ROCKS OF THE WAI TEMATA GROUP
WHANGAPARAOA PENINSULA
NORTHLAND

A Thesis
Presented to
The University of Auckland

In Partial Fulfilment
of the Requirements for the Degree
Master of Science

by
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FRONTISPIECE:

Slump folding on a large scale in normal Waitemata beds at G.R. 339920 about three quarters of a mile west of Huaroa Point.
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Fig. 1 LOCALITY MAP

Whangaparaoa Peninsula
CHAPTER I

INTRODUCTION

LOCATION:

Whangaparaoa Peninsula is located on the east coast of Northland some twenty miles north of the City of Auckland, (v. fig.1). The peninsula has an area of approximately 10 square miles, it extends eastwards from the Orewa Bridge for about 10 miles and has a greatest width of 1½ miles. Its northern coast-line is marked by a number of long sandy beaches separated by extensive steep cliffs at the base of which there are broad wave cut shore platforms. Beaches are not as extensive, and the shore platform is not so well developed on the southern coast. The island of Tiritiri Matangi, two miles to the east of Whangaparaoa Head was visited briefly during this study.

Except for Tiritiri Matangi, for which a boat or an amphibious aircraft is needed, access within the area is easy, the main peninsular road branching off the Great North Road a short distance north of Silverdale and no place is more than half an hours walk from it.

Following removal of the forest cover in the late nineteenth century the peninsula was extensively farmed. Today there are a few patches of regenerating bush and scrub, small pine plantations near the mouth of the Weiti river, as well as near Hobbs and Okoromai Bays, and three small areas of coastal Pohutukawa forest in sheltered valleys of Tiritiri Matangi.

Because of the gently rolling nature of the country, ready access to Auckland, superb views of the islands of the Hauraki Gulf and a number of sheltered safe sandy beaches, farmland is vanishing under a forest of multi-coloured week-end baches. At present much of the land with a northerly aspect that is not built upon, is being sub-divided. Even so, there are considerable areas fronting the Weiti estuary, about Hobbs Bay and as well, the defence area east of Army Bay that are farmed.

Tiritiri Matangi is also famed but the only permanent inhabitants are the families of the lighthouse keepers.

MAP COVERAGE:

Grid references quoted (e.g. CR.860910) are taken from the Waivera, Silverdale and Whangaparaoa sheets of the N.Z.M.S.2. series published by the New Zealand Lands and Survey Department. The relevant parts of these sheets, which are at a scale of 1: 25000
Fig. 2. Development of Whangaparaoa Peninsula as the divide separating watersheds of extended Orewa and Weiti River systems. Note the underfit nature of the drainage with the heads of many valleys lying within a few yards of the coast yet yet draining in the opposite direction. Reconstruction of streams very diagrammatic.
were enlarged to a scale of 1: c 8000 for field mapping. They are parts of N.34,38 and 42, topographical maps at a scale of 1:63360, of the N.Z.M.S. series. Whangaparaoa Peninsula and Tiritiri Matangi lie wholly on N.38.

**PHYSIOGRAPHY:**

Whangaparaoa Peninsula and Tiritiri Matangi are interpreted as the remnant parts of a divide which separated watersheds of extended Weiti and Okura Rivers (v. Grant-Mackie, 1960; fig.3), and the Orewa River, which, when sea level stood lower than it does now, discharged somewhere east of Tiritiri Matangi (fig.2). These rivers may have been fault controlled (v. fig.10).

Despite precipitous cliffs which dominate much of the coastline, it is essentially an area of gently rolling relief. Drainage is clearly underfit and adjusted to a time when watersheds were more extensive than they are today. The heads of many valleys lie within a few yards of cliff-lines yet drain away from them and other valley systems are entrenched at the cliffs - e.g. along the north-facing cliffs east of Army Bay.

The heads of most bays (e.g. Arkles Bay, Stanmore Bay and Okoromai Bay) are backed by flat areas a few feet above present high tide level. These are built of unconsolidated silts, sands and some peaty deposits and are defined landwards in many instances by abandoned cliffs now covered in vegetation. The flats are regarded as terraces built in post-Pleistocene times at the maximum of the Flandrian Transgression.

Apart from prominent dip slopes east of Army Bay and the possibility that some stream valleys and aligned coastal features transgressing the peninsula are fault controlled there is little evidence for any structural control of topography.

Clearly defined terraces or erosional levels such as are recognised closer to the Auckland isthmus (e.g. Searle, 1956) are not found on either Whangaparaoa Peninsula or Tiritiri Matangi. Neverthe less, it must be recognised as a possibility that the prominent N-S ridge varying in height between 200 ft. and 250 ft, which extends for most of the length of Tiritiri Matangi and similar ridges with sub-concordant heights about Whangaparaoa Peninsula (the main peninsula road often follows these), are in fact the dissected remnants of erosion surfaces prominent at that height, and other heights near Auckland. Marine erosion has been so active and cliffs have retreated far from former coasts so that it is not surprising that little evidence should persist of earlier coastal terraces; this is true also of areas near Auckland city outside harbour limits.
Features of the shore platforms, prominent about Whangaparaoa Peninsula and Tiritiri Matangi, are discussed in the appendix.

SYNOPSIS OF GEOLOGY:

Sub-horizontal and gently dipping alternating sandstones and siltstones of Otaian age outcropping about Whangaparaoa Peninsula are interpreted as a turbidite facies of the Waitemata Group and interbedded with them are a number of distinctive volcaniclastic grits. The latter are often associated with disturbances of bedding resulting from penecontemporaneous slumping. These grit beds, accepted as having been emplaced by submarine volcanic mud- or ash-flows, are often quite fossiliferous containing a rich and varied polyzoan fauna together with Foraminifera, corals, and the broken and worn tests of echinoids as well as molluscs and brachiopods. In contrast the normal Waitemata beds of Whangaparaoa Peninsula contain a few Foraminifera, no macrofossils other than a single crinoid* being known. However, trace fossils are very common in some siltstones.

The upper and lower limits of the Waitemata Group can not be seen about Whangaparaoa Peninsula but at Tiritiri Matangi a basal conglomerate and overlying silty sandstones rests unconformally on metasediments of the Waipapa Group.

Cretaceous and lower Tertiary sediments outcrop immediately west of the area studied.

AIMS OF STUDY:

Notwithstanding a considerable amount of information scattered in the local literature (v. Lillie, 1959) the normal Waitemata beds though first recognised over a century ago were never subject of a detailed study until the recent advances of Ballance (1964 b.)

Broadly, this thesis is concerned with the sedimentology of Waitemata Group rocks of Whangararoa Peninsula and Tiritiri Matangi; emphasis being placed upon;

a) the relationship of grit beds to the normal Waitemata beds;

b) primary (or depositional) features of both the grits and the normal Waitemata beds and their mode of origin;

c) The provenance of these rocks and the environmental conditions under which they accumulated;

d) the origin of complex deformation often associated with the grit beds.

Whangaparaoa Peninsula was selected for detailed study because its high cliffs offer some of the most extensive and relatively undisturbed sequences of normal

* Collected by Mr. J.G. Wright, technician in the Physics Department, University of Auckland.
Waitemata beds. Even though the area studied covers but a small part of the total extent of the Waitemata Group, it is hoped that this study will further knowledge of these rocks, and suggest possible lines of research, profitable for any future investigation.

PREVIOUS WORK:

The first recorded visit of a geologist to the area is that of Hochstetter, who in 1864, commented briefly on some geological phenomena he observed there (e.g., disturbances of bedding associated with coarse grained breccias and conglomerates. Brief visits were paid by early survey workers, Cox (1881,1882); McKay (1884,1888) and Park (1886,1887) during the course of their wider geological investigations of the Auckland Province, Hector, without visiting the area, commented in his report of 1886 on the significance of some features previously illustrated by Hochstetter in 1864.

Independent and detailed accounts of volcanic grits and breccias (Parnell Grit) outcropping about the Auckland isthmus were made by Mulgan (1902) and Fox (1902); both these writers referred to rocks of similar lithology outcropping about Whangaparaoa Peninsula.

Turner and Bartrum (1929) discussed in some detail certain aspects, in particular they considered the grit beds and associated disturbances of bedding. However, their field work was hurried (Turner, 1927) and restricted to short stretches of the north and north-eastern coast.

The most recent work is that of Ferrar (1934) who, like Turner and Bartrum (1929) made particular reference to the grit beds. Ferrar also visited Tiritiri Matangi.

In addition there are numerous other works that refer to rocks of the Waitemata Group but which do not make particular reference to the area of this study. A detailed bibliography of these is given by Lillie (1959).

Until Ballance's 1964b) study of the Takapuna section the typical Waitemata sequence of alternating sandstones and siltstones had not been the subject of any detailed investigation.

