Recent stratigraphic studies at Matata: implications for Kawerau geothermal field modelling and subsurface interpretation

D.C.H. HIKUROA[1]
School of Geography, Geology and Environmental Science, The University of Auckland, N.Z.

D.M. GRAVLEY[1]
School of Geography, Geology and Environmental Science, The University of Auckland, N.Z.

C.J.N. WILSON[1]
School of Geography, Geology and Environmental Science, The University of Auckland, N.Z.

P.R.L. BROWNE[1]
School of Geography, Geology and Environmental Science, The University of Auckland, N.Z.

A.W. OLSEN[2]
Ngati Umutahi Marae Trust, Matata, N.Z.

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Full addresses/phone/fax

[1] School of Geography, Geology and Environmental Science, The University of Auckland, PB 92019 Auckland Mail Centre, Auckland, N.Z.
Ph.(09) 373-7599 Fax (09) 373 7435

[2]Ngati Umutahi Marae Trust, Matata, N.Z.

RECENT STRATIGRAPHIC STUDIES AT MATATA: IMPLICATIONS FOR KAWERAU GEOTHERMAL FIELD MODELLING AND SUBSURFACE INTERPRETATION

D.C.H. HIKUROA[1], D.M. GRAVLEY[1], C.J.N. WILSON[1], P.R.L. BROWNE[1], A.W. OLSEN[2]

[1]School of Geography, Geology and Environmental Science, The University of Auckland, Auckland, N.Z.
[2]Ngati Umutahi Marae Trust, Matata, N.Z.

SUMMARY – Following the debris flows at Matata, eastern Bay of Plenty, on May 18, 2005, detailed field investigations of the geology, freshly exposed in the scoured channels of the Awatarariki and Waitepuru streams, were performed. Within a sequence of marine and terrestrial sediments, previously thought to be as old as early Pleistocene, the Rangitawa tephra (correlated with the ~320-340 ka Whakamaru group ignimbrites) has been recognised, resting on a palaeosol above a sequence of shallow marine, beach and fluvial sediments. The tephra is overlain by several packages of cross-stratified fluvial sediments dominated by coarse Whakamaru-derived pumice clasts, then by a mixture of terrestrial sediments and two packages of shallow marine sediments recording incursions of the sea across a gently sloping alluvial plain. The sequence is capped by the ~280 ka Matahina ignimbrite, which rests on thin terrestrial sediments above the upper of the two marine incursion sequences. The Rangitawa tephra and Matahina ignimbrite are key chronostratigraphic markers that can be used to predict the stratigraphy above and below their correlatives which are widely distributed beneath the Kawerau geothermal field. Stratigraphic work at Matata serves to provide models for the geometry, age and origins of rock units important in determining permeability structure in the Kawerau geothermal field, and in providing a framework for development of structural controls on growth of the Whakatane Graben.

1. INTRODUCTION

New Zealand contains one of the most magmatically, volcanically and geothermally active regions on Earth, the Taupo Volcanic Zone (TVZ: Figure 1). There are 24 geothermal fields in the TVZ that together have a total heat output of 4200 ± 500 MW (Bibby *et al.*, 1995). The geothermal fields are concentrated in the central TVZ where magma production rates are highest and volcanism is dominated by large silicic caldera-forming eruptions. In the central TVZ, caldera-forming events with magma volumes >100 km^3 occur, on average, every 50 kyr; however, these eruptions are not evenly distributed in time but are clustered into periods of more intense activity (Houghton *et al.*, 1995). The biggest cluster was a flare-up event, at ~340 to ~240 ka (Gravley *et al.*, in press), that included at least 7 ignimbrite-forming and numerous smaller eruptions, totalling at least 1500 and probably 3000 km^3 of magma, and forming calderas that pepper a 90×40 km area (Figure 1). The flare-up began after ~370 kyr of relative quiescence (Houghton *et al.*, 1995) with the Whakamaru group ignimbrite eruptions and finished with the paired Rotorua and Ohakuri caldera-forming eruptions (Gravley *et al.*, in press). Wilson *et al.* (1995) and Gravley *et al.* (in press) suggest that this ignimbrite flare-up marked the birth of the central TVZ in its present form.

