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10

The Middle Waikato Basin and Hills

M J SELBY AND D J LOWE

INTRODUCTION

The middle Waikato (or Hamilton) Basin is a roughly oval-shaped depression more than 80 km north to south and more than 40 km wide. The basin, except in the south, is almost completely surrounded by ranges up to 300 m high, broken by only a few gaps. In the south the basin floor rises gradually and merges with the dissected plateaux of the King Country.

South of Te Awamutu the floor of the basin consists of rounded hills rising 30 to 60 m above the narrow flood plains of the numerous small streams which drain the region. Northward the relief is lower; the rounded hills are more widely spaced and protrude through an extensive alluvial plain. In the middle part of the basin this plain is the dominant feature of the landscape and protruding hills are few and small.

The Waikato is the largest river of the basin. It enters the basin in the Maungatautari Gap through the southeastern ranges and flows in an entrenched course which becomes progressively shallower towards Taupiri Gap, through which the river leaves the basin. The main tributary of the Waikato is the Waipa River which rises in the Rangitoto Ranges and joins the Waikato at Ngaruawahia.

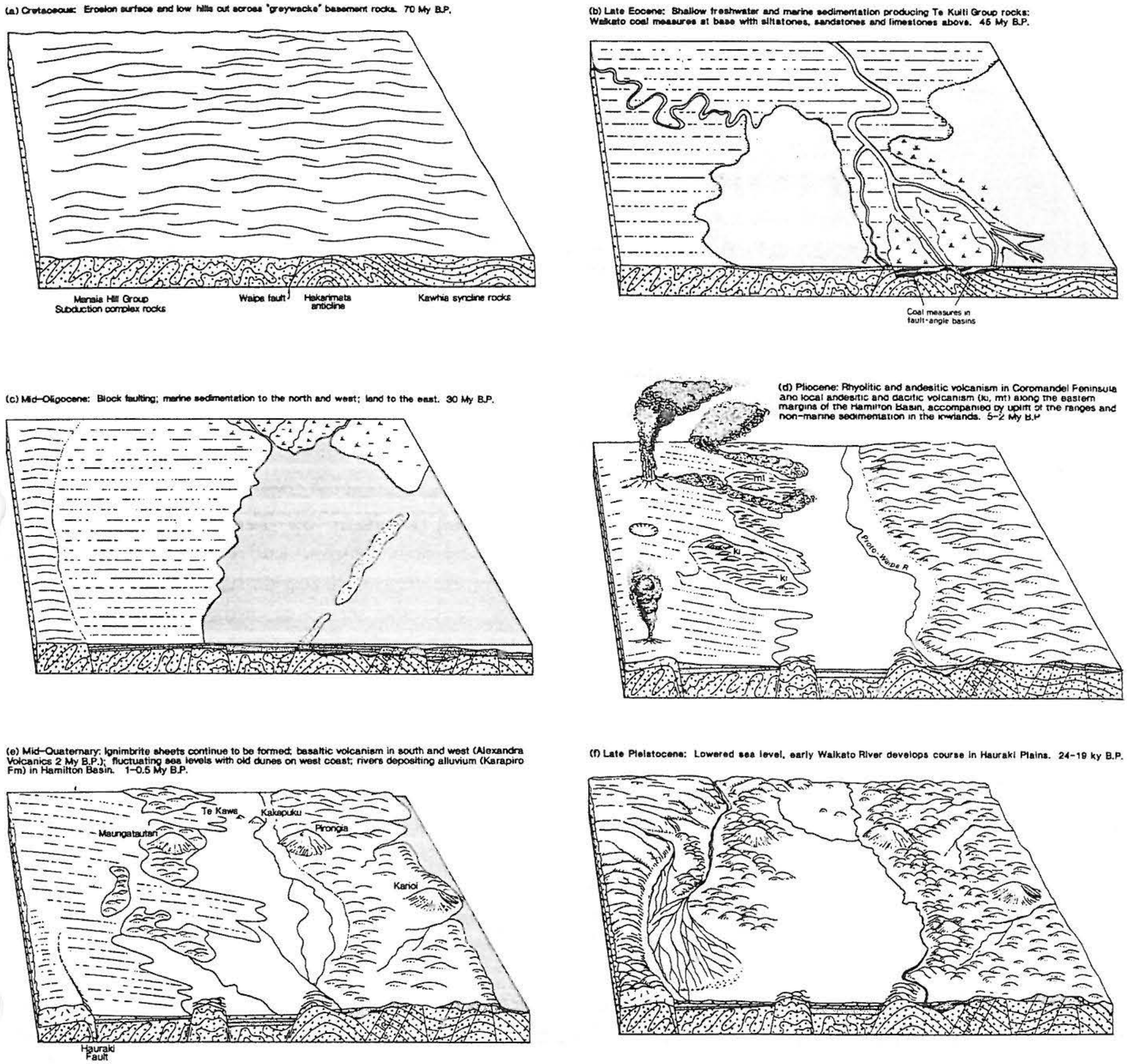
The hills to the west and east are composed of 'greywacke' sandstone, siltstones, and conglomerates. In the west these Triassic and Jurassic rocks are overlain by Tertiary coal measures, sandstones, siltstones, and limestones. In a few places Pliocene-Pleistocene basaltic volcanoes and lava sheets and scoria mounds have been injected through the sedimentary rocks and emplaced over them. To the east, any Tertiary rocks which may once have been overlying the greywacke have been stripped away and volcanic rocks occur only as small cones on the Pakaroa Range.

The geomorphic development of the basin and hills can best be understood from its geological history which has been described by Schofield (1967a), Kear (1967), and Kear and Schofield (1978). This geological evolution is depicted in seven schematic diagrams (Figures 10.1(a)–(g)) summarising the relationships between geological events and landforms.

DEVELOPMENT OF THE BASIN

Tectonic Development, Volcanism, and Basin Infilling

The pre-basin history is shown in Figures 10.1(a)–(c) which cover the period from c70 to 30 million years ago. The middle Waikato Basin then began to take on aspects of its present form in early Pliocene times when, during the Kaikoura Orogeny four to five million years ago, faulting and differential uplift caused the basin to remain a



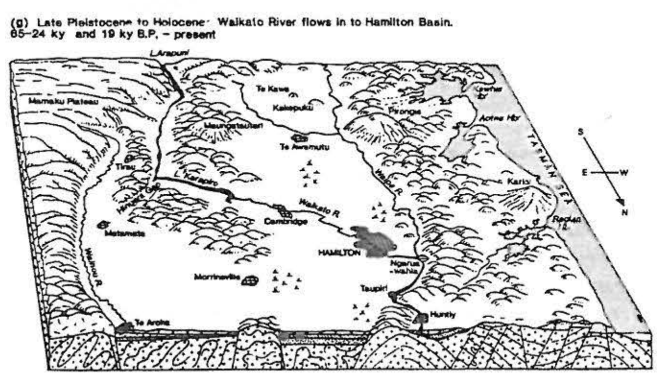


Figure 10.1 Generalised geological evolution of the Waikato region. The key is shown in diagram (g).

relatively depressed graben while the Raglan Hill blocks to the west, and the Hapuakohe-Hangawera-Pakaroa-Maungakawa Hills to the east, were uplifted as horsts and gently tilted. Faulting along the margins of the horsts was later accompanied by outbreaks of volcanic activity, including emplacement about 5.6 My BP of the andesitic Kiwitahi Volcanics (Figure 10.1(d)) which consist of the three deeply eroded and aligned (305°) cones of Kiwitahi, Maungakawa, and Te Tapui (Briggs, 1986). Later, at about 1.8 My BP, the isolated andesite-dacite composite volcano of Maungatautari was erupted to the south.

Basaltic eruptions produced the low-angle composite cones of Te Kawa, Kakepuku, Pirongia, and Karioi, which have been dated at between 2.74 and 1.60 My BP (Briggs *et al*, 1989). Constructed mainly of thick lava flows and volcanic breccias, these notable volcanoes lie on a remarkably straight, northwesterly-orientated (300°) line (Figure 10.2), although there is no known surface fault with this orientation in the Waikato region. Based on the apparent decrease in degree of erosion from Karioi to Te Kawa (ie, NW to SE), it was suggested that the stratovolcanoes become progressively younger to the southeast. However, radiometric data now indicate that Karioi, Pirongia, Kakepuku, and Te Kawa have broadly similar ages and do not young in any direction (Briggs *et al*, 1989). Numerous basaltic scoria cones and associated thin lava flows and tuff rings, forming the Okete Volcanics, were erupted in the region south of Raglan, chiefly around the flanks of Karioi and Pirongia; their ages (2.69–1.80 My BP) overlap with those of the large stratovolcanoes. All these basaltic volcanoes and associated deposits are collectively referred to as the Alexandra Volcanic Group (Briggs, 1986). Their peculiar petrology is described by Briggs and McDonough (1990).

