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The Geology of the Tuakau-Mercer Area, Auckland

By M. H. Battey, Auckland Museum.

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Summary: An account is given of the general geology of the northern part of Lower Waikato Basin, where, in a fault-block terrain, Tertiary sediments (including coal-measures) rest on a basement of (?) Triassic-Jurassic greywackes and are themselves covered by a younger series (? Late Pliocene or Pleistocene) of pumice silts and conglomerates, capped in places by basaltic volcanics.

Evidence concerning the geological history is interpreted as indicating that the tectonic birth of the Hauraki Graben came very late in the geomorphic development of Auckland, while a modification of the generally-accepted scheme regarding the early history of Waikato River is suggested and a hypothesis of regional superposition of drainage is put forward.

Minor features such as sedimentary dykes and "chalazoidites" occur in the area described.

INTRODUCTION AND ACKNOWLEDGMENTS.

The area described in this paper comprises about 125 square miles in the basin of Lower Waikato River, and lies between the Hunua Hills earth-block and Whangamarino Swamp, extending from Tuakau in the west to Mangatangi Valley in the east.

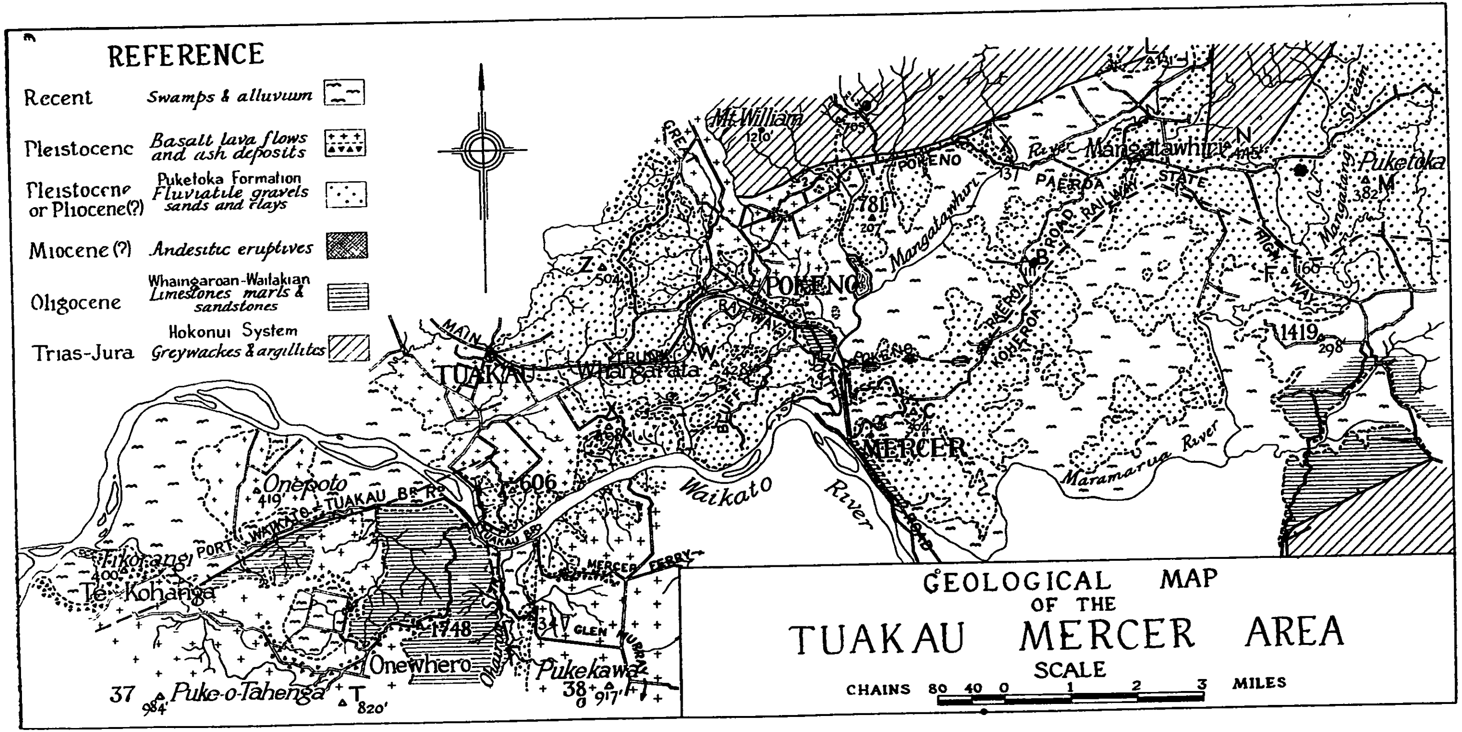
Since the area lies athwart the main transport route of the North Island, it has received mention in a number of early reports. Hochstetter (1864, 1867) traversed it, and its Tertiary rocks find a place in his stratigraphic scheme. The early geologists were concerned mainly with the extent and accessibility of the coals of Lower Waikato Basin, which were reported on by Hutton (1867, 1871a, 1871b), Cox (1877a, 1877b, 1882) and Denniston (1877). More recently areas adjoining that now studied have been described, namely, Port Waikato district (Gilbert, 1921), the Mangatangi area (Lyons, 1932) and the Bombay-Happy-Valley region (Bartrum and Branch, 1936).

The present account is condensed from a thesis submitted for the Master's degree of the University of New Zealand, and the work on which it is based was carried out under the guidance of Professor J. A. Bartrum, of Auckland University College, to whom the writer's grateful thanks are due for help in the discussion of problems and for an early suggestion that Waikato River followed its present course through Maungatautari Gorge before it was diverted to the Firth of Thames. Thanks are also extended to Dr. H. J. Finlay, of the New Zealand Geological Survey, who determined the ages of microfaunules from the Tertiary sediments.

TOPOGRAPHY.

Relief.

The district is a lowland which includes large areas of swamp, and is bounded by an incomplete " frame " of uplands composed of basement greywacke rocks. On the south-west this frame is formed by Putataka Range, inland from Port Waikato; on the north and north-east, by Hunua-Otau Ranges; and on the east, by Rataroa and the



Text-figure 1.

northern part of Hapuakohe Ranges, which separate Lower Waikato Basin from Hauraki Plains. To the north-west the " razor-backs " of the Bombay area separate Lower Waikato Basin from Manukau Lowland. Within these boundaries the relief nowhere greatly exceeds 400 ft.

Rivers.

Waikato River in its northward course enters the area near Mercer, but soon turns abruptly west and, flowing close under Putataka Range, enters Tasman Sea some fifteen miles outside the area described.

The tributaries that come from the high country inside the bend of Waikato River are short; from the north-east, however, come two considerable streams which drain a wide area of low-lying country. These are Mangatawhiri and Mangatangi rivers, which, rising in the heart of Hunua-Otau Range, debouch from narrow mountain gorges on to wide swampy lowlands across which they meander, the one to a confluence with Waikato River north of Mercer, and the other to Whangamarino River, which in turn discharges into the Waikato south of Mercer.

MAJOR STRUCTURE.

The area is a down-faulted block of the basin-and-range geomorphic province of South Auckland developed by the Kaikoura orogeny which began in the late Pliocene period (Cotton, 1916, 1945). The elevated blocks around its margins are bounded by faults, most of which fall into one of two groups trending respectively north-north-west and east-north-east. Masking of this downthrown block by Pleistocene and Recent sediments prevents determinations of the amounts of throw along these faults.

Faults Trending East-north-east.

1. *Waikato Fault:* As described by Gilbert (1921) this fault truncates northward the Jurassic greywackes and argillites of Putataka Range. Its continuation in the Onewhero-Tuakau area has produced a scarp reaching 300 ft. in height which runs east-north-east from a point half a mile south-east of Te Kohanga, and is transected by Waikato River three-quarters of a mile north-west of Tuakau Bridge. It continues for just under a mile north-east of the river as a scarp over 100 ft. in height, which has been modified by later basalt lavas that have flowed down over its face. The same thing has happened south-east of Te Kohanga, and Te Kohanga-Onewhero Road ascends the resulting lava slope.

2. *Pokeno Valley Fault:* This fault, described as Pokeno Fault by Bartrum and Branch (1936), is expressed topographically by an almost rectilinear scarp about 650 ft. in height (Plate 45, Fig. 1), which trends east-north-east from a point two miles north of Pokeno to the mouth of the Mangatawhiri Gorge, where it meets Wairoa Fault. It forms the southern boundary of Hunua Ranges.

It has been suggested (Bartrum, 1927; Lyons, 1932, footnote) that this fault is a continuation of Waikato Fault, and in fact a prolongation of the latter can be made to join up with Pokeno Valley Fault, though the alignment is far from exact. There is, however, no evidence of faulting in the intervening five miles. In addition, the upthrow of Waikato Fault is to the south, while that of Pokeno

Valley Fault is to the north, so that if the two are parts of one fault this must be of the pivotal type, and both parts should diminish in throw towards an axis at right angles to the fault-plane somewhere on a line joining the two scarps. While Waikato Fault may diminish east-north-eastwards, Pokeno Valley Fault does not die out west-south-westwards, but appears to reach a culmination in this direction at Mount William (1,210 ft.), and to owe this termination to intersection with Papakura-Drury Fault of Laws (1931). While, therefore, the two faults may be parts of one pivotal fault, later cut across by Papakura-Drury Fault, it is possible that they should be regarded as independent fractures.

3. *Kopuku Fault:* A mile south of Kopuku River, greywacke hills on the eastern edge of the area give place northwards to a gently rolling surface of Tertiary beds at the base of an east-north-east–west-south-west scarp which dies out eastwards near Kopuku–Waerenga Road and westwards intersects the prominent scarp of Maungaroa Fault. This scarp is taken to mark approximately the line of a fault with downthrow to the north which is herein called Kopuku Fault.

Faults Trending North-north-west.

1. *Maungaroa Fault:* An abrupt rectilinear scarp 500 ft. in height forms the west margin of the elevated earth-block that lies south of Kopuku. This scarp is the topographic expression of a major fault with downthrow to the west towards the wide expanse of Whangamarino Swamp, which covers the downthrown block and prevents any assessment of the maximum amount of displacement. The fault has been named from Maungaroa Hill (Trig. 40, 673 ft.) on the upthrown block one and a-quarter miles east of the scarp.

2. *Wairoa Fault:* The ultimate southerly extension of this fault (described by Laws, 1931, and Bartrum and Branch, 1936) bounds the west side of a spur of greywacke which projects south from Hunua Hills earth-block east of Mangatawhiri.

Other Faults.

1. *Mangatangi Fault:* This fault, mapped by Lyons (1932), extends north-north-east along the west side of the middle Mangatangi River and separates the uplands on the west from a broad alluvium-filled valley on the east.