TERMINOLOGY:

Hochstetter (1864) introduced the terms "Waitemata sandstone" (p.332) and "Waitemata beds" (p.40) for the "complex of chiefly horizontally bedded regular strata consisting of alternating light coloured argillaceous marls and shaley sandier layers..." that outcropped in the cliffs about the Waitemata Harbour. He recognised
that rocks of similar lithology outcropped extensively to the north of Auckland. "Waitemata beds" has been used frequently since (e.g. Ferrar, 1934).

In 1881 Cox called these same sediments the "Waitemata Series", a term that subsequently gained wide acceptance amongst local workers (e.g. Turner and Bartrum, 1929).

Following modern accepted usage and the recommendations of Brown (1942) Finlay and Marwick (1948) and Brothers (1954a, 1959), these sediments have been included in a Waitemata Group. The Waitemata Group includes a number of distinctive lithologies (e.g. Manukau Breccia, Orakei Bay Greensand, Albany Conglomerate etc., see Brothers, 1959).

Turner and Bartrum (1929) referred to the alternating sandstone-siltstone sequences typically exposed in the cliffs about the Waitemata Harbour and widespread to the north, as the "normal Waitemata beds." More recently these same sediments have been designated Waitemata formation (Brothers, 1954a).

Apart for a basal conglomerate at Tiritiri Matangi and interbedded volcaniclastic grits the sediments of this study can all be included in the Waitemata Formation. Waitemata beds or normal Waitemata beds will be used in an informal sense.

In his early description of the Waitemata beds Hochstetter (1864) recognised that highly distinctive volcaniclastic grits were interbedded with them about the Waitemata Harbour and to the north along the northeastern coast of Whangaparaoa Peninsula. Similar beds have since been recognised as far north as Waiwera (Bartrum, 1919) and Mahurangi Peninsula (Ferrar, 1934), and southwards to Howick (Pirth, 1930). Early workers referred to these outcrops of volcaniclastic grits under a wide variety of names depending upon the locality and the dominant lithology, e.g. Cheltenham Breccia (Park, 1890b); Okura Breccia and Ponsonby Tuff (Fox 1902) etc., v. Brothers (1959). Cox (1881) and Hector (1881) were the first to make reference in print to a Parnell Grit when discussing the bed exposed at Parnell Point. In recent years the practice has been to group collectively all these distinctive beds as the Parnell Grit(s). Exceptions are Hopgood's (1961) use of Mahurangi Grit and Chappell's (1963) use of East Tamaki Grit.

There are a number of these grit beds in the Waitemata sequence of Whangaparaoa Peninsula. As they are often lensoid or in fault contact with adjacent strata and because it is impossible to demonstrate lateral continuity with those to the south (i.e. Parnell Grit - sensu stricto) they will be called informally the Whangaparaoa Grits.
At this point it is probably advisable to consider the meanings of a number of terms already used or to be used in describing the distinctive volcaniclastic beds referred to as the Whangaparaoa Grits. Genetic inferences necessitate making passing reference to the manner in which these beds were emplaced, a topic covered in some detail in Chapter 8. Here it is sufficient to express the belief that they were deposited by submarine volcanic mud-flows, thus they are true sedimentary rocks.

There is no adequate term under which beds showing every gradation from coarse breccia or conglomerate to fine grained tuffaceous sands or silts can be grouped. In calling them grits the writer is fully aware that this term is usually applied to coarse grained sandstones (v. Twenhofel, 1932) but is following a long accepted local usage first established in 1881 (Cox). Perhaps these beds may better be referred to as laharc breccias (or epiclastic laharc breccias) following Fisher's classifications of 1960 and 1961.

Volcanic is used in the sense of Fisher (1958, 1960, 1961) not that of Wright and Bowes (1963); volcanic and volcaniclastic indicate clasts of volcanic rock, no inference being made as to the process of fragmentation.

Following earlier workers (e.g. Fox, 1902; Mulgan, 1902; Turner and Bartrum, 1929 etc.), the coarse rubbly base often common in these beds, is described as a breccia, though many clasts are sub-rounded and conglomerate would often be a better description.

Lapilli is used indiscriminately for all clasts of volcanic debris between 4 mm. and 32 mm. in diameter. Again no inference is intended as to the process of fragmentation.

Despite the recommendations of Hay (1952) the writer prefers to describe the finer grained fraction of the distinctive volcaniclastic beds (that which is less than 4 mm. in diameter) as tuffaceous rather than volcanic. Similarly, turbidite sandstones rich in volcanic debris like that of the grits are described as tuffaceous.
Stratification in the normal Waitemata beds is usually emphasised by preferential weathering. Here a sequence of thin siltstones alternating with thicker sandstones (turbidites) is overlain by a sequence of thinly bedded sandstones (mostly laminites and tractive sandstones) and siltstones (Height of cliff approximately 30ft.)
Fig. 4  Sub-horizontal silty sandstones of the Waitemata Formation conformably overlying the crudely bedded basal conglomerate which rests on a highly irregular surface cut in metasediments of the Waipapa Group (cf. fig. 24).

(Drawn from field notes and sketches; diagrammatic section in the vicinity of GR 394922; approximate height of section 75 ft.)
Fig. 5. Typical exposure of sub-horizontal Waitemata beds in extensive cliff section at G.R. 301906. Note the varying thicknesses of beds, especially the thick massive composite, cavernous weathering sandstone at the top of the cliff. (Height of cliff c. 125 ft.; length of exposure c. 250 yards.)
Fig. 6. Lensing strata at G.R. 234909 immediately west of Army Bay. Some of the thicker sandstone beds are composite. Note the prominent washout (for detail v. fig. 53).
A number of distinctive lithologies has been recognised in the Waitemata Group (v. Brothers, 1959). In the area covered by the present work apart from a basal conglomerate at Tiritiri Matangi and beds of volcanlastic grits about Whangaparaoa Peninsula the only rocks of the Waitemata Group to outcrop are monotonous, well-stratified sequences of yellowish-brown weathering, alternating sandstones and siltstones - the Waitemata Formation of Brothers (1954a), the normal Waitemata beds of Turner and Bartrum (1929).

About Whangaparaoa Peninsula the sandstone layers average about a foot in thickness though this can vary considerably (fig.3) from less than half an inch to four or five feet and, exceptionally, fifteen feet. Very thick sandstone beds are generally composite in nature (p.87). Siltstone layers average only three or four inches in thickness but like the sandstones, this too, can vary considerably.

Stratification is emphasised by preferential weathering and erosion of the less resistant siltstones (fig.3).

Many of the sandstone layers display small scale sedimentary features of the types commonly taken as indicative of turbidites. These and other primary features of the normal Waitemata beds are comprehensively described in Chapter 4. This alternating sandstone-siltstone sequence is hence identified as a turbidite facies of the Waitemata Group comparable to the Takapuna Section recently described by Ballance (1964b).

THE STRATIGRAPHIC SUCCESSION

TIRITIRI MATANGI:

The lowermost beds of the Waitemata sequence in the area are exposed about the northern part of Tiritiri Matangi where the basal member of the Waitemata Group is an unfossiliferous, loosely cemented, limonite-stained conglomerate, with a maximum thickness of about 60 ft., filling hollows in a highly irregular surface cut in metasediments of the Waipapa Group (fig.4). This conglomerate consists of well-rounded pebbles, commonly up to two inches across but sometimes exceeding six inches, which have been derived locally from the indurated rocks of the Waipapa Group,
Occasionally near the base of the conglomerate there are large angular blocks of the same material. This is a similar situation to that at Kawau Island and Cape Rodney, some 20 miles to the north described by Hopgood 1961).

Apart from the large blocks the conglomerate is not graded. In places it displays a crude horizontal stratification and appears to lap on to the highly irregular greywacks surface (fig.4). The upper surface of the conglomerate is planar and horizontal, and locally (e.g. GR.396921) marked by a 'hard-pan' limonite concentration. At GR.395293 and 393913 it is abruptly and conformably overlain by a deeply weathered sequence of fine, even grained silty sandstones. At GR.396922 however, the silty sandstones rest with sharp angular discordance upon the (horizontally bedded) conglomerate (fig.24). This ascribed to penecontemporaneous slumping (p.47).

The total thickness of Waitemata strata at Tiritiri Matangi cannot be determined but there must be a minimum of 80 feet of silty sandstones overlying the basal conglomerate (Col.1*).

---

**WHANGAPARAOA PENINSULA:**

In the extensive cliffs about Whangaparaoa Peninsula the normal Waitemata beds are particularly well exposed (e.g. fig.5). Inland exposures are practically non-existent. As can be seen in fig.5, individual beds can be followed frequently for some distance with little variation in thickness. However, instances of abrupt lensing (fig.6) are not unknown. Unfortunately neither the upper, nor lower limits of the Waitemata Formation is visible about Whangaparaoa Peninsula and there is possibly some considerable stratigraphic gap between the sequences here and at Tiritiri Matangi.

