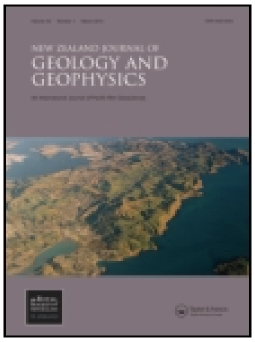

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Late Pliocene distal silicic ignimbrites, Port Waikato, New Zealand: implications for volcanism, tectonics, and sea-level changes in South Auckland

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Abstract At least five distal silicic ignimbrites occur in coastal alluvial plain pumiceous sandstone, mudstone, and peat of the basal Kaihu Group at Oruarangi, 5 km south of Port Waikato on the southwest Auckland coastline. The ignimbrites are 0.1–3.0 m thick, include rip-up paleosol clasts, carbonised logs, and gas-escape pipes, and are intimately associated with synignimbrite sedimentary wash deposits. The ignimbrite-bearing succession rests on Jurassic Huriwai Group and is unconformably overlain by thick dune-sand deposits of the mainly Pleistocene Awhitu Formation. Palynomorphs supported by magnetic polarity data suggest a latest Pliocene age for the succession, from late Mangapanian(?) to Hautawan (c. 2.5–1.8 m.y. B.P.). Correlative units include the Ohuka Carbonaceous Sandstone Member of the Kaawa Formation at the nearby Kaawa–Ohuka section, and the widespread Puketoka Formation of inland South Auckland. The eruptive source(s) for the ignimbrites may have included sites in southern Coromandel Peninsula and/or Taupo Volcanic Zone, both over 100 km east of Oruarangi. Fluvial reworking of these and other silicic pyroclastics in the hinterland across a broad west-facing plain provided the bulk of the pumiceous sediments in the coeval Late Pliocene deposits. Significant glacio-eustatic sea-level oscillations in the Hautawan may be registered in the Oruarangi sequence by formation of paleosols or erosion surfaces during the glacials, and sedimentation during the interglacials. Stratigraphic relations indicate basalts of the Ngatuturu Volcanics at Kaawa had erupted by 1.8 m.y. B.P. (late Hautawan) and therefore were coeval with the arc-related silicic volcanics further east. The Pliocene–Pleistocene boundary, now aged as c. 1.6 m.y. B.P., probably lies within the basal part of the Awhitu Formation, stratigraphically higher than previously suggested.

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Keywords Pliocene; Kaawa Formation; Kaihu Group; Port Waikato; Pliocene–Pleistocene boundary; ignimbrites; pumiceous sediments; palynology; correlation; tectonics; sea-level changes

INTRODUCTION

Sedimentary deposits of late Neogene age in northern North Island are mainly referable to either the Kaihu Group or Tauranga Group. The Kaihu Group occupies a thin (0–10 km) strip along much of the western coastline of the North and South Auckland regions (Fig. 1A) and is dominated by weakly consolidated coastal sand deposits of shallow marine, beach, and dune origin, often associated with terraces (Brothers 1954; Kear 1957a; Chappell 1970, 1975; Barter 1976; Richardson 1985). In contrast, the Tauranga Group occupies extensive lowlands inland in South Auckland (Fig. 1A), and is dominantly composed of terrestrial sediment of mainly fluvial and lacustrine origin, but includes some older estuarine and shallow marine deposits (Kear & Schofield 1978; Nelson et al. 1988). Correlations between the two groups that may permit the (Kaihu) coastal marine record to be integrated with the coeval (Tauranga) terrestrial record, for an interval when significant global climatic and sea-level changes occurred, have never been achieved. Here we report details for a succession near Port Waikato where typical Tauranga Group facies occur within Kaihu Group. In addition, the succession contains several distal silicic ignimbrites. We explore the local and more regional geological implications of the stratigraphic correlations made here, based largely on the identification and occurrence of ignimbrites.

STRATIGRAPHIC CONTEXT OF THE KAIHU GROUP

Well-exposed sections through the Kaihu Group in the southwest Auckland region occur on Awhitu Peninsula (Barter 1976) and along the wave-dominated, cliffed coastline between the mouth of Waikato River and Kawhia Harbour (Fig. 1A). The best known sections occur in the Kaawa–Ohuka area (Fig. 1B), described, sketched, and (re-)interpreted by many geologists over the years (e.g., Bartrum 1919; Gilbert 1921; Henderson & Grange 1926; Kear 1957a; Purser 1961; Chappell 1964, 1970; Stipp et al. 1967; Spratt 1971, 1974; Rodgers et al. 1973; Rodgers & Grant-Mackie 1978; Heming 1980). The Kaihu Group here comprises the Awhitu (formerly Kaihu) Formation over the Kaawa Formation (Barter 1976), the two being separated by a locally channellised erosion surface upon which basaltic flows and breccias of the Ngatutura Volcanics may occur and are in turn unconformably overlain by the Awhitu Formation (Kear 1957a). The basalts have been interpreted as lying close to the Pliocene–Pleistocene boundary, suggested to be 2.5 m.y. B.P. by Stipp et al. (1967), but later argued by Rodgers et al. (1973) to be about 1.8 m.y.

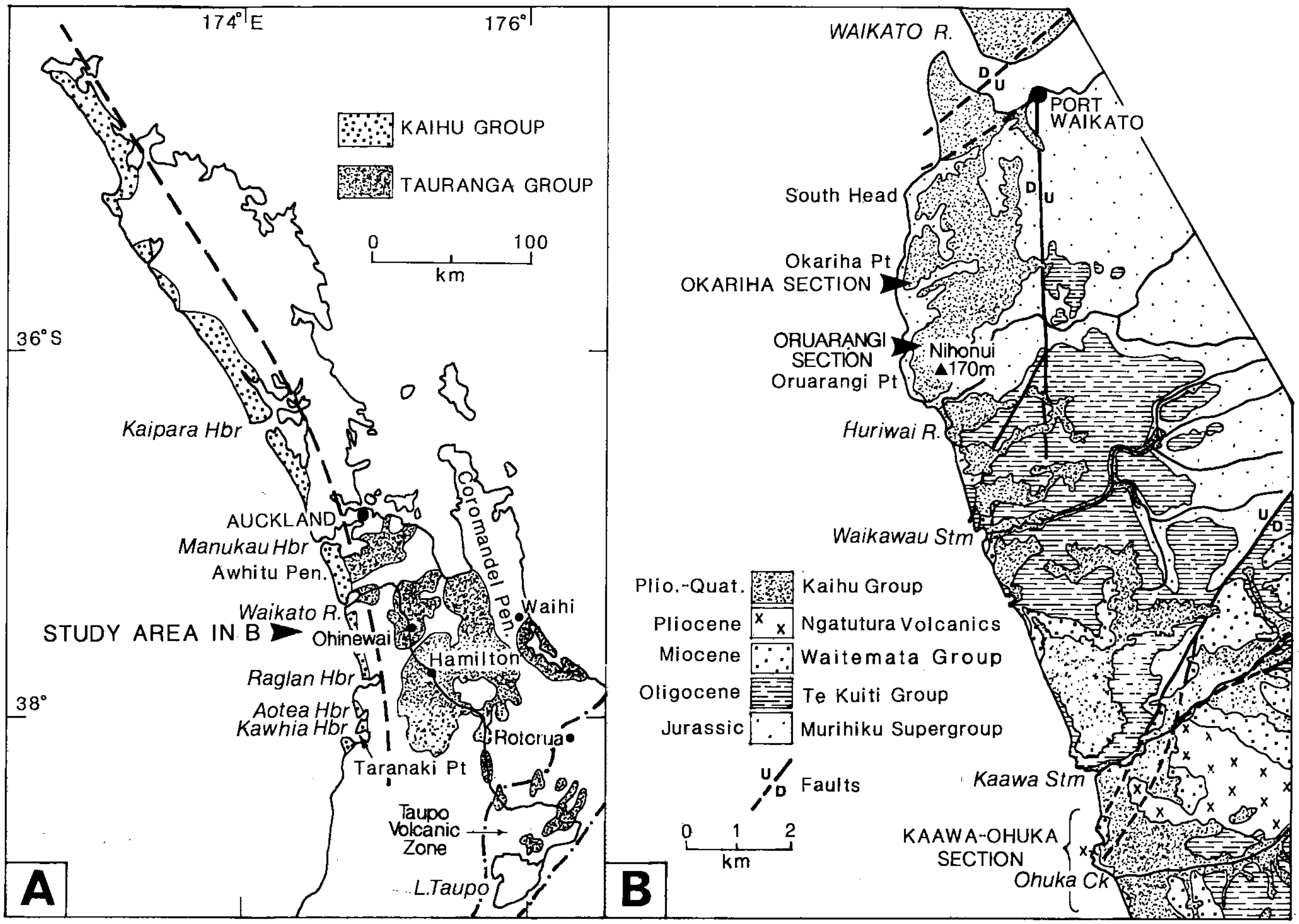


Fig. 1 Locality maps showing (A) the general distribution of coeval late Neogene deposits of the Kaihu and Tauranga Groups in northern North Island (simplified from Kear (1978)), and (B) the general geology of the coastal region south of Port Waikato (from Kear (1966) and Waterhouse (1978)) and the location of the Oruarangi and Okariha sections in relation to the well-studied Kaawa–Ohuka section.