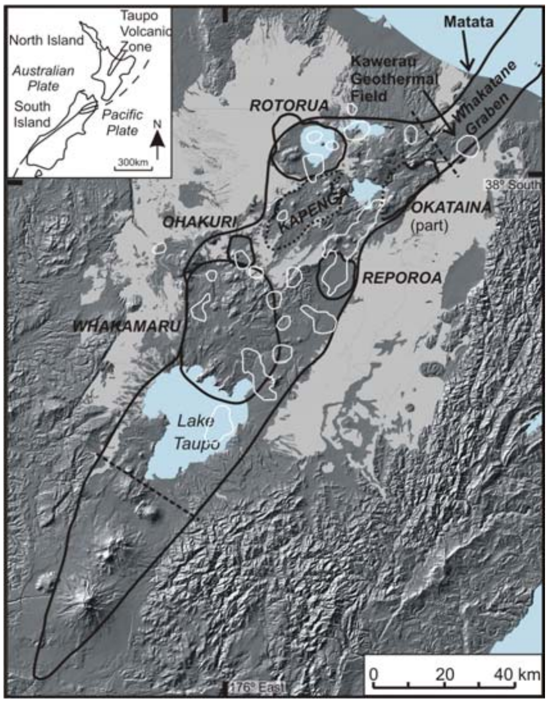

Figure 1. Summary map of the TVZ, showing calderas active in the 340-240 ka period (named black outlines), the extent of the ignimbrites erupted in this time period (grey shading) and modern geothermal fields (white outlines). The positions of Matata on the Bay of Plenty coast and the Kawerau geothermal field are shown.

Considering Bibby *et al.*'s (1995) proposal that locations of the geothermal fields have varied little in the last 200 kyr and possibly longer, interpreting the geological footprint left behind by the ~340 to ~240 ka flare-up is fundamental to understanding the subsurface conditions beneath modern TVZ geothermal fields. In this paper, we present preliminary results from studies of a fortuitously exposed sedimentary sequence on the Bay of Plenty coast at Matata. A catastrophic rainfall event led to intense erosion and scouring in stream catchments, revealing an exceptionally well exposed sequence of marine and terrestrial sediments, with associated fall deposits and one ignimbrite, which collectively can be matched with part of the 340-240 ka flare-up sequence of eruptions. We here briefly summarise the Matata sequence and use it to draw attention to geological and structural controls that may be important in interpreting the subsurface conditions at the Kawerau geothermal field.

2. STUDY AREA

Heavy rainfall in the catchments behind Matata township (Figure 2) in the Bay of Plenty on May 18, 2005, triggered widespread landslips and generated debris flows that destroyed 27 homes. Local stream beds were heavily scoured, yielding excellent exposures of Pleistocene marine and terrestrial sediments with interbedded primary pyroclastic and secondary reworked volcaniclastic deposits. The most complete sequences in the Matata area are exposed in the catchments of the Awatarariki and Waitepuru streams, and form the basis for the stratigraphy presented below. The Awatarariki Stream sequence correlates well with coastal cliff sequences west of Matata that Nairn and Beanland (1989) and Beu (2004) suggested were as old as ~1 Myr.

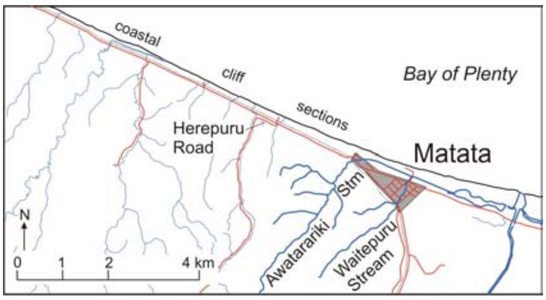

Figure 2. Locality map for the Matata area.

