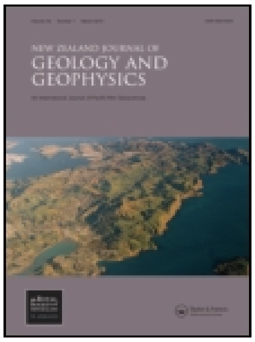

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Michael F. Ridd

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SUCCESSION AND STRUCTURAL INTERPRETATION OF THE WHANGARA–WAIMATA AREA, GISBORNE, NEW ZEALAND

MICHAEL F. RIDD

BP Shell and Todd Petroleum Development Limited, Gisborne*

With coloured geological map (Fig. 8) in pocket inside back cover

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ABSTRACT

In the Whangara–Waimata area, there are over 25,000 ft of geosynclinal Tertiary rocks: pale grey, streaky, calcareous mudstone and bentonite in the Lower Tertiary, and predominantly medium grey mudstone, siltstone, sandstone, and turbidites in the Upper Tertiary. The Upper Cretaceous is represented only by occasional fault-involved slivers of argillite and by blocks of *Inoceramus*-bearing, impure limestone. A break in deposition at the base of the Miocene and a local unconformity at the base of the Pliocene have been recognised.

Post-Miocene to early Pliocene, sinistral, north-east–south-west transcurrent faults and southward-directed thrusts have been proved. They are believed to be the surface expression of sinistral transcurrent faults in the Cretaceous "basement", the bentonitic Lower Tertiary having acted as a zone of décollement.

INTRODUCTION

The 200-square-mile Whangara–Waimata area lies to the north of Gisborne and covers the northern half of NZMS 1 (1 inch to 1 mile) Sheet N98 between the Waipaoa River and the Pacific Ocean and the southern halves of subsheets N89/8 and N89/9 (Fig. 1).

Whereas the Lower Tertiary rocks of the inliers produce low-lying country, Upper Tertiary rocks give rise to hills up to 1,600 ft high. Except the Waipaoa River, which occupies a Pleistocene syncline, streams are actively downcutting and many meanders incised; waterfalls in the upper reaches are common, and hills are steep-sided and prone to slip. Access to the area is good; tar-sealed state highways run north-west from Gisborne and up the coast, and no point in the area is more than 5 miles from a metalled road.

The area was mapped in 1962 in the course of a survey for BP Shell and Todd Petroleum Development Limited. Field data were plotted directly on to aerial photographs having a scale of approximately 4 inches to 1 mile.

PREVIOUS WORK

The Whangara–Waimata area has received varying degrees of attention from oil companies attracted to the East Coast by its oil and gas seepages, and from the New Zealand Geological Survey (Henderson and Ongley, 1920).

*Present address: c/o BP Exploration Co. Ltd., BP House, Ropemaker Street, London E.C. 2, England.

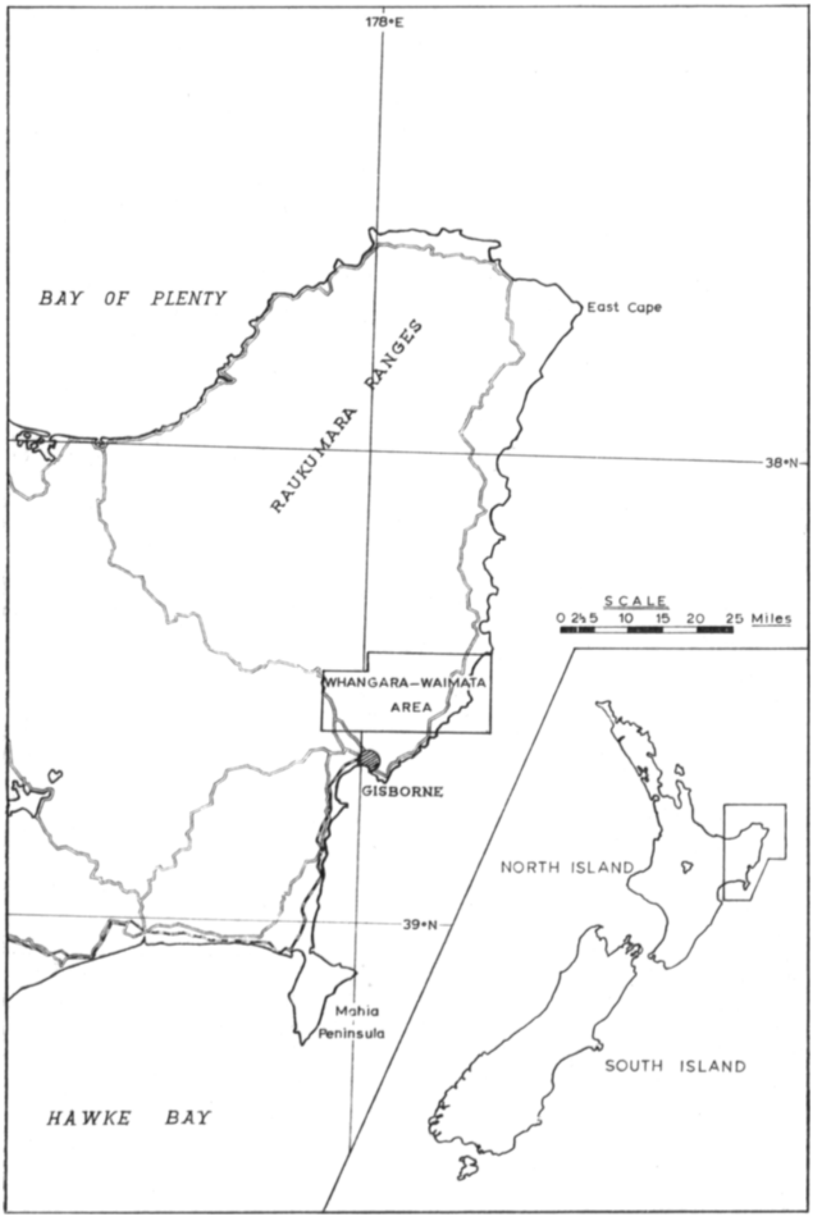


FIG. 1—Location map of the Whangara–Waimata area.

Correction: The lines of latitude on this map should be marked "38° S" and "39° S".

Wanner (1911) was one of the first to note the east–west structural connection between the Whangara and Waimata Inliers.* More detailed reports by Whitney and Miller on the western and eastern halves of the Waimata Inlier respectively are contained in the general report by Clapp (1925). Whitney and Miller noted the east–west trend of the structure and the steepening of dips towards its faulted axis.

Steineke (1933) produced a good 1 inch to 1 mile map of the whole Whangara–Waimata area and accounted for the presence of the inliers by a combination of thrusting and diapirism.