B.P. Away from the Kaawa–Ohuka area, the Kaihu Group includes several other, mainly younger formations (Chappell 1970; Barter 1976; Waterhouse 1978; Richardson 1985).

At Kaawa, the Pliocene Kaawa Formation rests unconformably on a marine-planed and bored surface cut across older Tertiary sedimentary rocks. It includes basal shellbeds (Kaawa Shellbed Member) of Early Pliocene age (Kear 1957a) and overlying shallow marine, bioturbated, and fossiliferous sandstone (Kaawa Sandstone Member; Kear 1957a), up to 14 m thick but exceeding 200 m in the subsurface north of Waikato River (Barter 1976). South of Kaawa, at Ohuka Stream and Taranaki Point, the marine Kaawa Sandstone Member is overlain by the Ohuka Carbonaceous Sandstone Member, a nonmarine facies of the Kaawa Formation comprising a few metres of carbonaceous sandstone with thin interbedded lenses of siltstone and peat, and rare scattered basalt pebbles (Kear 1957a). The nature of the contact between the Kaawa and Ohuka Members has been disputed; Kear (1957a) and Chappell (1970) favoured gradation, but Spratt (1974) favoured an unconformity, a view we share. Palynology indicates a basal Hautawan (Late Pliocene) age for the Ohuka sandstone (Mildenhall 1975). Although Kear (1957a, b) noted that sandstones of Kaawa Formation are locally pumiceous, he (and subsequent workers) did not record any interbedded tephras, the principal topic of this paper.

The unconformity separating the Kaawa Formation from the overlying Awhitu Formation is a planar to undulating erosion surface with, according to Chappell (1964, 1970), occasional steep-sided valleys up to 50 m or more deep. Basaltic flows and breccias of the Ngatutura Volcanics intervene locally between the Kaawa and Awhitu Formations. Despite the fact that these volcanics may occupy channelled surfaces in the Kaawa Formation, Kear (1957a) emphasised that at Kaawa the main unconformity surface at the base of the Awhitu Formation cuts across, and therefore postdates, both Kaawa Formation and Ngatutura Volcanics alike.

The Awhitu Formation, to date assigned an exclusively Pleistocene age, crops out southwards from Port Waikato to Kawhia Harbour and comprises upwards of 120 m of reddish brown, prominently cross-bedded quartzofeldspathic and titanomagnetite-rich sands of mainly eolian origin (Kear 1957a; Chappell 1970). Unlike the underlying Kaawa Formation, several discrete, typically thin (<1 m), pumiceous tephra beds, presumed to be derived from silicic volcanic eruptions in the Taupo Volcanic Zone, have previously been noted within the Awhitu sand deposits (Kear 1957a; Chappell 1970; Barter 1976).

With this background, we turn attention to the description of some lower Kaihu Group deposits about 10 km north along the coast from the Kaawa–Ohuka section, at Oruarangi and Okariha Points (Fig. 1B). We show that these deposits are

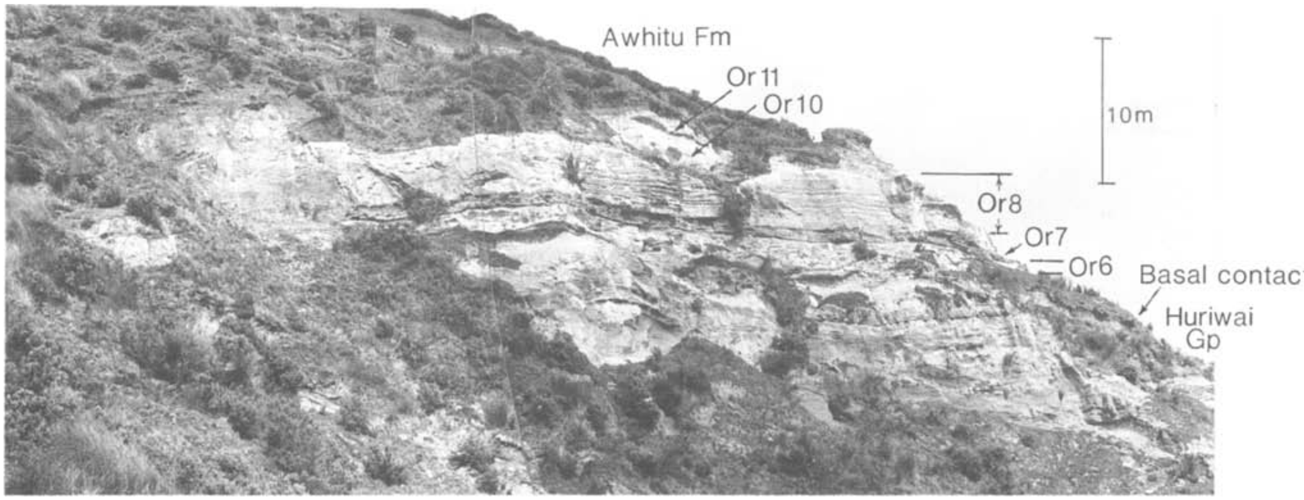


Fig. 2 North-facing wall of the logged Oruarangi section in the lower Kaihu Group at Oruarangi Point. Labelled are some of the lithologic units identified in the stratigraphic column of the Oruarangi section in Fig. 3.

correlatives of the upper part of the Kaawa Formation, include several distal silicic ignimbrites, and comprise typical facies of the coeval Tauranga Group inland.

ORUARANGI/OKARIHA SECTIONS

Oruarangi Point (grid reference NZMS 260, R13/609175) forms the headland immediately north of the famous Late Jurassic plant bed locality in the Huriwai Group at the northern end of Huriwai Beach, south of Port Waikato (Purser 1961). The section of primary interest here occurs on the northern side of the point within a steep-sided gully extending inland for about 250 m (Fig. 1B). On the southern wall of the gully the Kaihu Group is more or less continuously exposed for 80 m vertically, with overlying but more sporadic exposures up to the elevation (170 m) of Nihonui Trig. The group sits unconformably on a gently undulating surface at about 43 m above sea level cut across Huriwai Group. The upper two-thirds or so of the main section consist of several thick (4–15 m) units of massive and (cross-)bedded orange-brown sands, with common knobbly iron-pan horizons and occasional interbedded and discontinuous grey tephras and (tephric) paleosols. This upper sequence correlates with the Awhitu Formation. A conspicuous (up to 4 m thick) pinkish white ignimbrite within the lower part of this formation at Oruarangi is a correlative of one recorded at the Kaawa–Ohuka section, equivalent to Pumice Silt P2 of Stipp et al. (1967, fig. 3) or Pehiakura Ash of Barter (1976).

Well below this ignimbrite the basal 20 m or so of the Oruarangi section is highly distinctive (Fig. 2) because the deposits exposed in low bluffs and slopes are mainly pale in colour, rather than orange-brown, and are texturally variable, highly pumiceous, and include some thin interbeds of carbonaceous mudstone. Lithologically they cannot be part of the Awhitu Formation. The same beds crop out above Okariha Point, about 1.5 km north of (and seen from) the Oruarangi section (Fig. 1B). The nature, origin, and significance of these lower Oruarangi and Okariha beds is discussed in the remainder of this paper.

Stratigraphic logs

The lithologic properties of the lower Oruarangi and Okariha sections are summarised on stratigraphic logs (Fig. 3). The information is recorded using standard sedimentologic nomenclature (e.g., Andrews 1982), despite the fact that subsequently some of the beds have been interpreted as tephra deposits. Distinctive variations in lithology, grain size, structures, and composition define 14 stratigraphic units at Oruarangi (Or units) and 21 at Okariha (Ok units). A suggested correlation between these units, together with their possible depositional environments and/or origins, is included in Fig. 3. More specific details of lithology, palynology, and facies interpretation for each unit are given in Appendix 1.

Some preliminary microscope and X-ray diffraction analyses of representative samples from the 14 units at Oruarangi identify the general mineralogy of the deposits (Fig. 3). Two compositional end-members are evident, one dominated by quartz + feldspar (plagioclase ≫ potash feldspar) ± micaceous minerals, consistent with derivation from mainly the underlying Jurassic strata, the other by pumice + glass shards + halloysite, indicative of a silicic volcanic source. Small to moderate amounts of carbonaceous matter occur in either assemblage. Lower and upper units (Or1, 2, 4, 13, and 14) in the logged Oruarangi section are predominantly quartzofeldspathic but include some vitric material; all others are dominated by vitric components or their alteration products, such as halloysite and minor α-cristobalite. Dominant heavy minerals are opaques, hornblende, augite, and hypersthene, with subordinate zircon.

