Proc. 7th NZ Geothermal Workshop 1985

HYDROTHERMAL ERUPTIONS AT THE ROTOKAWA GEOTHERMAL FIELD, TAUPO VOLCANIC ZONE, NEW ZEALAND

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ABSTRACT

At least eight large hydrothermal eruptions have occurred within the Rotokawa Geothermal Field in the last 20,000 years; the latest took place about 3700 years ago. However, there are likely to have been many smaller eruptions also - some possibly within the last 1800 years of which no record remains. .

The products of the large hydrothermal eruptions cover an area of approximately 15km^2; they consist of poorly sorted, matrix supported, polylithologic materials. Clasts comprise several rocks types, including Wairakei Breccia - exposed at the surface - and deeper formations penetrated only by drillholes (lacustrine sedimentary rocks, pyroclastic rocks and rhyolite lava). Many of the clasts are hydrothermally altered; a common assemblage consists of abundant alunite and kaolinite. Other clasts contain hydrothermal feldspars and zeolites. Very few clasts show hydraulic fracture textures.

Some of the eruptions may have had deep focal depths. There is mineralogial evidence that alkali chloride waters discharged at the surface at one time but ceased to do so as the water table lowered, possibly causing some of the hydrothermal eruptions *as* pressures in the shallow part of the field declined.

The deduced locations of the eruption vents, aligned in a northeast direction, extend over a distance of 1.7km, parallel to the regional and local fault trends.

INTRODUCTION

The Rotokawa Geothermal Field, located 9.5km east of Wairakei (Figure 1), has been the site of at least eight hydrothermal eruptions that produced extensive breccia deposits. All post-date the Wairakei Breccia Fm. (20,000 years old) and the latest major eruption occurred about 3700 years ago. The distribution of these breccia deposits has been mapped and the products examined petrographically; the purposes of this work were to deduce the character and frequency of the hydrothermal eruptions and to learn about the past and present shallow subsurface hydrology of the Rotokawa field.

Geological Setting

Lake Rotokawa (Figure 1) itself is the main thermal manifestation in the Rotokawa area. It covers an area of about 0.6 km^2, has a pH of near 2.5 and was the site of a large hydrothermal eruption 6060 ±60 years of ago (Figure 2). The lake occurs in a small.?, graben, in the southern portion of the field (Figure 1), defined by NE striking normal faults that cut the 20,000 year old Wairakei Breccia (Figure 2) - the oldest formation exposed in the main thermal area. Hydrothermal eruption breccias and interbedded C^{14} dated tephras overlie this formation which are themselves covered by the ca.1800 year old Taupo Pumice; in places this is up to 50m thick as a result of ponding in hydrothermal eruption craters then present. The main feature north of the Waikato River is Mt. Oruahinaewae, a Quaternary rhyolite dome.

The subsurface stratigraphy of the Rotokawa field has been. explored by shallow and deep (to 2780m) drilling. Interbedded silicic pyroclastic rocks, lacustrine sediments and rhyolite lava overly thick (>1100m) andesite lava flows resting unconfornably upon the Mesozoic greywacke and argillite basement rocks of the region (Grindley et al., 1985).

SURFACE ALTERATION AND PRESENT ACTIVITY

The surface and near surface alteration consists of kaolinite, silica residue, abundant sulphur (Jury, 1984) and alunite together with lesser amounts of goethite, jarosite, hematite, cinnabar and amorphous metaliferous precipitates. There are extensive areas of steaming ground, numerous fumaroles and many collapse craters in the main thermal area, close to hydrothermal eruption vents (Figure 1). Patches of mainly acid alteration also exist north of the Waikato River; in places these formed more than 1800 years ago, since they are locally overlain by unaltered Taupo Pumice.

Springs along both banks of the Waikato River discharge dilute bicarbonate-chloride water and acid sulphate-chloride springs occur in, and near to, the main thermal area to the south. No alkali chloride springs now discharge within the field, but the occurrence of silicified Wairakei Breccia along the south bank of the Waikato River, as well as locally within the main thermal area is evidence that deep thermal waters discharged at the surface less than 1800 years ago. In addition, sinter 'float' occurs in the northeast portion of the main thermal area (Collar, 1985).