Jones (1940) produced a 4 inches to 1 mile map of the Waimata Inlier. He disregarded the abundant evidence of faulting and, like Macpherson (1946), who had worked extensively on other East Coast structures, Jones postulated a growing east–west anticlinal fold, over which each of his Tertiary formations was deposited unconformably.

The Whangara and Waimata Inliers were considered by both Vacuum Oil Company and New Zealand Petroleum Company too complex to warrant drilling. The only hole in the area was that drilled at Waihirere in 1911–12 by New Zealand Oilfields Limited. It is reported by Henderson and Ongley (1920) to have reached a depth of 1,380 ft, but no log of the well is known.

Stoneley (1962) mapped the Lower Tertiary inlier immediately to the south of the Whangara–Waimata area. The juxtaposition of an area of subsidence in Upper Tertiary rocks with the bentonitic Lower Tertiary inlier led him to believe that the inlier was the result of diapirism, associated with gravitational sliding of Upper Tertiary rocks from the south-east. This paper proposes an alternative interpretation of what is broadly a similar structure to that described by Stoneley.

STRATIGRAPHY

Lateral variation and lack of persistent marker beds make detailed lithological mapping impossible. Subdivision of successions of lithologically uniform strata was by means of a zonal scheme devised by Jenkins (BP Shell and Todd, unpublished) based on evolutionary series of pelagic Foraminifera, and over 700 micropaleontological age determinations were made in the company's laboratory at Gisborne. Jenkins's faunal zones are only the approximate equivalent of the New Zealand Series and Stages, which are in turn only approximately equivalent to the International Time Scale adopted throughout this paper (Eames *et al.*, 1962).

A generalised stratigraphic column is given in Fig. 2. In the Whangara–Waimata area, 25,000 ft of rocks are exposed, ranging in age from Late Cretaceous to Quaternary. The thickness of the Upper Cretaceous and Paleocene–Eocene (Dannevirke) is quite unknown and is not included in this figure. The rocks are, with the exception of the Quaternary, geosynclinal sediments deposited in shelf and deep-water environments.

*For descriptive purposes the Whangara Inlier is considered to be the area of Lower Tertiary rocks bounded to the west by Thrusts II and III and the Waimata Inlier to be the area of Lower Tertiary rocks bounded to the south by Thrust IV (Fig. 8).

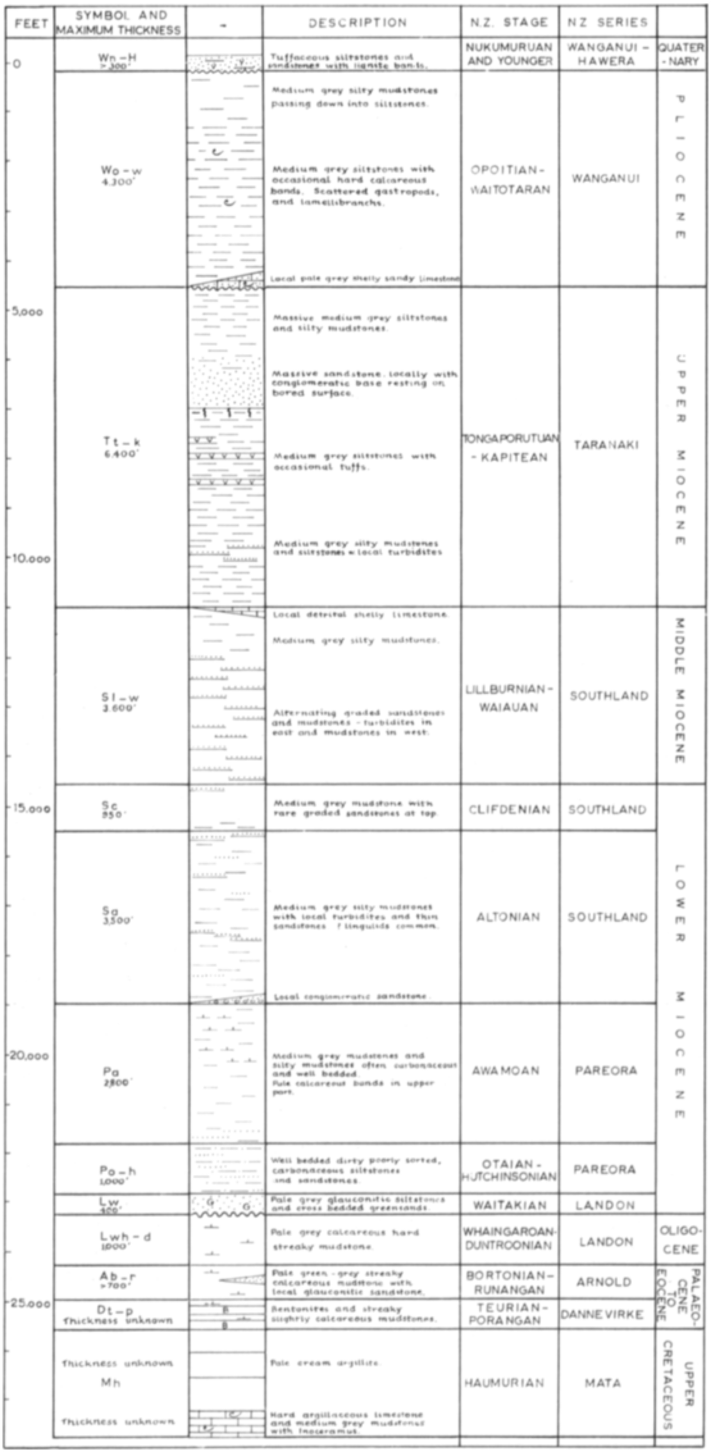


FIG. 2—Generalised stratigraphic column for the Whangara–Waimata area

Upper Cretaceous

Rocks of the Late Cretaceous age occur as fault slivers within the eastern end of the Whangara Inlier and as exotic boulders associated with Dannevirke and Arnold bentonites and mudstones.

The road-metal quarries on the Tolaga Bay Road and the Panikau Road provide the best exposures of Upper Cretaceous rocks in the area. These have been identified as Mata (Haumurian) and are pale-grey-cream, rusty-weathering, very sheared and crumbly, siliceous mudstones or argillites. Neither top nor base of the Haumurian has been seen and its thickness is unknown. These argillites lack macrofossils but usually have a good microfauna. They probably represent a deep-water facies.

Boulders up to 5 ft in diameter yielding fragments and whole specimens of *Inoceramus* have been identified as Mata (Haumurian). These occur, in some places in profusion, in the area of the Whangara and Waimata Inliers, associated with Dannevirke and Arnold bentonites and mudstones (Fig. 3). These *Inoceramus*-bearing boulders are usually very hard, argillaceous limestone, but soft, medium grey mudstone with *Inoceramus* and a boulder of partly silicified argillaceous limestone with *Inoceramus* and a coral have also been found. These are all believed to be shallow-water deposits.