Distal ignimbrites

Five of the units (Or3 = Ok3a; Or6a = Ok7; Ok10; Or10a = Ok14; Or11 = Ok16) in the logged sections at Oruarangi/Okariha are interpreted as having a primary volcanic rather than sedimentary origin (Fig. 3). We interpret them as distal ignimbrites and here collate some of their essential features from the lithologic descriptions given in Appendix 1.

The ignimbrites, from a few centimetres to more than 3 m thick, are preserved within coastal plain alluvial sediments,

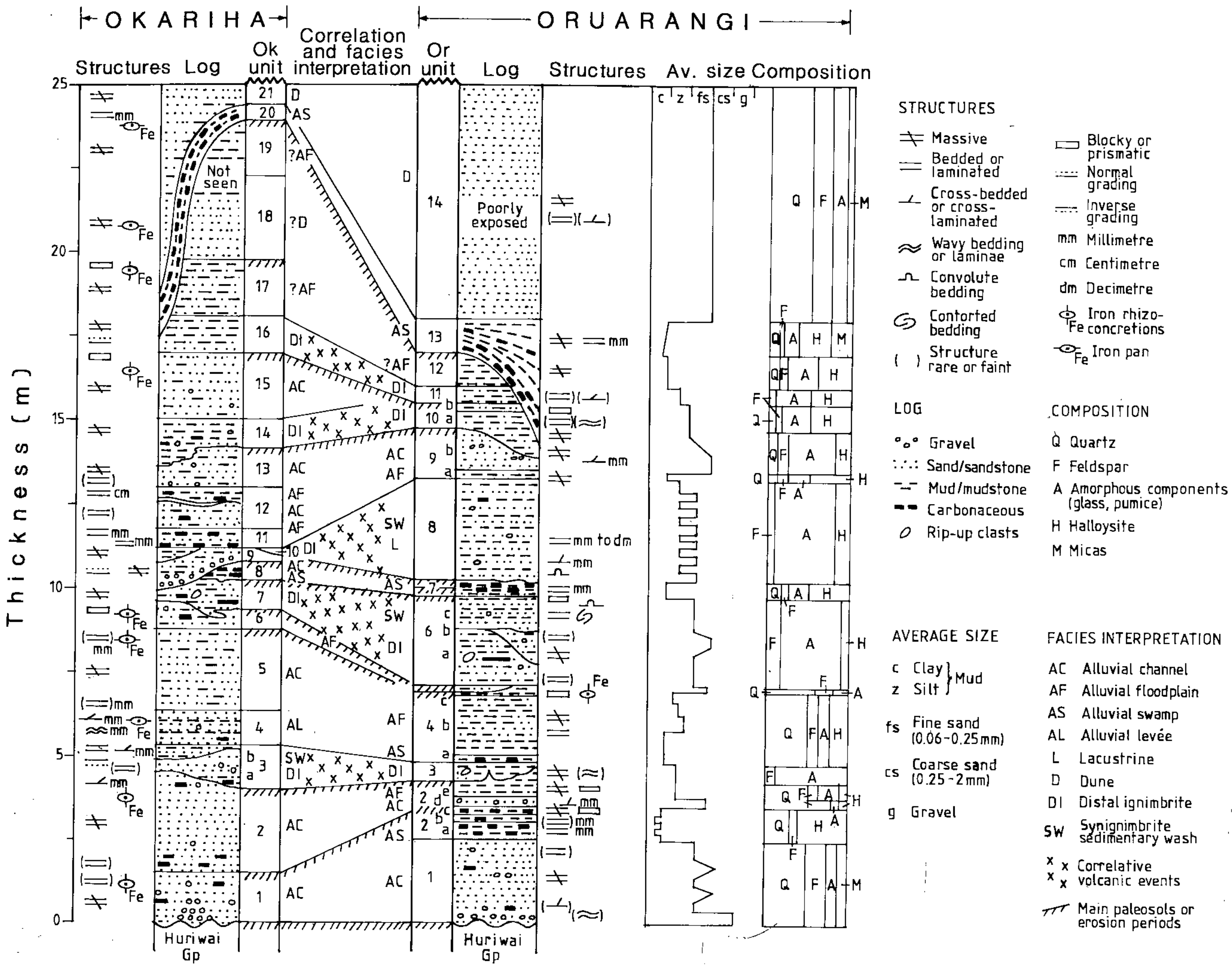
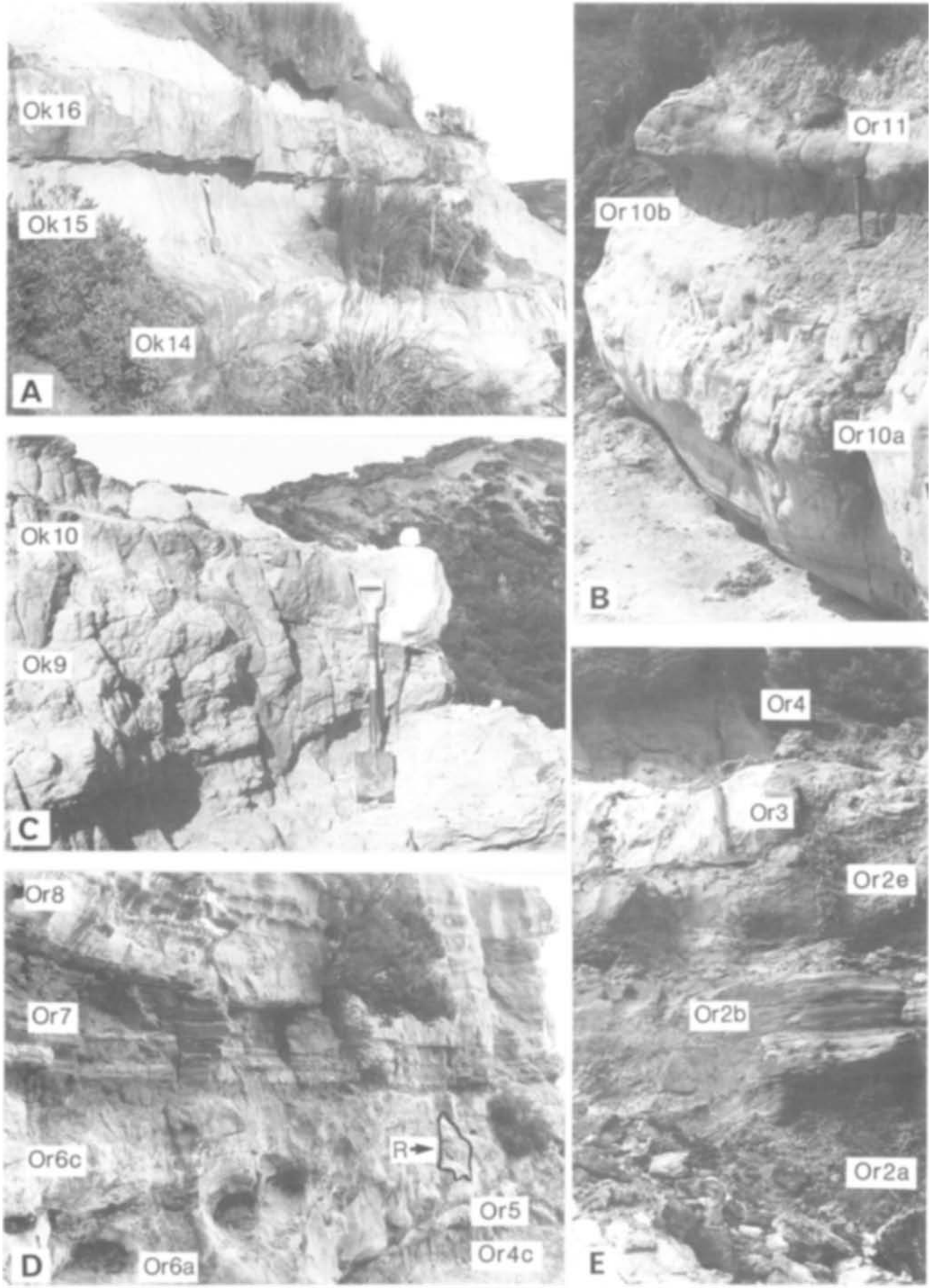


Fig. 3 Stratigraphic logs, correlation, and facies interpretation for the Oruarangi and Okariha sections, including average size and general compositional data for the Oruarangi column alone. The Oruarangi pumiceous beds include units Or1–Or12 at Oruarangi, and correlative units Ok1–Ok19 at Okariha. The overlying units mark the base of the Awhitu Formation. Lithologic descriptions of units are detailed in Appendix 1.

typically resting on peaty beds or on paleosols. They are distinguished in the field from the enclosing facies by their coherent protuberant profiles, whitish colour, highly pumiceous nature, and mixed silt and sand sized (ash) texture (Fig. 3, 4). A textural plot of median diameter versus sorting for the sand fraction from all units at Oruarangi broadly separates the inferred volcanic units from the sedimentary units, the former exhibiting generally poorer sorting and a much wider range of average grain sizes (Fig. 5). The volcanic units are primarily pyroclastic flow and not airfall deposits because, among other reasons (see below), they do not uniformly mantle the underlying topography and they show thickness changes of up to 1 m or more over short distances, commonly pinching out entirely against local paleorelief. In thin section, the coarser pumiceous deposits have a vitroclastic texture.

