During the Plio-Pleistocene regression in the North Wanganui Basin, modern rivers began to establish their courses in the Pliocene marine strata. In the Waiouru area, where these rivers rapidly downcut, they encountered relatively soft Pliocene sediments and hard basement greywacke. The latter is resistant to fluvial incision and now forms deep narrow gorges. These gorges reflect a drainage pattern originally cut into the softer Pliocene strata and then superimposed onto the harder greywacke (Lillie 1949).

There are 5 distinct gorges along the course of the Moawhango River within the study area, each formed by superimposition. These gorges are located at the Moawhango Dam GR T20/470960, Imjin Camp GR T20/475935, Zone 27 GR T20/496916, Zone 28 GR T21/530880 and Spur GR T21/564870. Other smaller gorges also exist in the study area at GR T20/509945, GR T20/515938 and GR T20/542915 where tributary streams to the Moawhango River have cut into the greywacke basement (Fig 12).

The superimposed drainage pattern is emphasized by the course of the Moawhango River in the gorge located in Zone 27 at GR T20/496916 (Figs 13 & 14). In this gorge, cut along and into a ridge of greywacke, the river takes a 2 km long, twisting course strongly resembling a meander pattern. While folds and bedding are distinct in the greywacke exposed in the gorge walls, they do not appear to have influenced the river course or the development of this gorge. The formation of these superimposed gorges therefore suggests that they mark the path of the rivers flowing across this landscape during the Plio-Pleistocene uplift.

Following the formation of a drainage system the paleo-Moawhango River would have begun active downcutting into the easily erodible Pliocene strata, to form deep gorges similar to those found in the lower Rangitikei River. These deep gorges would have controlled the river course onto the greywacke as it became exposed by the River.

The relatively hard and resistant greywacke forming the gorges now acts to control the grade of the present River between each set of gorges, i.e. between the gorges, the River can only incise into the soft Pliocene strata at the same rate as it cuts into the harder greywacke. Tributary streams have also had their grade controlled by the gradient of the main river. This restriction on the rate of downcutting, has thus produced a mature basin landscape in the softer Pliocene strata between each set of youthfully incised gorges.

2.4 MOAWHANGO DAM GORGE

A study of the Moawhango Dam site geology found that the gorge downstream of the Dam was the result of superimposition rather than the river cutting through a zone of weakness such as a fault (Hancox 1975). The present course of the Moawhango River is cut through the northwestern tip of a northerly striking greywacke ridge (Datum B ridge). On emerging from the gorge, the river flows along the western side of the ridge before turning east and cutting through the southern flank of this ridge forming the Imjin Camp gorge (Fig 2).

The riverbed between the Moawhango Dam gorge and the Imjin Camp gorge forms the western boundary of Zone 20. There is only limited access to Zone 20, (due to it being used as a live firing zone with a large number of unexploded shells). However, ground investigations along the Datum B ridge show that the Pliocene strata have been eroded off the greywacke ridge crest westwards down to the level of the Moawhango River bed.

The ridge crest of the Datum B ridge shows little sign of fluvial erosion, suggesting that the Datum B ridge represents the pre-Pliocene landscape. However, east of the Datum B ridge, Pliocene marine strata fill a basement valley between the exposed greywacke forming Datum B ridge and the Te Rotete feature at GR T20/502965, (Fig 11).

Within the riverbank to the west of Datum B ridge are further Pliocene marine strata. Lacustrine deposits and river terraces found along this part of the river are considered to have formed from ponding during floods. Before the construction of the Moawhango Dam, the Imjin Camp gorge controlled the rate of flow during flood events, acting as a choke and briefly forming a flood lake.

2.5 IMJIN CAMP GORGE

The Imjin Camp gorge is approx 200 m long, cut through the southern tip of Datum B ridge where the river course turns abruptly to the east. Once entrenched within the greywacke, the Moawhango River's course became fixed.

2.6 ZONE 27 GORGE

The Zone 27 gorge is the most visually spectacular of the gorges in the study area, with part of the gorge wall forming a 200 m vertical face. Folds with a scale of 10-30 m are clearly visible in the greywacke within the walls of the gorge but seem unrelated to the river course. Nor do the tight and narrow bends of the river inside the gorge appear to be controlled by faulting or folding of the greywacke.

The course of the Moawhango River within this gorge has been established roughly parallel with the northwest axis of a dome-shaped ridge of greywacke. The eastern side of the ridge dips steeply at 30°-40° to the northeast under the southern rim of the Argo Basin. Along the northeastern side of the gorge, gently rounded tops of greywacke exposures at GR T20/499918, and GR T20/501912 are remnants of the Westlawn Surface and show no evidence of faulting (Fig 15).

On the northwestern margins of the dome-shaped ridge and prominent towards the gorge exit, the height of the greywacke exposed above the river level and to the Pliocene strata above, is often less than 50 m (Fig 14). This demonstrates that the Moawhango River has cut straight down into the greywacke from the course which was cut into the Pliocene strata overlying the greywacke basement.

Fig 12 . View of minor gorges (middle distance, arrowed), on the eastern rim of the Zone 27 Basin. View is from the Imjin Road in Zone 27 looking northeast towards the Kaimanawa Mountains. These minor gorges represent a superimposed drainage pattern cut into greywacke basement by tributary streams of the Moawhango River. Pliocene strata in the foreground, partly infill the Zone 27 Basin.

Fig 13

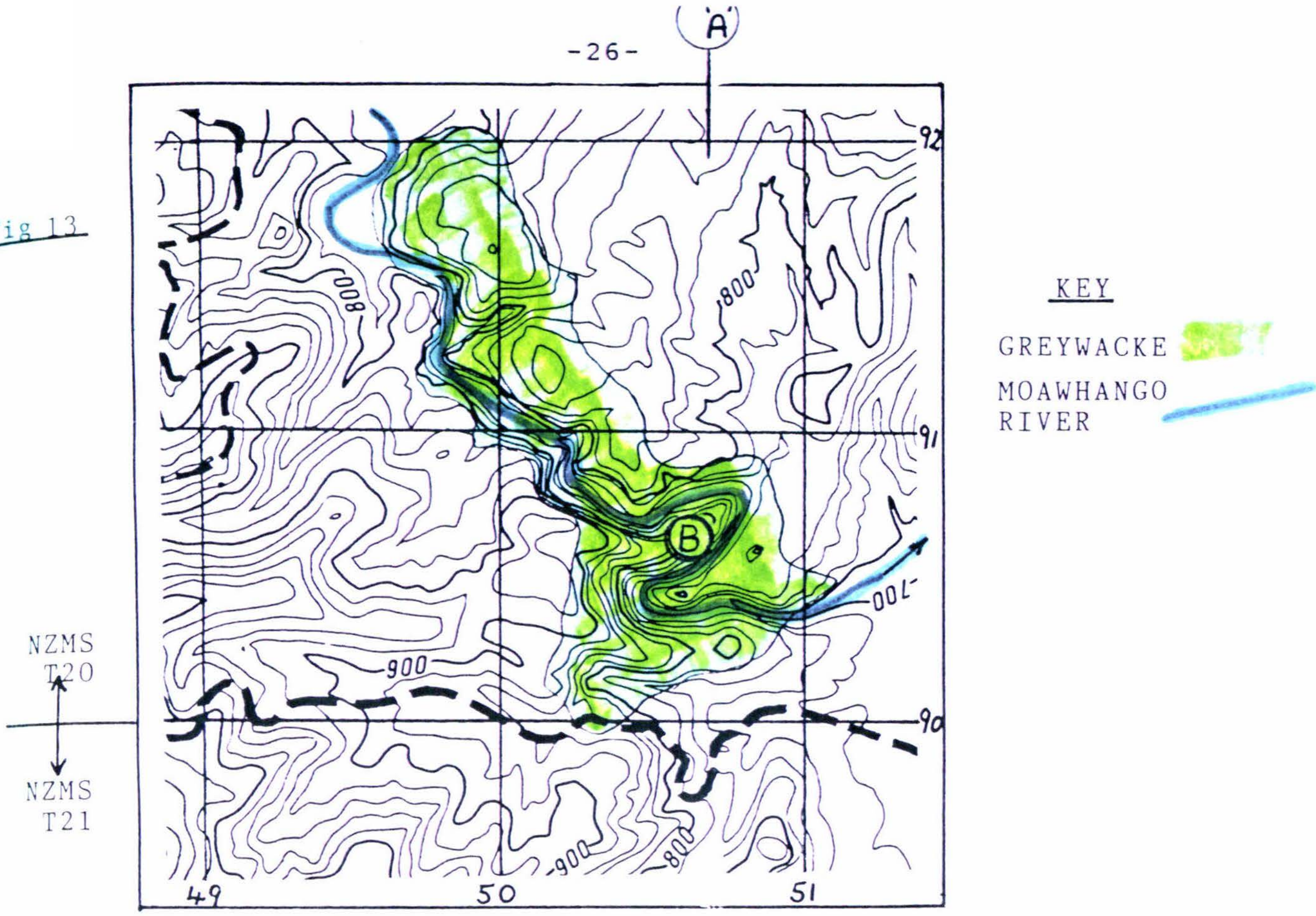


Fig 14

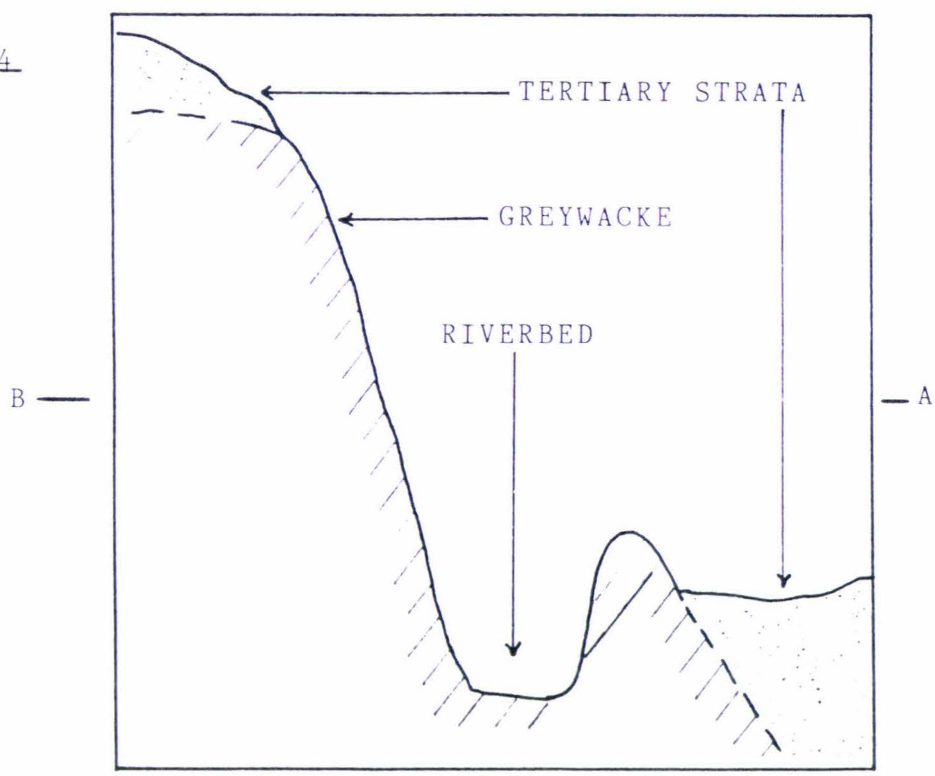


Fig 13 Zone 27 Gorge.
Present course of the Moawhango River, originally through Tertiary strata and now incised into basement greywacke by uplift of the Crag Anticline. Grid lines represent the 1000 m grid on NZMS T20 and T21.

Fig 14 Cross section of Moawhango River in Zone 27 Gorge at T20 506907 on the line A-B in Fig 13. (Not to Scale).

Fig 15 . The Zone 27 gorge. Photo taken from T20/492913 on the Imjin Road overlooking the Zone 27 gorge and looking east across the Argo basin to the Westlawn Surface in the background. In the foreground are Pliocene strata which overly the basement exposed in the Zone 27 gorge. The greywacke surfaces on each side of the minor gorge at left centre are remnants of the Westlawn Surface.

Mapping of deformation in the Opoitian age shell limestone beds (Chapter 4) shows the formation of a post-Opoitian anticlinal structure (the Crag anticline), with the inferred uplift axis close to the Zone 27 gorge. This is likely to have initiated local aggradation in the Zone 27 Basin and started a period of rapid downcutting across the rising greywacke on the anticlinal axis.

2.7 ZONE 28 GORGE

The Zone 28 gorge cuts directly through a prominent spur of the Westlawn Surface, the spur having the appearance of a large flat-topped causeway, here informally referred to as the Causeway (Figs 17 & 20). The accordant height of the Causeway on each side of the Zone 28 gorge and its regular shape on both sides of the river make it unlikely that there has been any recent faulting along the course of the river. The greywacke exposed in the gorge walls is lithologically similar to that found in the other gorges. There is no preferred structure in the greywacke here to have aided formation of the gorge.

West of the Zone 28 gorge are Pliocene strata forming the steep southwest oriented rim of the Argo Basin. Greywacke exposures in gullies draining into the Argo Basin from this rim are inferred to be the flank of the Causeway feature and thus allow mapping of the peneplain to a small gorge in exposed greywacke on the Argo stream at GR T21/509881, here named Horse gorge.

2.8 SPUR GORGE

The Spur gorge is located at GR T21/564870 (Fig 18), and is a superimposed gorge cutting through a spur of greywacke from the main plateau of the Westlawn Surface, here named Spur. The valley on each side of Spur remains partly infilled with Pliocene strata, thus demonstrating a pre-Pliocene origin for Spur.

Movement on the Snowgrass Fault has upthrown the toe of the Spur feature 200 m to the south and displaced it 300 m to the west to produce an isolated greywacke feature at GR T21/565867, here named Facet. The field name of Facet was given to this feature because of the scarp face on the Snowgrass Fault (Fig 19).

2.9 THE ARGO BASIN

The Argo Basin, named from the Argo Road (Fig 2), occupies most of Zone 30 and parts of Zones 27 and 28. The boundaries are defined in Fig 21. The margins of the Argo Basin are defined by the contact between Pliocene marine strata and the harder and less erodible greywacke. Clearly, the pre-Pliocene basement relief had been infilled by marine Pliocene strata and later erosion by the Moawhango River and its tributary streams has preferentially reduced the height of the Pliocene strata to form a geomorphic basin and partly expose the pre-Pliocene relief (Figs 8 & 23).

On the western margin of the Westlawn Surface, the Argo Basin edge is represented by two southwesterly draining valleys in the basement exposed between the Atawhitiki Bush (GR T20/540940) and the Zone 28 gorge. Pliocene marine strata found within these two valleys demonstrate that these valleys predate the Pliocene sedimentation.

The majority of Zone 30 is occupied by the steep sided catchment of the Argo stream which drains into the Moawhango River. From the Zone 28 gorge to the Horse gorge, isolated exposures of greywacke are visible in gullies cut into the steeply sloping Pliocene strata, showing direct contact with the underlying greywacke. The steep-faced western margin of the Argo stream catchment is cut into Pliocene marine strata that culminate in the prominent spur at GR T21/494893, here named Beu Spur.

To the east of the Home Valley saddle, the Argo Road descends into the Argo Basin and crosses the most southerly exposure of the greywacke forming the Zone 27 gorge high.

Close to the road at GR T20/500900, is a quarry, here referred to as Road Quarry, where the greywacke is well exposed. No other greywacke is exposed between Horse gorge and Road Quarry, indicating that the area between is one of deep relief in the basement.

An irregular and deeply incised ridge of Pliocene marine strata between the greywacke exposures in the Zone 27 gorge and Atawhitiki Bush, marks the northeast margin of the Argo Basin. Inferred subsurface contours for the basement greywacke here, indicate that, like the area between Horse gorge and Road Quarry, this also is an area of deep relief in the basement.

Lying on the greywacke basement on the southwest boundary of Zone 28 at GR T20/521903 are Pliocene age conglomerates formed from rounded greywacke pebbles interbedded with coarse marine sands. These dip steeply to the west and southwest and are interpreted as beach deposits which have originated from alluvial fans of terrestrial streams depositing debris onto the Pliocene beaches.

A red sand/greywacke conglomerate at GR T20/519903 was examined for evidence of any preferred direction of clast orientation. Measurement of 30 clasts with a length/width ratio greater than 1.5 from this exposure did not find any significant preferred direction of clast orientation.

Red sands with layers of weathered greywacke pebbles and red clays are found on the eastern and western margins of the Argo Basin. This indicates that the pre-Pliocene basement was deeply weathered and was being readily eroded immediately prior to the Pliocene transgression. No evidence was found to indicate a formation period for the red weathering of the greywacke. It may represent weathering during the formation of the original surface of the Late Cretaceous peneplain, or it may have originated nearer to the time of the Late Tertiary transgression.

Some deposits of angular and subangular, clast-supported breccia are found at T21/533890, lying on the greywacke near the Zone 28 gorge. While covered by Pliocene marine strata, they show no evidence of marine reworking and are interpreted as a remnant of a non-marine alluvial fan.

Remnants of beaches and wave cut platforms remain prominent on basement exposures as a smoothed wave cut platform with a basal layer of rounded pebble- and cobble-sized greywacke debris covered by greywacke derived coarse sand and fine gravel. The most well preserved and exposed beach remnant is found close to the Argo Road at the Westlawn Quarry, GR T20/535903, (Fig 22). Similar beach and wave erosion features are seen on the western margin of the Argo Basin where the Moawhango Bridge Road descends to Road Quarry (GR T20/500901). Quarrying for road metal by the Army has destroyed most of the exposure since the start of this study.

2.10 ZONE 27 BASIN

The Zone 27 Basin has been formed by Pliocene marine sedimentation within a depression of harder greywacke, in a similar manner to the Argo Basin. To the north, the margin of the Basin is delineated by Pliocene marine strata filling a deep valley in the basement between the greywacke exposed at the Datum B ridge and the Te Rotete Trig (Fig 11). Southeast of Te Rotete Trig, the margin is delineated by the Westlawn Surface greywacke which runs to the Argo Basin boundary at Atawhitiki Bush.

Both the Argo and the Zone 27 Basins share a common boundary in the Pliocene strata filling an area of deep basement relief between the Atawhitiki Bush and the Zone 27 gorge. The western margin of the Zone 27 Basin lies in Zones 25 and 18. Here, it is defined by the watershed of streams cut in the Pliocene strata that drain north and east into the Moawhango River. Basement contours derived from seismic investigations (Ingham 1969) and paleocurrent data (Chapter 5), indicated two areas of deep relief in the basement, one underlying Zone 20 and the other located between the Imjin Camp and Zone 27 gorges (Fig 9).

<u>Fig 16</u> . Aggradational terrace of the Moawhango River is exposed in road cutting at T20/487925, in Zone 27. Spade is 1 m long and rests on the top of colluvium containing greywacke gravels derived from the upstream Moawhango Dam and Imjin Camp gorges. The colluvium is topped by approximately 0.4 m of finely laminated overbank deposits and above these are 4m of mainly andesitic tephra and loess. The prominent tephra layer (arrowed) is the Ngamatea -1 and -2 lapilli of the Upper Bullot Formation (Donoghue 1990) dated as not younger than 11 250- 10 000 years B.P.

Fig 17 . View looking southwest along a narrow greywacke spur of the Westlawn Surface forming Causeway in Zone 28. The Moawhango River has cut the Zone 28 gorge (middle distance) through the spur. Rock terraces are seen as bluffs in the Pliocene marine sandstone unconformably lying on the upper surface of greywacke. In the background are exposures of Crag reef (arrowed), downthrown by the Snowgrass Fault.

Fig 18 . View along splinter fault (dotted), of the Snowgrass Fault. A fault scarp of this fault is visible in Pliocene strata (middle left), and as a step in the greywacke spur at middle centre. At top left, the greywacke of the Westlawn Surface slopes down in scrub-covered spurs to the Moawhango River. At middle right (arrowed), the Spur gorge has been formed where the Moawhango River has cut through the lower part of Spur.

Fig 19 . Looking south from Zone 28 gorge along the Moawhango River. Foreground and middle left, exposed greywacke at the downstream end of Zone 28 gorge. In the middle distance (arrowed), is the greywacke spur cut through to form the Spur gorge. At centre (arrowed), and covered in scrub, is a fault scarp of the Snowgrass Fault. Movement on the Snowgrass Fault has displaced the toe of the Spur feature 200 m vertically and 300 m horizontally to produce an isolated feature at GR T21 565867, here named Facet. The river bend at centre is cut in Pliocene strata of Argo sandstone which is also seen exposed in the steep bluff at extreme right.

Fig 20 . The Zone 28 gorge at left centre, cut through the greywacke of Causeway. Photo taken from greywacke exposed above the Moawhango River on the eastern side of the Argo Basin. At upper centre, on Causeway, are rock terraces of Argo sandstone unconformably deposited on the greywacke. To the right centre are degradational river terraces cut into Pliocene strata filling the Argo Basin.

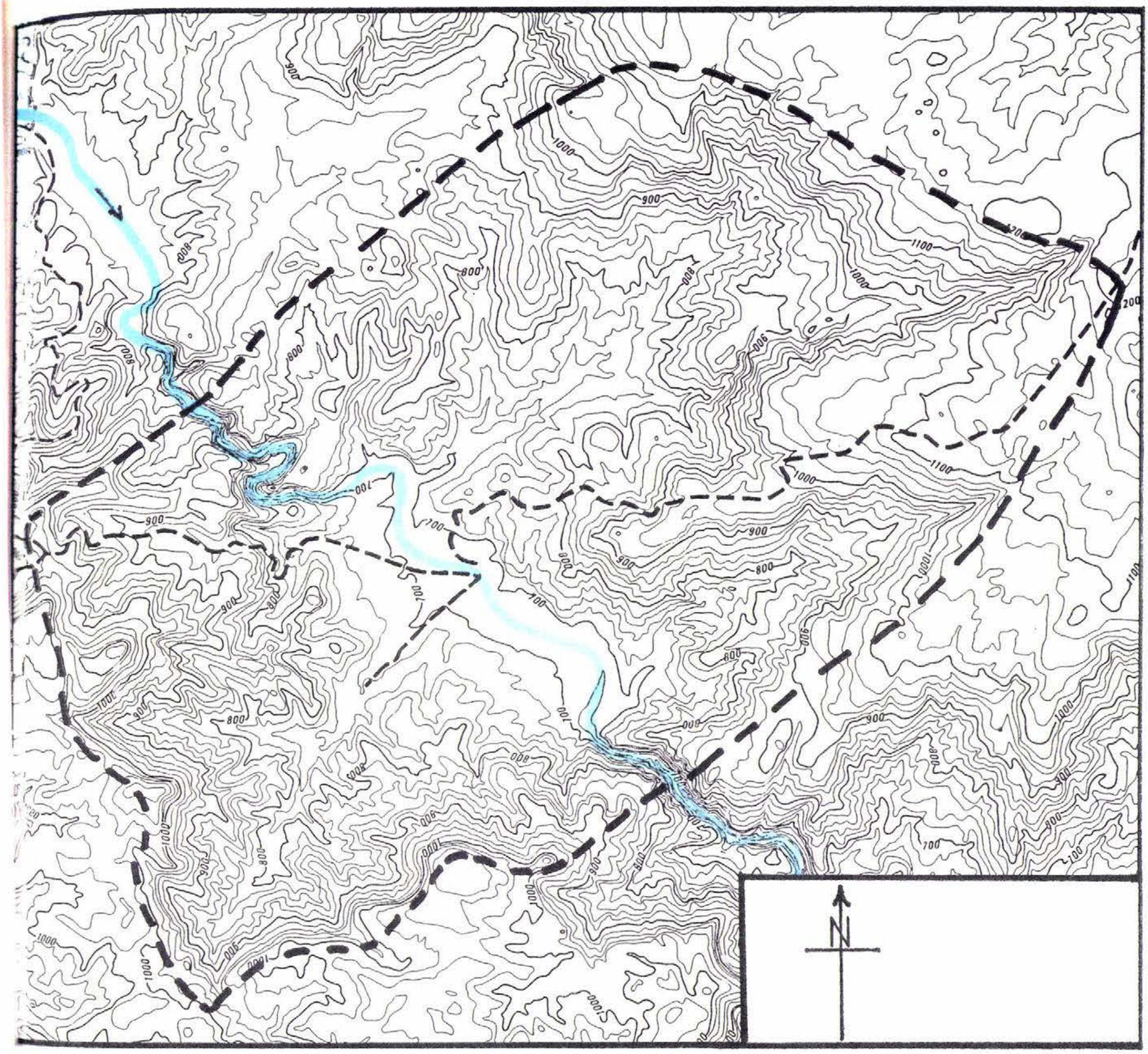


Fig 21 . The Argo Basin. The margins of the Argo Basin are delineated by the heavy dashed line. Background is at 20 m vertical interval from NZMS 317. The lighter dashed line aligned east-west is the Argo Road, entering the Basin at the Home Valley Saddle at extreme left and crossing the Moawhango River (N.B. indicated in blue), and then ascending the prominent spur separating two pre-Opoitian valleys in the basement. Scale is 1:50 000

The prominent shell limestone beds of the Argo sandstone are only seen at the southwest margin of the Basin in Zone 25. Most of the Pliocene marine strata in the Zone 27 Basin is covered with Late Quaternary tephra and exposures in road cuttings have few distinct features for correlation. With the exception of some areas of Zone 25 and along the Imjin Road, this study has used the more complete exposures found in the Argo Basin.

2.11 RIVER TERRACES IN THE ARGO BASIN

River terraces are a prominent landscape feature in Zone 30 where it was found convenient to classify the terraces into three groups based on field characteristics.

The first group of terraces are rock terraces formed as distinct cliff-like exposures of coarse-grained Opoitian age sandstone, here named Cliff, usually containing thin conglomerate layers and rare macrofossils. These sandstone exposures were the first strata deposited on the greywacke basement and are found perched above the greywacke exposures of the Zone 27 and 28 gorges of the Moawhango River. These exposures are considered to be the remains of the original gorge walls, cut into the Pliocene strata as rock terraces before the river cut into the basement (Fig 20).

The second group of terraces, here named Scrub, are found around the margin of the Argo Basin, generally at a height between 780 and 840 m. They are terrace remnants cut into Pliocene marine strata with a planar tread and deeply incised frontal risers (Figs 23 & 24). The Scrub terraces are here interpreted as the remains of degradational terraces cut into Pliocene strata infilling the Argo Basin shortly after downcutting began into the greywacke at the Zone 28 and Zone 27 gorges.

The third group of river terraces, here named Meadow, are found close to the Moawhango River in Zone 30, with five terraces rising southwest in sequence from river level at GR T21/524894, (Fig 25). In contrast with the Scrub terraces, the Meadow terraces appear fresh and uneroded.

The uppermost terrace of this sequence is at a height of approx 760 m. These terraces typically have a tread of between 25 and 100 m, with a front riser 5-10 m high, formed as the river continued to incise the Zone 28 gorge.

A trench was dug in the lower Meadow terrace at GR T21/522895 (Figs 26 & 27) where the Moawhango River has incised into the Pliocene marine strata, to expose Late Quaternary tephra overlying river terrace gravels of the Moawhango River. The section showed two distinctive andesitic tephra layers, the lower of which was 0.55 m above the river gravels. These were identified from field appearance and stratigraphic position, as the Ngamatea lapilli -1 and -2 of the Upper Bullot Formation (Donoghue 1990) which have been dated as younger than 11 250 - 10 000 years B.P. The 0.55 m of tephra underlying the lapilli layers is consistent with them being unidentified members of the Upper Bullot Formation, described (Donoghue 1990) at the Ngamatea Swamp at GR T21/413874.

The age inferred for the lowest terrace is consistent with the ages derived for similar terraces formed during the Ohakean (Oh3) age and thus the lower Meadow terrace may be of similar aggradational origin.

Since these lapilli rest within 55 cm of the top of the terrace gravels, the lowest Meadow terrace is likely to be in the order of 12 000 years B.P. Since the height of the lowest Meadow terrace above the present floodbank levels is 12 m, and the inferred age of the terrace is approx 12 000 years B.P. the rate of downcutting by the Moawhango River at this point is on average, about 1 mm per year.