Pirongia has a complex and long volcanic history with an age of 1.60 My BP at the summit and 2.74 My BP on its southern slopes — ie, spanning the entire duration of the Alexandra Volcanics. It

Figure 10.2 Oblique aerial view of the northwesterly (300°) alignment of the Alexandra Volcanics in the southern part of the Hamilton Basin. The crater of Te Kawa (214 m asl) is in the foreground, the cone of Kakepuku (449 m) is in the middle distance, and the larger low-angle cone of Pirongia (859 m) is on the skyline. Mt Karioi (756 m) is obscured directly behind Pirongia. The distance from Te Kawa to Pirongia is 20 km (from Briggs, 1983). (R R Julian)

rises 959 m above sea level and its dissected flanks spread across the Waipa Fault Scarp which separates the Hamilton Basin from the Raglan Hills, indicating that it has developed since the major vertical displacements occurred in the basement rocks (Figures 10.1(e), 10.2 and 10.3).

While the horsts were rising, the basin was still occupied by a shallow arm of the sea and marine Pliocene beds record this period. During the whole of the Quaternary (from about 1.8 My BP to the present) terrestrial deposits have been formed indicating that the sea had receded by the end of Pliocene times (Nelson *et al*, 1988; Figure 10.1(e)). Early Quaternary terrestrial formations occur at the surface in many parts of the Hamilton area: they form the many prominent low hills which rise above the surface of the alluvial plain. The oldest of these deposits is the Puketoka Formation which contains both well-sorted, pale-grey pumiceous clays, sands, and breccias and also unsorted beds which are the distal portions of rhyolitic ignimbrite sheets. Such ignimbrite deposits are also recognised in drillcores from the Ohinewai area near Huntly, and from exposures near Port Waikato (Nelson *et al*, 1988; 1989) (see chapter 11 for a discussion on ignimbrites). The Waerenga Gravels are rather younger and consist of weathered greywacke debris which was probably deposited in fans extending from the surrounding ranges. Still younger is the Karapiro Formation; it is composed of current-bedded rhyolitic sands and gravels which are often strongly weathered and hence are clayey. These three formations — the Puketoka, Waerenga Gravels, and the Karapiro — together form the Walton Sub-Group, a division of the Tauranga Group as defined by Kear and Schofield (1978).

The bulk of the Walton Sub-Group beds were laid down by both braided and meandering streams from the south and the surrounding ranges, or as lacustrine deposits. They probably formed a multiple low-angled fan surface, with little relative relief, which occupied the floor of the Hamilton Basin. When deposition of these beds ceased, the streams began cutting down and formed a very dissected landscape with hills some tens of metres high. This landscape probably existed with only slight changes for thousands of years, for the Karapiro Formation deposits are strongly weathered where they are exposed, suggesting that there was a prolonged period of soil formation after their deposition.

Quaternary Tectonism

There is little evidence of major faulting episodes in the middle Waikato Basin since the late Tertiary. However, the influence of tectonism in the Quaternary period is recorded by at least 400 m of vertical movement on the Hauraki Fault, which marks the eastern margin of the Hauraki Plains and the uplifted Kaimai Range (Figure 10.1(e)), between 0.84 and 0.14 My BP (Houghton and Cuthbertson, 1989). The only major active fault known in the Waikato region is the Kerepehi Fault which runs NNW through the centre of the Hauraki Plains as far south as Okoroire. Vertical fault movements, in the form of at least four paleoearthquakes, amount to about 1.6 m of displacement over the past 10 700 years (de Lange and Lowe, 1990), and support other geological and geophysical evidence that the Hauraki Plains lie in a zone of active continental rifting (see chapter 1).

Tephra Deposits

During the Quaternary period of basin infilling by the fluvial, lacustrine, and ignimbrite deposits, and their subsequent erosion to form a hilly landscape, a series of airfall tephra (or volcanic ash) layers was deposited. Volumetrically, most of these were erupted from the large rhyolitic caldera volcanoes of the Taupo Volcanic Zone (see chapter 11), but tephras derived from the andesitic stratovolcanoes of the Tongariro and Egmont Volcanic centres, and the offshore volcano of Mayor Island (Tuhua Volcanic Centre), have also been recorded (Lowe, 1988).

The lowest, and hence the oldest, of this sequence of tephra deposits is a group of strongly weathered, clay-rich, rhyolitic beds collectively named the Kauroa Ash Formation (Ward, 1967). Much of this formation has been removed by erosion and in the basin it is seldom thicker than 1–2 m, but near Raglan it may be up to 9 m thick

Figure 10.3 The western boundary of the Hamilton Basin near Whatawhata. The Waipa Fault Scarp forms a steep break between the undulating topography on early Quaternary sediments in the foreground and the higher greywacke hills capped by Tertiary sediments beyond. (M J Selby)

and comprises up to 15 beds (K1–K15 from bottom to top) with 10 associated paleosols (Kirkman, 1980; Briggs *et al*, 1989). Stratigraphic interfingering of some of the Kauroa Ash beds with radiometrically-dated Alexandra Volcanics has enabled the earliest member, K1, to be dated at 2.3 My BP; K12 is dated at about 1.8 My BP and the youngest bed, K15, is estimated to have been deposited about 1.5 My BP, or later. Where it is preserved, the uppermost bed (K15) has an extremely prominent buried paleosol, dark reddish-brown in colour with a strongly developed blocky or prismatic structure, which represents the tiny remnants of an old land surface that persisted, apparently, for perhaps as long as a million years.

Limited exposures in the Hamilton Basin indicate that some members of the Kauroa Ash Formation overlie and interfinger with the Puketoka and Karapiro Formations, but more evidence is required before a definitive chronostratigraphy can be erected for all these formations.

Briggs *et al* (1989) suggested that the Kauroa beds represent a series of early, widespread rhyolitic eruptions from the Taupo Volcanic Zone, but could not rule out alternative sources in the southern Coromandel Volcanic Zone where volcanism was active at around the same time.

After a long period of erosion, which stripped away most of the Kauroa Ash beds and some of the weathered sediments below them, another tephra mantle from 3–5 m thick was deposited on the landscape marked, in places, by the prominent paleosol on K15. This group of tephra deposits, known as the Hamilton Ash Formation, is made up of at least eight separate beds labelled H1 to H8 from bottom to top, respectively. The oldest bed (H1) is typically pale greyish brown and has a sharp lower boundary marked by a coarse yellow sandy layer forming a prominent marker bed. Based on tentative correlations with other tephra deposits in the Central North Island, and in deep sea cores, H1 is estimated to be aged about 350 000 years old (Nelson, 1988). The overlying Hamilton Ash beds are usually strongly-weathered, clay-textured, and friable to firm with reddish-yellow to strong brown colours. The age of these beds is unknown, but the presence of some paleosols suggests that the eruptions which produced the tephra layers were spread over many thousands of

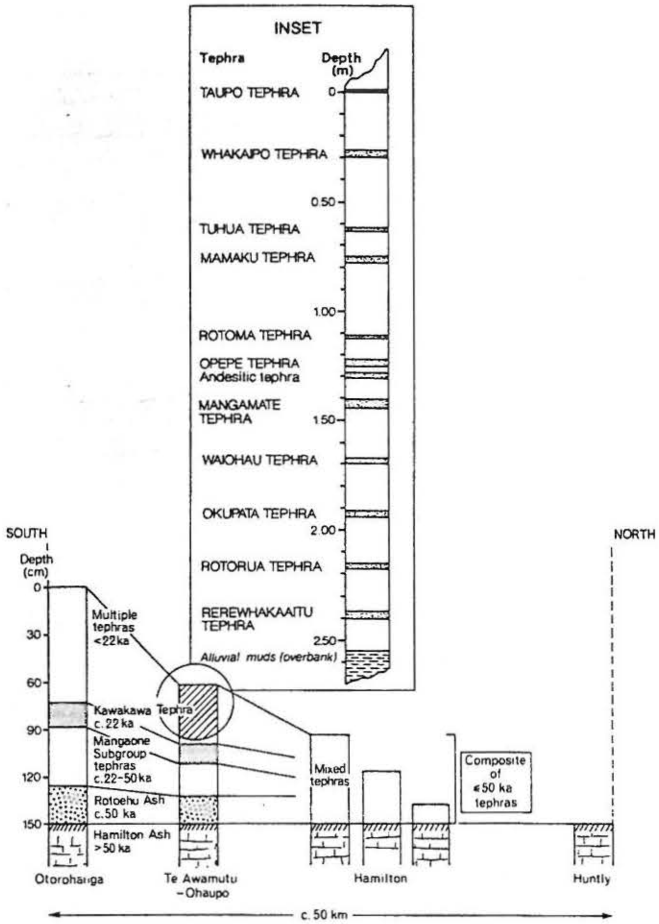


Figure 10.4 Transect across the Hamilton Basin showing the simplified stratigraphy and age of late Quaternary tephra deposits overlying Hamilton Ash on the low hills. Marker beds are distinguishable in the field in the south (Otorohanga and Te Awamutu-Ohaupo profiles) but around Hamilton the tephra deposits, thinning away from their sources, become intermixed to form a composite cover bed with no distinguishable marker beds. Where this cover bed is eroded, exhumed Hamilton Ash occurs at the surface, as for the Huntly profile, but thin late Quaternary tephras are present further north towards Auckland. The inset shows the stratigraphy of prominent tephra layers preserved in lake sediments in a core from Lake Maratoto, a 17 000-year-old peaty lake about midway between Ohaupo and Hamilton (see Figure 10.5). It indicates potential contributions of specific tephras as probable parent materials in the upper soil profile (hatching). ka = 1000 years BP. After Lowe (1986).