Where the flows were emplaced on water-saturated sediment, such as peat, unstable density stratification has resulted in loading and localised diapiric intrusion of liquefied peaty mud up into, and sometimes through, the thinner deposits (Fig. 6C). Some rip-up clasts of paleosols formed on the underlying sediments or on older ignimbrites are incorporated into the flow deposits. They range up to boulder

Fig. 4 (*opposite*) Some of the distal silicic ignimbrites and associated deposits at the Okariha (A, C) and Oruarangi (B, D, E) sections (see Fig. 3 for unit positions). A Two protuberant ignimbrites, Ok14 and 16, correlatives of ignimbrites Or10a and 11 respectively in B. B Faint laminations in ignimbrite Or10a and a well-developed paleosol (Or10b) at its top. C Intense white colour (where spaded), shaved lower surface, and lens shape of ignimbrite Ok10, the probable source ignimbrite for the synignimbrite sedimentary wash of unit Or8 (see Fig. 2, 3, 4D). D Ignimbrite Or6a with concentration of several preferentially aligned logs (towards observer) and a large (0.9 m long) rip-up clast (R) of paleosol unit Or4c. The prominently laminated top (Or6c) to Or6, spaded clean in Fig. 6E, is interpreted as synignimbrite sedimentary wash. A paleosol, laminated carbonaceous mudstone (Or7), and thick synignimbrite wash (Or8) overlie this unit. E Ignimbrite Or3, with injection structure of carbonaceous material at left, overlying a paleosol developed upon a sequence of massive to laminated carbonaceous mudstone of unit Or2.


Ok16
Ok15
Ok14
A
Or11
Or10b
Or10a
B
Ok10
Ok9
C
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Or8
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Or6c
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Or5
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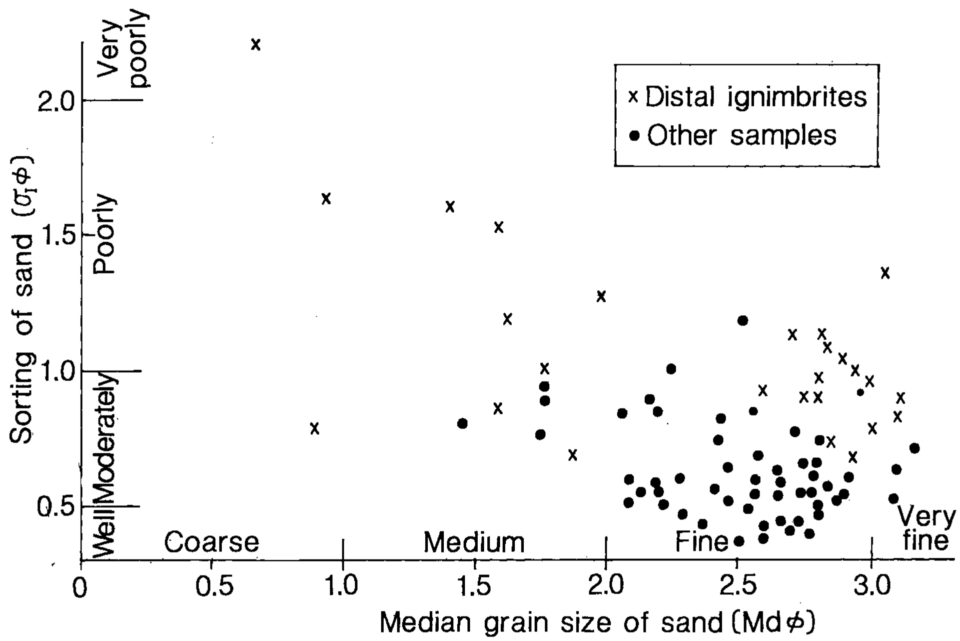


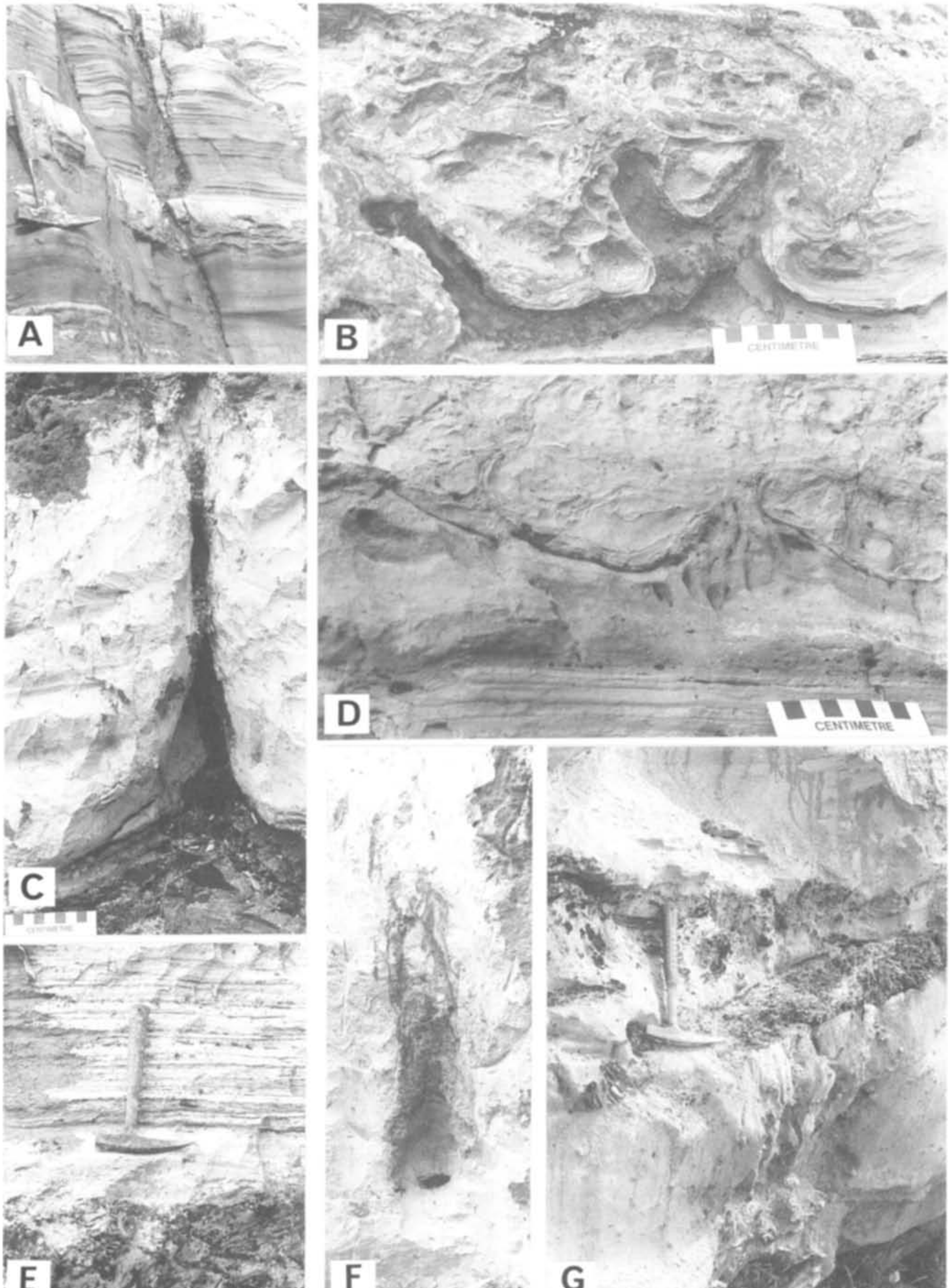
Fig. 5 Textural plot of sorting versus median diameter (Folk 1968) for the sand fraction (coarser than 4ϕ) of samples from all units (Fig. 3) at Oruarangi. Those interpreted as volcanically emplaced (distal ignimbrites) are mainly more poorly sorted and typically either finer or coarser grained than the bulk of the sedimentary units.

(block) size (Fig. 4D). Largest clasts occur towards the top of flows, presumably buoyed up by particle interactions in the flowing mass and/or by upward escape of gases, and supported by the strength of the accumulating pumiceous material. Assuming long axes of clasts dip in an up-flow direction (cf. Walker 1984), the fragments in unit Or6 indicate pyroclastic flow emplacement from the east.