The excellent coastal sections have permitted the erection of detailed stratigraphic columns (sheet 3; in pocket). However, these columns can be erected for coastal stretches only, and, as others working with flysch-type sediments have found (e.g. Ten Haaf, 1959), attempts to correlate, or trace individual beds from exposure to exposure and to synthesise a composite stratigraphic column met with little success. Reasons for this are:

1) Probably the foremost reason is the monotonous uniformity of lithology in the normal Waitemata beds. As is shown later the distinctive volcanic grits are of limited value as stratigraphic markets.

---

* Refers to selected stratigraphic columns presented on a separate sheet (3) in pocket at rear.
Thickesses of individual beds are not satisfactory criteria upon which
to base correlation because of this monotony of lithology and continual
repetition of beds of comparable thicknesses.

Faults are common. Many are intraformational having small displacements
and it is possible to match strata across them (e.g. fig. 7a). Where dis-
placements are great and/or individual beds cannot be matched, correlation
is seldom feasible.

Because of widespread penecontemporaneous slumping (Chapter 3) there are
clear possibilities of repetition (or omission) in the stratigraphic
succession.

Correlation across beaches and other gaps in the cliffs is hazardous, if
not impossible, for these may mask faults, lensing strata or slumped beds.
Likewise, correlation between the peninsula's northern and southern coasts
is seldom possible.

Some particular examples are discussed below.

a) Despite what has previously been stated, comparable thicknesses of
slumped strata about Tarihunga and westwards from Red Beach (35-45 ft. in both
instances) are thought to be part of the one horizon. Further, they can be matched
possibly with small exposures of disturbed strata at GRs.251885 and 245865 (v,fig.26).
Even so slumping at Tarihunga has involved a thin grit bed while at the other three
localities it has not, though the slumped horizon west of Red Beach is stratigraphi-
cally above a 'gritty' bed poorly exposed in the shore platform 28 chains east of
Orewa Bridge.

b) Grit beds outcrop discontinuously along the peninsula's northern coast
from Tarihunga to Whangaparaoa Head, and from there, a short distance to the south.
The only exposures of grits on the southern shores are in the cliffs along the western
side of Okoromai* Bay from GR322887 to GR323895, on the western side of Hobbs Bay
(GR,302886) and in the shore platform about the north of Kotanui.** At low tide a
number of reefs are laid bare off-shore from the northern coast east of Army bay. On
all to which the writer had access, coarser phases of the grits were exposed.

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* This bay has been variously called, Korimai Bay (Fox, 1902); Maori Bay (Turner
and Bartram, 1929); False or Okoroma: Bay (Ferrar, 1934). Today it is popularly
known as Shakespear Bay but this name should be kept for that immediately to the
east, i.e. Te Haruhia Bay (N.Z.M.S.2).

** Called Kohanui by Fox (1902) and Notanui by Ferrar (1934).
Because grit beds are often lensoid (fig. 88) or in fault contact with adjacent strata (fig. 89) and because they are sometimes associated with slumped strata, together with the fact that the character of a grit bed can vary abruptly (Chapter 8) correlation of grit beds from exposure to exposure cannot be made with certainty. Furthermore, if the grits were emplaced by submarine volcanic mudflows as is believed, it is highly unlikely that one great bed stretches over a distance of 30 miles, from Mahurangi in the north to south of Howick as collectively grouping grit exposures over this area in the "Parnell Grit" would suggest.

Despite previous arguments, some general comments upon correlation of grit horizons exposed at a number of localities about Whangaparaoa Peninsula can be made.

A grit bed, 25-35 ft. in thickness can be followed in the shore platform and at the base of the cliff for some distance east of Coal-mine Bay (between GRs. 297902 and 299906). To the east it is faulted out, though a small upfaulted block reappears further east at GR. 304906; to the west it apparently lenses out and overlies strongly contorted, thinly-bedded, alternating sandstones and siltstones. Characteristics of grit beds are discussed in Chapter 8, but briefly, this bed, weathering to a distinctive greyish-brown, is moderately well graded with lapilli-size concentrations near its base passing upwards into a fine tuffaceous sandstone and siltstone. A bed, closely comparable in lithology, but with a coarse breccia variant at the point immediately west of Coal-mine Bay (GR. 291902), can be followed for some distance westwards of this last locality, at first in a large anticlinal slump structure visible in a shore platform (see p. 45: also fig. 23) and then at the base of the cliff to GR. 286899. At GR. 291902 the breccia variant appears to be a lens which has been pushed into alternating sandstones (including some thicker ones) and siltstones, folding the latter about the former. It also overlies contorted thinly bedded strata. To the west (GR. 289902), in the anticlinal slump structure the grit conformably overlies thinly bedded strata but further westwards (e.g. GR. 287900) it rests on similar sediments which are severely contorted and disturbed. At GR. 286899, though the contact is obscured by vegetation this bed 'cuts-out' abruptly, with a fault-like contact, against contorted thinly bedded strata. A few yards southwest of the last locality the stratigraphic position occupied by this grit is taken by a very calcareous fine-grained, tuffaceous grit 20+ ft. in thickness which can be followed southwards to GR. 287892, about 200 yards north of Tyndalls Beach, where it lenses out and overlies contorted, thinly bedded strata which are faulted against more massive strata. These two beds are clearly distinguishable from each other, (the first can be considered a typical Grit of the Parnell type, the second is a finer grained more calcareous type - v. Chapter 8). It is impossible to
follow strata stratigraphically above these two beds continuously across the break between them at GR.286899. The relationship between these two beds is ascribed to penecontemporaneous slumping - the topic of the next chapter.

A very distinctive grit horizon conformably interbedded with alternating sandstones and siltstones and consisting of two well-marked layers (the lower of which is coarse with large 'floaters' of sediment and contains many andesite lapilli with some larger fragments; the upper is fine grained and tuffaceous) occurs some 50 ft., stratigraphically above the thick grit exposed east of Coal-mine Bay (v. Co14).

Where this bed first appears (GR.315910) west of Army Bay it is approximately 8 feet in thickness but westwards it thins, the lower layer ultimately disappearing and at GR.301906 the upper layer (when viewed from more than 40 feet away) is indistinguishable from the normal Waitemata sandstones. With some confidence this bed can be correlated with one of closely comparable lithologic character seen in the cliffs on the western side of Okoromai Bay (f. fig.103) and which varies in thickness from 10 ft. at GR.322887 to 4 feet at GR.322895 (v.Co1.12). It is tempting to correlate this bed with a grit bed 2½ ft. thick in which lapilli-grade fragments predominate, and which is extensively exposed in the shore platform about the north of Kotanui (v. Co1.10) as well as with the 4 foot band of grit recorded by Fox (1902) from 30 feet above the base of the cliffs opposite this island (v.Co1.11) but which is no longer visible though rounded pebbles of grit lie in the shore platform in this vicinity (e.g. GR.880295).

The stratigraphic succession in the area east of Army and Okoromai Bays is difficult to elucidate. To the east of Army Bay between GRs.331912 and 332916 a well graded, distinctive greyish weathering grit, approximately 30 feet thick is prominent in the cliffs (fig.90). This bed is conformably interbedded with alternating sandstones and siltstones though locally there is the appearance of an unconformity a short distance below it (v. p.165). To the south it is in fault contact with similar sediments while to the north it disappears at the top of the cliff. A few yards to the north its position at the top of the cliff is taken by a highly calcareous, buff-coloured and cavernous weathering fine grained tuffaceous grit, 35 ft. thick, which, forming a prominent dip slope can be followed eastwards to GR.338920. The geological relationship between these two beds is reminiscent of that between the two grit beds of comparable lithology and thicknesses outcropping between Coal-mine Bay and Tyndall's Beach. In the vicinity of GR.333919 east of Army Bay a grit of the coarse gnared greyish-weathering type is extensively exposed in the shore platform and appears to be stratigraphically below the fine grained calcareous type of grit prominent at the top of the cliff. Though confirmation of this is difficult because strata in this general area have been severely affected by penecontemporaneous slumping, the writer is in broad agreement with Ferrar's (1934) comment that between 50 and 100 feet of
strata separate these two beds (v. Col. 2).

It is interesting to note that at GR. 340921 almost three-quarters of a mile west of Huaroa Point a very coarse breccia is associated with, but not necessarily an integral part of, the fine grained, tuffaceous and more calcereous type of grit while at other localities (e.g. GRs. 340921, 291902, 338925) it is associated with beds more comparable with the Parnell Grit (sensu stricto).

Unfortunately the relationship between the sequences exposed east and west of Army Bay (Cols. 2 and 4) is hidden by a boat ramp at GR. 329909.

On the grounds of lithological similarity and comparable thicknesses it is tempting to correlate those grit beds exposed east and west of Coal-mine Bay with those east of Army Bay. Likewise it is tempting to correlate the finer grained, calcereous and tuffaceous grit beds north of Tyndalls Beach and east of Army Bay. There is one serious difficulty in that if this were so, then a thick calcereous fine grained grit should be visible in the cliffs somewhere between GRs. 299906 and 320910. That it is not, may be the result of penecontemporaneous slumping but there is no evidence over this stretch of the coast-line of disruption that could account for the absence of a grit y' bed 25-35 feet in thickness. Perhaps the bed seen immediately east of Coal-mine Bay is at a different stratigraphic level to those beds of comparable lithology west of Coal-mine Bay and east of Army Bay.