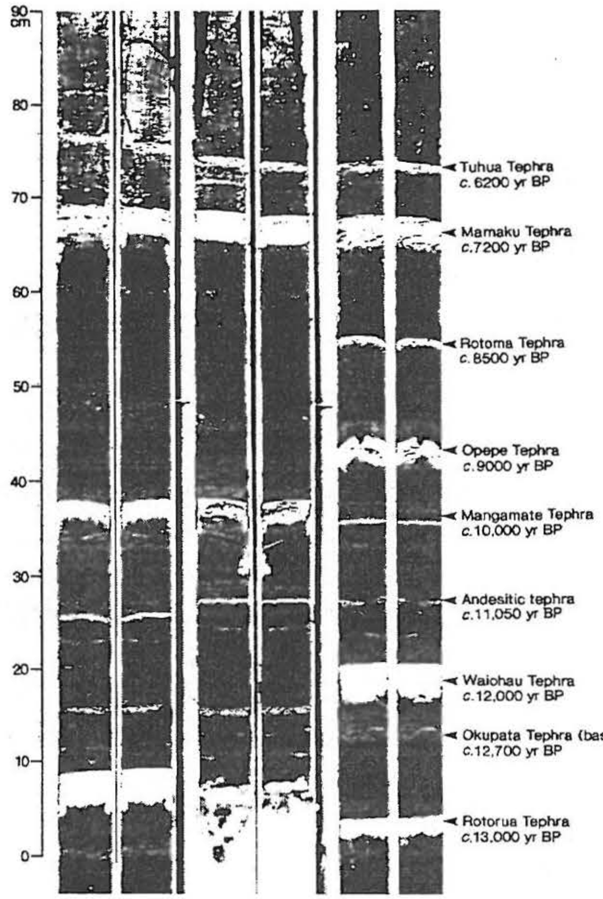


Figure 10.5 Three longitudinally sliced cores from Lake Rotomanuka (near Ohaupo) showing prominent, compact ash-grade tephra layers preserved within dark, fine-grained organic lake sediment. Additional thin tephra layers are present but are indistinct or not visible. From Lowe (1988). (R R Julian)

years, including some long periods without eruptions. The youngest bed in the sequence, H8, is estimated to be aged about 100 000 years old. The Hamilton Ash beds are of rhyolitic composition (Shepherd, 1984). They extend over a very large area (see chapter 2) and similar beds have been observed in places as far apart as Henderson and Wellington, Gisborne and Raglan. If these beds have a common origin, probably in the Taupo Volcanic Zone, the eruptions which produced them must have been of enormous power. North of Hamilton City the beds are thin and of patchy distribution, probably because of erosion. Where the Hamilton Ash materials are exposed at the surface, well-developed and strongly-structured, clayey soils occur.

Overlying the Hamilton Ash beds is an airfall cover bed, usually between 0.5 and 1.5 m thick, comprising multiple tephra layers that have accumulated over the past 50 000 years to the present day. This late Quaternary cover bed caps many of the low hills and is a composite of more than 40 individual distal tephra layers, each a few millimetres to centimetres in thickness, that were erupted from six rhyolitic and andesitic volcanic centres located about 70–200 km from the middle Waikato Basin (Lowe, 1986, 1988). At sites to the east and south of Hamilton, where the tephra cover bed deposits are usually 1 m or more thick, some of the constituent tephra layers are of sufficient thickness to be recognisable in the field. These include the basal tephra layer, Rotoehu Ash, aged about 50 000 years, and Kawakawa Tephra, aged about 22 000 years old and deposited at the approximate midpoint of the late Quaternary tephra column (Figure 10.4). At many sites, however, and particularly to the north of Hamilton where they have 'collapsed' or 'telescoped' down to only about 0.5 m in total thickness, the individual tephras making up the composite cover bed deposits have been weathered and blended together by soil-forming processes, especially bioturbation, so that their original character has been almost completely masked. In addition, these shallow cover bed deposits have undergone weathering in a wetting and drying environment because of restricted drainage (due to the underlying impermeable paleosol on Hamilton Ash beds) and a seasonal moisture deficit that commonly occurs north of Hamilton, so that they have lost many of the characteristics evident in the equivalent tephra deposits in the Ohaupo-Te Awamutu area. Instead of being yellowish-brown, friable (allophanic) deposits with sandy loam–silt loam textures and low bulk densities as at Ohaupo, they are brownish, firm (halloysitic) deposits with silt loam–silty clay loam textures and compact, high bulk densities (Parfitt *et al*, 1983; Lowe, 1986). Different proportions of andesitic to rhyolitic material may also have influenced weathering and argillisation in the late Quaternary tephra cover beds (Lowe, 1986). Together with Hamilton Ash materials, exposed where the cover bed deposits have been lost entirely through erosion (Figure 10.4), the late Quaternary tephra deposits form the main parent materials for the soils on the low hills, and are thus of great economic importance.

Some of the tephras underlie, or are incorporated in, the alluvium and lake and peat deposits which were formed during the period of cover bed accumulation of the last 50 000 years (Green and Lowe, 1985). The identification of the tephras younger than about 20 000 years old making up the cover bed deposits has been made possible by the study of numerous cores taken from the lakes that form an important feature of the Waikato landscape (see section on lakes below). The cores contain a succession of tephra layers preserved within organic lake sediment (Inset, Figure 10.4; Figure 10.5) and, once correlated and radiometrically dated by laboratory 'fingerprinting' techniques, have provided the basis for a comprehensive record of late Quaternary tephra fall and distribution in the middle Waikato Basin (Lowe, 1988).

The tephras are of considerable geomorphic importance because they make it possible to estimate the extent of hillslope erosion since they were deposited. Tephra units cover virtually all hillslopes with inclinations of less than about 12°, suggesting that erosion processes have been of limited power for a long period, and that on such slopes they are largely confined to solution processes. Slopes steeper than about 12° seldom have intact tephra units on them and are clearly characterised by erosion and thinner soils. In many places this erosion appears to have been predominantly by deep rotational slumping, but elsewhere may be largely confined to soil creep.

Another geomorphic application of the tephra deposits is that they provide time-stratigraphic marker beds in multidisciplinary studies on paleoenvironmental changes utilising cores from the Waikato lakes and bogs, as described in later sections. The tephras facilitate the correlation of such changes both regionally and nationally using principles of tephrochronology (see chapter 2).

The Hinuera Formation and Surface

During most of the Quaternary the main river draining the middle Waikato Basin was probably the Waipa River. It may have been able to maintain its outlet through the rising Hakarimata Range to form the Taupiri Gap, but there is little surviving evidence of the drainage pattern of early Quaternary times. The Waikato River drains Lake Taupo and much of the northern part of the Central Volcanic Region with its ignimbrite flows and airfall tephra-mantled surfaces. The original outlet of the Waikato River to the sea was through the Hauraki Lowlands. It was recognised by Healy (1945) and earlier geologists that an early Waikato River drained through the valley now occupied by the Arapuni hydrolake and into the Hauraki Plains through the Hinuera Gap. This gap is still fringed by river cliffs which are similar to those of present river gorges also cut in ignimbrite, and its floor is formed on alluvial sands and gravels of the Hinuera Formation (Figures 10.6 and 10.7). The earliest known deposition of Hinuera Formation sediments in the Hauraki Plains was between 140 000 and 50 000 years ago because remnants from this depositional episode overlie Mamaku Ignimbrite (aged 140 000 years* old) and are covered by the 50 000 year-old Rotoehu Ash (Houghton and Cuthbertson, 1989). Sparse radiocarbon dates indicate that a second period of deposition began about 24 000 years ago and ended about 19 000 years ago (Hogg *et al*, 1987), producing an extensive Hinuera Surface evident in the Hauraki Plains today that is marked by two major systems of paleochannels from both the ancestral Waikato and Waihou rivers (Figure 10.1(f)) (Houghton and Cuthbertson, 1989).