Scattered charred logs and charcoal fragments occur within some of the deposits (Fig. 4D, 6E, G). They tend to be concentrated nearer the middle and upper portions of units or where the deposits thin against paleohighs, suggesting shear effects during flow have buoyed the logs towards the top and sides of the ignimbrite. In unit Or6 their preferential alignment in a northeast–southwest direction (Fig. 4D) probably parallels flow direction, the associated rip-up clast orientations supporting emplacement from the northeast. Charcoal fragments often occur in clusters that resemble the general shape of former logs, suggesting they formed by spontaneous disintegration of burning logs. Coarse-grained crystal-rich pods or pipes, up to 10 cm in diameter and 50 cm long, occur locally above the burnt logs (Fig. 6F), as though formed by the filtering out of fines by ascending gases from the burning logs within the ignimbrite. The pyroclastic deposits are rather massive (Fig. 6C), or may exhibit subtle normal grading, and the thinner deposits and parts of the thicker ones can include some vague, flat, low-angle, and/or wavy laminations (Fig. 4B, 6G). Collectively, these structural features, and their sequential arrangement, are similar to those associated with low-aspect-ratio pyroclastic deposits erupted from Mt Pelée in 1902 (e.g., Fisher & Heiken 1982). Charland & Lajoie (in press) regard many of these latter deposits as having accumulated by rapid aggradation from both suspension and traction at the head of high-energy, relatively low concentration, stratified, turbulent pyroclastic flows. Despite obvious differences in scale, this may be an appropriate emplacement model for the Oruarangi distal ignimbrites.

Some of the Oruarangi pyroclastic deposits are abruptly overlain by an additional volcaniclastic unit, with no evidence of a significant time break (Fig. 6E). This division is often prominently laminated and/or bedded, and includes normally size-graded intervals, convolute, flame, and other deformational structures, and small rip-up clasts (Fig. 6B, D). We interpret this upper well-bedded division with its Bouma-type structures as representing mainly the rapid vertical accretion of successive pulses of slope-wash deposits derived from pluvial and/or fluvial reworking, and redeposition of parts of the associated, newly emplaced pyroclastic flow—essentially a synignimbrite sedimentary wash (cf. secondary deposits of Wilson & Walker (1985, table 1)). Unit Or8 is unusual because an associated underlying flow is not present at Oruarangi, and the entire thick deposit is interpreted as synignimbrite wash. However, a source ignimbrite (Ok10; Fig. 4C) occurs in the correct stratigraphic position at Okariha (Fig. 3).

Fig. 6 *(opposite)* Some structures associated with the distal silicic ignimbrites and synignimbrite wash deposits at Oruarangi. **A** Well-bedded and laminated pumiceous fine sandstone and siltstone with Bouma-like divisions in unit Or8, interpreted as synignimbrite sedimentary wash deposits, possibly into a shallow lake. **B, D** Close-ups of part of the pumiceous fine sandstone and siltstone of subunit Or6c showing massive, laminated, and convoluted and deformed (including flame structures) intervals, which may be repeated in Bouma-like sequences interpreted as successive sheets of synignimbrite sedimentary wash. **C** Injection structure produced by loading of highly carbonaceous mud by ignimbrite Or3. **E** Sharp contact between pyroclastic flow deposit Or6a, with charcoal fragments concentrated near the top, and the overlying prominently laminated synignimbrite sedimentary wash of subunit Or6c. **F** Vertical, coarse-grained crystal-rich column, up to 8 cm diameter, interpreted as a gas-escape pipe in the otherwise fine-grained pumiceous ignimbrite Or6a. **G** Ignimbrite Or6a showing generally massive to faintly bedded lower part and concentration of carbonised logs and charcoal fragments in the upper portion of the flow. The capping deposit (Or6c), prominently laminated when spaded (see Fig. 6E), is interpreted as synignimbrite sedimentary wash.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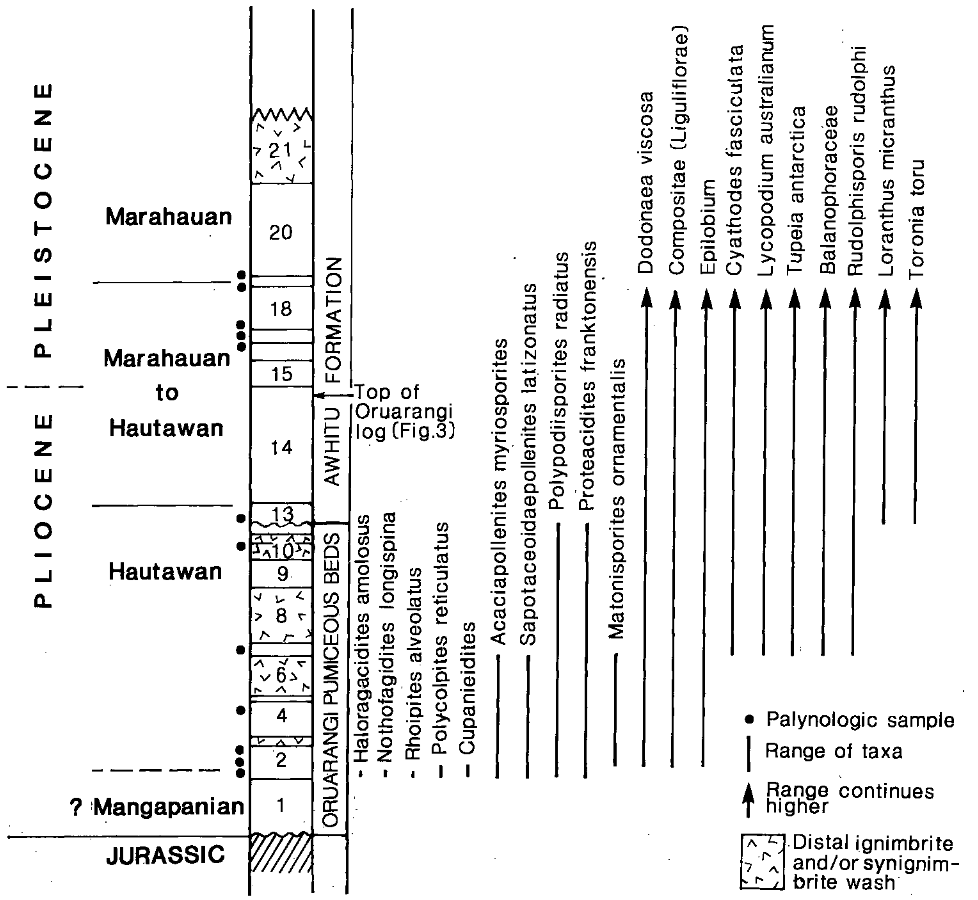

Fig. 7 Key palynologic taxa used for age assessment of the Oruarangi section (adapted from Mildenhall 1982, unpubl.). The Oruarangi units 15 – 21 shown here in the lower part of the Awhitu Formation are based on our unpublished field data and are not discussed elsewhere in this paper.

Age and correlation

The only previous reference to the deposits described above was made by Purser (1961, p. 15), who included them within his Pleistocene Sediments and described them as "... 40 ft of soft, poorly bedded, grey-white pumice silt containing thin layers of carbonaceous material." New palynologic data from the carbonaceous mudstones and paleosols in the section have been recorded by Mildenhall (1982, unpubl.) and noted briefly by Mildenhall & Pocknall (1984). The ranges of key taxa used to date the sequence at Oruarangi are summarised in Fig. 7. Several extinct taxa occur in units Or1–14 which indicate a Late Pliocene age, certainly Hautawan (or Lower Nukumaruan) and probably as old as Mangapanian at the base. Magnetic polarity measurements on samples collected from four of the ignimbrites (Or3, 6a, 10a, and 11) indicate that, from bottom to top, these deposits have reverse, reverse, transitional, and normal polarity, respectively (G. M. Turner, pers. comm.). Given the late Mangapanian–Hautawan age indicated by the palynoflora, the upward sequence from reverse to normal polarity could correlate with passage from the lower Matuyama to Olduvai paleomagnetic intervals (Fig. 8). On this basis, the distal ignimbrites at Oruarangi/Okariha are inferred to have absolute ages in the range 2.4–1.8 m.y. B.P.

