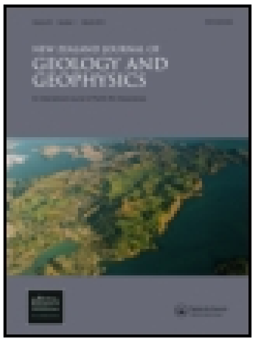

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Tectono-volcanic implications of provenance changes in the late Neogene coastal sand deposits of Kaihu Group, South Auckland, New Zealand

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Abstract Broad, sequential changes in sand mineralogy through the late Neogene (Pliocene–Quaternary) formations comprising the coastal deposits of the Kaihu Group in South Auckland reveal a series of provenance transitions for the group. An initial late Pliocene, mainly silicic volcanic provenance, was superseded in the early Pleistocene by a predominantly Mesozoic basement sedimentary provenance. Subsequently, during the early late Pleistocene, a mixed andesitic volcanic and basement sedimentary provenance developed. In the later Quaternary the andesitic volcanic provenance became predominant. The observed provenance transitions are consistent with major tectono-volcanic events associated with the evolution of the late Cenozoic volcanic arc–backarc system in western North Island. Transitions include the initial supply of silicic volcanic material from inferred late phases of the Coromandel Volcanic Zone; the initiation of the Taupo Volcanic Zone and related development of horst and graben topography in the South Auckland region, with accelerated erosion and supply of basement-derived clastics but diversion of Taupo-derived silicic detritus; and the supply of behind-arc andesitic volcanic detritus from Egmont Volcanics.

Keywords coastal sediments; mineralogy; provenance; Kaihu Group; late Neogene; Quaternary; South Auckland; silicic volcanism; andesitic volcanism; tectonics

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INTRODUCTION

The late Neogene (Pliocene–Quaternary) tectonic setting for the South Auckland region of New Zealand, included by Suggate et al. (1978, p. 676) within a Northland–Auckland extensional block-faulting province, is that of a backarc region extending more or less from North Auckland to Taranaki and inland to a silicic volcanic arc, the Taupo Volcanic Zone (Fig. 1). The modern backarc setting partly overprints a series of earlier (Miocene–Pliocene) backarc basins (Ballance 1976). The main features of such backarc regions are tilted fault blocks forming arc-subparallel linear ridges and troughs, modified to varying degrees by volcanism and by high rates of sedimentation (Karig 1971). Active extensional tectonism has characterised South Auckland for much of the late Neogene (e.g., Kamp 1988). This has formed a north–south to northwest–southeast trending basin and range topography involving basement blocks, centres of mafic through silicic volcanism, and widespread deposition of volcanogenic sediments in the grabens (Fig. 1).

This paper outlines the evidence for late Neogene shifts in sediment provenance during backarc-region evolution as exemplified by broad petrographic variations within the Kaihu Group of poorly consolidated sandstones in coastal South Auckland. The trends of mineralogical variation indicate that a regional tectono-volcanic history may be inferred from changes in sediment provenance through time.

STRATIGRAPHY AND SAMPLE ANALYSIS

The Kaihu Group (Kear 1965; Chappell 1970) includes all late Neogene formations of coastal and incidental volcanogenic facies along the western coastal strip of the South and North Auckland regions (Fig. 1). Despite often limited outcrop, and some reliance on borehole data and homogenised subsurface samples, a regionally applicable stratigraphy for the group has been developed (see Fig. 4 and Stokes (1988) for more details). The Kaawa Formation comprises variably fossiliferous, marginal to fully marine sediments, often strongly bioturbated. The Ohuka Formation consists of fluvio-estuarine silty sands and muds, and includes paleosols and silicic pyroclastic deposits (e.g., Nelson et al. 1989). The remaining formations, comprising the bulk of the group, are completely dominated by eolian coastal dune sands, with some littoral sands and occasional paleosols and tephras (e.g., Stokes et al. 1989a). The predominance of eolian deposits, and the occurrence of interformational erosion and soil development, particularly during glacial periods (Stokes 1987; Nelson et al. 1989), means that many of the formational contacts are strongly unconformable, and the regional correlation of units is difficult without good age control (Stokes 1988).

Samples used in this study were derived from Kaihu Group formations at three South Auckland localities, in part from two previous studies: (1) the Awhitu Peninsula (Fig. 1; Barter 1976); (2) the Kaawa–Ohuka coastal section, south of Port