Well graded grey-blue weathering grit beds up to 35 ft. in thickness are present in northeast trending reefs at Whangaparaoa Head and a short distance to the north as well as in the shore platform at Huaroa Point and in a number of reefs offshore in this general vicinity. At Whangaparaoa Head the grit bed occurs near the base of an approximately 300 foot sequence of alternating sandstones and siltstones which have been involved in penecontemporaneous slumping (v. p. 40). The relationship of these exposures to those east of Army Bay between GRs. 331912 and 347918 is not known but because of widespread penecontemporaneous slumping over this area repetition (and/or omission) of strata is highly probable, though it cannot be proven.

It is impossible to correlate any of the previously mentioned grit beds and one exposed as a lensoid body south of Huaroa Point (fig. 88) with those caught up in slumped strata at Tarihunga and in the foreshore on the western side of Hobbs Bay, though admittedly there is some similarity in thickness and lithology between the grit beds at Tarihunga and those seen at Kotanui and on the western side of Okoromai Bay.

Summarising, it would seem there are at least three grit beds intercalated with the Waiatemata sandstones and siltstones of Whangaparaoa Peninsula but in all probability there are a number more.
THICKNESS OF THE WAI TEMATA GROUP:

Because of the impracticability of synthesizing the stratigraphic succession it is impossible to determine the total thickness of Waitemata strata exposed about Whangaparaoa Peninsula. Col. 4 shows a total thickness in excess of 400 feet and comparable thicknesses are suggested elsewhere, (e.g. Whangaparaoa Head and to the south, Col. 3).

A minimum thickness of over 1,300 feet is given by recent drilling to a depth of c.1250 ft. below sea level near Red Beach (v.N38/575) which, on lithological and microfaunal evidence, did not pass out of Waitemata beds.

AGE OF WAI TEMATA SEDIMENTS:

During field work for this study no attempt was made to collect material for microfaunal dating. Previous collections from near Coal-mine Bay (N38/505 and 508) have yielded Paeora assemblages while N38/506 is taken to be Otaian, and 25 chains east of Crewa bridge (GR.220912) a lower Paeora (Po-h) age is indicated (v.N38/513). More recently, samples taken from a deep bore hole near Red Beach (N38/575 A,B,D,E) have proven to be Waitakian - Otaian.

Further strong evidence for an Otaian age is the presence of the hermatypic corals Leptastrea cf. transversa Klunzinger and Cyphastrea cf. C. chaldidum Forskaal together with an octocoral, Graphularea longissima Squires, in the breccia phase of the grit at GR.340921 (v.N38/577). These fossils have been reported previously from fossiliferous beds of the Manukau Breccia at Kaijara and Hokianga (e.g. Squires, 1958) once taken to be Altonian but now accepted on microfaunal evidence to be Otaian (Hornibrook and Scott, in Squires, 1962). An Otaian age for sediments of the Waitemata Group elsewhere in the Auckland Province has been reported on a number of occasions (e.g. Brothers, 1959; Hornibrook, 1959; Hornibrook and Schofield, 1963; and Kear, 1961).

STRUCTURE:

Viewed broadly, the structure of the rocks studied is simple. Over most of the area strata are sub-horizontal (e.g. fig. 5), or dip gently yet persistantly at very low angles (usually less than five degrees and seldom more than eight degrees) in a predominantly westerly direction (v. Sheet I, in pocket at rear). Steeper dips are commonly associated with slumped strata, or where of restricted extent, with faults (e.g. fig. 7c).

Fig. 7a. Caves like this are commonly developed along faults. This intraformational fault has a displacement of less than 18".

Fig. 7b. Small intraformational faults in slumped sediments at GR 3559906.

Fig. 7c. Prominent fault at GR 306906 down throw to the west, 25 ft.
Fig. 8  Fault Rose. Only more prominent faults have been recorded; syndepositional faults have been ignored. 88 measurements
Fig. 9. Striking keystone faults in the cliffs a little east of Orewa bridge. (GR 220912).
Fig. 10  Observed and inferred major faults.
Faults: Numerous faults are visible in the cliffs and shore platform about Whangaparaoa Peninsula. At the foot of cliffs caves are commonly developed along faults (fig.7a).

Three classes of faults can be recognised.

i) Numerous, very minor intraformational faults, affecting strata over a maximum thickness of a few feet, having displacements of up to three or four inches, and commonly dying out within the basal part of thicker turbidites. These (v. p.62), and closely related faults having displacements seldom exceeding two feet which affect the soles of grit beds (fig.91) are considered to be syndepositional and will not be considered in this section.

ii) Intraformational faults affecting several to tens of feet of strata before they die out and having displacements varying from a few inches to a few feet, and across which beds can be matched with ease (e.g. fig.7a and b). Faults of this type dip at angles varying from less than 45 degrees to vertical; most are normal but reverse faults are not uncommon.

iii) Major faults with displacements of several tens or even hundreds of feet across which beds can only sometimes be matched with any confidence (e.g. fig.7c) and which, when their fault plane is visible, are predominantly steeply dipping and normal.

Origin and Orientation of Faulting: In constructing the rose diagram (fig.8) faults included in (i) above have been ignored; likewise faults and glide surfaces (or thrusts) within slumped strata have not been recorded. The pronounced ENE-WSW trend of faulting shown in fig.8 compares with that of the strike of folds in slumped strata at Tarihunge and east of Army Bay (v. figs.24 a, b). This is unlikely to be coincidental and is suggestive that some of the faulting at least was associated with slumping. However, because of Whangaparaao Peninsula's E-W orientation, and because most faults were recognised in cliff sections, the fault rose may be biased to an unknown extent.

In associating some intraformational faulting with penecontemporaneous slumping it is interesting to note that striking keystone faults (fig.9) to be seen in the cliffs 25 chains east of Cressa bridge are in the lateral underformed equivalent of the slumped strata illustrated in figs.16a and 16b (also fig.17).

Not all intraformational faults are necessarily associated with slumping, for fig.8 shows two other preferred trends (NNW-SSE and WNW-ENE). Many may have originated in shaking or settling responses to earthquake shocks as suggested by Ballance (1964b), or shocks associated with contemporaneous volcanism, others may
Fig. 11a. Diagrammatic section across Whangaparaoa Passage showing fault interpretation of the relationship between the Waitemata beds of Tiritiri Matangi and Huaora Point. (Not to scale).

Fig. 11b. Alternative to a (above) involving rapid onlap of Waitemata sediments over the greywacke basement.
reflect consolidation processes in an accumulating pile of sediment while some may well be of tectonic origin.

It is thought that the inferred and observed major faults (v. fig. 10) are of tectonic origin, though because of its absence about Whangaparaoa Peninsula they cannot be demonstrated to have affected the 'greywacke' basement and some of these faults may well be intraformational and of slump origin as above. It can be noted that the trends of these faults are comparable with the NWW-SSE and ENE-WSW trending faults blocking out the Hunua Ranges to the south of Auckland (e.g. Firth, 1930 Laws, 1931).

Evidence for a major fault (the Tiri Fault) hidden by Whangaparaoa Passage is circumstantial.

i) Throughout the area Waitomata beds are largely sub-horizontal yet basal beds present at Tiritiri Matangi are not seen about Whangaparaoa Peninsula.

ii) Similarly the greywacke basement is only exposed at Tiritiri Matangi. It is not seen at Huaroa Point 2½ miles to the east and was not reached at a depth of 1200 feet in a bore hole near Red Beach (N38/575).

As there is no evidence of a very abrupt lateral facies change the writer is lead to postulate a major fault hidden by Whangaparaoa Passage. If, as seems reasonable, this fault can be related to those of the Hunua area, it trends NWW-SSE, being upthrown to the east as shown in fig. 11a. Admittedly the alternative situation involving considerable onlap of Waitomata sediments over the greywacke basement could exist (fig. 11b) but this amount of regional relief is not known elsewhere.

The Silverdale and Okura faults have been recognised previously though not extended as far east as in fig. 10 (v. e.g. Ballance, 1965; p. 5). Mr. B. C. Waterhouse of the N.Z.G.S. (pers. con.) has inferred from bore hole evidence near Silverdale that the former fault is down thrown to the north approximately 300 feet, however, stratigraphic evidence of the present writer (displacement of a 35-45 ft. slumped horizon) suggests that where this fault reaches the coast (GR. 230921) it is upthrown to the south at least 125 feet (v. sheet 2). The two views are difficult to reconcile unless there has been considerable scissors movement, though Waterhouse (pers. con.) allows that the fault he records could trend more to the north reaching the coast near Orewa Bridge (not shown on fig. 10). Borehole evidence (v. N38/525) suggests the Orewa fault is down thrown to the north at least 1000 feet.
Evidence for displacement of approximately 30 feet on the Kotanui fault is circumstantial. Fox (1902) reported a thin grit band 30 feet above the base of the cliffs opposite Kotanui; this can no longer be seen, but a seemingly identical grit bed is exposed at low tide in the shore platform about the north of this island.