An attempt is made in Fig. 8 to correlate the Oruarangi section with the Kaihu Group deposits at the nearby Kaawa–Ohuka section and the inland Tauranga Group. Ages for the Kaawa–Ohuka section were mentioned earlier; those for the Tauranga Group are based on palynologic information from continuously cored drillholes at Ohinewai, near Huntly (Nelson et al. 1988). The lower Oruarangi beds (units Or1–12) are regarded as lateral equivalents of the Ohuka Carbonaceous Sandstone Member of the Kaawa Formation. These sections have comparable palynology, belonging to the *Acaciapollenites* Assemblage of Mildenhall (1975), and the Restionaceae Zone of Nelson et al. (1988) at Ohinewai, and in particular are dominated by Myrtaceae and include conspicuous *Acacia* pollen (Mildenhall 1975, 1982). The basal Hautawan age assigned the thin (4 m max.) Ohuka Carbonaceous Sandstone (Mildenhall 1975) suggests that it is probably coeval with only the lowermost few units at Oruarangi (Fig. 7), and that time-equivalent sedimentary and pyroclastic deposits of the remainder of the logged Oruarangi section of Hautawan age are mainly absent at Kaawa–Ohuka (see later). Although neither Kear (1957a) nor Chappell (1970) commented on a pumiceous component in the Ohuka Carbonaceous Sandstone, our observations at Ohuka indicate it contains both vitric material and interbedded pyroclastic flow deposits, emphasising lithologic similarity with the Oruarangi beds.

Palynologic data of Mildenhall (1982, unpubl.) and Nelson et al. (1988) support correlation of the Oruarangi pumiceous deposits with (a part of) the Puketoka Formation of the inland Tauranga Group (Fig. 1A, 8). The key taxa common to both sections are *Cupanieidites* sp., *Nothofagidites longispina* (Couper), *Acaciapollenites myriosporites*, *Polycolpites reticulatus* (Couper), *Proteacidites franktonensis* (Couper) (last appearance), *Toronia toru*, *Cyathodes fasciculata*, and *Dodonaea viscosa* (first appearance). The Puketoka Formation consists of highly pumiceous sand, silt, and interbedded peat, probably deposited in a low-energy, distal, braided river system on a coastal plain supporting, at times, extensive lakes

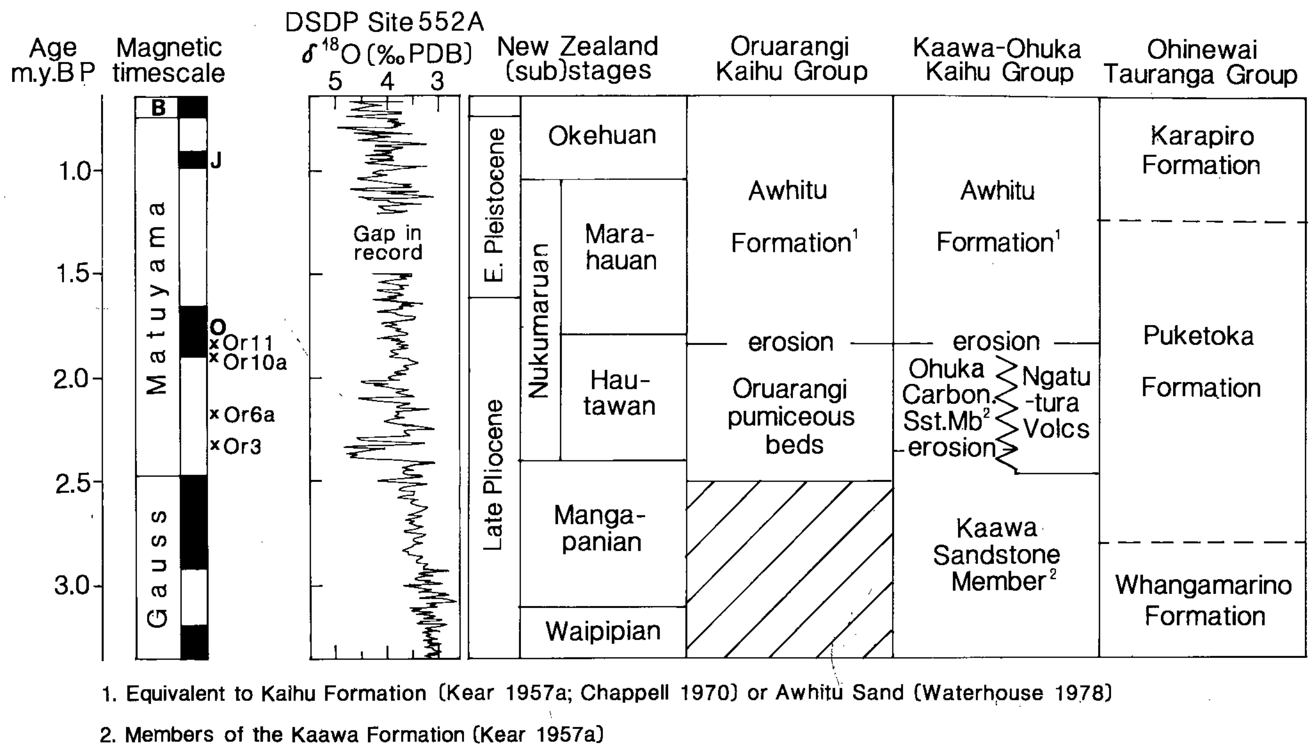

Fig. 8 Correlation diagram, for the Late Pliocene–early Pleistocene interval only, of the Oruarangi pumiceous beds with the Kaawa Formation and associated deposits at the nearby Kaawa–Ohuka coastal section and the inland Tauranga Group at Ohinewai (Fig. 1A), and with the oxygen-isotope record from DSDP Site 552A (Shackleton & Hall 1984). Absolute time-scale for New Zealand stages is from Edwards (1987), while formation ages are based mainly on palynologic data (Mildenhall 1982, unpubl.; Nelson et al. 1988). The magnetic polarity (black, normal; white, reversed) of four distal ignimbrites (Or3, Or6a, Or10a, and Or11) at the Oruarangi section is shown. B, Brunhes; J, Jaramillo; O, Olduvai.

(Nelson et al. 1988). The formation also includes some distal ignimbrite deposits (Kear & Schofield 1978; Nelson et al. 1988). Lithologic resemblance to the Oruarangi pumiceous beds is striking.

IMPLICATIONS FOR LATE PLIOCENE SOUTH AUCKLAND ENVIRONMENT

Silicic volcanism

The occurrence of at least five silicic pyroclastic flow deposits of Late Pliocene age at Oruarangi demands a coeval source of explosive rhyolitic volcanism. Given that the Oruarangi sequence is unconformity bound (Fig. 3), the total number of Late Pliocene pyroclastic flows involved is probably greater than five: a major period of explosive silicic volcanism is indicated.

The Taupo Volcanic Zone is a potential source region of the ignimbrites at Oruarangi. This is supported by recently obtained ages by Grindley et al. (1988) of 2.1 and 1.8 m.y. B.P. on thick ignimbrites at depth in the Matahana Basin, southwest of Rotorua, that indicate Late Pliocene silicic volcanism occurred in the region. Another plausible source is one of the Neogene volcanic centres of the Coromandel Volcanic Zone in eastern Coromandel Peninsula, where the Coroglen Subgroup in particular is characterised by silicic ignimbrite and associated pumice tuff and breccia, including epiclastic sediment (Skinner 1986). Late Pliocene activity appears to have been centred mainly in the Waihi area (Fig. 1A), although to date only two major ignimbrites are reported from there with glass fission-track ages of about 2.9 and 1.5 m.y. B.P., respectively (Skinner 1986). An incomplete volcanic record at the source can be explained by the deposits having been buried or eroded; or perhaps simply because of insufficiently detailed field investigations. A large magnetic and gravity anomaly occurs in the Waihi area (Woodward 1971; Hunt & Syms 1977), suggestive of a now-buried caldera of major size.

Thus, on available evidence, either or both of southern Coromandel Peninsula and Taupo Volcanic Zone are potential source regions for the distal ignimbrites at Oruarangi. Both regions are over 100 km away from Oruarangi (Fig. 1A). Based on a radial dispersal pattern and an (unrealistically) uniform ignimbrite thickness of only 3 m, the total volume of eruptives associated with the five ignimbrites at Oruarangi is conservatively estimated to be at least 500 km³.

Landscape

For the pyroclastic flows to have reached Oruarangi and beyond, the Late Pliocene South Auckland landscape probably lacked the prominent north–south trending horst-and-graben topography which characterises it today. A much more subdued relief is envisaged, involving a semicontinuous alluvial plain draining west and northwest to the Tasman Sea from an active volcanic hinterland in, and south of, southern Coromandel Peninsula, interrupted only locally by low hills of Mesozoic basement or Cenozoic sedimentary rocks. The inland Puketoka Formation of highly pumiceous fine sand and silt, with common interbedded peat, provides an insight into the sedimentary environment of this plain in the Late Pliocene (Kear & Schofield 1978; Nelson et al. 1988). Deposition during the Hautawan occurred mainly in a fine sand- to silt-dominated, distal braided river system on a coastal plain (Nelson et al. 1988), analogous to the modern Slims River in Yukon or Yellow River in China (Rust 1978). Braidplain conditions occurred in response to a sudden and large supply of pumiceous sediment delivered onto the plain, inferred by us now to have been associated with the emplacement and reworking of silicic eruptives from the Coromandel and/or Taupo Volcanic Zone centres. The Puketoka sediments, more than the ignimbrites, indicate reduced relief and the absence of pronounced block-faulted topography as occurs today.