In the intervening period, the ancestral Waikato River flowed into the Hamilton Basin, with the earliest-known deposition beginning after 65 000 years and before 45 000 years ago but ceasing by about 24 000 years ago when the river evidently returned to flow through the Hauraki Plains (McGlone *et al*, 1978; Hogg *et al*, 1987). Sometime around 19 000 years ago the Waikato River had built up its sediments to such a thickness in the area of Piarere, at the western end of the Hinuera Gap, that the river diverted its channel back into the Hamilton Basin through the Maungatautari Gorge east of Cambridge (Figure 10.7). The most active phase of deposition of the Hinuera sediments in the Hamilton Basin occurred between 19 000 and 17 000 years ago (Hogg *et al*, 1987), coinciding with the coldest part of the Last Glacial (Otira) when the region was largely unforested. Sedimentation slowed dramatically after about 15 000 years ago when it finally ceased, coinciding with regional reafforestation and climatic amelioration. At the same time the Waikato River stopped building up its flood plain and began entrenching itself into its present course (Figure 10.1(g)). Thus, the course of the Waikato River has alternated between the Hauraki Plains and Hamilton Basin at least four times in the past c 100 000 years.

South of the Hinuera Gap towards Arapuni the Hinuera Formation occurs in two sets of high-level terrace remnants which converge down river towards the gap. The older and higher surface is regarded as that of the earlier Hinuera deposits emplaced before about 24 000–19 000 years ago, and the lower and younger surface represents deposition after then. The term 'Hinuera Surface' was given to the single extensive alluvial plain in the Hamilton Basin and Hauraki Lowland (Schofield, 1965), and applies to all the depositional surfaces of the Hinuera Formation, regardless of age. In the Hamilton Basin, where the pre-19 000 years Hinuera deposits are entirely buried, the Hinuera Surface is about 15 000 years old; in the Hauraki Plains it is about 19 000 years old apart from the small area where the surface of the Hinuera sediment pre-dates 50 000 years, as noted previously. A composite cover bed of multiple airfall tephra layers, now intermixed, has accumulated on the Hinuera Surface since active alluvial deposition ceased (Lowe, 1986, 1988), and is equivalent to the upper part of the late Quaternary tephra mantle covering the low hills. The cover bed of tephras on the Hinuera Surface, sometimes patchy and probably reworked in places, is generally thicker (about 0.7 m thick) in the Hauraki Plains than in the Hamilton Basin (about 0.4 m thick).

The sediments making up the Hinuera Formation are dominated by quartz, feldspar, rounded rhyolitic rock fragments, pumice, and heavy minerals (Hume *et al*, 1975). They have been aptly described as volcanogenic and were probably derived in large part from the erosion products of ignimbrite and airfall tephra deposits associated with voluminous eruptions including those of the Mamaku Ignimbrite (0.14 My BP), Rotoiti Tephra (c 50 000 years ago), Mangaone Subgroup tephra formations (c 45 000–28 000 years ago), Kawakawa Tephra (22 000 years ago), Te Rere Tephra (21 000 years ago), and Okareka Tephra (c 18 000 years ago) and later deposits

* Mamaku Ig. 220,000 - 230,000 BP

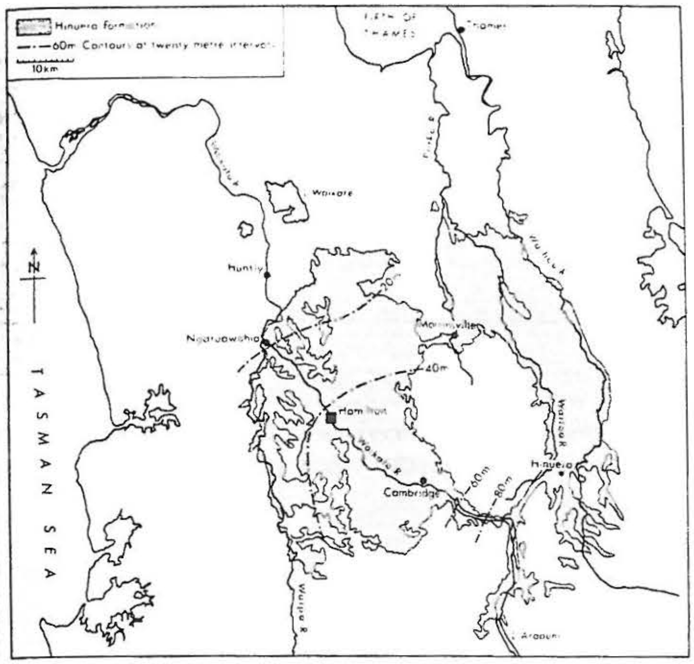


Figure 10.6 The areal extent of the Hinuera Formation in the Hamilton Basin and the Hauraki Plains. After Hume *et al* (1975). Contours indicate the fan form.

(Froggatt and Lowe, 1990). Vigorous volcanic activity may have had two effects: it could greatly increase the supply of debris to the rivers of the Central Volcanic Region; and it may have destroyed much of the vegetation in areas close to the eruptions, so that accelerated erosion of older soils and pyroclastic deposits may have increased the debris load of the rivers.

The Hinuera deposits in the Hamilton Basin have been likened to those of an alluvial fan with its apex in the Maungatautari Gap and its distal margin forming an extensive arc along the line of the Waipa River and the edge of the Hapuakohe Range to the north (McCraw, 1967). In the Hauraki Plains the apex is in the Hinuera Gap. This fan does, however, have many features which make it unlike most other fans. A significant feature is the very gentle slope on the surface. Near the apex this is only 0°60′, and on the main body of the fan less than 0°30′. Slopes of this order are usually more characteristic of floodplains than of fans. A second difference is that streams passing

Figure 10.7 The Hinuera Gap seen from west of the elbow in the Waikato River and looking towards the Hauraki Plains. The line of the Gap is indicated by the arrow. (M J Selby)

over the apex of a fan usually deposit their coarsest bedload material there, and their bedload deposits become finer grained towards the periphery of the fan. In the Hinuera deposits there is no overall decrease in the mean grain size of sediment between Cambridge and Taupiri. The grain sizes range from small pebbles to medium silts with the most common particles being of coarse and very coarse sand size. The sediments are strongly cross-bedded with individual cross-beds having heights of 20 cm or less and a lunate dune form, implying that they were formed in the bedload material of a shallow braided channel (Hume *et al*, 1975).

When the characteristics of the sediments and the geometry of the fans are considered together, it becomes apparent that the Hinuera fan in the Hamilton Basin was built up by multiple braided channels which migrated laterally across the fan surface, so building it to a uniform height and slope. The suspended sediment in these ancient channels was carried through the Hamilton Basin and has been deposited either in the lower

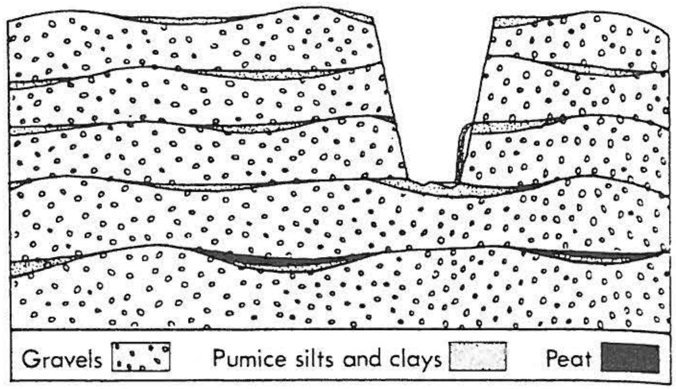
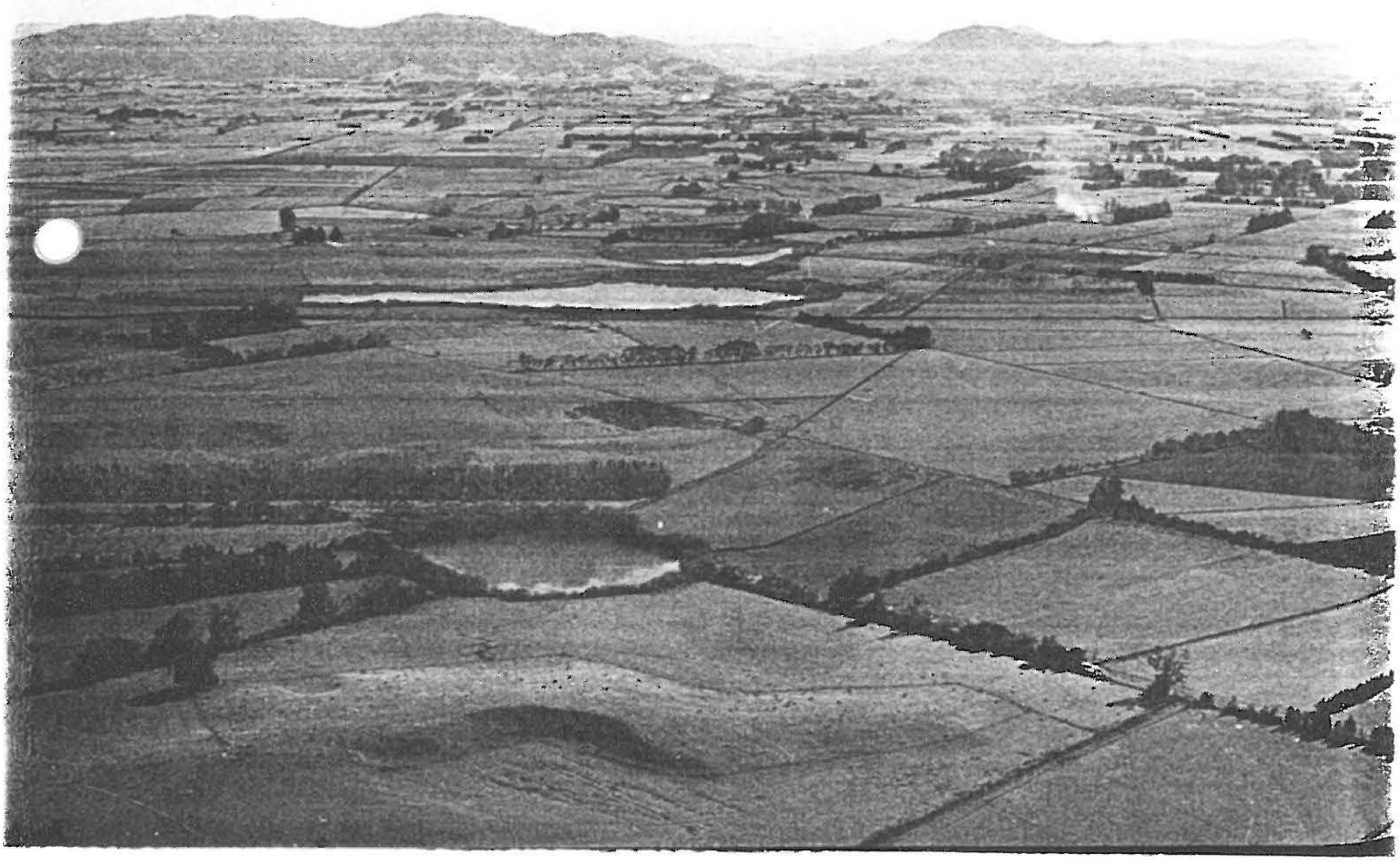