Major faults have little topographic expression. A few valleys may be fault aligned (e.g. fault 1) and there is some alignment of coastal features across the peninsula from its northern to its southern side, (e.g. Kotanui fault and fault 2). The postulated Tiri fault may be topographically expressed in the Whangaparaoa Passage.

CONCLUSIONS:

On the accompanying geological map (sheet 1, in pocket) outcrops of the grit beds have been generalised. No attempt has been made to indicate the extent of outcrop away from the shore platform and cliffs, for the grits and other locally distinctive strata can rarely be traced inland where exposures (in road cuttings and streams) are few and poor.

The writer is inclined to the belief of others (e.g. Ferrar 1934), that the Parnell Grits (sensu lato) are restricted to a limited interval of the Waitemata sequence and that locally (as about Whangaparaoa) they can be used as a broad marker horizon. If this is so, it is very tempting to speculate on the existence of one great slump sheet that extends from West of Red Beach to Huaora Point. The fact that immediately south of Whangaparaoa Head slumped strata are overlain by a calcareous tuffaceous (gritty) sandstone, and that a similar situation exists at Tarihunga (Col.6) and further that a bed of comparable lithology outcropping near the mouth of the Weiti estuary GR.248958 is probably stratigraphically above disturbed, thinly bedded strata, poorly exposed a short distance upstream helps this speculation. In the next chapter instances of slumped strata are described in detail and arguments for the above speculation further developed.

In addition to the cyclic alternation of sandstone (typically turbidite) and siltstone, it was apparent in the field and is also apparent in the detailed stratigraphic columns (v. Sheet 3) that a broader pattern of cyclic sedimentation is imposed upon the Waitemata beds studied. Viz. Thick sequences of thinly bedded alternating sandstones (typically laminites and t coarse sandstones) and siltstones tend to separate other thick sequences, in which thicker, often composite bedded turbidites alternate with thin siltstones (e.g. fig. 3). The significance of this is not fully understood but a tentative explanation is given on p.136.
CHAPTER III

INTRAFORMATIONAL DEFORMATION - PENECONTemporaneous Slumping

As was noted in the previous chapter, the attitude of bedding over most of the area is sub-horizontal, but locally as was observed by early geologists (e.g. Hochstetter, 1864; Park, 1887; Turner and Bartrum, 1929; Ferrar, 1934), and usually in the vicinity of grit beds, strata may be intensely and intricately deformed.

Consideration of the following points shows why deformation is ascribed to penecontemporaneous slumping involving downslope movement of poorly consolidated sediments rather than the tectonic deformation of consolidated ones.

1) Although intense deformation may involve a few feet, a few tens of feet, or even hundreds of feet of strata it is often of a local nature and the affected beds can be traced laterally over a short distance into undeformed strata.

2) The deformed horizon whether involving a few or hundreds of feet is commonly both underlain and overlain by sub-horizontal undeformed strata.

3) There is never evidence of a stratigraphic (or paleontologic) break above or below the deformed strata.

4) The presence of welded contacts between deformed and adjacent undeformed strata.

5) Welded contacts between books of deformed strata within slump sheets.

6) The intricate and intense nature of folding and disruption with a general absence of fracturing and shearing indicates that sediment was poorly consolidated - plastic rather than rigid - when deformation took place.

7) Structures similar to what Kuenen (1950) has called 'slump balls' can be seen in the shore platform at a few places.

8) The disordered and highly irregular style of deformation - it is chaotic.

9) Tensational and compressional directions may correspond to each other or vary considerably in any deformed horizon. There may also be evidence of sudden change from one regime to the other over very short distances.

Two orders of magnitude, can be recognised in this penecontemporaneous deformation.

a. Small scale - where deformation has been restricted to a maximum of a few feet of strata.
Fig. 12. Small scale deformation west of Arkles Bay. A narrow zone of intricately folded, thinly bedded alternating sandstones and siltstones is overlain and underlain by regularly bedded sub-horizontal strata. Note the slightly irregular base of the turbidite immediately overlying the slumped horizon. (GR 264859).

Figs. 13a - e. Illustrate deformation in a slumped horizon c 6 ft thick exposed in the base of the cliff east of Little Manly. (eastwards from GR 283864).

Fig. 13a. This tight recumbent fold is evidence of the highly plastic nature of the sediments during deformation. Note that the slumped horizon is overlain and underlain by sub-horizontal strata. Suggested direction of movement, left to right (N.W. to S.E.).
Fig. 13b. Dyke-like apophyses extending from the immediately overlying turbidite into the slumped horizon. As in Fig. 13b below, it is clear that much sediment 'flowed' during deformation.

Fig. 13c. Tightly overturned fold with one limb torn off. 'Flow' of sediment in an extremely plastic state is obvious.
Figs. 13d and e. (closer view). These imbricated small 'packets' or 'books' of strata illustrate that folding is not the only style of deformation present in thin slump sheets. The packets have been thrust into and over each other with little disruption other than at their margins.

A comparison of 'd' and 'e' with 'a' illustrates the difficulty of determining the sense of movement in slumped horizons. In 'a' movement from left to right (i.e. from N.W. to S.E.); in 'd' and 'e' movement from right to left (i.e. from east to west) yet the two localities are less than 150 yards apart.
b) Large scale - usually associated with grit beds and where considerable thicknesses of strata (measurable in tens or even hundreds of feet) are deformed.

A. SMALL SCALE DEFORMATION

At a number of localities deformation has involved strata through thicknesses of a few feet. A good example can be seen at the base of the cliff immediately west of Arkles Bay where a number of thinly bedded alternating sandstones and siltstones are intensely deformed through a thickness of c. 2 ft. (fig. 12), although beds above and below this horizon have not been affected. Traced laterally for 30-40 yards this complexly folded horizon passes into beds in which deformation becomes progressively less intense and ultimately into an undeformed and conformable sequence of approximately equal thickness.

An even more striking example occurs near the foot of the cliffs a short distance east of Little Manly. Here, a number of thicker sandstones, together with thinly bedded sandstones and siltstones have been intensely deformed through a thickness of six to eight feet (figs. 13a - e). Deformation varies in style from gentle undulatory folds to tight recumbent ones (fig. 13a), sometimes with a limb torn apart (fig. 13c). Deformation also takes the form of an imbricate series of 'books' or small packets of otherwise undeformed strata thrust into and over each other (figs. 13d-e). Here too, strata immediately above and below are sub-horizontal and have not been deformed. This horizon can be followed for about 300 yds. to the east after which it dies out.

In the above figured examples, the intensity of folding, coupled with lack of shearing and fracturing, indicates the extreme plasticity, verging on fluidity of some sediment during deformation. Many beds have kept their individuality (e.g. fig. 13a) but it also is clear that often mud, silt, or thixotropic mixtures of mud, silt and/or dilatant sands have flowed, or been squeezed into their present position (figs. 13b-c).

In the first of the above two examples (i.e. west of Arkles Bay) the deformed strata are overlain by a few inches of thinly bedded sandstones and siltstones which are followed by a sequence of thicker sandstones. The base of the lowermost of these thicker sandstones is wavey (fig. 12) and together with the thinly bedded sandstones and siltstones fills in minor irregularities at the top of the deformed horizon.
In the second example (east of Little Manly) the slumped horizon is similarly overlain by a sequence of thinly bedded strata followed by thicker beds (fig. 13d). Locally, however, it is followed directly by a thick sandstone filling in irregularities at the top of the slumped horizon, and from which dyke-like apophyses extend into the deformed strata (fig. 13b).

In both the above examples it is possible that slumping was of the open cast type and that "...sediment slid over a surface of decollement..." as suggested by Ballance (1964b) for a similarly deformed horizon in the Takapuna Section. Following movement, irregularities in the sea floor were partially obliterated by accumulating minor silt and sand layers, until the sea floor was smoothed by the deposit from a turbidity current. Such an argument is not fully acceptable for the example illustrated in fig. 13b for it demands, that where dyke-like apophyses extend from the overlying turbidite into the deformed horizon, voids with overhanging walls persisted for some time after deformation took place. In view of the high plasticity, if not fluidity of these sediments during deformation this is unlikely.

Deformation could have been induced as a response to the frictional drag of a turbidity current which deposited the overlying thick sandstone. However, it is difficult to accept that a current depositing a bed only one or two feet thick would have had sufficient energy to deform two feet let alone eight feet of accumulating sediment. Further turbidity currents depositing beds of greater thickness have not caused deformation.

A more reasonable explanation for both examples is that the deformed horizons represent glide zones between two relatively moving sheets which were themselves not deformed in any way. Movement may have been a response to rapidly accumulating sediment overloading depositional slopes, or to earthquakes or shocks associated with contemporaneous volcanism. However, it is more likely to have accompanied the tilting of the sea floor invoked to account for large scale deformation.