No age identification could be made for the other Meadow terraces. For safety reasons, excavation was restricted to a depth of 3 m. Within this depth, allophanic clays derived from andesitic tephra were encountered, but the excavation did not reach the underlying terrace gravels. Rhyolitic tephras that could date the terraces were not found at this site but were easily seen in sections elsewhere. A more intensive effort than the scope of this study would be needed to give accurate dates for the terraces.

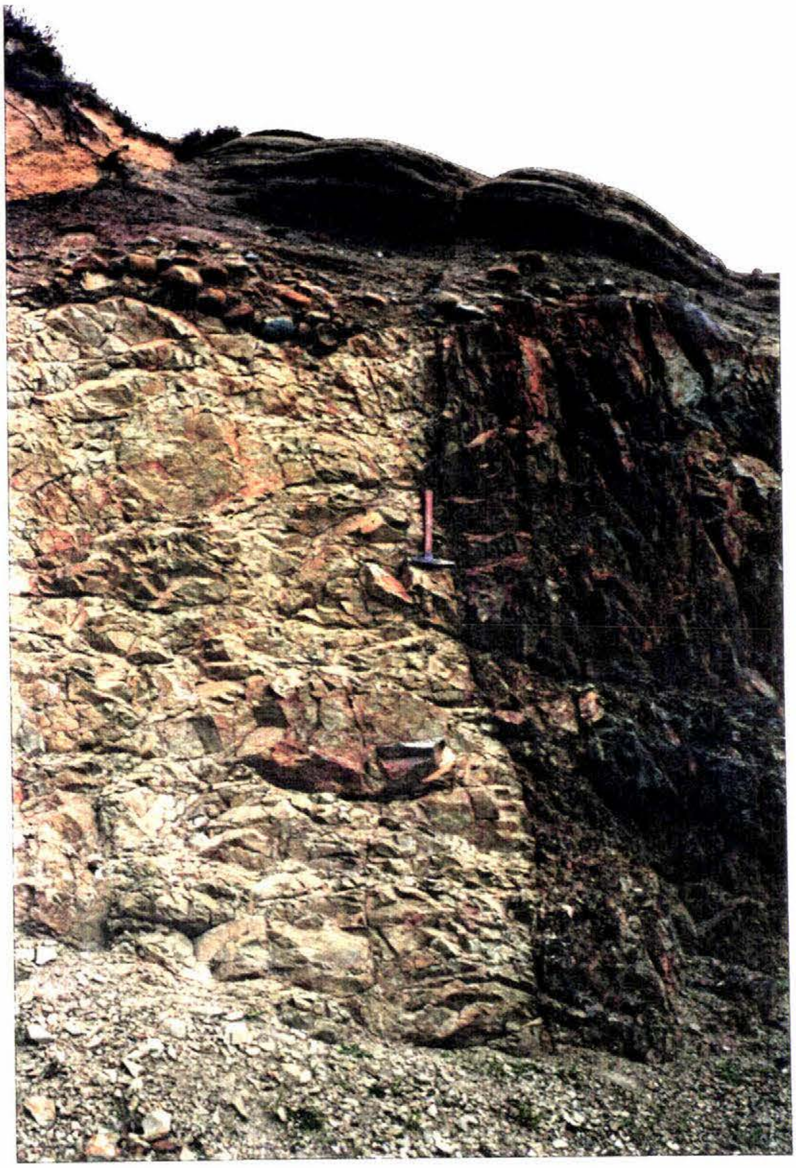


Fig 22 . Wave-cut surface of basement exposed at the Westlawn Quarry T20/536904. The fault visible at centre (hammer for scale), does not displace the wave-cut surface of the exposed greywacke, indicating there has been no movement since the Opoitian transgression. Greywacke derived cobbles and pebbles are overlain by gravels and sands of the Opoitian transgression. Shell fragments are common in the material lying on the basement.

Fig 23 . View of southeastern margin of Argo Basin. At extreme left, the Zone 28 gorge and Causeway with capping rock terraces overlain with marine Pliocene strata. At centre (arrowed), the flat tread surface of a well preserved Scrub terrace.

Fig 24 . On the Argo Road at T20/547907, looking west across Argo Basin to the downstream exit of Zone 27 gorge greywacke exposure (arrowed). Crag is to the right of Home Valley saddle (arrowed), with Flat Top partly visible behind Crag (to right). Note that exposure of shell limestone beds has given a similar stepped shape of the north-facing slope of Crag and Flat Top. Scrub terraces on this side of Argo Basin are seen as planar surfaces to right of Zone 27 gorge.

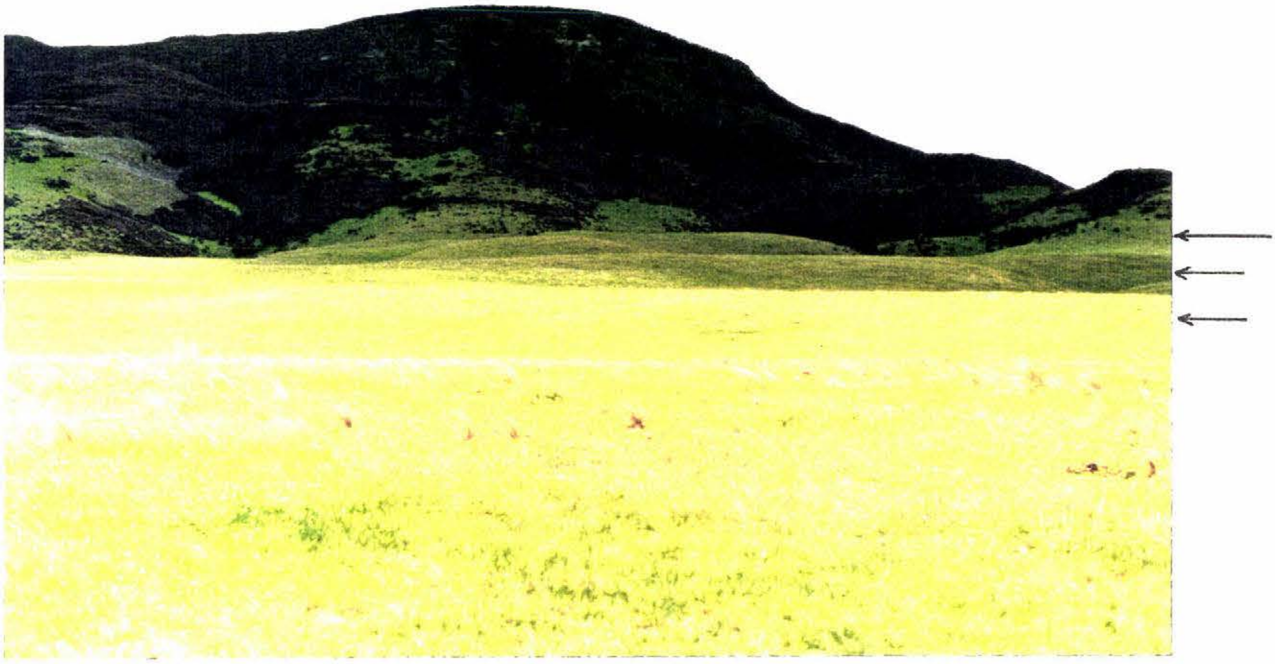


Fig 25 . River terraces, here named Meadow terraces in Argo Basin at T21/524895. Photo is taken looking southwest from the tread of the second terrace above river level, to the risers of terraces 3 to 5 (arrowed). Scrub covered background is the southwestern margin of Argo Basin.

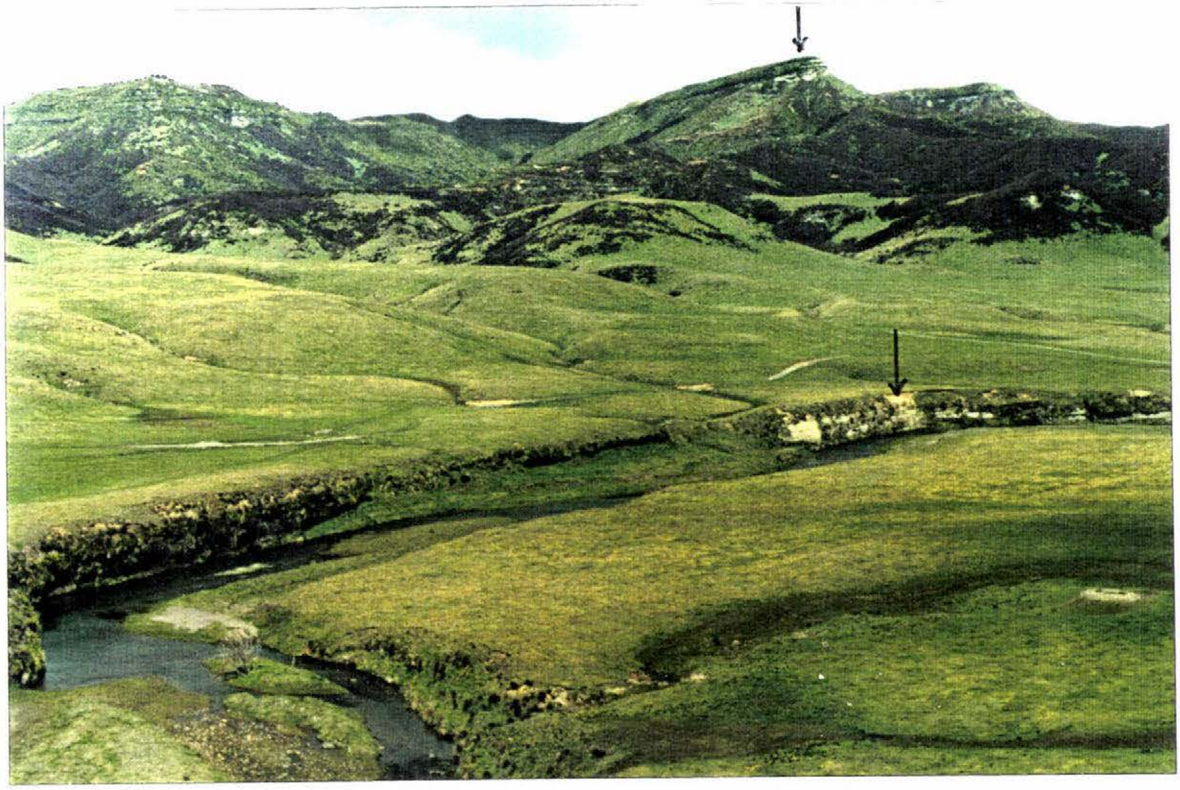


Fig 26 . Incised bed of the Moawhango River in Pliocene marine strata infilling Argo Basin. Photo taken from Zone 28 looking west to Beu spur (arrowed). Height of the terrace riser is 12 m above river level. Location of trench (Fig 27) in lower Meadow terrace is arrowed.

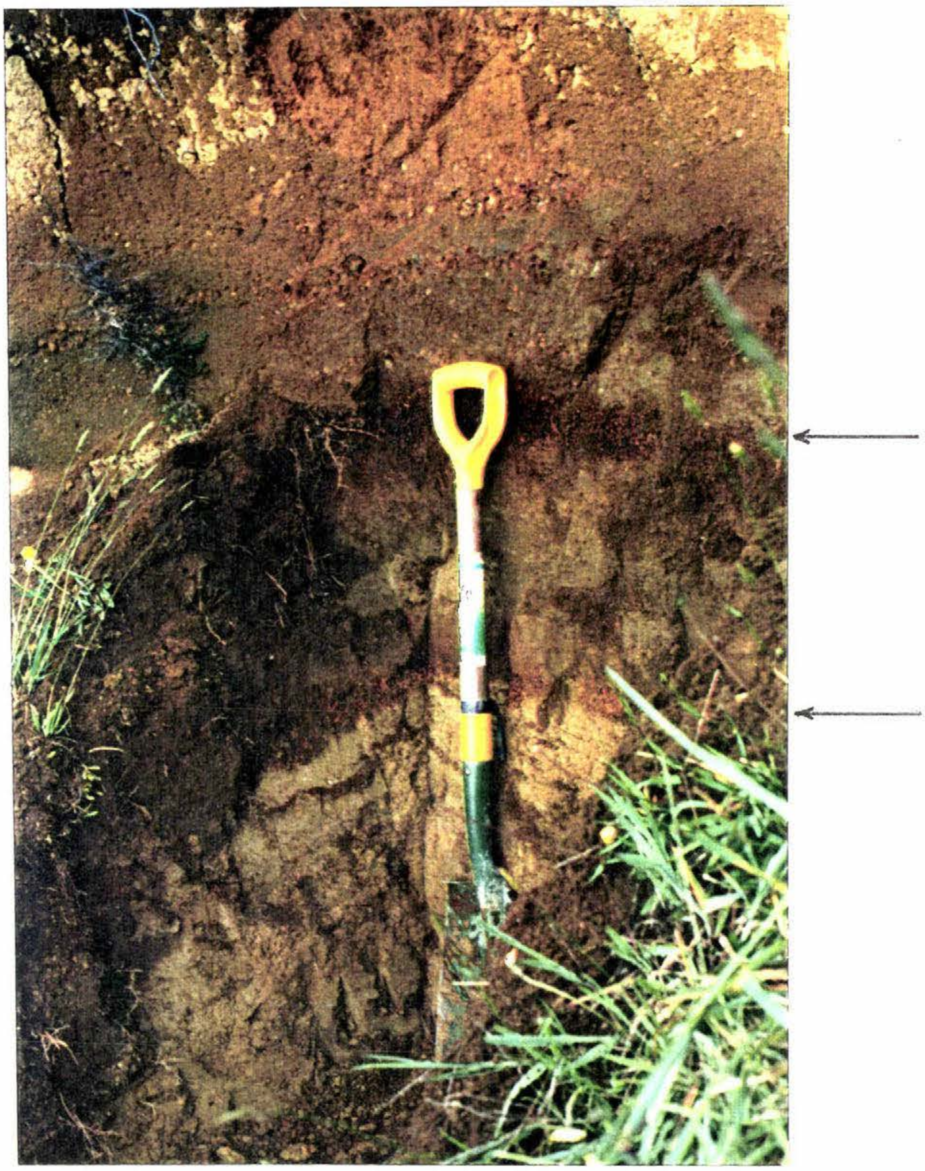


Fig 27 . Trench in the lowest Meadow terrace at T20/524895. Spade is 1 m in length and rests on river gravels which cover Pliocene marine strata. Indicated are Late Quaternary tephra (Ngamatea lapilli -1 and - 2) of the Upper Bullot Formation (Donoghue 1990) which have been dated as not younger than 11 250 - 10 000 years B.P., giving a probable age for the terrace of 12 000 years B.P. The river gravels at the base are 12.2 m above the current river level (Fig 26).

CHAPTER 3

NEOGENE STRATA

3.0 WAIOURU FORMATION

The Waiouru Formation consists of Late Tertiary strata deposited within the North Wanganui Basin. South and southwest of Waiouru, the Waiouru Formation is progressively overlapped by younger, lithologically differentiated strata of the Taihape Mudstone, Utiku Sandstone and Mangaweka Mudstone (Ker 1991). As the depocentre of the Wanganui Basin shifted to the southeast, offlap and emergence occurred to the north in the Ruahine Ranges and Kaimanawa Mountains, including the site of this study.

Waiouru Formation (Ker 1991) has previously been used to describe all Late Tertiary strata within the study area as a single member. This study proposes subdivision of the Waiouru Formation in the study area into two informal members, the marine Lower to Mid-Kapitean mudstone at GR T21/473893, in the Home Valley, here named the Home Valley mudstone, and the marine Opoitian sandstone with minor mudstone and limestone, here named Argo sandstone. See App B(d).

Early descriptions of the Waiouru Formation failed to give a type section for the Formation, however Ker (1991) gave a type area as, " 16 km east of Waiouru in the gorge of the Moawhango River in T21B". This type area is within Zone 33 where the Opoitian section is 400 m thick between the basal section at 600 m altitude near the Spur gorge and the top of the section at 1021 m altitude at Te Rei Trig (T21/563852). This section is here designated part of the Argo sandstone.

3.1 KAPITEAN UNCONFORMITY

The Home Valley mudstone contains Kapitean faunas and is unconformably overlain by the Opoitian Argo sandstone at a height of 940 m. However, it is some 260 m higher in altitude than the lowest exposure of the younger Argo sandstone some 4 km to the east.

The presence of an unconformity between strata of the Kapitean and Opoitian Stages is not uncommon in New Zealand. Moore (1981) reported an unconformable Kapitean/Opoitian sequence at Cape Turnagain which was considered to be caused by lowering of sea level during early Opoitian time. Opoitian strata of the shallow-water Ormond Limestone unconformably overly Kapitean upper bathyl siltstone near Gisborne (Bishop 1968), and a similar section in the Ormond Limestone at Cave Road, is interpreted to represent a significant shallowing at the end of the Kapitean (Francis and Scott 1987). Grammer (1971) reported deep-water deposited Kapitean strata unconformably on the greywacke basement at the Manawatu Gorge and underlying shallow-water Opoitian strata.

Browne (1981) in a study of the Kuripapango-Blowhard District located 50 km to the east of the study area, noted that the Blowhard Formation indicated initial uplift of the Ruahine-Kaweka Ranges in the Kapitean. In western Wairarapa, Wells (1989) reported an unconformity at the Miocene-Pliocene boundary, with Early Opoitian limestone unconformably overlying Kapitean mudstone, and suggested that this was due to the combined effect of a global fall in sea level and local uplift after 5.5 ma.

At Mangapoike River, determination of the magnetostratigraphy allowed a low angle unconformity between Miocene and Pliocene strata to be dated (Wright and Vella 1988), as between 6.3 ma and 5.41 ma, consistent with the global sea level fall at this time determined by Haq et al. (1987). Other reports (Ridd 1964, Kennett 1966 a & c, Katz 1973 and Carter et al. 1991), also suggest a marine shallowing for most of the New Zealand landmass during the Kapitean.

For Kapitean strata to be higher in the sequence than the younger Opoitian strata normally implies a tectonic cause such as folding, uplift, faulting or overthrusting. No evidence has been found within Opoitian strata, or the greywacke of the Westlawn Surface to indicate any major tectonic faulting, folding, or overthrusting which could explain the position of the Home Valley mudstone.

There is minor tectonic uplift in the study area which has created the Crag anticline and a newly identified fault along the Home Valley. However, post-Opoitian deformation from this cause does not exceed 60 m at GR T21/473893, thus making it unlikely that the unconformity is of post-Opoitian origin.

The most likely mechanism to emplace strata of the Home Valley mudstone high within the Argo sandstone is a regression after sedimentation of the Home Valley mudstone in late Kapitean time. This marine regression would have allowed a subsequent period of erosion to produce a dissected landscape later infilled by marine strata of the Opoitian transgression. The regression/transgression that produced the unconformity is more likely to have been due to tectonic movements affecting most of the New Zealand landmass, rather than a local movement in the Waiouru area.

It is likely that the uplift of the Ruahine-Kaweka Ranges reported by Browne (1981) was also accompanied by uplift of the Kaimanawa Mountains immediately north of the study area. Anderton (1981) noted that during Late Pliocene times, sedimentation in the Wanganui Basin was controlled by movements of basement blocks and the Kaimanawa Mountains would have represented such a block.

3.2 THE HOME VALLEY MUDSTONE

Exposed in a road cutting in the Home Valley at GR T21/472892 and at a height of 940 m is the blue/grey Home Valley mudstone (Fig 28). This exposure has been reported to contain sparse macrofossils of Tongaporutan-Kapitean faunas (Ker 1991). A microfossil determination by Dr R.H.Hoskins, Institute of Geological and Nuclear Sciences, (IGNS), (NZ Fossil Locality No T21/f12), reported an age of lower-mid Kapitean. A report of Tongaporutuan faunas was possibly based on an identification of the Tongaporutuan bivalve *Sectipecten grangei* as well as the Kapitean index fossil *Sectipecten wollastoni* (Boreham 1961, Kennett 1966 a).

The age determination of Tongaporutuan macrofossils and Kapitean microfossils from T21/f12 was resolved by Ker (1991) who noted that ages based on foraminiferal determinations and those based on macrofossils did not necessarily correspond. Attempts during this study to refine this age determination saw several recollections at this site, aided by major road works which exposed many more macrofossils (Fig 29), but no further Tongaporutan faunas were found.

Macrofossils of *Sectipecten wollastoni* and *Cucullea hamptoni*, which are index fossils for the Kapitean stage, were however, abundant, but *Sectipecten grangei* was absent. Several valves showing high, narrow and widely spaced ribs typical of *Sectipecten grangei* were found but were identified as being left valves of *Sectipecten wollastoni* by Dr A.Beu (IGNS). It is considered that macrofossils found during this study at T21/f12 are consistent with a Kapitean age as determined by the microfossils and thus this exposure is likely to be not older than mid-Kapitean to late-Kapitean.

Locations outside the study area were also briefly visited. Exposures in a road cutting located on the access road to the Moawhango Dam at GR T20/458976, and a traverse along the eastern boundary of Lake Moawhango to the XV gorge at GR T20/495982, showed the same field characteristics as the Argo sandstone inside the study area. An Opoitian age for the Pliocene strata as far north as the northern shore of Lake Moawhango is thus likely.

North of the study area, micaceous mudstones and siltstones possibly of Kapitean age, had been reported from the vicinity of the Mangaio Stream close to the Desert Rd (N122/510 of Gregg 1960) at GR T20/458012. This locality was investigated because it could allow correlation to other Kapitean exposures. However, these mudstones contained indeterminate age faunas which were assigned to the period between the Kapitean-Waipipian stages. They did not resemble the Home Valley mudstone in field appearance, containing numerous micas which this study has found to be a diagnostic feature for all the Opoitian sediments.

Thus the Mangaio Stream locality is probably of Opoitian age, contemporaneous with Argo sandstone. The Home Valley mudstone locality is here considered to be the only exposure of Kapitean strata in the study area.

3.3 IDENTIFICATION OF THE HOME VALLEY MUDSTONE

The Home Valley mudstone is a blue/grey mudstone with no visible bedding planes. It is superficially similar to Opoitian age mudstones within the Argo sandstone. However, Opoitian strata, otherwise resembling the Kapitean Home Valley mudstone, show bedding and contain abundant muscovite flakes. In the Opoitian sandstones interbedded with the mudstones, these mica flakes were often up to 2 mm across. This criterion became the most important characteristic for rapid field differentiation of these strata (Fig 31), no similar micas being found in the Home Valley mudstone. A further characteristic was that, when examined in thin section (Fig 30), the Home Valley mudstone had abundant foraminifera, whereas few foraminifera were found in Opoitian strata.

The local greywacke does not show any significant muscovite content so the micas could not be derived locally. Thus, they must be derived from a distant post-Kapitean granitic source (Fleming and Steiner 1950), giving a limiting age for the incoming of detrital micas in the Waiouru region. Marshall and Murdoch (1920) suggest an origin from granites of the Nelson area of the South Island for micas found in the Wanganui Basin. Transport of these materials 300 km from the Nelson area would need strong littoral currents.

With the creation of the Kuripapango and Manawatu straits in the early Pliocene (Fleming 1962, 1975, Stevens 1974 and Hayward 1987), tidal driven littoral currents may have become locally active and strong enough to transport material over considerable distances. Carter (1992) has reported tidal currents of 1.0 m/s in 225 m of water in the Cook Strait, forced by propagation of the tidal cycle around the New Zealand landmass.

It is here suggested that the micas originated from a post-Kapitean active offshore current system from the northwest Nelson region. Erosion of this granitic source area was possibly initiated by Plio-Pleistocene uplift in northwest Nelson, contemporaneously with the uplift to the north of the study area.

3.4 OCCURRENCE OF THE HOME VALLEY MUDSTONE

The major findings of this study are; the development of pre-Opoitian relief on the Westlawn Surface; its later infilling by Opoitian marine strata; the survival of the marine Home Valley mudstone deposit altitudinally higher than younger Opoitian strata, and the gentle nature of major post-Opoitian deformation.

The planar surface of the Westlawn Surface is interpreted to represent the Late Cretaceous Peneplain which has been exhumed by removal of its covering strata. Erosion in mid-Tertiary times had probably stripped Paleogene strata from the surface and initiated the deep basement relief before the onset of Kapitean time. The degree of relief before the Kapitean is critical in determining the depth of the Kapitean sedimentation, i.e.: if the basement in the Argo Basin had approximated the present contour when infilled, the pre-Kapitean transgression would have to be at least 300 m. In addition, removal of the infilling Kapitean strata implies a long period of active post-Kapitean erosion.

The presence of *Sectipecten wollastoni* indicates a shallow water depth of perhaps 10-75 m (Kennet 1966 c). Beu et al. (1990) however, report that *Sectipecten wollastoni* also occurs sparsely in normal shelf blue-grey mudstones, as well as in shallower facies. A nominal location for the Home Valley mudstone, not inconsistent with the paleoenvironment for *Sectipecten wollastoni*, is here taken to be as an inner shelf deposit on the greywacke basement at a water depth of 50 m and approximately 5-10 km offshore.

Fig 28 . The Kapitean exposure on Moawhango Bridge Road at T21/473893 (T21/f12). Blue-grey mudstone containing Kapitean macrofossils is exposed in this road cutting in Home Valley and for 500 m further east along the road.

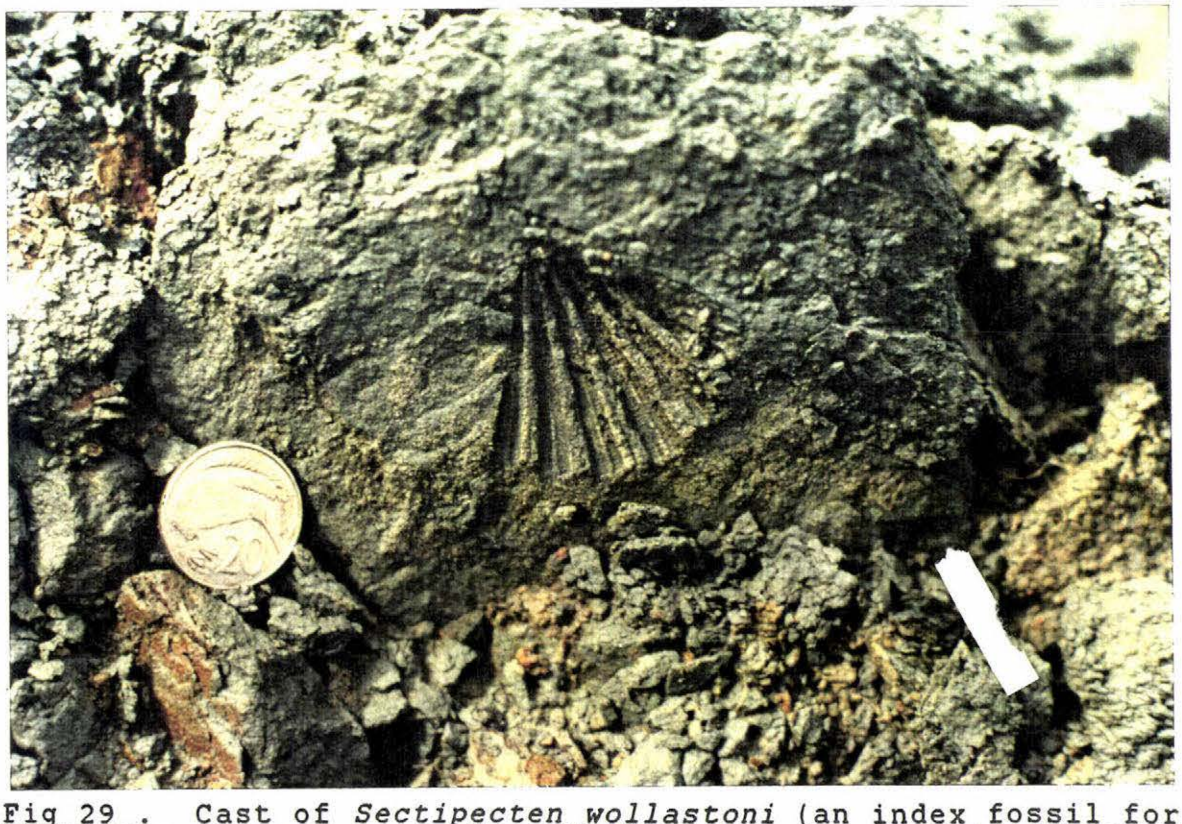


Fig 29 . Cast of *Sectipecten wollastoni* (an index fossil for the Kapitean Stage), in Home Valley mudstone at T21/473893. The Home Valley mudstone is Kapitean marine mudstone unconformably deposited on basement greywacke. It is also unconformable with overlying Opoitian Argo sandstone. This exposure of Home Valley mudstone is the only Kapitean deposit identified in the study area. Coin is 28 mm in diameter.