2. *Ohairoa Fault:* As is noted later, the Tertiary beds around Onewhero and Tuakau Bridge cease abruptly eastwards on a north-south line which passes very close to Tuakau Bridge and are replaced by post-Tertiary sediments capped by basalt lavas. This boundary is regarded as probably determined by a fault with downthrow to the east located along the west side of Ohairoa Valley. Evidence supporting this belief is found in the considerable breadth of Ohairoa Valley, which contrasts with the narrow valleys cut by streams in Tertiary rocks to the west; it is inferred that Ohairoa Stream has degraded in post-Tertiary beds of less coherent nature than the Tertiary strata. In addition, just north of Tuakau Bridge, clays that overlie disturbed Tertiary beds are involved in a noteworthy slip, while in contrast flat-lying Tertiary rocks immediately north-west of the clays maintain almost vertical walls over 30 ft. high in road cuttings. This disturbance and associated slipping is believed to mark the line of the postulated fault,

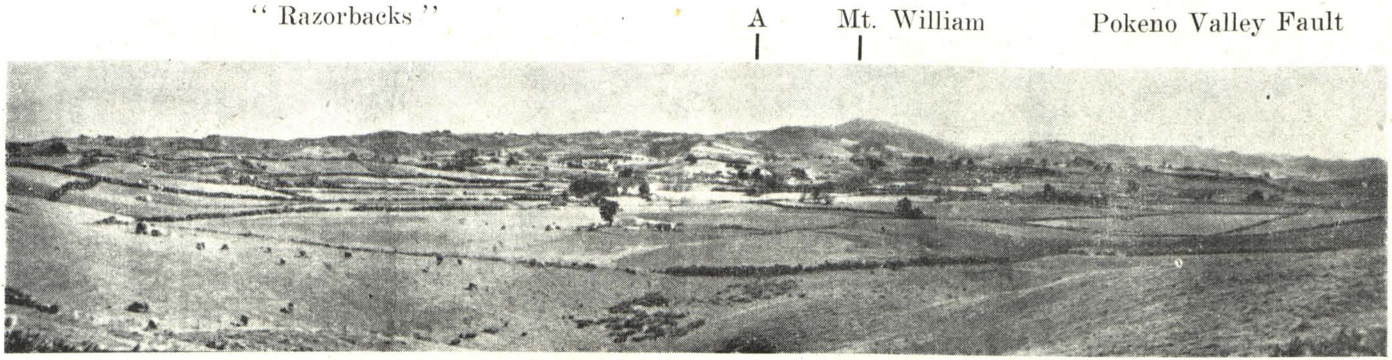


FIG. 1—View towards North from South of Pokeno. Pokeno Valley Fault-line scarp and Hunua earth-block to right; junction between greywacke (on right) and basalt at "A"; "razorbacks" to left.

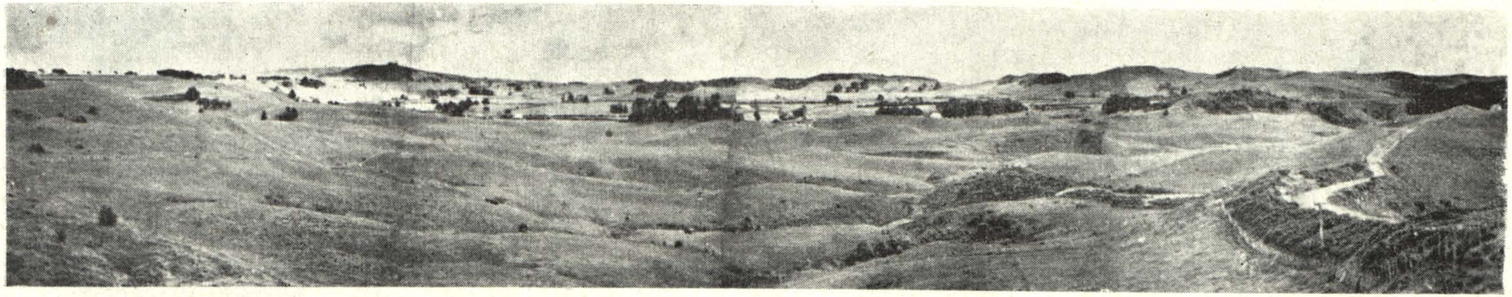


FIG. 2—Panorama of Onewhero Caldera from the East.

(Photos. Prof. J. A. Bartrum)

PLATE 45

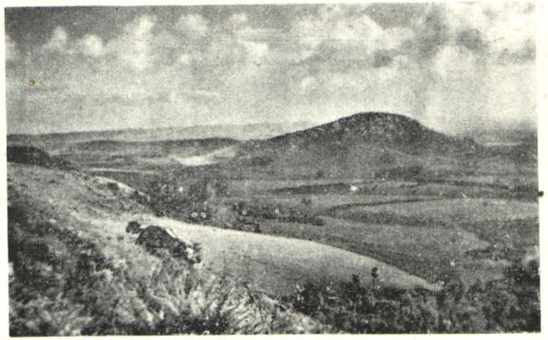


FIG. 1—Tikorangi Hill. Sunlight catches the possible crater remnant. The tuff-ring of a maar is on left behind hill.

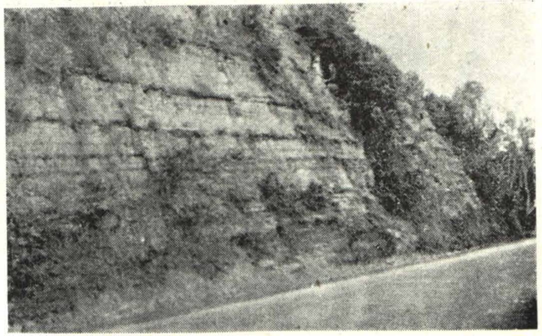


FIG. 2—Tertiary (Waitakian) sandstones North of Tuakau Bridge.

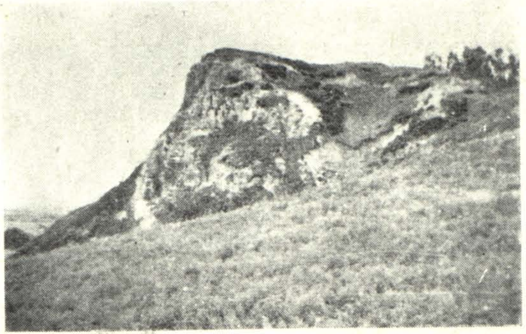


FIG. 3—Bluff of pumice silt S.E. of Puketoka Hill.

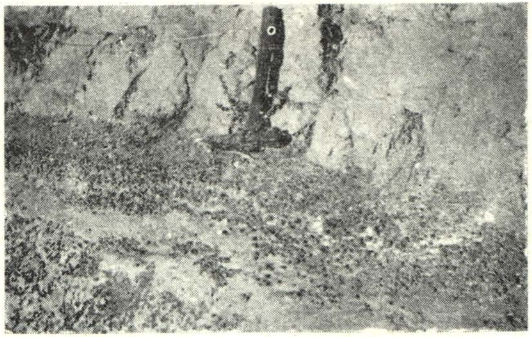


FIG. 4—Chalazoidites *in situ*, Pokeno-Paeroa Railway.

(Photos. Prof. J. A. Bartrum)

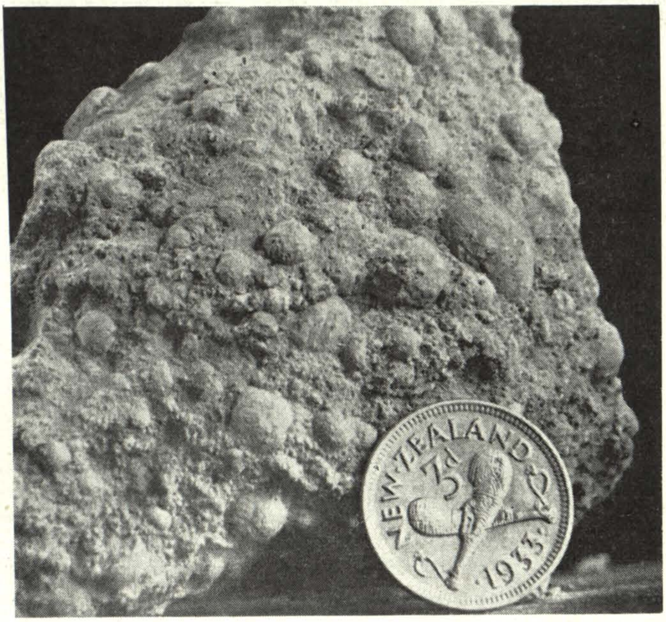


FIG. 1—Chalazoidites from Napier.

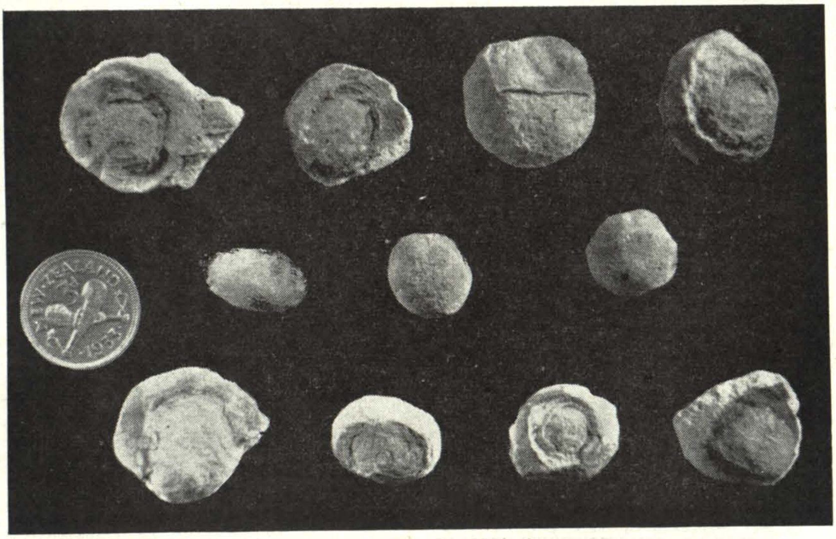


FIG. 2—Chalazoidites from Mangatangi Valley.