FIG. 3—Boulders of Haumurian *Inoceramus*-bearing argillaceous limestone, associated with reconstituted Lower Tertiary bentonites and mudstones, about 3 miles north of Whangara. Saline springs and gas seepages also occur here. (N98/3 Grid Ref. 598539).

Lower Tertiary

The Lower Tertiary consists mainly of pale, calcareous, streaky mudstone, green and blue-grey in the Dannevirke and Arnold and pale grey in the Whaingaroan–Duntroonian. In the Waipawan to Heretaungan Stages of the Dannevirke, grey, green, and maroon bentonites occur. Unweathered bentonite is highly fractured and slickensided, often tectonically drawn out and streaked, and has obviously undergone severe deformation in the dry state (Fig. 4). A 20 to 30 ft impersistent bed of very fine-grained slightly glauconitic sandstone occurs within the Arnold streaky mudstone of the Whangara Inlier. In the Arnold of the Waihirere Inlier, a 15 ft bed of medium grey, slightly silty mudstone occurs; the medium grey "Upper Tertiary" appearance of this bed is unique in the Lower Tertiary of the Whangara–Waimata area.

Although the streaky mudstone of the Dannevirke is a consolidated rock, outcrops are nowhere extensive and it typically occurs as blocks within chaotic slips of bentonite and mud with exotic boulders. Because of its mode of occurrence, its thickness and relations are unknown. A minimum of 700 ft of overturned Arnold beds is present in one of the south-flowing streams on the Waimata Inlier; elsewhere the Arnold, like the Dannevirke, is too contorted to measure. Whaingaroan–Duntroonian rocks are confined to the Whangara Inlier, where there is an estimated maximum thickness of 1,000 ft of very uniform streaky mudstone, giving rise to a characteristic, low, rounded-hill topography.

The pale, streaky mudstones of the Lower Tertiary succession are difficult to allocate to a particular depositional environment. Their calcareous content, usually high in the Whaingaroan–Duntroonian, suggests deposition in shallow, warm seas. However, their vertical and lateral extent and uniformity, their association in the Dannevirke with bentonite, the absence of macrofossils, and the occasional graded bands with flute casts in the Dannevirke and Arnold, place them on balance in a deep-water facies.

Upper Tertiary

After the predominantly pale, calcareous, streaky mudstone sedimentation of the Lower Tertiary, a fundamental change of sedimentary regime occurred. The Waitakian consists of greensand, and medium grey detrital rocks dominate the Otaian and younger succession, owing probably to uplift and rapid erosion of the Raukumara greywacke mountain range.

In the Whangara–Waimata area, there was local vertical movement after deposition of the Whaingaroan. On the eroded and somewhat irregular surface that resulted, Lower Miocene sedimentation began. The shallow-water basal facies is represented by the Waitakian greensands. This was overlapped in places by the Otaian–Hutchinsonian (Fig. 5).

Whangara Island provides the best exposures of *Waitakian*. At low tide about 100 ft of finely glauconitic, pale grey siltstone can be seen to overlie Whaingaroan–Duntroonian streaky mudstone. This in turn is overlain by up to 400 ft of coarse-textured, very glauconitic, calcareous sandstone with

FIG. 4—Highly contorted Dannevirke bentonite and mudstone with "augen" of ?Dannevirke redeposited sandstone, Waiomoko River, near Whangara. (N98/6 Grid Ref. 585483.)

abundant large benthonic Foraminifera, bryozoan fragments, and worm tubes. Thin pseudo-conglomerate bands are common. Much of the coarser material is cross-bedded in units up to 3 ft thick. Wherever the Waitakian is exposed in the Whangara–Waimata area it consists of similar, easily recognisable, glauconitic sandstone and very finely glauconitic siltstone.

A basal Southland disconformity has previously been thought to account for the apparent widespread absence of the Pareora Series over much of the East Coast of the North Island (Fleming, 1959). Such a disconformity has been proved in some localities in the Gisborne district, but in the Whangara–Waimata area there is no hiatus and over 4,000 ft of Pareora is present.

The *Otaian–Hutchinsonian* of the coast south of Whangara Island is typical of the Whangara–Waimata area. Here 1,800 ft of well bedded, poorly sorted, carbonaceous, slightly glauconitic, dirty sandstone and siltstone occur. Intraformational contortion of the sandstone beds is common,

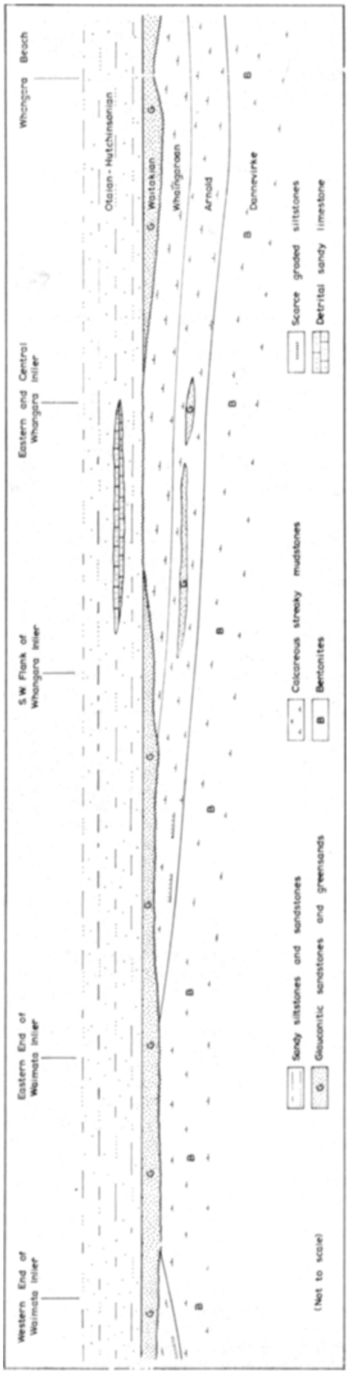


FIG. 5—Diagram showing the stratigraphic relationship of the Miocene and Lower Tertiary in the Whangara–Waimata area.

although graded bedding as seen higher in the succession is absent. These characteristics were usually constant enough for an Otaian–Hutchinsonian determination to be made in the field.

Right-bank tributaries of the Waiomoko River, draining the south-west flank of the Whangara Inlier, provide the best exposures of *Awamoan*. Here, although complicated by overturning, is a succession of medium grey, fairly well bedded, slightly carbonaceous, silty mudstones. Many thin siltstone beds occur, and in the upper part paler, calcareous, siltstone bands and lenses up to 6 in. thick are common. Sandstones are frequent near the base, and in the Whangara coastal section the basal Awamoan sandstones are graded. A maximum thickness of 2,800 ft is estimated for this stage on the south-west flank of the Whangara Inlier. No lithological lateral variations or thickness changes have been observed.