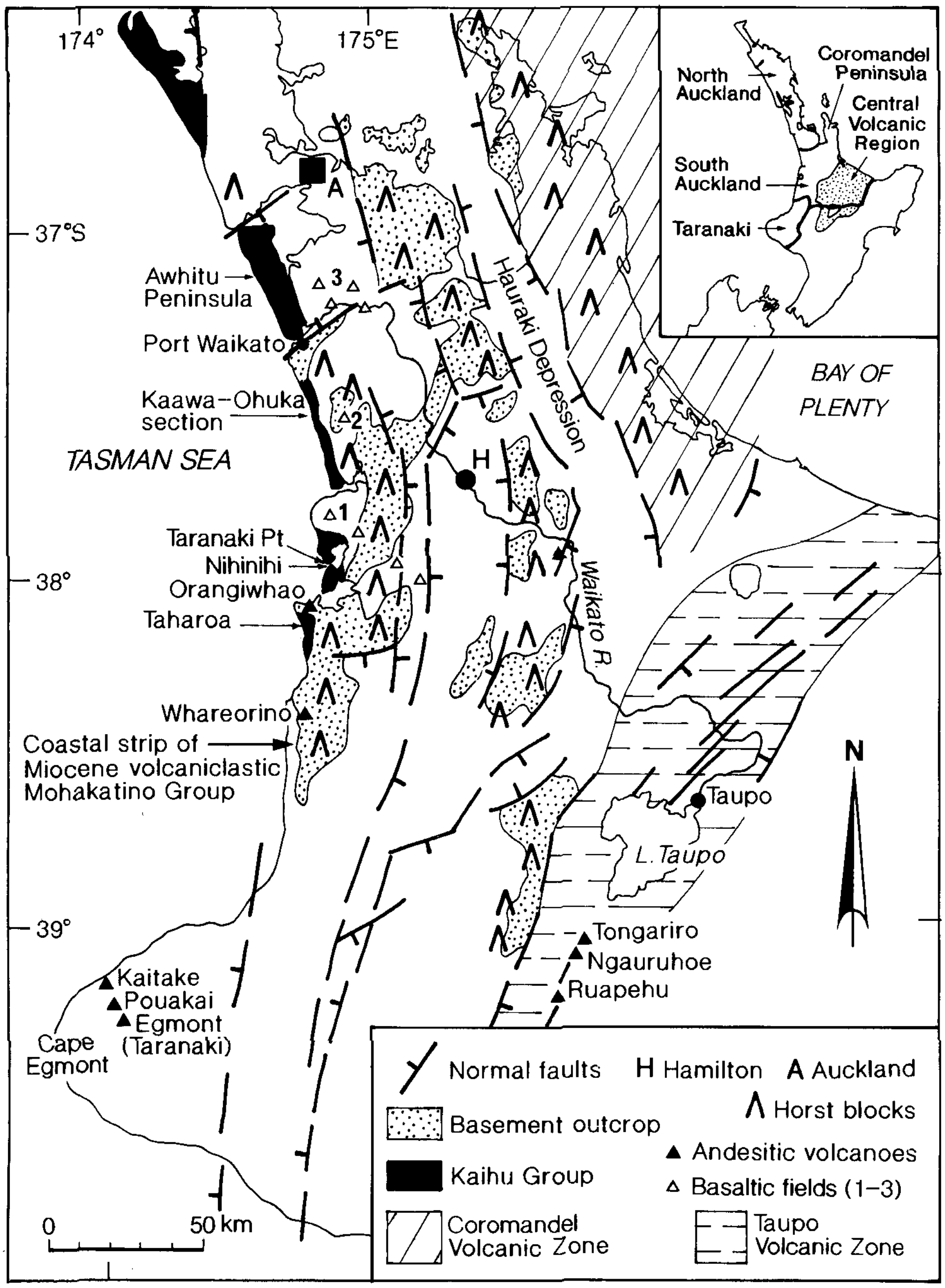


Fig. 1 Northwestern North Island showing: place names; the principal study sites for the late Neogene Kaihu Group sediments (see Fig. 4 for stratigraphy) along the South Auckland coastline at Awhitu Peninsula, Kaawa–Ohuka, and Taharoa; the outcrop distribution of basement Mesozoic sedimentary rock; and some major structural and volcanic features in the region. Basaltic fields 1, 2, and 3 refer to Alexandra Volcanics, Ngatutura Basalts, and South Auckland basalts, respectively.

Waikato (Fig. 1; Spratt 1974); and (3) the Taharoa sand deposit and the coastal sections at Nihinihi and Taranaki Point on the south and north sides, respectively, of the entrance to Aotea Harbour (Fig. 1; Stokes 1987). Samples from Awhitu ($N = 80$) and Kaawa–Ohuka ($N = 40$) came from surface outcrops, as did eight samples from Taharoa. The majority of Taharoa sediments ($N = 35$) were homogenised drillhole samples obtained by New Zealand Steel Mining Ltd in the course of establishing subsurface ironsand reserves at Taharoa (Stokes et al. 1989b).

The percent sand content of samples was determined by wet sieving through a 4ϕ (63 μm) screen. Subsamples of the sand fraction were impregnated with epoxy resin and thin sectioned for standard petrographic analysis. Mineral constituents were identified and point counted (400 counts per slide). Point counts of quartz (Q) and feldspar (F) were confirmed for a selection of QF-rich samples by recounting following a cobaltinitrite staining procedure (Bardsley 1975). Additionally, constituent quartz grains were classified into monocrystalline (straight or undulose extinction) or polycrystalline varieties (Folk 1968). Impregnated mounts of 10 petrographic samples were polished to establish the types and abundances of opaque mineral constituents.

RESULTS

A tabulation of all sample results is available on request and is included in Stokes (1987).

