© *Journal of the Royal Society of New Zealand,*
Volume 16, Number 1, 1986, pp 25-41

Tephrostratigraphy and chronology of the Kaipo Lagoon, an 11,500 year-old montane peat bog in Urewera National Park, New Zealand

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Eleven well-preserved Holocene tephras occur interbedded with peat in the Kaipo Lagoon bog in Urewera National Park, North Island. They are identified chiefly by their field appearance, stratigraphy, and ferromagnesian mineralogy. Glass shards from one tephra (Hinemaiaia) were analysed by electron microprobe.

The tephras originate from the Taupo, Okataina, and Tongariro Volcanic Centres and, from youngest to oldest, are: Kaharoa Ash, Taupo Pumice, Mapara Tephra, Waimihia Lapilli, Hinemaiaia Tephra, Whakatane Ash, Rotoma Ash, Opepe Tephra, Poronui Tephra, Karapiti Tephra, and Okupata Tephra. Thirteen new radiocarbon ages were obtained on six of the tephras (old T½, years B.P.): Waimihia, 3,250 ± 70 (Wk498), 2,910 ± 60 (Wk499), 3,040 ± 50 (Wk500); Hinemaiaia and Whakatane, 4,490 ± 60 (Wk496), 4,530 ± 60 (Wk497); Whakatane, 4,860 ± 70 (Wk501); Rotoma, 5,440 ± 170 (Wk493), 7,380 ± 80 (Wk494), 7,560 ± 100 (Wk495) (Wk493–495 are all considered anomalously young); Opepe, 8,710 ± 80 (Wk492); Poronui, 10,160 ± 130 (Wk351), 9,960 ± 90 (Wk352), 9,560 ± 80 (Wk491). Estimated ages, assuming constant sedimentation rates, for Karapiti Tephra and Okupata Tephra are 10,100 and 10,300 years, respectively. Two peat horizons below the Okupata Tephra were dated at (old T½) 10,600 ± 90 years B.P. (Wk263) and 11,500 ± 80 years B.P. (Wk264) and date the initial growth of the Kaipo Lagoon bog. Peat accumulation rates have been slow (average 0.19 mm/year) but variable.

The identification and dating of the tephras at Kaipo extends their known distribution in eastern North Island, and improves their potential usefulness as isochronous stratigraphic marker units.

Keywords: pyroclastics, tephra, volcanic ash, stratigraphy, radiocarbon dates, Holocene, Taupo Volcanic Zone, ferromagnesian mineralogy, glass chemistry, sedimentation rates.

INTRODUCTION

Late Quaternary tephras (volcanic ashes) erupted from the Taupo Volcanic Zone (Fig. 1A) have been intensively studied over the past 20 years, and are becoming increasingly useful as datable stratigraphic marker beds for a wide variety of purposes (*e.g.*, see Howorth *et al.*, 1981). Many studies have concentrated on the stratigraphy, age, and distribution of the tephras near their volcanic source areas (*e.g.*, Healy, 1964; Vucetich and Pullar, 1964, 1973; Topping, 1973; Howorth, 1975; Froggatt, 1981a, b) whereas comparatively few have examined them in detail as distal deposits far (~100 km or more) from their source areas

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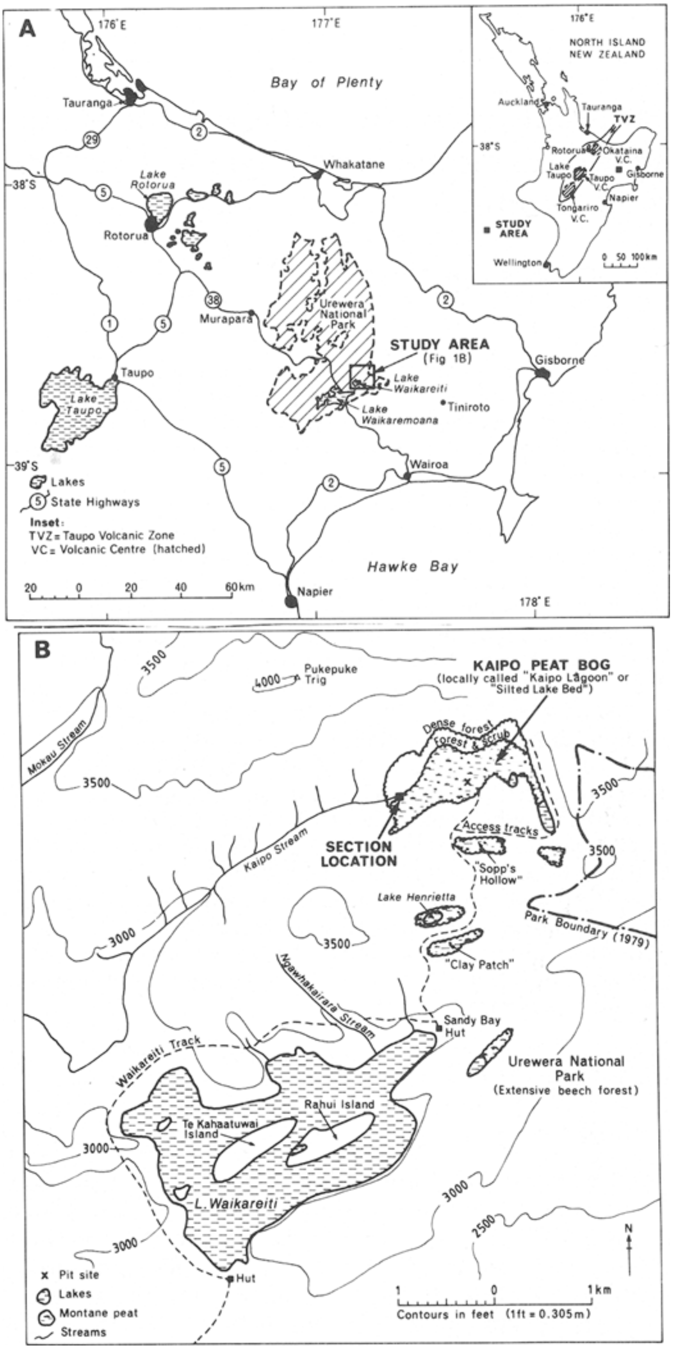

Fig. 1 – Location of the Kaipo Lagoon in the Urewera National Park, North Island. A. Location map of eastern North Island. The inset (based on Cole and Nairn, 1975) shows the relationship of the study area to the Taupo Volcanic Zone (TVZ) and the volcanic centres (V.C.) that were sources of the tephras deposited at Kaipo. B. Map of the south-eastern part of the Urewera National Park showing access to the Kaipo Lagoon and the location of the reference section investigated. Other wetland clearings in the area are shown also. (Based on sheet N96 of the topographical map series NZMS 1).