(*Photos. Prof. J. A. Bartrum*)

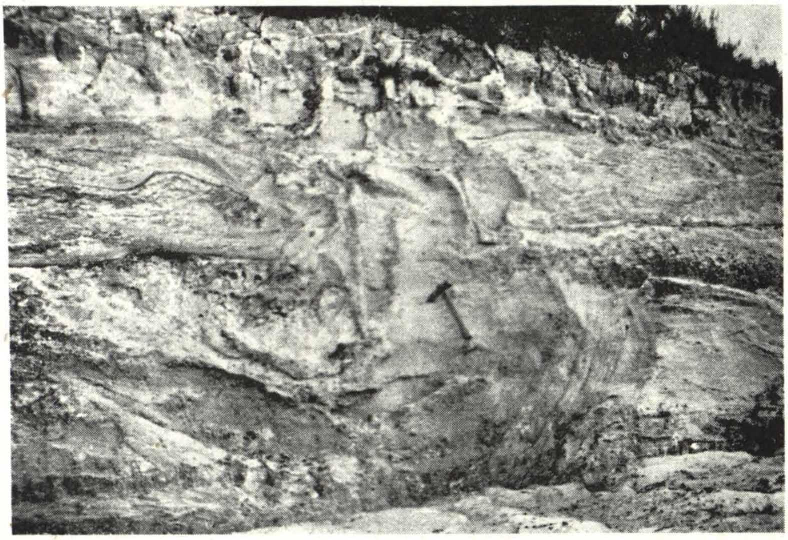


FIG. 1—"Diaper" Structure in Pumice Silts, Pokeno-Paeroa Railway.

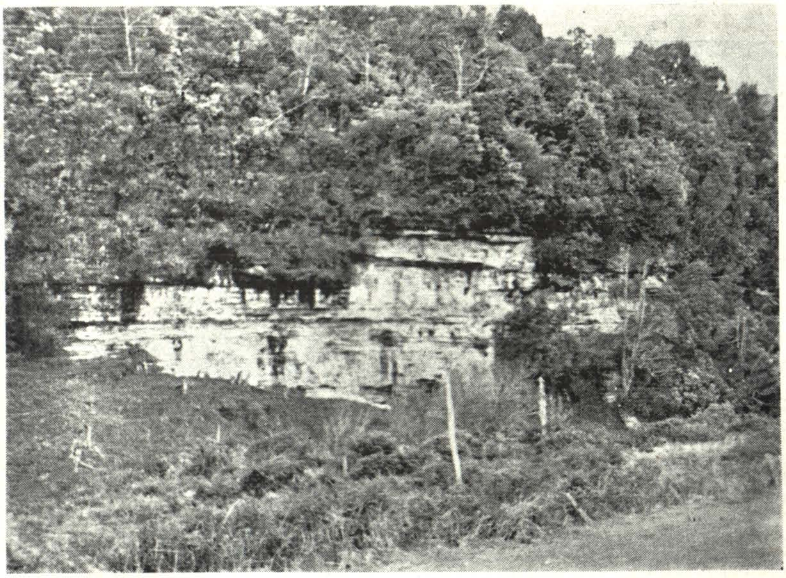


FIG. 2—Ash Beds at Outlet Gorge of Onewhero Caldera.

(*Photos. Prof. J. A. Bartrum*)

STRATIGRAPHY.

SUMMARY.

A basement of greywacke, probably of Trias-Jura age, is overlain in places by a series of early mid-Tertiary marine limestones, marls and sandstones. A single occurrence of andesitic eruptive rock is tentatively placed as Miocene in age. Separated from the Tertiary marine sediments by strong unconformity is a group of fluviatile gravels, sands and silts of Late Pliocene or Pleistocene age, which are followed in turn by basaltic lava flows and associated ash deposits of the later Pleistocene period.

Recent alluvial and paludal deposits cover large areas in the district.

BASEMENT ROCKS.

Indurated greywackes and argillites occur in the ranges, mentioned above, which border Lower Waikato Basin. As in many adjoining districts, they here show little sign of bedding and are closely jointed. No fossils were found to determine their relative age, although at Waikato Heads alternating shales and sandstones contain fossils of Upper Jurassic age (Bartrum, 1921; Gilbert, 1921; Edwards, 1934), while Triassic shells have been found in greywackes at Ngaruawahia (Cox, 1877a). In these circumstances the writer cannot do otherwise than follow the precedent of Lyons (1932) and Bartrum and Branch (1936) and refer the basement rocks to the comprehensive Hokonui System of probable Trias-Jura age.

TERTIARY SEDIMENTS.

A summary of earlier views on the Tertiary stratigraphy of South Auckland is superfluous in view of the synopsis given by Henderson and Grange (1926), who have shown that the conflicting opinions of the older geologists cannot form a basis for modern work. The stratigraphic classification that was presented by Henderson and Grange (*loc. cit.*) is that currently accepted, and is set down in the following table alongside the Tertiary stage names adopted by Finlay and Marwick (1940), with the modification that the Mahoenui beds are now to be referred to the Otaian stage (Finlay and Marwick, 1947), instead of to the Hutchinsonian-Waitakian stages as formerly. The Waitakian stage probably occurs in the Huntly-Kawhia district, but its precise representatives have not been defined.

Stratigraphic formations	Generalised Lithology	Stages
Kaawa	Green, blue and yellow sandstone; pumice present.	? Opoitian
Unconformity		
Waikawau	Massive green sandstone. Bluish-green claystone and sandstone.	Awamoan
Unconformity		
Mahoenui	Calcareous claystone and sandstone. Sandy limestone.	Otaian
Unconformity		
Te Kuiti	Limestone with sandstones and claystones.	Duntroonian (? and Waitakian in part)
Overlap		
Whaingaroa	Blue calcareous marls.	Whaingaroan
Overlap		
Coal Measures		
Epi-Hokonuian	Unconformity	

The Tertiary beds of the present area occur in three disconnected areas and, as they are in general of uniform lithology and macro-fossils are poor and infrequent, correlation has been made possible only by the study of microfaunules. These were kindly investigated by Dr. H. J. Finlay, of the New Zealand Geological Survey, whose identification and age determinations are set out in an Appendix.

1. *Tuakau Bridge—Onewhero Area.*

The sequence here is as follows:—

(a) *Whaingaroan:* The oldest Tertiary rock is a grey-white sandy limestone which belongs lithologically to the Te Kuiti formation, and outcrops for 600 yards as a 90 ft. escarpment, with its lip 315 ft. above sea level, one and a-half miles due east of Te Kohanga School. This is the scarp already mentioned as representing the continuation of Waikato Fault as mapped by Gilbert (1921). To the west-south-west it is covered by later basalt flows.

Bedding is poorly shown in these Whaingaroan beds apart from darker streaks in the limestone which dip at 2°–3° to N. 17°E. A single brachiopod was found in addition to a microfauna.

(b) *Duntroonian:* At 252 ft. above sea-level, in a gully at the eastern end of the limestone scarp mentioned above, 45 ft. of fine grey calcareous sandstone appear, overlain by weathered brown sandstone, but without visible bedding. From consideration of the dip of the limestone, however, it appears that the sandstones overlie the latter, as is demonstrated independently by the microfossils.

(c) *Waitakian:* These beds outcrop on both banks of Waikato River for three-quarters of a mile north-west of Tuakau Bridge (Plate 46, Fig. 2), at one or two points along the eastern end of the scarp of Waikato Fault, and in the valley of the stream that drains Onewhero Caldera. On the higher land around Onewhero and above the river-gorge section north of Tuakau Bridge, the Tertiary beds are covered by basalt lavas. A poor exposure of calcareous sandstone of Waitakian age does occur, however, in the east wall of Onewhero Caldera at 330 ft. above sea-level. In addition a two-foot stratum of resistent marl is exposed in the bed of the stream draining Onewhero Caldera.

Broadly speaking, the Waitakian beds are coarse, brown, limonitic, compacted but poorly cemented sandstones and fine-grained grey calcareous sandstones, which quite often contain foraminifera. In addition to these latter, remains of an irregular echinoid were found half a mile north-west of Tuakau Bridge and a few marine shells were discovered during road-forming work a hundred yards north of the bridge.*

Along Waikato Fault the dip of the Waitakian beds is variable and is sometimes at high angles to the north, but in the outlet stream of Onewhero Caldera fairly consistent dip averaging 15° to S. 37° E. is shown. The structure may thus be summarized by stating that Waikato Fault with a northward downthrow and a trend that is slightly oblique to the strike, truncates a succession of Tertiary beds which have a general south-easterly dip. On the east the Tertiary beds of this area are probably cut off by the postulated Ohairoa Fault noted above, for they do not reappear east of Ohairoa Valley.

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* Reported by Mr. Bettany, Franklin County Engineer.

2. *Mercer Area.*

Tertiary beds are exposed (1) along the Main Trunk Railway from Whangamarino River to about one mile south-east of Pokeno, (2) along the partly-built Pokeno-Paeroa Railway, and (3) along Great South Road about half-way between Pokeno and Mercer.

Between Whangamarino River and Mercer there is a succession of about 368 ft. of well-bedded poorly-cemented yellow and grey sandstones with minor whitish claystones, which dip fairly consistently at 3°–4° to the north-west. Denniston (1877) recorded a dip of 3° to the south-west at Whangamarino River, but this is not the prevailing attitude. These beds were not found to contain fossils, but in the railway cutting immediately south of Mercer Railway Station 40 ft. of hard grey marly fine sandstone, well-bedded and dipping at 8° to N. 49°W., contains a poor microfaunule determined as Waitakian in age.

At Mercer Railway Station the section is interrupted for half a mile, which is equivalent to about 270 ft. of strata, but 650 yards north of the railway station there outcrops 40 ft. of massive coarse brown uncemented sandstone, with several interbedded white claystone bands 4 in. thick, dipping at an average of 4½° to N. 38°W. These beds resemble others seen in the Tertiary sequence elsewhere and, though they are unfossiliferous and are not here to be observed in contact with definitely Tertiary beds, they are assumed to form part of the Tertiary succession.

On the railway line north of Mangatawhiri River brown sandstones again appear at lower levels, while on Great South Road at a higher level fine-grained grey calcareous sandstone is exposed and contains crushed brachiopods and a Waitakian microfauna. The dips in this area are variable; Cox (1882) reports a dip of 33° to N. 30° E. (Mag.), which differs from the attitudes observed by the writer. Disturbance of the beds has resulted in intense small-scale crumpling shown on the railway line 70 chains south-east of Pokeno Railway Station. At this point the Tertiary beds are overlain by younger sediments (Pliocene-Pleistocene), which abut on a steeply rising surface of the older beds south-west of the railway. This steep old surface, together with the crumpling of the Tertiary beds and their absence to the north and east, suggests that these latter beds are here terminated by a fault. The only indication of their former northerly extension is a small outcrop of sandstone, which in lithology resembles neighbouring Tertiary beds, close under the scarp of Pokeno Valley Fault, one and a-half miles east of Pokeno Valley Anglican Church.

3. *Kopuku Area.*

Coal was formerly mined at Bridgewater Colliery near Kopuku Landing in the extreme east of the area studied, and though the mine has long been closed a revival of interest in the prospects there has recently been apparent.

