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# Diagenesis in Early Miocene Waitemata Group sediments, Upper Waitemata Harbour, Auckland, New Zealand

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**Abstract** The Waitemata Group in the Upper Waitemata Harbour area is a turbidite sequence with interbedded volcaniclastic sandstones, rhyolitic granule-sand and tuff horizons, and conglomerate lenses containing metamorphic, volcanic, plutonic and sedimentary clasts. Clastic debris in the sediments is little altered except for devitrification of volcanic glass. Zeolites and clay minerals encrust clastic grains and fill pores. There is a strong lithologic control on diagenetic assemblages. Lithic-rich sandstones poor in volcanic debris have calcite cement. Volcaniclastic sandstones have zeolite cement with the paragenetic sequence clinoptilolite (+ mordenite) → chabazite and/or erionite, and finally rare analcime. Rhyolitic granule-sand horizons contain the paragenetic sequence analcime → clinoptilolite → chabazite and/or erionite. Conglomerate horizons, which frequently lack any vitric debris, have analcime cement. In rhyolitic tuff only mordenite occurs crystallising directly from devitrified glass shards. Clay minerals present are smectite and illite, and chlorite in highly altered volcaniclastic sediments. Interbedded mudstones sealed fluids into volcaniclastic sandstone and tuff horizons and diagenesis occurred in a closed hydrologic system. The original pore fluid, believed bicarbonate-rich, precipitated calcite cement in the absence of vitric debris. In volcaniclastic and vitric rocks devitrification of glass liberated alkalies and silica into pore fluids leading to crystallisation of zeolite. Conglomerates filling channels cut into other sediments were an open hydrologic system and analcime crystallised from Na-saturated fluids flowing through them.

**Key words**: zeolites, analcime, rhyolitic tuffs, volcaniclastic sediments, Waitemata Group, New Zealand.

## INTRODUCTION

Early Miocene Waitemata Group clastic sediments outcrop over large areas of the Auckland Region (Fig. 1A). They rest unconformably either on the Northland Allochthon (Ballance & Spörli 1979) or on the basement rocks of the North Island – the Permian to Jurassic metagreywackes and enclosed ocean floor material of the Waipapa terrane. The Waitemata Group sediments are all marine and are believed to have been deposited in a rapidly subsiding extensional basin in an intra-volcanic arc environment (Ballance 1974; Hayward 1979, 1993; Ricketts *et al.* 1989). They also represent the last significant period of Tertiary sedimentation and in the Northland – Auckland region are stratigraphically overlain only by sediments of Quaternary age.

The stratigraphy (Ballance 1976), sedimentology (Ballance 1974; Ricketts *et al.* 1989) and the heavy mineral content (Hayward & Smale 1992) of the Waitemata sediments are now well known. Basal and early sediments appear to have been derived entirely from the local Waipapa Group basement rocks. However, study of the clastic material contained in the Waitemata sediments (Hayward & Smale 1992) has shown that the bulk of the succession was largely derived from two main sources: (i), allochthonous rocks of Cretaceous-Oligocene age (Tangihua Volcanics and sedimentary rocks of the Northland; Allochthon) which outcrop over much of central Northland; and (ii), the contemporaneous and largely andesitic arc volcanism (Fig. 1A). The predominant sediments in the older part of the Waitemata sequence are flysch type and derived largely from the older allochthonous rocks. Locally, rhyolitic tuffaceous and pumiceous horizons occur interbedded in the sedimentary sequence. Basic-intermediate volcanic-derived sedi-