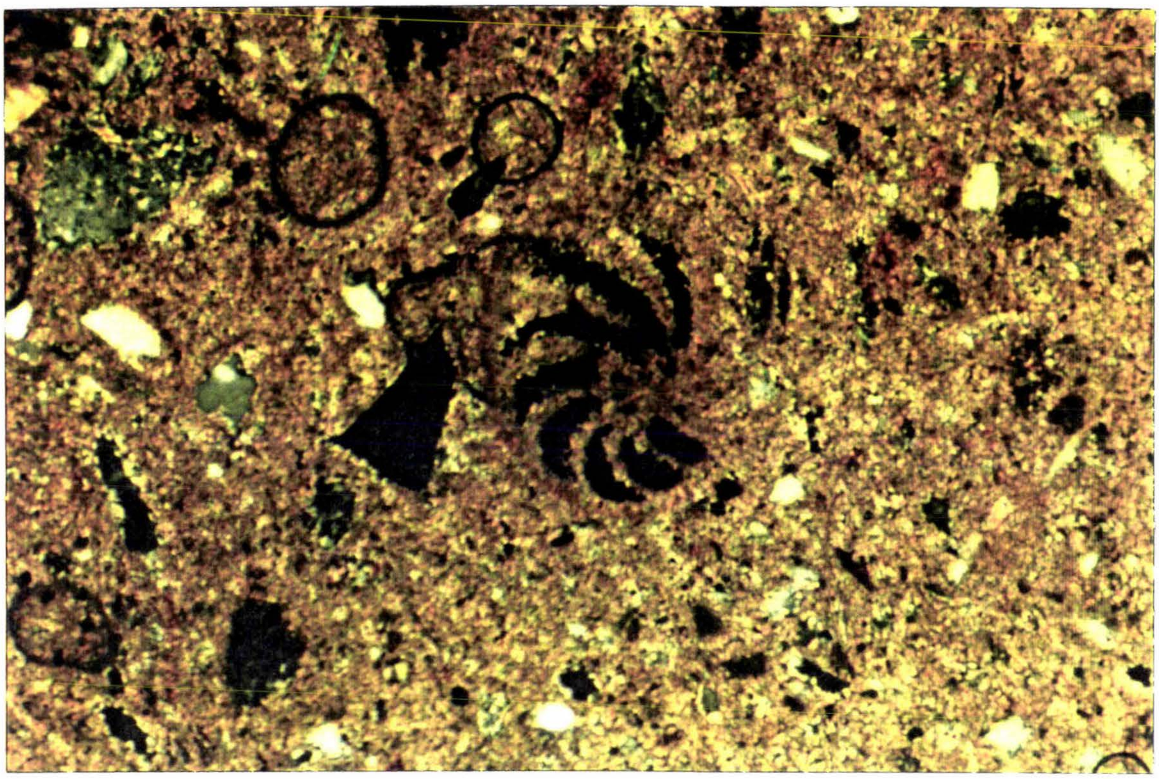


Fig 30 (a). Thin section through an internal fossil cast of a macrofossil in the Home Valley mudstone. Spiral structure at centre is an unidentified foraminifera typical of an abundant foraminiferal population in the mudstone. Sharp-edged shard of glass is next to the foraminifera. The majority of the section is a calcite-bound matrix of fine grains 0.1-0.05 mm diameter, with rarer grains of anhedral quartz and feldspar up to 0.2 mm in diameter. Some glass, traces of carbonaceous material and altered clays make up the body of the section.

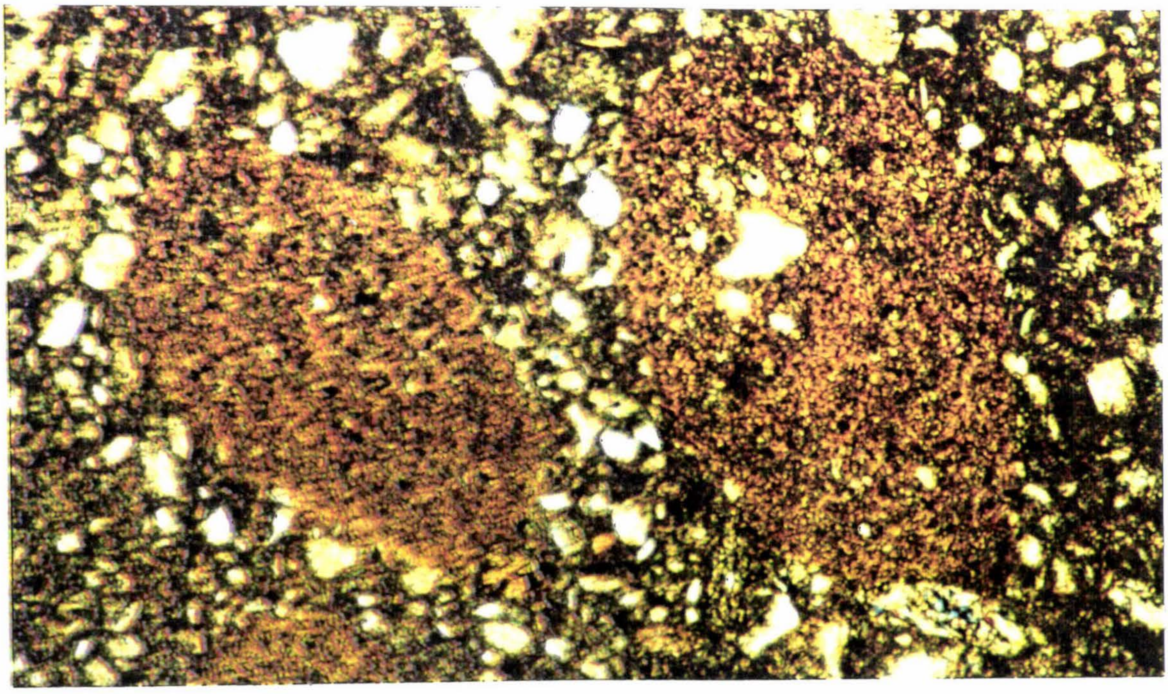


Fig 30 (b). Thin section of Home Valley mudstone showing a fine grained matrix of angular to sub-angular quartz and feldspar 0.1-0.05 mm diameter. Altered clays make up the remainder of the matrix. Two pellets 1 x 2 mm diameter are visible containg some grains of quartz and other smaller mineral grains. Originally thought to be faecal pellets, these pellets are here interpreted as weathered greywacke particles.

Fig 31 . Coarse yellow-brown marine sands of the Argo sandstone. Darker silt layers capping sand layers are clearly seen, as is a small slip plane displacing the silt layers. Several of the large mica flakes typical of the Opoitian sediments are also visible (arrowed). Coin diameter is 19 mm.

Models implying active faulting in the basement were discarded as there is no evidence for major displacement in the study area. Likewise, there was no evidence for reworking as a plausible mechanism for emplacement of the Home Valley mudstone.

One poorly preserved specimen of *Sectipecten wollastoni* found in the massive and unbedded Home Valley mudstone still retained two valves indicating a life position. If the Home Valley mudstone had been reworked from Kapitean age strata, the exposure would show typical Opoitian-bedded strata with abundant mica flakes. As described, the Home Valley mudstone does not show any bedding and has no visible mica flakes.

Two possible models are considered:

3.4.1 Model A

An extensively dissected greywacke landscape with relief similar to the modern day, was submerged before the Kapitean Stage, and the relief was infilled by marine Kapitean sediments. A regression at the end of the Kapitean exposed the newly emergent marine Kapitean strata to terrestrial erosion which preferentially eroded the unconsolidated Kapitean strata filling the pre-Kapitean relief. Kapitean remnants from this erosion interval would survive to be later inundated by the Opoitian transgression.

The regression implied by this model would require a sea level fall of approx 300 m to expose and erode the valley bottoms which were later infilled by the basal Opoitian.

3.4.2 Model B

A greywacke peneplain surface with little or only mild relief was submerged in pre-Kapitean time and a marine transgression flooded across the surface during the Kapitean.

A regression at the end of the Kapitean Stage started a period of aggressive erosion on the uplifted surface to remove the Kapitean marine strata and increase the degree of dissection on the basement relief. The depth of the regression is unknown.

Critical differences between Model A and Model B are in the thickness of the Kapitean marine strata and the amount and depth of the relief of the greywacke basement before the Kapitean regression.

3.5 EROSION OF KAPITEAN STRATA

The Kapitean macrofossils in the Home Valley mudstone give a limiting age for the unconformity prior to the Opoitian transgression and imply a restricted period for any development of the basement relief and erosion of other Kapitean strata.

Considerable erosion is implied in both models either; to remove Kapitean strata from pre-existing relief in the greywacke basement, or to develop the relief in the greywacke of the Westlawn Surface. A time gap is thus required for terrestrial erosion between the Kapitean regression and the Opoitian transgression and/or an efficient mechanism to remove Kapitean strata.

The magnitude of the time gap proposed to fit each model can be related to erosion of the present landforms since the Plio-Pleistocene regression. Lack of strata younger than Opoitian in the study area implies that this area may have emerged as the Wanganui Basin depocentre shifted southeast and erosion thus started early in the Plio-Pleistocene regression.

The greywacke of the exposed basement has been deeply incised in the superimposed gorges of the Moawhango River, but this incision of the basement is minor compared to that which has formed the Argo Basin, demonstrating that the relief probably pre-dated the Kapitean as well as the Opoitian transgression.

The lack of landforms similar to the present superimposed gorges are taken to imply that pre-Kapitean basement relief was either (1) restored following the Kapitean regression, or, (2) continued existing during the Kapitean transgression. Kapitean strata had covered this relief as demonstrated by the exposure of the Home Valley mudstone above altitudinally lower Opoitian strata infilling the basement relief. The Kapitean strata previously infilling this relief were either efficiently removed prior to, or during the Opoitian transgression, thus leaving the Home Valley mudstone as an isolated exposure.

A likely mechanism aiding removal of Kapitean strata from the basement relief was the onset of the Opoitian transgression. Changes in sea level and consequent shoreline erosion may have aggressively removed strata of an earlier transgression. Tidal inlets are primary sources of material for transport in a transgression, with the tidal motion scouring 15-30 m down and releasing large amounts of material from the previous depositional cycle (Swift et al. 1991, Haq 1991).

The pre-Opoitian basement relief had antecedent valleys acting as tidal estuaries as the Opoitian transgression progressed. Scouring of the estuary by tidal action (Swift et al. 1991) would have eroded from or bypassed material across the estuary floor through tidal channels into lagoons, where sediment would accrete on point bars. This author considers this process would have been an efficient agent in removing Kapitean strata to re-expose the basement relief during the Opoitian transgression.

It is likely that the stratigraphic thickness of Kapitean strata was not comparable to that of the Opoitian transgression. The lack of coarse material in the Kapitean strata demonstrates a slow deposition regime and possibly a consequent thin Kapitean sedimentation. A less aggressive erosion regime would be needed if the Kapitean strata in the study area were thin and overlying a resistant layer on the basement and/or were soft and easily erodible.

It is here suggested that the basement relief may still have been extant as submerged valleys in the sea bottom topography, clad with relatively thin layers of sediment. The regression at the end of the Kapitean might thus have produced an emergent landscape already possessing a muted relief in the Kapitean strata. Erosion would then have acted on the emerged landmass and newly established rivers would have preferentially established their channels conformably with the existing relief. Pre-existing relief on the emergent surface would have reduced the amount of material required to be eroded, compared to a totally infilled landscape.

It is here suggested that the Home Valley mudstone thus rests on part of the greywacke basement representing the Westlawn Surface. The pre - Opoitian relief indicates that the Home Valley is situated between two buried valleys in the basement aligned northeast/southwest (Fig 9), and the intervening ridge is here considered to have retained an isolated exposure of Kapitean strata.

The inferred height of the basement at the site of the Home Valley mudstone is approximately 800 m. However, because no seismic investigations are available for this area, the basement may be even higher, possibly up to 900 m. High basement relief under the Home Valley is indicated at Road Quarry T20/501903. The Opoitian deposits exposed here are indicative of deposition in a small valley cut in the side of the ridge. This site was first inundated with unconsolidated coarse yellow-brown sands during the Opoitian transgression. Within these yellow-brown sands, at 900 m altitude, is a wedge-shaped layer of debris which thins to the east and is composed of weathered greywacke cobbles and boulders with angular and broken chunks of greywacke in a blue/grey muddy matrix (Fig 32). This lithology is interpreted to be a debris flow from a nearby ridge of higher elevation, onto the Opoitian beach sands. These deposits are not consistent with the remainder of the Opoitian sequence. Thin-section examination shows the muddy matrix is consistent with being reworked from the Home Valley mudstone which caps the ridge to the west.

Similar boulders to those in the debris flow are found lying on the basement above the Zone 27 gorge where erosion has removed covering Opoitian strata.

Weathering of basement reported from the Intake Tunnel site (Hegan 1980) is rarely found in the study area. Most basal Pliocene contacts do not show weathered material underlying the Opoitian marine strata. It is possible that such weathered greywacke was removed by marine shoreline erosion during the onset of the Opoitian transgression.

3.6 CONCLUSIONS

The Home Valley mudstone exposure is here considered to be an erosional remnant of marine Kapitean strata on basement greywacke.

Tectonic activity submerged a dissected Late Cretaceous Peneplain surface in pre-Kapitean time and sedimentation commenced on the submerged surface. The sedimentation was influenced by the bottom topography and the pre-Kapitean basement relief was only partly infilled. Abundant oceanic foraminifera found in the blue-grey muds indicate slow deposition in an offshore environment. A quiet tectonic period with little terrestrial erosion is inferred.

The presence of Kapitean index fossils (*Sectipecten wollastoni* and *Cucullea hamptoni*), provides a limiting age for the following regression. As the sea receded, emergence may have continued until the shore line was to the west of Waiouru. The horizontal basement at 600 m, lying below the 7 mile peg on the Desert Road (GR T20/434985), reported from geophysical surveys, may represent a wave cut platform of the Kapitean regression. If this is so, the regression would be in excess of 300 m depth.

A period of aggressive erosion immediately began on the emergent surface with streams and rivers preferentially establishing their courses compliant to the pre-Kapitean basement relief.

The softer and easily erodible Kapitean strata which had only partly infilled the relief were then mostly eroded and removed before the Opoitian transgression. Aggressive tidal erosion is attributed for the efficent removal and reworking of any remaining Kapitean strata as the succeeding Opoitian transgression progressed. Such active erosion of the Home Valley mudstone left one known remnant on an underlying basement ridge.

As the Opoitian transgression infilled the relief, marine erosion and reworking became less aggressive and the spur with the Home Valley mudstone exposure became a coastal headland. Swift et al. (1991) note that headlands retreat at a slower rate in a transgression than the coastal sand barriers. Wave refraction down the sides of the headland may have reduced the effect of wave erosion and transported material from the littoral currents would have been rapidly deposited. If sufficient material (usually sand) is deposited, the headland eventually becomes buried by the transgression, If sufficient sand is not available the headland will be eroded away. It is here considered that the Home Valley mudstone represents such a buried headland.

Erosion following the Plio-Pleistocene regression, has established entirely new river courses in the Opoitian strata. Some of these have formed superimposed gorges where they have cut into basement greywacke.

3.7 THE ARGO SANDSTONE - TYPE SECTION

Basal Opoitian strata were described by Ker (1991) as,

> " ..... thin non-marine greywacke derived conglomerate, sandstone, and thin beds of carbonaceous siltstone resting unconformably on basement. These non-marine sediments grade upwards into shallow water marine sediments including lenses of pea sized greywacke gravel, poorly consolidated current bedded coarse to medium yellow brown sandstone, muddy sandstone, and siltstone interspersed with thin detrital shelly limestone beds."

This study has revealed a substantial difference in lithological assemblage within the study area to Ker's (1991) description. Only two small non-marine deposits have been found in the study area; and the role of the basement relief in causing rapid lateral variations in lithology of the Pliocene strata has not previously been recognised. Where sedimentation is distant from the basement there is little change in lithology, but where sedimentation has been on or close to it there is considerable lateral lithological variation.

The type section of the Argo sandstone is here defined as from GR T21/530885, at the intersection of Tor Valley stream with the Moawhango River, to the summit of Crag at GR T20/475905. This represents the Pliocene marine strata in the study area, from the basal contact of Opoitian strata with the basement, to the prominent shell limestone beds on the summit of Crag. Waiouru Formation strata eroded from Crag and which, to the south, underly the onlapping Taihape Mudstone, are not included in this type section.

Fig 32 . Road Quarry exposure T20/500903, looking north. At centre, a wedge shaped debris flow thinning to the east within loosely consolidated yellow-brown Opoitian marine sands. The debris flow consists of reworked Kapitean blue-grey mudstone, angular blocks of unweathered greywacke and rounded boulders of weathered greywacke. This is interpreted as a debris flow of Kapitean mudstone and weathered greywacke boulders. The debris flow fell onto rapidly accumulating sands which quickly buried the debris flow. Hammer at centre is 32 cm in length.

CHAPTER FOUR

MAPPING, STRUCTURE AND AGE DETERMINATION

4.0 RELATION OF NO 1 REEF TO THE ARGO SANDSTONE

The first detailed structural mapping of the area to the south of Waiouru produced a map (Appendix A), based on a distinctive shell limestone bed named No 1 Reef by Feldermayer et al. (1943). Ker (1991) described No 1 Reef as the lowest prominent shell-bed in the Waiouru area.

Two prominent shell limestone beds are visible on the north face of Crag at GR T20/476906. The lower of these, at 1143 m height (Fig 33), is here recognised as being 49 m lower than No 1 Reef. This newly recognised shell limestone bed, is here named Crag reef, and is underlain by a 10 m thick sandstone layer with abundant concretions. These concretions, increasing in abundance towards the top, merge into the overlying shell limestone bed and act as a distinctive feature for field recognition (Fig 34). No 1 reef would thus have been at a height of 1192 m at Crag, but has been eroded from the summit. Small outcrops of shell limestone in Zone 30 at T21/495881, are correlated as remnants of No 1 Reef (Fig 35).

To the south, No 1 Reef was located (Ker 1991) about 100 m below the overlying Taihape Mudstone. To the west, in the Turakina River Valley (McGuire 1989), No 1 Reef is 58 m below the Taihape Mudstone, a 42 m difference. The differing location of No 1 Reef below the Taihape Mudstone may reflect local variation of sediments on the seabed. Similar variations in sediment accumulation are reported for Cook Strait by Carter (1992), who interprets them as being caused by local changes in tidal flows. In contrast, No 1 Reef probably represents a time plane rather than a local condition, as it is regionally persistent, being mapped for over 80 km (Ker 1991).

In Waiouru, tidal conditions through the nearby Kuripapango Strait would have generated similar conditions to those reported for Cook Strait, and caused local variations in sediment thickness. Sediment accumulation rates are thus unreliable for dating relatively thin sequences near Waiouru, unless there is a considerable margin for error, or it can be related to a time plane such as No 1 Reef.

4.1 AGE OF THE ARGO SANDSTONE

Attempts to find datable microfossils in the Argo sandstone were generally unsuccessful. Samples proved to be poor in condition and indeterminate in age (*Notorotalia sp* and *Florilus parri*, Appendix C, T20/f29), indicating a Kapitean-Waipipian age, 6 ma to 3.1 ma.

Conditions for preservation of macrofossils in the Argo sandstone were generally poor. Almost all specimens in the sequence were chalky and deformed, although macrofossils in the shell limestone beds near the top of the Argo sandstone are better preserved. All macrofossils found in the Argo sandstone in this study (listed in Appendix C), are consistent with an Opoitian age. Numerous specimens of *Phialopecten marwicki (Beu)* (Beu 1978) in the Crag reef are assigned a Late Opoitian age (Dr A.Beu, pers.comm.).

South of Waiouru, the Waiouru Formation is overlain by the 270 m thick Taihape Mudstone, (Feldermayer et al. 1943; Fleming 1953, 1959 and Ker 1991). The contact between the two is exposed at Turangarere (GR T21/450765) (Ker 1991). Biostratigraphic datums within the Taihape Mudstone have been reported by Collen (1972), who located Opoitian faunas in the lower part of the Taihape Mudstone, and Waipipian faunas in the upper 50 m.

Previous geomagnetic dating in Pliocene age sections (Lienert et al. (1972) related stage boundaries to specific magnetic polarity intervals. This technique was used to understand Pliocene sediments and their magnetostratigraphy in the Rangitikei River Valley (Seward et al. 1986) and in the Turakina River Valley (McGuire 1989).

The base of the Turakina River sequence was located just below the base of the Taihape Mudstone and included the No 1 Reef of the Waiouru Formation. These studied sequences could thus help establish a more accurate chronocorrelation for the Argo sandstone.

Seward et al. (1986) reported the Taihape Mudstone as the base of the section in the Rangitikei River, because the Waiouru Formation is inaccessible there. Although biostratigraphic boundaries were difficult to locate (many species being absent), the Opoitian/Waipipian boundary was placed at approximately the top of the Taihape Mudstone, which was assigned as the base of the Gauss magnetic interval (3.4 ma). The base of the Rangitikei River section was reported as 4.2 to 4.3 ma, based on a correlation with the upper part of the Gilbert epoch. A sedimentation rate of 1.7 m/1000 yr was then interpreted for the Taihape Mudstone.

Biostratigraphic boundaries in the Turakina River Valley were established by McGuire (1989) who placed the last appearance datum (LAD) of *Cibicides finlayi* within the Taihape Mudstone. The LAD of *Cibicides finlayi* is an important datum in New Zealand, having being used as an indicator of the Opoitian/Waipipian boundary (McGuire 1989). However, Edwards (1987) points out that the boundary has usually been taken at the LAD of *Chlamys (Phialopecten) triphooki ongleyi* and immediately underlying the first appearance datum (FAD) of *Chlamys (Phialopecten) triphooki marwicki*, which is well below the LAD of *Cibicides finlayi*. Edwards (1987) places the LAD of *Cibicides finlayi* at 3.3 ma, above the now commonly accepted Opoitian-Waipipian boundary at 3.6 ma given by Beu et al. (1990). Thus the LAD of *Cibicides finlayi* indicates a near mid-Waipipian age.

McGuire (1989) placed the LAD of *Globorotalia puncticulata* in the Taihape Mudstone at 3.69 ma; older than other dates obtained for the Taihape Mudstone. This date appears to be in error, because it would place the datum within Opoitian Argo sandstone and not in the Waipipian age Taihape Mudstone. In the Turakina River Valley sequence, the LAD of *Globorotalia puncticulata* is more likely to fit at c. 3.5 ma.

The base of the Gauss interval is located within the Taihape Mudstone by McGuire (1989), differing from Seward et al. (1986) who placed this datum at the top of the Taihape Mudstone. Age boundaries of 3.56 to 3.11 ma were assigned to the Taihape Mudstone by McGuire (1989). Thus the sedimentation rate calculated for the Turakina River Valley is 1.7 m/1000 yr, a similar rate to that deduced for the Rangitikei River Valley by Seward (1986).

4.2 DISCUSSION

The data of McGuire (1989) for the Taihape Mudstone is here taken as more accurate than that of Seward et al. (1986), because (1) the base of the Taihape Mudstone is visible in the Turakina River Valley and not in the Rangitikei River Valley, and (2) the identification of the LAD of *Cibicides finlayi* allows a correlation to a known biostratigraphic boundary. The 4.2 to 4.3 ma date for the base of the Rangitikei River section is thus probably in error.

The use of the LAD of *Cibicides finlayi* as the Opoitian-Waipipian boundary does not fit the now generally accepted date of 3.6 ma given by Beu et al. (1990). However, the base of the Taihape Mudstone is given as 3.56 ma by McGuire (1989), a date entirely consistent with this being the Opoitian-Waipipian boundary. This is because (1) it marks a change in facies, (2) the date falls close to the 3.6 ma boundary date of Beu et al. (1990), and (3) there is a Late Opoitian age determination on macrofossils near the top of the Argo sandstone.

It is here suggested that the Taihape Mudstone was deposited in the Waipipian and that the contact with the top of the Waiouru Formation marks the Opoitian-Waipipian boundary, giving an age of 3.6 ma for the top of the Waiouru Formation.

The similar sedimentation rates derived for the Pliocene sequence in Rangitikei and Turakina River Valleys, indicates that this sedimentation rate can apply to the Waiouru Formation.

However, local variation on the sediment accumulation rate, as discussed above, do not make it reliable for other than general age indication.

No 1 Reef is reported at 100 m below the Taihape Mudstone to the south of Waiouru (Ker 1991) and this study has placed the No 1 Reef in the Waiouru area as 49 m above the Crag reef in the Argo sandstone. Crag reef is thus placed 149 m below the base of the Taihape Mudstone here taken to be 3.6 ma. This places Crag reef at approximately 3.7 ma, based on the sedimentation rate of 1.7 m/1000 yr for the Turakina and Rangitikei River Valley Pliocene sequences.

Local variation in sediment thickness would affect the above age. However, using No 1 Reef as a reference time plane, the lesser value of 58 m between No 1 Reef and the base of the Taihape Mudstone in the Turakina River Valley (McGuire 1989) would lessen the age by 25 k.y. The age of 3.7 ma for the Crag reef is thus a reasonable approximation.

Rates of sedimentation are critical for this study, i.e.: if the average accumulation rate for Argo sandstone was slower, the onset of sedimentation for the Argo sandstone would be nearer to the Kapitean-Opoitian boundary. However, a relatively fast rate of sedimentation for the Argo sandstone is implied by the unconformity between Kapitean Home Valley mudstone and Opoitian Argo sandstone (Chapter 3). The longer the period between the uplift of the Home Valley mudstone and the commencement of sedimentation to form the Argo sandstone, the shorter the time available to deposit the Argo sandstone in the Opoitian (and the faster the sedimentation rate required).

The Argo sandstone is typically a shallow water nearshore facies. Macrofossils and lithology indicate the same relative shallow water environment throughout the section, implying that sedimentation kept pace with subsidence.

The lowest mapped strata of the Argo sandstone is 460 m below Crag reef. Based on the 1.7 m/1000 yr sedimentation rate above, it would take 270 000 yr (270 kyr) to deposit the 460 m of Argo sandstone underlying Crag reef, and thus a date of approximately 4 ma could be assigned to the lowest visible strata and beginning of the Opoitian transgression.