3. STRATIGRAPHY

Based on their geometry, fossils and rock lithologies we have identified 16 stratigraphic units that we can group according to their inferred broad depositional origins. The sediments and biota record either terrestrial environments on a gently sloping alluvial plain or a shallow, quiet marine environment, both quite different to the present-day setting of the area. The stratigraphy discussed (Figure 3) is a composite based mostly on two sections, one in the Awatarariki Stream, and the other 3 km to the west on Herepuru Road.

3.1 Shallow-water marine sediments

These are represented by units 1, 3-5, 10 and 14 (Figure 3). The dominant lithology (Units 1, 3, 5, 10 and 14) is massive to weakly laminated, and grades between fine to very fine sandy mudstone to fine to very fine muddy sandstone, with minor amounts of biotite and rare muscovite. Marine mollusc shells (bivalves, gastropods, echinoids, crustaceans) are scattered throughout, and trace fossils (worm burrows, echinoid feeding structures) are present as concentrated horizons or, more commonly, randomly throughout these units. These deposits are interpreted as having been deposited in a shallow, low energy marine environment, most likely a harbour/estuary or protected embayment, from the general lack of wave- or current-induced structures.

Unit 4 shows a marked contrast in lithology. Sandwiched between blue-grey silts, unit 4 is 2 to 8 m thick and comprises medium to very coarse (~80% coarse), weakly consolidated, parallel laminated to metre-scale cross-bedded quartz/feldspar dominated crystal sand. Rare mafic grains are concentrated throughout, along laminations and cross-beds. Unit 4 is interpreted, from the abundance of fresh volcanically-derived crystals as a shallow-shelf sand wave, possibly the fully marine analogue to unit 7, formed by a short-lived influx of volcanic debris into the sea.

3.2 Terrestrial sediments

There are several distinct lithologies within the sequence that are inferred to represent terrestrial sedimentation.

Gravel-grade units occur in two forms. The first is with greywacke (lithic) clasts dominating, forming a prominent horizon 18 metres thick in unit 2 in the Awatarariki Stream, and thinner horizons within units 9 to 13. The greywacke pebbles range in size from 2 to 75 mm, are sub-spherical and sub- to well-rounded. The gravels are clast supported, tightly packed, moderately sorted and display weak imbrication. Predominantly cross-bedded sand lenses are present throughout the greywacke gravels at irregular intervals, but comprise only a small portion of the overall gravel unit. The degree of rounding of the greywacke gravels indicates considerable residence time in a dynamic system. The lack of marine fossil evidence and the trough cross bedding supports the interpretation of a fluvial setting. However, at some horizons there appears to be traces of bioturbation, possibly indicating a shallow marine environment, and some of the parallel laminated medium-coarse sands may be beach sands. Rare