Only two examples of small scale deformation have been figured but there are other examples, similar in style and magnitude about the peninsula.

Convolute bedding, a characteristic feature of the turbidite rhythm is an intrastratal phenomenon of depositional origin - it is not a slump effect - and will not be considered in this section.

Direction of movement: Even when it is assumed that the axes of folds in these slumped horizons lie transverse to the direction of movement, and that sense is indicated by overturning (Ten Haaft, 1959; Weller, 1969), it is extremely difficult to assess this direction with any certainty. In the above instances, stikes of fold axes
Fig. 14. In the slump sheet at Tarihunga thick massive sandstones (turbidites) and a prominent thin bed of grit have been tightly folded.

Fig. 15. A very tight fold involving the same grit bed illustrated above. The grit bed has been folded back on itself and the overlying beds have been squeezed out of the core of the fold. Coarse rubble can be followed about the nose of this fold with no sign of rupture - clearly the beds must have been very plastic when slumping occurred.
Fig. 16a. The slump sheet west of Red Beach has involved mostly thinly bedded strata. At GR 910225 it abuts sub-horizontal, undeformed strata. The break cannot be traced into the underlying beds.

Fig. 16b. The sharp transition from the chaos of the slump sheet to the underlying undeformed strata is better shown in this photograph. Note the thinly bedded strata separating slumped material from thick massive turbidites. (Figure top left, gives scale).
Fig. 17  Diagrammatic view of the cliff section west of Red Beach showing part of the thick slump sheet resting non-deformed strata. Note the abrupt fault-like break between disrupted and non-deformed strata, and the narrow zone of deformation to the west thought to have originated when a crack, which appeared as a great sheet of strata moved bodily to the east was infilled from above.

(Drawn from photographs - v.figs.16a and b - field sketches and notes; not to scale, approximate maximum height of cliff 70ft., thickness of slump sheet c.40ft.)
Fig. 18 Simplified stratigraphic columns showing the slumped horizons at the following localities. 
(1) Weiti Estuary
(2) Tarihenga
(3) Red Beach
(4) Stanmore Bay

Scale

[10 ft]
[5 ft]
[0 ft]
(roughly NE-SW) and overturning suggest movement from a northwesterly quarter, however, there is evidence of movement in the opposite direction (cf. fig. 13a with figs. 13d and e)

B. LARGE SCALE DEFORMATION

For the next 9 pages, instances of large scale slumping in the following two areas are described in detail.

a) From Tarihunga westwards to near Red Beach.

b) Eastwards from Tyndall's Beach.

There is some repetition of information given in the previous chapter and the reader, if he wishes, may proceed directly to a discussion of the cause of slumping, as well as comments on the style of deformation (p. 47).

a) Tarihunga and to the west

i) Tarihunga. A slump sheet* varying in thickness from 30-45 ft, is exposed in the cliffs about this promontory. Immediately west of Manly it rests upon a sequence of thick composite bedded sandstones. To the north it is overlain sub-horizontally by a coarse calcareous and tuffaceous sandstone 1-9 ft. thick which is followed by a sequence of thinly bedded strata (Col. 6). On the eastern side of Tarihunga largely thinner beds are involved in slumping but at CR, 266887 a small lens of lapilli grit is also incorporated in this sheet. On the western side of Tarihunga (e.g. CR, 262886) tightly folded alternating thick sandstones and thin siltstones are incorporated in the slump sheet (fig. 14). These probably include some of the beds immediately underlying the slump sheet on the eastern side of the promontory. A well graded grit (v. fig. 15) three to four feet thick with a coarse rubble base and which is conformably overlain by at least 30 ft. of alternating sandstone is also included in the slumped strata at this locality.

The intensity of folding accompanied by lack of shearing or fracture is clearly illustrated in fig. 15. Here the grit bed has been folded back on itself and the beds immediately overlying it have been squeezed out of the core of the fold and the appearance is given of a single bed with coarse rubble concentrated at its base and its top.

* Slump sheet: This almost self explanatory term includes bodies of slumped strata of varying thicknesses which are underlain and/or overlain by undeformed and commonly sub-horizontal strata. Slump packets are masses of undeformed strata caught up in slump sheets.
ii) West of Red Beach. A similar slump sheet of c.40ft. involving thinly bedded sandstones and siltstones with occasional thicker sandstone beds (turbidites) but lacking lenses of grit, is exposed in the cliffs for a short distance west of Red Beach (between GRs. 227909 and 225910). The upper surface of this slump sheet was not clearly distinguishable but it is thought to be overlain by sub-horizontal strata. As at Tarihunga, this slump sheet rests on a sequence of thick sandstones and thin siltstones (figs. 16a-b). The slumped strata abut against regularly bedded sub-horizontal strata in a small cliffed amphitheatre at GR. 225910 where there appears to be a fault contact between slumped and non-slumped strata, yet the underlying thicker beds have not been disrupted and can be followed beneath the break without interruption (figs. 16b and 17).

This striking exposure was first figured by Park (1887 p. 227) and described by him as an "...instructive example of how overlying strata may be folded and plicated without disturbing underlying beds of a more rigid character..."

It is impossible to follow individual beds across the break between slumped strata and their non-deformed equivalents. Fifteen chains to the west there is a narrow zone of intense deformation (v.fig. 17) in these beds and further west (GR. 220912) there is an occurrence of keystone faulting (figs. 9 and 17).

iii) Stanmore Bay. Towards the centre of this beach (GR. 251385) a small area of intensely deformed and disrupted strata is exposed at low tide. It is separated by a few yards of sand from a low bank near the bottom of which similar disturbed beds are visible. This slump sheet has a minimum thickness of 40 ft. Its base and the underlying beds cannot be seen. To the northwest it is overlain by gently dipping strata.

iv) Weiti Estuary. Because of mangrove swamps and mudflats, exposures are poor, of limited extent and difficult of access northwest from the wharf (GR. 246862) on the eastern bank of the estuary. Where seen sediments, consisting mostly of thinly bedded strata, are horizontally disposed or dip at very low angles. Twenty chains northwest of the wharf they are thrown into a series of shallow NNE striking folds. A calcareous 'gritty' sandstone poorly exposed immediately south of the wharf possibly overlies this slump horizon (v.fig. 18).
Correlation: The difficulty of correlating stratigraphic columns taken at even closely spaced intervals in the Waitemata Group of Whangaparaoa Peninsula was stressed in the previous chapter. However, when one considers the following points:

i) Close spatial relationship between these horizons in an area of gently dipping strata.

ii) Thicknesses of the slumped horizons where determined are closely comparable.

iii) The stratigraphic succession at the above localities are broadly similar (fig.18).

It seems reasonable to assume that the deformed strata at the above four localities are part of the one slump sheet, or separate slumps at approximately the same horizon within the Waitemata Formation.

b) In the eastern parts of the peninsula

i) East of Army and Okoroomai Bays. The intensity of folding and disruption of strata east of Army Bay has been commented upon by Hochstetter (1964) and others (e.g. Ferrar, 1934). In the shore platform immediately east of the beach at Army Bay alternating sandstones and siltstones roll about in a series of shallow anticlines and synclines. Further west at Huaroa Point and near GR.352918 tight scrolls similar to Kuenen's (1950) slump balls are etched in the shore platform (fig.19). In other instances large packets of sediment have been pushed into and over each other with little deformation, other than at their margins (cf. fig.13d but on a greater scale). In accordance with their idea of tectonism being the cause of deformation, Turner and Bartram (1929) called the glide surfaces separating packets of strata, thrusts.

At Whangaparaoa Head at least 300ft, of steeply dipping and locally overturned strata are exposed in the cliff face (fig.20), in the shore platform and in a reef extending to the NNE. Near the base of this sequence there is a well graded grit bed. Immediately south of this headland the steeply dipping sequence merges with a large recumbent fold (figs.21a-b and fig.22) which can be followed southwards in the cliff for about half a mile. In the strata involved in this great fold there are numerous instances of minor intraformational faults (e.g. figs.6 and 29), boudinage-like structures (fig.30) and other evidence of stretching (fig.31).
Fig. 19. Tight scrolls similar to Kuenen's (1950) slump balls etched in the shore platform at Huaroa Point. (GR 352918).

Fig. 20. Steeply dipping and locally overturned strata at Whangaparaoa Head. Here slumping has involved a minimum of 300 feet of strata. (GR 356910).
Figs. 21a (upper) and b (lower). Two views of a large recumbent fold which can be followed for some distance south of Whangararoa Head. (GR. 355907).
Fig. 22. Slump fold south of Whangaparaoa Head overlain by gently dipping massive sandstones. This part of the same great fold illustrated in Figs. 21a - b. (GR 354905).
Fig. 23. Anticlinal-like outcrop of a resistant grit in the shore platform West of Coal-mine Bay. Numerous small faults and clastic dykes can be traced to the base of the grit. Note the conformable relationship between the grit and underlying strata except to the left.
(View looking north).
Although instances of intense deformation are common in this eastern area they are of local occurrence and there are extensive stretches of regularly bedded, little deformed strata (fig. 134). In general thicker grit beds exposed over this area give the appearance of having been rafts, against which normal Wintemata beds have piled up or folded.