The Tertiary beds in this locality are bounded on the south by Kopuku Fault and pass on the west beneath Whangamarino Swamp. Coal outcrops as a seam at least 3 ft. thick on the Kopuku-Island Block Road near Kopuku Fault, and dips at 20° to N. 77°W. Northward along this road buff claystones occur and are believed to overlie the coal. At one point they dip at 34° to S 34°E. as a result of disturbance by Kopuku Fault. Half a mile south of Kopuku River Bridge these claystones are rich in foraminifera, but Dr. Finlay reports that the shells are so leached that no satisfactory faunule could be extracted and that the fragmentary material obtained might indicate any age from Bortonian to Waitakian.

On Mr. Finlayson's property south of Kopuku River, a shallow pit exposes at least 6 ft. of coal with two intercalated shaly bands which dip at 17° to N. 30°W.

North of Kopuku River, Tertiary beds again appear and produce a good north-east dip-slope, but time and transport difficulties prevented investigation of this part of the area. Unfossiliferous brown sandstones exposed on the Kopuku-Waerenga Road dip at 20° to N. 52°W., and coal from a small outcrop at about 500 ft. above sea-level in the East Block of Maramaru State Forest is used locally (*fide* Ranger J. L. Harrison-Smith) and demonstrates the former southward extension of Tertiary deposits.

North of Kopuku the Tertiary beds are covered by later alluvial deposits and only reappear three and a-quarter miles to the west-north-west on the east flank of Surrey Redoubt (Lyons, 1932), where a seam of coal was formerly worked (Denniston, 1877). Outcrops in this locality are now obscured by slumping and a heavy growth of scrub.

Conditions of Tertiary Deposition.

The general sequence of events in the Tertiary period in South Auckland has been elucidated by Henderson and Grange (1926).

Coals were laid down in the north close above the greywacke basement, followed in succession by Whaingaroan, Te Kuiti (Duntroonian), and Mahoenui (Otaian) marine deposits; continuing south into Taranaki, still younger marine beds were successively laid down. It is clear that the marine transgression that covered the coal-swamps extended over the Western Uplands during the time occupied by the deposition of the Whaingaroa and the Te Kuiti beds, while subsequently the shallow seas concerned moved southwards into Taranaki as a result of gradual warping uplift which affected northern areas.

The presence of coals at Huntly, Kopuku and near Surrey Redoubt shows that the swamps in which they were formed extended north from Huntly in an arc concave to the west, while the reported presence of coal in the hills on the northern (upthrow) side of Pokeno Valley Fault between one and two miles east of Pokeno Valley Fault suggests that the coal swamps extended over here also and possibly linked up with those which gave rise to coals near Drury. Early writers (e.g. Hutton, 1871a) considered that the Drury coals represent deposits of the same period of paludal conditions as those of Lower Waikato Basin and this opinion is supported by Laws (1931). The coals at Huntly are earlier than Whaingaroan; unfortunately, a foraminiferal sample from marine beds above the coals at Kopuku proved inadequate to indicate their age. The formation of coals may have been more or less contemporaneous throughout the region discussed, or alternatively those around Kopuku and Surrey Redoubt may have been formed on the margins of a sea that was transgressing eastwards only by the time that the seas to the west had deepened, in which case these coals would be contemporary with some or other of the higher beds farther west.

Beds of the Te Kuiti formation and higher Tertiary formations are absent from Kopuku and other parts of eastern Lower Waikato Basin, so that either they have been completely removed by erosion, or never were deposited in that area. The second alternative is probably correct, since, had they once existed there, the resistant limestone and marls of the Te Kuiti formation and higher beds, which are widespread on the Western Uplands, should have been in part preserved on the lower of the up-faulted blocks in the east and in the low-lying area of Tertiary rocks around Kopuku. It appears, therefore, that the Kopuku coal-swamps were inundated by the sea for only a short period before westward marine regression supervened, while marine conditions continued much longer in the west, in which direction lay the open sea. Any evidence of such a regression—for example eastward thinning of the members of the western Tertiary succession—is hidden beneath the extensive post-Tertiary deposits of Lower Waikato Basin.

In the western and central parts of the district now described. a succession ranging from Whaingaroan to Waitakian in age was laid down; all the beds apparently are the product of fairly shallow-water deposition, as was found to be the case farther south (Henderson and Grange, 1926). The Whaingaroan stage in the Tuakau-Mercer area is represented by sandy limestone belonging lithologically to the Te Kuiti formation which is thus equivalent in age to the blue-grey marls of the more southerly sequence, while marly fine-grained sandstones in the area dealt with here correspond in age to the limestone of Te Kuiti, which is shown by the study of foraminifera (Finlay and Marwick, 1940) to be Duntroonian in age farther south. At Waikawau Stream, south of Port Waikato, 200 ft. of limestone of Te Kuiti type is also shown by foraminifera to be of Duntroonian age.* The lithological horizons of the Tertiary sequence thus cross the time zones concerned in the region between the Huntly-Port Waikato area and that now described, and the problems of lateral variation in beds of the same age and their possible implications regarding conditions of deposition can be settled only by surveys of the unmapped region between Onewhero and Glen Murray.

The elucidation of the relation of Tertiary beds of the present area to those around Bombay and to the Papakura Series farther north cannot be attempted here. A complete change of facies occurs between marine strata around Tuakau and Mercer and the marine beds that overlie the coal measures near Bombay. Even within the Bombay area itself variation in facies is so rapid that, with the rarity of fossils, "it is impossible at present to make correlations between beds of different areas with any degree of assurance" (Bartrum and Branch, 1936).

MID-TERTIARY ANDESITES.

A prominent knoll of hypersthene andesite, 10 chains across, rises about 100 ft. above surrounding beds of the Puketoka formation (? Pliocene–Pleistocene) 20 chains south-south-west of Mangatangi

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* Determination by Dr. H. J. Finlay in personal communication to Professor J. A. Bartrum.

Bridge. It appears to be older than the surrounding beds, from beneath which it has probably been resurrected by erosion, although no contacts with any of the local sedimentary strata are visible. Failing other evidence, the rock is tentatively correlated with the petrographically similar rocks of Cape Colville Range, which are thought to be about Upper Miocene in age (Henderson and Bartrum, 1913). The occurrence may be compared with one of similar rock described by Lyons (1932) from the broad depression between Mangatangi and Miranda and compared by him to the types found in Waitakere Ranges near Auckland, and with the rock that builds Pukekamaka (Trig. 1531, 910 ft., Piako S.D.), a peak in Hapuakohe Ranges about six and a-half miles south-east of Maramarua.

The rock from near Mangatangi Bridge proved on microscopic examination to be a porphyritic type with large phenocrysts of acid labradorite, hypersthene and augite set in a matrix of small, stumpy prisms of feldspar, tiny lath-shaped prisms of clinopyroxene and sparse grains of magnetite enwrapped by a residuum of glass. The phenocrystic labradorite forms about 20 per cent. of the rock; it commonly is zoned and contains zonally arranged inclusions of glass and of minerals of the groundmass.

The hypersthene, which forms about 5 per cent. of the rock, shows pleochroism in very pale green and yellow tints and has low birefringence and a relatively large optic axial angle, so that it would appear to have a fairly low content of iron.

Brown augite, in amount subequal to that of the hypersthene, occurs in crystals which often show the orthopinacoidal contact twin and have a tendency to glomeroporphyritic grouping.

A few pseudomorphs of haematite occur which, as judged by their shape and characteristic curving cracks, represent original olivine.

The rock just described differs from the pyroxene-hornblende andesite described by Lyons (1932) from between Mangatangi and Miranda in its complete lack of hornblende.

LATE-TERTIARY SEDIMENTS.

Variable, poorly consolidated fluviatile beds of latest Tertiary or Quaternary age are widely distributed throughout the area described and are here named the Puketoka formation, since they attain their greatest thickness at Puketoka Hill (Trig. M, 382 ft., Opaheke S.D.). The formation includes pumice silts, various sands and conglomerates; these last are commonly of greywacke boulders, but in places, especially in the higher parts of the sequence, contain boulders of vein-quartz and banded rhyolite which, as is later shown, imply a region of provenance in Cape Colville Range or in some former westward extension of this range.

The westward limit of the Puketoka formation is thought for reasons already given to be along Ohairoa Fault on the west side of Ohairoa Valley. The nature of the accidental ejecta* in ash from a crater east of that valley indicates that Puketoka beds underlie the lavas from Pukekawa Hill.

Beds of the formation are seen in railway cuttings half a mile east of Whangarata Railway Station as sands containing well-preserved logs and overlying 4 ft. of carbonised plant remains, while

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* Usage of Tyrrell, 1931.

its presence east of Tuakau Railway Yards is shown by the occurrence of clays with prominent fractured quartz grains and magnetite to a depth of 30 ft. in railway cuttings.

Two pieces of evidence support the supposition of Henderson and Grange (1926) that their Older Pleistocene Group of the Huntly area, which is represented in the present area by the Puketoka beds, extends northwards under the "razor-backs" south-west of Bombay, towards the Manukau Lowland. First, a bore in the floor of an explosion crater north of Bombay-Pukekohe Road passed through white pumiceous running sands similar to many in the Puketoka formation.* Secondly, along Whangarata Razorback, which is followed by Brewster's Road, ash outcrops on the higher flanks of the ridge, but gives place to poorly exposed clays below, the presence of which has caused the development of small swamps in the heads of steep gullies that drain the south slope of the ridge, whereas, had lava or ash formed the whole depth of the razorback, percolation would have been unimpeded. A contact between ash and clays of the Puketoka formation not far below the summit of the ridge is inferred from the altitude of these swamps.

The contact of beds of the Puketoka formation with Tertiary rocks is shown at a number of places along the partly formed Pokeno-Paeroa Railway. In general, sub-horizontal Tertiary beds had here been eroded into subdued topography which was later covered with strong unconformity by the younger silts and gravels, with little trace of any old soil horizon above the earlier beds.

On the Main Trunk Railway line 70 chains south-east of Pokeno Railway Station, the Puketoka formation is seen in contact with locally-crumpled Tertiary beds. The surface of the Tertiary rocks apparently rose steeply on the south-west side of the line here, for they appear along Great South Road immediately alongside the railway, but 40 ft. above it. On the north-east side of the railway, Tertiary beds that dip at 20° to N. 32° W. are truncated by a 2 ft. layer of dark sand and mud rich in decomposed vegetal matter, which is interpreted as an old swamp soil and rises at 6° to the south-west. Above this is 8 ft. of greywacke conglomerate, with pebbles from 0·5 in. to 4 in. across, which is in turn overlain by 12 ft. of blocky basalt which follows the contours of an earlier surface eroded from Puketoka beds and passes beneath the level of Mangatawhiri Swamp 5 chains to the south-east.