The sand content (coarser than 4ϕ) and sand petrography of the Kaihu Group formations are variable (Fig. 2). Quartz is ubiquitous, occurring mainly as straight or slightly undulose monocrystalline grains, and more rarely as slightly to strongly undulose polycrystalline grains. Feldspars are mainly multiple twinned and sometimes compositionally zoned plagioclase,

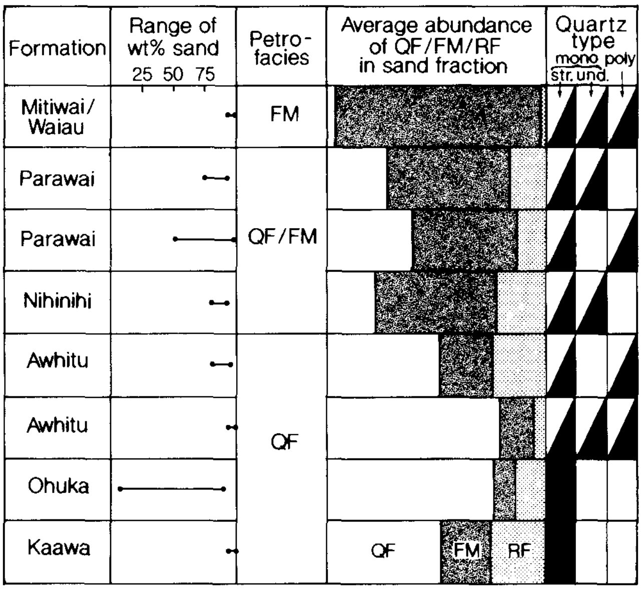


Fig. 2 Summary of petrographic and some textural data for the Kaihu Group formations (see Fig. 4 for stratigraphy). Abbreviations are FM, ferromagnesian; QF, quartzofeldspathic; RF, rock fragments; mono, monocrystalline quartz; poly, polycrystalline quartz; str., straight extinction; und, undulose extinction. Half shaded boxes = quartz types present; fully shaded boxes = sole quartz type present.

usually andesine, but ranging from oligoclase to labradorite; orthoclase and microcline are rare. Ferromagnesian minerals include hacksaw-terminated pale green augite, colourless and pleochroic pale green to pale pink hypersthene, and three varieties of amphibole —pleochroic pale green to dark green common hornblende; pleochroic green-brown to red-brown oxyhornblende (probably lamprobolite); and a scarce, pleochroic blue-green to blue variety (probably actinolite). A variety of volcanic (rhyolitic and andesitic), metamorphic, and sedimentary rock fragments occurs, as well as scarce shell fragments. Opaque minerals are ubiquitous and include dominantly titanomagnetite (homogeneous $\gg$ exsolved varieties), often rimmed with maghemite and containing inclusions of apatite and various sulphides, and some ilmenite, in which sulphide inclusions may occur. Accessory minerals include detrital glauconite, biotite, titanite, and chlorite. Many detrital grains support thin (< 15 μm), brown to red-brown authigenic ferric coatings.

The modal mineralogy of sand samples is plotted on ternary diagrams (Fig. 3). The sediments are compositionally immature (often containing >50% of ferromagnesian and opaque components and/or of rock fragments), and classify on the Folk et al. (1970) triangular diagram as lithic feldsarenite, feldspathic litharenite, and litharenite (cf. Fig. 3C). Quartz rarely exceeds 60% in abundance, and in some formations, particularly the Mitiwai Formation, heavy minerals are so abundant that the combined quartz, feldspar, and rock fragment content of the sands is less than 10% (Fig. 2, 3).

Sample plots define two stratigraphically confined clusters or petrofacies: a relatively quartzofeldspathic-rich cluster (< 50% ferromagnesian minerals, opaques, and rock fragments), named the QF-dominated petrofacies; and a relatively ferromagnesian/opaque-rich cluster, named the FM-dominated petrofacies. Samples of the Kaawa, Ohuka, and Awhitu Formations consistently plot within the QF-dominated petrofacies, and the Mitiwai and Waiau Formations plot mainly within the FM-dominated petrofacies (Fig. 2, 3). The Nihinihi and Parawai Formations have more variable, intermediate compositions on all ternary diagrams, occurring both within each of the clusters and near cluster boundaries. These latter formations are considered to constitute a QF/FM co-dominated petrofacies.

PROVENANCE IMPLICATIONS

The distinctive mineral assemblages of the petrofacies (Fig. 2, 3) are suggestive of specific and differing source rocks, the QF/FM co-dominated petrofacies reflecting subequal contributions from both sources. The QF-dominated assemblage is further considered to be derived from two sources. An initial, predominantly silicic volcanic source during Kaawa/Ohuka sedimentation is suggested by a preponderance of monocrystalline, straight extinction volcanic quartz varieties (Fig. 2), common volcanic glass (grouped as volcanic rock fragments), and the rarity or absence of sedimentary and metamorphic rock fragments. Within the Awhitu Formation the strong influence of a sedimentary basement rock provenance appears in the QF-dominated petrofacies with the introduction of undulose and polycrystalline quartz types (Fig. 2), as well as sedimentary and metamorphic rock fragments, and a reduction in the content of volcanic glass. The nature and abundance of ferromagnesian and iron-oxide minerals in the FM-dominated petrofacies (Fig. 2) is suggestive of sediment derivation mainly from andesitic volcanics or andesitic volcanic detritus (Gill 1981). The persistence of both common and slightly undulose quartz throughout the FM-dominated petrofacies nevertheless indicates that the provenance transition was not exclusive, and that quartzofeldspathic sedimentary rocks and silicic volcanics continued to make small contributions to the youngest formations.