The *Altonian* varies lithologically and thickens westwards across the Whangara and Waimata Inliers. The coastal section south of Gable End Foreland exposes 1,340 ft of beds, but the base was not seen. The total thickness of Altonian here is about 2,000 ft. Medium grey mudstone, silty mudstone, and thin beds of siltstone, with 4-in. sandstone bands in the lower part, are overlain by 120 ft of alternating mudstone and redeposited sandstone. Elsewhere, the sequence of rock types varies. Redeposited beds occur at the base and in the middle of the succession on the south-west flank of the Whangara Inlier, where the Altonian is well exposed in right-bank tributaries of the Waiomoko River. Although the sequence is complicated by the Waiomoko Fault, 2,200 ft is estimated to occur here. In the upper tributaries of the Waiomoko River, more than 3,500 ft of similar silty mudstone, siltstone, subordinate sandstone, and redeposited beds occur. Restricted to east of Seymour Road and between Thrusts III and IV there is a prominent feature-forming basal Altonian sandstone. It is up to 500 ft thick, massive, fine-grained, slightly glauconitic, and with conglomerate bands. The top is transitional to the overlying siltstone. Although this bed indicates local shallow-water conditions, neither here nor elsewhere in the Whangara–Waimata area is there evidence of a break in sedimentation before the Altonian. Characteristic of, and apparently restricted to, the Altonian throughout the Whangara–Waimate area are "nests" and streaks of poorly preserved, flattened, oval casts half an inch long. They lack detailed structure but have the shape of elongate lingulid brachiopods.

The *Clifdenian* is represented by medium grey, unbedded, deep-water mudstone with rare bands of redeposited sandstone at top and base. Where best developed, in the Gable End Syncline and along the south-west flank of the Whangara Inlier, it has a thickness of 950 ft. However, in the Waimata Inlier the Clifdenian is apparently very thin or absent, and the few localities where it has been identified have been mapped as Clifdenian to Waiauan. There is no evidence of a basal Lillburnian unconformity to account for the thinness or absence of this Stage.

Like the preceding stages of the Southland, the *Lillburnian–Waiauan* is best exposed along the coast to the north and south of Gable End Foreland. Here, 1,700 ft of redeposited sandstone with subordinate mudstone is overlain by 1,000 ft of poorly bedded silty mudstone, at the top of which is a band of very calcareous, pseudo-conglomeratic sandstone up to 33 ft thick.

A lateral change takes place north-westwards along the south-west flank of the Whangara Inlier. To the south-east and for 1½ miles north-east of the Pateika Fault the succession is the same as the above-described coastal section. However, a mile further north-west along the outcrop, where exposed in the Wharekire Stream, the Lillburnian–Waiauan is represented by deep-water medium grey mudstone, rarely with thin, finely laminated sandstone beds. Similar grey mudstone with infrequent, finely laminated sandstones forms the Upper Southland throughout the Waimata Inlier. A shallow-water facies is absent from the top of the succession on the south-west flank of the Whangara Inlier, but is locally present as a detrital, shelly limestone on the north and south flanks of the Waimata Inlier.

Flute casts in the reposited sandstone of the Gable End Foreland district indicate derivation from the east and west of north.

The *Taranaki* is divisible into two parts: these, however, are not believed to coincide with the Tongaporutuan and Kapitean Stages. The lower part is about 4,000 ft thick and consists of medium grey silty mudstone and siltstone with subordinate intervals of turbidite facies towards the top. Coarse-grained, water-laid, quartz-magnetite tuffs occur, many beds showing intraformational contortion and forming prominent topographic features. The base of the upper part is marked by massive, locally tuffaceous sandstone which forms a prominent and easily mappable feature. It is not apparent, however, on the northern flank of the Glenrôy Syncline. At some places the base of this sandstone is glauconitic and conglomeratic, with worm tubes extending down into the underlying silty mudstone, and there is evidence of a break in sedimentation. This sandstone attains its maximum thickness of at least 1,500 ft in the Titirangi Syncline and at Gable End Foreland.

Considerable earth movements took place at the close of the Taranaki, resulting in an irregular *Wanganui* sea floor. The lithology of the basal Wanganui is determined by the presence or absence of a Wanganui unconformity. Thus, in the depositional basins (which since the Pliocene have undergone further downwarping to produce the present synclines), there is no evidence of a sedimentary break between the Miocene and Pliocene, and deposition of silty mudstone and siltstone continued throughout. However, over the "highs", including the Waimata Inlier and the Horoweka structure, shallow-water, shelly, and in places conglomeratic sandstone and limestone were deposited unconformably. The unconformable contact was not seen but can be confidently inferred in a number of localities. In a right-bank tributary of the Horoweka Stream, Pliocene shelly conglomerate dipping at 29° occurs 200 yards up stream from highly sheared, vertical, Taranaki silty mudstone and tuff.

Above the locally shallow-water basal facies, the Pliocene comprises uniform, shelf-deposited, massive, silty mudstone, siltstone, and very fine-grained sandstone with occasional shell beds. At least 4,300 ft of Pliocene beds occur in the Waihora Syncline.

Quaternary

Well exposed along the Ngakaroa Road at about 300 ft above sea level are poorly consolidated ash, clay, and sand with lignite bands. A poor, probably derived, foraminiferal fauna was obtained from them, and they are probably an estuarine facies of the Quaternary. Further seaward, lying unconformably on the Wanganui at Waihirere, are calcareous, slightly shelly gravel and sand representing a shallow-water marine facies. Dips of up to 15° have been measured on these beds, which probably extend as a shallow basin beneath the Waipaoa alluvial plain.

Alluvium occurs in river valleys throughout the Whangara–Waimata area and is particularly extensive in the broad flood plain of the Waipaoa River, where it includes coarse heterogeneous gravel.

Much of the less dissected country has a blanket of ash from recent eruptions in the Taupo volcanic province.

STRUCTURAL GEOLOGY

Thrusts

A group of arcuate thrusts has been mapped, which brings Lower Tertiary rocks to the surface in the roughly east–west-aligned Whangara and Waimata Inliers. They have been numbered I to VIII in the approximate order in which they were formed (Figs. 8 and 9).

Conventional thrusting of old rocks over young occurs in Thrusts I, II, IV, and an inferred thrust shown on Section A-A′ (Fig. 9), postulated to account for the overturning in the Kohatu Stream valley. Their shatter belts are relatively narrow and they are believed to be high-angled near the ground surface. This type of thrust occurred by shearing of the lower limb of an overfold.