Within the Puketoka formation itself the pumice silts, of which the material must have been transported from the Central Volcanic Plateau, occur mainly in the east in the terraces of middle Mangatangi Valley and at the east end of Koheroa Ridge, where they are exposed in cuttings along the Pokeno-Paeroa Railway. They are chiefly of interest in that in many places they contain concretions which, as is shown by Plate 47, closely resemble those described as "chalazoidites" by Berry (1928) and regarded by him as having been formed by accretion of volcanic dust around globules of moisture in the higher atmosphere during pumice eruptions. Marwick (1946, pp. 69–70), in recording the occurrence of similar bodies in Te Kuiti Subdivision,

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* Personal communication from Mr. J. C. Browne, driller.

recommends that the term chalazoidites be used for them without any genetic implication, and this suggestion is followed here.

These chalazoidites are well developed in Mangatangi Valley on the west side of the road to Miranda, about a mile from Mangatangi Township, where they are distributed sporadically but quite plentifully through the enclosing pumice silts. In cuttings of the Pokeno-Paeroa Railway 14 chains east of Koheroa Road level-crossing, however, they are densely crowded in a layer 4 to 6 in. thick, which is exposed for 7 chains (Plate 46, Fig. 4), though absent from the silt beds above and below. They are generally arranged with the short axis perpendicular and are clearly the product of concentration by running water of chalazoidites formed elsewhere in the silts.

In shape they are smoothly and regularly spherical, spheroidal or ellipsoidal, and vary from 4 mm. to 19 mm. in maximum length. Their surfaces are often coated thinly but unevenly with limonite.

Examples sectioned and microscopically examined show a nucleus of a fragment of pumice around which are concentric layers of tiny shreds of pumiceous glass arranged mainly tangentially, especially in the outer layers, together with clayey material. Colloform structures exactly comparable with those described by Bartrum (1941) in mud-balls from Waiotapu are plentiful and one or two possible fragments of diatoms were noted. The matrix that encloses the chalazoidites is essentially similar to them in its material.

Space does not permit of a detailed discussion of the origin of these bodies, but the writer believes that for the examples studied a mechanism of accretion in gently agitated waters provides the most satisfactory explanation of chalazoidite formation. This is a return to the view of Hewitt (1928), who discussed "pisolites" from Arapuni, and to that of Bartrum (1941) dealing with analogous mudballs from Waiotapu hot springs. Since the material of which the chalazoidites are made is only partially clay, the objections offered by Bell (1940) to Gardner's (1908) explanation of the formation of clay balls in the manner suggested above do not hold in this case. The large surface area of the vesiculated pumice shreds of which they are mainly composed implies great susceptibility to the forces of surface tension, which may reasonably be supposed to play an important part in the process of accretion. Richards and Bryan (1927) have remarked upon the common association of chalazoidites with bodies of water, and with water-laid deposits of volcanic ash.

A vital objection to Berry's (1928) hypothesis of aerial formation, during pumice eruptions, of the Napier chalazoidites is the presence of important numbers of diatoms in thin sections of these bodies which have been studied.* The theory is thought, too, to make excessive demands in requiring a dense, moisture-laden ash-cloud and conditions of great atmospheric turbulence at great distances from the volcanic vents, while the fact that the bodies are not flattened by impact with the ground constitutes a serious difficulty.

Pink pumiceous silts half a mile east of Koheroa Road level-crossing are transected by a considerable number of steeply-inclined "dykes" of white silt which are regarded as the result of injection of material from below into fissures developed in the enclosing beds by

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* Professor J. A. Bartrum, personal communication.

sliding comparable with subaqueous gliding of deltaic material. The material of which they are composed is finer in grain and more densely compacted than that of the enclosing silt beds, while a lamination parallel to the "dyke-walls" is detectable. They range in width from mere threads to veins 4 in. across and follow cracks, though all fissures are not occupied by "dykes." In some cracks resistant sheets of limonite have been deposited and occasionally this material may occur along one side of a "dyke." One or two "dykes" reach the surface of the ground, but others, including many of the larger ones, do not do so. Their upward terminations are not accordant with any observable bedding-plane or erosion surface that might represent a former surface to which they extended. They commonly give rise to subhorizontal sill-like offshoots an inch or so in thickness which may themselves divide into thinner members producing a somewhat dendritic pattern of which the ultimate branches wedge out. No relative displacement occurs where one "dyke" intersects another. In general, there is no gradation from "dyke" to country-rock, but a definite surface of contact.

Since the "dykes" do not end at ground level or at any earlier surface, the possibility of their being cracks infilled by surface wash must be discounted, even if it were allowed that narrow fissures, particularly if inclined, could remain open in the relatively incoherent silts concerned to permit such filling. Nor is evidence of infilling such as that recorded in clastic dykes by Lupher (1944) displayed.

The possibility of the pink silt having been bleached by percolating waters is opposed by the sharp contact between "dyke" material and the enclosing silt, while accretion of the sheets by the agency of vadose waters is negatived by the insoluble nature of the material.

The writer therefore regards injection of material from below as affording the best explanation of the phenomenon. The fissures into which injection occurred are clearly the result of local lateral sliding of the silt beds which is well exemplified nearby. The static load of the former considerable thickness (not less than 300 ft.) of Puketoka beds would appear adequate to produce the upward movement into fissures of lower plastic silty-clay layers. A very clear example of analogous upward "diaper" movement is afforded a short distance farther east (Plate 48, Fig. 1).

Of the Puketoka conglomerates, those near Puketoka Hill and at Mangatangi Bridge have been described by Lyons (1932). The layer-by-layer correlation of the beds of the two localities that he attempts is almost certainly incorrect, because the heavy conglomerate at Puketoka Hill is 200 ft. higher than the conglomerate at Mangatangi Bridge only three-quarters of a mile away and overlies easily eroded pumice silts, so that local base-level when it was laid down must have been almost 200 ft. above the Mangatangi Bridge deposits.

Since it provides evidence for conclusions regarding the date of origin of Hauraki Graben which lies a few miles further east, the occurrence at Puketoka Hill must be described in some detail. Prominent bluffs (Plate 46, Fig. 3), which rise to 258 ft. above sea-level a-quarter of a mile south-east of Puketoka Hill, expose 150 ft. of cream-coloured pumice silt which probably continues masked by soil and vegetation a further 50 ft. downwards to the level of Rau-o-te-

Huia Stream at the foot of the bluffs. This silt is capped by 20 ft. of conglomerate with andesite and greywacke pebbles and boulders up to 4 in. in diameter. There is a gentle slope north-west from the crest of the bluffs which is littered with boulders as much as 18 in. across of quartz vein-stone or of cryptocrystalline silica; these are regarded as relics that indicate the former south-eastward extension of a heavy boulder bed which forms a bluff 60 ft. high on the south-east face of Puketoka Hill where it overlies pumice silt and grit. The total thickness of the bed is probably 100 ft., and its constituent boulders, poorly cemented together, are well-rounded and often over a foot in diamenter; most of them are of andesite, but there are many others of quartz vein-stone, of cryptocrystalline silica and of banded rhyolite.

Boulders of cryptocrystalline silica with cracks lined by encrusting quartz, and one of material that exactly resembles the "quartz pseudomorphous after calcite" that is characteristic of veins in the Te Aroha and Waihi Mining Districts (see Henderson and Bartrum, 1913, pp. 89-90) were also found 500 yards south-east of the Great South Road railway overbridge near Pokeno.

In addition, in a disused gravel pit 250 yards north of Tuakau Bridge-Mercer Ferry Road, three-quarters of a mile from Tuakau Bridge, 18 ft. of conglomerate is exposed which, though predominantly of greywacke, also contains pebbles of quartz and of banded rhyolite and other igneous rocks, all affected by silicification.

Conditions of Deposition of the Puketoka Formation.

The Puketoka formation is composed of fresh-water beds and is in the main, if not wholly, the product of fluviatile deposition. This is shown by the presence of current-bedding in places, by rapid lateral and vertical variations in lithology, and by the fact that the only fossils found are those of plants. Lyons (1932) states that a 3 ft. layer of pumice at Mangatangi Bridge is of subaërial origin, basing his conclusion largely on the presence of " chalazoidites " and Berry's (1928) view of their origin. As noted, this view is still open to question, and other criteria for the recognition of subaërial deposits are few and unsatisfactory. Grading, whether by water or air transport, has had time to operate, since the nearest known source of pumice eruption is south of Rotorua, while the relation of bedding to underlying contour is not shown in the outcrop in question. In any case the bulk of the bed claimed as subaërial is so small as not to affect the foregoing generalisation about the mode of origin of the Puketoka formation as a whole.

The present highest level of the fluviatile Puketoka beds (382 ft.) obviously represents the minimum height to which a widespread sheet of alluvium was built up at the time of its formation, since there is no evidence that the beds have been affected by later differential vertical movements. This implies that the bulk of the deposit at the time of its formation was very considerable. The events that are believed to have taken place during its deposition are detailed on a later page.

Correlation of the Puketoka Formation.

On their distribution, stratigraphic position and lithological character, together with their height above sea-level, the Puketoka beds may reasonably be correlated with those of Middle Waikato Basin that have been termed " Older Pleistocene Beds" by Henderson and Grange (1926), and which have been called the Hamilton Hills formation by Healy (1945). The Walton beds (Henderson and Bartrum, 1913) of Hauraki Graben appear to be congenetic with the Hamilton Hills beds, but are not necessarily coeval with them.

The position of the Puketoka formation in the stratigraphic column is not certain. This is in part due to lack of definition of the end of the Pliocene period; for example, Healy (1945) discusses the age of the Hamilton Hills formation and shows that the recent tendency has been to relegate it to the Pliocene, though the beds were earlier regarded as of older Pleistocene age (Henderson and Grange, 1926) and were held to be the product of erosion of the ignimbrite sheets of Patatere Plateau. Healy suggests, in an appendix to his paper, that the Hamilton Hills beds may possibly be older than the ignimbrite, and hence may be entirely Pliocene, unless the ignimbrite belongs to a much later phase of rhyolitic eruptions than has previously been supposed.

As will appear later, the Puketoka formation seems to have been laid own during the period occupied by the Kaikoura block-faulting orogeny which is generally regarded as of later Pliocene age, so that it may be tentatively relegated to the Pliocene period until more definite evidence is available.

VOLCANIC DEPOSITS.

Basaltic lavas and pyroclastic deposits of post-Puketoka time occur prominently in the Onewhero, Pukekawa and Tuakau districts and less extensively elswhere.

Onewhero Area.

(1) *Lava flows.* Lavas which probably emanated from a source under Trig. T (800 ft.), three-quarters of a mile south-south-west of Onewhero, have capped a moderately elevated tract of Tertiary rocks which appear around the margins of the flows. They have flowed down over the scarp of Waikato Fault between 30 and 40 chains south-east of Te Kohanga and, spreading out at the base of the scarp, pass below the alluvial flats of Waikato River.