On the available evidence it is the writer's opinion that the disturbed strata of this area are part of one great slump sheet.

The thickness of this slump sheet is difficult to assess but at Whangaparaoa Head at least 300 ft. of strata is involved. To the south of this locality it is overlain by thick massive sandstones dipping gently to the west and immediately east of Te Haruhi Bay the undeformed lateral equivalents of this sequence are in fault contact with, but stratigraphically below a 75 ft. sequence of predominantly thick massive sandstones (Col. 3).

The base of this slump sheet is never seen with certainty. At GR. 329:910 it is possibly 'thrust' over the sequence exposed westwards from Araroa Bay (Col. 4), although the relationship may well be a faulted one. A boat ramp at this locality obscures the contact.

ii) Along the northern coast from Tyndalls Beach to Coal-mine Bay. A brief description has already been made of the grit beds in this area (p. 16). It will be recalled that in general they rest on contorted and disrupted thinly bedded strata, but that locally (e.g. fig. 23) a conformable relationship may exist, while at GR. 291902 alternating sandstones and siltstones are folded about a lens of coarse grit that appears to have been thrust into its present position.

About G.R. 289902 a well graded grit, and conformably underlying strata have been bent into a large northerly plunging anticlinal-like structure (fig. 23). The westward continuation of this bed at the base of the cliff to GR. 286899 is separated from the 'anticline' by a thin sliver of highly contorted, thinly bedded sandstones and siltstones. At GR. 286899 there is a break of a few yards occupied by similarly contorted thinly bedded strata, between two grit beds of different character, but occupying the same level with the cliff; to the east a bed comparable with the Parnell Grit (sensu stricto), to the west and south a finer grained, more calcareous type of grit bed which can be
Fig. 24  Fine grained silty Waitemata beds resting unconformably on the basal member of the Waitemata Group, which is a greywacke conglomerate, at the northern part of Tiritiri Matangi. The greywacke basement is very irregular having a relief of 60 ft.
(Drawn from field sketch, CR.396923; approximate height of section 70ft.)
followed to within two hundred yards of Tyndalls Beach. In the strata above the break between the distinctive grit beds (GR.286899) there is no evidence of disruption - sub-horizontal strata can be followed continuously across it. Elsewhere (p.17), it was suggested that the more calcareous fine grained grit may be stratigraphically above the coarser grained one of the Pernell Grit type. Penetcontemporaneous slumping adequately accounts for the irregular and disordered deformation over the area westwards from Coal-mine Bay.

iii) Hobbs Bay. There is a small exposure of slumped sediments in the shore platform and low cliffs on the western side of Hobbs Bay at GR.302886. Here slumping has involved mainly thinly bedded sediments though as in the three previously described areas a grit bed has also been involved.

iv) Tiritiri Matangi. About the north of Tiritiri Matangi, the basal member of the Waiterana Group is a conglomerate which is overlain abruptly and conformably by a sequence of sub-horizontal, silty sandstones and siltstones (v.p.13). However, at GR.396922 similar silty sandstones rest with a sharp angular discordance upon a horizontally bedded conglomerate (fig.24). A welded contact exists between the conglomerate and the dipping beds. As a distance of only a few chains separates localities where the silty sandstones rest conformably on the conglomerate, from the locality where an unconformable relationship exists, and as the top of the conglomerate is at approximately a constant height within the cliffs, deformation is ascribed to penetcontemporaneous slumping.

C. DISCUSSION: THE CAUSE AND STYLE OF DEFORMATION

Large scale deformation such as seen to the east of Amy Bay was believed by Turner and Bertram (1929) to be of tectonic origin, the result of thrusting from the southwest; the lensoid grits "...acted as obstructive masses against which more yielding beds have been piled up in folds...". Earlier, Hochstetter (1864) suggested that the deformation in this same area was associated with "...an eruptive rock, that penetrating between the sandstones... has torn and broken them assunder and by lateral pressure to the west has displaced them from their original horizontal position."
Likewise, Park (1910) considered the section illustrated in figs. 16a-b and 17 was a "...peculiar dynamical effect of faulting combined with lateral thrust caused by local volcanic action..."

Deformation of strata, similar in magnitude to that referred to as small scale was interpreted by Turner and Bartum (1929) as probably being caused by "...subaqueous gliding of delta-beds...when growth has caused over-loading...

Similarly, Ferrar (1934) suggested that intraformational unconformities in Waitemata beds north of the present study may be "...explained by subaqueous gliding, possibly induced by earthquakes of the mid-Waitematang volcanism." However, slumping on a larger scale in Waitemata sediments was not recognised until (Kuenen's 1950) comments upon structures he observed at Titirangi and Milford.

Kuenen (1950) cited evidence from these two localities similar to that given on p. 31. In suggesting an alternative to a tectonic interpretation, he considered it was unlikely that the effects of tectonic thrusting could have been transmitted through poorly unconsolidated sediments in such a fashion, that deformation could be localised to the extent it is. He further considered it improbable "...that a thin sheet of poorly consolidated sandstones was pushed over beds of the same composition without any internal deformation..."

It is commonly accepted, that in the marine environment under suitable conditions, slumping may occur in beds having depositional slopes of as little as 3 degrees (Fairbridge, 1946). This view is not fully supported, for unconsolidated recent sediments in beds up to a meter thick have been reported as being stable on slopes of 18 degrees (Moore, 1961). The Waitemata beds of Whangaparaoa Peninsula belong to a turbidite facies and are thought to have been deposited near the axial parts of an elongated basin of moderate depth. In such an environment depositional slopes would be minimal (e.g. Moore, 1961) and even the sudden emplacement (by submarine volcanic mud-flow) of a grit bed and consequent overloading is unlikely to have initiated gravity sliding (slumping) as envisaged by Brothers (1954b).

The impression is given at some localities (e.g. about 3/4 mile west of Huaeroa Point and immediately west of Coal-mine Bay) that mud-flows came to rest by ploughing into the sea floor, rucking up poorly consolidated sediments and turning them aside in a series of folds. Hopgood (1961) considered this situation existed at Mahurangi, 8 miles to the north. This impression cannot be substantiated, for while it is possible that denser phases of mud-flows (those depositing coarse breccias) may have had sufficient momentum forcibly to disrupt accumulating sediment for a short distance below the sea floor it is inconceivable that any great thickness could have been involved. It is also inconceivable that the fine grained silty (or tuffaceous) upper parts of grit beds (those which must have taken some time to settle after
Fig. 125 Strikes of fold hinges in slump sheets at:

a. West of Red Beach
b. About Tarihunga
c. From Army Bay to south of Whangaparaoa Head.

Suggested direction of movement
Fig. 26. Disrupted blocks of sandstone which have been rotated during slumping. Up dip from this photograph disruption and rotation of the blocks becomes progressively less and they pass into a thick sandstone bed which is well jointed.
Fig. 27. Closer view of Fig. 26 illustrating that thinly bedded sandstones (laminites and tractive sandstones) and siltstones have been crushed during rotation of the blocks. Note the crudely laminated nature of the sandstone block.
deposition of coarser phases) were ever sufficiently coherent during this period forcibly to thrust into and disrupt any great thickness of consolidating sediment causing folding of the style and magnitude illustrated in the frontispiece. The fact that field evidence often shows grit beds to have been emplaced in stages \( p, 177 \) is further indication that deformation in the manner suggested by Hopgood was unlikely.

Locally the frictional drag and over-riding movement of a mud-flow may have caused disruption and folding (e.g. Chappell, 1963) - certainly minor faults (including drag thrusts) affecting the bases of some grit beds are synsedimentary but otherwise evidence is very strong that intense deformation occurred sometime after deposition of a grit bed. An excellent example of this time lapse is the presence in the slump sheet at Tarihunga of a well graded grit, conformably interbedded with normal Waitemata beds and folded with them (e.g. fig.14). Similarly at Whangaparaoa Head a thick well graded grit, conformably interbedded with normal Waitemata strata, is near the base of a slumped sequence at least 300 ft. in thickness. In both instances there is no evidence of a thick grit, of the Parnell type higher in the stratigraphic succession.

Axes of folds in slumped deposits are generally conceded to lie transverse to the direction of movement (Ten Haaf, 1957; Weller, 1960) but there can be wide divergences from this (Waterhouse and Bradley, 1957). The sense of movement is given by asymmetric, overturned and dragged-out folds, torn-off limbs of folds, small faults, drag effects, etc. Strikes of numerous fold axes were measured in exposures west of Red Beach, about Tarihunga and to the east of Army and Okotromai Bays. These are plotted radially in fig.25(a-c respectively). The patterns from the last two localities are broadly consistent and suggest movement either to or from a north-westerly quarter. Overturning of folds, etc. suggests (though not consistently) movement from northwest to southeast.