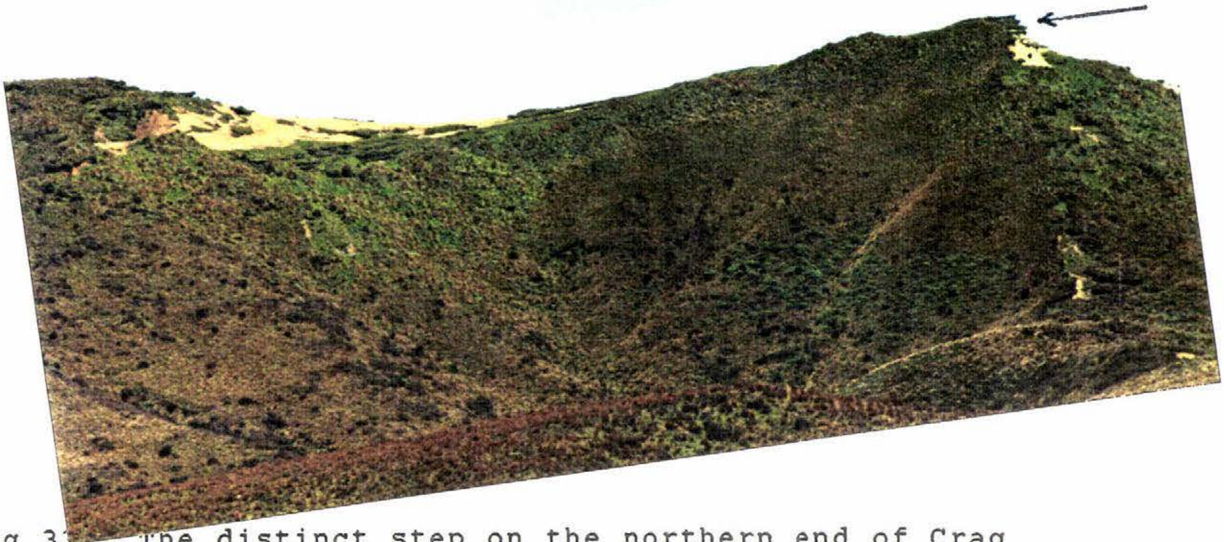


Fig 33 . The distinct step on the northern end of Crag T20/476906, formed by erosion of the two prominent shell limestone beds capping Crag. The upper bed at left and Crag reef (arrowed) at the right.

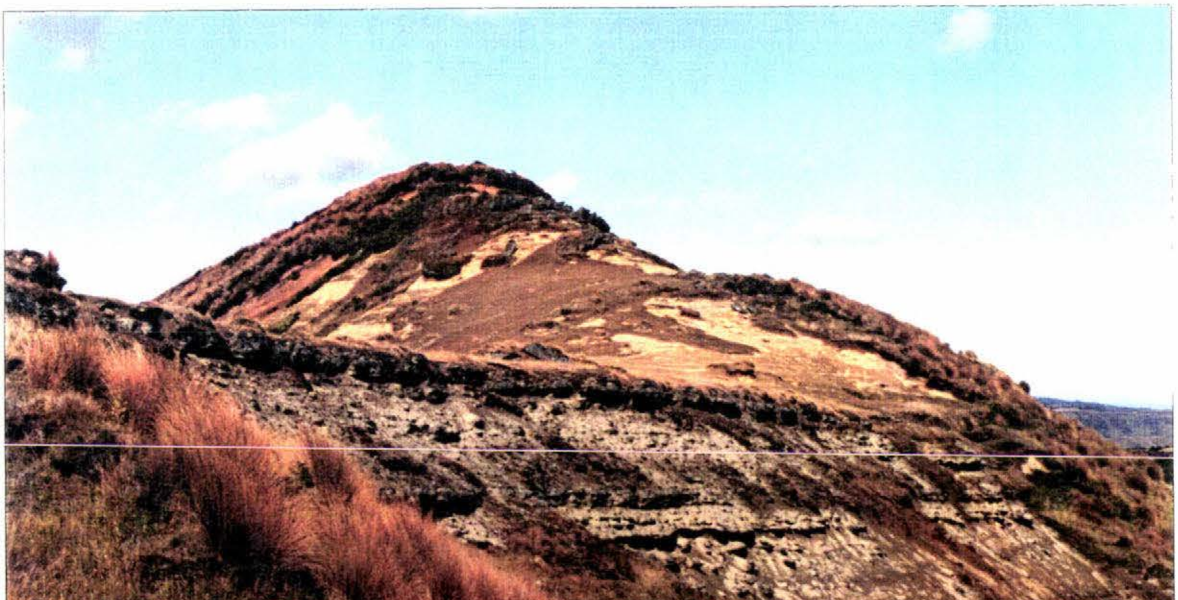


Fig 34 . Crag reef on Crag T20/476906. The north face of Crag at 1143 m height, with Crag reef at centre and concretion layers visible in the sandstone underlying the Crag reef. Between Crag reef and the overlying upper shell limestone bed are approx 14 m of sandstone. The eroded layers of the upper shell limestone bed are thinly covered by Late Quaternary tephra.

Fig 35 . Remnant of No 1 Reef. Photo taken from Zone 28 gorge looking west across the Argo Basin to the Argo sandstone sequence exposed on the steep basin margin. Three shell limestone beds are prominent below the rim, the uppermost is a remnant exposure of No 1 Reef at T21/498880, (arrowed). The two shell limestone beds underlying No 1 Reef are well exposed on Crag (Fig 33), the lowermost here being Crag reef.

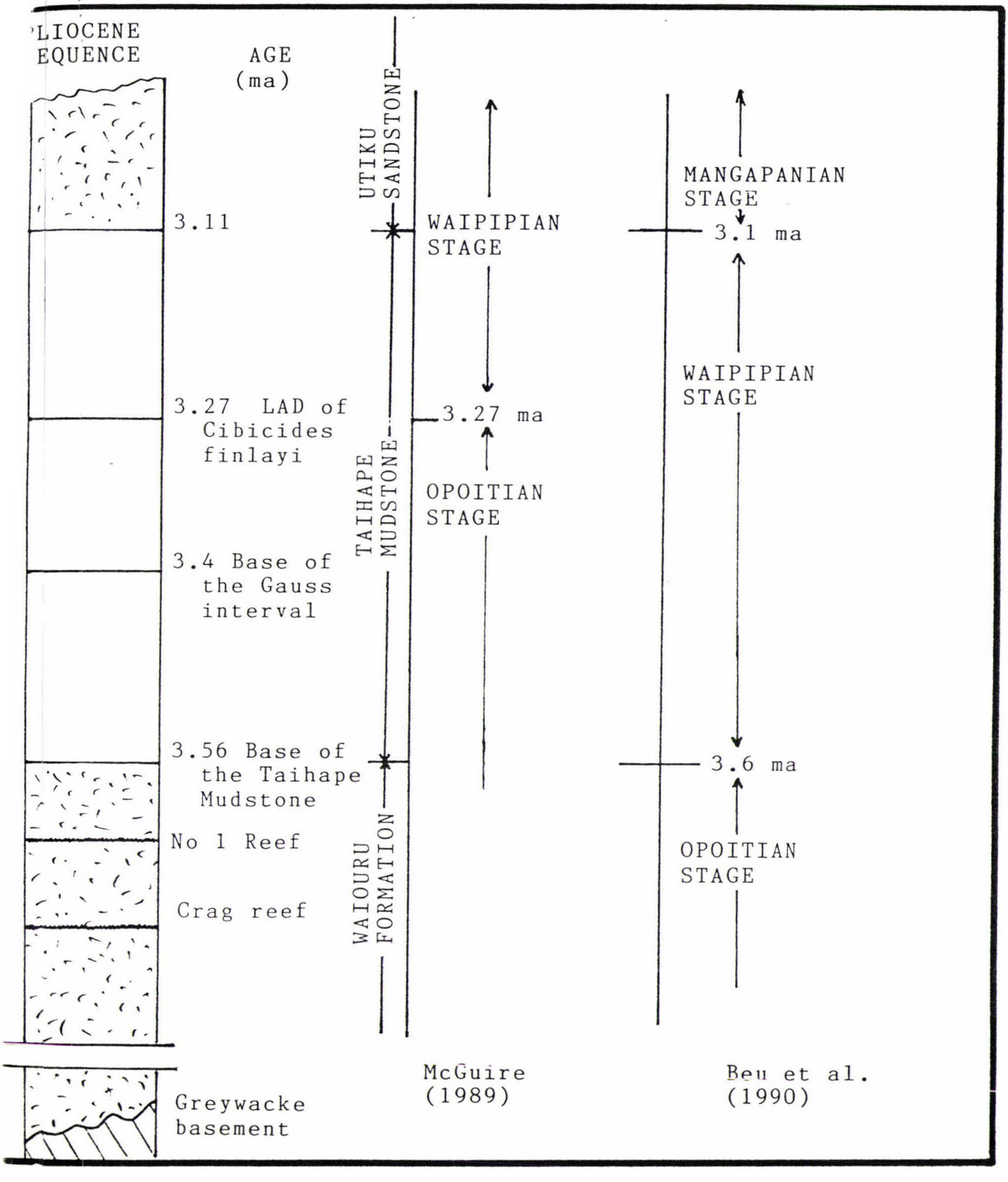


Fig 36 . <u>AGE SEQUENCE OF THE TURAKINA RIVER VALLEY</u>.
(after McGuire 1989)

The stratigraphic sequence for the Turakina River Valley section is based on the magnetic polarity intervals and biostratigraphic datums identified by McGuire (1989), who has taken LAD of *Cibicides finlayi* at 3.27 ma as the Opoitian-Waipipian boundary. However, the dates of stage boundaries given by Beu <u>et al</u>. (1990), indicate that the base of the Taihape Mudstone is at the Opoitian-Waipipian boundary, a finding consistent with this study. This would place the top of the Waiouru Formation at 3.6 ma and Crag reef at 3.7 ma.

4.3 STRUCTURAL MAPPING

Post-Opoitian deformation to the south of the Snowgrass fault was mapped by Feldermayer *et al*. (1943) based on structural contours of No 1 Reef. This mapping was not extended north of the Snowgrass Fault and into the study area, possibly due to restrictions imposed on access to the military training area during the 1939-1945 period and the few exposures of No 1 Reef.

Mapping of Crag reef in this study has allowed post-Opoitian deformation to be identified in the study area, and establishing the relationship between Crag reef and No 1 Reef allows extension of the southern structural map across the Snowgrass Fault.

4.4 HEIGHT FIXING OF SECTIONS

Traverses over the study area indicated that deformation of Opoitian strata had been relatively minor and would need accurate height determinations to identify any deformational structures. Use of maps to determine location and height for an exposure would not be suitable due to limitations on position and height determination.

More accurate height and position determinations require the use of a compass, an Abney level, barometer, a surveying theodolite or satellite based technologies. A theodolite was used for the survey of Crag reef. Additional spot heights and small trig stations overprinted on NZMS 317 (Fig 2), assisted in selection of observation points and baseline measurement. Trig stations or reference points of known height up to 10 km away from the observer were located; as corrections for refraction and curvature of the Earth are minor up to this distance.

The error range in the plotting of heights was expected to be in the order of 1 m per 1000 m between observer and target for this study, based on my previous survey experience in this area on construction of the Argo Road during 1973-5.

4.5 SURVEY PROCEDURE

A TM 20C theodolite was used to measure vertical angles to selected points from an observation point. Ground distances between the observed point and the theodolite position were measured directly from the 1:50 000 scale map and used as the baseline for calculation of height differences.

For each set of observations, a point was chosen that would allow observation of part of the Crag reef and two or more points of known height, enabling a gross error check as standard procedure. The position for siting the theodolite was selected to be of similar height to the point being observed, as the smaller the height difference between the two points, the smaller the height error caused by any error in calculating the distance between the two points.

After alignment and levelling of the theodolite, each point of known height was observed and bearings and vertical angles recorded to fix the height and position of the observation point. The procedure was then repeated for observations onto exposures of Crag reef. The ground distance between the observer and the target was then measured from the map and recorded. Horizontal angles between trig stations were also measured for triangulation of the true position on the ground of the observer and the target.

The vertical angle recorded between the observer and the target was converted to a tangent angle. The distance in metres between the theodolite and the point being observed, when multiplied by the tangent angle gives the difference in height between the two points. This is corrected for the height of the theodolite above the ground surface and for refraction and curvature of the Earth to give the actual height difference between the two points. The top of Crag reef was the horizon to be measured; thus any variation in thicknesses of the shell limestone bed would not affect the measurement. From these measurements as described above the structural contours on Crag reef were constructed as described by Wellman (1961). The map appears at Appendix A and a sample calculation is included in Appendix C.

4.6 STRUCTURAL MAP NO 1 REEF

Identification of Crag reef had been by its relationship to No 1 Reef at the southern boundary of the study area in Zone 33. This relationship was traced northwards for 10 km to the Zone 30 remnant exposure. There was little, if any, variation in vertical distance between No 1 Reef and Crag reef over this distance. Thus, on completion of the mapping of Crag reef, it was determined to use this information to link into the structural mapping by Feldermayer et al. (1943).

The structural map plotted by Feldermayer et al. (1943) south of the Snowgrass Fault was originally at 100 ft contours, and has been converted to 50 m contours in this study. The vertical distance between No 1 Reef and Crag reef is 49 m, so this height was added to height data of the Crag reef and structural contours interpolated to represent No 1 Reef in the study area (Appendix A).

Only one fault other than the Snowgrass Fault was identified, the Home Valley Fault. This fault has developed following the gentle folding of the Crag reef that forms a small asymmetrical anticline, the Crag anticline. The anticline plunges at 230 degrees, with a steep southeast limb.

Local development of the Crag anticline in post-Opoitian time contrasts with the more extensive deformation shown around Snowgrass Dome. This may be attributed to the study area acting as a single basement block, in contrast to a succession of fault bounded slices further to the south and southeast (Feldermayer et al. 1943). Thus a re-interpretation of the Snowgrass Dome as the buried southern toe of the Kaimanawa Mountains (Ker 1991), is needed. Opoitian strata in the study area overlying or abutting basement relief (Datum B ridge, Zone 27 gorge), have not shown the degree of draping of sediments or the steep dips reported around the Snowgrass Dome. It is therefore likely that the Snowgrass Dome is a fault bounded upwarping of the basement rather than a simple draping of sediments over a basement high.

4.7 THE KAPITEAN-OPOITIAN INTERREGNUM

One minor exposure of angular to subangular clast-supported breccia at GR T21/532886, has been interpreted as a terrestrial debris fan buried by the Opoitian transgression. There are no other deposits found within the study area that can be traced to the period between the Kapitean and the Opoitian marine transgression. Elsewhere, this time period is represented by an unconformity, i.e between the Kapitean Home Valley mudstone and the Opoitian Argo sandstone (Chapter 3).

The Waiouru area was clearly above sea level and subject to terrestrial erosion during this period, possibly lasting from the end of the Kapitean at 5 ma to the commencement of the Opoitian transgression in Waiouru approx 4 ma.

CHAPTER 5

THE OPOITIAN MARINE TRANSGRESSION

5.0 INITIATION OF THE OPOITIAN TRANSGRESSION

A possible tectonic mechanism initiating the Opoitian transgression may relate to changes in boundary conditions between the Pacific and Australian Plates. As the Pacific Plate became obliquely subducted under the Australian Plate, a belt of high shear strain developed through New Zealand where the change in relative motion between the plates became accommodated in consequent deformation over a very broad zone several hundred km wide (Walcott 1987).

Paleomagnetic constraints on movement of the southern part of the Hikurangi Trough reflecting the Pacific/Australian plate boundary position (Roberts 1992) suggest a Late Pliocene change in motion of the Pacific Plate. The change in motion was relatively rapid, possibly occurring between 3.4 and 3.9 ma (Harbert and Cox 1989), although Walcott (1987) indicates an earlier start, possibly at 5 ma.

Late Pliocene tectonic movements suggested to have been driven by this change of motion are, the folding and thrust faulting of the Ruahine Ranges (Melhuish 1990), back-arc spreading in the Central Volcanic Region (Stern 1987), opening of the Lau and Havre Basins around 4 ma (Wright and Walcott 1986), uplift in the Ohara Depression/Wakarara region of Hawke's Bay (Erdman and Kelsey 1992) and initiation of subsidence in the Wanganui Basin (Stern et al. 1993), who suggest that subsidence was driven by rapid re-orientation of the plate boundary east of central New Zealand.

Subduction of the Pacific Plate then formed (from east to west), a frontal wedge, a fore-arc basin, uplifted basement forming an arc and the Taupo Volcanic Zone. The Taupo Volcanic Zone is an area of extension caused by back-arc spreading into the continental crust. At present day rates, it would have produced the required extension to form the zone in about 5 ma (Walcott 1987).

Resultant Plio-Pleistocene subsidence of the fore-arc basin may be the result of crustal thickening to the west under the axial ranges, that created a regional downward flexure extending for 200 km. Later underplating by sediments subducted under the frontal wedge is suggested to be the cause of Late Quaternary uplift of the fore-arc basin (Walcott 1987).

It is suggested here that subsidence of the southern Kaimanawa Mountains in the Late Pliocene, initiating the Opoitian marine transgression in the Waiouru area, was directly controlled by the above events. The suggested commencement of deposition for the Argo sandstone at approx 4 ma is close to the date suggested by Harbert and Cox (1989) for the change of plate motion.

5.1 FLOODING OF THE BASEMENT

Following the regression at the end of the Kapitean, erosion removed Kapitean strata from the majority of the basement relief, giving the inferred basement contours shown at Fig 9.

Submergence of the dissected peneplain in the marine transgression would thus represent the infilling of incised valleys up to 3 km across and almost 300 m in depth. Sedimentation in the study area was thus dominated by the basement relief. The commencement of the transgression, possibly by downwarping of the peneplain surface to the west, saw flooding of river valleys, to form tidal channels which expanded and isolated higher elevations as the transgression progressed. This formed a precipitous Waiouru shoreline with two offshore islands, one represented by the Datum B ridge in Zone 20 and the other by the ridge underlying the Home Valley. The main channel located between the islands and the coast is here named Argo channel.

A coast with a gently sloping profile has a shoreline which retreats horizontally under transgressive flooding (Swift _et al_. 1991 and Haq 1991), but where the coast rises steeply, as in the incised valleys of the study area, the shoreline has to migrate vertically.

This constrained the movement of the Waiouru shoreline until flooding of the planar Westlawn Surface allowed the shoreline to move horizontally (Fig 37). Thus, near shore deposits can be found at the bottom of the Argo Basin and also over 300 m higher and less than 1 km away, representing progressive onlap of the shoreline up the side of the Argo channel to produce stacked sequences of near shore deposits.

During the initial phase of this study, it was found that the Argo sandstone sequence could be subdivided into three groupings, which were informally named Basal, Middle Sequence and Shell Limestone beds, reflecting the major facies in the study area. Basal strata are coarse grained sands/sandstones generally close to or on the basement, with the Middle Sequence representing finer grained muds interbedded with sands. Shell Limestone beds are found above these with layers of calcareous sands and shell limestone. Near-shore shallow water environments, mostly of tidal sand and mudflats, dominate the entire sequence.

Petrological analysis of sand grains showed two groupings, representing differing origins for the sand grains. One group of sand grains, dominantly subrounded and rounded is clearly derived from erosion of a greywacke terrain (Fig 38). The other group is generally angular to subangular, discrete grains of quartz and feldspar with abundant muscovite flakes. As suggested in this study (para 3.3), these originated from a granitic source, possibly northwest Nelson. It is suggested here that these were deposited from material transported by currents from North-west Nelson.

5.2 MECHANISM OF TRANSGRESSIVE SEDIMENTATION

Transgressive flooding of a landscape of this nature causes initial retreat of the shoreline, forming lagoons and widening river estuaries. These now act to trap suspended sediment, both from the river and from the littoral current. Erosion of antecedent strata generally ceases and autochthonous sedimentation becomes dominant, filling the lagoons and estuaries until a balance is reached between sedimentation and wave and tidal erosion.

At the estuary mouth, barrier sand systems develop from material transported and deposited from the littoral current and the river, to move shoreward as sealevel continues to rise, overrunning the lagoon and estuary sediments. This cycle of prograding barrier sands and muds continues until the transgression comes to an end. (Swift, Phillips and Thorne 1991).

5.3 BASAL DEPOSITS OF THE ARGO SANDSTONE

Typical basal Opoitian strata found in the Argo Basin in contact with the greywacke basement are loosely consolidated deci-metre (dm) bedded coarse sand (Te Punga 1953, Suggate 1978). The basement here represents the transgressive surface described by Haq (1991), with only the remnant exposure of Home Valley mudstone representing strata from a previous sedimentary cycle.

Some basal sand layers near the basement have thin silt layers on their upper surface, but most show an erosion surface, interpreted as normal marine tidal erosion. Further up the sequence and away from the basement, are bedded sand layers typical of the tidal swash water zone with interbedded silts (Collinson et al. 1989).

Marine fauna as shells or shell impressions are present but rare. Near the basement these coarse sands are often interbedded with thick layers of well rounded greywacke-derived conglomerate, averaging 30-60 mm in diameter, interpreted as reworked alluvial fan deposits similar to those described by Carryer (1966). Similar deposits were described by Reineck and Singh (1980), also derived from coastal cliff erosion and rounded by working in the tidal swash zone.

These conglomerates are generally 1-3 m thick, infilling small tidal channels in basal strata of the Argo Basin. Away from the tidal channels, the conglomerates appear as thin lag gravel layers at the base of discrete sand layers.

It is unlikely that these lag layers represent individual flooding events redistributing material from the previous sedimentary cycle, (the ravinement surfaces of Haq 1991), as the steepness of the basement relief provided an abundant supply of greywacke material derived from the basement to the Opoitian beaches.

Thin carbonaceous layers are found in the sands close to the basement relief, as well as carbonaceous structures ranging up to 20 cm in diameter in the sands, interpreted as the remains of plant debris (Fig 39). Small muddy deposits with plant remains are also found in sands at the Road Quarry site and are interpreted as a marginal estuarine or lagoonal facies buried by the prograding barrier sand deposit.

Prograding basal sand deposits are also exposed on greywacke basement at the Causeway feature (Fig 17), the Road Quarry and on the Westlawn Surface as remnant tors (Fig 40). These outcrops were deposited on planar parts of the basement when the transgression overtopped the offshore islands, and flooded across the Westlawn Surface, emplacing the barrier sand deposits of the initial transgressive sequence.

Sandstone tors 8-12 m high on the Westlawn Surface are interpreted as remnants of this initial transgressive sand sequence. The base of most of the sand layers in the tors is marked by thin layers of small pebbles and very coarse sand. Mica flakes are abundant to super-abundant throughout each exposure. The sandstones show the strong cross-bedding, ripple cross laminations and small shell fragments typical of the tidal swash zone.

Each sandstone tor lies on a roughly level part of the greywacke basement of the Westlawn Surface (Fig 40). The tors appear to have formed by a simple combination of the planar basement being resistant to headwater erosion by gullying, and erosion of a more extensive but thin sandstone veneer.

Away from the basement and in locations indicative of a tidal inlet, are thick sequences of coarse, well sorted sands with strong cross-bedding, tidal flow structures, overturned bedding and ripple markings interpreted as bar deposits in a tidal environment. These typically have foreset beds with dips of 20° to 40° in the direction of dominant flow, and are found in the Argo Basin at the Big Bend section (Fig 41), Zone 30 between Horse Gorge and Road Quarry and in Zone 20 on the site of the buried valley (Fig 11).

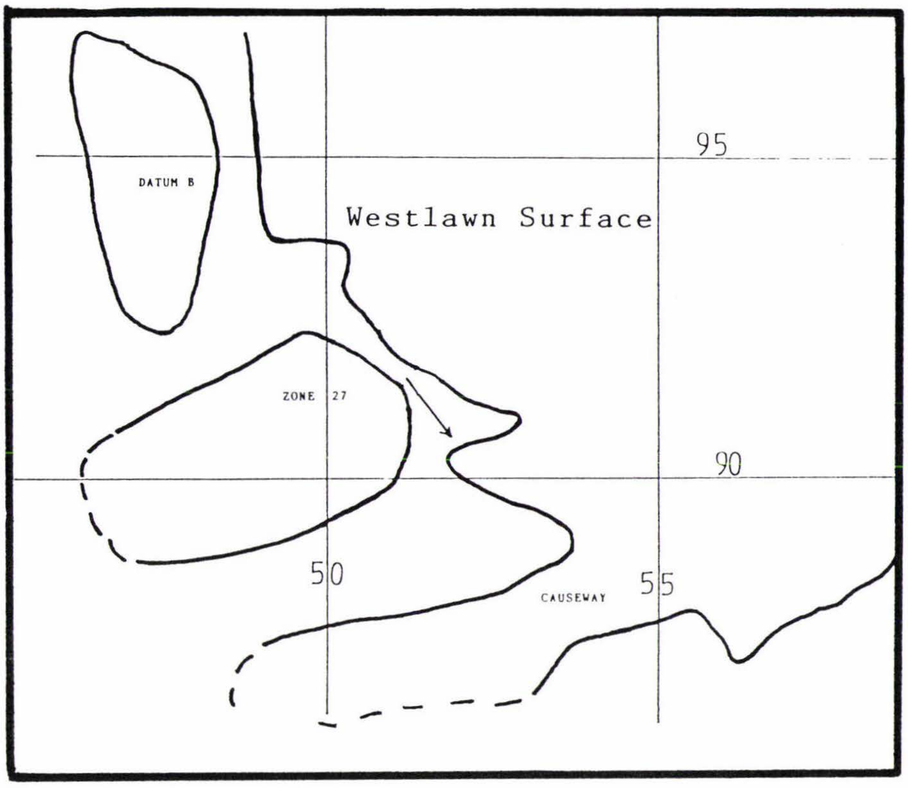
Close to the basement but away from areas indicative of tidal inlets are strata of dm-bedded calcareous sands and shell beds. At Imjin Camp (Fig 2), these shell beds merge laterally into strata of the tidal inlets. Mud roll-up clasts (Fig 42), are visible at the base of sand layers averaging 0.6 m thick. The thin mud layer capping the sand and forming the roll-up clasts represents sub-aerial drying out between tides. The presence of oyster and other tidal zone fauna in the sand layers indicates that this was a sandbar and not a dried up pond or lagoon behind a beach.

Rapid flooding of the sandbar is indicated by the flow structures (Fig 42), demonstrating a substantial tidal range, both to allow drying out of the upper surface and to deposit 0.6 m thick sand layers. The magnitude of the tidal range may have been assisted by the embayed coast.