A small, gently-sloping basalt dome called Onepoto (419 ft.) rises above the alluvial flats of the upper end of Waikato delta three and a-half miles west of Tuakau Bridge.

(2) *Volcanic depressions and pyroclastic deposits.* After the emission of lava, a circular depression was formed averaging one and five-eighths miles across and surrounded by a well-developed tuff-ring on the south-east portion of which Onewhero Township now stands. Its floor lies at 350 ft. above sea-level and consists of a flat sheet of alluvium, which is regarded as sediment of a lake which in the past probably occupied the depression. The tuff-ring is generally over 500 ft. and reaches as much as 650 ft. above sea-level. (Plate 45, Fig. 2).

This feature falls into the class of calderas as defined by Howel Williams (1941, p. 242), who concludes that " it may well be doubted if there is anywhere an explosion crater, unmodified by slumping of the walls, which measures more than a mile across." In Onewhero

Caldera there is little sign of slump scarps on the walls or of slump topography at their base, while gullying has affected only a limited area on the east wall. It is possible, therefore, that the caldera should be regarded as a crateral sink consequent upon withdrawal of the lava column, rather than as a result entirely of explosion.

Tikorangi Hill (400 ft.) at Te Kohanga is a conical pile of ash (Plate 46, Fig. 1) which lacks a summit crater, but a shallow depression on its west-south-west flank may represent the explosive focus. The pronounced asymmetry of the ash with respect to the supposed vent appears to be too great to be the result of wind having carried the ash to one side during eruption; it seems more probable that the southern half of the edifice was destroyed by the explosion that produced a maar about a mile across with its nearer lip 25 chains west of Tikorangi summit. The broad low tuff-ring of this maar has been breached on its western side by the lateral cutting of Waikato River.

Pukekawa Area.

East of the Onewhero basalts and separated from them by the valley of Ohairoa Stream, there is a volcanic edifice composed of three gently-rounded domes, namely, Pukekawa (Trig. 38, 917 ft.), another dome 750 ft. high one and a quarter miles north-west of Pukekawa, and Trig. 100 (525 ft.) two and a quarter miles north by east of Pukekawa. Lavas from this group form a meridional scarp 200 ft. high on the east side of Ohairoa Valley, but thin out above beds of the Puketoka formation towards Waikato River. At Smeed's Quarry, two and a-quarter miles upstream from Tuakau Bridge, the flows must have occupied a former valley which extended below the present base-level in this area, for a 100 ft. face of basalt here extends below the level of Waikato River.

Explosive activity followed the main lava outpourings in this area as at Onewhero, for immediately east of the basalt scarp along Ohairoa Valley and between Tuakau Bridge–Mercer Ferry and Tuakau Bridge–Glen Murray Road, there is a sub-circular explosion crater a little under a mile across, which is drained by a stream which passes west in a water-gap through the scarp to Ohairoa Valley. Ash derived from this centre of explosion contains accidental fragments of white mudstone, sandstone and quartz derived from the underlying Puketoka beds.

Tuakau Area.

Lavas which probably came from near Trig. 606 south-east of Tuakau, where coarse pyroclastics occur, cap the river-gorge section north-west of Tuakau Bridge and have flowed over the face of Waikato Fault-scarp north-east of Waikato River to extend widely around Tuakau Township. Just north of the railway-line at Tuakau, differences in the petrographic characters of the basalts and the fact that the lava slope starts to rise northward indicate the coalescence of flows probably from Trig. 606 with others from north of the township.

Three occurrences of basaltic lava along the north bank of Waikato River may be noted. The first is between half a mile and one mile east of Trig. 606, where a spur, capped by basalt, runs south to the river; next, a small patch of fine-grained basalt crowns a knoll 240 ft. high three-quarters of a mile east-south-east of Trig. X (Onewhero S.D.), and finally another small area of similar rock lies one mile east-south-east of Trig. X. There is no evidence that these last two occurrences are remnants of an earlier wide sheet, for it may be noted that a spur lying between them and higher than either is free from basalt.

Immediately south of Trig. X (Onewhero S.D.) an explosive eruption has produced a crater which is now breached upon its south side. Tuff here contains rounded pebbles of greywacke, jasper and silicified rhyolite, in addition to the predominant basaltic lapilli.

Another focus of explosive eruption was located in the middle of Waikato River about three and a quarter miles upstream from Tuakau Bridge, for remnants of a tuff-ring with beds dipping radially outwards with respect to a centre in mid-stream occur as prominent bluffs on the north bank of the river at this locality. The ejecta are mainly basaltic scoriae which are coarse near the river bank but become finer in grade farther back from it; included well-rounded greywacke and quartz pebbles suggest, however, that Puketoka beds underlie the pyroclastic material.

Other Occurrences.

Just over a mile due south of Pokeno Railway Station basalt lava outcrops over a small area on a south-facing slope at the head of Cole's Road, while ash deposits, composed almost entirely of small basaltic lapilli, form a line of north-facing bluffs almost half a mile in length which extends east and west three-quarters of a mile south of Pokeno Railway Station. Other deposits of weathered ash are exposed in cuttings of Great South Road north of Pokeno, and on Pokeno-Paeroa State Highway at Pokeno Valley Anglican Church. In this latter locality they overlie basaltic lava (met with in a well) which has come from the heights near Bombay and extends south-east of Pokeno to the edge of Mangatiwhiri Swamp. The junction of this flow and the greywacke of Mt. William at the south-west corner of Hunua earth-block is marked by a well-entrenched stream (Plate 45, Fig. 1).

The " razorback " ridges north of Whangarata are capped by basaltic ash which outcrops as bluffs high up on their flanks, and are separated by deep, steep-walled valleys cut in underlying clays and sands. The source of the ash is not obvious, but undoubted examples of explosion craters occur north of the area mapped along Bombay-Pukekohe Road and others, now greatly modified by erosion, may have existed nearer at hand.

A crater with a breached rim and a central plug of lava and agglomerate lies just east of Mercer, while along Pokeno Valley Fault-scarp a number of small flows of basalt have descended from the highlands of the upthrown block to the north. The first of these is one and a quarter miles east of Pokeno Valley Church and is believed by Bartrum and Branch (1936) to have come from a vent one mile east of Trig. 616. Two and a half miles further east, Trig. X (131 ft., Opaheke S.D.) is located on the remnant of the tuff-ring of a crater which formerly held the recently-drained Mangamate Lake. A small patch of basaltic lava a hundred yards across lies 30 chains west of the tuff-ring, but its relation to the crater is not clear. It is not connected with any flow from the highlands.

One and a quarter miles north-by-east of Mangatawhiri Township, where Twining's Road ascends the scarp of Pokeno Valley Fault, a tongue of basalt has flowed down from the uplands, and it has been suggested (Lyons 1932) that its source was a vent north-west of Paparata Valley which has subsequently been mapped by Bartrum and Branch (1936).

Petrography of the Basalt Lavas.

Marshall (1912a, p. 104, 1912b, pp. 30, 45) consistently referred to the lavas of Lower Waikato Basin as basanites, but no felspathoids could be identified in the rocks examined during the present study. Henderson and Grange (1926), while they were unable to find evidence of modal nepheline, noted that " basalts occurring in the northern half of the (Huntly-Kawhia) subdivision are decidedly alkaline and the norms contain from 1.70 to 8.24 per cent. of nephelite.'' These writers give the following analysis of a basalt from Mercer (Henderson and Grange, 1926, p. 70).

SiO_2	44.34
TiO_2	2.67
ZrO_2	none
Al_2O_3	12.68
Cr_2O_3	0.02
Fe_2O_3	3.21
FeO	11.12
MnO	0.23
NiO	0.02
MgO	7.21
CaO	9.38
SrO	0.07
BaO	0.06
Na_2O	3.76
K_2O	1.62
P_2O_5	0.94
V_2O_3	0.03
S	0.07
CO_2	0.06
H_2O above 105°C.	1.44
H_2O below 105°C.	0.90
	99.83

Norm.	
Quartz	—
Orthoclase	9.45
Albite	16.77
Anorthite	13.07
Nephelite	8.24
Diopside	22.75
Olivine	14.85
Magnetite	4.64
Ilmenite	5.17
Apatite	2.02
Pyrite	0.12
Calcite	0.10

Limburgose

Fifteen thin sections of basalts were studied, representing nearly all the occurrences of basic lavas in the area. All prove to be holocrystalline olivine basalts of very uniform mineralogical composition. Two quite clear-cut textural divisions may be recognised, namely, a porphyritic fine-grained type forming the smaller often isolated flows throughout the district, and a porphyritic coarse-grained intergranular type which seems to be associated with the more widely spreading lava flows from major centres of extravasation.

Porphyritic fine-grained olivine basalt: The typical rock of this group has predominant phenocrysts of olivine and somewhat smaller ones of clinopyroxene, set in a fine-grained groundmass of feldspar laths, granular pyroxene and magnetite.

The olivine is sometimes idiomorphic, but more often is much corroded. The proportions of the constituent minerals naturally vary in the different members of the group, but olivine generally forms about 10-15 per cent. of the rock.

The pyroxene is purplish in colour and, therefore, is probably slightly titaniferous, but it does not exhibit pleochroism. Hour-glass zoning is very common, the extinction angle Z to c ranging from 40° to 53° and increasing in the outer zones, a feature which suggests progressive enrichment of the magma in iron (and possibly titanium) as crystallisation went on. 2V as estimated from the curvature of the isogyres is fairly large. Phenocrystic pyroxene generally forms about 10 per cent. of the rock.

The feldspar that occurs in the usual pilotaxitic groundmass is labradorite; in some cases it shows a tendency to ophitic relations to the pyroxene.

Magnetite evenly distributed as small granules is an abundant accessory and a little fine apatite is identifiable in some cases.

The rocks are generally quite unaltered unless the presence of somewhat rare patches of radially-crystallised carbonates indicates alteration. Since the primary minerals are quite fresh, however, these carbonates probably represent products of a late magmatic phase of crystallisation.

Porphyritic coarse-grained intergranular basalt: The mineralogical constitution of this rock is much the same as that of members of the fine-grained group and, although the rocks are of much coarser grain throughout, phenocrysts of olivine and pyroxene still occur as large crystals, the former mineral making up about 20 per cent. of the rock and the latter 15 per cent. or more. The pyroxene does not exhibit the hour-glass structure so prominent in the other group.

Along with intergranular texture some examples of true ophitic relations are to be seen, while in specimens from near Tuakau Dairy Factory pilotaxitic arrangement of the feldspars is combined with the other structures. In specimens from the Pukekawa lavas there is glomeroporphyritic arrangement of the pyroxene crystals.

Examples of this type of basalt come from the east side of Ohairoa Valley on Tuakau Bridge–Glen Murray and Tuakau Bridge–Mercer Ferry Roads, from the falls on the outlet stream of Onewhero caldera and from the railway cutting south of, and the stream just north of, Tuakau Dairy Factory.