HYDROTHERMAL ERUPTION BRECCIAS

Distribution and Vent Locations

Field mapping suggests the stratigraphy summarised in Figure 2.

Individual eruption breccia deposits up to 11m thick occur in and around the Rotokawa lake basin; cumulative sections locally exceed 40m in thickness. However, it is often difficult to differentiate between breccia deposits, particularly older ones, because the separating tephras are locally obscured or some eruptions were so closely spaced in time that paleosols did not develop.

Delineation of units g and h (Figure 2) is only possible at a few places; elsewhere they are undifferentiated. Limited exposures of breccia occur northeast of Lake Rotokawa in the cliffs along the banks of Parariki Stream. These breccias thicken towards the lake suggesting that their vents were located there. However, the presence of "proximal breccia" in the cliffs here, with numerous clasts of Wairakei Breccia, 1–2m in diameter, combined with smaller clasts in the deposits adjacent to the lake indicates that theirvents were located northeast of the present lake but are now filled by Taupo Pumice.

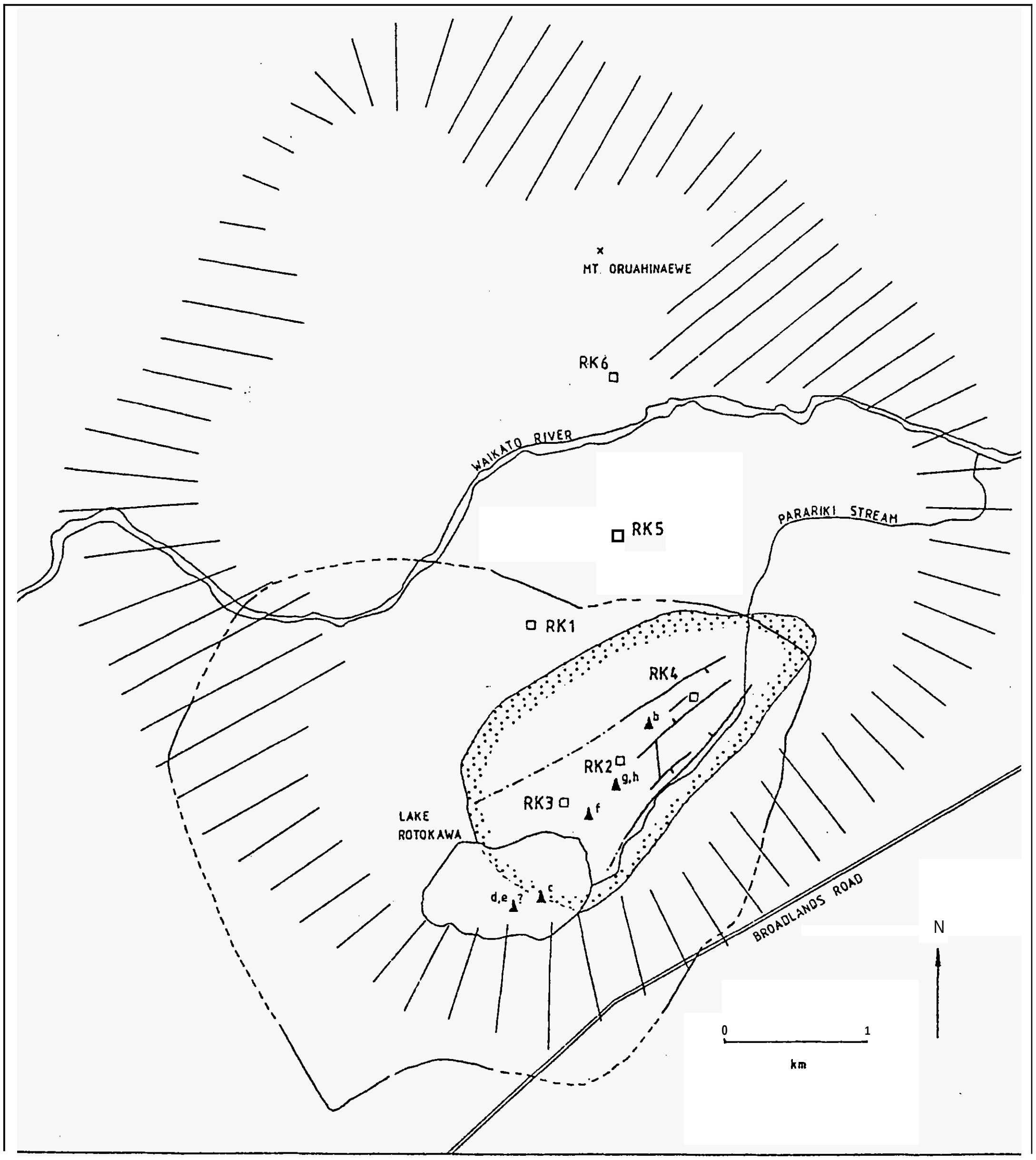

Figure 1: Summary map of the Rotokawa Geothermal Field showing the main thermal area (within stippled region), faults (tick on downthrown side, dash/dot where inferred/concealed), geothermal wells (open squares), hydrothermal eruption vents (solid triangles - letters refer to Figure 2), the extent of eruption breccia deposits (dashed where uncertain) and major geographic features. Waikato River runs from left to right. Resistivity boundary from Risk (1985).

Unit f (Figure 2) is in places indistinguishable from units d and e; it is possible that its vent was beneath the lake, as the limited amount of isopach data indicates, but clast size comparison suggests that its vent was located near that of g/h (Figure 1), i.e. north east of the present lake.