A second type involves thrusting of young rocks over older, which occurs in Thrusts III, V, VI, VII, and VIII. Their wide and vague shatter belts and their sinuous surface traces suggest that they are low-angled fractures. Because of the wide shatter belts, the effect of the topography on an individual thrust often cannot be mapped. No overturning of beds occurs with this type of thrust.

Fig. 6 shows the formation of both types of thrusts. After the development of an overfold with a conventional thrusted lower limb (1), a second thrust develops behind (that is to the north of) the first (2). This is mainly a bedding thrust, in which the thrust plane follows the bedding, but toward the surface, where the dip of the beds through which it is cutting exceeds the dip of the thrust plane, young beds are thrust over old. Erosion then produced the characteristic pattern of a strip of Lower Tertiary rocks fault-bounded to north and south by younger rocks (3). This process occurred twice, first when Thrusts I, II, and III produced the western and northern horns of the Whangara Inlier, and second when Thrusts IV, V, VI, VII, and VIII produced the Waimata Inlier. The second phase was complicated by the inferred conventional thrust in the Kohatu Stream area referred to previously and by additional bedding thrusts.

Thrusts I and II

These cannot be dated relative to each other but were formed before Thrust III, which truncates the north-eastern and the north-western ends of Thrusts I and II respectively.

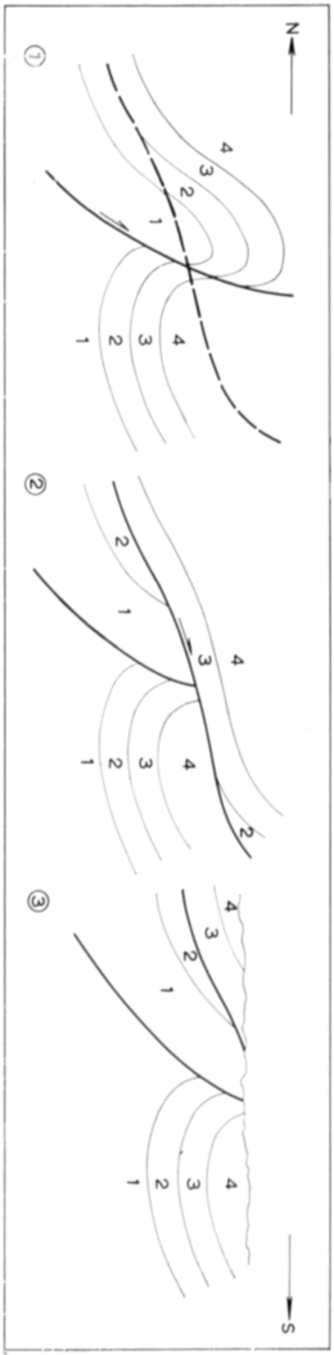


FIG. 6—Sequence of cross sections showing the formation of the Whangara and Waimata Inliers by thrusting.
(1) Conventional thrusted overfold.
(2) Young rocks thrust over previously thrusted overfold.
(3) Erosion produces inlier, thrust-bounded to the north and south.

Thrust I cannot confidently be recognised as a thrust. To its north-west there is a structureless *mélange* of Lower Tertiary rocks and subordinate Haumurian argillite. To its south-east are steeply dipping and overturned Whaingaroan and Pareora beds. Traced southwards this overturning is not evident and the structural relation of the Upper and Lower Tertiary is obscure.

Thrust II is a clearly recognisable thrust. Haumurian–Arnold rocks, where their structure can be seen, strike parallel to the thrust on its north-eastern side. Their contact with Whaingaroan and Pareora beds is high-angled and easily seen from the air and on the ground. The relation of this thrust to the north-east-trending structures at its south-east end is unknown. Its maximum displacement, between highly contorted Haumurian and Whaingaroan, is in the region of Panikau Road. North-westwards, a fault downthrowing to the north offsets to the west the northern part of the thrust.

The key to the nature of Thrust II is provided by the rocks on its south-western side. In the region of Panikau Road, as the succession is descended approaching the thrust, dips steepen to vertical. Along the strike to the north-west (Section D-D′, Fig. 9), as the thrust is approached, dips steepen, pass through a zone about half a mile in width of steep and overturned beds, and then, still descending the succession, dips are towards the north-east until the thrust is reached. This is interpreted as an overturned synclinal limb over which an overfolded anticline has been thrust. The almost structureless Lower Tertiary core of the anticline is now exposed, and all that can be seen of its north-eastern limb is a sliver of Whaingaroan projecting from beneath Thrust III. The zone of steep and overturned dips has been interpreted as crumpling in the core of the overfolded syncline. This zone of inferred crumpling continues westwards past the Wharekire Stream and the strike swings to west-south-west. Thrust II, however, disappears westwards beneath Thrusts III and V. The sliver of Dannevirke streaky mudstone on the northern end of the Waewaetapahia Fault may be bounded on its south-eastern side by the continuation of Thrust II projecting from beneath Thrust III.

Thrust III

Thrust III is ill-defined at its eastern end and its truncation by Thrust IV is inferred. It is, however, earlier than Thrust V. This is a bedding thrust, the thrust plane being within the upper part of the Awamoan or the lower part of the Altonian. Rocks of this age have been thrust southwards over Upper and Lower Tertiary exposed earlier by Thrusts I and II. Variation in throw along this fault is therefore considerable though no actual throw reversal is seen. As expected with a bedding thrust, the strike of the beds to the north parallels the thrust trace.

At its western end Thrust III reappears from beneath Thrust V and swings to the south-west to become the Waewaetapahia Fault.

Thrust IV

In the Wharekiri and Otaiwai Streams area, the relations of Thrusts IV, V, and VI can be established. Thrust IV occurred before Thrust V, which in turn occurred before Thrust VI. Its truncation by Thrust VI at its eastern end, however, is inferred. This is a conventional thrust in which old rocks have been thrust over younger. East of Kohatu Stream, synclinal Waitakian and Otaian–Hutchinsonian are thrust scuthwards over Altonian. West of Kohatu Stream the overthrust Waitakian and Lower Tertiary rocks form the southern limb of an overthrust anticline (Section B-B′, Fig. 9), and in places are overfolded. This structure is present to the east and west of the Thrust V lobe and its presence beneath this lobe can be confidently inferred.

One and a half miles west of the Thrust V lobe, Waitakian greensand is preserved in two downfaulted blocks that have displaced Thrust IV to the south. This minor faulting must have occurred after Thrust IV but before erosion had removed most of the Waitakian from the southern limb of the overthrust anticline. Half a mile east of the Arakihi Road, the relation of the Altonian to the Dannevirke and Arnold is unknown. However, Altonian here is overfolded, with a core of Awamoan. South of Thrust IV Clifdenian–Waiauan mudstones are steeply dipping and overturned. This structure is truncated to the west by the Waimata Fault. An identical thrusted overfold in Southland rocks is present to the west of the Waimata Fault (Section E-E′, Fig. 9); as will be discussed later, this is believed to be the continuation of Thrust IV, which has been displaced by sinistral transcurrent movement along the Waimata Fault.