It is notoriously difficult to assess the sense of movement in slumped strata (Ten Haaf, 1959) and this well illustrated about Whangaparaoa Peninsula where within distances of a few yards evidence may be contradictory. An example of this in a thin slumped horizon has already been cited \( v, p, 33 \). A further excellent example, and in passing, of slump deformation is found about three quarters of a mile west of Huaora Point (immediately west of the 'horse' illustrated in fig.114). Here a 2 ft. bed of crudely laminated sandstone has been broken into a number of blocks which have been drawn apart and rotated during slumping (fig.26 and 27). Up dip from the photographs, the blocks become progressively less widely spaced, are not rotated to the same extent and pass into a jointed sandstone. In fig.27 it can be seen that thinly bedded sandstones and siltstones above and below this bed
(a) Slumping into the fault angle from the west with the most intense deformation being at the bottom of the slope

(b) Slumping into the depression from both east and west

Figs. 28 a and b. Diagrammatic representations of the large scale slumping. (after Waterhouse and Bradley, 1957).

Not to scale.

--- indicates direction of movement, shaded parts are grit beds
have been crushed as the blocks rotated. Following the arguments of Waterhouse and Bradley the overlying beds, and hence the slump sheet as a whole moved from left to right (i.e. westwards). Nearby there is equally strong evidence for movement in the opposite direction. Conceivably, in a large slump sheet although the bulk of the movement could have been eastwards, locally, beds may have been held against some resistant stratum (e.g. a grit bed) so that underlying beds moved eastwards (to the left) more rapidly than those above.

In many instances it is difficult to suggest a direction of movement with any confidence (e.g. frontispiece).

Because of earlier mentioned difficulties -

i) doubt being cast on mud flows ever having been sufficiently coherent to severely disrupt any great thickness of strata,

ii) well graded grits are conformably interbedded with normal Waitemata beds in slumpcd strata at some localities,

iii) gradients of depositional slopes were probably minimal, and

iv) considering the evidence of Moore (1961) that unconsolidated sediments can be stable on depositional slopes of 18 degrees -

the writer cannot accept the views that slumping of the magnitude observed could have been initiated by mud-flows gouging into the seafloor (e.g. Hopgood, 1961) or by the frictional drag exerted by mud-flows as they passed across the sea floor (e.g. Chappell, 1963). Likewise, despite a close correspondence of the easterly - southeasterly facing paleoslope (v. Chap.6). with the inferred direction of slumping he finds it difficult to accept fully Brothers (1954) suggestion that slumping was a response to rapidly accumulating sediment overloading depositional slopes.

Slumping is considered to have been a response to tilting of the sea floor as has been invoked for other occurrences of slumping (v.e.g. Natland and Kuenen, 1951; Waterhouse and Bradley, 1957; Grant-Mackie and Lowry, 1965). Tilting is envisaged as having accompanied early movements on the postulated Tiri Fault - possibly tectonic spasms heralding the onset of the Kaikoura Orogeny.

Following tilting, a great sheet of poorly consolidated sediment (now extending from at least a short distance east of the Orewa Bridge, to Whangaparaoa Head and possibly Tiritiri Matangi) became unstable and slid down slope into the fault angle (fig.28a). Although there is some evidence to the contrary the sense of movement seems to have been predominantly eastwards. A certain amount of movement to the west, off the rising block may have occurred (e.g. fig.28b).
Sections of such a large slump sheet would probably move independently of each other, some coming to rest after moving but a short distance and being little deformed, other sections may have been drawn apart so that later, when coming together their margins were severely crumpled to give local areas of intense deformation. Tension cracks may have developed in this sliding mass, and before they could close, sediment fell into them from above - this could account for the unusual, narrow zone of intense deformation in otherwise undisturbed strata a short distance east of Orewa Bridge (fig.17).

Up slope, small thicknesses of less consolidated sediments were involved, stresses were not great and deformation was predominately of a plastic nature. Towards the bottom of the slope maximum thicknesses of strata were involved, deformation was more intense, great packets slid over each other with little deformation, other than at their margins. These packets are now separated by planar and curved or slightly irregular surfaces - what Turner and Bertram (1929) termed 'thrusts' but which are better thought of as 'glide' surfaces. Thin beds of grit were deformed in the same style as the beds with which they were interbedded. Thicker beds of grit were torn apart in the early stages of slumping to give lensoid bodies. Later as the moving mass of sediment came to rest these largely maintained a horizontal attitude and acted as rigid bodies against which more yielding sediments were piled.

East of Army Bay and south of Whangaparaoa Head where maximum thicknesses of strata were involved in slumping as well as deformation of a plastic nature, there is ample evidence of yielding by rupture. This is well illustrated by -

i) displacement occurring along numerous mesoscopic faults (fig.29);

ii) the development of boudinage-like structures (fig.30) and other evidence of tension (e.g. fig.31);

iii) development in thicker sandstones of coarse, subparallel joint systems along which there may or may not be displacement;

iv) an incipient cleavage (closely spaced mesoscopic fractures resembling the cleavage of more indurated rocks) is frequently developed in thin siltstones or silty sandstones. This feature is comparable, if not identical to what Crook (1964) has called 'reticulate cleavage' and;

v) numerous obscure lineations and wrinkles developed in beds and on bedding planes about the hinges of some folds and lying roughly parallel to fold axes.
Fig. 29. Mesoscopic faults in the laminated interval of a turbidite involved in the large slump fold south of Whangaparaoa Head.

Fig. 30. Boudinage-like structures in slumped beds south of Whangaparaoa Head.
(Hammer gives scale)

Fig. 31. Mesoscopic faults in disrupted and strata south of Whangaparaoa Head.
(Length of penknife 2½").
The above features resemble closely those described from tectonically deformed strata, yet, from the previous evidence, their limited extent and absence in undeformed strata they are undoubtedly a response to penecontemporaneous slumping - not tectonism. Some comparison can be made to the style of deformation associated with gravity tectonism - the difference is only one of magnitude. In the rocks studied the development of these structures is an indication that towards the bottom of the slope where the greatest thicknesses of strata were involved in slumping, the intensity of deformation was greatest and that the sediments were better consolidated. Upslope where thicknesses of strata involved in slumping was not as great this style of deformation was of less significance.

One can now comprehend why evidence on direction of movement in slumped sheets is often anomalous or contradictory. Slumping was neither regular nor ordered, differential movement within a slump sheet, differences in the degree of consolidation and in the thickness of strata involved and variations in the stresses to which they were subjected caused deformation to occur in a number of styles. What must have initially been a tensile regime changed to a compressional one as moving masses of sediment came to rest, and at the bottom of the slope there was probably rapid vacillation between the two as it piled up and fell back on itself.

D. CLASTIC (SEDIMENTARY OR NEPTUNIAN) DYKES

Although not strictly a slumping phenomenon, clastic dykes are conveniently discussed in this chapter for the two are associated in the rocks studied.

Clastic dykes are not common. All those seen were associated with slumped strata, the greatest number being found penetrating beds immediately below the grit bed illustrated in fig. 23. These lacked any persistent orientation; some could be followed for distances in excess of 75 yards with little variation in thickness which averages about 6 in.; they were of uniform lithology - 'gritty' and calcareous; most could be traced to the base of the grit bed but they are always finer grained than its basal parts; like the grit bed to which they could be traced they were more resistant than the strata which they penetrate.

A few finer grained clastic dykes penetrate strata above this grit bed and some of these can be traced into its upper parts.

As these clastic dykes, although intimately associated with slumped strata, are never complexly disrupted their emplacement did not pre-date slumping. More probably they were emplaced after the first great surge of slumping or during its final
stages as the sheet came to rest. At that time a few tensional fissures may have opened and fine grained 'gritty' sediment, mobilised by water being forced out of the thick grit bed, could have flowed into them. Slight displacements of some dykes (e.g. fig. 32) could have resulted from further minor slump movements or movements associated with later settling and compactional processes.

The persistent and intimate association of clastic dykes and slumped sediments in the area a short distance west of Coal-mine Bay, together with the fact that they were never seen in undisturbed strata make it improbable that their emplacement was a response to settling and compactional processes alone.

While the above dykes appear to have flowed into pre-existing fissures (e.g. fig. 32), there is evidence about a mile south of Whangaparaoa Head of one forcibly injected, disrupting, turning aside, and down-buckling adjacent strata (fig. 33). Emplacement here is also thought to have been associated with slump movements in the overlying strata which include a 4ft, band of intensely deformed thinly bedded sandstones and siltstones (just visible at the top of fig. 33) which is overlain by a massive fine grained, tuffaceous (gritty) and calcareous sandstone.
Fig. 34  Comparison of generalised Turbidite rhythm as recognised at Whangaparaoa with those described Bouma and Ballance.