Presence of xenocrystic quartz: Quartz is present as small grains or aggregates of crystals in four sections of the fine-grained type of basalt and in a section of the intergranular type from near Tuakau Dairy Factory. In all cases the quartz is surrounded by a reaction rim of tiny pyroxene crystals so that it must represent allocthonous material caught up by the lava from sediments or other source during its ascent or extrusion. In some cases complete resorption has occurred, the former presence of quartz being inferred from the occurrence of little clusters of minutely crystalline pyroxene.

Conclusions.

It is clear from the relations of the volcanic accumulations to the underlying rocks and from what can be learned of the surface covered by the basaltic series, that the main period of volcanism was subsequent to the deposition and sculpture of the Puketoka beds and that it occurred when the land was higher with respect to sea-level than it is now. Since then alluviation has taken place in the valleys and swamps of the district.

Modification of the surfaces of the basalt flows by erosion is not far advanced, as is shown by the unfurrowed slopes of the Pukekawa mass, although marginal streams such as Ohairoa Stream have lowered their beds considerably in underlying sedimentary formations.

The explosive eruptions seem to have followed the outpourings of lava in all cases where their mutual relations are discernible; their location, however, does not seem to bear a close relation to that of the sources of major lava extravasation, though a small amount of basalt is often associated with an explosive focus. This is in accord with the broad scheme of the volcanic cycle as enunciated by Tyrrell (1931), who writes (p. 25): " When the volcanic cycle is viewed broadly and as a whole, the emission of lava is the dominating form of activity in its earlier stages, and the explosive discharge of gases in its later stages." Nothing like the complete volcanic cycle of Tyrrell is shown, however, for lava emission seems to have been restricted to central eruptions from the outset (no true fissure eruption stage) while the phase of the building of stratovolcanoes has been omitted.

ORIGIN OF PUKETOKA FORMATION AND DEVELOPMENT OF MODERN DRAINAGE.

The problem of the modern drainage relationships in Lower Waikato Basin is so closely bound up with that of the origin, deposition and partial removal of the Puketoka Formation that the two topics may be conveniently discussed under the same heading.

Henderson (1918) believed that Waikato River did not enter its present course through Maungatautari Gorge until aggradation of its former course through Hinuera Valley, because of heavy overloading with pumice from the huge eruptions in the centre of the North Island forced it to spill over into its present route past Cambridge. Healy (1945) has shown, however, that long before this event an early gorge deeper than the present one was eroded across a greywacke ridge on the site of the present Maungatautari Gorge and was later filled with deposits that he has referred to the Hamilton Hills formation.

It is suggested, therefore, that the ancient Waikato River carved this now partly-buried gorge, after which aggradation took place which led to the deposition of the Hamilton Hills formation. The basal pumice deposits of the Puketoka formation are regarded as having been laid down at the same time as the Hamilton Hills beds by Waikato River, which at this time appears to have passed through the greywacke ranges between Middle and Lower Waikato Basins in a narrow valley now represented by an alluviated air-gap 90 ft. above sea-level at Mangawara between Taupiri Range and Hapuakohe Range, and to have made its way to the present Manukau Lowlands, depositing *en route* the Puketoka beds that now lie beneath the basaltic material of the Bombay " razorbacks." Following this phase, after a great mass of pumiceous deposits had been laid down, Waikato River was diverted for a time at Hinuera Valley into a course leading to the Firth of Thames, while still later its adopted its present resequent course through Maungatautari Gorge.

Undoubtedly it was only as a consequence of the subsidence that created Hauraki Graben that a route was provided by which it was possible for Waikato River to forsake its earlier course through Maungatautari Gorge and to take that through Hinuera Gap. This change of course is thought to have taken place at a relatively late stage in the geomorphic history of the region, for it will be shown later that there seems to be good reason to regard the formation of the graben as a comparatively recent event. The return of Waikato River to the resequent course that it now pursues through Maungatautari Gorge may reasonably (but speculatively) be ascribed to its capture and diversion, above Hinuera Gap, by a stream from Middle Waikato Basin eroding headwards in the poorly-consolidated alluvium that had earlier filled the gorge.

This sequence of events is quite different from that postulated by Henderson (1918), but nevertheless it seems to be strongly supported by the facts at present known.

As has been noted, Puketoka formation includes in its upper part conglomerates with pebbles and boulders of banded rhyolite and vein-quartz. Two possible sources of this material present themselves (cf. Lyons, 1932) :

(a) In the ancestral Cape Colville Range, in the modern representative of which these rock types are known to occur widely, or

(b) in less distant but as yet unknown outcrops.

It is considered highly improbable that rhyolites and quartz-veinstone occur in Hapuakohe Ranges, which seems to be the only geologically unmapped area from which they could have come, since the veinstone in particular would command instant attention from any person traversing the hills, and the following hypothesis is based on the conclusion that the first alternative is correct.

The coarse nature of the deposits in which these rock types occur, for there are boulders as much as 18 in. across, indicates that they were carried by a steep, swift stream from a not-far-distant highland area. It seems impossible that such material was transported across the present Hauraki Graben without leaving therein a great mass of coarse deposits, not only of huge thickness but of wide lateral extent. No traces of such deposits have been found either at the surface or in borings, yet it seems impossible to believe that they can have been removed by the necessarily weak waves of any former extension of the Firth of Thames, or by such streams as may have occupied the graben.

It appears, then, that while transport of material from Cape Colville Range was taking place Hauraki Graben was not yet in existence, at least as far as its southern part is concerned. The subsidence of this area began in the north and extended southwards (Henderson and Bartrum, 1913) and may not have extended very far south at this time. This conclusion that the subsidence of Hauraki Graben was a relatively late event in Quaternary history is supported by the suggestion of Bartrum (1927) that relatively recent uplift has taken place on the upthrown side of its western boundary fault.

The stream that carried the boulder material from the western extension of Cape Colville Range must have made a sudden irruption into Lower Waikato Basin, for had a swift stream capable of transporting the constituent boulders of the conglomerate at Puketoka Hill traversed this basin during the period represented by the pumice silts below the conglomerate, these silts, which are the deposits of relatively sluggish water could not have been laid down. This stream probably took a more northerly course until the upbuilding of its fan permitted it to enter the present district. Since the pumice basement was not destroyed by erosion, it may be inferred that its surface lay near sea-level at the time of the invasion of the stream from the east.

After the phase of alluviation that is represented by the Puketoka formation, degradation was initiated by relative uplift of the land and led to the removal of a very large part of the extensive sheet of sediment that had been laid down.

Hypothesis of Regional Superposition of Drainage.

A number of interesting features of the modern drainage lead to the conclusion that the streams of Lower Waikato Basin have been superposed upon the buried under-mass without regard to its topography from valleys initiated in the younger covering beds. These features are as follows:—

(1) *Taupiri Gorge:* Although, as judged from their height in Puketoka Hill, the younger fluviatile beds reached at least as high as 400 ft. above present sea-level, Taupiri Mountain (967 ft.) probably projected island-like above them in common with the tops of other greywacke ridges. It is suggested, however, that immediately west of this mountain at the site of the present narrow gorge of Waikato River a greywacke saddle between Taupiri and Hakarimata Ranges was low enough to be covered by the sheet of alluvium and that, when uplift caused the streams to incise their beds, Waikato River (or possibly the ancient Waipa River (see below), which had been following this route between the greywacke elevations, was superposed upon this saddle in which the present water-gap has since been excavated. Prior to the phase of alluviation represented by the Puketoka formation the river probably traversed the barrier ranges of greywacke by way of the present air-gap at Mangawara, as has already been suggested. This earlier gorge was buried beneath the later alluvium but has since been partly re-exposed by the activity of Mangawara and Matahura Streams which have removed the alluvium concurrently with the deepening by Waikato River of its gorge at Taupiri.

(2) *The Narrows at Mercer:* A similar hypothesis of superposition may be applied in explanation of the Narrows at Mercer, where Waikato River transects a ridge of Tertiary rocks.

(3) *Tuakau Gorge:* For a mile north-east of Tuakau Bridge Waikato River passes in a gorge through Tertiary rocks upfaulted between Ohairoa and Waikato Faults. This feature is regarded as the result of superposition of the lower course of the main stream of Lower Waikato Basin at the time of the degradation of the river system, its position and direction being relict features of the former much greater volume of drainage from the east before the subsidence of Hauraki Graben was completed.

(4) *Round Hill Gorge, Mangatangi Stream:* Support for the concept of regional superposition of drainage is found in the way that Mangatangi Stream has entrenched itself across the greywacke

spur that forms Round Hill (380 ft.) in its middle valley about two miles north of Mangatangi township. An alluviated air-gap exists immediately east of the obstruction through which the gorge has been cut, while eastwards again of the air-gap greywacke reappears.

It has already been postulated on lithological evidence that a stream which flowed west from an earlier westward extension of Cape Colville Range deposited the Puketoka boulder bed. The former existence of this stream is supported by the evidence of two physiographic features, first the remarkable bend of Waikato River one mile north-west of Mercer and secondly, a curious water-gap in the course of Mangatawhiri River one mile above its confluence with Waikato River.

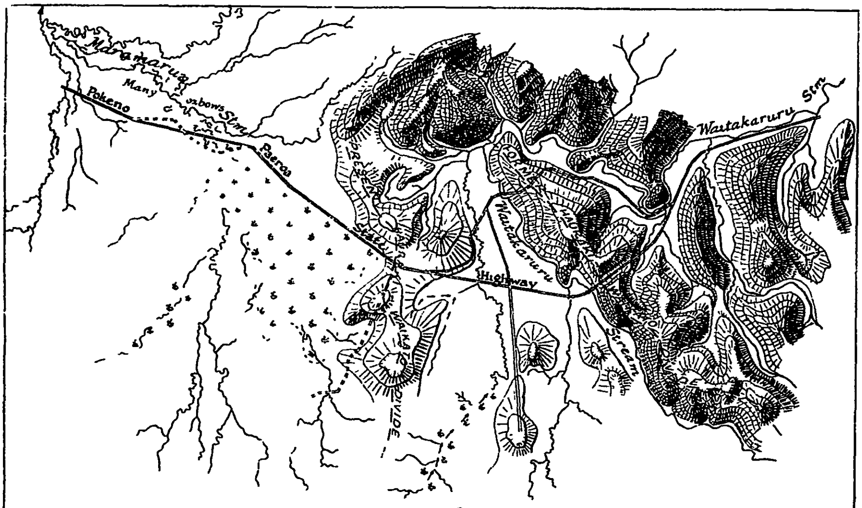
It is suggested that the pressure of the coarse-textured fan-material of this early strong west-flowing stream deflected Waikato River from a northerly course to its present westerly one and thus caused the development of its unusual bend. Terraces rising to 300 ft. and following the concave side of the bend show that its inception dates back at least to an early stage of the degradation of the Puketoka beds.