Geothermal drillholes RK 2 and 3 encountered about an 80m thick sequence of interbedded eruption breccias and lake sediments supporting the view that hydrothermal eruption vent(s) were located nearby. Moreover, these two drillholes did not encounter Wairakei Breccia Fm, which was probably removed from these regions by hydrothermal eruptions.

Breccia units d and e, recognisable at only a few localities, provide inadequate isopach information so their vent(s) location is uncertain. However, deposits exposed in the cliffs along Parariki Stream are finer grained than the older deposits, possibly indicating a more distant vent source, perhaps located within Lake Rotokawa itself.

Unit c is a widespread deposit; evidence as follows suggests that its vent was sited within ancestral Lake Rotokawa.

(1) The presence of pyritiferous lake sediments occurring as clasts within the eruption breccia;

(2) tree trunks within a lobe of the eruption deposit that are aligned in a direction pointing towards the lake, and

(3) up to 33m of eruption breccia deposit in and around the lake, thought to correlate with this unit, which contain rare 3m diameter clasts.

Further, some shallow holes drilled within the lake apparently did not encounter Wairakei Breccia, presumably because it was ejected during the hydrothermal eruptions.

Yapping suggests that breccia unit b erupted from a vent located in a shallow depression northeast of the lake, but the latest eruption (unit a) produced products recognisable in only a few exposures. Other shallow focus eruptions may have occurred after deposition of the Taupo Pumice, but these must have been much smaller since no evidence of their occurrence was seen.

Relationship of eruption vents

The locations of the deduced vents forms a zone aligned in a northeast direction, coihcident with the strike of faults in the field and to the shape of the shallow Subsurface thermal anomalies (Banwell, 1965).