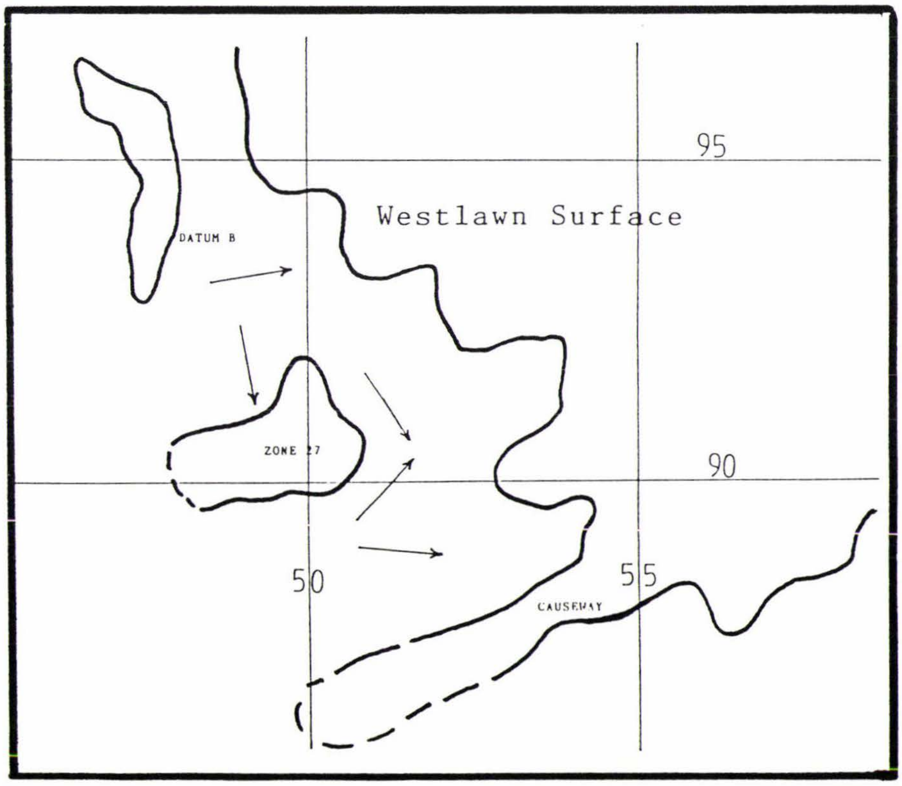
5.4 DEPOSITS OF THE MIDDLE SEQUENCE

Strata of the informally named Middle Sequence have few sand layers and are found away from inferred tidal inlets. Basal silt and sand layers described above, merge upwards into blue-grey muds of the Middle Sequence, with abundant to super abundant macrofossils indicating a dense faunal population whose members are typically found at depths of 10-30 m (Beu et al. 1990). Ripple markings, small channels and flow structures indicate a shallow, muddy bottom environment. Load structures (Fig 43), are seen in this sequence indicating rapid sediment accumulation. Preservation of fossils is generally poor, most being flattened and chalky.

a. 700 m



b. 800 m

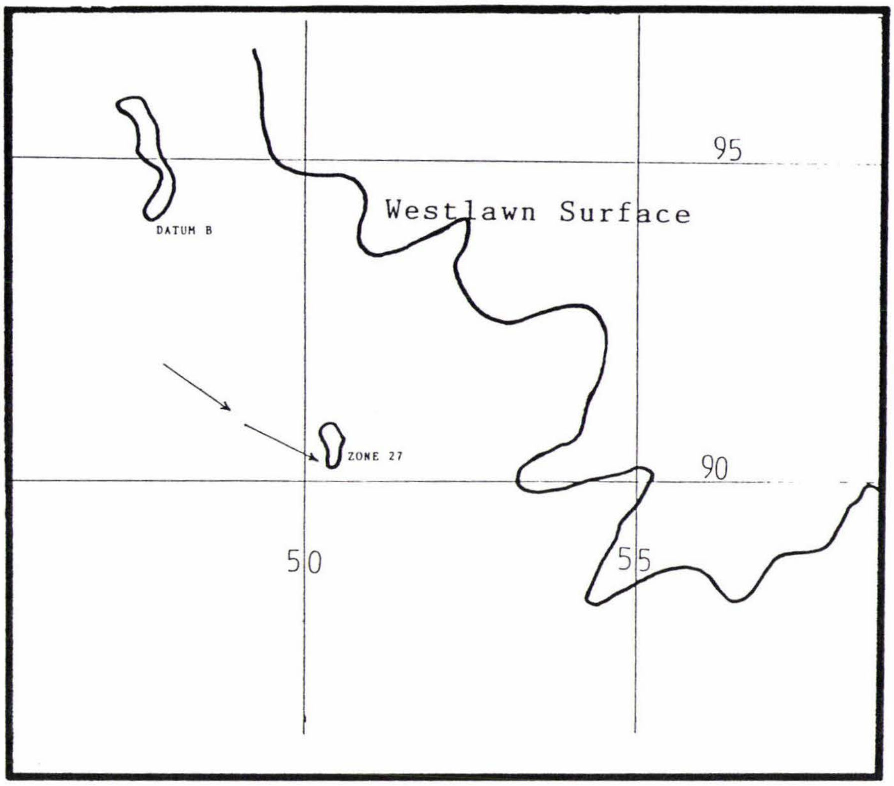


37 . Reconstruction of the Opoitian shoreline.

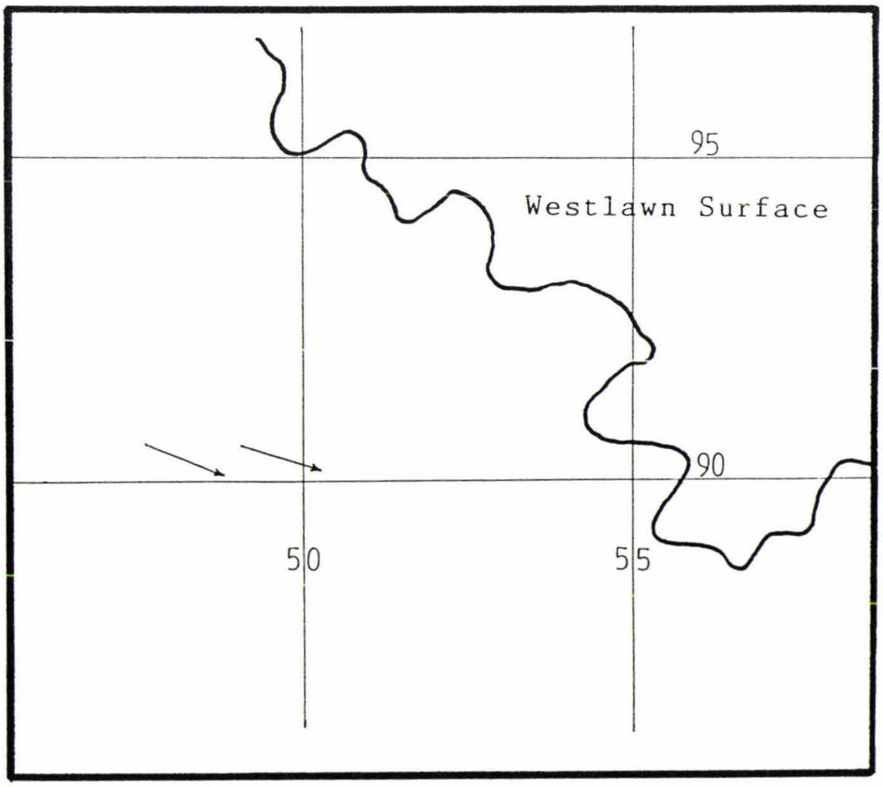
ses of the Opoitian transgression and development of the reline is shown. Each phase represents a sealevel rise of 100 n a basement contour representing the present 700, 800, 900 and 0 m contours. Downwarping of the basement saw initial rapid oding along the floor of the incised river valleys. However, m the present 700 m contour to the 1000 m contour, a rise of m, the shoreline was only to move 2 to 3 km inland.

d lines represent a 5 km spacing on NZMS 260 T20/T21. Arrows resent paleocurrent directions detailed at Fig 46.

c. 900 m



d. 1000 m



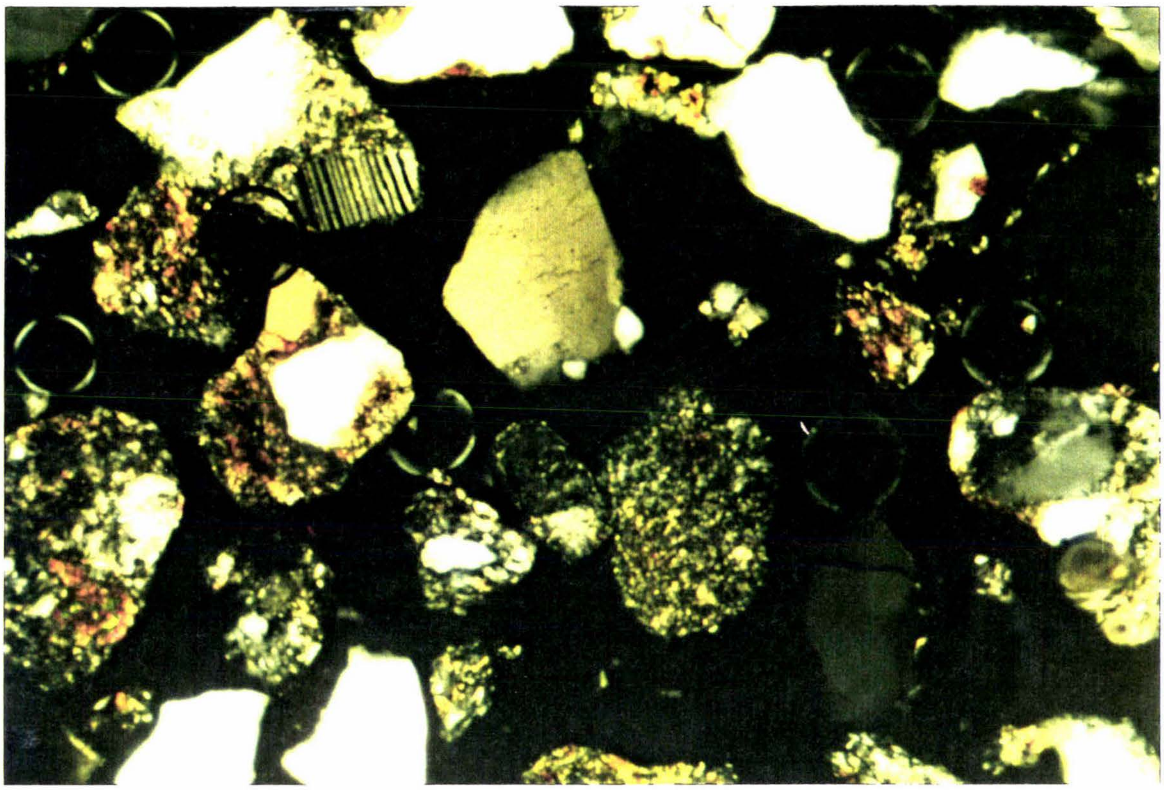


Fig 38 . At Big Bend section T20/516907. Thin section of Opoitian basal sand layer in epoxy matrix. Grains of quartz (pale to white angular grains), feldspar (grain showing lamellar twinning at upper left), and rounded to subangular grains derived from local greywacke terrain. The latter are aggregates of finer grains, many altering to clays between grain boundaries. The quartz and feldspar grains are not consistent with a local source and are derived from a granitic source, possibly granites of northwest Nelson.

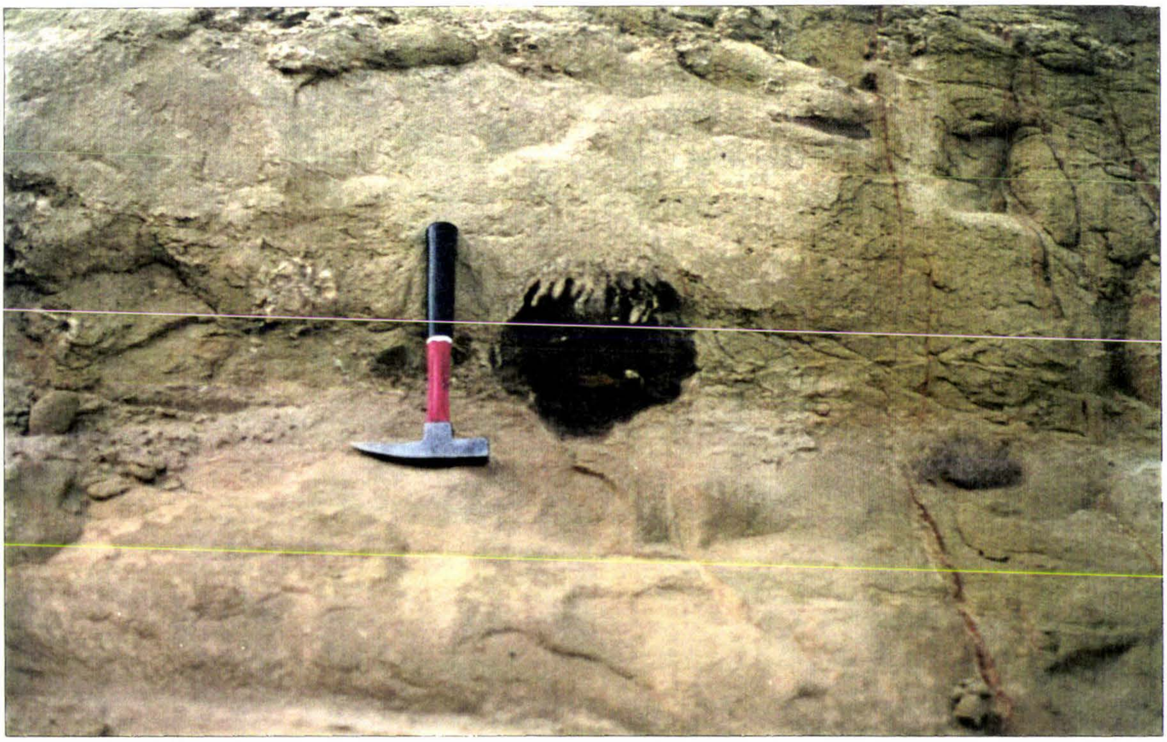


Fig 39 . Plant debris in Argo sandstone at Road Quarry T20/500901. Carbonaceous structures interpreted as the remains of plant debris are found in the coarse yellow-brown sands typical of the Argo sandstone. The circular dark structure is 20 cm in diameter and is the remains of a log washed up on the Opoitian beach. Hammer is 32 cm long.

Exposures on the south bank of the Moawhango River at GR T20/489929 (T20/f32), (Fig 44), are typical of the Argo sandstone and contain a mixed fauna, comprising *Zeniata acinaces, Dosinia (Raina) cf bartrumi Laws, Glycymeris sp, Penion sp, Stiracolpus sp, Zeacolpus cf vittatus (Hutton), Cominella sp*, and abundant *Ostridae* as *Crassostrea ingens.* These are all shallow water fauna found in dm-bedded sand and mud layers with most bivalves showing hinged valves.

Zenatia acinaces is a typical member of this assemblage, living deeply buried in sand, off beaches in shallow water approx 10-30 m depth and found off oceanic and large open bays (Beu 1966). The assemblage at T20/f32 is thus interpreted as a shallow water environment, 5-10 m in depth.

The type exposure of the Middle sequence covers 1 km along the Imjin Road and 110 m vertically. Major realignment of the Imjin road during the study gave access to an unweathered section of these deposits (Fig 45), (see Appendix B).

The base of the Imjin Road section is located in a road cutting at GR T20/490917 and the top of the section is at GR T20/490908. In the lower part are mixed sand and mud strata lacking strong current structures, interpreted as a tidal estuary environment, but located away from the main tidal channel. inlets. Macrofossils are common but not abundant.

As the Imjin Road is followed southwards and higher in stratigraphic sequence, strata of sand-muddy sand merge into a blue-grey mudstone with some thin sand layers. Accumulation of such muds is considered to have been aided by (1) erosion and reworking of Kapitean mudstones capping the Zone 27 island, and (2) the majority of sand particles transported by the littoral current may have been locally trapped from the littoral current by the enlarged tidal estuaries (fine sediment thus tends to dominate deposition for some distance down-current from such sand traps).

At the 900 m level on the Imjin Road, the blue-grey muds merge upwards into a more sandy environment with rare, well rounded greywacke pebbles 0.5 - 2 cm diameter found at the base of sand layers, but these pebbles are not found above an altitudinal level of 900 m, where an 11 m thick layer of coarse sand marks both the top of the Middle Sequence and a major paleocurrent direction change (Fig 46).

This coarse sand layer is here interpreted as also marking the flooding of the offshore islands. Consequent upon this was the burial of the local basement and infilling of the tidal estuaries by sand.

5.5 THE SHELL LIMESTONE BEDS

Blue-grey muds of the Middle Sequence merge into well layered yellow-brown sand and silt with interbedded thin layers of calcareous sand and shells, from an altitudinal height of approx 900 m to the summit of Crag at 1160 m. Three sections are shown (Appendix B), which cover the sequence from 900 m to 1000 m. These are, point 966 GR T20/489904, Whalebone GR T20/482915 and the Imjin Road. Sand and muddy sand layers with sparse but distinct layers of calcareous sand and shells and shell fragments, averaging 0.2-0.4 m thick, are common to all the sections.

In the Crag section, the above sequence is capped by two thick shell limestone beds exposed on Crag, (Figs 33 & 34). Each of these two beds averages 4-5 m thick and consists of closely packed layers of calcareous sand and cemented shells. Barnacles make up the majority of the fauna in these beds, contrasting their virtual absence in the lower shell beds, together with bivalves and broken shell fragments derived from them, with *Austromegabalanus sp, Ostrea, Crassostrea sp, Phialopecten, Glycymerita, Crepidula radiata* and various other shallow water fauna making up a typical assemblage.

The lower bed exposed on Crag is distinctive because of a 6 - 8 m thick band of calcareous concretions underlying the main shell limestone bed (Fig 34). This bed was used for mapping of the post-Opoitian deformation (para 4.3 of this study).

The Shell Limestone Beds are considered to represent a slightly offshore and shallow water environment. They lack any evidence of sub-aerial exposure. The thin layers of calcareous sand and shells are indicative of periods of current activity with shells and shell fragments derived from the tidal zone.

5.6 PALEOCURRENT DIRECTIONS

Paleocurrent directions within the Argo sandstone were found by recording ripple orientations, climbing ripple marks, foreset beds or cross-bedding as described by Collinson and Thompson (1989), and Reineck and Singh (1980).

Where the exposure allowed, bedding planes showing a ripple layer were exposed to give a good direction indication. Current orientations derived from the above indicators were taken to the nearest 10^{o} and plotted on a rose diagram (Fig 48). Where the section was in an area inferred as a tidal estuary (marking a now buried valley), strong tidal deformation structures were seen. These structures were usually mud roll-up clasts, foreset beds, trough cross lamination and overturned bedding. Current directions in these sections were taken to be tidal and controlled by the topography.

Below 900 m in the Imjin Road section, the current directions indicate an almost north/south current, but above 900 m, the current orientation was found to abruptly change approx 80^{o} to a southeast direction (Fig 46). This change of current direction is interpreted as a change from a regime where the coastal topography influences the current direction to one where the current is controlled by the bathymetry.

Two other sections in this study show a similar paleocurrent direction change above the 900 m level. The point 996 section at GR T20/492905, and the Crag section at GR T20/475907. Paleocurrent orientation plots from Zone 30 show indications of more variable currents. This is interpreted to show a more confused tidal pattern indicative of a location close to a headland or channel point.

Fig 40 . Sandstone tor on the Westlawn Surface, T21/554892. Looking south from Zone 28, at left centre, a tor of Argo sandstone unconformable on greywacke basement at a height of 1014 m. Exposed basement greywacke of the Westlawn Surface is exposed to each side (arrowed). In the background, marine Pliocene strata (which include Crag reef) make up the steep southwest face of the Moawhango River Valley in Zone 33. The Snowgrass Fault runs between this location and the background slope. To the extreme right (arrowed), the Crag reef is visible in downthrown Pliocene strata on this side of the Snowgrass Fault.

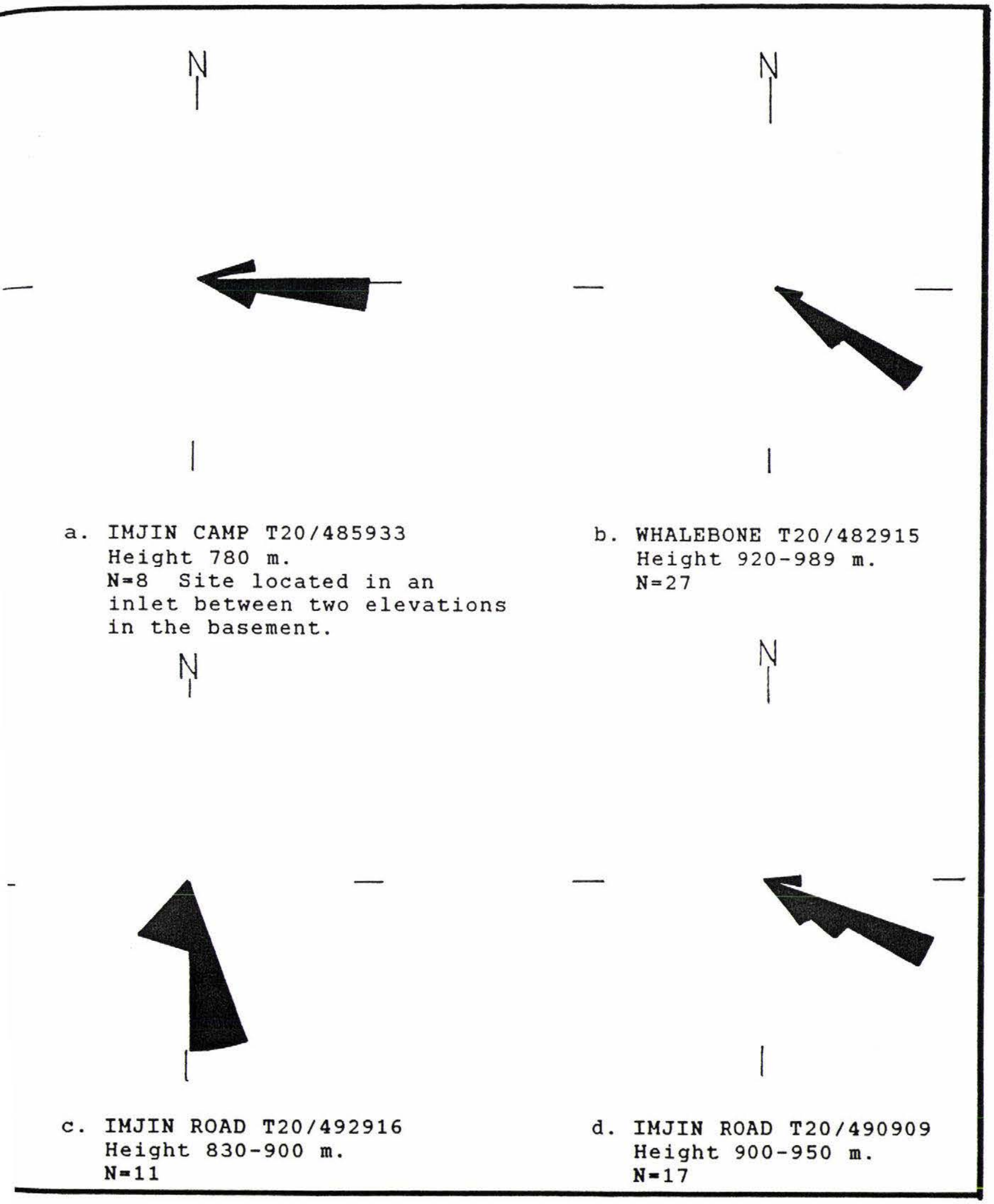
Fig 41 . Overturned bedding in Argo sandstone at Big Bend Section T20/516907. A sequence interpreted as sandbar migration in a channel with strong tidal flow. At top, crossbedded sand layers overlie overturned bedding (arrowed), above an eroded surface of regularly spaced foresets forming the base. Overturned bedding is common to rapidly deposited sands which undergo partial liquefaction while still subject to a water current (Collinson and Thompson 1989). Direction of current is from left to right of the picture.

Fig 42 . Tidal flow structure in Argo sandstone at Imjin Camp, T20/486933. Thin light coloured mud layers seen within the sandstone represent suspended sediment accumulation during tidal slack water period. Ripple markings and flaser bedding are visible and indicate bimodal tidal flow almost due east-west, (east at left of picture, west at right). In centre, above the pen are mud roll-up clasts indicating exposure and drying of the surface mud layer (low tide), and a preserved subsequent reworking structure when the sand was disturbed and reworked on the next tidal flooding. Pen is 140 mm in length.

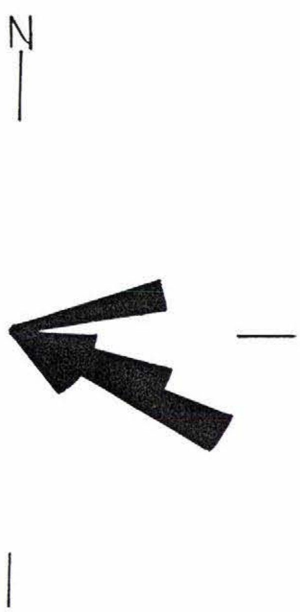
Fig 43 . Load structures at Whalebone section T20/482915. Interbedded sandstones and mudstones showing load deformation structures. This type of deformation is usually found where there has been rapid sedimentation. An overlying layer will sink into a weaker underlying layer which deforms and gives the rounded lobes and flame structures (upward pointing wedges of the underlying unit, arrowed). The hammer is 32 cm in length.

Fig 44 . Basal sandstone exposed by the Moawhango River in Zone 27 at T20/489929. Riverbed is in Pliocene marine strata with common macrofossils typical of a tidal environment of 10-30 m depth. Greywacke river gravels in riverbed are debris from the upstream Moawhango Dam and Imjin gorges. Flow of river prior to the construction of the Moawhango Dam was 13.6 cubic metres/sec and is now less than 0.5 cubic metres/sec.

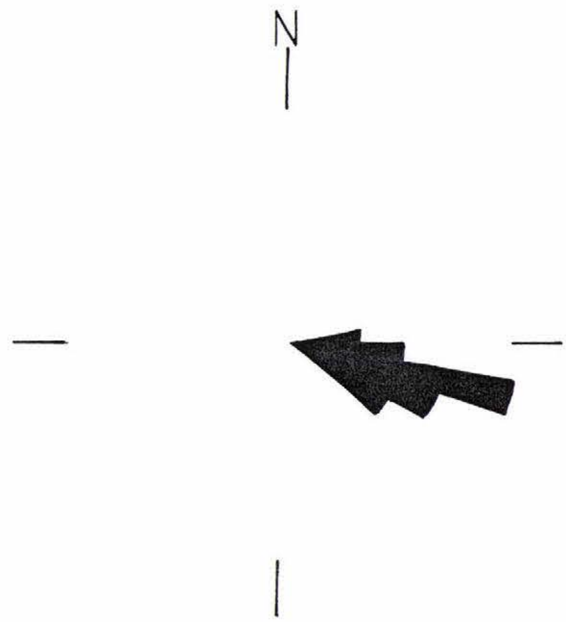
Fig 45 . Imjin Road section (Appendix B) at T20/490498, looking north over the Zone 27 basin. Blue-grey mudstone and sandstone (the informally named Middle Sequence of this study), of Argo sandstone are exposed in the road cutting at centre foreground. The Moawhango River is seen at centre, flowing left to right through Zone 27 basin. At left background, Pliocene marine strata cover most of Zone 20 (dark coloured area of burnt off pine trees), and infill the buried valley in the basement between the Datum B ridge and Te Rotete ridge (Fig 11). The exposed greywacke of the Te Rotete trig is at top middle (arrowed).



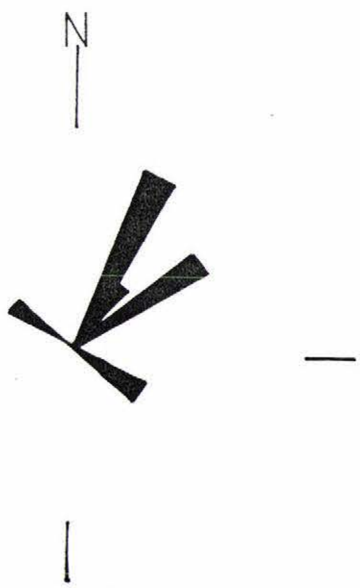
<u>Fig 46</u> . <u>PALEOCURRENT DIRECTIONS</u>.
Current directions are shown in 10° sectors and represent directions taken from ripple markings, climbing ripple markings, cross-bedding, overturned bedding and flute marks. The change in current direction shown above 900 m for (d) is interpreted as the change from current directions controlled by a coast, to one where it is controlled by the bathymetry.



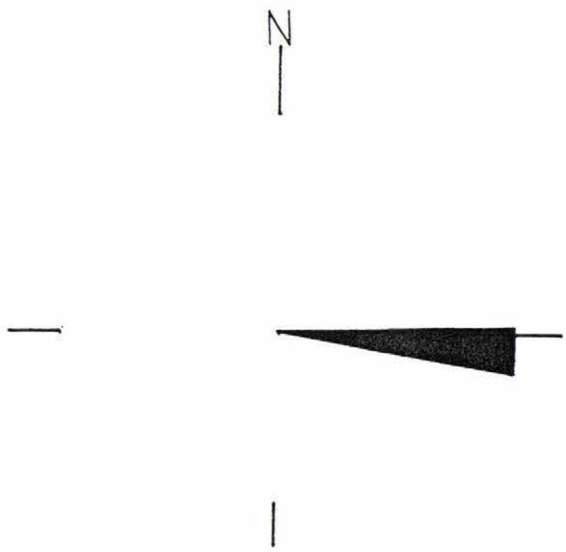
e. POINT 996 T20/489904
Height 900-1000 m
N=20



f. CRAG T20/475907
Height 1060-1140 m
N=37



g. ZONE 30 T21/507895
Height 780 m
N=18 Site is located close to basement at an inferred channel point or bend in the channel, thus giving a confused set of current directions.



h. ZONE 30 T21/507890
Height 780 m
N=16 Site is located in inlet channel between two basement elevations.

At the Big Bend section GR T20/516907, located in the inferred mid-section of the Argo channel, the alignment of foreset beds and overturned bedding (Fig 41), indicate that the dominant littoral current was from the northwest and towards the nearby Kuripapango Strait.