(*e.g.*, Pullar *et al.*, 1977; Howorth *et al.*, 1980; Lowe *et al.*, 1980; Hogg and MCraw, 1983). Some of these latter studies have utilised cores or sections of peat and organic lake sediments to provide a detailed stratigraphy and an improved chronology for many of the tephras. A similar approach is evident in several overseas studies (*e.g.*, Borchardt *et al.*, 1973; Mathewes and Westgate, 1980; Mehringer *et al.*, 1984). In addition to extending the known distribution of Late Quaternary tephras in New Zealand, peat and lake sediment cores can also provide an accurate record of the stratigraphic relationships of interbedded tephras derived from different volcanic centres (*e.g.*, Lowe, 1986).

In this paper we examine the stratigraphy and chronology of 11 distal, rhyolitic and andesitic tephras interbedded with peat in a section through an 11,500 year old* peat bog, the Kaipo Lagoon, in the Urewera National Park (Fig. 1A,B).

The main purposes of the study are to establish a more certain Holocene tephrostratigraphy for the Urewera-Waikaremoana area, and to obtain new dates on several tephras that have few or no previous dates, thus improving their potential usefulness as time stratigraphic marker beds. In addition, we provide a detailed chronology for further studies on the paleoecological history of the Kaipo Lagoon area. Such a chronology is important because many previous palynological studies in New Zealand have been hampered by limited time control (McGlone and Topping, 1977).

KAIPO LAGOON STUDY AREA

The Kaipo Lagoon is a 73 ha montane peat bog lying at an altitude of 1,100 m in the south-eastern part of Urewera National Park (Fig. 1). It is the largest of a group of natural enclosed clearings in the vicinity of Lake Waikareiti that form

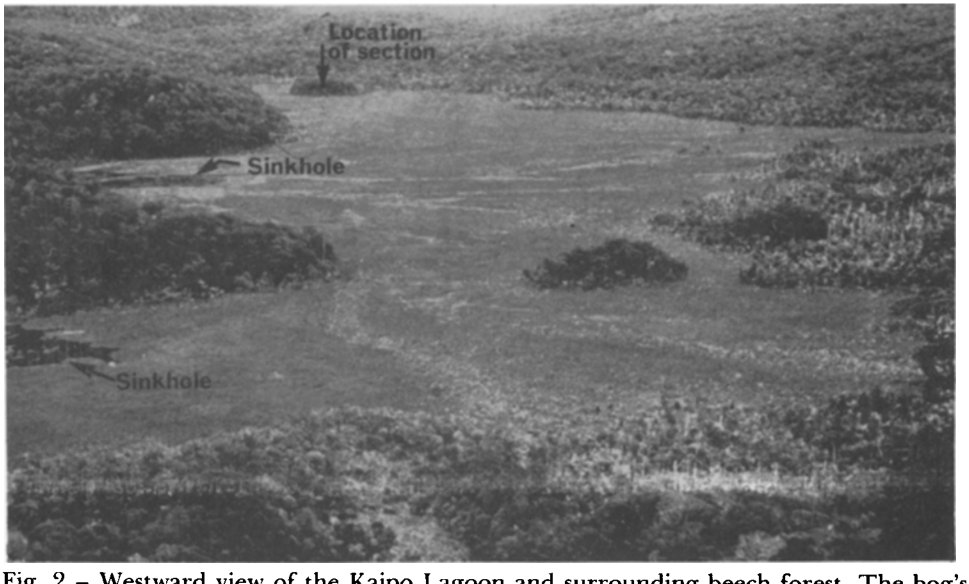

Fig. 2 – Westward view of the Kaipo Lagoon and surrounding beech forest. The bog's hummocky surface has a shrub bog vegetation with numerous small pools; surface channels drain towards sinkholes on the southern margins (on the left). White Kaharoa Ash occurs in patches on the bog's surface and is especially evident around the upper sinkhole. (Photo courtesy of N. B. Rogers).

* All ^{14}C ages discussed in the text are conventional ages based on the (old) Libby half-life of 5,568 years (Hogg, 1982).

distinctive, small peaty wetlands and lakelets surrounded largely by mature silver beech (*Nothofagus menziessi*) and red beech (*N. fusca*) forest (N.Z. Forest Service, 1969; Rogers, 1984). The block-faulted valley in which the bog has formed (Fig. 2) mainly comprises sandy to muddy soft blue-grey siltstones of Miocene age (Grindley, 1960). It is thought that erosion of these sediments, perhaps accelerated by a post-glacial increase in rainfall, empounded the valley sometime before or about 11,500 years ago impeding drainage and creating boggy conditions (Rogers, 1984). Alternatively, an earthquake many have triggered a landslide to form the initial bog basin (*cf.* Adams, 1981).

Although the Kaipo Lagoon is neither a lagoon nor a silted lake bed as noted on topographic maps, the name is retained here because of its common colloquial usage. It is essentially an ombrogenous shrub bog dominated by *Empodisma minus* (a rush) and *Gleichenia dicarpa* (a fern), with occasional *Sphagnum spp.*, which form unusual hummocks amidst numerous small, permanent pools (Rogers, 1984). Marginal sinkholes allow subterranean drainage of water from channels draining the surface of the bog (Fig. 2). A more detailed description of the vegetation and ecology of Kaipo Lagoon is reported by Rogers (1984).

Tephra exposure in the Waikaremoana-Kaipo Lagoon area

The landscape in the Waikaremoana area is mantled with Late Quaternary tephras, which are exposed in limited road cuttings and above slip scarps in generally steep terrain. These tephras, up to about 3 m total thickness, have been described and mapped by Gibbs (1959), Vucetich and Pullar (1964, 1969), and Pullar and Birrell (1973) as part of wider surveys in the Bay of Plenty-Gisborne region. Rijkse (1979) has described the soils in part of the Urewera area and mapped them at a scale of 1:100,000. At Tiniroto, 35 km east of Urewera National Park (Fig. 1A), a sequence of Holocene tephras preserved within muddy organic lake sediments has been examined by various workers (Vucetich and Pullar, 1964, 1973; Howorth and Ross, 1981; Kohn *et al.*, 1981) but positive tephra identifications have proved problematical (*see* Lowe, 1986).