A brief review of the petrographic data for surrounding sedimentary and volcanic rocks follows to determine whether the defined petrofacies may be uniquely associated with any particular source rock(s) in central western North Island.

QF-dominated petrofacies

All surrounding older sedimentary rocks, including particularly those of the Murihiku Supergroup and the Te Kuiti, Mahoenui, Mokau, and Mohakatino Groups (see Nelson & Hume 1977, fig.1), are potential sediment sources to this petrofacies (Table 1). The rarity or absence of phenocrystic quartz in most volcanic source rocks (e.g., Ewart 1966; Gow 1968; Smith 1987) precludes them as significant contributors to the petrofacies.

The presence of quartz, plagioclase, and orthoclase in Mesozoic to middle Tertiary sedimentary rocks provides an obvious series of potential sources for the QF-dominated units, all of these lithologies undergoing contemporary, and probably also late Neogene, erosion and reworking of clastic particles. The specific occurrence of stretched and polycrystalline (metamorphic) quartz types, prominent in the Awhitu Formation, and of orthoclase, testifies to the significance of Mesozoic basement rock sources, the only substantial source of such material locally (Keane 1986). Occasional gravel beds occur in the Kaihu Group formations, and they are dominated by granitic pebbles (Stokes 1987). The only known major source of such igneous material in South Auckland is the Triassic Moeatoa Conglomerate (Keane 1986), exposed at the coast north of Whareorino (Fig. 1).