5.7 PALEOENVIRONMENT OF THE ARGO SANDSTONE

5.7.1 Temperature

The molluscan fauna found throughout the Argo sandstone is typically comprised of warm-water dwellers. *Glycymeris*, *Lutria*, and *Polinces* have modern subtropical members, while extinct taxa classed as warm-water faunal elements (Beu 1973, Beu et al. 1990), include *Glycymerita*, *Phialopecten*, *Pteromytea*, *Dosina (Raina)*, and *Struthiolaria (Callusaria)*. Thus a warm-water environment is interpreted during the Opoitian transgression in the Waiouru area.

5.7.2 Formation of the shell limestone beds

The abundant barnacle population near the top of the sequence contrasts with their relative absence lower in the sequence. Kamp et al. (1988) reported that dominance of barnacles was promoted by shallow (< 30 m, inner shelf) water depths with strong tidal currents removing fine sediments, but which provide abundant nutrients. This environment encourages rapid growth and turnover of barnacles, the resultant accumulation of their plates becoming the dominant carbonate skeletal component in the sediment.

The thin shell beds and calcareous sand layers in the section are interpreted as having been formed by tidal processes which have concentrated shells as tidal bar deposits.
The two main shell beds at the top of the Argo sandstone at Crag, formed on a submarine high after the submergence of the Westlawn Surface.

Fine sediments were removed by currents and the submerged Westlawn Surface became the carbonate "factories" (Kamp et al. 1988) that produced the thick and extensive sequences of shell limestone seen at the top of the Waiouru Formation.

5.7.3 Sea level change

The Turakina River Valley section, is interpreted as having been deposited in depths rarely exceeding 100-200 m (outer shelf) McGuire (1989). No close relationship was established between the fossil paleobathymetry and the eustatic sea level curves of Haq et al. (1987). Nor were any breaks in sedimentation detected (McGuire 1989). This study involving the shallow water depositional environment of the Argo sandstone, has also found no relationship to the eustatic sea level curve of Haq et al. (1987) and Haq (1991).

The dates inferred for the Argo sandstone are between 4 ma and 3.7 ma whilst the 3rd order eustatic cycles 35 and 36 of Haq (1991) are dated at 3.8 and 3.2 ma. The 3.8 ma date falls close to the base of the Argo sandstone but this study has found no evidence for the 3rd order cycle 35 at 3.8 ma. The 3rd order cycle 36 at 3.2 ma falls outside the date assigned by this study to the top of the Argo sandstone, but is close to the top of the Taihape Mudstone, dated at 3.11 ma by McGuire (1989).

No evidence for 4th order cycles was found in the Argo sandstone sequence. From this study, it appears unconformities and changes in sedimentation characteristics were dictated by the basement topography and not eustatic sea level changes. The basement topography, the tidal dominated sedimentation and the continuing tectonic subsidence during the Opoitian transgression are all here considered to have effectively masked any eustatic sea level changes that may have occurred.

5.7.4 Location and age of the Kuripapango Strait

Waiouru is located at the southwest extremity (Fig 47) of the greywacke mapped by Grindley (1960). The strong tidal currents existing during deposition of the Argo sandstone thus indicate that Waiouru was the northern edge of the Kuripapango Strait during the Opoitian transgression i.e. the southern coastline of the paleo-North Island was along the southern boundary of the Kaimanawa Mountains. This would place the southern coastline at approximately south latitude 39° 30′ during the Opoitian transgression in Waiouru.

Littoral currents and the sedimentation regime then, may have had similarities to those reported from the Cook Strait today (Carter 1992), with the Argo sandstone, closest to the shoreline, being mostly tidally deposited.

However, it is probable that Kuripapango strait had formed before the Opoitian transgression at 4 ma. Submergence of basement at the Manawatu Gorge and Waiouru and deposition of Kapitean sediments indicates a broad seaway existing during Kapitean time, between the coast to the north of Waiouru and to the south of the Manawatu Gorge, possibly extending to the paleo-South Island.

Grammer (1971) reported possible Kapitean age strata deposited on basement greywacke at the Saddle Road, Manawatu Gorge. This was later overlain by shallow-water Opoitian strata. This is consistent with the similar unconformity found in the study area; a general submergence of the New Zealand landmass in pre-Kapitean time, followed by Kapitean uplift and emergence and a subsequent Opoitian transgression.

The Manawatu Gorge strata may thus represent, (1) uplift of basement above sea level contemporaneous with the Kapitean uplift in Waiouru, with Kapitean strata at the Manawatu Gorge thus being emplaced in the same manner as the Home Valley mudstone, or (2) Kapitean uplift and shallowing only, with later deposition of shallow-water strata in the Opoitian, i.e. retention of a seaway through the Manawatu Gorge area.

Grant-Taylor et al. (1964) in a study of Opoitian strata at Makara, suggested that there was a continuous axial ridge in the lower paleo-North Island in the early Opoitian, and subsidence saw overtopping of this ridge and deposition of Opoitian strata at Makara, Manawatu Gorge and Kuripapango. This suggestion tends to support uplift and emergence at the end of the Kapitean, as in (1) above.

However, differential movement of blocks of basement in the Kapitean regression are also likely to have retained some low-lying areas, forming islands representing the uplifted higher portions of the basement, rather than an axial ridge. This possibility would support the existence of straits at Manawatu Gorge and Kuripapango, before the Opoitian transgression, as suggested by (2) above.

Although the Manawatu Gorge represents a low-lying part of the basement (Lillie 1950), the data available for the marine strata at Saddle Road is insuffícent to determine the sequence of events. It is thus likely that uplift and emergence has occurred, similar to that in the study area.

However, the continued existence of Kuripapango strait after the Kapitean regression is indicated by the presence of a trough in the basement south of Waiouru. A study of gravity profiles in the Wanganui Basin (Hunt 1980), reported a trough in the basement extending from Taihape northeast towards Erewhon (T21/655838). This low-lying portion of basement is consistent with the location of the Kuripapango strait.

It is clear that Kuripapango strait was in existence at the beginning of the Opoitian transgression in Waiouru at approximately 4 ma, and thus it is here suggested that it formed during the Kapitean regression. A connecting seaway between the eastern Hawke's Bay and Wanganui Basins may have been present from the start of subsidence in both basins.

A map based on Fleming (1962), Grant-Taylor et al. (1964) and Stevens (1974) is at Fig 48, detailing an interpretation of the paleogeography based on this study.

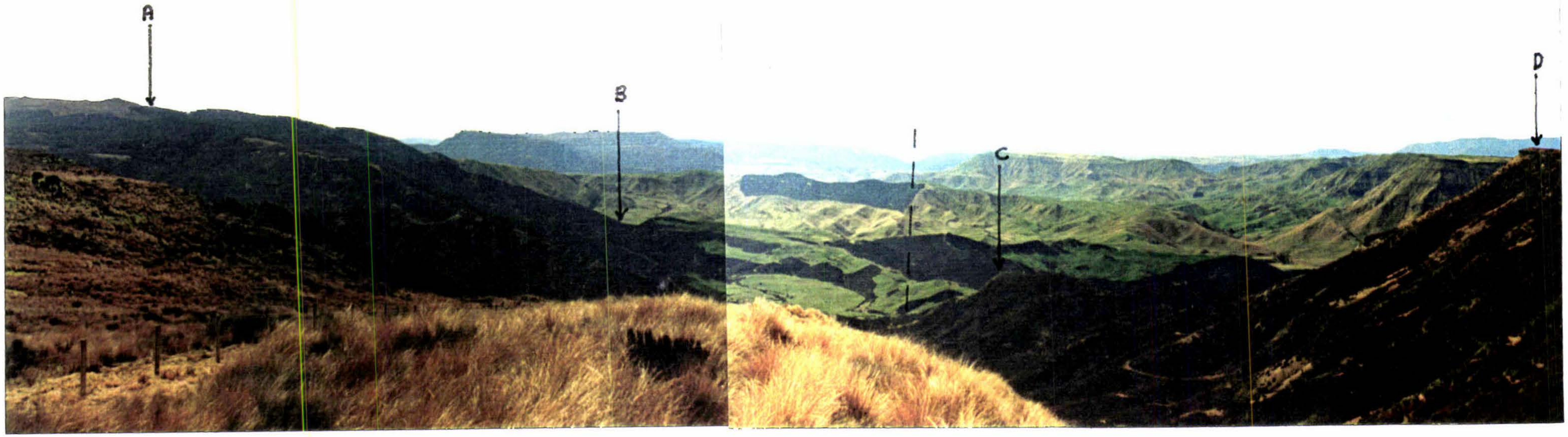
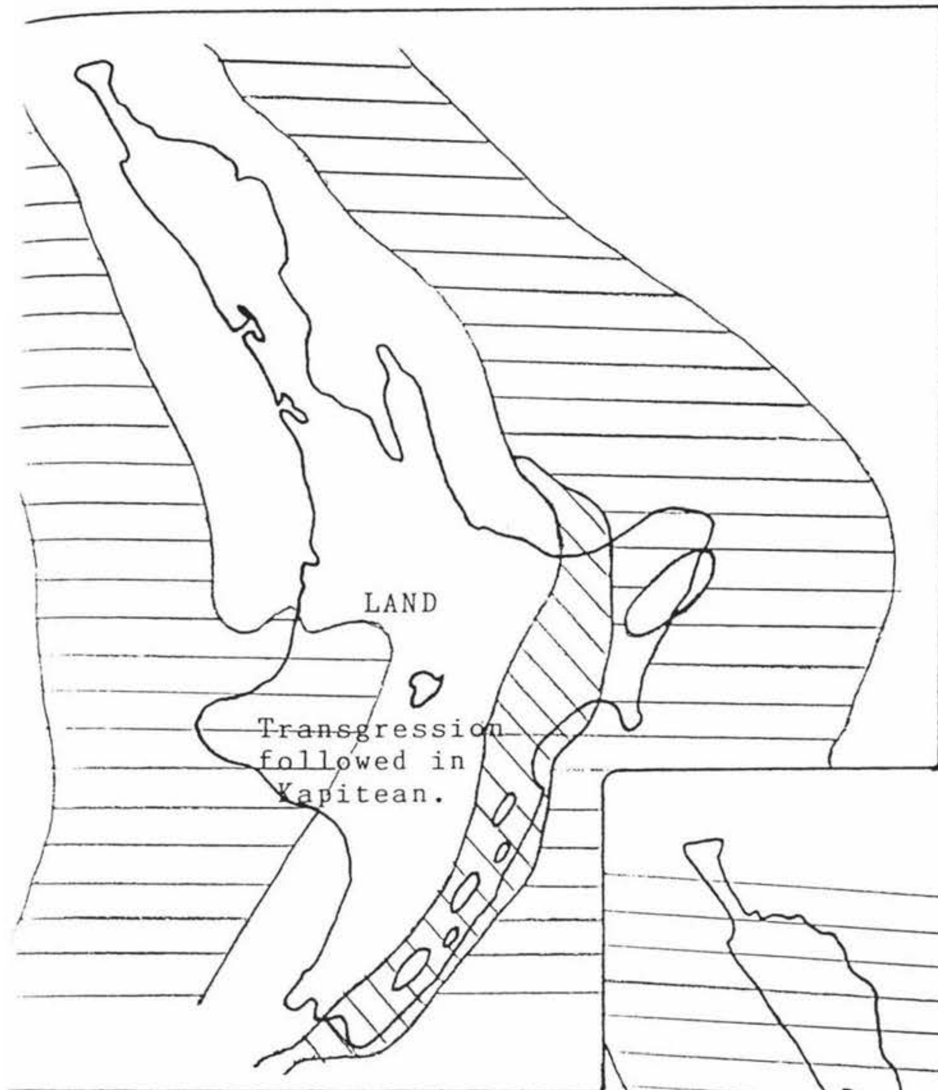


Fig 47 . The southern exposure of the Kaimanawa Mountains. View from T20/535855 in Zone 33, with the trace of the Snowgrass Fault (dotted), at centre. At top left, greywacke spurs from the Westlawn Surface slope to the centre, (arrow A to B). At the middle right (arrow C), is an uplifted portion of basement greywacke; the fault scarp of the Snowgrass Fault, here named Facet, exposed by erosion of the overlying marine strata of the Waiouru Formation.

Visible from the foreground to the extreme right, scrub covered Pliocene marine strata rise up to the Te Rei trig (arrow D), with well dissected Waiouru Formation strata in the background. This locality marks the boundary of the Kuripapango strait during the deposition of the

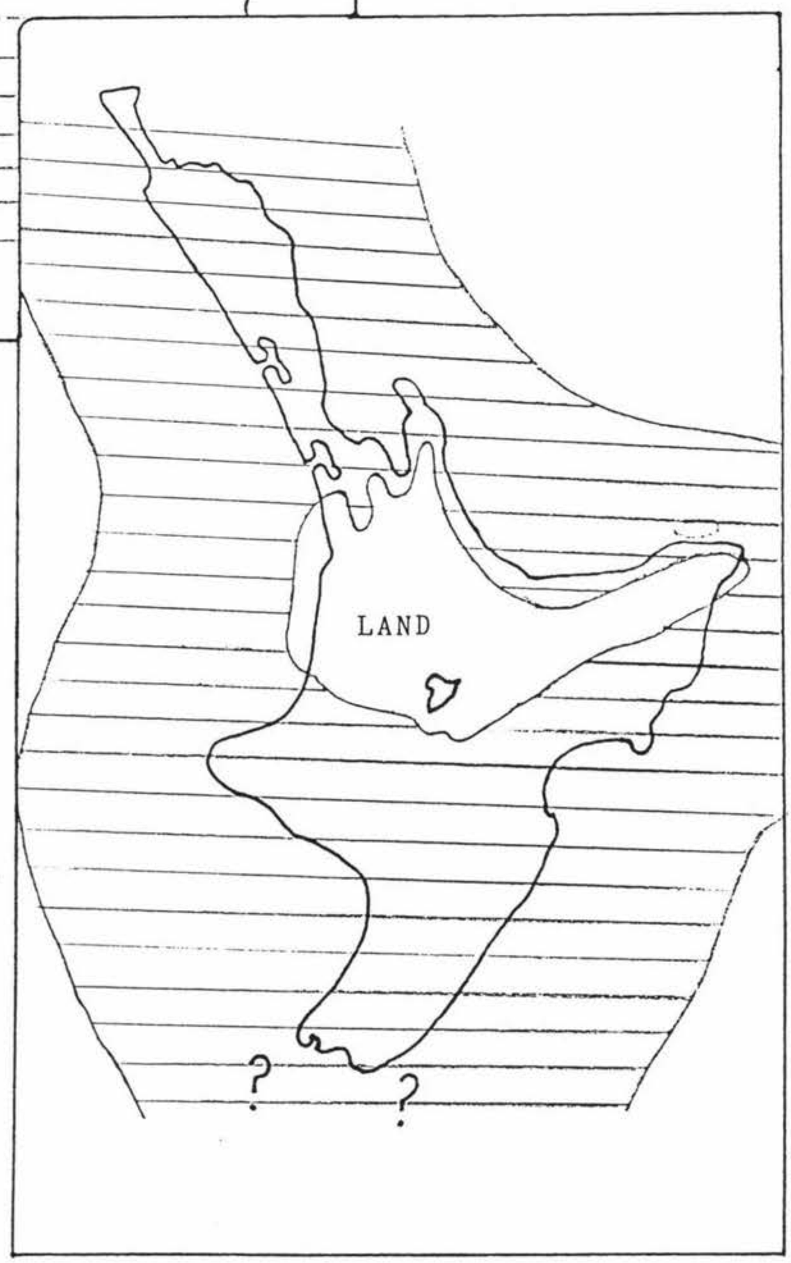


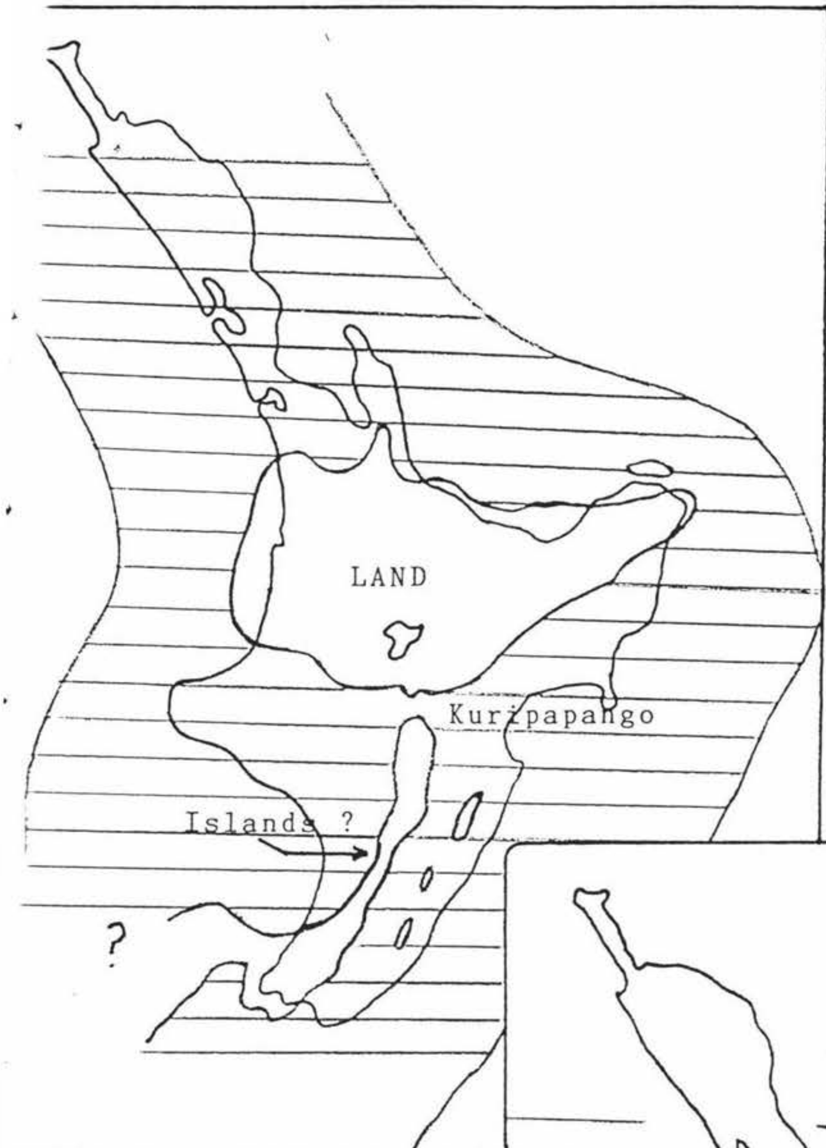
48. PALEOGEOGRAPHY OF THE NEW ZEALAND LANDMASS (after Fleming 1962).

: Shelf sands and shallow -water facies

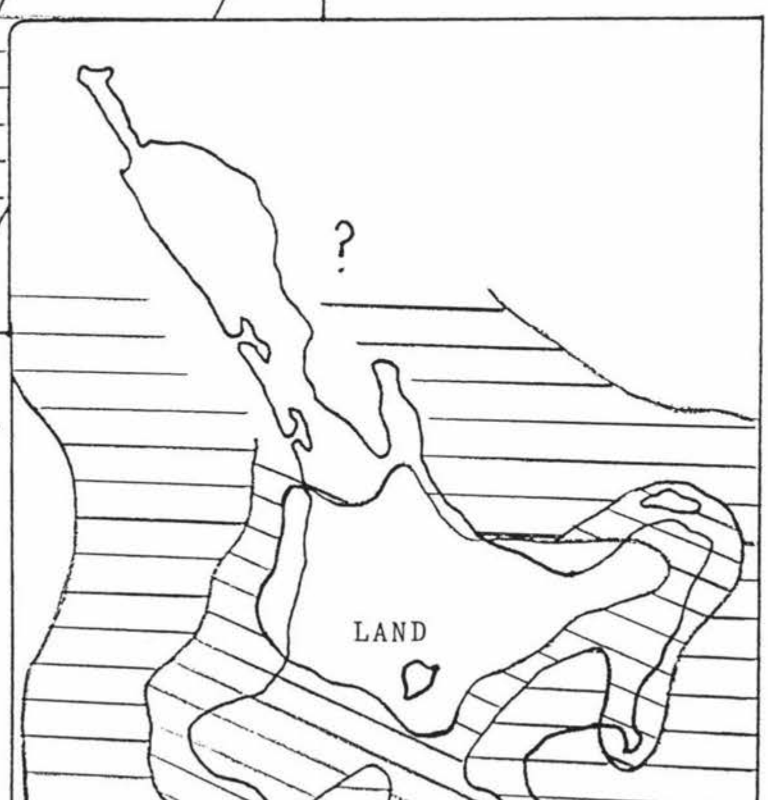
Silts and general marine sediments

Kapitean (this study) →





c. Kapitean regression
(this study)
Uplift of basement formed islands along the axial ranges and may have left the Kuripapango strait open before the Opoitian transgression



:tian-Waipipian →
:er Fleming 1962)

:nce in the basement
ı to produce a shallow-
leposition in the east
s Bay), and the west
ıui).

REFERENCES CITED

Aerial Photos. Map Reference: NZMS 260, T 20 & T 21, Metric, 1:50,000. Photo Ref: SN 5752: Run G on 25.10.80, SN 5291: Run A on 29.10.78. New Zealand Aerial Mapping Ltd, Hastings.

Anderton P.W, 1981. Structure and Evolution of the South Wanganui Basin, New Zealand. *New Zealand Journal of Geology and Geophysics* 24: 39-63.

Andrews P.B and van der Lingen G.J, 1968. Environmentally Significant Sedimentologic Characteristics of Beach Sands, *New Zealand Journal of Geology and Geophysics* 12: 119-137.

Beetham R.D, Watters W.A, 1985. Geology of Torlesse and Waipapa Terrane Basement Rocks encountered during the Tongariro Power Development Project, North Island New Zealand *New Zealand Journal of Geology and Geophysics* 28: 575-594.

Benson W.N. 1935. Some landforms in southern New Zealand. *Australian Geographer* 2 : 3-22.

Benson W.H, 1941. The Base Igneous Rocks of Eastern Otago and their Tectonic Environment. *Transactions of the Royal Society of New Zealand* 71: 208-222.

Beu A.G. 1966. The Molluscan Genera Lutria, Resania and Zenatia in New Zealand. *Transactions of the Royal Society of New Zealand, Zoology* 8 : 63.

Beu A.G, 1973. Molluscan Evidence of Warm Sea Temperatures in New Zealand During Kapitean, (Late Miocene), and Waipipian, (Middle Pliocene), Time. *New Zealand Journal of Geology and Geophysics* 17 : 465-479.

Beu A.G, 1978. Taxonomy and Biostratigraphy of Large New Zealand Pliocene Pectinidae, (Phialopecten and Mesopleplum), *New Zealand Journal of Geology and Geophysics* 21: 243-269.

Beu A.G, Grant-Taylor T.L, Hornibrook N DE B. 1980, The Te Aute Limestone Facies, (Poverty Bay to Northern Wairapapa), *New Zealand Geological Survey miscellaneous series map 13.* Wellington, New Zealand. Department of Scientific and Industrial Research.

Beu A.G, Maxwell P.A, 1990. *New Zealand Geological Survey Paleontological Bulletin 58.*

Bishop D.G, 1968. The Age and Correlation of the Ormond Limestones in the Gisborne District. *New Zealand Journal of Geology and Geophysics* 11: 279-298.

Bishop D.G, 1972. Progressive metamorphism from prenhite-pumpellyite to greenschist facies in the Dansey Pass area, Otago, New Zealand. *Bulletin of the Geological Society of America* 83: 3177-3198.

Browne G.H, 1981. The Geology of the Kuripapango-Blowhard District, Western Hawke's Bay. Unpublished MSc Thesis lodged in the Library of the University of Auckland.

Boreham A.U.E, 1961. The New Zealand Tertiary Genus Sectipecten Marwick, (Mollusca). *Transactions of the Royal Society of New Zealand* 88 : 655-688.

Carryer S.J, 1966. A Note on the Formation of Alluvial Fans. *New Zealand Journal of Geology and Geophysics* 9: 91-94.

Carter L. 1992. Acoustical Characterisation of Seafloor Sediments and its Relationship to Active Sedimentary Processes in Cook Strait, New Zealand. *New Zealand Journal of Geology and Geophysics* 35 : 289-300.

Carter R.M, Abbott S.T, Fulthorpe C.S, Haywick D.W, Henderson R.A. 1991. Application of Global Sea Level and Sequence-stratigraphic Models in Southern Hemisphere Neogene Strata from New Zealand. In *Special Publication 12 of the International Association of Sedimentologists.* MacDonald D.I.M. Ed : 41-65.

Collen J.D.H. 1972. Studies in the Wanganui Series: Pliocene foraminifera from the Wanganui Basin. Unpublished Ph.D thesis lodged in the Library, Victoria University of Wellington.

Collinson J.D, Thompson D.B, 1989. Sedimentary Structures, 2nd ed, Unwin Hyman Ltd.

Cotton C.A, 1957. An Example of Transcurrent-Drift Tectonics. *New Zealand Journal of Science and Technology*, Sec B:939-942.

Duder J.N, Hancox G.T, Withers G.R, 1977. Engineering Geology and Foundation Engineering of the Moawhango Arch Dam. *Transactions of the New Zealand Institute of Engineers* 4 (1).

Donoghue S.L, 1991. Late Quaternary Volcanic Stratigraphy of the Southeastern sector of the Mt Ruapehu Ring Plain, New Zealand. Ph.D Thesis lodged in the Library, Massey University.

Edwards A.R, 1987. An integrated biostratigraphy, magnetostratigraphy and oxygen isotope stratigraphy for the late Neogene of New Zealand. *New Zealand Geological Survey Record 23.*

Erdman C.F, Kelsey H.M, 1992. Pliocene and Pleistocene stratigraphy and tectonics, Ohara Depression and Wakarara Range, North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 35: 177-192.

Feldermayer A.E, Jones B.C, Firth C.W, Knight J, 1943. Geology of the Palmerston North - Wanganui Basin, West Side, North Island, New Zealand : The Superior Oil Co of NZ Ltd. NZGS Unpublished open file petroleum report No 171.

Fleming C.A, Steiner A, 1950. Sediments Below Ruapehu Volcano *New Zealand Journal of Science and Technology* B, 32: 31-32.

Fleming C.A, 1953. The Geology of Wanganui Subdivision, *New Zealand Geological Survey Bulletin 52*, Department of Scientific and Industrial Research.

Fleming C.A, 1959. Lexique Stratigraphique International Vol VI, Oceanie Fascicule 4, New Zealand.

Fleming C.A, 1962. New Zealand biogeography: a paleontologist's approach. *Tuatara* 10 : 53-108.

Fleming C.A, 1975. The Geological History of New Zealand and its Biota. Biogeography and Ecology in New Zealand. Kuschel G Eds. Published by Junk, The Hague.

Francis D.A, Scott G.H, 1987. Opoitian Ormond Limestone on Late Kapitean siltstone near Cave Road, Gisborne. *New Zealand Geological Survey Record* 20 : 145-149.

Gage M. 1980. Legends in the Rocks. ISBN 0 7233 0602 8 Whitcoulls Publishers.

Grammer T.R, 1971. The Geology of the Eastern Saddle Road area, Manawatu Gorge, North Island, New Zealand. Unpublished BSc (Hons) Thesis lodged in the Library, Otago University.

Grant-Taylor T.L, Hornibrook N.DE B, 1964. The Makara Faulted Outlier and the Age of Cook Strait. *New Zealand Journal of Geology and Geophysics* 7 : 299-313.

Gregg D.R, 1960. The Geology of Tongariro Subdivision. *New Zealand Geological Survey Bulletin* 40.

Grindley G.W, 1960. Sheet 8, Taupo. *Geological Map of New Zealand 1: 250 000*, New Zealand Department of Scientific and Industrial Research, Wellington, New Zealand.

Hancox G.T, 1975. Completion Report on the Engineering Geology of the Moawhango Dam. *New Zealand Geological Survey, Engineering Geology Report* 213 : 1-53.

Haq B.U, Hardenbol J, and Vail P.R, 1987. Chronology of Fluctuating Sea Levels Since the Triassic. *Science* 235 : 1156-1167.