The water-gap, which is over 25 chains across and is followed upstream by extensive swamps, seems too wide to have been carved by so small a stream as the modern Mangatawhiri River. It is true that in the past Mangatwhiri River received drainage from Happy Valley, a short distance to the north in the Hunua Hills (Bartrum and Branch, 1936; Bartrum, 1939), but the loss of this tribute seems insufficient to account for its present underfit character. To explain this it seems necessary to invoke another former accession of drainage, which as far as can be seen can only have come from the east and which, under the present hypothesis, may be identified with the postulated stream from an extension of Cape Colville Range. It is believed that the saddle in the Mangatawhiri-Mangatangi divide at the north-eastern end of Koheroa Road, which stands only 70 ft. above sea-level and is underlain by Puketoka alluvium, represents an air-gap left by this earlier trunk stream from the east, which, towards its confluence with Waikato River, was joined by the waters of Mangatawhiri and Mangatangi Rivers. When relative elevation of the land caused degradation to succeed deposition, this stream must have played an important part in removing much of its earlier deposits, the Puketoka beds, before it was beheaded by subsidence of Hauraki Graben.

The latest phase of stream history in Lower Waikato Basin has been one of aggradation which has resulted in the formation of swamps which fill the lower parts of the valleys, as is well exemplified in Mangatawhiri and Whangamarino Swamps and in the valleys of small tributaries of the Waikato between Tuakau Bridge and Mercer. Small levees built by Waikato River across the margins of small swamps upstream from Tuakau Bridge are evidence of the same process (Mead, 1932, p. 322).

The Waitakaruru Capture

An interesting example of river piracy is displayed in Waitakaruru Stream at a point five miles east-south-east of Maramarua Township. The north-west-flowing upper part of Waitakaruru Stream here doubles back in a remarkable elbow-bend to flow south-east for a little over half a mile, after which it pursues an east-north-easterly course to Hauraki Plains. At this sudden bend the stream is entrenched across a prominent north-west south-east ridge of greywacke which apparently was formerly the divide between Waikato and Hauraki Plains drainage (see Text-fig. 2). It seems clear that the upper part of Waitakaruru Stream in the past formed the headwaters of. or was tributary to, an extended Maramarua Stream and that its drainage flowed to Waikato River. The capture of this reach by Waitakaruru Stream has caused the Waikato-Hauraki divide to leap half a mile westward to an inconspicuous rise in the broad alluviated depression that represents the old course of the diverted stream. Typical results of beheading are shown to the west of the new divide where the diminished Maramarua Stream rises in a swampy tract with low bordering slopes and meanders sluggishly westward.



Plan of
THE WAITAKARURU CAPTURE
Approximate Scale of Chains
20 10 0 20 40 60

TEXT-FIGURE 2.

The gorge at the elbow of capture seems to be a composite feature, for the narrow trench in which the river now flows occupies the north-west side of a broad saddle which has a width of three-quarters of a mile at the 300 ft. contour, and of a mile and a half at the 400 ft. contour. The only explanation of this feature that seems feasible is that its origin extends back to the time when the sheet of Puketoka alluvium had masked all topography below the level of its surface, which was probably over 400 ft. above present sea-level. The broad gap at the elbow of capture could then have been carved by an earlier eastern headwaters extension of the present Maramarua Stream, a process interrupted by the subsidence of Hauraki Graben and the initiation of east-flowing drainage on the western side of this latter depression. Later headward erosion by the vigorous Waitakaruru Stream, which falls from about 150 ft. to near sea-level in three miles, has allowed it to capture still further drainage from Maramarua Stream.

SUMMARY OF GEOLOGICAL HISTORY.

In conclusion the sequence of events in the Tuakau-Mercer area may be summarised as follows: In Oligocene times a marine transgression took place over the eroded surface of a series of greywackes and argillites which were probably laid down in Mesozoic times and since then had suffered tectonic stress and induration. As this surface was submerged, the sea advanced over littoral coal swamps which flourished in places on the margins of the sinking land. A period of deposition in shallow seas ensued which produced a succession of beds ranging in age from Whaingaroan to Waitakian. After this, the seas retreated southwards and there is a break in the geological record which extends till latest Tertiary time, although a hint of great events in nearby regions remains in the presence of a solitary knoll of andesite which was probably emplaced in Miocene times.

Towards the end of the Tertiary began the block-faulting that is responsible for the topographic outlines of the present day and depressed Lower Waikato Basin relatively to the surrounding areas. Before the faulting was completed, rivers from both the centre of the North Island and the ranges of the East Coast spread huge deposits of alluvium over the Lower Waikato area, which then stood much lower with respect to sea-level than it does now.

Then came uplift and removal of most of this accumulation of sediment, and reorganisation of the river systems into their present condition took place.

Extensive outpourings of basic lavas succeeded these events and were accompanied by explosive eruptions. Finally, a small relative depression of the land and aggradation of the valleys brought the geologic evolution of the area to its present stage.

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APPENDIX.

Microfaunal Identifications.

By Dr. H. J. Finlay, N.Z. Geological Survey.

The following are the localities from which the samples were collected, together with the age determined for each faunule:

Sample No.	Locality	Age
A.	*Tuakau Bridge-Onewhero Area* (see p. 434).	
7.	Scarp south of Port Waikato Road; 1 mile 10 chs. on 108½° from Tikorangi, Trig. 5, Onewhero S.D.	Whaingaroan
3	2 miles on 93½° from Tikorangi, Trig. 5, Onewhero S.D.	Duntroonian
4.	As for No. 3. 30 ft. higher in sequence.	”
5.	As for No. 4. 15ft. higher in sequence.	”
6.	4½ chs. along Port Waikato Road from Tuakau Bridge; Onewhero S.D.	Waitakian

8.	27 chs. on 25° from Aiselbee's Road corner, Onewhero Settlement; Onewhero S.D.	Waitakian
11.	9 chs. along Onewhero Road from Tuakau Bridge; Onewhero S.D.	„
1.	10 chs. along Glen Murray Road from Tuakau Bridge; Onewhero S.D.	„
2.	3½ chs. along Tuakau Road from Tuakau Bridge; Onewhero S.D.	„
13–17.	Collected in ascending order at approximately 6 ft. intervals at 48 chs. along Tuakau Road, N.N.W. from Tuakau Bridge; Onewhero S.D.	„

B. *Mercer Area* (see p. 435).

9.	50 chs. S. along Great South Road from overhead bridge near Pokeno; Maramarua S.D.	„
12.	Railway cutting south of Mercer Railway Station yards; Maramarua S.D.	„

CHECK LIST OF FORAMINIFERA.

	7	3	4	5	6	8	11	1	2	13	14	15	16	17	9	12
1. *Anomalina miosuturalis* Fin.				×												
2. *Arenodosaria antipoda* (Stache)	×															
3. *Astacolus* cf. *crepidulus* (F. and M.)										×						
4. *Bolivina anastomosa* Fin.					×				×							
5. *Bolivina lapsus* Fin.									×							
6. *Bolivinopsis cubensis* C. and B.								×								
7. *Bulimina miolaevis* Fin.					×											
8. *Bulimina pupula* Stache						×				×		×			×	×
9. *Cassidulina subglobosa* Brady	×	×	×	×												
10. *Chilostomella* sp.								×	×							
11. *Chrysalogonium* spp.						×				×						
12. *Cibicides collinsi* Fin.	×															
13. *Cibicides novozelandicus* (Karr.)	×			×												
14. *Cibicides molestus* n.sp.		×	×	×												
15. *Cinibides thiara* (Stache)			×	×												
16. *Dentalina soluta* (Reuss)										×						
17. *Discorbis* cf. *turgidus* Fin.				×												
18. *Ditrupa* sp. (a worm tube)		×	×	×												
19. *Ellipsonodosaria subconica* (Kreuz.)				×					×						×	
20. *Eponides umbonatus* (Reuss)												×			×	
21. *Gaudryina reussi* (Stache)	×															
22. *Glandulina aperta* (Stache)				×												
23. *Globigerina bulloides* d'Orb.		×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
24. *Globorotalia dehiscens* C., P., and C.					×	×	×	×	×	×	×	×	×	×	×	×
25. *Guttulina communis* d'Orb.		×														
26. *Gyroidina neosoldani* Brot.	×	×	×	×	×		×	×	×	×				×	×	
27. *Haeuslerella textilarioides* (Stache)			×	×												
28. *Karreriella* cf. *chilostoma* (Reuss)									×							
29. *Karreriella novaezelandica* Cush.	×								×							
30. *Lagenonodosaria scalaris* (Batsch)				×	×											
31. *Listerella weymouthi* Fin.								×			×					
32. *Loxostomum basistriatum* n.sp.						×		×				×	×			
33. *Marginulinopsis* n.sp.				×												
34. *Marssonella* cf. *indentata* C. and J.								×								
35. *Nodosaria longiscata* d'Orb.										×	×	×		×		
36. *Nonion maoricum* (Stache)	×															
37. *Notorotalia* cf. *stachei* Fin.			×	×												
38. *Planulina wuellerstorfi* (Schwag.)					×											
39. *Plectofrondicularia proparri* n.sp.					×				×							
40. *Plectofrondicularia whaingaroica* (Stache)		×	×			×			×		×	×	×			
41. *Polymorphina nodosa* n.sp.				×												
42. *Pullenia sphaeroides* d'Orb.															×	
43. *Ramulina* sp.				×												
44. *Reophax* sp.					×				×							
45. *Rhabdammina* tubes					×											
46. *Robulus dicampylus* (Franz.)		×	×	×												
47. *Rotaliatina sulcigera* (Stache)	×															
48. *Semivulvulina capitata* (Stache)	×															
49. *Siphogenerina ongleyi* Fin.											×					
50. *Siphogenerina* cf. *striatissima* (Stache)			×													
51. *Siphogenerina* cf. *vesca* Fin.					×			×								
52. *Siphonina australis* Cush.			×	×	×				×							
53. *Siphonodosaria* spp.						×	×					×			×	
54. *Sphaeroidina bulloides* d'Orb.		×	×	×				×		×		×				
55. *Technitella legumen* Norman										×						×
56. *Textularia* cf. *zeaggluta* Fin.								×								
57. *Trochamminoides* cf. *irregularis* (White)					×											
58. *Uvigerina canariensis* d'Orb.						×										
59. *Uvigerina dorreni* Fin.									×							
60. *Vaginulina elegans* Cush.										×						
61. *Vaginulina legumen* Linné								×								
62. *Vaginulinopsis hochstetteri* (Stache)	×			×												
63. *Valvulineria* cf. *saulcii* d'Orb.										×						