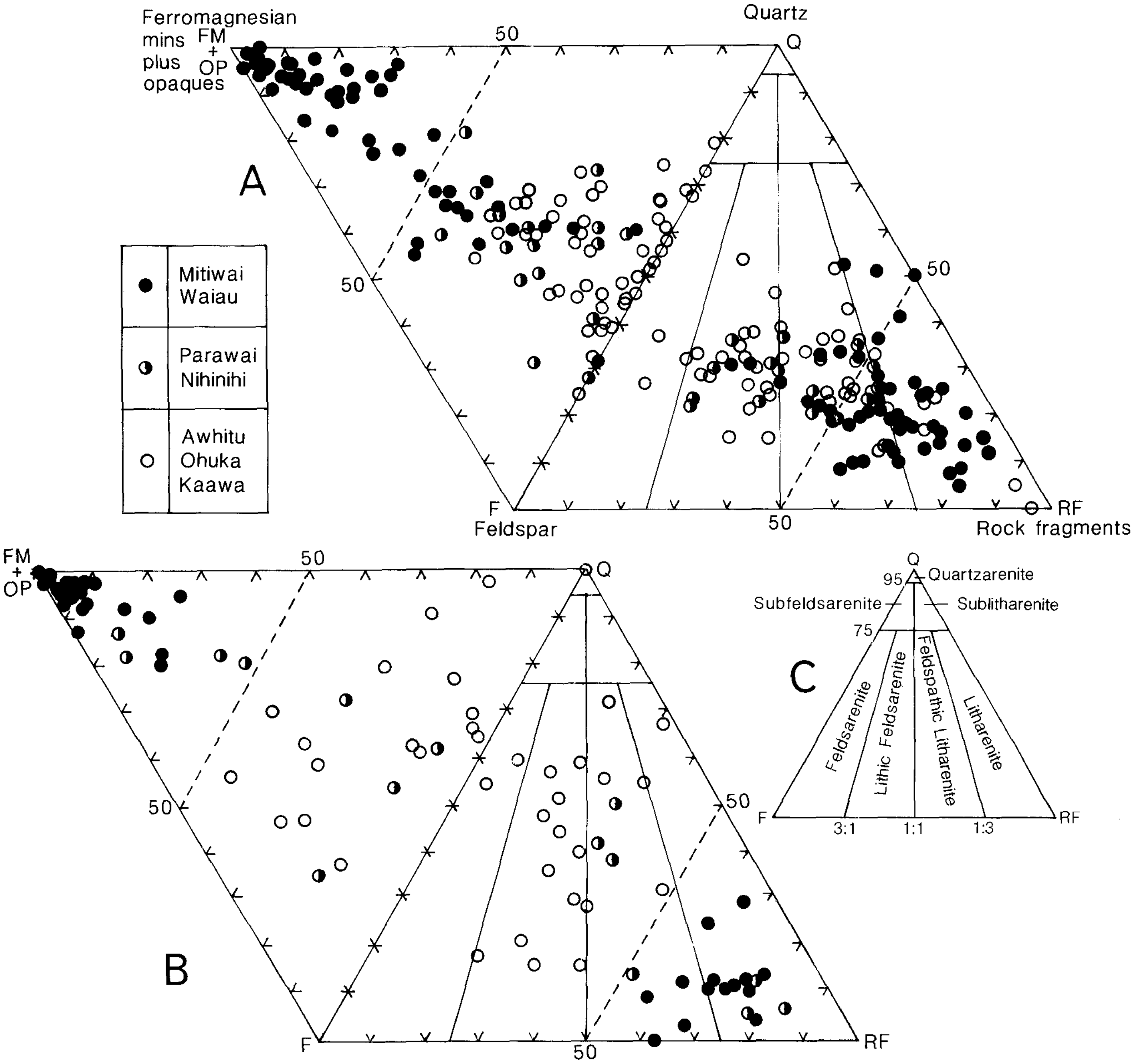


Fig. 3 Ternary detrital sediment classification diagrams based on recalculation to 100% of each of the Q/F/RF and Q/F/FM+OP mineral content of samples. **A**, Data from Spratt (1974), Barter (1976), and Stokes (1987) for samples from Kaawa–Ohuka, Awhitu Peninsula, and Nihinihi–Taranaki Point, respectively (Fig. 1). **B**, Data from Stokes (1987) for samples from Taharoa (Fig. 1). **C**, Classification scheme of Folk et al. (1970). Samples are coded according to petrofacies (solid symbols, ferromagnesian dominated; open symbols, quartzofeldspathic dominated; half-shaded symbols, quartzofeldspathic/ferromagnesian co-dominated), which in turn correspond mainly to the keyed Kaihu Group formations (see Fig. 4 for stratigraphy).

In QF-dominated units forming the Kaawa and Ohuka Formations, a predominantly silicic volcanic rather than Mesozoic–Tertiary sedimentary rock provenance is indicated by the occurrence only of volcanic-derived common quartz in the quartz fraction (Fig. 2) and the inclusion of pre-Marahauan (late Pliocene) silicic tephras, notably distal ignimbrites, in these formations (Nelson et al. 1989). Nelson et al. (1989) have argued for the probable importance of Coroglen Subgroup silicic volcanic deposits in the Coromandel Volcanic Zone of eastern Coromandel Peninsula (Skinner 1986) as a major source of sediment for the lower Kaihu Group. This suggestion is strongly supported by the recent work of Bowling (1989) who described Coromandel-derived late Pliocene ignimbrites and associated epiclastic sediments from west of the western margin of Hauraki Depression (Fig. 1). East to west emplacement of the ignimbrites occurred prior to the major faulting responsible for formation of Hauraki Depression, and some of the flows probably reached as far as the Tasman Sea coast, as suggested by Nelson et al. (1989).

FM-dominated petrofacies

The dominance of an augite-hornblende-opaque (titanomagnetite ≫ ilmenite) mineral assemblage within this petrofacies is consistent with an andesitic provenance (Gill 1981). This is further supported by the presence of compositionally zoned plagioclase and augite, the occurrence of opaque inclusions within the augite grains, and the presence of andesitic rock fragments. A silicic volcanic provenance is inferred to have been of subordinate importance in contributing to the FM-dominated petrofacies in this study because of the relative scarcity in the deposits of otherwise characteristic Taupo Volcanic Zone mineral components, such as hypersthene, ilmenite, and silicic rock fragments (cf., Ewart 1966; Hamill & Ballance 1985). Possible andesitic volcanic (Orangiwhao, Egmont, Taupo Volcanic Zone) and andesitic detrital (Mohakatino Group) sediment sources (for locations see Fig. 1) are considered briefly below.

Andesitic volcanics: A strong similarity exists between phenocryst assemblages of the Egmont Group and Orangiwhao–Whareorino Volcanics and the FM-dominated petrofacies (Table 2). The hypersthene-dominated, green hornblende-poor, brown hornblende-absent nature of the Taupo Volcanic Zone andesites (Clark 1960) precludes them as possible significant sources of Kaihu Group sediments.

Andesitic volcanic detritus: Low-quartz petrofacies sediments defined by Utley (1987) within the Miocene sedimentary strata of the Mohakatino Group exhibit a strikingly similar mineralogy to that of the FM-dominated petrofacies (Table 2). They were ultimately derived from now-buried andesitic volcanoes centred 30 km offshore from Taharoa (Fig. 1) and delineated by geophysical anomalies and seismic surveys (Hatherton et al. 1979; Utley 1987).

Despite the virtual absence of quartz in andesitic sources, quartz grains do persist in small amounts within the FM-dominated petrofacies (Fig. 2), suggesting that, although specific source rocks can be recognised, there has been a degree of mixing of sedimentary material and volcanic detritus during transportation and deposition.

In addition, some glass-dominated tephra or tephric subunits within each of the described petrofacies were derived from primary pyroclastic or secondary epiclastic emplacement of silicic volcanics and silicic volcanic detritus (Stokes 1987, 1988). Presumably much of this material was supplied initially from silicic volcanic centres in Coromandel Volcanic Zone (e.g., Nelson et al. 1989) and later from explosive rhyolitic volcanism in Taupo Volcanic Zone (Wilson et al. 1984).