Kaharoa Ash, the most recent tephra deposited in the region, occurs on the bottom of Lake Waikareiti and in patches on the surface of Kaipo Lagoon (Fig. 2). At the western end of Kaipo Lagoon (Fig. 1B), a small stream (Kaipo Stream) draining from it has exposed a 2.8 m-high section that exhibits interbedded tephras and peats overlying muddy peats and muds (Fig. 3). The description, correlation, and dating of the well-preserved tephras in this reference section, and in a pit dug near the centre of the bog (Fig. 1B), forms the basis of this report.

STRATIGRAPHY AND CORRELATION OF THE TEPHRAS

Eleven tephra formations are recognised in the Kaipo Lagoon. From youngest to oldest these are: Kaharoa Ash, Taupo Pumice, Mapara Tephra, Waimihia Lapilli, Hinemaiaia Tephra, Whakatane Ash, Rotoma Ash, Opepe Tephra, Poronui Tephra, Karapiti Tephra, and Okupata Tephra (defined in Healy, 1964; Vucetich and Pullar, 1964, 1973; Topping 1973; Froggatt, 1981a, b, d).

The tephras, illustrated and described in Figs. 3 and 4, are compact, predominantly medium to coarse ash with a pumiceous or vitric character, and often with normal but occasionally reverse bedding. They range in thickness from 1-20 cm and have a total thickness of about 1.2 m. Some of the tephra layers, particularly the very thin ones, are hard to distinguish visually from the enclosing peat because of brownish staining (Fig. 3).

The top three tephras are only poorly represented in the reference section

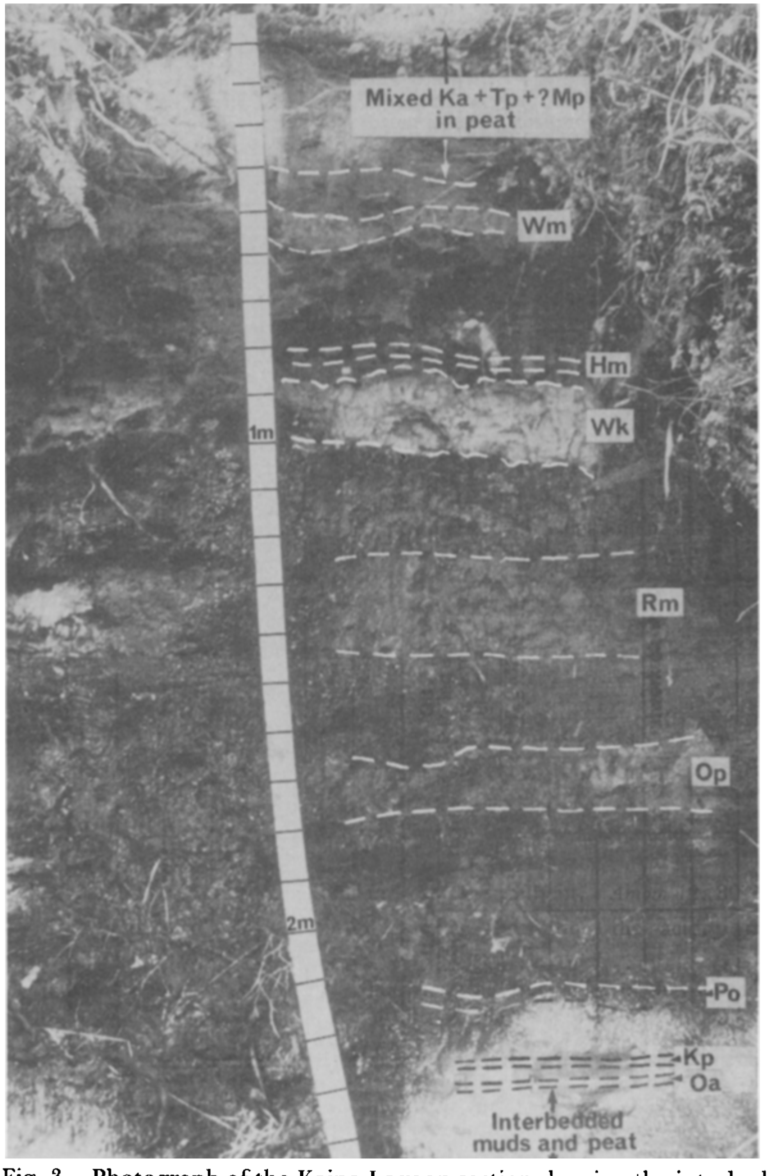

Fig. 3 – Photograph of the Kaipo Lagoon section showing the interbedded tephras and peat overlying muddy peats and muds. The scale is in 10 cm units. The lowest peat layer in the section (at 2.7 m depth) has been dated (Wk264) at 11,500 ± 80 years B.P. (see Figs. 4 and and 5). Note the coarse roots and sticks protruding from parts of the section face. Tephra symbols are: Ka, Kaharoa Ash; Tp, Taupo Pumice; ?Mp, possibly Mapara Tephra; Wm, Waimihia Lapilli; Hm, Hinemaiaia Tephra; Wk, Whakatane Ash; Rm, Rotoma Ash; Op, Opepe Tephra; Po, Poronui Tephra; Kp, Karapiti Tephra; Oa, Okupata Tephra.

(Fig. 3), which has probably been truncated by erosion; however, they can be found as discrete units elsewhere in the bog (*e.g.*, in the central pit, and also in an 85 cm-long core taken by N.B. Rogers) (Fig. 4).