Thrust V

In the Otaiwai and Wharekire Streams area, Altonian and Awamoan beds extend southwards as a lobe over Thrusts III and IV. The base of this thrust sheet is a wide, diffuse zone of contortion, and the thrust plane, which has been mapped, is in some places an arbitrary line within this wide contorted zone.

That this lobe is thrust and not an unconformable boundary is indicated by: (a) the intense contortion of its base; (b) the dips, which are towards the north and east and unrelated to its base; and (c) the fact that its base varies from Awamoan to near the top of the Altonian.

As this thrust lobe does not coincide with topographically high ground, the surface of the thrust plane must be quite irregular to account for its preservation from erosion. To the north, Thrust V is truncated by Thrusts VI and VIII.

Thrusts VI and VII

At the eastern end, where Thrust VI runs out to sea at Waitanguru, Taranaki rocks are thrust over Altonian, and the zone of considerable deformation, in which dips are oriented at random, is about 500 ft wide. The thrust runs in a gently sinuous line westwards, and 3½ miles from the coast is displaced by a roughly north–south fault. At its northern end this fault can be demonstrated to downthrow eastwards. The manner of the displacement of Thrust VI by this fault confirms the northward dip of its thrust plane. In the Kohatu Stream area, strongly deformed Taranaki and Southland rocks are thrust southwards, removing the northern limb of the Lower Tertiary anticline previously formed by Thrust IV west of Panikau Road.

The lobe of Taranaki rocks bounded by Thrust VI occupies high ground and the thrust plane is nearly horizontal. The northward dips in this lobe have not been satisfactorily explained.

Thrust VII affects rocks of Southland and Taranaki age and although for its entire length there is considerable contortion, nowhere does it show much displacement. At its western end it is truncated by Thrust VIII. It is believed that Thrusts VI and VII converge at depth.

Thrust VIII

Taranaki beds have been thrust southwards over Thrusts V and VII, and over the northern limb of the Lower Tertiary structure formed with Thrust IV. The Taranaki rocks exposed in the upper Waimata River valley strike north–south into the thrust. This, and the extent of contortion along the contact, preclude the possibility of this being a sedimentary contact. At its western end Thrust VIII disappears beneath the unconformable Wanganui. Local steepening of dip immediately north of the thrust may be due to slight, post-thrusting, diapiric rise of the Lower Tertiary bentonite and calcareous mudstone.

Other Thrusts

The Whangara Thrust is inferred. The coastal section south of Whangara Island shows Waitakian and Pareora rocks increasing in dip as one ascends the succession, until at the mouth of the Waiomoko River they are overturned. South of the Waiomoko River the dips are again moderate in upper Pareora and Southland beds. Although little or none of the succession may be removed by thrusting, this is at all events a southward-directed overfold, very little different from the overfolds associated with Thrusts II and IV.

The Lower Tertiary beds in the Waihirere Inlier may be the result of thrusting; they occupy a similar position regionally (though turned through 180°) to the thrusts of the Waimata Inlier.

Transcurrent Faults

The *Waimata Fault* is one of a group of rectilinear to gently arcuate north-east-trending faults including the Arakihi, Urutoranga, and Horoweka Faults. The slips that reflect the fault zone can be seen crossing the hills where the Waimata Fault leaves the Waimata River, and it is evident that this is a high-angled fracture. On the Waimata Fault sinistral transcurrent displacement of up to 1¼ miles has been established. The thrusted overfold associated with Thrust IV to the east of the Waimata Fault is identical to, and is expressed in the same rocks as, the thrust shown on Section E-E′ (Fig. 9). As well as this displacement of Thrust IV, there is displacement of the axis of the overfold, of the east–west-striking belt of steeply dipping and overturned Clifdenian–Waiauan south of the thrust, and of the base of the Taranaki. Since no displacement of the pre-Wanganui Thrust VIII can be seen, this thrust must die out westwards beneath the Wanganui before reaching the Waimata Fault. The east–west-trending fault to the west of the Waimata Fault was probably coeval with and subsequent to transcurrent movement along the Waimata Fault.

It is reasonable to believe that the following gently arcuate and rectilinear north-east-trending faults in the Whangara–Waimata area are also sinistral transcurrent.

Southwards, the Waimata Fault converges with the more north–south-trending *Mangaehu Fault* system. The shatter zone is some 200 yards wide, and although dip of the beds on either side is away from the fault, there is no apparent axial steepening. At the northern end of the Mangaehu Fault, although Wanganui rocks have not been faulted, they are gently up-arched.

The *Patukoura Fault* has a prominent shatter belt. At its northern end it disappears beneath Wanganui; and at its southern end the Wanganui is folded into an anticlinal nose, resting unconformably on steeply dipping and vertical Taranaki.

The *Horoweka Fault* is a prominent feature from the air and on the ground. It affects Wanganui beds and shows throw reversal. Southwards it bifurcates, the westerly branch curving into the Waihirere Inlier (which, as stated earlier, from regional considerations may have a thrust component), and the south-west-trending branch downthrowing upper Taranaki on the east against lower Taranaki on the west. A single, poor exposure of Dannevirke mudstone was found on the south-west-trending branch.

The *Arakihi* and *Urutaranga Faults* are strong, post-Wanganui, rectilinear structures. Their fault zones are relatively narrow (less than 50 yards) and there is no dip reversal across them.

The *Pahi* and *Waewaetapahia Faults* are broadly arcuate and separate the Waimata and Glenroy Synclines. They show little vertical displacement and there is a dip reversal or strike swing across them. The Pahi Fault is, at least in part, post-Wanganui. As described earlier, the northern end of the Waewaetapahia Fault swings eastwards into Thrust III and probably Thrust II.

The north-east-trending belt of country from Waitanguru to the *Tangimatai Fault* is the extension of Stoneley's Axial Fault (1962) and consists of poorly exposed and highly deformed rocks of Cretaceous to Southland age. The strike of the beds and the frequent shearing is generally north-east. The belt is in part bounded on the east by the well defined Pakarae Fault. The structure becomes simpler and involves younger rocks to the north. The relation of this structurally complex north-east–south-west belt of country to the approximately east–west-trending thrusts has not been established.

The *Waitotara Stream Fault* is a north-north-east-trending rectilinear feature running parallel to the Pakarae Fault. Beds on opposite sides dip asymmetrically away from the fault with the steepest dips to the east. The fault exhibits throw reversal with apparent downthrow to the west at the northern end and to the east at the southern end.