Sea level, climate, and Ngatutura basaltic volcanism

The presence of the marine Kaawa Sandstone Member at Kaawa and in the subsurface of Manukau Lowland indicates that the Early – Middle Pliocene shoreline lay inland from the present coast, probably enclosing an enlarged, shallow marine Manukau embayment (cf. Fig. 1A). Deposition of pumiceous alluvium, peat, and distal ignimbrite at Oruarangi points to Late Pliocene emergence and the creation of an extensive coastal plain. Kear (1957a) attributed this paleoenvironmental change to a sea-level regression, as inferred from the appearance of "cooler" climate (Hautawan) floras in the Ohuka Carbonaceous Sandstone Member, implying it to be an expression of the first major late Cenozoic glacial episode marking the onset of the Pleistocene as it was then understood. Based on inferred correlation of K/Ar-dated basalts further south near Aotea Harbour with the Ngatuturu basalts, considered to lie above the Ohuka sandstone at the Kaawa–Ohuka section, Stipp et al. (1967) proposed a minimum age of 2.5 m.y. B.P. for this Pliocene–Pleistocene boundary cooling event at Kaawa. Rodgers et al. (1973) criticised the lithologic correlations made by Stipp et al. (1967) and amplified on Kear's (1957a) original stratigraphic descriptions which showed that the Ngatutura basalts may also intercalate with the upper part of the Kaawa Sandstone, and lie between it and the overlying Ohuka Carbonaceous Sandstone (e.g., Fig. 8). Influenced by "... technically good ages of 1.7 m.y." (p. 371) on basalt boulders from the "cool" climate Ohuka sandstone, Rodgers et al. (1973) argued instead for a 1.8 m.y. B.P. age for the Pliocene–Pleistocene boundary. However, because Stipp et al. (1967) found the Ngatuturu basalts from Kaawa–Ohuka unsuitable for dating, with ages ranging from 1.0 to 2.3 m.y. both within and between samples, these ages are of questionable value for dating any stratigraphic events.

As an alterative, we know the Ohuka Carbonaceous Sandstone and Oruarangi pumiceous beds are time-equivalents and mainly Hautawan (or Lower Nukumaruan) in age (Fig. 8), based on extinct palynomorphs common to both sections (Fig. 7). In turn the Hautawan, with its distinctive cool-water fauna in New Zealand marine deposits (e.g., Fleming 1953), has been independently dated as beginning about 2.4 m.y. ago (Edwards 1987), which coincides with the onset of major Northern Hemisphere ice accumulation (Shackleton & Hall 1984). We therefore favour this age for approximating the boundary between Kaawa Sandstone and Ohuka Carbonaceous Sandstone at Kaawa–Ohuka. Kear (1957a, p. 838) described the contact between these two units as "... a sharply defined horizontal surface, and, locally within the 3 chains, a thin fine conglomerate is exposed." We have re-examined this contact and, like Spratt (1974), consider it an unconformity. The conglomerate is probably a lag deposit that accumulated following erosion of an unknown amount of Kaawa Sandstone associated with the sea-level drop that accompanied the first major glacial event at about 2.4 m.y. B.P. (Fig. 8). The Ohuka Carbonaceous Sandstone is therefore regarded as one or more interglacial freshwater deposits, equivalent to one or more of the carbonaceous sedimentary units in the lower part of the Oruarangi sequence, and its maximum age would be about 2.3 m.y. B.P. (Fig. 8).

The unconformity-bound nature of these Hautawan terrestrial deposits offers a possible explanation for the conundrum that their pollen consistently do not indicate cool-climate conditions (Mildenhall 1975, 1982), despite their correlation with the start of the Northern Hemisphere and New Zealand glaciations: the interglacials are represented by the pollen-bearing beds, whereas the glacials are mainly "contained" within the unconformities. During the interglacials the environment was generally moist, and warm to temperate, although at times it may have been dry and/or windy. Floodplain or lake depositional environments, where pollen could be preserved, only existed during the interglacials when higher sea levels promoted vertical accretion on a coastal plain. In contrast, a more meagre record of the glacials exists, comprising the paleosols and perhaps the ignimbrites and synignimbrite wash. The first and most intense of the glacials was important, however, in causing or promoting extinctions, such that when the appropriate depositional environment was re-established during the first succeeding interglacial, a different (Hautawan) floral assemblage existed from before. This pattern would, of course, be superimposed upon the more equable glacial climates in the northern North Island compared with the rest of New Zealand.

That no marine units occur within the pumiceous sequence at Oruarangi, despite slow subsidence, supports an implication of the oxygen-isotope curve that, following 2.4 m.y. B.P., interglacial sea levels were on average lower than they had been before. This feature, combined with increased sediment supply from silicic volcanism, explains why the inland Puketoka (Tauranga Group) facies prograded westward to at least the present coastline during the Late Pliocene.

The Oruarangi section helps constrain the minimum age of the Ngatutura Volcanics at the Kaawa section. The unconformity at the top of units Or12 and Ok19 (Fig. 3), separating the Oruarangi pumiceous beds from the Awhitu Formation, is probably the same one that separates the Ohuka Carbonaceous Sandstone and Ngatutura Volcanics from the overlying Awhitu Formation at Kaawa. The longer Hautawan sequence at Oruarangi, which extends into the Olduvai on the evidence of the magnetic polarity of unit Or11 (Fig. 8), indicates that the formation of this unconformity (completed by deposition of Awhitu) occurred later rather than earlier in the Hautawan; the time value of the unconformity, however, is evidently greater at Kaawa and Ohuka than at Oruarangi. Therefore the basaltic volcanism at the Kaawa section had ceased by the middle of the Olduvai Subchron (about 1.8 m.y. B.P.), but probably before the Olduvai Subchron. Hence, we demonstrate stratigraphically the Late Pliocene coincidence of arc-related silicic volcanism in southern Coromandel and/or Taupo Volcanic Zone with backarc basaltic volcanism at Kaawa, the respective centres of which are separated by at least 100 km.

If the correlations of our magnetic data at Oruarangi with the magnetic polarity time scale are correct (Fig. 8) then definite Hautawan, on palynologic grounds, ranges from about 2.4–1.8 m.y. B.P., to within the early part of the Olduvai Subchron, in agreement with Edwards (1987). Because intra-late Hautawan palynomorphs occur at the base of the Awhitu Formation at Oruarangi (unit Or13, Fig. 7), the Pliocene–Pleistocene boundary, internationally accepted as about 1.6 m.y. B.P. (Berggren et al. 1985), must, in the Port Waikato region, occur within the lower Awhitu deposits and not within the underlying Kaawa Formation, as has been previously suggested (see above).

We view the change in facies from the Oruarangi pumiceous beds to the Awhitu Formation as one induced primarily by a change from slow subsidence to slow uplift of the Port Waikato block. Chappell's (1970) suggestion of a post-Kaawa transgression to 550 ft (168 m) culminating in the upper Nukumaruan, is now clearly untenable in view of the deep-sea oxygen-isotope records, which show that interglacial sea levels were at most only a few metres higher than present sea level (e.g., Shackleton & Hall 1984). We have found no unequivocally marine beds within the thick (100 m) Awhitu sequence at Oruarangi, and therefore consider the whole sequence as one that accumulated in a coastal sand-dune environment above sea level. The textural and compositional contrasts between the mud-dominated silicic volcaniclastic facies of the Oruarangi pumiceous beds and the sand-dominated quartzofeldspathic facies of the Awhitu Formation primarily record a major increase in supply of more locally derived basement (greywacke) sand. This originated from accelerated erosion of horsts in the South Auckland–Waikato basin-and-range province, differentially uplifted at a greater rate after about 1.8 m.y. B.P. Hydrodynamic sorting and concentration of the sand at the coastline, along with the supply by longshore drift of increasing amounts of ferromagnesian mineral sand from the Taranaki region to the south through the Pleistocene (Barter 1976), has led to the sand-dominated coastal geomorphology of the northern North Island west coast.

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REFERENCES

Andrews, P. B. 1982: Revised guide to recording field observations in sedimentary sequences. *New Zealand Geological Survey report 102*.

Barter, T. P. 1976: The Kaihu Group (Plio-Quaternary) of the Awhitu Peninsula, Southwest Auckland. Unpublished Ph.D. thesis, lodged in the Library, University of Auckland, Auckland.

Bartrum, J. A. 1919: A fossiliferous bed at Kaawa Creek, west coast, south of Waikato River, New Zealand. *Transactions of the New Zealand Institute 51*: 101–106.

Berggren, W. A.; Kent, D. V.; van Couvering, J. A. 1985: The Neogene: part 2. Neogene geochronology and chronostratigraphy. Pp. 211–260 *in*: Snelling, N. J. *ed.* The chronology of the geological record. *The Geological Society of London memoir 10*.