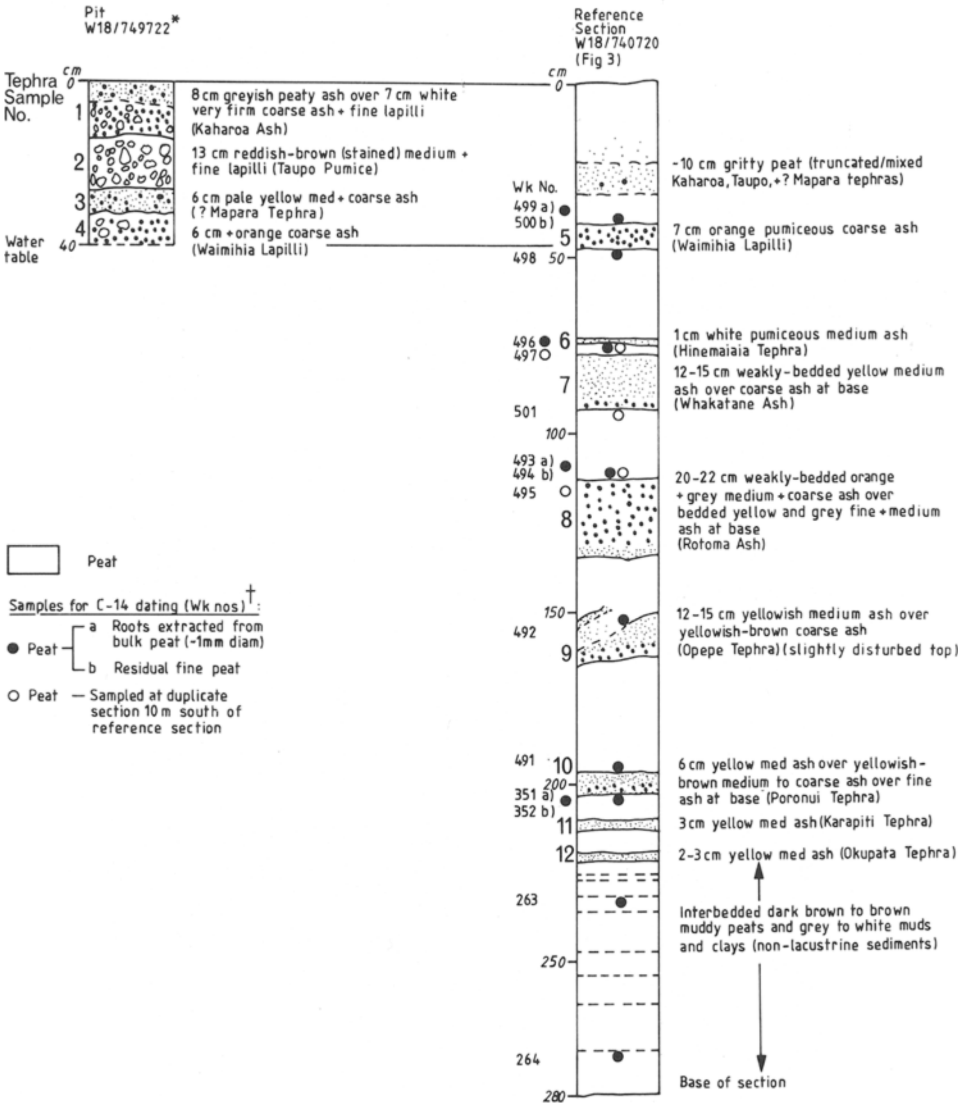

Fig. 4 – Peat and tephra stratigraphy of the Kaipo Lagoon. The positions at which tephra and peat were sampled are indicated. Peat samples were about 2 cm in thickness. The basal muds and clays, which lack diatom remains (Rogers, 1984), appear to grade into massive blue-grey silt below 2.8 m depth. The grain size descriptions are approximate and based on: fine and medium lapilli 2-16 mm; coarse ash ½–2 mm; medium ash 1/16–½ mm; fine ash <1/16 mm. Note: med = medium.

* Grid reference based on the 1,000 m grid of the 1:50,000 topographical map series (NZMS 260).

† Numbers prefixed Wk refer to the University of Waikato Dating Laboratory number. In the text, numbers prefixed NZ are New Zealand Radiocarbon Dating Laboratory numbers.

Recognition of the tephras was based on field appearance and stratigraphic position (Fig. 4) together with ferromagnesian silicate mineralogy. The identifications were supported by radiocarbon dates. In addition, glass shards from one of the tephras (Hinemaiaia) were analysed by electron microprobe to help confirm its identification.

Tephra sources and identifications

The lowermost tephra, Okupata Tephra, is andesitic and derives from the Tongariro Volcanic Centre; it is included in the Tongariro Subgroup (Topping, 1973). The others are all rhyolitic, derived from either the Taupo Volcanic Centre (Taupo Subgroup: Howorth *et al.*, 1981) or the Okataina Volcanic Centre (Rotorua Subgroup: Howorth *et al.*, 1981). The three volcanic centres are located between 100-150 km distance from Kaipo Lagoon (Fig. 1A).

The topmost tephra in the stratigraphic column, Kaharoa Ash, is distinguished by it hard, white pumice grains and the dominance of biotite in its ferromagnesian mineralogical assemblage (Table 1). It has an Okataina Volcanic Centre source (Cole, 1970).

Underlying Kaharoa Ash are Taupo Lapilli, Mapara Tephra, Waimihia Lapilli, and Hinemaiaia Tephra, each with an hypersthene-dominant mineralogy (Table 1) characteristic of a Taupo source (Ewart, 1963; Froggatt, 1981c). The identification of Mapara Tephra is tentative, as its close stratigraphic proximity to the overlying Taupo Lapilli (tephra 2 in Fig. 4) suggests that it may represent Hatepe Tephra, the lowest member of the Taupo Pumice Formation (Froggatt, 1981d; Walker, 1981). We prefer Mapara Tephra, however, because this tephra has been identified in another montane peat deposit in the Urewera National Park (at Te Rangaakapua) clearly separated from Taupo Lapilli by a layer of peat 3-6 cm thick (W. B. Shaw and D. J. Lowe, unpublished data). Also, Mapara Tephra is known to occur well beyond the Kaipo Lagoon area, in organic-rich sediments at Lake Poukawa (Howorth *et al.*, 1980) and at Tiniroto (Howorth and Ross, 1981; Kohn *et al.*, 1981), whereas Hatepe Tephra is not recorded at either of these

Table 1 – Dominant ferromagnesian mineral abundances of the tephras at Kaipo Lagoon.*

Tephra	Sample No. (See Fig.4)	Ferromagnesian silicate minerals (summed to 100%)					Opaques (vol%)†	H.M.§
		Hyp	Aug	Hbe	Cgt	Bio		
Kaharoa Ash	1	37	5	12	—	46	15	Low
Taupo Lapilli	2	100	—	—	—	—	9	Low
Mapara Tephra	3	97	2	1	—	—	13	Low
Waimihia	4	94	6	—	—	—	14	Low
Lapilli	5	100	—	—	—	—	12	Low
Hinemaiaia Tephra	6	95	5	—	—	—	17	Low
Whakatane Ash	7	30	1	4	65	—	19	Low
Rotoma Ash	8	5	—	8	87	—	21	Low
Opepe Tephra	9	84	16	—	—	—	14	Low
Poronui Tephra	10	83	17	—	—	—	7	Low
Karapiti Tephra	11	84	13	2	1	—	10	Low
Okupata Tephra	12	72	28	—	—	—	2	High

* Determined by point-count of the 2-4φ size fraction of the heavy mineral assemblage ($\geq$2.95 g.cm^{-3}). Between 200 and 500 grains were counted.