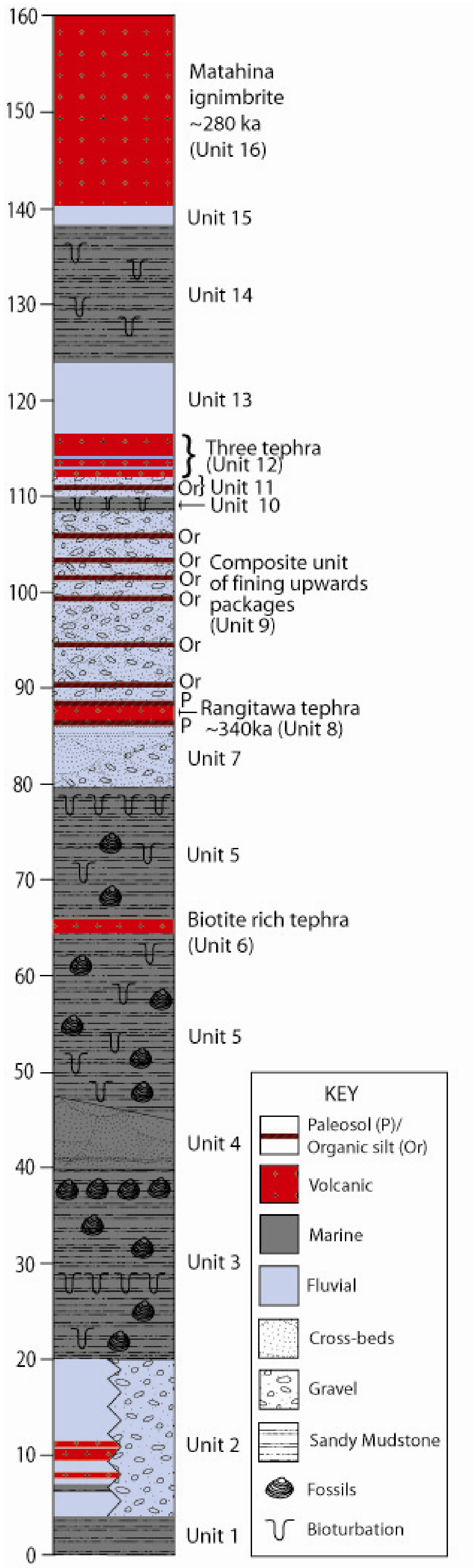

Figure 3. Composite stratigraphic log from Awatarariki Stream and Herepuru Road. Vertical scale is in metres.

crystal-rich welded ignimbrite clasts were recorded in the unit 2 gravel, and sparse pumice clasts occur in greywacke gravels at higher levels. The second type of gravel unit is pumice pebble- to cobble-rich, occurring immediately above unit 8 (the inferred Rangitawa tephra; see below) and forming stacked sequences up to 15 metres thick, punctuated by carbonaceous soils. For all the gravel units, the nature of the sediments and their structures (e.g. trough-cross beds, asymmetric ripples) are used to infer a terrestrial, fluvial depositional setting, possibly in some horizons into very shallow marine waters. The contrasting dominant clast lithologies are used to infer two broad source areas for the parental rivers. For the greywacke-rich, volcanic-poor gravels, we infer the source was the axial greywacke ranges, i.e., a proto-Rangitaiki River. For the pumice-dominated gravels, the uniformity of the pumice lithologies and the intimate temporal association with a major volcanic unit suggest that these gravels represent a catastrophic sedimentation event following a large eruption (see below).

As well as occurring as a subordinate fraction in silt-or gravel-dominated deposits, sand-grade terrestrial sediments occur as a prominent marker horizon forming unit 7 (Figure 3). Unit 7 is 6 m thick and varies laterally in lithology from coarse grained, well sorted, rounded sands to greywacke pebble gravels in a coarse grained, well sorted, rounded sand matrix. Mafic and felsic rich sand layers demarcate bedding and laminae surfaces. The sedimentary structures exhibit the same pattern through the section of trough and cross-bedding with minor asymmetrical ripples in the lower 4 to 5 m, changing to parallel laminated sands in the upper metre. This unit is capped by a weakly developed paleosol of variable thickness up to ~20 cm, over which lies unit 8. Unit 7 is interpreted to represent a transition from probably very-shallow marine into a subaerial setting via a beach environment, reflecting a drop in relative sea-level.

Parts of units 2 and 9 to 13 are composed of silt-grade material which ranges between purely volcaniclastic and carbonaceous material, the latter often associated with tree stumps in positions of growth. The silt material is interpreted in some cases to be wind-blown dust, and in other to be flood-plain deposits. The carbonaceous layers, from their association with in-situ tree stumps are interpreted to represent immature palaeosols.

3.3 Pyroclastic deposits (tephra)

Numerous tephras (fall deposits of ash to lapilli-grade) occur throughout the sequence, but are thicker and better preserved in the terrestrial sediments. Three thin rhyolitic tephras occur within terrestrial sand-to silts in unit 2. Within the overlying marine silts of unit 5, a ~1.5 m thick biotite rich, poorly bedded tephra occurs (labelled unit 6 here, and described elsewhere by Nairn and Beanland, 1989 and, labelled as the Herepuru tephra, by Manning, 1996). It consists of coarse ash to lapilli, with angular to sub-angular pumice clasts up to 50 mm long. Well-rounded pumices of similar mineralogy but larger size also occur in the overlying mudstone of unit 5.