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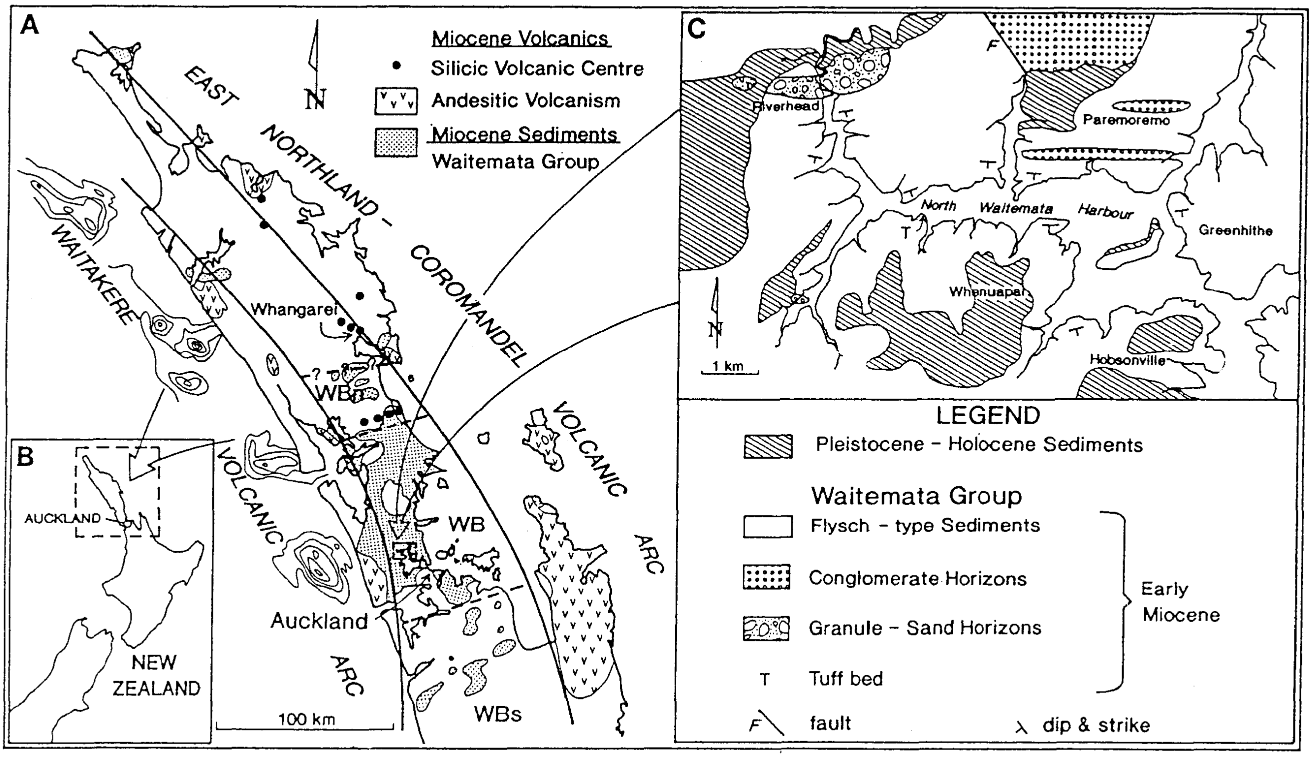


Fig. 1 1A = Map showing distribution of early to mid Miocene rocks in northern New Zealand including the positions of the parallel volcanic arcs. Lines indicate the eastern and western limits of volcanics belonging to the Waitekere and Northland-Coromandel Volcanic arcs respectively. Offshore contoured positive magnetic anomalies (Davey 1974) delineate probable centres of the Waitekere Volcanic Arc. The Waitemata Basin is an elongate interarc basin with northern (WBn) and southern (WBs) shelf facies separated by a deeper water facies (WB). 1B = inset map showing location of Fig. 1A. 1C = simplified geology of the Upper Waitemata Harbour area.

ments, apparently sourced in the west (Waitakere Group Volcanics), interdigitate with and later overstep the typical flysch sediments and airfall tuff layers. The Waitemata Group sediments have been subjected to two syn-basinal phases of thrusting and folding, a post-basinal phase of gentle regional tilting and a late block faulting phase (summarised in Hayward 1993). They show negligible burial "metamorphic" effects and indeed lack evidence for any major postdepositional compaction but, as may be expected for a young volcanogenic sequence, most of the sediments are diagenetically altered.

Professor Teruhiko (Terry) Sameshima was the first to systematically investigate diagenetic minerals in the Waitemata Group. He recognised and described the widespread occurrence of zeolites in the volcaniclastic and tuff horizons of the Waitemata succession and published a paper recording and presenting mineralogical and chemical data for analcime, clinoptilolite, chabazite, erionite, mordenite and phillipsite (Sameshima 1978). In this paper Terry also highlighted some unusual features of the Waitemata Group zeolitisation which included the first records of chabazite and erionite in marine sediments. He also noted that all the zeolites were, in general, Si-poor varieties of the individual mineral species. The characterisation and potential uses of the zeolitised Waitemata tuff horizons remained one of his major research interests during his Auckland years.

In this paper we examine the diagenetic processes in a variety of Waitemata Group sediments in the Upper Waitemata Harbour area with particular emphasis on understanding the distribution of diagenetic minerals and the paragenetic relations between the zeolite minerals. The study was part of a Masters thesis (Davidson 1990ms). During the course of the thesis Terry Sameshima gave considerable help with X-ray diffraction methods and identification of zeolites and the clay mineralogical techniques used were those had been developed by him. This paper is dedicated to the memory of Terry Sameshima as an acknowledgement of his work and the stimulation he provided which encouraged others to work on zeolites and zeolitised tuff horizons in the Auckland-Northland area.