† Proportion of opaque minerals (mainly titanomagnetite) in 2-4φ heavy mineral fraction.

§ Approximate abundance of heavy minerals in the whole 2-4φ fraction. Low = 1-5%; High = 20-30% (by weight).

Hyp = Hypersthene; Aug = Augite; Hbe = Calcic Hornblende; Cgt = Cummingtonite; Bio = Biotite; — = not observed.

Table 2 – Chemical analyses of glasses from Hinemaiaia Tephra at Kaipo Lagoon as determined by electron microprobe.* The analyses are presented on a normalised 100%-loss-free basis.

	1	2	3	4	5	6	7	8	9	10	11	12	13	**Mean(lsd)**
SiO_2	76.88	76.93	77.03	77.12	77.22	76.30	77.08	76.70	76.83	76.99	76.93	77.00	76.84	**76.90(0.23)**
Al_2O_3	12.98	13.01	13.07	12.80	12.97	13.20	12.86	13.03	12.95	12.99	13.01	12.97	13.00	**12.99(0.10)**
TiO_2	0.15	0.18	0.17	0.20	0.14	0.20	0.18	0.25	0.23	0.18	0.22	0.15	0.22	**0.19(0.03)**
FeO†	1.58	1.52	1.52	1.50	1.56	1.72	1.54	1.69	1.65	1.54	1.68	1.56	1.67	**1.60(0.08)**
MgO	0.21	0.14	0.15	0.19	0.12	0.18	0.19	0.18	0.18	0.18	0.17	0.17	0.16	**0.17(0.02)**
CaO	1.32	1.26	1.27	1.31	1.42	1.39	1.21	1.25	1.21	1.26	1.34	1.36	1.25	**1.30(0.07)**
Na_2O	3.81	3.87	3.68	3.71	3.44	3.85	3.82	3.76	3.84	3.79	3.59	3.74	3.81	**3.75(0.12)**
K_2O	2.97	2.98	3.01	3.07	3.02	3.00	3.00	3.06	2.97	2.98	2.94	2.94	2.96	**2.99(0.04)**
Cl	0.10	0.11	0.10	0.10	0.11	0.16	0.12	0.08	0.14	0.09	0.12	0.10	0.09	**0.11(0.02)**
Water§	1.40	1.77	2.93	3.81	2.16	1.62	2.48	2.18	4.84	1.61	2.24	2.36	3.01	**2.50(0.96)**

* Glass shards in the 2-4φ size fraction of sample 6 (Fig.4) were mounted in epoxy resin, polished, carbon-coated, and analysed using a JEOL JXA-733 SUPERPROBE at Victoria University of Wellington (Froggatt and Gosson, 1982). A 10 μm beam diameter and 8.0 nA beam current, and other analytical conditions as described in Froggatt (1983), were used. Concentrations are given in oxide weight percent except for Cl which is in atomic weight percent. 1sd = 1 standard deviation of the mean of analyses 1-13.

† All Fe calculated as FeO

§ Difference between original analytical total and 100. The glasses also contain detectable Mn and P (not analysed).

localities. (Isopach maps show thin deposits of Hatepe Lapilli extended to Gisborne: Vucetich and Pullar, 1964; Walker, 1981).

Hinemaiaia Tephra (as defined by Froggatt, 1981a) occurs stratigraphically just above Whakatane Ash at Kaipo Lagoon (Fig. 4). Until recently, Hinemaiaia Tephra (definition of Froggatt, 1981a) had been tacitly regarded as underlying Whakatane Ash, following the stratigraphic and chronologic relationships described by Vucetich and Pullar (1973) for Hinemaiaia Ash. However, Lowe (1986) has demonstrated that it stratigraphically overlies Whakatane Ash and is probably widespread over much of the North Island. Lowe (1986) based his correlation in part on the electron microprobe analyses of glass shards from the Hinemaiaia Tephra at Kaipo Lagoon (Table 2). The 13 chemical analyses reported in Table 2 show it to be of rhyolitic composition and support an origin in the Taupo Volcanic Centre (*cf.* glass chemistry analyses of Taupo-derived tephras in, for example, Ewart, 1963, Froggatt, 1983, and Lowe, 1986). The close similarity of each of the analyses, and the consequent low standard deviations (Table 2; *cf.* Froggatt and Gosson, 1982), indicate that the sample is relatively pure, despite the inherent problems that may be associated with probing glass (Froggatt, 1983). These analyses, together with those on the same tephra elsewhere, confirm its identification as Hinemaiaia Tephra (Lowe, 1986).

Underlying Hinemaiaia Tephra are the Whakatane and Rotoma tephras, which are positively identified by their high cummingtonite content (Table 1). This amphibole, diagnostic of tephras derived from the Haroharo complex in the Okataina Volcanic Centre (Ewart, 1971), occurs in only these 2 tephras in the Rotorua Subgroup (Kohn and Glasby, 1978; Howorth *et al.*, 1980).

The next 3 tephras below Rotoma Ash are Opepe Tephra, Poronui Tephra, and Karapiti Tephra. Each of these has an hypersthene-rich ferromagnesian mineralogy (Table 1) characteristic of a Taupo source (Froggatt, 1981c).