A prominent 1.4-m thick white to pink-coloured tephra (unit 8) rests on the palaeosol developed into the sands of unit 7. In its bedding characteristics in the field and its crystal-rich, biotite-bearing nature, unit 8 bears a close resemblance to the Rangitawa tephra described by Manning (1996) from the eastern Bay of Plenty. We thus infer that unit 8 is the Rangitawa tephra, widely interpreted (e.g., Froggatt *et al*., 1986; Pillans *et al*., 1996) to be the fall deposit equivalent of the Whakamaru group ignimbrites which have $^{40}Ar/^{39}Ar$ ages ranging from 320 to 340 ± 40 ka (Houghton *et al.*, 1995). The Rangitawa tephra itself has been separately dated using a number of techniques including astronomical tuning to marine oxygen isotope stratigraphy (340 ± 7 ka), $^{40}Ar/^{39}Ar$ (302 ± 8 ka, and fission track (345 ± 12 ka) (see Pillans *et al.*, 1996). Based on the published Whakamaru and Rangitawa dates, we use an approximate age of 340 ka in our discussion.

Other tephras occur in or form parts of units 9 to 13, the thickest being a characteristic triplet of beds composed of crystal-poor moderately- to well-sorted pumice lapilli forming unit 12. The whole sequence is then capped by tens of metres of the 280 ka Matahina ignimbrite (Bailey and Carr, 1994; Houghton *et al*., 1995). The ignimbrite locally rests on a thin fall deposit, and this in turn rests on thin terrestrial sediments then the unit 14 marine silts to sands. Along the coastal cliffs to the west of Matata, the basal part of the Matahina deposits appears to have been emplaced on land close to sea level or into very shallow water, but most of the thickness of the ignimbrite was subaerially deposited, from the presence of welding and thermal oxidation colours indicative of high temperatures.

4. DISCUSSION

The Awatarariki Stream sequence can be correlated with coastal cliff sequences west of Matata that are presumed to be as old as ~1 Ma. However from the preliminary identification of unit 8 as the Rangitawa tephra (~340 ka) we suggest that most of the sequence is significantly younger. The ~1 Ma maximum age is based on biostratigraphic correlations of marine sediments beneath the tephra deposit of unit 6, biotite from which was reported to have a K/Ar age of 620 ± 30 ka (T. Itaya, cited in Nairn and Beanland, 1989). We infer that the K/Ar age may be inaccurate because there is no evidence for any prolonged time break (i.e. erosion, soils, sharp change in depositional environment to indicate a period of hundreds of thousands of years) between the biotite-rich unit 6 and unit 8 (inferred Rangitawa) tephras. Instead, there appears to be a consistent and gradational sequence upwards from the shallow marine silts that enclose unit 6 through beach and fluvial sands into the establishment of a soil underlying unit 8. New $^{40}Ar/^{39}Ar$ dates for the Rangitawa and biotite-rich tephras may confirm whether the sediments between them represent ~300 kyr of sedimentation and/or erosion, but we suggest that instead of being as old as Marine Isotope Stage (MIS) 15 (see Beu, 2004), the Awatarariki sequence may provide a useful proxy for the global glacio-eustatic sea-level cycles corresponding to MIS 10 – 8.5 (~350 – 280 ka).

The chronostratigraphy suggested by the Rangitawa and Matahina deposits provide valuable correlations with the rock sequences penetrated in geothermal drillholes beneath Kawerau geothermal field. The Rangitawa is inferred to correlate with the Rangitaiki ignimbrite (part of the Whakamaru-group of ignimbrites: see Wilson *et al*., 1986) that lies several hundred metres beneath the Whakatane Graben and the Kawerau geothermal field (Browne, 1978). Using information from our sedimentary sequence from the western, uplifted side of the Whakatane Graben at Matata, it may be possible to more accurately identify and predict the characteristics of the lithological units above and below the Rangitaiki ignimbrite beneath Kawerau. This could have important implications with respect to development of the geothermal field if gross lithological and permeability differences recorded in the Awatarariki Stream stratigraphy are present beneath Kawerau. In addition, the same stratigraphic correlations can potentially be used to interpret structural controls beneath the geothermal field.