## WAITEMATA GROUP SEDIMENTS OF UPPER WAITEMATA HARBOUR AREA

There are no basement rocks exposed in the upper Waitemata Harbour area. The rocks outcropping are Waitemata Group sediments belonging to the Paremoremo Facies of Schofield (1989). They are believed to have a thickness of the order of 4000 m (Schofield 1989) and are stratigraphically overlain only by Pleistocene sands, peats, ashes and muds which form terrace deposits on the Miocene sediments. The Waitemata Group sequence is stratigraphically upright with a broad regional tilt to the south.

Waitemate Group strata in the Upper Waitemate Harbour area can be divided into five distinct lithofacies:

(i) A well bedded flysch sequence composed of alternating thin sandstones and mudstones which are interpreted as a marine turbidite facies (Ballance 1974). The turbidite sandstones are largely litharenites composed dominantly of clasts of sedimentary (argillaceous) debris but with variable amounts (0 to 60%) of volcanic lithic material which is typically a fine-grained basaltic andesite. The inter-turbidite siltstones are mineralogically very similar, differing only in that they are laminated and have carbonaceous matter concentrated in the laminations. The turbidite sequence is considered by Hayward & Smale (1992) to have been largely derived from Tangihua Volcanics and sediments of the Northland Allochthon.

(ii) Interbedded with the more usual sedimentary lithic-rich and mixed turbidites are occasional thin (<0.5 m thick) poorly sorted, ungraded medium to coarse grained volcanic sandstones. Lithologically they are composed of angular, highly altered basaltic to andesitic clasts and detrital mineral grains removed from them. The source of the volcanic material is believed to be the Manukau Volcanic Centre of the Waitakere Volcanic Arc which is situated approximately 15 km to the west (Davidson 1990).

(iii) A 100 m thick series of well cemented, laterally extensive, granule-sand beds, usually individually no more than 300 mm thick. This horizon is localised in the Riverhead area (Fig. 1C). The dominant lithic clast in the granule-sand beds is rhyolite (60-80%) with minor siliceous mudstone and biotite as the major detrital mineral constituent. A petrographic survey of all known mid to late Tertiary silicic volcanics has shown that only the rhyolite domes in the Brynderwyn-Mangawhai area (Pukeroro Dacites of Hayward 1993), 30 km south of Whangarei (Fig. 1A), contain abundant phenocrystal biotite and since sedimentary structures also indicate an origin for the rhyolitic debris from the north (Davidson 1990), we presume that the Brynderwyn-Mangawhai rhyolite domes are the source of the silicic volcanic debris.

(iv) Massively bedded conglomerates which occur in distinct horizons in the lower (north) parts of the stratigraphic sequence (Fig. 1C). They belong to the Albany Conglomerate facies, the oldest of three conglomerate facies recognised in the Waitemata Group (Hayward 1993). Each conglomerate horizon in the Upper Waitemata Harbour area has its own distinctive lithologic constitution. Two of the conglomerates were studied in detail – the Paremoremo and Riverhead conglomerates (Fig. 1C). The Paremoremo conglomerate outcrops as a series of crosscutting channel infillings composed of unconformably bedded lenses, each of which has a width along strike of up to 20 m and a maximum thickness of 1 m. The lenses contain pebble to boulder sized clasts of andesitic material (>80%) with minor (<5%) rhyolitic clasts, <5% material derived from the Waipapa Group and rare diorite and scoriaceous basalt fragments. The Riverhead conglomerate horizons are contained within the rhyolitic granule-sand horizon as channel fills of pebble-size clasts of weakly to low grade metamorphosed (greenschist) basic volcanics and dolerite derived from Tangihua Volcanic massifs.

(v) Although silicic vitric tuff horizons are known in many areas of Waitemata Group and are particularly notable in the Kaipara region (Sameshima 1978), only one has been recorded in the Upper Waitemata Harbour region. This tuff occurs as a discrete, 0.8 m thick, fine grained, cemented horizon conformably interbedded with flysch beds in the estuary south-east of Riverhead (Fig. 1C). The tuff is highly sorted and is composed of silicic glass shards and feldspar grains and also contains foraminifera.

In the section exposed around the Upper Waitemata Harbour, rhyolitic debris is concentrated in the stratigraphically lowest part of the section (Riverhead region) while volcaniclastic sandstones are increasingly abundant in the upper parts of the succession, interbedded with normal flysch sandstones and mudstones, and apparently thicken to the west (Davidson 1990). The observed stratigraphy is compatable with known age relations of volcanic source rocks and allows an estimation of the age of the sediments. The Brynderwyn-Mangawhai domes, believed to be the source of the rhyolitic debris, have been K-Ar dated as 18-20 Ma (Doi 1993ms; Hayward 1993), older than the Manukau Volcanic Centre of the Waitakere Volcanic Arc which is 15 km to the west and for which K-Ar dates cluster at 16-18 Ma (Doi 1993; Hayward 1993). We conclude that the Waitemata Group sediments in the Upper Waitemata Harbour area were deposited during the time interval 18 to 20 Ma BP.