Haq B.U, 1991. Sequence Stratigraphy, Sea Level Change, and Significance for the Deep Sea. In *Special Publication 12 of the International Association of Sedimentologists.* MacDonald D.I.M. Ed : 3-39.

Harbert W, Cox A, 1989. Late Neogene Motion of the Pacific Plate. *Journal of Geophysical Research* 94 : 3052-3064.

Hayward B.W, 1987. Paleobathymetry and Structural and Tectonic History of Cenozoic Drillhole Sequences in Taranaki Basin. *New Zealand Geological Survey Report* PAL 122.

Hector J, 1870. Notes on the Geology of the Hawke's Bay District. *Reports of the New Zealand Geological Survey* 2, 1870-71.

Hector J, 1871 (b). Geological Structure of the Kaimanawa Range. *Proceedings of the New Zealand Institute* 3: 16-17.

Hegan B.D, 1980. Engineering Geology of the Moawhango to Tongariro Tunnel. *New Zealand Geological Survey Report* EG 343

Hill H, 1899. Descriptive Geology of the District between Napier and Ruapehu Mountain via Kuripapanga and Erewhon. *Transactions and Proceedings of the New Zealand Institute* 22: 422-429.

Hunt T.M, 1980. Basement Structure of the Wanganui Basin, Onshore, Interpreted from Gravity Data. *New Zealand Journal Of Geology and Geophysics* 23 : 1-16.

Ingham C.E. 1969. Tongariro Power Development Geophysical Surveys, (3), Seismic Investigations: Moawhango Dam Site and Paradise Valley. *Geophysics Division, Department of Scientific and Industrial Research Report* 56.

Ingham C.E. 1971. Tongariro Power Development Geophysical Survey, (5). *Geophysics Division, Department of Scientific and Industrial Research Report 66.*

Ingham C.E, 1972. Re-interpretation of Paradise Valley Seismic Survey, October 1972. Unpublished Notes.

Kamp P.J.J, Harmsen F.J,Nelson C.S, Boyle S.F, 1988. Barnacle-dominated limestone with giant cross-beds in a non-tropical, tide-swept, Pliocene forearc seaway, Hawke's Bay, New Zealand. *Sedimentary Geology* 60 : 173-195.

Katz H.R, 1973. Pliocene Unconformity at Opau Stream, Hawke's Bay, New Zealand. *New Zealand Journal of Geology and Geophysics* 16 : 917-925.

Ker D.S, 1991. Provisional Geological Map of 1:50 000, Sheet T21AC, (Hautapu), *New Zealand Geological Survey Report* G144.

Kennett J.P, 1966 (a). Recognition and Correlation of the Kapitean Stage, (Upper Miocene, New Zealand). *New Zealand Journal of Geology and Geophysics* 10 : 1051-1063.

Kennett J.P, 1966 (c). Stratigraphy and Fauna of the Type Section and Neighbouring Sections of the Kapitean Stage, Greymouth, N Z. *Transactions of the Royal Society of New Zealand, Geology* 4 : 1-77.

Kingma J.T, 1957 (a). The Geology of the Kohurau Fault Block, Central Hawke's Bay. *New Zealand Journal of Science and Technology* B, 38 : 342-353.

Kingma J.T, 1957 (c). The Tectonic Setting of the Ruahine - Rimutaka Range, *New Zealand Journal of Science and Technology* B, 38 : 858-61.

Kingma J.T, 1962. Sheet 11 Dannevirke. *Geological Map of New Zealand 1:250 000*, Wellington. Department of Scientific and Industrial Research.

Lillie A.R, 1950. Two New Zealand Rivers Following Tertiary Transverse Furrows. *Transactions of the Royal Society of New Zealand* 78 : 329-341.

Linert B.R, Christoffel D.A, and Vella P, 1972. Geomagnetic Dates on a New Zealand Upper Miocene-Pliocene Section. *Earth and Planetary Science Letters* 16 : 195-199.

Marshall P, Murdoch R, 1920. The Tertiary Rocks near Wanganui *Transactions and Proceedings of the New Zealand Institute* 52: 115-120.

Melhuish A, 1990. Late Cenozoic deformation along the Pacific-Australian plate margin, Dannevirke region, New Zealand. Unpublished MSc thesis lodged in the Library, Victoria University of Wellington.

McGuire D.M. 1989. Paleomagnetic stratigraphy and Magnetic properties of Pliocene Strata, Turakina River, North Island, New Zealand. Unpublished Ph.D Thesis lodged in the Library of Victoria University of Wellington, 236 p.

Moore P.R, 1981. Geology of the Late Tertiary section at Cape Turnagain. *Journal of the Royal Society of New Zealand* 11: 223-230.

Morgan P.G, 1919. The Limestone and Phosphate Resources of New Zealand. *New Zealand Department of Mines, Geological Survey Branch, Bulletin* 22 (New series).

Park J.1886. On the Geology of the Western Part of Wellington Provincial District, and Part of Taranaki. *New Zealand Geological Reports, New Zealand Geological Survey* 6: 1855-88.

Reineck H.E, Singh I.B, 1980. Depositional Sedimentary Environments, 2nd ed, Springer-Verlag, Berlin, Heidelberg, New York.

Ridd M.F, 1964. Succession and Structural Interpretation of the Whangara-Waimata Area, Gisborne, New Zealand, *New Zealand Journal of Geology and Geophysics* 7: 279-298.

Roberts A.P. 1992. Paleomagnetic Constraints on the Tectonic Rotation of the Southern Hikurangi Margin. *New Zealand Journal of Geology and Geophysics* 35: 311-323.

ward D, Christoffel D.A, Lienert B, 1986. Magnetic polarity ratigraphy of a Plio-Pleistocene marine sequence of North land, New Zealand. *Earth and Planetary Science Letters* 80: 3-360.

ott G.H, 1982. Review of Kapitean Stratotype and Boundary th Opoitian Stage, (Upper Neogene, New Zealand). *New aland Journal of Geology and Geophysics* 25: 475-485.

ssons B.A, Dibble R.R, 1981. A Seismic Refraction periment Southeast of Ruapehu Volcano. *New Zealand Journal f Geology and Geophysics* 24: 31-38.

eden I.G. 1966. Paleoecology and the Study of Fossil nthic Assemblages and Communities. *New Zealand Journal of eology and Geophysics* 9 : 408-423.

orli K.B, Barter T.P, 1973. Geological Reconnaissance in e Torlesse Super-group of the Kaimamawa Ranges along the wer Reaches of the Waipakihi River, North Island, New aland. *Journal of the Royal Society of New Zealand* 3: 3, 363-380.

porli K.B, 1987. Airphoto Lineaments and Fracturing in the xial Ranges of the Central North Island, New Zealand. *ournal of the Royal Society of New Zealand* 17 : 139-156.

tern T.A, 1987. Asymmetric back-arc spreading, heat flux and tructure associated with the Central Volcanic Region of New ealand. *Earth and Planetary Science Letters* 85: 365-276.

tern T.A, Quinlan G.M, Holt W.E, 1993. Crustal Dynamics ssociated with the Formation of Wanganui Basin, New Zealand. outh Pacific Sedimentary Basins, Sedimentary Basins of the orld 2. Ballance P.F. ed, (Series Editor: Hsu K.J) Elsevier cience Publishers B.V, Amsterdam. 213-223.

tavely-Parker R.J. 1978. Geology and Metamorphism Of orlesse Rocks in the Central North Island. Unpublished MSc Thesis lodged in the Library, Auckland University.

Stevens G.R. 1974. Rugged Landscape. The Geology of Central New Zealand. ISBN 0 589 00762 9. A.H & A.W. Reed Ltd

Suggate R.P, Stevens G.R, Te Punga M.T (Eds). 1978. The Geology of New Zealand. Government Printer, Wellington.

Swift D.J.P and Thorne J.A, 1991. Sedimentation on Continental Margins, 1: a general model for shelf sedimentation. Shelf Sand and Sandstone bodies. *Special publication number 14 of the International Association of Sedimentologists.* D.J.P Swift, G.F Oertel, R.W Tillman and J.A Thorne Eds, Blackwell Scientific Publications.

Te Punga M.T, 1953. The Geology of Rangitiki Valley. *New Zealand Geological Survey Memoir 8.* Department of Scientific and Industrial Research.

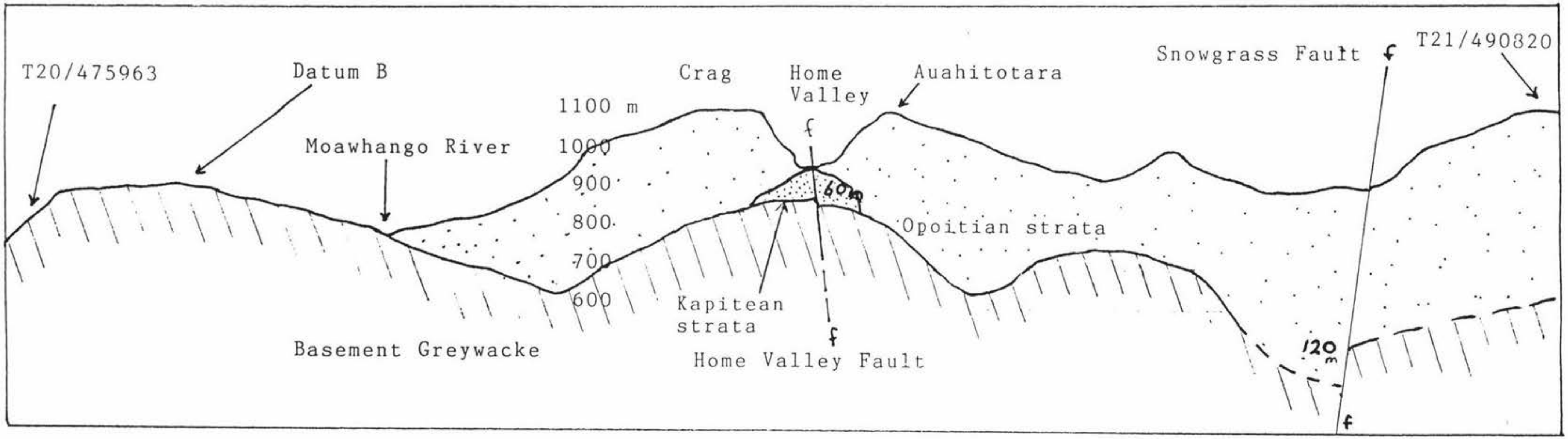
Walcott R.I, 1987. Geodetic strain and the deformational history of the North Island of New Zealand during the late Cainozoic. *Philosophical Transactions of the Royal Society of London* (A) 321: 163-181.

Wellman H.W, 1961. Notes on Mapping and Structure. Geology Department, Victoria University of Wellington.

Wells P.E, 1989. Late Neogene stratigraphy of the Carrington area, western Wairarapa, North Island, New Zealand. *Journal of the Royal Society of New Zealand* 19 : 283-303.

Wright I.C, Vella P.P, 1988. A New Zealand Late Miocene magnetostratigraphy: glacioeustatic and biostratigraphic correlations. *Earth and Planetary Science Letters* 87 : 193-204.

Wright I.C, Walcott R.I, 1987, Large tectonic rotation of part of New Zealand in the last 5 Ma. *Earth and Planetary Science Letters* 80: 348-352.

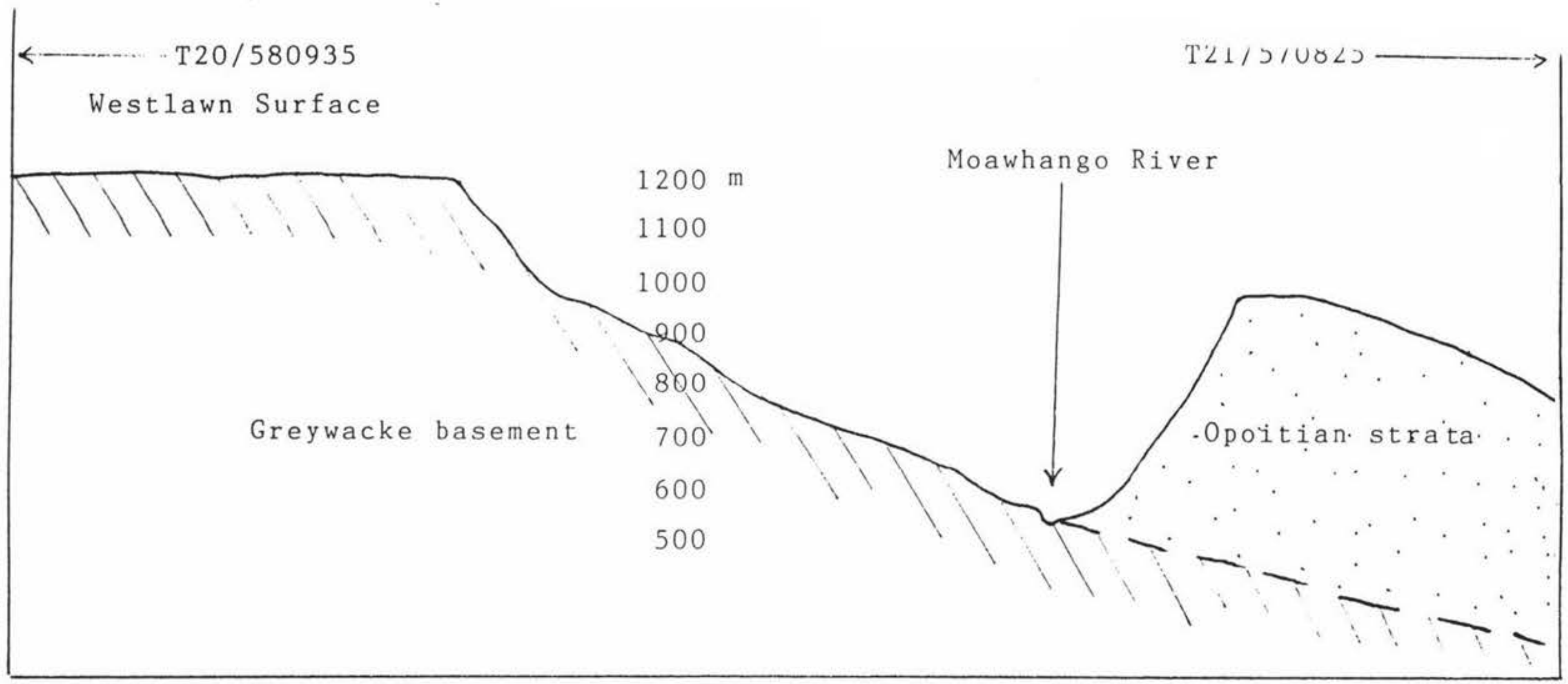


1. North-south cross section. Horizontal Scale 1:50 000

a. Datum B T20/475963 to Snowgrass Dome T21/490820.

This section crosses several depressions in the basement, representing the courses of former tributary streams of the Paleo-Moawhango River. These valleys drained eastwards into the main river which exited between the Datum B and Te Rotete ridges (Fig 9). Downwarping of the peneplain to the west, possibly by movement on the Desert Road Fault, is indicated. Well dissected marine strata of the Waiouru Formation overlie the basement which is cut by the Home Valley and Snowgrass Faults. Depth of the basement upwarping under the Snowgrass Dome is not known.

Shown underlying the Home Valley are Kapitean strata of the Home Valley mudstone.



b. North-south cross section Horizontal Scale 1:50 000

T20/580935 to T21/570825

The planar surface of the Late Cretaceous pleneplain (Westlawn surface) is shown at left. The eroded greywacke margin slopes down at approximately 9° to the Moawhango River where a steep margin formed of Argo sandstone, rises up to the flat-topped plateau around the Te Rei trig. This surface then slopes away to the southwest, where it is overlapped by younger Taihape Mudstone.

APPENDIX C

1. SURVEY PROCEDURE: SAMPLE CALCULATION

1.1 Table A. Refraction/Curvature Correction

Distance (km)	Correction (m)	Distance (km)	Correction (m)
1	0.06	6	2.4
2	0.3	7	3.3
3	0.6	8	4.3
4	1.0	9	5.5
5	1.7	10	6.8

1.2 Calculation

LOCATION OF OBSERVER: GR 541903 (by back bearing)
LOCATION OF TARGET: GR 503965 Te Rotete Trig
MAP HT OF OBSERVER: 960 m plus
MAP HT OF TARGET: 1154 m
HT OF THEODOLITE: 1 m
MEASURED VERTICAL ANGLE: 91° 21" 50'
MAP DISTANCE ON GND: 7375 m
7375 X tan 1° 21" 50' = 175.6 m.

This must now be corrected for refraction and curvature of the Earth over 7375 m. From Table A, this is 3.5 m, giving 179.1 m as the height difference. Subtract the height of the Theodolite (1 m) to give the height of the Observation Point, (OP) as 178.1 m. This figure is then subtracted from the target height (178.1 m from 1154 m) = 975.9 m for OP.

The calculated height of the OP is thus 16 m higher than that deduced from contours on the map.

2. The Home Valley Mudstone.

Location GR T21/473893 on the floor of the Home Valley, height 940 m. Double sided cutting on the Home Valley Rd. Fine grained non-bedded, blue/grey colour, silt/mudstone with several concretions of various sizes, 20 cm diameter to 50 mm. No layering seen within deposit, probably bioturbidated. No mica flakes seen, in contrast to mudstones in Argo basin and otherwise similar mudstones 100 m west of the cutting. The exposure is also visible in road cuttings east along the road to a weathered mudstone at GR T21/480895.

Definite marine deposit, macrofossils present. Many shells seen as fragments and in matrix. *Cucullea* and *Sectipecten wollastoni* identified. The muds conformably overlie a greensand, containing broken shells, including *Sectipecten wollastoni*. A slow deposition environment, and abundant foraminifera seen in thin section.

Note: In NZGS Map T21AC, HAUTAPU (NZGS G144), which covers part of the area, this is fossil loc T21/f12. Identified by Dr A Beu, (IGNS). " *Bivalvia: Sectipecten wollastoni*, pieces of one, small left valve and other fragments. Observed and not collected; *Cucullaea hamptoni* several poor. *Marama sp.*

AGE: Tk. A typical Tk offshore, mudstone fauna, ie; a very different facies from the Wo age shallow water crammed *Crepidula* shellbeds just over the hill on the Imjin Rd."

150 M upstream from this site, in the bed of Waiouru stream, there is massive yellow/brown sst with 0.3 m layer of coarse blue/grey sand. Abundant micas seen in 2 m section above water level, then 0.4 m laminated blue/grey muds then yellow/brown sands in layers. Typical Opoitian. No shells seen. Perhaps close to the Opoitian contact with Kapitean but no angular unconformity with Kapitean.

Comment: Thin sections taken off several fossil casts have shown some glass, but all show abundant foraminifera to the extent that any thin section from here is readily identified from similar mudstone elsewhere in the section.

2.1 Microfossils

" From NZ fossil record form No T 21/f12 collected by R.H.HOSKINS (IGNS) and D.S.KER (IGNS) on 30 Oct 1981. Identification by Dr R.H.HOSKINS on 27 Oct 1982. Stage identification Kapitean, Lower to Middle, NZGS Lab No F23157."

Robulus sp	*Nodosaridae (rare)*
Uvigerina	*Bolivinita pohana*
Bolivina parri (common)	*Bulminia aculuata*
Bolivina spathulata	*Florius flemingi (common)*
Cassidulina neucarinata	*Evolvocassidulina orentalis*
Ammonia bellarri	*Elphidium*
Notorotalia cf taranakia(abundant)	*Astrononion*
Anomalinoides parvumbilia	*Globorotalia miotumida*
Globoquadrina dehiscens	*Globigerina*

3. Macrofossil Localities

Fossil Name	Fossil Site Loc
Phialopecten marwicki (Beu)	T21/f80,T21/f77
Tawera sp	T21/f80
Glycymeris sp	T21/f77,T20/f27
Glycymerita (mania).cf manaiaensis	T20/f31
Maorimactra chydea	T20/f30
Zenatia cf.acinaces (Quoy & Gaimand)	T20/f32,T20/f25
	T20/f28
Dosina (raina).cf bartrumi (Laws)	T20/f32
Penion sp	T20/f32
Stiracolpus	T20/f32,T20/f26
Crepidula radiata	T20/f30,T21/f77
	T20/f26,T20/f28
Sigapatella sp	T21/f77
Crassostrea igens	T21/f77
Fissidentalium cf zealandicum	T21/f77
Austromegabalanus sp	T21/f77
Antisolarium sp	T20/f27
Polinces sp	T20/f27
Maoricolpus sp	T20/f27
Fellaster sp	T20/f27
Sectipecten wollastoni	T21/f12

:sil Name	Fossil Site Loc
ullea hamptoni	T21/f12
:uthiolaria callusaria obesa	T20/f30,T20/f28
iopea sp	T20/f28
›strea chilensis	T20/f30
:ria solida	T20/f30
isula aff.aequilatesa	T20/f30
:nea (anchomasa)	T20/f30
rnea similis	T20/f30

1 Microfossil Location (Other than Home Valley mudstone)

crofossil Name	
.orilus parri	T20/f29
›torotalia sp	T20/f29

ıbove microfossils from NZ fossil record T20/f29 collected
y Dr A.Beu (IGNS) 20 May 1992. Identification by Dr
.H.Scott (IGNS) on 21 Aug 1992. Stage identification
apitean-Opoitian).

. Fossil Locations on National Fossil Register

ossil No	Grid Ref	Fossil No	Grid Ref
21/f12	473893	T20/f25	489928
20/f26	490908	T20/f27	489896
20/f28	489904	T20/f29	487929
'20/f30	489913	T20/f31	458976
:20/f32	489929	T21/f77	489896
T21/f78	491882	T21/f80	491884

SECTION DESCRIPTIONS

Big Bend section.

Bend, is a composite section of Opoitian marine strata ated generally in the middle of the Argo Basin. The base at the river bend T20/516907 (Fig 41), and a complete osure of the sequence was traced to T20/515921. It covers n 680 m to 920 m. Except at the base, where greywacke ived conglomerates are interbedded with sands, this tion is away from the basement.

is a monotonous sequence of coarse sandstone, metre to i-metre bedded, with sparse marine shells or shell casts some greywacke pebbles at the base of many sand layers. y of the layers have an eroded top while others have thin pings of mud. Cross-bedding and foresets are common. This uence is interpreted as sandbar accumulation in a tidal ironment. There are few layers of calcareous sand or lls in this section except near the top, and these are thin i die out laterally.

rrent directions and mapping of the greywacke basement ntour indicate that a deep narrow gorge, aligned north to uth, underlies the Big Bend. This is interpreted as the rth flowing paleo-Moawhango River which exited through a rge between the Datum B and Te Rotete ridges.

Point 996 section

int 996 is located at T20/489904 and is a single exposure Opoitian strata in a north facing hillside. It covers om 909 m to 1001 m. The sequence is a mixture of poorly nsolidated sand and mud layers with many calcareous sand d shell limestone layers within the sequence. Ripple rkings and tidal flow structures indicate a shallow-water dal deposited environment. The layers of calcareous sands d shells are derived from the near shore faunal population.

lack of greywacke pebbles and the current directions ,nd in this sequence, indicates that this was deposited er submergence of the offshore islands and represents a ghtly offshore location subject to the littoral current.

Imjin Road section

s section is exposed along the Imjin Road for over 1 km l from 836 m to 948 m in height. The base T20/490916, is ;tly sand but this merges into blue-grey muds and then into nainly sandy environment at the top of the section at)/490909. Layers of calcareous sand and shells are found roughout. This location supported an abundant, often per-abundant fauna. Tidal flow structures, channels and e abundant faunal population indicate development of tidal dflats.

leocurrent directions in this section show a change above e 900 m level, interpreted to mark submergence of the fshore islands. The mud dominated facies also begin to lange above this height, becoming dominated by sand, but mud yers remain common. Deposition of this section began on le edge of the Imjin Camp tidal estuary, and away from the iin tidal channel. As the transgression progressed, idening of the estuary saw the development of tidal mudflats ı the south or down-current side of the Imjin Camp estuary.

rapping of sand from the littoral current by the inlet, stablished a mud dominated sedimentation down-current, until nfilling of the Imjin Camp inlet allowed sand to be bypassed nd accumulate in the section. The littoral current now ended to remove fine sediments, thus allowing sand to become more dominant member.

. Whalebone section

his section is located on a hillside at T20/482915. ssentially, it is almost identical to the Point 996 section ınd indicates a similar slightly offshore location. A bone fragment interpreted as a whalebone, was found in a shellbed at 948 m height, possibly transported from the shoreline.

Craq section

s section is well exposed on the north face of the Crag
ture at T20/476907. The base is obscured by the debris
tle on the lower slopes until 1069 m where a small section
ongly resembles the upper parts of the Whalebone and Point
sections. Above this, however, are sand and mud layers
h no apparent calcareous sand or shell layers as are found
er down. However, concretions appear and merge into a
tinct 9 to 10 m thick shellbed, the Crag reef, made up of
tiple layers of calcareous sand and shell fragments. This
separated from a similar overlying bed by 14 m of sand
ers.

s is interpreted as initial deposition similar to the
ver sections at Whalebone and Point 996 in a shallow-water
ial environment. Above 1000 m, prograding basal sands were
ing deposited on the Westlawn surface as the transgression
ogressed and the shoreline retreated. Accumulation of the
o thick shell beds (and similar shellbeds found in the
iouru Formation above the Crag reef), was by current
rting of skeletal material from an abundant faunal
pulation established on the submarine high of the now
bmerged Westlawn Surface, the carbonate "factories" of Kamp
al. (1988).

KEY: (Symbols used here are those in Andrews (1982). Revised Guide to recording Field Observations in Sedimentary Sequences).