Figure 10.8 A schematic section through Hinuera Formation sediments in the region of Hamilton. After McCraw (1967). The sediments may be up to 100 m in thickness.

Figure 10.9 Topography in the Hamilton Basin near Taupiri. In the foreground, low undulating hills are formed on early Quaternary sediments and at their foot are lakes and drained peat bogs formed at the end of the Hinuera depositional phase. In the background is the Hakarimata Range, to the left, and the Taupiri Hills to the right. Between these two hills is the Taupiri Gap. (M J Selby)



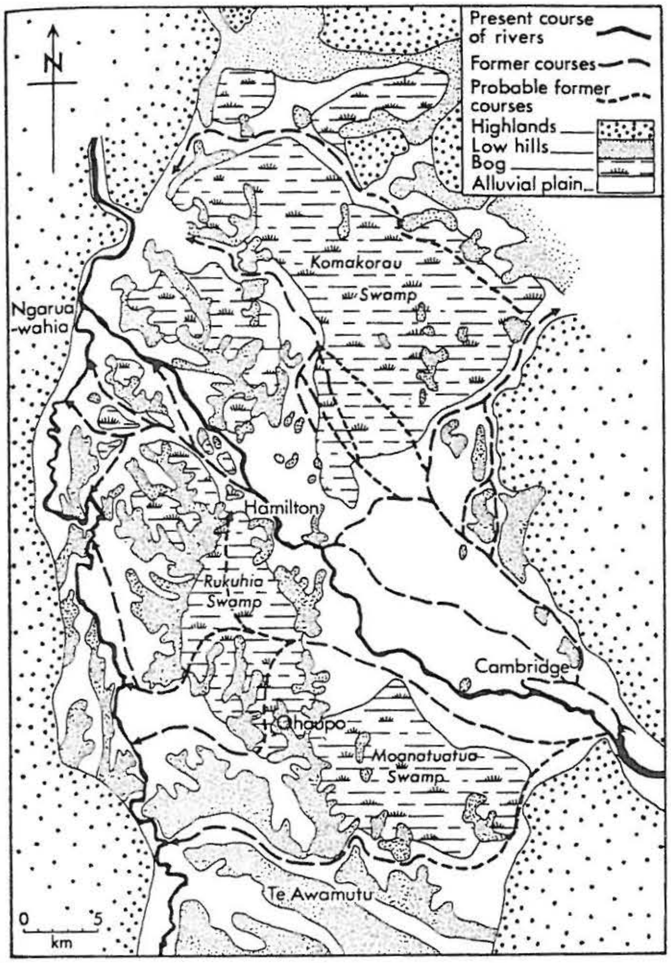


Figure 10.10 The Hamilton Basin, showing the main topographic features and the old courses of the Waikato River. After McCraw (1967).

Waikato Basin around Mercer or in the Tasman Sea. The braided channels seldom overtopped their banks and left few flood deposits, except during the final stages of aggradation where they are preserved near the top of stratigraphic sections following the end of Hinuera deposition.

The bedding of the Hinuera sediments has had some important consequences. Abandoned braided channels became hollows in which white to pale grey impervious silt could accumulate, so that the upper part of the Hinuera deposits contain lenses of these silts separated from each other by the gravels of point bars and bedform dunes. In places peat also grew in the hollows of abandoned channels and now parts of the deposits are gravels containing lenses of silt and peat. At the surface this variety of materials, together with the thin mantle of airfall tephra deposits, has produced a range of parent materials for the soils of the area with poorly drained silt-filled hollows and permeable, well drained gravelly ridges (Lowe, 1986; Singleton *et al*, 1989).

As the Waikato River fixed itself in its present channel during the period of incision beginning after 15 000 years ago, tributary drainage channels formed and cut back as steep-sided gullies dissecting the fan surface. These gullies cut through the peat and silt lenses. Engineers and householders have been set many problems by this depositional pattern. The silt lenses prevent soil drainage and promote spring seepage in walls of gullies; this promotes landslides on the edges of gullies, particularly where storm water has been diverted into sumps, which allows water pressure to build up so that seepage towards a gully face is under high hydrostatic pressure. Buildings and roads close to gully faces thus have to be protected by deep drains through silt lenses (Figure 10.8).

The apex of the Hinuera fan is near the south-eastern corner of the Hamilton Basin and the sediments there are so thick that they bury the old undulating or hilly relief cut upon the beds of the Walton Sub-Group deposits. Northward the Hinuera Formation gets thinner until, near the Waipa River and near Taupiri, it is too thin to bury the old topography. The relief of the basin thus gets increasingly hilly to the west and the north. The relief of the basin is directly dependent upon the geological history (Figure 10.9).

The Hinuera Formation, together with the Hauraki Clay (found in the lower Hauraki Plains) and the Taupo Pumice Alluvium (described below), make up the Piako Sub-Group of the Tauranga Group (Kear and Schofield, 1978).

Old River Courses and Lakes

The landforms of the basin and the soil pattern on them have been described in detail by McCraw (1967). The fan of the Hinuera deposits has formed, like other alluvial fans, by the migration of stream courses across its surface and by the frequent blocking of one channel and the development of another (Figure 10.10). Many of these old courses can still be recognised. Old river beds,