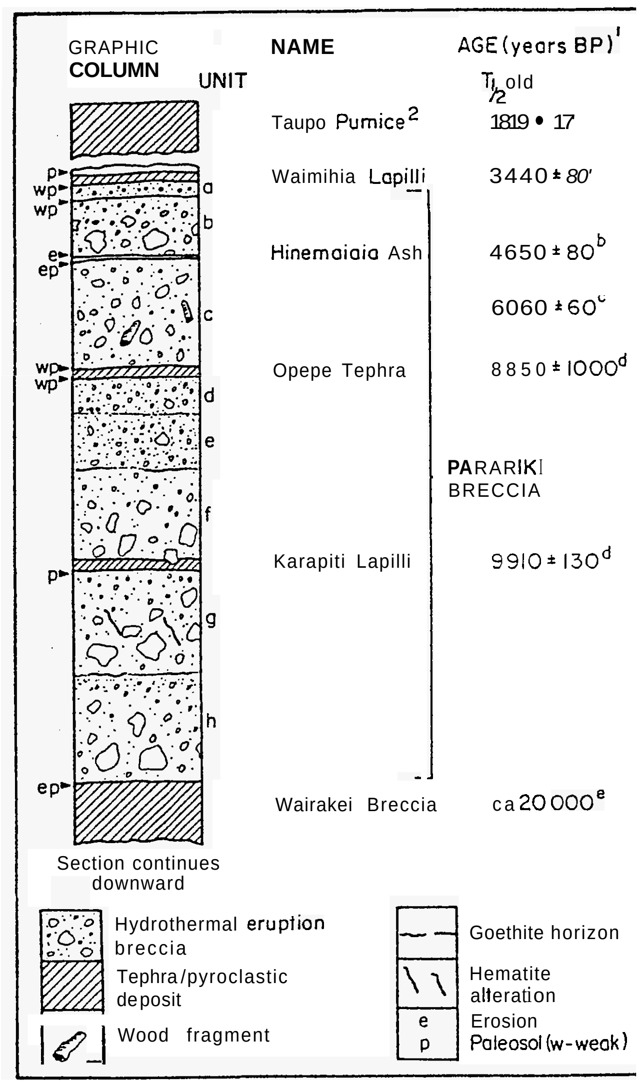

Figure 2: Schematic stratigraphic column of rocks exposed at the surface of the Rotokawa Geothermal Field. 1 - Dates for interbedded C^{14} dated tephras with respect to reference date; 2 - see reference a: a - Vucetich and Pullar, 1973; b - Froggatt, 1981a; c - Collar, 1985; d - Froggatt, 1981b; e - Vucetich and Pullar, 1969.

PETROGRAPHY OF EJECTED CLASTS

Rock types ejected

All the deposits at Rotokawa are poorly sorted, matrix supported, polylithologic and consist of angular to subangular clasts of hydrothermally altered, to nearly fresh, materinl derived from the Subsurface.

Examination of several hundred clasts from different breccia units (Figure 2) shows that silicic pyroclastic rocks, many of uncertain affinity and epiclastic/volcanoclastic sediments, are most abundant; rhyolite clasts are minor. The proportion of clasts derived from subsurface formations (as revealed by drilling) decreases in the older deposits. Among the identifiable formations, Wairakei Breccia and Huka Falls Formation clasts predominate; the relative abundance of clasts derived from the Waiora Formation is difficult to estimate because it is very similar in appearance to the Wairakei Breccia Formation.

The presence of rhyolite clasts in all the breccia deposits is important, since rhyolite flows have so far been only encountered by drillholes below approximately 450m depth. However, rhyolite clasts found only in breccia unit b correlate with a specific drill core (RK1; 850m). A green coloured, vitrophyric rhyolite common in unit c probably also correlates with the deep rhyolite. These observations may mean that the focal depths of some of the Rotokawa hydrothermal eruptions were very deep (possibly 450m or more) or, more likely, that rhyolite lavas occur much closer to ground surface than has so far been indicated by drilling.

No juvenile volcanic clasts were seen, nor were any silica sinter clasts recognised. The absence of the latter probably reflects extreme fragmentation and dispersal of any such material formerly present.

Hydrothermal alteration mineralogy of breccia clasts

Since the eruption breccias derive from the subsurface of an active geothermal field it is not surprising that many of clasts were hydrothermally altered prior to their eruption.

Table 1 summarises the occurrence and relative abundance of hydrothermal minerals seen in the clasts and matrices of the breccias. Some primary minerals survive, especially quartz and plagioclase, but the observed hydrothermal minerals comprise three groups:

(a) the sulphates and kaolinite,
(b) the silicates and calcite,
(c) the iron and titanium oxides and sulphides.

Group (a), commonly represented by alunite ± kaolinite ± opal, indicates reactions have taken place between the host rocks and hot acid sulphate fluids. Alunite, in particular, forms from fluids with a pH of less than 3.5, i.e. within the pH value of the present lake water (2.5). Acid sulphate themal fluids can form from steam condensate made acid by oxidation of H_2S ascending from deeper alkali chloride water of near neutral pH. The presence of this group of minerals in the ejected clasts indicates that they derive from shallow depths within the Rotokawa system since drillcores and cuttings from below 50m to 100m in some wells contain hydrothermal minerals formed from reaction with fluids of near neutral pH.