Concretions

Channel structure

Conglomerate

Pebble layer

Erosion resistant layer

Mud layers or streaks

Ripples

Macrofossils

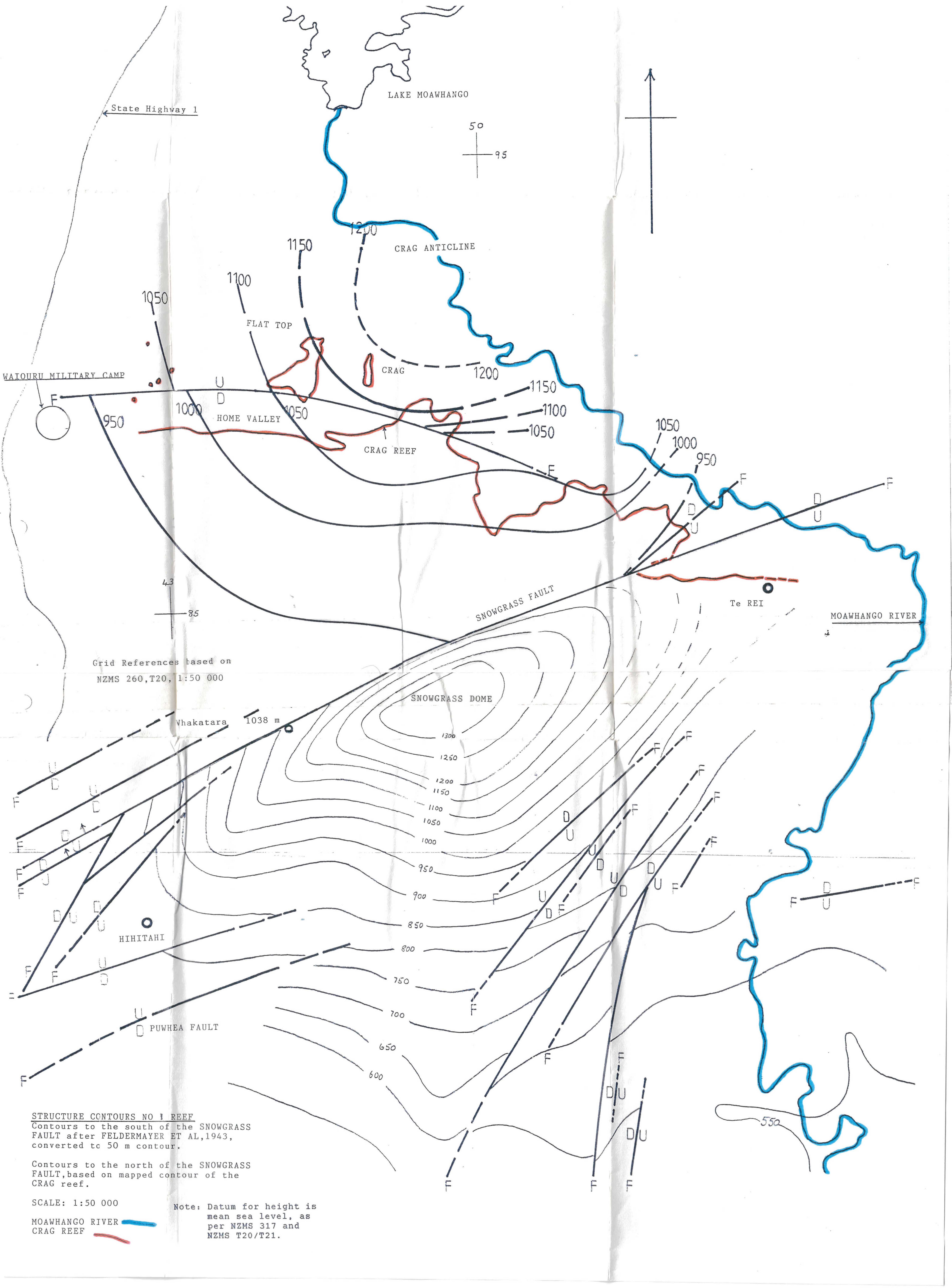
Coarse sands

Load structures

Calcareous layers or streaks

Moderately soft


STRUCTURAL CONTOUR MAP: CRAG REEF AND CRAG ANTICLINE.
SCALE. 1:25 000
KEY:
CRAG REEF
EXPOSED GREYWACKE
25 M CONTOUR ON CRAG REEF
MOAWHANGO RIVER
N
Background is the 20 m vertical interval of NZMS 317.
Deformation of Crag reef is shown at 25 m vertical interval
Note: Datum for height is mean sea level, as per NZMS 317 and NZMS T20/T21.
Contour map of NZMS 317, at a scale of 1:25 000, is reproduced by permission of the Department of Survey and Land Information.
MOAWHANGO DAM
ZONE 27 GORGE
WESTLAWN HUT
FLAT TOP
CRAG
HOME VALLEY FAULT
WAIOURU
HOME VALLEY
MOAWHANGO RIVER
HOME VALLEY FAULT
ZONE 38 GORGE
SPUR GORGE
FACET
SNOWGRASS FAULT
AORANGI STREAM
SNOWGRASS FAULT
SNOWGRASS DOME



STRUCTURE CONTOURS NO 1 REEF

Contours to the south of the SNOWGRASS FAULT after FELDERMAYER ET AL,1943, converted tc 50 m contour.

Contours to the north of the SNOWGRASS FAULT,based on mapped contour of the CRAG reef.

SCALE: 1:50 000

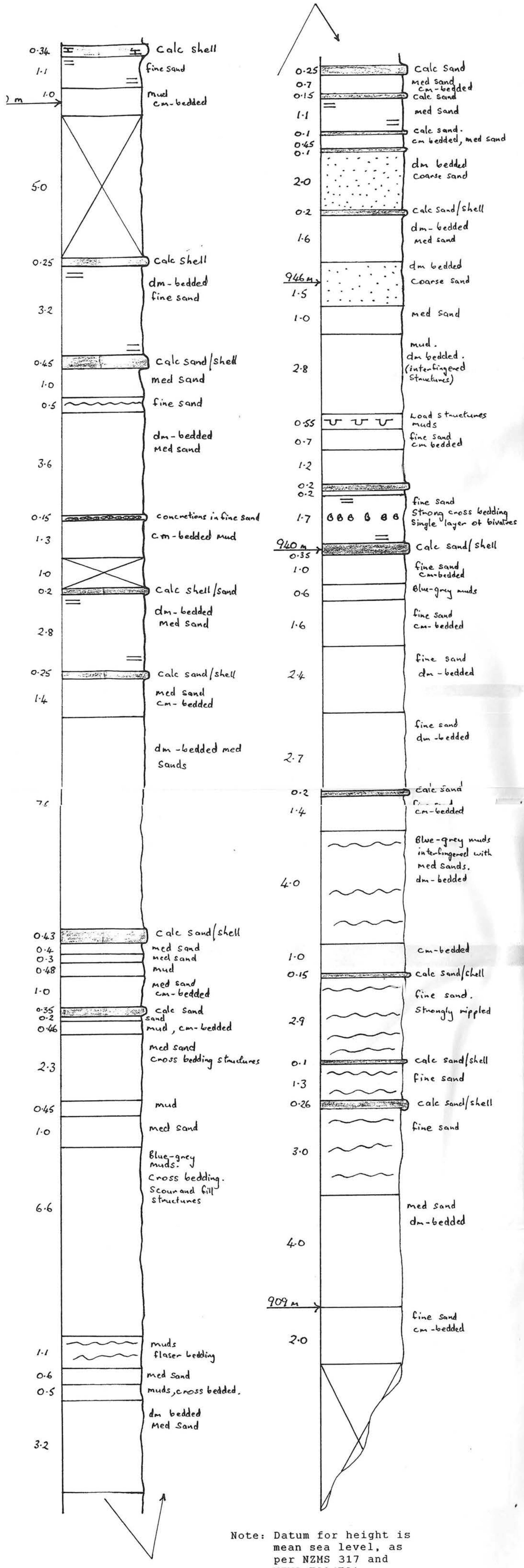
MOAWHANGO RIVER

CRAG REEF

Note: Datum for height is mean sea level, as per NZMS 317 and NZMS T20/T21.

Appendix B.9
Sections: Point 996 and Imjin Road

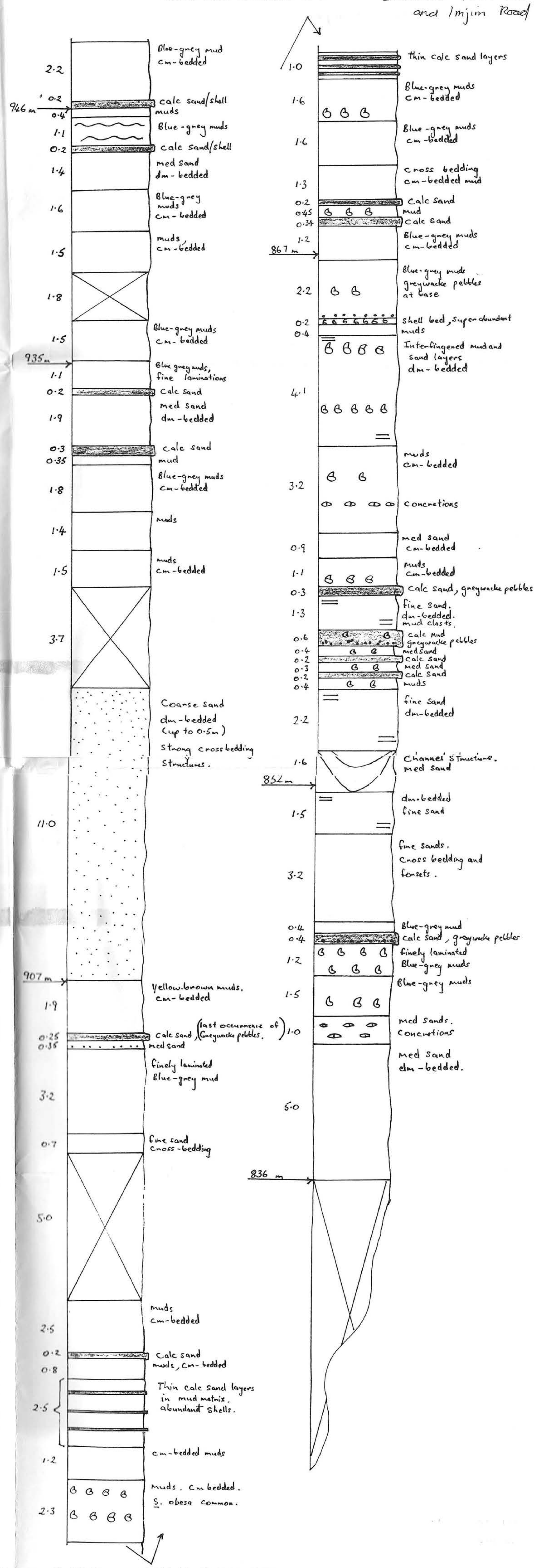
POINT 996 SECTION. T20/489904



Note: Datum for height is mean sea level, as per NZMS 317 and NZMS T20/T21.

Scale. 1cm = 1m.

IMJIN ROAD SECTION. T20/490908



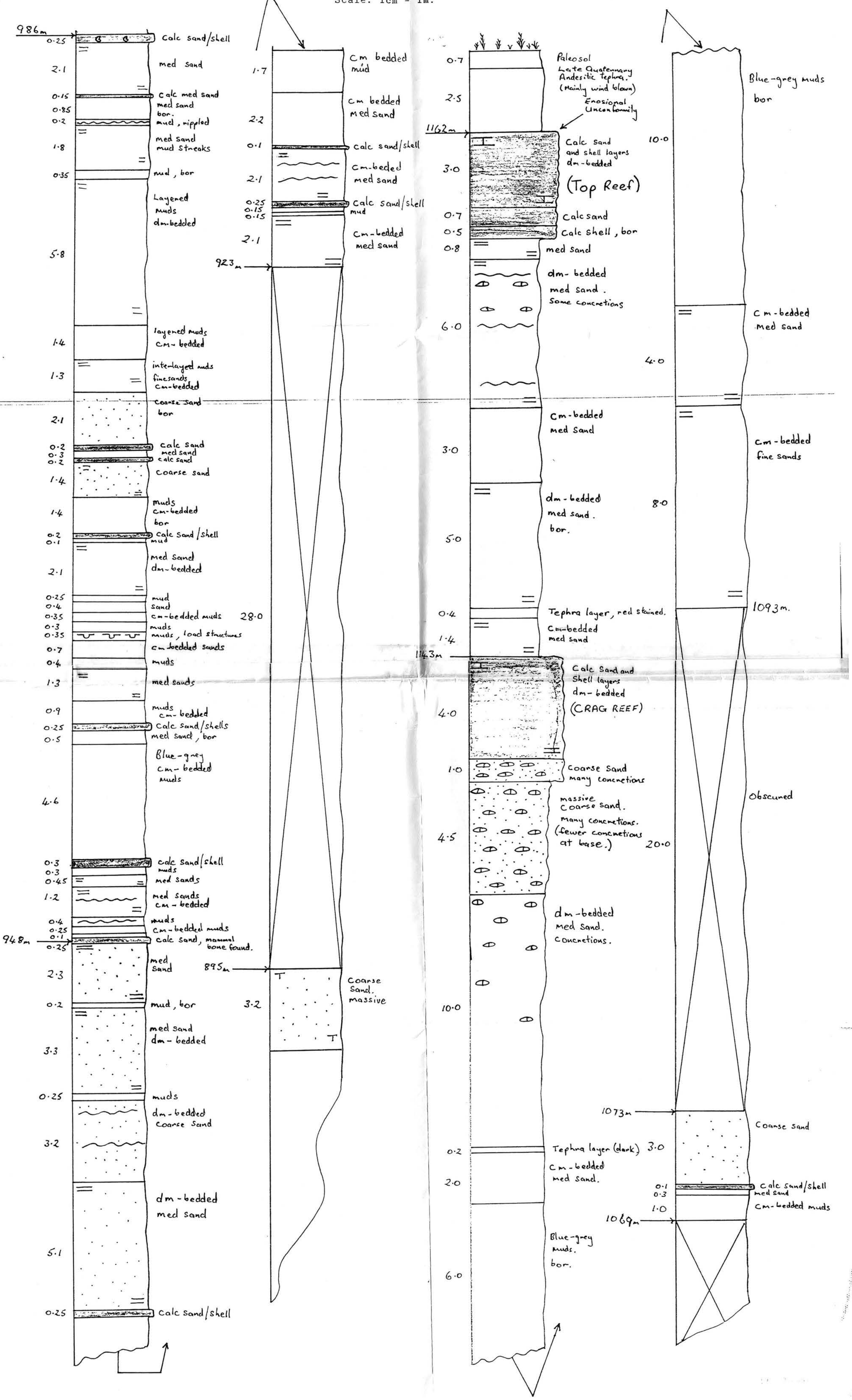
Appendix B.b.
Sections: Whalebone and Crag

WHALEBONE SECTION. T20/482915

Note: Datum for height is mean sea level, as per NZMS 317 and NZMS T20/T21.

Scale. 1cm = 1m.

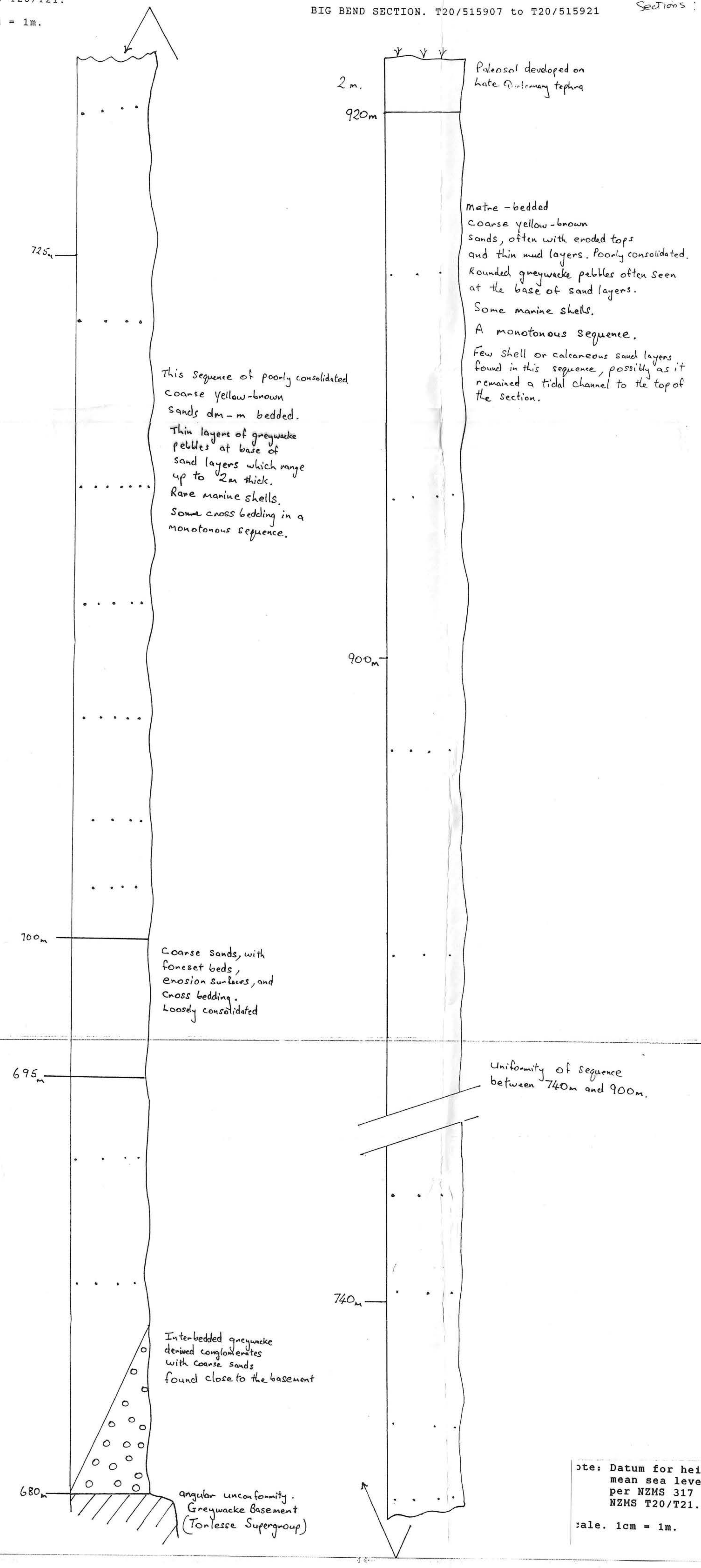
CRAG SECTION. T20/476907



mean sea level, as ← Datum for height is
per NZMS 317 and
NZMS T20/T21.
Scale
e. 1cm = 1m.

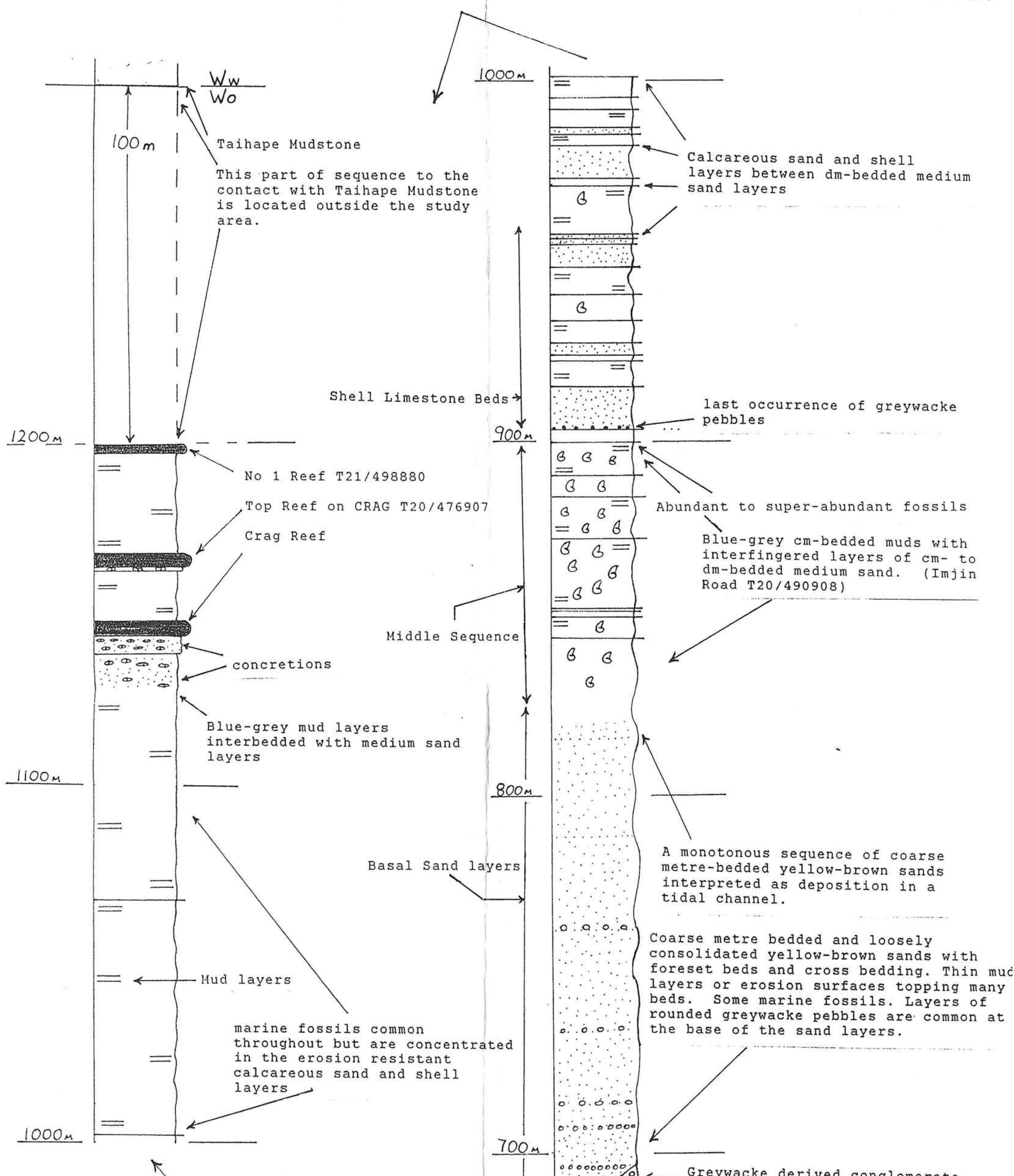
Appendix B.c
Sections : Big Bend

BIG BEND SECTION. T20/515907 to T20/515921



ote: Datum for height is
mean sea level, as
per NZMS 317 and
NZMS T20/T21.

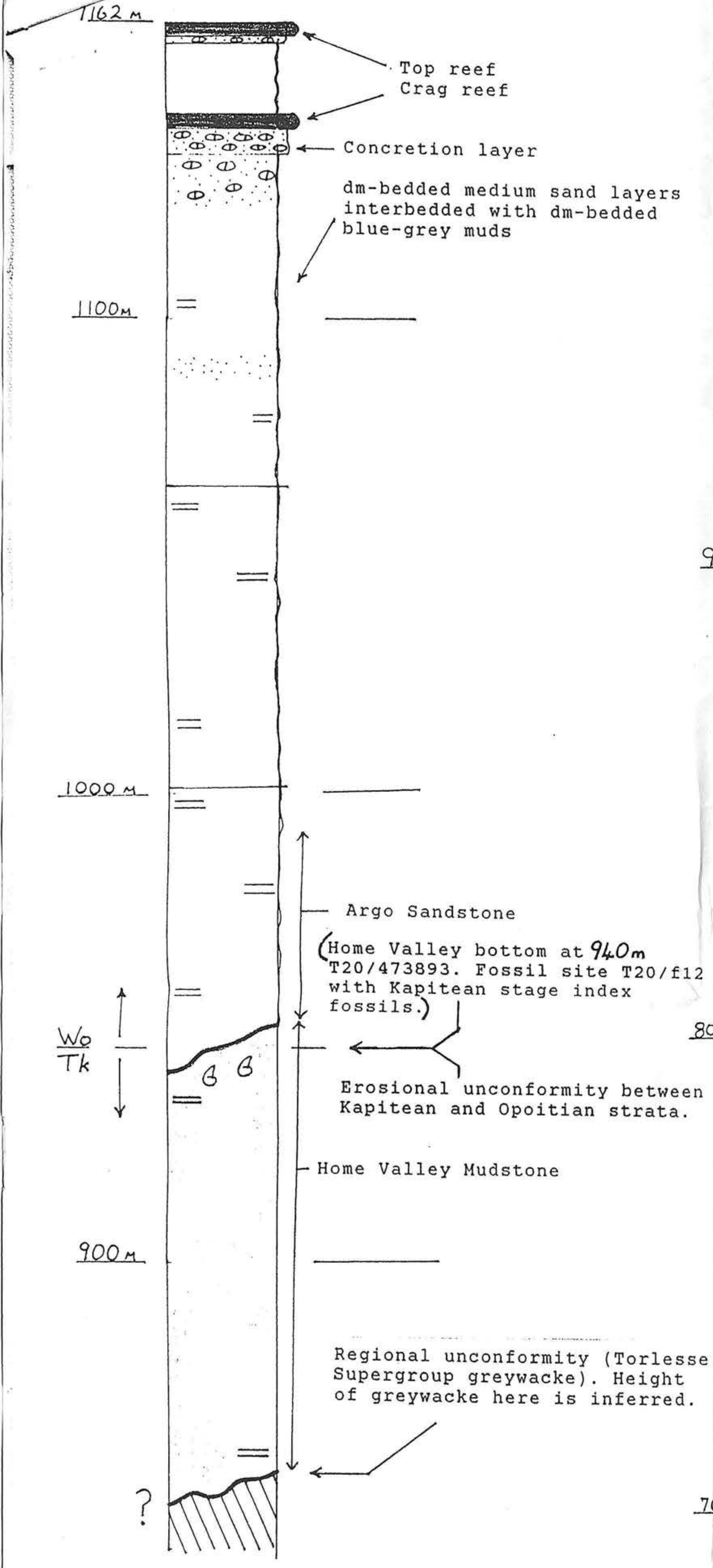
ale. 1cm = 1m.



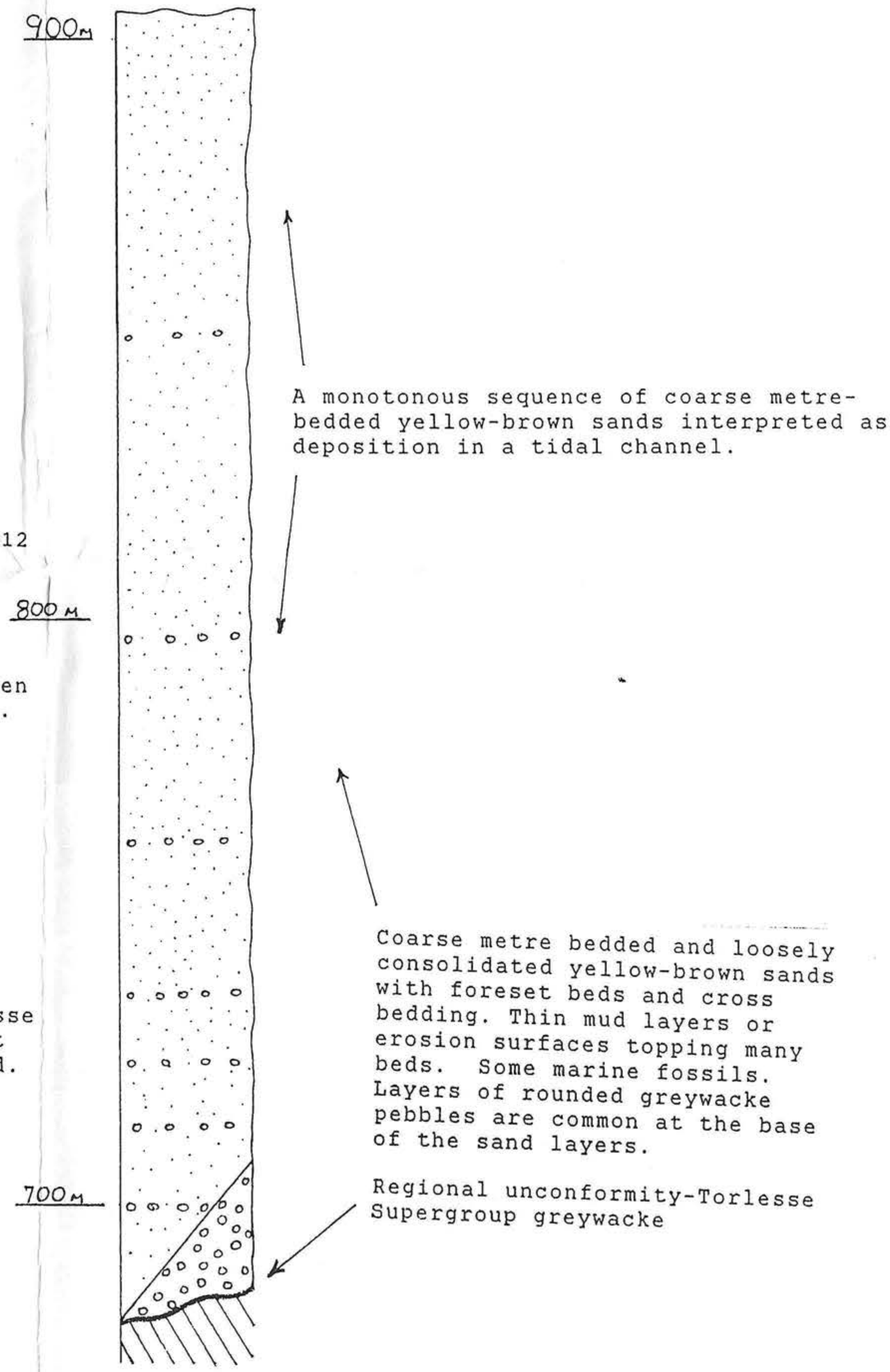
GENERALISED STRATIGRAPHIC SECTION OF THE ARGO SANDSTONE MEMBER OF THE WAIOURU FORMATION.

Heights refer to mean sea level datum as per NZMS T20/T21

Scale 1:1000 1cm = 10 m



Inferred section in Home Valley at T20/473893



This section typical of Basal Sand member in the ARGO basin, (Big Bend section) T20/515907.

Scale 1:1000 1cm = 10 m

Heights refer to mean sea level datum as per NZMS T20/T21