DISCUSSION

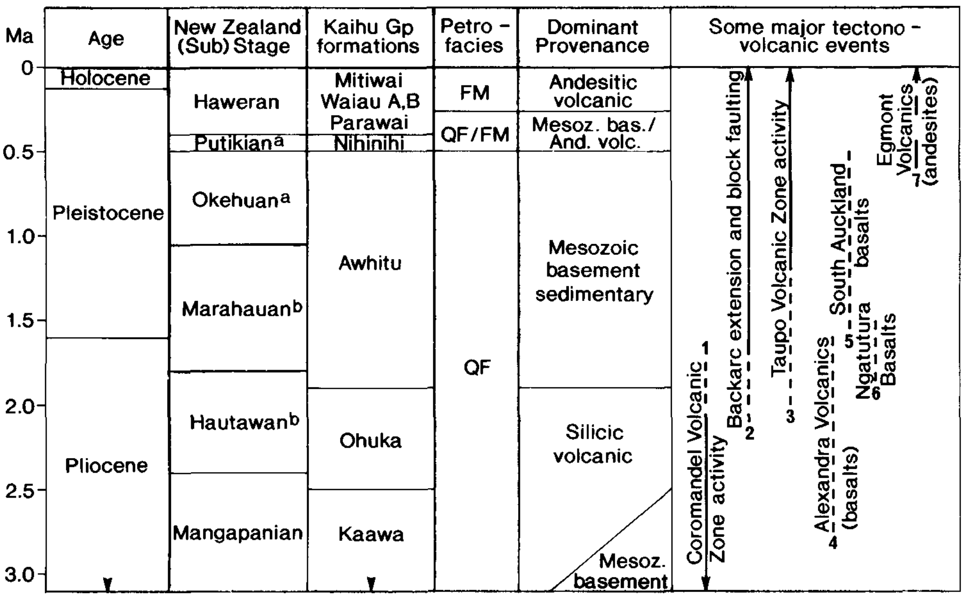
The initiation of the Indian-Pacific plate boundary in the form of the Alpine Fault through New Zealand in earliest Miocene (Kamp 1984), and the resulting transition from a dominantly extensional to compressional tectonic regime, strongly influenced sedimentation in western and central North Island (Nelson & Hume 1977). A general trend of increasing basement uplift and erosion was reinforced in the southwest of this region by the introduction of incipient-rift andesitic volcanism and its resulting detritus (Nelson & Hume 1977; Kamp 1984; Utley 1987). To the north and northeast, an active subduction system evolved and migrated south, commencing about 23 Ma ago in North Auckland through to 5 Ma ago and younger beneath southern Coromandel Volcanic Zone (Ballance 1976; Skinner 1986). This resulted in coeval eruption of volumetrically

Table 1 Simplified mineralogy of selected Mesozoic and Tertiary sedimentary rocks compared with the quartzofeldspathic (QF)-dominated petrofacies of the Kaihu Group. The felsic and clay mineral data for the sedimentary rocks are based mainly on X-ray diffraction analyses of about 20–50 samples from each group, which do not identify specifically the presence of rock fragments. Data sources include Nelson (1973), Nelson & Hume (1977, 1987), Hume (1978), Suggate et al. (1978), Stokes (1987), and Utley (1987).

Component	Murihiku Supergroup	Te Kuiti Group	Mokau Group	Mahoenui Group	Mohakatino Group	QF-dom. petrofacies
	Triassic–Jurassic	Eocene–Oligocene	Early Miocene	Early–mid Miocene	Mid–late Miocene	Late Neogene
% Quartz	20–25	10–45	5–20	30–40	15–40	15–50
% Plag	25–35	<5–10	5–15	20–25	10–30	5–20
% K Feld	3–5	<5	<5	<5	<10	<5–15
% Calcite	<5	<5–100	<20	<20	<5	<5
% Clay mins	30–40	10–90	5–50	30–40	<5	<5
Species[1]	chl m/l mic smec	smec ill kaol chl	smec ill chl m/l	ill smec chl m/l kaol	ill smec chl m/l kaol	hall ill m/l smec
Other components include[2]	biot opaq hbl aug epid chl zirc tit	opaq epid zirc ap garn sph biot hbl	n.d.	n.d.	g hbl b hbl aug opaq micas epid glauc	hbl aug opaq VRF MRF SRF glauc chl

[1]ill, illite; smec, smectite; chl, chlorite; kaol, kaolinite; mic, micaceous clays; hall, halloysite; m/l, mixed layer clays.