Hydrothermal minerals of group (b) therefore derive from below the surficial acid sulphate zone. Indeed, the occurrence of silica sinter at the surface, aibeit as 'float', suggests that this water discharged from surface springs. We suggest that prior to the first hydrothermal eruptions at Rotokawa, the alkali chloride water level was at the surface but it gradually lowered by 50 to 100m by the time of the later eruptions. Hydrothermal minerals produced from this water, and present in the reservoir rocks, would be quickly attacked and either removed, or replaced, by the more corrosive acid fluids. The group (c) minerals (pyrite, hematite, leucoxene) have no useful significance in deducing the composition of their formation fluids since they are known to form from both acid and near neutral pH fluids.

TABLE 1: Summary of hydrothermal alteration of clasts in different hydrothermal eruption breccia deposits.

DEPOSIT[1]	FRAGMENTS											MATRIX[3]								INFERRED TEMPS. (°C)
	pb_1-b				pb_1-c				$pb_{2\&3}$-d-h			pb_1-b	p -c		$pb_{2\&3}$					
MINERAL / FORMATION	wb	hu	wa	ha	wb	hu	wa	ha_1	wb	hu	ha_1?		Weathered	'Juvenile'	d	e	f	g	h	
*quartz	x		xxx	xxx	x	x	x x x x			x	xxx									
*opal[2]	xx			x	xxx				xxx		x									
*albite				x							x									
adularia			x		x															
*mordenite	x x x x			x		xx	xx		xxxx	xxxx			√		√	√		√	√	90-130[7]
*clinoptilolite							x		x	x										
*heulandite										x										
*calcite						x														
pyrite	x		x x x x			xxx	xx	xx	xx		xx			√						
leucoxene			x	x			x	x	x		xx									
sphene				x					x		x									
hematite	x		x	xx	x	x	x		xxx	x	x									
*alunite	x				xxxx				xx			√	√	√	√			√	√	< 160[6]
*jarosite												√	√		√	√				
*sulfur					x															
*kaolinite								x	x			ow	oo		oo		o	oo	oo	
*smectite	xxx	x	xx	xx		x	x	x	xx	xx	xx	.oo	o		ooo	oo	oo	ooo	ooo	< 140[5]
illite	x		x						x	x	x						o			140-180
	xxxx-common xxx-minor xx-trace x-rare[4]											ooo-major oo-moderate o-minor (clays)								

[1]Deposit a omitted due to limited exposure; d-h combined due to similar fragment lithologies.
[2]Includes various forms of opal
[3]Analyzed by x-ray diffractometer.
[4]Abundances relative to other minerals
[5]Browne, 1984a.
[6]This study.
[7]Browne, 1984b.

Symbols under "Formation" heading refer to subsurface units recognized as clasts:
wb = Wairakei Breccia Fm., hu = Huka Falls Fm., wa = Waiora Fm ; ha = Haparangi Rhyolite.
pb_1, pb_2, pb3 refer to member divisions (Collar, 1985).

Estimates of hydrothermal mineral formation temperature (Table 1) are based upon the clay composition and crystallinity characteristics as revealed by drilling, and on fluid inclusion homogenisation studies. The latter indicate that boiling has taken place at shallow depths beneath the sites of subsequent eruption vents. The absence of calc-silicate minerals such as wairakite and epidote indicates that temperatures at the focal depths of the hydrothermal eruptions did not exceed 220°C.

Textures of clasts

Some clasts present in breccia unit c, and rare brecciated clasts from units b and c, are cemented with quartz; many brecciated clasts of Wairakei Breccia from unit c are cemented with alunite. Cementation obviously occurred prior to their ejection. Fracturing of the subsurface rocks here may be due to natural hydraulic fracturing above, or close to, the water table, possibly at the time of a previous eruption. Subsequently, the fractured rocks reacted with circulating fluids until they were themselves ejected during a subsequent eruption.

POSSIBLE HYDROTHERMAL ERUPTION MECHANISMS

No unambiguous eruption mechanism has been revealed by this study. Examination of clasts indicates that there was no widespread mineral deposition that would have formed a shallow 'cap rock' leading to over-pressuring and hydrothermal eruptions.