The oldest tephra observed in the Kaipo section differs from the others in having a high proportion of heavy minerals (20-30%) in the whole 2-4φ (63-250 µm) size fraction, a very low abundance (2%) of opaque minerals in the heavy mineral suite, and at least twice as much augite (28%) in the ferromagnesian mineral assemblage (Table 1). These properties indicate an andesitic rather than rhyolitic origin, and Tongariro Volcanic Centre is the likeliest source — its eruptives typically contain abundant phenocrysts of hypersthene and augite but low concentrations of opaque minerals (Clark, 1960; Lowe *et al.*, 1980). We consider that the tephra is a member of Topping's (1973) Okupata Tephra Formation, which immediately underlies Karapiti Tephra in the Tongariro area (Topping and Kohn, 1973). The "unnamed andesitic ashes" that underlie Karapiti Lapilli to the east of Lake Taupo, and described by Vucetich and Pullar (1973), are hence probably correlatives of the Okupata Tephra.

CHRONOLOGY

Radiocarbon dating and sample reliability

To support the identification of the tephras, and to determine rates of peat accumulation, 15 new radiocarbon dates have been determined (Fig. 5). Whilst nine samples comprised bulk peat, the other three samples, taken from the top, middle, and bottom of the section exposure, were each split into a coarse and fine fraction. The coarse fraction consisted of handpicked roots generally larger than about $\sim$1 mm in diameter, and the fine fraction residual peat after the root extraction (Fig. 5). This splitting procedure was done to determine whether the abundant coarse root-like material and occasional sticks present in the reference

Tephra (source)	Waikato Radiocarbon Lab. No	Age (years B.P.) Old T½	New T½	Sample*	Comments
Kaharoa (Okataina)					Age is c.700 years old (McGlone,1983)
Taupo (Taupo)					Age is c.1800 years old (Healy, 1964)
Mapara (Taupo)					Age is c.2100 years old (Vucetich & Pullar,1973)
	Wk499	2910±60	2990±60	PR	
Waimihia (Taupo)	Wk500	3040±50	3130±60	PF	
	Wk498	3250±70	3340±70	P	
Hinemaiaia (Taupo)	Wk496	4490±60	4620±60	P	
	Wk497	4530±60	4660±60	P	
Whakatane (Okataina)	Wk501	4860±70	5000±70	P	
	Wk493	5440±170	5600±170	PR	Sample severely diluted (24% sample)
Rotoma (Okataina)	Wk494	7380±80	7590±80	PF	
	Wk495	7560±100	7780±100	P	
Opepe (Taupo)	Wk492	8710±80	8970±80	P	
Poronui (Taupo)	Wk491	9560±80	9840±80	P	
	Wk351	10160±130	10500±130	PR	
Karapiti (Taupo)	Wk352	9960±90	10290±90	PF	
Okupata (Tongariro)	Wk263	10600±90	10900±90	P	
	Wk264	11500±80	11900±90	P	

Fig. 5 – Radiocarbon dates on peaty material associated with the various tephras identified at the Kaipo Lagoon section. Tephra sources are indicated in Fig. 1A (inset). The reliability of the dates is discussed in the text. *P = Peat (bulk sample); PR = Roots (coarser than ~1 mm diameter) extracted from the bulk peat; PF = Fine peat residual from the bulk peat after root extraction.

section (Fig. 3) represented contemporary (*i.e.*, autochthonous) or modern vegetation growth. As a further precaution, we also took three bulk peat samples from a nearby duplicate section that had fewer obvious roots in the Hinemaiaia Tephra-Rotoma Ash zone (Fig. 4).

The results indicate that, apart perhaps from the zone of peat between the Whakatane and Rotoma tephras, very little mixing or contamination has taken place in the section. The dates progressively increase in age down the section with no stratigraphic inversions from tephra to tephra. Comparison of the three coarse and fine pairs of dates, using the statistical method in Currie (1981), shows that both the top pair (Wk 499-500) and the bottom pair (Wk351-352) are probably not significantly different at a 90% significance level. The middle pair of samples (Wk493-494) are significantly different from each other, with Wk493 several thousand years younger than either Wk494 or Wk495. Presumably the rootlets making up Wk493 represent natural contamination of the peat overlying the Rotoma Ash deposit (see further discussion below). The large counting errors on Wk493 stem from its small sample size and consequent severe dilution in the dating procedure (Fig. 5).

Ages of tephra deposition

The Kaharoa, Taupo, and Mapara tephras were not dated at Kaipo Lagoon, but have been dated elsewhere at ~700, ~1,800, and ~2,100 years B.P., respectively (Fig. 5).

The three dates associated with Waimihia Lapilli (Wk498, 499, 500) all fall within the range of previous dates for this tephra (Froggatt, 1981c), although their average of ~3,070 years is younger than the commonly accepted age of ~3,400 years (Pullar and Heine, 1971; Vucetich and Pullar, 1973; Walker, 1981).

The two dates on the thin (3 cm) layer of peat between Hinemaiaia Tephra and Whakatane Ash (Wk496, 497) apply to both tephras, and average ~4,510 years. This average is thus a maximum age for Hinemaiaia Tephra and a minimum for Whakatane Ash. Hinemaiaia Tephra has an average age, based on reliable dates from several sites elsewhere, of ~4,500 years (Lowe, 1986).

A maximum age on the Whakatane Ash at Kaipo is (Wk501) 4,860 ± 70 years B.P., which agrees closely with the previously accepted best estimate of ~4,800 years for this tephra (Cole and Nairn, 1975; Lowe, 1986).

Disregarding Wk493, the other 2 dates on Rotoma Ash (Wk494, 495) average ~7,470 years. This age concurs with initial age estimates of (NZ1152) 7,050 ± 77 years B.P. and (NZ1199) 7,330 ± 235 years B.P. for Rotoma Ash (Pullar and Heine, 1971; Vucetich and Pullar, 1973), but is considerably younger than more recently obtained dates of (Wk522) 8,370 ± 90 and (Wk523) 8,350 ± 100 years B.P. (Green and Lowe, 1985) and (NZ1945) 8,860 ± 120 years B.P. (Nairn, 1980) that are probably more accurate because of better stratigraphic control. Consequently, we regard all of the dates on the peaty material above Rotoma Ash, particularly Wk493, as too young — with respect to the deposition of Rotoma Ash — by possibly 1,000 years or more. The explanation for this apparent anomaly is uncertain, although it may be partly the consequence of an excessive sample size given the particularly slow peat accumulation rate (between 0.06 — 0.07 mm/year) evident for this period (see Fig. 6 below).