The *Gable End Fault* trends north–south. Where exposed, north of Gable End Foreland, the fault zone is less than 50 yards wide and is high-angled. On aerial photographs the fault can be traced southwards for more than a mile out to sea. Apparent downthrow is entirely to the east. A cross fault downthrowing to the west connects the Gable end and Waitotara Stream Faults.

Other Faults

On the south-west flank of the Whangara Inlier and in the Glenroy Syncline are a number of rectilinear faults. Except the Wharekire Fault, no strike swing occurs across them. Their shatter belts are up to 50 yards wide and they are probably high-angled fractures.

The *Jobson Fault* and *Wharekire Fault* are of interest. The throw on each increases eastwards, but beyond their point of convergence they die out. Seemingly the segment of Upper Tertiary rocks between them has been downfaulted, leaving the surrounding rocks of the south-west flank of the Whangara Inlier unaffected.

Mud Volcanoes

Violent eruptions of "mud" have occurred from the now extinct Mangaehu Stream mud volcano, the most recent being in 1931. The eruption of 6 May 1930 is the best documented (Strong, 1931), when material was ejected 300 ft into the air. This material, consisting of reconstituted Lower Tertiary mudstone and boulders, flowed downhill and can be seen forming the banks of the Mangaehu Stream, overlying solid though sheared Southland mudstone. This Lower Tertiary material, then, has travelled from a considerable depth and, moreover, was extruded in a sufficiently dry state to walk upon within eight hours of its extrusion. The eruption was accompanied and followed by the escape of gas and saline water.

The active gas seepages alongside the Arakihi Road coincide with an area of Lower Tertiary material presumed also to have been extruded from a mud volcano.

Both the Mangaehu Stream and Arakihi Road mud volcanoes lie on cross faults associated with the major Mangaehu and Waimata transcurrent faults, and in the former, eruptions were in periods of earthquake activity. That material was ejected to a height of 300 ft suggests that it was forcibly squeezed to the surface by deep-seated compression. The cross faults probably served as lines of weakness up which the material could escape.

The plasticity of dry Lower Tertiary rocks suggested above is also indicated by the fact that whenever bentonites occur in the solid state, that is, uncontaminated by meteoric water, they are extremely contorted. This plasticity is of great importance in considering the structural evolution of the Whangara–Waimata area.

SYNTHESIS AND SUGGESTED STRUCTURAL EVOLUTION

Tectonic activity was at its peak in post-Taranaki and early Wanganui times; and although the Waimata Fault demonstrably post-dates Thrust IV, it is believed that the transcurrent faults and thrusts are the result of the same deep-seated compression. The Waewaetapahia Fault, for example, swings eastward at its northern end to become Thrust III and probably Thrust II.

Although large bodies of Cretaceous rocks occur in the complex Waitanguru–Tangimatai transcurrent fault bed and associated with Thrust II, the Cretaceous occurs elsewhere only as exotic blocks within the bentonitic Lower Tertiary. For this reason it is believed that the Cretaceous "base-

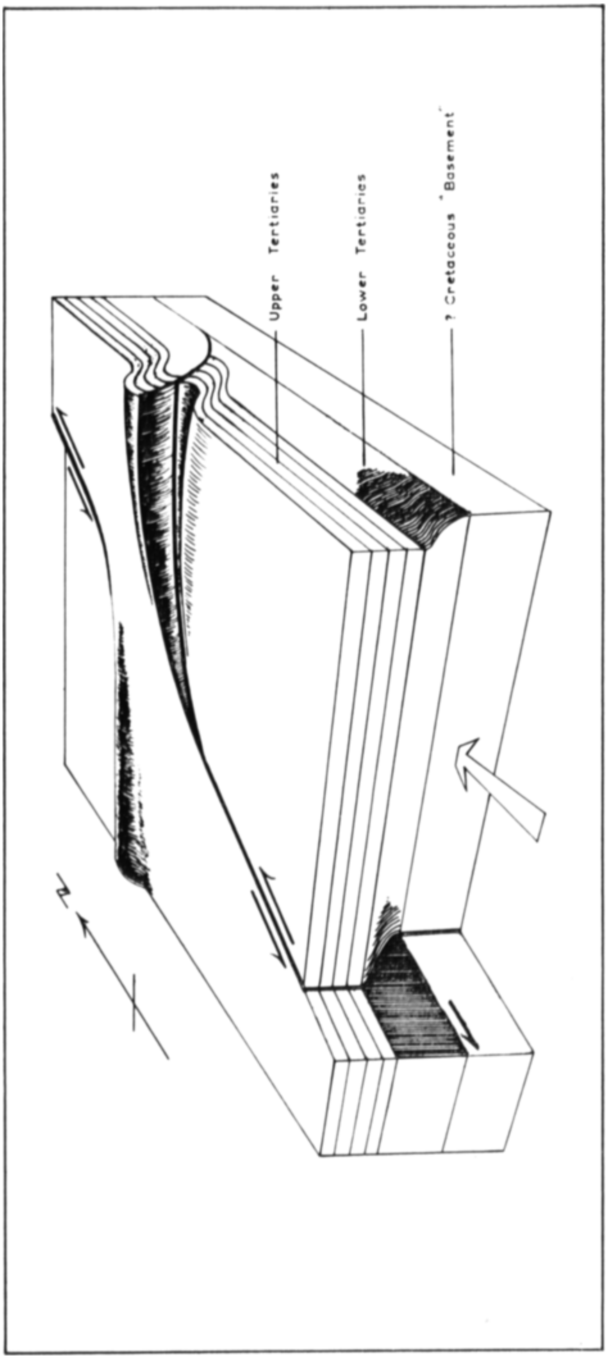
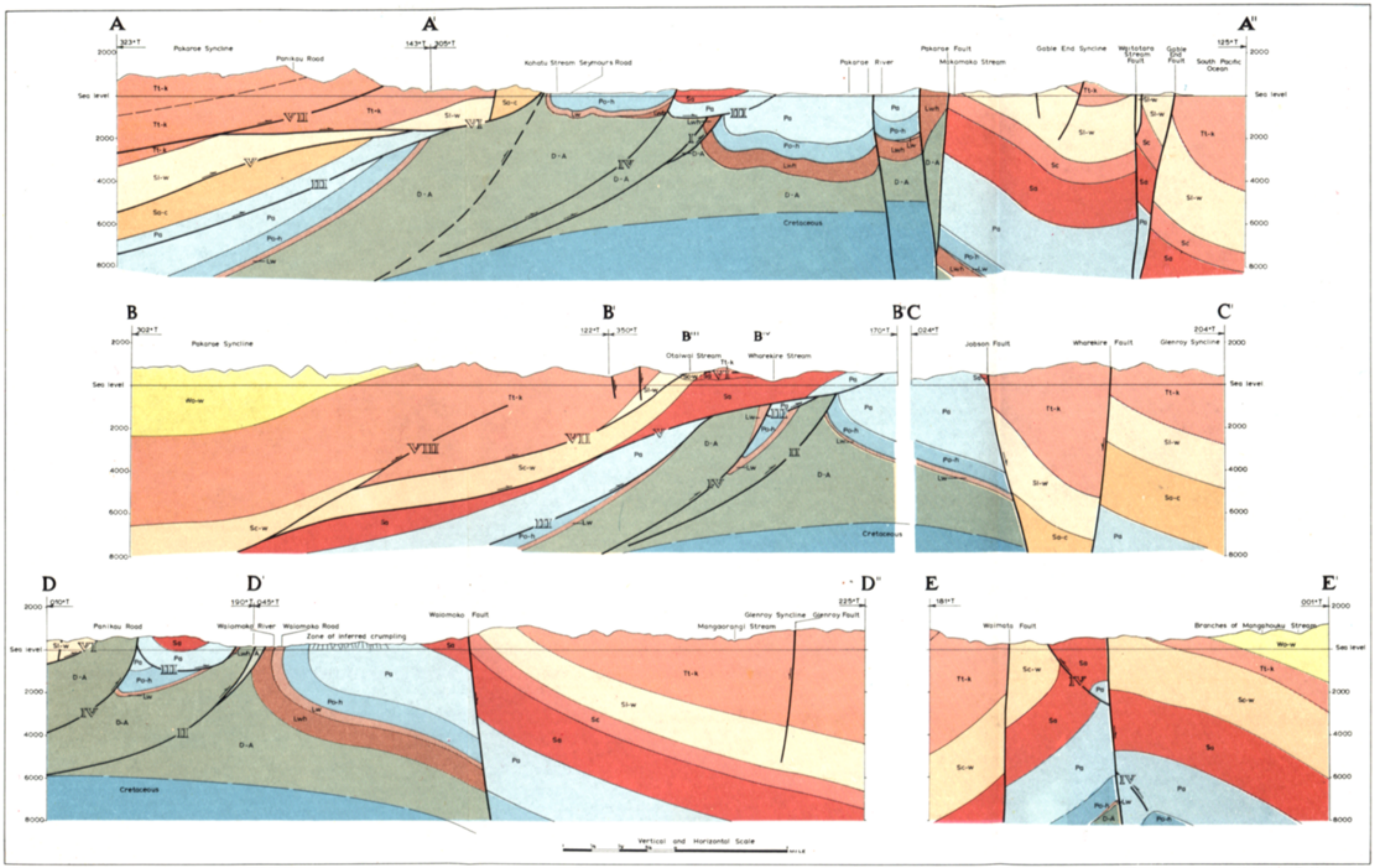