Brothers, R. N. 1954: The relative Pleistocene chronology of the south Kaipara district, New Zealand. *Transactions of the Royal Society of New Zealand 82*: 677–694.

Chappell, J. M. A. 1964: Quaternary geology of south-west Auckland and north Taranaki coast. Unpublished M.Sc. thesis, lodged in the Library, University of Auckland, Auckland.

———1970: Quaternary geology of the south-west Auckland coastal region. *Transactions of the Royal Society of New Zealand 8*: 133–153.

———1975: Upper Quaternary warping and uplift rates in the Bay of Plenty and west coast, North Island, New Zealand. *New Zealand journal of geology and geophysics 18*: 129–155.

Charland, A.; Lajoie, J. in press: Characteristics of pyroclastic deposits at the margin of Fond Canonville, Martinique, and implications for the transport of the 1902 nuées ardentes of Mount Pelée. *Journal of volcanological and geothermal research.*

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

Fisher, R. V.; Heiken, G. 1982: Mt Pelée, Martinique: May 8 and 20, 1902, pyroclastic flows and surges. *Journal of volcanology and geothermal research 13*: 339–371.

Fleming, C. A. 1953: The geology of Wanganui Subdivision. *New Zealand Geological Survey bulletin 52*.

Folk, R. L. 1968: Petrology of sedimentary rocks. Texas, Hemphill's.

Gilbert, M. J. 1921: Geology of the Waikato Heads district and the Kaawa unconformity. *Transactions of the New Zealand Institute 53*: 97–114.

Grindley, G. W.; Oliver, P. J.; Seward, D. 1988: Stratigraphy, geochronology and paleomagnetism of ignimbrites in the Matahana Basin, Taupo Volcanic Zone. *Geological Society of New Zealand miscellaneous publication 41a*: 71.

Heming, R. F. 1980: The Ngatatura diatreme. *New Zealand journal of geology and geophysics 23*: 569–573.

Henderson, J.; Grange, L. I. 1926: The geology of the Huntly–Kawhia subdivision, Pirongia and Hauraki divisions. *New Zealand Geological Survey bulletin 28*.

Hunt, T. M.; Syms, M. C. 1977: Sheet 3—Auckland. Magnetic map of New Zealand 1:250 000 total force anomalies. Wellington, Department of Scientific and Industrial Research.

Kear, D. 1957a: Stratigraphy of the Kaawa–Ohuka coastal area, west Auckland. *New Zealand journal of science and technology B38*: 826–842.

———1957b: Pumice chronology in New Zealand. *New Zealand journal of science and technology B38*: 862–870.

———1966: Sheet N55—Te Akau. Geological map of New Zealand 1: 63 360. Wellington, Department of Scientific and Industrial Research.

———1978: [Stratigraphy] Lower Quaternary, Auckland. Pp. 554–556 *in*: Suggate, R. P.; Stevens, G. R.; Te Punga, M. T. *ed.* The geology of New Zealand. Wellington, Government Printer.

Kear, D.; Schofield, J. C. 1978: Geology of the Ngaruawahia Subdivision. *New Zealand Geological Survey bulletin 88*.

Mildenhall, D. C. 1975: Lower Pleistocene palynomorphs from the Ohuka Carbonaceous Sandstone, south-west Auckland, New Zealand. *New Zealand journal of geology and geophysics 18*: 675–682.

Unit Or9: Lower 10–15 cm of unit Or9 is massive greyish olive, slightly sandy mudstone (subunit **Or9a**), forming weathering indent locally, that grades up into massive, soft olive-yellow fine sandstone (subunit **Or9b**), with small lenses of cross-laminated gravelly sand. Upper sandy subunit differentially eroded, possibly during emplacement of overlying unit Or10, and varies laterally in thickness from 0.5 to 2.0 m. Bulk of unit Or9 interpreted as alluvial channel or lake-margin sand body.

Correlative deposits at Okariha (**Ok11, 12,** and **13**) are thicker (up to 3 m) and internally more complex. Ok11 (to 60 cm thick) is laminated purplish carbonaceous mudstone with an iron-stained gritty sand interbed; Ok12 (to 1.3 m thick) is greyish white muddy fine sandstone and sandy mudstone, sometimes laminated and carbonaceous and including distinctive irregular band of white pumice silt, a few to several centimetres thick; and Ok13 (to 1.3 m thick) is massive to faintly laminated, greenish grey, slightly gravelly, variably muddy fine sandstone, with scattered lenses of rounded and weathered (Huriwai) mudstone clasts. Upwards transition from alluvial floodbasin to channel deposits is suggested. The thin pumice silt layer is possibly tephra. Upwards of three poorly developed paleosols may occur in sequence.

Unit Or10: Gradational and blurred erosional contact between units Or9 and Or10. Latter is 0.5–1.6 m thick, whitish or cream-coloured protuberant deposit with silty sand to mud texture (Fig. 4B). Antipathetic thickness relationships between units Or9 and Or10. Unit Or10 generally massive, but includes vague subhorizontal to wavy laminated structures, particularly nearer bottom and top. Iron-stained Leisegang structures present. Upper 20 cm or so of unit (subunit **Or10b**) forms distinctive weathering indent in light yellow muddy sandstone with weakly blocky to prismatic structure (Fig. 4B). This is probably a paleosol above a distal pyroclastic flow deposit.

At Okariha the ignimbrite (**Ok14**) averages 80 cm thick, has protuberant profile (Fig. 4A), is sandy textured over basal 10 cm but silty above (i.e., normally graded), and includes scattered pumice lapilli up to 1 cm size and thin layers of disseminated carbonaceous material. Basal contact may be scoured deeply into underlying fluvial sand (Ok13) with blurred and jumbled contact relationships between the two units. Above ignimbrite (Ok14) up to 2 m of yellow grey, massive, slightly muddy fine sandstone (**Ok15**), with scattered grit and small pebbles (<1 cm) of weathered mudstone. Prismatic structure and occasional limonitised rhizoconcretions in upper 40 cm may represent weak paleosol development (Fig. 4A), corresponding to subunit Or10b at Oruarangi (Fig. 4B).

Unit Or11: Light grey, laterally discontinuous, thin (0–60 cm) protuberant unit with sandy silt texture (Fig. 4B). Like unit Or10, is generally massive but includes some subtle horizontal and wavy or low-angle cross-laminations. Iron-stained Leisegang structures occur locally. Occasional vertical cracks pass through unit. Interpreted as distal pyroclastic flow deposit.

At Okariha the same ignimbrite (**Ok16**) is thicker (av. 1.1 m) and more continuous, with protuberant profile (Fig. 4A). Grossly normally graded from basal medium or fine sand-dominated texture to silt-textured at top, but includes thin coarse sand band about 5 cm thick in middle of unit.

Unit Or12: Up to 1 m of grey massive mudstone is poorly exposed before passing into colluvial deposits of yellow-brown sand supporting modern vegetation (Fig. 2). Erosion surface with relief of many metres cuts across unit Or12 and down through several underlying units, which terminate against it when traced laterally. Origin of unit Or12 uncertain.

At Okariha, three units (**Ok17, 18,** and **19**) totalling about 6 m thick occur before the same unconformity reached (Fig. 3). They are massive grey sandy mudstone, muddy fine sandstone, and clean very fine sand with occasional rhizoconcretions, prismatic structure, and iron-pan layers. Origin uncertain, although weakly developed pedogenetic features support a terrestrial setting. The poorly exposed, clean sand unit (Ok18) may be a dune deposit. None are tephras.

Unit Or13: At Oruarangi, as the erosion surface descends eastwards in elevation, overlying "valley-fill" deposits are greyish massive mudstone and purplish, laminated carbonaceous mudstone with abundant woody material. Thicknesses difficult to determine because of lateral variability and poor exposures, but are at least 1 m and probably as much as 4 m. Palynomorphs dominated by *Metrosideros* (and ?*Eucalyptus*), *Podocarpus* spp., and *Leptospermum*, consistent with derivation from coastal rata/podocarp forest. Moist, temperate conditions suggested by presence of number of proteas, parasitic shrubs, and marsh plants (e.g., *Toronia toru*, *Loranthus micranthus*, Balanophoraceae, *Typha*, and *Phormium tenax*). Coastal swamp or floodplain environments suggested.

Traced eastwards the unconformity capping unit Ok19 at Okariha cuts down at least as deep as Ok16. Surface covered by about 0.5 m of grey mudstone and laminated carbonaceous mudstone (**Ok20**), more or less draping topography and equivalent to unit Or13 at Oruarangi.

Unit Or14: At least 7 m of poorly exposed, yellowish brown, massive fine to very fine sandstone, including some horizontal and low-angle cross-laminations, occur above unit Or13. Mark top of logged section reported here (Fig. 3) and are probably coastal dune deposits at base of Awhitu Formation. Similar deposits (**Ok21**) occur at Okariha.