The minimum date we obtained for Opepe Tephra is (Wk492) 8,710 ± 80 years B.P.Taking errors into account, this is not significantly different from the previously published date of (NZ185) 8,850 ± 1,000 years B.P. on Opepe Tephra near Taupo (Pullar and Heine, 1971; Vucetich and Pullar, 1973), and is only slightly younger than a maximum age of (Wk230) 9,370 ± 210 years B.P. obtained for Opepe Tephra in Lake Maratoto (Green and Lowe, 1985).

The three dates associated with Poronui Tephra (Wk351,352,491) are the first to be obtained on it and average ~9,900 years. Previously, Poronui Tephra had an extrapolated age estimated to be about 9,740 years (Topping and Kohn, 1973).

Neither Karapiti Tephra nor Okupata Tephra were dated directly, but their stratigraphic positions within a few centimetres of Poronui Tephra and the underlying ^{14}C sample Wk263 (10,600 ± 90 years B.P.) (Fig. 4) allow their ages to be estimated reasonably accurately. Assuming uniform accumulation rates, Karapiti Tephra has an estimated age of ~10,100 years, and Okupata Tephra ~10,300 years (Fig. 6). Karapiti Tephra has only one previous direct date, being (NZ4847) 9,910 ± 130 years B.P. (Froggatt, 1981b). Okupata Tephra, consisting of multiple units near source, has previously been dated between (NZ1374) 9,790 ± 160 years B.P. and (NZ1189) 12,450 ± 340 years B.P. (Topping, 1973), and the age of ~10,300 years is consistent with these dates.

Age of bog formation and peat sedimentation rates

The date (Wk264) 11,500 ± 80 years B.P. from the base of the section was from the lowest peaty horizon we observed in the area, and is assumed to represent a minimum age for the beginning of bog formation. The sediments overlying this horizon and underlying Okupata Tephra (Fig. 4) are muddy, suggesting that permanent bog-forming conditions were not attained for another thousand years or so, probably at around 10,500 years. This 11,500-10,500 year age for the initiation of bog growth at Kaipo is similar to dates of inception of bogs in other parts of the North Island (McGlone and Topping, 1977; Green and Lowe, 1985), and may indicate a response to post-glacial climatic change such as an increase in

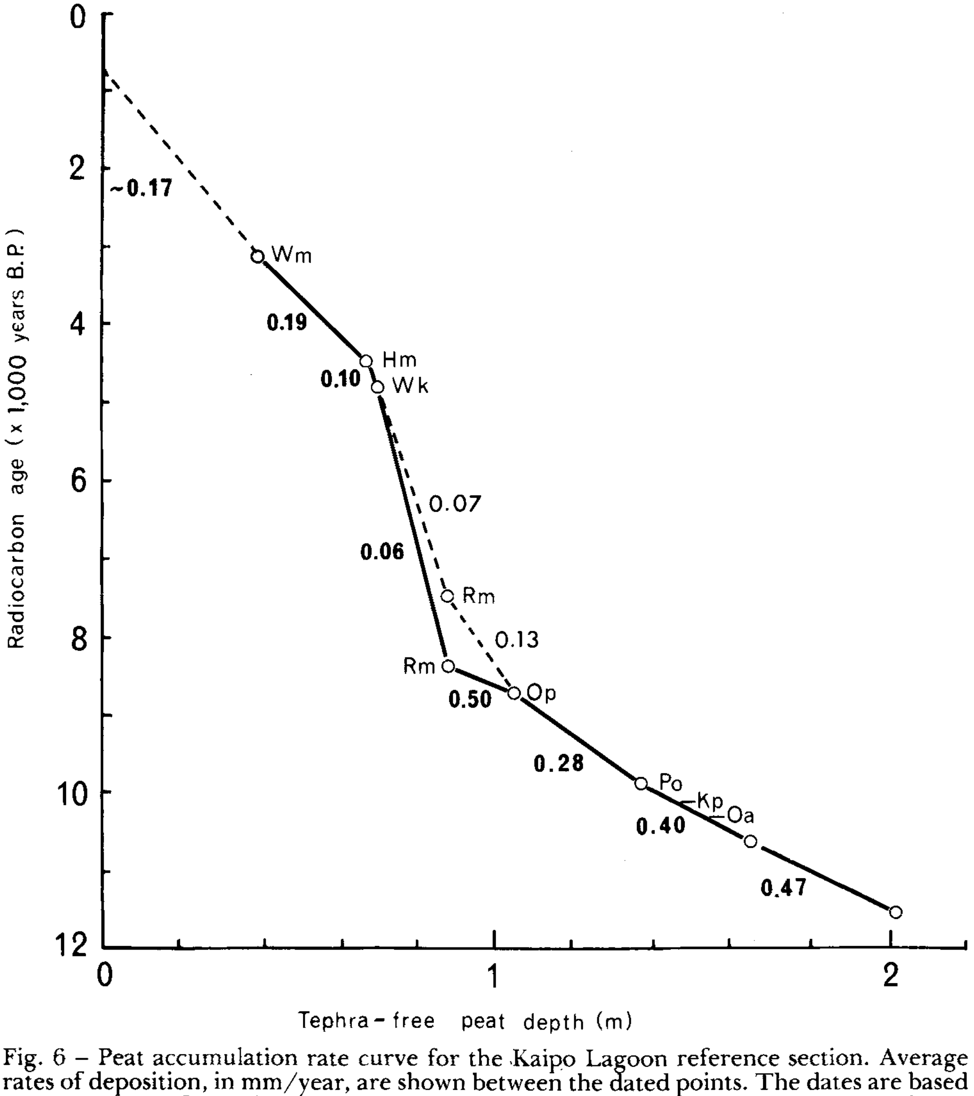

Fig. 6 – Peat accumulation rate curve for the Kaipo Lagoon reference section. Average rates of deposition, in mm/year, are shown between the dated points. The dates are based on average ages from Fig. 5. In the Opepe-Whakatane tephras period, the 2 curves drawn use ages of 7,500 years (dashed) and 8,400 years (solid — and preferred) for Rotoma Ash deposition. The post-Waimihia sedimentation rate is only approximate because of mixing, shrinkage, and possible erosion of the peat in the upper part of the section (the top surface is assumed to be aged ~700 years). Tephra symbols are as in Fig. 3.

rainfall, resulting in higher catchment erosion rates or higher water table levels, or both.