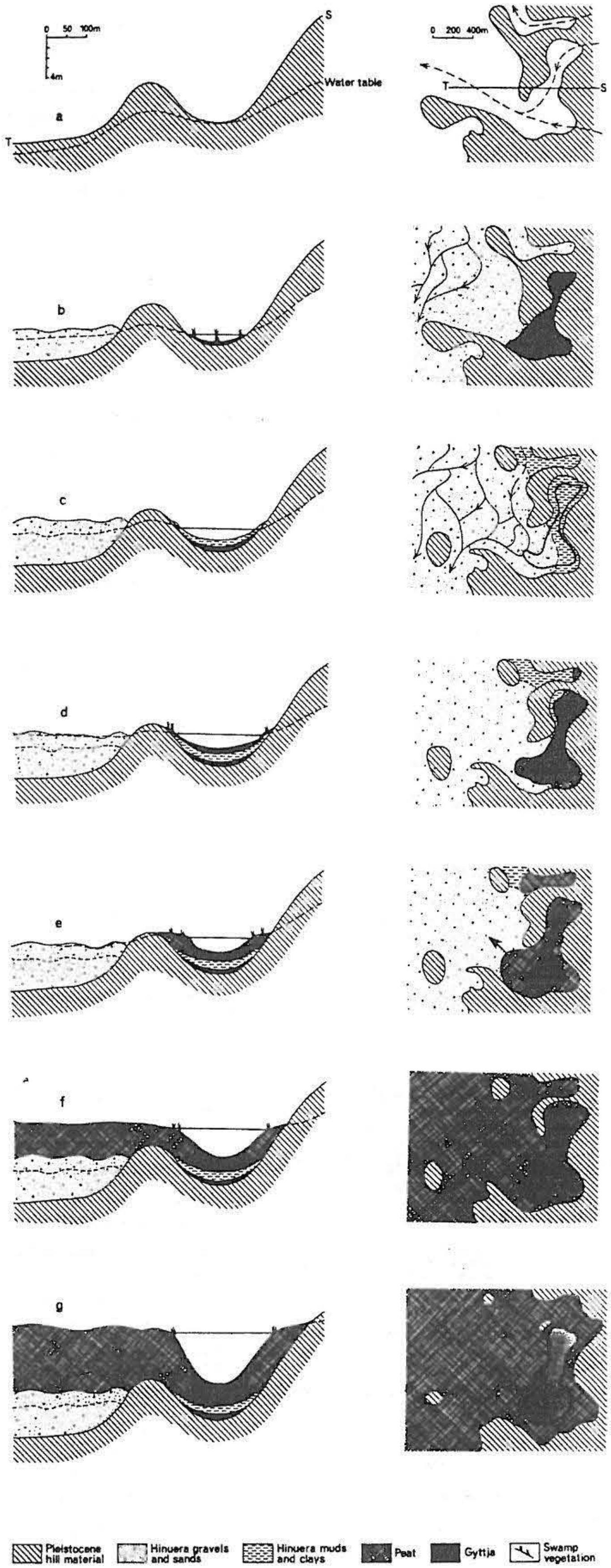


Figure 10.11 The developmental history of Lake Maratoto (bold outline) and adjacent Rukuhia bog. Cross-sections have a vertical exaggeration of X25. Many other Waikato lakes were formed in a generally similar way. From Green and Lowe (1985).

(a) *Before c 17 000 years ago.* Valley in Pleistocene hills draining to the southwest and west. Clear area represents land below c 40 m contour.

(b) *17 000 years ago.* First phase of Hinuera deposition in the area. Proto-Lake Maratoto forms by damming of the valley by alluvium. Basin swampy or with only very shallow water.

(c) *16 300 years ago.* Second phase of Hinuera deposition in the area. Coarse sediment deposited in valley mouth, fining to muds and clays at the head of the valley. Lake Maratoto forms, c 2 m deep. Lake water clear. No peat, and sparse vegetation in catchment.

(d) *16 300 to 14 000 years ago.* Initial lake development. Lake sediment olive-grey, low in organic matter; darkens later in the period because of development of marginal peat (at 15 200 years ago) and catchment vegetation. Water clear, still c 2 m deep.

(e) *14 000 to 10 000 years ago.* Marginal peat and swamp vegetation encroaches into lake and reduces its surface area by half at c 13 000 years ago. From 13 000 to 10 000 years ago, lake area expands again and water deepens. Main body of Rukuhia bog begins growth at c 11 000 years ago, and the peat growing westward (arrow) from the lake contributes to this development. Sediment is dark brown-black of high organic content because of peat growth and extensive catchment vegetation. Lake becomes acid with brown water, 2.5 m deep at 10 600 years ago.

(f) *10 000 years ago to present.* Rukuhia peat bog expands, most rapidly after c 7000 years ago. Water deepens as rate of peat growth is much greater than rate of sedimentation in the lake. Water depth perhaps 3.5 m at 7000 years ago, 6.5 m at 2000 years ago. Lake area gradually expands but is never larger than at present. Lake water acid and brown.

(g) *Present day.* The lake basin is formed in the surrounding peat, perched above and divorced from the initial lake basin in the valley floor. Area and depth (7.1 m) of lake at maximum.

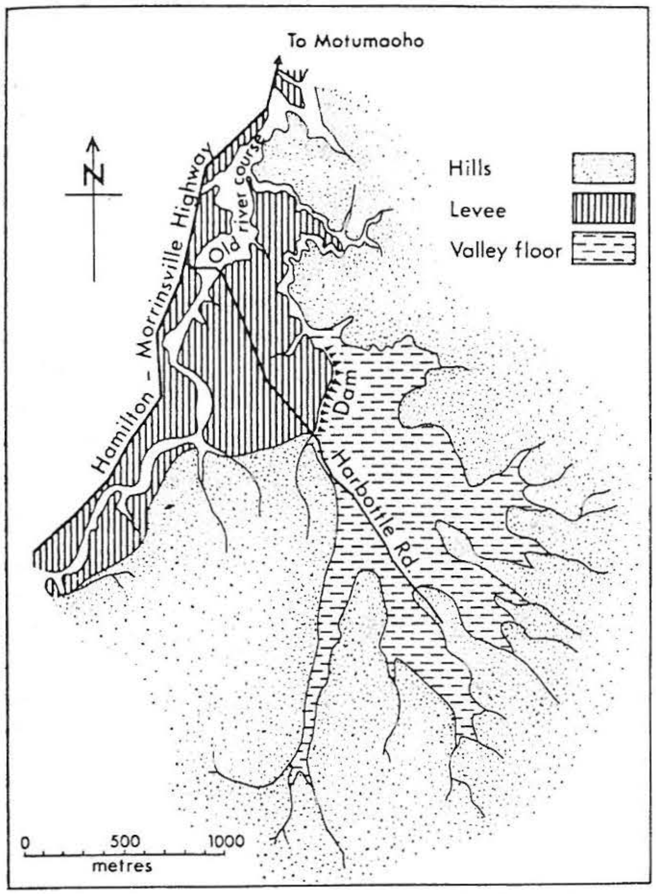


Figure 10.12 A dammed valley south of Motumaoho. After McCraw (1967).

incised several metres into the surface, run from Cambridge through Tauwhare to Morrinsville and from Puketaha through Gordonton to Taupiri. Elsewhere, old channel bars, point bars, and levees stand above the main surface of the fan. As bars and levees formed they impounded water behind them to form what are described as lateral lakes (refer to chapter 5). In most cases the water formed lakes in the embayments of the hills protruding through the Hinuera Surface. Such lakes are numerous in the middle Waikato Basin, and include Lakes Kainui ('D' Lake), Rotokauri, Rotoroa (Hamilton Lake), Maratoto, Rotomanuka, and Ngaroto. Radiocarbon dates from sediment cores of many of these lakes, together with tephrochronology, show that they formed at much the same time, between about 18 000–15 000 years ago during the final stages of Hinuera Formation deposition (Lowe and Green, 1987; Lowe, 1988). Several short-spaced episodes of alluvial deposition are evident in the formation of some of the lake basins, as illustrated for Lake Maratoto near the Hamilton Airport (Figure 10.11; Green and Lowe, 1985). Elsewhere, lakes were formed between two levees or in tributary valleys opening onto the plain from the surrounding hills. A good example of the latter has occurred at Harbottle Road, south of Motumaoho (Figure 10.12). The valley is about 4 km long and 1 km wide. The exit from the valley is blocked by an alluvial dam formed by a levee deposit. A lake was formed which eventually overflowed and its outlet stream drained once more into the old course of the Waikato River.

The subsequent development of many of the lakes of the Hamilton Basin has been affected by the growth of the large, deep peat bogs which formed on the Hinuera Surface (see section on bogs below). Studies on Lake Maratoto show that this lake, and others like it, was not obliterated by the peat growth around it as might be expected to occur, but instead increased in area from about 13 000 years ago to the present, probably because either drainage water from adjacent hills promoted microbial breakdown of encroaching peat, or because of erosion of peat at the lake margins by wave action, or both (Figure 10.11). Other lakes have not been directly affected by the growth of the peat bogs, although all are influenced to varying extents by local swamp development around their margins (eg, Lakes Rotomanuka, Ngaroto, and Rotokauri).

The Waipa River was several times dammed by alluvium deposited in its valley by the Waikato River. The Waipa River filled temporary lakes and then overflowed to cut new courses for itself through the dams or, as near Te Kowhai, the lake waters rose sufficiently to overflow through a low saddle in the hills west of Whatawhata and into a tributary of the Waipa. This has now become the permanent course of the river.

Post-Hinuera Events

After the deposition of the Hinuera Formation sediments had ceased, the Waikato River probably changed course several times. There is evidence that its present outlet through the Taupiri Gap was blocked for some time and that an extensive lake formed in the northern end of the basin (Figure 10.13). Waves on this lake cut narrow benches round the bases of many of the low hills which formed islands in the lake. The lake level probably rose until water overflowed through the Taupiri Gap. The river cut down and gradually incised itself into its present course, forming sets of terraces in the process. Such terraces are particularly well displayed above the shores of Karapiro hydrolake.

new para.