FIG. 7—Block diagram showing the relation of transcurrent faults and underthrusts in the Upper Tertiary rocks to a transcurrent fault in the Cretaceous "basement".



Drawn by BP Shell and Todd.
Colour prepared by Cartographic Section, D.S.I.R.

Fig. 9—Geological cross sections in the Whangara–Waimata area, along lines shown in Fig. 8. B'''–B'''' is half a mile east of B'–B''. For legend see Fig. 8.

ment" remains unaffected by the east–west-trending thrusts and that the plastic Lower Tertiary rocks form a zone of décollement.

Anderson's theory (1942), assuming the whole sedimentary pile to be subjected to equal tangential compression, would call for overthrusting from the south in the position of the east–west thrusts that form the Whangara and Waimata Inliers. However, it has been demonstrated that overthrusting here is from the north. This apparent anomaly can be satisfactorily explained if the thrusts are considered as underthrusts from the south. To achieve underthrusting, compression normal to the thrust line must increase with depth.

It is believed that sinistral movement along north-east–south-west transcurrent faults in the Cretaceous "basement" exerted a "drag" on the plastic Lower Tertiary. This "drag" would be greatest immediately above the Cretaceous, and least immediately beneath the Upper Tertiary. The competent Upper Tertiary responded to the underlying "drag" by north-east transcurrent faulting and by underthrusting (Fig. 7).

Theoretically, the underthrusts would be expected to trend at right angles to the transcurrent fault direction, because "drag", and therefore compression, would be greatest in the north-east–south-west direction. However, this theoretical ideal is attained only by the eastern end of Thrust II, the dominant trend of the thrusts being east–west, that is, oblique to the transcurrent faults. The anticlinal structure of some north-east–south-west-trending transcurrent faults is believed to be a secondary feature and not normal to the regional compressional field; after stress had been released by faulting, the edges of the adjacent blocks were upturned by residual compression between them.

Thrusts I to VIII were formed in approximate numerical order from south to north as the underthrusting masses of the Glenroy and Waimata Synclines advanced northward. Although the conventional thrusts (I, II, and IV) in which older rocks were thrust over younger (or rather, young rocks underthrust old) would extend down into, and probably to the base of, the Lower Tertiary, the bedding thrusts (III, V, VI, VII, and VIII) probably die out along the bedding planes within the Upper Tertiary.

The underthrusting concept may be extended to other parts of the Whangara–Waimata area. The east–west branch of the Horoweka Fault bounding the Waihirere Inlier may be due to southward underthrusting of Taranaki and Wanganui rocks beneath Lower Tertiary; the north-east-trending Thrusts I and VII may have a sinistral transcurrent element; and the seaward swing of the northern end of the Pakarae Fault may be due to its transition to an east–west underthrust. The relations of the east–west-trending Whangara Thrust are unknown.

Diapirism is thought to have played only a minor role in the structural development of the area. However, after the Lower Tertiary had been tectonically deformed, thickness variations would be considerable, and with erosion of the overlying Upper Tertiary, upwelling of the plastic Lower Tertiary may have occurred.

Although most tectonic activity took place soon after the Miocene, the continued post-Pliocene development of the synclines, indicated by dips of up to 40° in Wanganui rocks, may have been assisted by transfer of bentonitic Lower Tertiary material from beneath the synclines up into the "highs". This secondary diapiric effect may account for anomalous steepening of dip in the Upper Tertiary in some places near the thrust contact with the Lower Tertiary, and for the sinuous contact south of Thrust I, which in the field looks as if plastic Lower Tertiary had welled up and over Landon and Pareora rocks.

The nearest north-east-trending faults on which other workers have demonstrated transcurrent displacement are south of Hawke Bay, where movement has been dextral. It is appreciated that the sinistral movement on similar-trending faults described in this paper is totally at variance with this, but the fact remains that sinistral displacement has been proved on the Waimata Fault. Moreover, sinistral movement along the other north-east-trending faults in this area, many of which have little or no vertical displacement, is the only way that these structures can be reconciled with synchronous, proved, southward and south-westward-directed overthrusts.

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