The rate of peat accumulation in the bog since 11,500 years ago is plotted in Fig. 6; the average rate for the whole section is 0.19 mm/year. The rates for separate periods are variable, ranging from 0.47 mm/year (for the muddy peats at the base of the section) to only 0.06-0.07 mm/year in the Rotoma-Whakatane period. The average sedimentation rate between 11,500 years and Opepe Tephra (8,700 years) is 0.37 mm/year, but between Opepe Tephra and the bog's surface (marked by Kaharoa Ash) the average rate is much slower, about 0.13 mm/year. Assuming an age of 8,400 years for the deposition of Rotoma Ash, the bog growth rate in the short interval between this tephra and Opepe Tephra was apparently at a maximum 0.50 mm/year.

The fluctuations in accumulation rates may have several causes, such as variations in local drainage conditions, the effects of tephra fall, peat decomposition or erosion, or changes in climate, and we do not know which, if any, is dominant. However, the broad pattern of change, with relatively fast rates peaking between Opepe-Rotoma tephra depositions, then slowing considerably, is similar to the pattern of sediment accumulation in Lake Maratoto (Green *et al.*, 1984; Green and Lowe, 1985), and in peat deposits in the Tongariro region (McGlone and Topping, 1977). In these studies the changes in sedimentation rates were related largely to post-glacial climatic changes; in Lake Maratoto, Green and Lowe (1985) attributed the maximum sedimentation rate at around Opepe Tephra time to a short period of increased rainfall and windiness with enhanced catchment erosion. This climatic change explanation may thus apply also to the Kaipo Lagoon peat sequence.

The average sedimentation rate of 0.19 mm/year for the Kaipo bog is slow compared with rates of about 0.8-0.9 mm/year reported for the 10,000-11,000 years-old Rukuhia and Hauraki bogs in the Waikato region (Harris, 1963; Hogg and McCraw, 1983; Green and Lowe, 1985), about 1 mm/year for peat at Lake Poukawa (Howorth *et al.*, 1980; Froggatt and Howorth, 1980), and 0.36-0.75 mm/year for post-4000 year-old peat at Turakirae Head, Wellington (Mildenhall and Moore, 1983). Elsewhere in New Zealand, however, such relatively slow rates of peat accumulation have been recorded in Holocene-aged deposits at various localities (*e.g.*, 0.19 mm/year, Holden's Bay, Rotorua: McGlone, 1983; 0.03-0.15 mm/year, Longwood Range, Southland: McGlone and Bathgate, 1983).

Implications of the absence of Waiohau Ash at Kaipo

The basal peat date of 11,500 years has implications with regard to the age of the Waiohau Ash Formation. This tephra, which does not occur in the Kaipo section, was identified in a road cutting near Lake Waikaremoana, by Vucetich and Pullar (1964:71) only 10 km from the Kaipo Lagoon, and has been dated near source at 11,250 ± 200 years B.P. (NZ568), 11,100 ± 210 years B.P. (NZ878), and 11,800 ± 150 years B.P. (NZ1135) (Pullar and Heine, 1971). Its generally accepted age is around 11,300 years (Pullar and Birrell, 1973); the last date (11,800 years) has a less certain stratigraphy than the others and is rarely quoted.

Consequently, the apparent absence of Waiohau Ash from the Kaipo Lagoon section implies that either it was misidentified at Lake Waikaremoana by Vucetich and Pullar (1964), and also by Pullar and Birrell (1973), or the previous age determinations (done on charcoal) underestimated its real age by several hundred years at least. Assuming that there is no erosional unconformity above the 11,500 year date at Kaipo, we favour the second option because Green and Lowe (1985) report an age of about 12,400 years for Waiohau Ash in Lake Maratoto (based on four dates).

CONCLUSIONS

Eleven Holocene tephras occurring at Kaipo Lagoon are derived from the Taupo (7), Okataina (3), and Tongariro (1) Volcanic Centres, and have been identified chiefly from their field appearance, stratigraphy, and dominant ferromagnesian mineralogy. In addition, the glass chemistry of one of the tephras, Hinemaiaia Tephra, was analysed by electron microprobe. Six of the tephras have been radiocarbon dated by 13 new dates on enclosing peat or peaty material; two more tephras were dated by extrapolation assuming constant sedimentation rates. Three dates obtained on Rotoma Ash deposition are considered to be inexact, however, being at least 1,000 years too young in comparison with reliable dates on this tephra elsewhere. The other new dates obtained on the tephras generally accord with previous determinations.

The Kaipo Lagoon bog formed between about 11,500 and 10,500 years ago, perhaps partly in response to the effects of post-glacial climatic change, and peat has accumulated since then at a variable but mainly slow rate (average 0.19 mm/year). The pattern of change of sedimentation rates, relatively fast before and slow after the Opepe-Rotoma maximum, may relate to climatic change, but variation in local conditions could also have been important influences.

The positive identification of the tephras in the Kaipo Lagoon using diagnostic laboratory methods to supplement the field observations has resulted in a more certain Holocene tephrostratigraphy for the Urewera-Waikaremoana area. The identification of Opepe, Poronui, Karapiti, and Okupata tephras in particular has extended their known distribution in eastern North Island. Such improvements to tephra dispersal maps are potentially helpful in interpretations regarding volcanological processes associated with eruptions of tephra (*e.g.*, Walker, 1981; Lowe, 1986). The dates on Poronui Tephra, the first obtained for it, and most of those on the other tephras, are valuable additions to the few dates presently available, although the specific age of the Rotoma Ash eruption is still uncertain.

Finally, the identification and ^{14}C dating of the tephras in the Kaipo Lagoon provides an exceptionally detailed chronology for associated studies on the vegetational and climatic history of the Kaipo-Waikareiti area.

ACKNOWLEDGEMENTS

We thank N. B. Rogers, the late Professor H. S. Gibbs, and Mrs V. L. Lockwood (University of Waikato) for their assistance in the field or ^{14}C dating laboratory. Dr P. C. Froggatt, G. J. Gosson, K. Palmer, and J. Carter (Victoria University of Wellington) gave invaluable help in obtaining and interpreting the glass chemistry analyses. We appreciated helpful comments on the manuscript by Drs M. S. McGlone (Botany Division, DSIR), J. D. Green (University of Waikato), and R. Howorth (Victoria University of Wellington), and encouragement from Professor J. D. McCraw, K. Thompson, Dr T. G. A. Green (University of Waikato), and the Urewera National Park Board.

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Received 24 January 1985; accepted 10 June 1985.