A low-level discontinuous terrace, up to 6 m above river level and up to 200 m wide, flanks much of the course of the present-day river. This terrace is now above flood level but about 1850 years ago most of it was inundated when the Waikato River carried and deposited huge quantities of pumice sands, silts, and gravels from the Taupo Tephra eruption. These deposits, called Taupo Pumice Alluvium, may be up to 30 m thick (Kear and Schofield, 1978). Many of the small tributary streams which had become incised into the Hinuera Surface were dammed off where they crossed the terrace, which was covered with a veneer of coarse pumice to a depth of 2 m or more. Most of the tributary streams have since cut their way through the Taupo Pumice Alluvium, but at Cambridge a lake (Te Koutu) has been preserved in one of the gullies drained by the Karapiro Stream (see Figure 5.22). Lakes Hakanoa, Waahi, and Ohinewai, near Huntly, were also formed through deposition of the Taupo Pumice Alluvium. Lake Ohinewai, however, is a 'two-storeyed' lake because the present-day lake, although formed within Taupo Pumice Alluvium, overlies organic sediments deposited in an older Hinuera Formation-dammed lake (Lowe and Green, 1987). Since the Taupo Tephra eruptive episode about 1850 years ago, the Waikato River has aggraded its bed by about 9–10 m. There is some evidence that the rate of aggradation has increased in recent years because land development in the upper reaches of the river has increased the liability of the soil to erosion (Schofield, 1967b). Sand extraction from the lower reaches of the river over the past three decades has lowered

Figure 10.13 The Taupiri Gap, through greywacke ranges. The Hakarimata Range is beyond the river and in the foreground is the Mangawhara River — a right-bank tributary of the Waikato. (M J Selby)

the river bed there, however (Fenton, 1989).

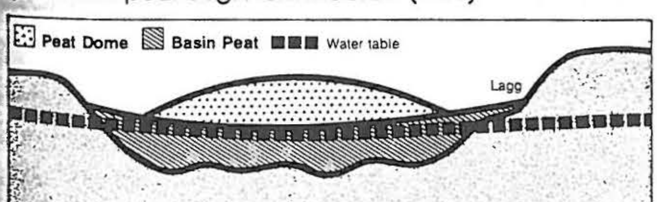
Reworking of the Hinuera deposits by local streams has taken place; radiocarbon dates on wood from deposits near Motumaoho on the Morrinsville Highway (Figure 10.12) show that such reworking occurred there 6000–7000 years ago (Hogg *et al*, 1987).

Peat Bogs

In many places in the Hamilton Basin, free drainage of water (from surface runoff, floods, and groundwaters) is impeded by levees and by impervious clays weathered from airfall tephra deposits. The resulting wet areas have, in many places, been gradually filled by vegetation and the formation of peat. There are two main kinds of bog in the area: the greater area is occupied by restiad bogs such as Rukuhia, Moanatuatua, and Motumaoho, which are of the high-moor or raised bog type; the second type is the *Cladium* bog of the low-moor or basin type, such as occurs at Hoe-o-Tainui and Whatawhata. The raised bogs of the Waikato region initially developed from small, localised patches of peat around lakes or in areas of restricted drainage on the Hinuera Surface. These patches then began expanding outwards from between 12 000 and 10 000 years ago, probably in response to an increase in net rainfall at this time, and combined to form massive bogs now up to 10 m or so deep (Green and Lowe, 1985). The fastest growth areas of the Rukuhia bog have occurred in the past 7000 years (Figure 10.11).

Raised bogs have a convex surface with a domed centre falling away steeply to a peripheral moat often marked by a small stream (the lagg) (Figure 10.14). The dominant plants on the domes of the Waikato bogs are two members of the *Restionaceae*, or jointed rushes: *Sporadanthus traversii* and *Empodisma minor* (which was previously called *Calorophus minor*). *Sporadanthus* is endemic to northern New Zealand and the Chatham Islands (Thompson, 1987). It grows as clumps of reed-like stems reaching to a height of 1.2–1.8 m. *Sporadanthus* provides shelter for the smaller plants of other species and its interweaving and branching rhizomes, anchored by stilt-like roots, support the rest of the surface vegetation. *Empodisma minor* occurs throughout New Zealand. In the Waikato bogs its slender wiry stems reach heights of 0.6 m in the open, and up to 1.2 m among the *Sporadanthus* clumps. The stems grow very densely above the surface of the bog, and beneath the surface thick masses of root hairs grow out of nearly horizontal main roots. The root hairs form a thick felted mat which is the main component of a fibrous peat. The mat retains rainwater very effectively and creates very acid conditions, around pH 3–5. In areas where the drainage pattern has been altered and the bog surface has partly dried out, manuka (*Leptospermum*) and *Gleichenia* fern have become established.

Figure 10.14 The development of a domed (raised) bog on a basin peat bog. From McCraw (1979).



The moat around the dome usually has drainage water from the surrounding hills flowing into it and hence contains more plant nutrients than the water in the centre of the bog which is derived entirely from rainfall. The plant species are therefore different and usually make a scrub with flax (*Phormium*) or a swamp-forest with stands of kahikatea (*Dacrycarpus*) on the better drained edges of the moats.

The *Cladium*, or low-moor, bogs have formed in lakes which have been cut off from a stream by deposits of alluvium. In the early stages the vegetation extends inward towards the open water and gradually covers it. The belt of plants farthest out in the water is made up of reeds up to 1 m high, while between the reeds and the edge of the lake sedges of several species (*Cladium glomerata, C. huttoni, C. teretifolium, C. capillaceum*) build up a partly floating mat of rhizomes and roots. Between the clumps of sedges other plants established themselves. As the lake silts up, the landward edges of the root mats become grounded, decaying vegetation accumulates, and the surface becomes firmer.

Table 10.1 Summary of palynology and inferred vegetation and climate in the Waikato region since c 18 000 years ago. From Newnham *et al* (1989).

*Yrs BP**	*RPAZ+*	*Key Pollen Taxa*	*Regional Vegetation*	*Climate*
0.15	5b	*Pteridium* — exotics	Cleared ground and podocarp — hardwood forest	
0.8	5a	*Pteridum* — charcoal		
1				
2	4b	*Agathis*		
3		*Phyllocladus*	Podocarp hardwood and kauri forest	Cooler and drier; droughts, frosts
4	4a	*Dacrydium* ratio (−)		
5		*Phyllocladus*		
6				
7	3b	Tree ferns decline		Warm and moist
8		*Ascarina* decline	Extensive Podocarp — hardwood forest	
9		*Dacrydium* ratio (+)		Warmest and wettest
10	3a	*Metrosideros*		
11		*Ascarina*		
12	2b	*Nestegis*, *Cyathea*		
13		*Dacrydium*	Early podocarp forest	Warmer and wetter
14	2a	*Prumnopitys*		
15	1c	*Nothofagus*, *Libocedrus*		? Moistening
16	1b	*Halocarpus*, *Coprosma*	*Nothofagus* scrub and grasslands	
17		*Phyllocladus*		
18	1a	*Gramineae*, *Phyllocladus*		Cool and dry

Yrs BP* = radiocarbon years ago (× 1000);
+RPAZ = Regional Pollen Assemblage Zone

Bogs are major landforms in the floor of the Hamilton Basin, especially to the west and north where the Pliocene relief rises above the Hinuera Surface and impedes the drainage, and also in the lower Hauraki Plains which are largely covered by the expansive, 14 m-deep Kopouatai bog. Since European settlement most of the bogs have been drained; where this has been achieved by using deep drains the peat has contracted and the local drainage has been disturbed. The Kopouatai bog is the only raised bog remaining in natural condition in the Waikato area, although a small part of the Moanatuatua bog has been placed into scientific reserve (Thompson, 1987). The bogs contain a series of thin, distal tephra layers, although these are generally not as well preserved as in the Waikato lakes which provide a longer and more comprehensive record (Lowe, 1988). Recent work has shown that some minerals in the tephra layers at Kopouatai bog have been chemically etched or dissolved because of its strong acidity (Hodder *et al*, 1991). The major tephra layers have been used as time planes to determine the developmental history of the bogs and, at Kopouatai, the timing and displacement of Holocene faulting (de Lange and Lowe, 1990).

Late Quaternary Vegetation and Climate

Cores from a number of Waikato lakes have been the focus of various paleoenvironmental studies. These have looked at changes in the lakes and their catchments since about 18 000 years ago using pollen, pigments, diatoms, animal microfossils, and sediment characteristics (Lowe and Green, 1987). The observed pattern of changes in the lakes is almost certainly the result of climatic changes since the end of the Last Glacial.

The most detailed vegetational and climatic history of the Waikato lowlands has been inferred from analysis of the pollen assemblages, or palynology, of sediment cores from Lakes

Rotomanuka and Rotokauri in the Hamilton Basin, and Lake Okoroire in the Hauraki Lowlands (Newnham *et al*, 1989). Correlations within and between the lakes were aided by the multiple tephra layers interbedded with the lake sediments, and showed that late glacial and postglacial vegetational and climatic changes were essentially simultaneous throughout the region (Table 10.1). These findings support those of previous palynological studies (McGlone *et al*, 1978, 1984).