4.1 Lithologic implications

The recognition of marine and non-marine lithologies at Matata suggests that reexamination of the coeval sedimentary sequences at Kawerau is desirable. Marine sediments have been observed in drill core from beneath Kawerau, i.e. marine shells at 450 m in drillhole KA 22; however, their vertical and lateral extent is unknown. A reinvestigation of the Kawerau subsurface geology is required to see if the widely distributed Huka Group sediments above and below the Rangitaiki ignimbrite there (Browne, 1978), may actually be marine in origin as opposed to lacustrine, as implied from the definition of Grindley (1965). The proper identification of the chrono-stratigraphic and genetic nature of the Huka Group sediments has important implications with respect to the sub-surface permeability structure. First, any presence of marine silts would mark widespread potential aquitard layers beneath Kawerau. Second, recognition of the source areas and distributions for sediments deposited from the proto-Rangitaiki River and other drainage systems could help predict the depth and extent of the highly permeable and laterally extensive fluvial gravel deposits.

Note that the lithological variations between marine and non-marine sedimentation in the Matata sequences in the 340-280 ka period reflect global fluctuations in sea level, rather than structural controls. This is inferred from the fact that we can identify near-shore marine and beach sediments at several levels through the Matata sequence, implying that at no stage was significant tectonic uplift occurring. Compilations of global sea-level curves for this time period (e.g., Waelbroeck *et al*., 2002) show sea levels fluctuating by as much as 130 metres over time periods of only 10-15 kyr. Thus changes from non-marine to marine sedimentation in areas like Kawerau and Matata, that are close to sea level during high-stand periods, have to be interpreted in the light of such short-term and drastic changes in base level.

4.2 Structural implications

There are two important implications from the Matata sequence for the structural development of the northern TVZ and the Kawerau geothermal field. First, the presence of the greywacke-dominated fluvial gravels indicates that a substantial river, comparable in size to the modern Rangitaiki River, was able to flow unhindered across to the Matata area up until ~280 ka. At present, lateral migration of the modern Rangitaiki River (or other rivers draining the active volcanic centres in the TVZ) is precluded by the 250-m-high western escarpment of the Whakatane Graben.

Second, from the low topographic relief and proximity to sea level of the basal contact to the 280 ka Matahina ignimbrite, the uplift of the western shoulder of the Whakatane Graben is inferred to have occurred in the last 280 kyr, i.e., at a minimum rate of c. 1 mm a^{-1}. However, this rate is no longer applicable at and west of Matata, as there is no sign of such uplift rates affecting any terrace generated by the c. 7 ka Holocene sea-level high-stand. The Matahina ignimbrite is extensively faulted and downthrown beneath the Kawerau geothermal field, and further work is required to see if the timing of this deformation can be tied in with the Matata sequence or represents a slower, long-term trend of rifting and subsidence in that part of the TVZ. Comparisons between the fault displacements of the Rangitaiki and Matahina ignimbrites at Kawerau will be valuable in showing when the onset of faulting occurred and linking that in with our ongoing structural studies at Matata.

5. CONCLUSIONS

We conclude that the sedimentary sequence exposed in the valleys behind Matata indicates a much younger age (of the order c. 350 to 280 ka) for the marine and terrestrial sedimentary sequences on the Bay of Plenty coastline. These age controls imply a more abrupt and rapid post-280 ka uplift and development of the western side of the Whakatane Graben. Coeval sedimentary sequences beneath Kawerau geothermal field require re-examination to see if sediments previously recorded below and above the Rangitaiki ignimbrite are marine or non-marine. Lack of the western topographic margin to the Whakatane Graben prior to 280 ka implies that rivers draining the axial greywacke ranges and volcanic areas south of Kawera could migrate unhindered across the Matata and Kawerau areas, depositing laterally extensive, highly permeable gravel sheets. Recognition and correlation of such gravels will be important in modelling the permeability structure of the Kawerau geothermal field.

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