[2]biot, biotite; opaq, opaques; hbl, hornblende (g, green; b, brown); aug, augite; epid, epidote; chl, chlorite; zirc, zircon; tit, titanite; ap, apatite; garn, garnet; VRF, volcanic rock fragments; MRF, metamorphic rock fragments; SRF, sedimentary rock fragments; glauc, glauconite; n.d., no data.



a Together equivalent to Castlecliffian
b Together equivalent to Nukumaruan

Fig. 4 Integrated summary of the stratigraphy, age, lithology, and inferred provenances for the Kaihu Group, and some major late Neogene tectono-volcanic events in the South Auckland region. Formational stratigraphy based on Kear (1965), Chappell (1970), Pain (1976), and Stokes (1987); age information for the group from Stokes (1987, 1988), and for the tectono-volcanic events from: 1, Skinner (1986); 2, Kamp (1984, 1988); 3, Wilson et al. (1984) and Grindley et al. (1988); 4, 5, 6, Briggs et al. (1989); 7, Stipp (1968) and Neall et al. (1986).

extensive silicic arc volcanics, backarc extension, and limited basaltic volcanism (Kamp 1984). Late Neogene sedimentation in South Auckland probably commenced with a predominantly Coromandel-derived silicic volcanic provenance, corresponding to deposition of the conspicuously pumiceous Kaawa and Ohuka Formations and their inland correlatives (Fig. 4; Kear 1957; Nelson et al. 1989).

Why the shift from a Coromandel-derived silicic volcanic provenance to a Mesozoic basement quartzofeldspathic provenance?

The transition from a predominantly silicic volcanic provenance (Kaawa and Ohuka) to a basement quartzofeldspathic (Awhitu) provenance is inferred to relate to the initiation of the Taupo Volcanic Zone and associated crustal movements (Fig. 4). Extensional tectonism in the backarc region has led to the development of the modern basin-and-range topography involving basement blocks (Fig. 1; Kamp 1988). Field evidence for such late Neogene activity includes the reactivation of paleofault traces, as described by Spörli (1987, fig. 5).

The development of roughly north–south trending uplifted coastal and inland ranges separated by rift basins had two important effects: (1) The ranges acted as a structural barrier between the Coromandel Peninsula in the east and the South Auckland coastline in the west, causing subsequent Coromandel-derived pyroclastic eruptives to become increasingly diverted and ultimately largely confined to the low-lying inland basins, particularly Hauraki Depression (e.g., Hochstein & Nixon 1979; Cuthbertson 1981); (2) The development of uplifted basement horst blocks led to an overall increase in the erosion and supply of basement-derived quartzofeldspathic detritus.

Why the shift from quartzofeldspathic-dominated to ferromagnesian-dominated sedimentation?

The shift from quartzofeldspathic-dominated to ferromagnesian-dominated sedimentation probably represents a major, broadly synchronous, west coast North Island sedimentary tectono-volcanic event. The shift was manifested initially by deposition of QF/FM co-dominated Nihinihi and Parawai Formations, dated palynologically as Marahauan–Castlecliffian (Mildenhall 1986). A late Castlecliffian (or Putikian) age for the inception of this shift is suggested on the basis of correlation of the underlying Awhitu Formation to QF-dominated Marahauan–Okehuan sequences (Fig. 4; Stokes 1987). Stipp (1968) radiometrically dated the volcanic centres of Kaitake, Pouakai, and Egmont (Fig. 1), which have close mineralogical similarity to the FM-dominated petrofacies, at about 0.57, 0.21–0.24, and 0.02 Ma, respectively (Fig. 4). The date of initiation of Kaitake volcanism corresponds closely with the initial influx of ferromagnesian detritus within the Nihinihi Formation (Barter 1976). These approximate age

Table 2 Mineral assemblages of selected North Island Tertiary andesitic volcanic rocks and andesitic lithic fragment-bearing sediments compared to those characterising the petrofacies of the Kaihu Group. Components are arranged in reducing abundance sequence. Data from Clark (1960), Gow (1968), Neall et al. (1986), Smith (1987), and Utley (1987).

Volcanic rock/ lithic fragment-bearing sediments	Mineral assemblage*
Taupo Volcanic Zone andesite	plag + hyp + aug ± ol ± glass ± hbl ± qtz
Egmont andesite	plag + cpx + g & b hbl ± ol ± mag ± opx
Orangiwhao andesite	plag + aug + g & b hbl + opaques ± biot ± qtz
Mohakatino Group	
High-qtz petrofacies	qtz + plag + orth ± biot ± musc
Low-qtz petrofacies	g & b hbl + aug ± plag ± opaques
Kaihu Group	
Quartzofeldspathic (QF) petrofacies	qtz + plag + orth ± IRF
Ferromagnesian (FM) petrofacies	opaques + g & b hbl + aug ± IRF ± qtz

*plag, plagioclase; hyp, hypersthene; aug, augite; ol, olivine; (g&b) hbl, (green & brown) hornblende; cpx, clinopyroxene; mag, titanomagnetite; opx, orthopyroxene; qtz, quartz; orth, orthoclase; biot, biotite; musc, muscovite; IRF, igneous (volcanic) rock fragments.

correlations provide further evidence for the Egmont andesites being a major source of upper Kaihu Group sediments.

If the Mohakatino Group low-quartz petrofacies of Utley (1987) was a major contributor of sediment to the FM-dominated petrofacies (Table 2), an explanation is needed for the virtual absence of such detritus for a duration of over 2 m.y. during earlier QF-dominated deposition. We suggest that ferromagnesian detritus from the Mohakatino Group, along with detritus from all other pre-existing sedimentary and volcanic rocks, has supplied a small proportion of material to the Kaihu Group for much of the late Neogene, accounting for the small amounts of ferromagnesian detritus within the QF-dominated petrofacies.