From about 18 000 to just before 14 000 years ago, the region remained largely unforested, being dominated with herb and shrub taxa. The extensive fluvial aggradation of the Hinuera Formation during much of this period must have presented a formidable barrier to the spread of forests. Tree taxa, mostly *Nothofagus* and *Libocedrus*, increased because the harsh climates — which were windy, relatively dry and cool (about 4°C below present temperatures) — were gradually improving. Tall podocarp trees were rare but not absent from the region. Reafforestation occurred quickly, beginning about 14 500 years ago and nearly coincident with the deposition of the Rerewhakaaitu Tephra. The earliest forests were dominated by *Prumnopitys taxifolia* (matai), and the persistence of *N. menziesii* (silver beech) until about 13 000 years ago indicates that temperatures may have been as much as 3°C colder than present. After that, *N. menziesii* disappeared and *Dacrydium* predominated, reflecting a trend towards moister and warmer conditions (Table 10.1).

From about 11 000 years ago the expansion of angiosperms (particularly *Metrosideros, Nestegis*, and *Ascarina*) and tree ferns within *Dacrydium*-dominated assemblages is consistent with evidence elsewhere in New Zealand of an early postglacial period of maximum wetness and warmth. By about 8500 years ago, however, *Ascarina* was already declining, probably because of increased frostiness or droughtiness, or both. Regular cycles in the *Dacrydium* pollen curves are thought to be related to low frequency, high intensity storms felling numerous emergent *D. cupressinum* (rimu) trees.

From about 5500 years ago, this drying trend continued as indicated by rarity of *Ascarina*, increases of *Phyllocladus* and *Agathis*, more microscopic charcoal, and decreases of *Dacrydium* relative to other tall podocarps. At all three lake sites, *Agathis australis* (kauri) is most prominent after about 3000 years ago, attaining maximum levels about 1000 years ago.

Many tree taxa (particularly *Agathis* at Lake Rotokauri) were adversely affected by Polynesian burning. The earliest recorded fires have been radiocarbon dated at 810 ± 90 years ago (between AD 1175–1280). The effects of such firings were to reduce forest cover dramatically, with a sharp and sustained rise in *Pteridium* (bracken) pollen, one of the characteristic indicators of such major disturbance (Newnham *et al*, 1989). Rates of sedimentation in many lakes increased markedly because of accelerated erosion of the catchments. At Lake Hakanoa, a layer of mud was deposited about 750–1000 years ago, coinciding with deforestation and erosion of the catchment (Hogg *et al*, 1987).

PERIPHERAL HILLS

To the north and east of the middle Waikato Basin the hills are formed on the sandstones and siltstones classed as greywacke; to the west they are formed on siltstones, sandstones, and limestones of the Te Kuiti Group (Kear and Schofield, 1978) or, where these have been removed by erosion, upon the underlying greywacke. All of these rocks are sedimentary and their intact strength is similar, but they produce very distinctive landforms. The hillslopes on greywacke are usually long and nearly straight with closely spaced first-order channels formed by shallow translational landslides (Figure 10.15). The hillslopes on the Tertiary rocks have stepped profiles with alternating steep and gently sloping segments. Shallow translational landslides are not common on the Tertiary rocks but there are numerous block falls along the steeper scarps and active earthflows at their bases (Figure 10.16).

The major factor in producing this difference in hillslope profiles appears to be caused by variations in the depth of regolith and the spacing of the joints. On greywacke the regolith is frequently

20 m deep on the broader interfluves and 1–5 m deep on the main slope segments. The rock is invariably shattered, or joints are very closely spaced, so that the strength of the regolith largely controls the resistance to erosion. Among the Tertiary rocks, resistance to erosion is variable: sandstones, such as those of the Glen Massey Formation, have little or no regolith cover, the slopes on them are nearly vertical, and joints are 1–5 m apart; the siltstones, such as the Whaingaroa Siltstone, are highly shattered and support hillslopes of 28–38° with thin regoliths, or are greatly weakened by water and support low-angle slopes of 1–8° with active earthflows; the Te Akatea Siltstone in places supports steep bluffs of 65–75° with very thin soils. Because the Tertiary rocks have a low-angle regional dip (of 1–5°), they underlie broad plateaux or very gentle dip-slopes which terminate abruptly above stepped scarp slopes. The valley floors are often ill-drained where they are underlain by siltstones. No detailed studies of the landforms on Tertiary rocks have yet been published.

The greywacke hills have provided the sites of a few investigations (Selby, 1966, 1967, 1976). Around Whitehall, in the Pakaroa and Maungakawa Hills, the interfluves are very broad and have a drainage pattern which rises in broad, deep, amphitheatre-shaped basins interpreted as ancient rotational slumps (Figure 10.17). These slumps occurred in the period between about 13 000–1850 years ago, as is indicated by tephra layers which were disturbed during the landslides or remain overlying the entire ground surface. Thus they formed at a period when there was a full forest cover (Table 10.1). The main slope segments are relatively straight and have rather regularly spaced scars, from shallow landslides, which form the heads of the present drainage systems. Some of these landslides occurred before the forest was cleared in the first half of this century but many have occurred since. Detailed studies have shown that the root systems of trees increase soil strength by 30 per cent or more, compared with pasture. Deforestation has thus reduced soil resistance to landsliding processes, and storm events with moderate intensity may now cause erosion, while much greater storm intensities are required to cause landsliding in forests.

Figure 10.15 Characteristic relief on greywacke ranges. Note the long straight slopes and the landslide scars forming the lowest order depressions. (M J Selby)

Figure 10.16 Topography on Tertiary rocks of the Raglan Hills. Note the stepped slope profiles and the earthflows occupying most valley floors. (M J Selby)

Figure 10.17 Broad interfluves of the greywacke hills around Whitehall. The head of each first-order channel is an ancient slump. Forest covers small andesitic cones of the Kiwitahi Volcanics. (M J Selby)

Figure 10.18 Shallow translational landslides caused by one intense rainfall in the southern Hapuakohe Range. (M J Selby)

In the greywacke hills where interfluves are narrow, there are no rotational slumps forming the heads of the drainage systems, only shallow translation landslides on the mid-slopes. In all greywacke areas the intensity of landsliding is so great that it is by far the most important geomorphic process and also a major influence upon the valley floors.

Major storms usually cause so much debris movement into the valley floors that most third and fourth-order channels (using the Strahler ordering system) receive an influx of sediment upon the floodplains and low terraces at frequent intervals. In areas like the southern Hapuakohe Range this has occurred on average once every three or four years, since 1965, in some part of the range. In each storm the area of maximum rainfall intensity is seldom more than a few kilometres square, so individual valleys are affected infrequently. The debris on valley floors is then moved down-valley by minor floods as a series of waves until either it is removed entirely or becomes immobile and is held by vegetation. Second-order channels are nearly always partly or wholly infilled with landslide debris. In areas of pasture this infill material forms a grassed, swampy earthflow which slowly flows downslope until, in a third or fourth-order channel, the stream energy is great enough to entrain all of the debris and the channel floors are then formed of gravel and boulders. In forests the landslide debris is not held by grasses and is available for transport by relatively low stream flows, so that channels there are always in gravels or boulders (Figures 10.18 and 10.19).

Figure 10.19 Infilling of the valley floor with sediment from the landslides shown in Figure 10.18. (M J Selby)

Drainage from the peripheral hills reaches the Hamilton Basin in small streams which are tributary to the Waipa or Waikato Rivers. Where they are incised into the Hinuera Surface their channels across the plains are steep-sided gullies and drainage does not present a problem for economic use of the land. Where the streams drain into the swamps or lowlands at the periphery of the Hinuera fan, drainage problems may occur. The lowlands were originally swampy, peat bogs or shallow lakes. Since European deforestation of the peripheral hills, runoff from the source areas has been more rapid and flood peaks made higher. It is now necessary to stopbank some channels, such as those of the Mangawhara Stream, to prevent flooding of the drained lowlands, and channel straightening has been attempted to permit more rapid passage of flood-peak discharges.

CONCLUSIONS

The middle Waikato Basin and its surrounding hills have evolved in response to regional tectonism which has shaped the general outline of the basin and ranges. Volcanic and climatic events of the last 100 000 years or so are largely responsible for the influx of volcanic debris which underlies the Hinuera Surface. The Waikato River channel is relatively young and has become incised in its present course in the last 15 000 years or so. The Waipa River may be older but it has also been affected by infilling of the Hamilton Basin floor. The landforms of the basin are now stable and being modified largely by human activity, especially by modifications to the drainage system of the swamps and peat bogs.

In contrast, the peripheral ranges are undergoing rapid, if episodic, geomorphic development. Landslide events occur frequently, especially on the greywacke hills, where landslide debris causes temporary infilling of valley floors and rapid channel modification in response to this infilling. In the area of Tertiary rocks, rates of change are not known, but may be less episodic and more strongly influenced by earthflow and solution processes than by rapid landsliding.

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