The sedimentary succession exposed in the Upper Waitemata Harbour area represents a microcosm of Waitemata Group lithologies and as such is important in providing information about the diagenetic processes which led to their cementation.

**Methods**

Fifty-seven Waitemata Group sediment samples were first examined by thin section to determine the nature and degree of diagenetic alteration in the framework (clastic) grains, the presence of cementing material and the location of deposits of diagenetic minerals. Because most of the diagenetic changes involve minerals of very small size which also occur in very minor amounts the diagenetic minerals had to be separated and concentrated. Thirty-six samples from a range of representative lithologies were selected and the clay mineral constituents were concentrated by dispersing the sample in water and separating the clay size fraction by settling techniques. The resulting clay fraction was then pipetted onto a glass side and allowed to air dry and sediment overnight. This provided an oriented air-dried sample for X-ray diffraction examination. After this sample was examined it was treated with glycol and then heated to 550℃ with X-ray diffractograms being run after each treatment. The zeolite fraction was concentrated by gently crushing the rock and hand picking the zeolites. These techniques allowed the identification of the diagenetic phases.

Twelve samples were also examined with a Philipps 505 Scanning Electron Miroscope fitted with an EDAX system which allowed qualitative analysis of the phases present and their paragenetic relations. Samples were prepared for SEM study by first breaking the airdried sample to provide a fresh fracture surface. The samples were then mounted on an aluminium stub and evacuated for 24 hours to remove any remaining moisture. The sample was then blown with compressed air, and dipped for several seconds in an ultrasonic bath filled with freon to remove any loose particles.


Fig. 2 Subequal amounts of clinoptilolite and smectite lining framework clasts in a porous sandstone. Hair-like fibres are mordenite. Authigenic growth of these minerals is considered to be contemporaneous. (Sample AU 42032)

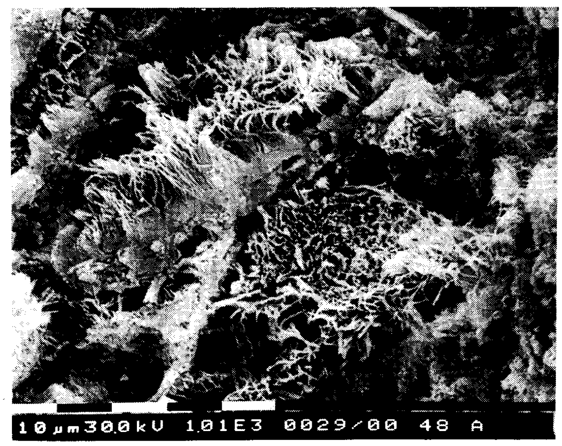


Fig 3 Mordenite "beards" growing from rhyolitic glass shards in Riverhead tuff horizon. (Sample AU 42056)

## DIAGENESIS IN WAITEMATA GROUP SEDIMENTS

In all the unweathered Waitemata Group sediments studied, feldspars, mafic minerals and most lithic clastic grains show little sign of alteration. In contrast, the volcanic glass shards and rhyolitic debris are extensively devitrified and overgrown by clays and zeolites (Fig. 2).

Five clay minerals (smectite, illite, chlorite, kaolinite and halloysite) have been recorded in the Waitemata Group sediments. The most widespread and abundant is smectite which is concentrated in volcaniclastic sediments and rocks with high permeability. Thin sections show it to be a matrix mineral except in the volcanic sandstones where it is occasionally seen to pseudomorph volcanic glass in lithic clasts. Smectite is notably absent from the strongly cemented rhyolitic granule-sand horizons at Riverhead. Illite occurs in most sediments but never in major amounts. Little chlorite is present and is confined to highly altered volcaniclastic sediments. The position of kaolinite and halloysite is uncertain. The amount of the kaolin group minerals increases with the degree of weathering and there is an inverse relationship between the amounts of smectite and kaolin which also suggests that the kaolins are the products of terrestrial weathering.

As already noted by Sameshima (1978), zeolites are widespread in the Waitemata Group sediments occurring chiefly in volcaniclastic and tuffaceous beds. In the Upper Waitemata Harbour area zeolites, often with clay minerals, commonly coat clastic grains, fill pores (Fig. 2), and have nucleated on precursor volcanic glass (Fig. 3). Zeolites do not replace the framework grains instead they occur most commonly as a cement. The most intensive zeolitisation is in the rhyolitic granule-sand horizons enclosing the