Rather than a direct shift from QF- to FM-dominated sediment deposition, it is probable that the rate of supply of ferromagnesian detritus has increased steadily to the present situation in which it overwhelms that of quartzofeldspathic material along the South Auckland coast. The hypothesis is supported both by the correlation of the timing of andesitic volcanism and ferromagnesian sediment domination, and by implied rates of sedimentation for the Kaihu Group, which increase from about 0.02 to 0.13 mm/yr on passage into the FM-dominated petrofacies (Stokes 1987).

Subordinate influence of Taupo Volcanic Zone as a provenance

The mineralogical data presented here identify at different but overlapping times the silicic volcanics of Coromandel Volcanic Zone, the South Auckland Mesozoic basement (and Tertiary) sedimentary rocks, and the andesitic volcanics of the Egmont Volcanics as the principal contributors of terrigenous clastics to the succession of Kaihu Group sediments. Significantly, the voluminous silicic volcanics of the Taupo Volcanic Zone are not a major provenance, accounting for only the occasional silicic pyroclastic fall or flow deposit within the Pleistocene formations of the group. This contrasts with the conclusion of Hamill & Ballance (1985, p. 503) that "The Taupo Volcanic Zone could have supplied all of the ironsand on the west coast north of the Waikato River mouth". We suggest that, as a consequence of backarc extension and horst and graben development in the South Auckland region, Taupo Volcanic Zone detritus was, for much of the Pleistocene, partitioned mainly into the Bay of Plenty, Wanganui–North Cook Strait Basin, and the Hawke's Bay region. Supply to the North Island west coast, north of the (paleo)Waikato River mouth, took place at those times in the river's history during which it discharged into the Tasman Sea rather than Hauraki Gulf (e.g., Healy 1945). Together with longshore sediment dispersal to the south, south of Cape Egmont, and to the north, north of Waikato River mouth (Carter 1975; Hume & Nelson 1986), the coastal stretch between Cape Egmont and Awhitu Peninsula tended to lie in a "shadow zone", largely free from the direct influence of any Taupo-derived clastics.

Subordinate influence of backarc basalts as a provenance

Three backarc basalt fields are sited near the modern west coast in the South Auckland region: Alexandra Volcanics, Ngatutura Basalts, and South Auckland basalts (Fig. 1). The ages of these fields, reviewed by Briggs et al. (1989) and summarised in Fig. 4, overlap partly with Kaihu Group sedimentation. However the basalts, dominated by a ferromagnesian assemblage of olivine, titanaugite, and augite, with minor or no hornblende, hypersthene, or phenocrystic titanomagnetite (Rafferty & Heming 1979; Briggs et al. 1990), have not made a significant mineral contribution to the Kaihu Group formations. This is in sharp contrast to the abundance of phenocrystic clastic detritus derived from the much younger Egmont andesitic volcanics. Possible reasons for the general dearth of basalt-derived components include the local extent of the fields, their predominantly inland rather than exposed coastal aspect, and the preponderance of resistant lavas over more easily erodible pyroclastic (scoriaceous) deposits in the fields (in a ratio of about 20:1 in the Alexandra and Ngatutura fields—R. M. Briggs pers. comm. 1989). For the Egmont Volcanics, Neall et al. (1986) estimated that the proportion of andesitic lava to that of fragmental material approaches 1:20.

CONCLUSIONS

At least two major transitions in provenance are manifested in the sand mineralogy of the late Neogene sedimentary strata of the Kaihu Group in the South Auckland coastal region. Biostratigraphic (lignite) datums within coastal sequences provide dates for both the provenance transitions themselves, and the tectono-volcanic conditions that induced the provenance shifts. As a result, the gross timing of the sedimentary and tectono-volcanic development of central western North Island is becoming clear.

Petrographic analysis enables the stratigraphic succession to be related to distinctive petrofacies, namely quartzofeldspathic-dominated, quartzofeldspathic-ferromagnesian co-dominated, and ferromagnesian-dominated, which in turn are related broadly to source rock types and areas. The record of petrographic variation supports the contention of an initial silicic volcanic provenance, probably Coromandel Volcanic Zone, and clearly demonstrates two major provenance transitions—first to a Mesozoic basement sedimentary rock provenance, and later to an Egmont andesitic rock provenance.

Andesitic and rhyolitic volcanism, uplift, and extensional tectonism in western North Island are natural consequences of late Neogene subduction of the Pacific plate beneath central North Island (Kamp 1984, 1988). Consideration of sediment provenance, and the mechanisms responsible for changing sediment provenance with time, serves to emphasise the ultimate importance of tectonism in influencing sedimentation within the South Auckland backarc region during the late Neogene. Tectonism has controlled both basin formation and sediment supply, directly via basement uplift and pyroclastic volcanic events, and indirectly via erosion of ferromagnesian-bearing, arc-associated andesitic volcanoes.

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