Perhaps the initial hydrothermal eruptions at Rotokawa were caused by a lowering of the alkali chloride water table reducing pressure and causing sudden boiling; these early eruptions were then slightly similar to, but much larger than, the eruptions at Tauhara in 1981 and the Craters of the Moon in 1983 (Scott and Cody, 1982; Allis, 1984). As the subsequent eruption vents were then low resistance flow paths for ascending, or laterally migrating, fluids, boiling will occur more readily here than at the same level elsewhere in the Rotokawa system. Alternatively, because of the lower pressures, the boiling surface will be deeper and later eruptions will have a deeper focus.

In some geothermal systems, for example Waiotapu (Hedenquist & Henley, 1985) and Mokai, hydrothermal eruption vents are situated above the main upflow zone for the fields. This suggests that the hydrothermal eruption vents and their products in geothermal prospects should be carefully mapped and dated in order to obtain information about the subsurface hydrology and lithology of the field prior to exploratory drilling.

AGE OF LAKE ROTOKAWA

The chronology and products of some hydrothermal eruptions suggest that Lake Rotokawa formed some time after the initial hydrothermal eruptions there, perhaps 9000 to 9700 years ago. However, the lake was modified by a large hydrothermal eruption dated at 6060 ±60 years ago (Figure 2). Some clasts from this eruption contain sulphur, demonstrating that a sulphur deposit was present below the lake at this time.

Acknowledgements

R.J.C. received financial support from a Fulbright study grant. Assistance from the University Grants Committee is also gratefully acknowledged.

References

ALLIS, R.G. (1984): The 9 April, 1983 steam eruption of Craters of the Moon thermal area, Wairakei. DSIR Geophys. Div. Rep. 196.

BANWELL, C.J. (1965): Wairakei geophysics. In, Thompson, B.N., Kermode, L.D. and A. Ewart, eds., New Zealand Volcanology, Central Volcanic Zone; DSIR Info. Series 50: 165.

BROWNE, P.R.L. (1984a): Lectures on geothermal geology and petrology. United Nations University Geothermal Training Programme, Iceland, Report 1984-2

(1984b): Petrological report: cores and cuttings from Rotokawa drillhole, RK4. Letter to the Geothermal Engineer, MWD, Wairakei, dated 19 June 1984.

COLLAR, R.J. (1985): Hydrothermal eruptions in the Rotokawa Geothermal System, Taupo Volcanic Zone, New Zealand. Unpubl. Geothermal Institute Report, University of Auckland.

FROGGATT, P.C. (1981a): Motutere tephra formation and redefinition of Hinemaiaia tephra formation, Taupo volcanic centre, New Zealand. N.Z. Journal of Geol. and Geophys. 24: 99-105.

(1981b): Karapiti tephra formation: a 10,000 years b.p. rhyolite tephra from Taupo. N.Z. Journal of Geol. and Geophys. 24: 95-98.

GRINDLEY, G.W., BROWNE, P.R. L. and M.W. GARDNER (1985): Geological Report. In, Mongillo, M.A., compiler, Rotokawa geothermal field: A preliminary report of the scientific investigations. Unpubl. DSIR Report.

HEDENQUIST, J.W. and R.W. HENLEY (1985) (in press): Hydrothermal eruptions in the Waiotapu geothermal system, New Zealand: their origin, associated breccias and relation to precious metal mineralization. Econ. Geol.

JURY, A.P. 1984: The Rotokawa sulphur deposits. In, The Mineral Potential of the North Island, New Zealand, The Australian Institute of Mining and Metallurgy, New Zealand Branch, 18th Annual Conference, Auckland.

RISK,, G.F. (1985): Resistivity and magnetic investigations. In, Mongillo, M.A., compiler, Rotokawa geothermal field: A preliminary report of the scientific investigations. Unpubl. DSIR Report.

SCOTT, B.J. and A.D. CODY: (1982): The 20 June, 1981 hydrothermal explosion at Tauhara geothermal field, Taupo. N.Z. Geol. Survey Report 103.

VUCETICH, C.G. and W.A. PULLAR, (1969): Stratigraphy and chronology of late Pleistocene volcanic ash beds in central North Island, New Zealand. N.Z. Journal of Geol. and Geophys. 12: 784-837.

(1973): Holocene tephra formations erupted in the Taupo area, and interbedded tephras from other volcanic sources. NZ Journal of Geol. and Geophysics. 16: 745-780.