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Advances in Quaternary tephrostratigraphy and tephrochronology in New Zealand

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Abstract

This paper summarises recent studies on Quaternary tephra deposits in New Zealand, and refers to a range of tephrochronological applications including sequence stratigraphy, palaeoclimatic reconstruction, and archaeology. Topics touched upon include tephrostratigraphy, geochronology, geochemical correlation techniques, volcanology, and volcanic hazards and impacts. Some key tephra marker beds, ranging in age from 0.65 ka to 1.63 Ma, are identified. Recently-acquired tephra-bearing cores from both terrestrial and deep-sea environments, extending through or beyond the Quaternary, provide great potential for detailed, fine-resolution volcanological and palaeoenvironmental studies. The tephra-based research in New Zealand demonstrates the importance of tephra deposits as stratigraphic markers, dating tools, and recorders of volcanic eruption history. An extensive reference list is provided.

Introduction

Tephra studies have been undertaken in New Zealand since last century (Lowe, 1990). Currently, major advances are being made in understanding the physical volcanology of pyroclastic deposits in the North Island and their stratigraphic and chronologic inter-relationships, methods of correlation and the application of tephra layers to stratigraphic and palaeoenvironmental studies (i.e., tephrochronology). Petrological studies are also being undertaken (e.g. Dunbar et al., 1989; Sutton et al., 1993; Graham et al., 1995; Nakagawa et al., 1998; Price et al., 1999). The tephra-based studies complement new volcanological studies.

A particularly important step forward has been the acquisition of long terrestrial cores from Auckland (Newnham et al., 1999a) and from the deep sea to the east of New Zealand on ODP Leg 181 (Hayward, 1998; Carter et al., 1999) where potentially exquisitely-detailed Quaternary (and older) records await analysis at fine-resolution scale. A review of Quaternary environmental change in New Zealand that documents the important roles of tephrochronology and geochronology is given by Newnham et al. (1999b). A series of papers integrating tephrochronology and other disciplines in New Zealand was edited by Lowe (1996). A paper describing tephra nomenclature has been prepared recently by Hunt and Lowe (in press).

Quaternary volcanism and geochronology

Quaternary volcanism in the North Island consists primarily of four types (Fig. 1): (1) intraplate, mainly basaltic volcanism arising from mantle upwelling in the back-arc region, forming volcanic fields (e.g. Smith et al., 1993; Briggs et al., 1994); (2) subduction-related, mainly andesitic volcanism in both the back-arc region and Taupo Volcanic Zone (TVZ), typically forming stratovolcanoes (e.g. Goles et al., 1996; Price et al., 1999); (3) crustal-derived, explosive, mainly rhyolitic volcanism in southern Coromandel Volcanic Zone (CVZ) and in central TVZ, forming multiple calderas and producing voluminous ignimbrite sheets and widespread tephra-fall deposits and some lava dome-building (e.g. Brooker et al., 1993; Wilson, 1993; Wilson et al., 1995a); and (4) isolated, rift-related volcanoes of Mayor Island (peralkaline) and Gannet Island (nephelenite) (Houghton et al., 1992; Barclay et al., 1996; Briggs et al., 1997).

There have been considerable advances in understanding the structure, eruptive processes and products and chronology of the volcanic complexes in the TVZ (e.g. Houghton et al., 1991, 1995; Pringle et al., 1992; Briggs et al., 1993; Bailey and Carr, 1994; Nairn et al. 1994; Smith and Houghton, 1995a, 1995b; Wilson et al., 1995a, 1995b; Black et al., 1996; Krippner et al., 1998). The

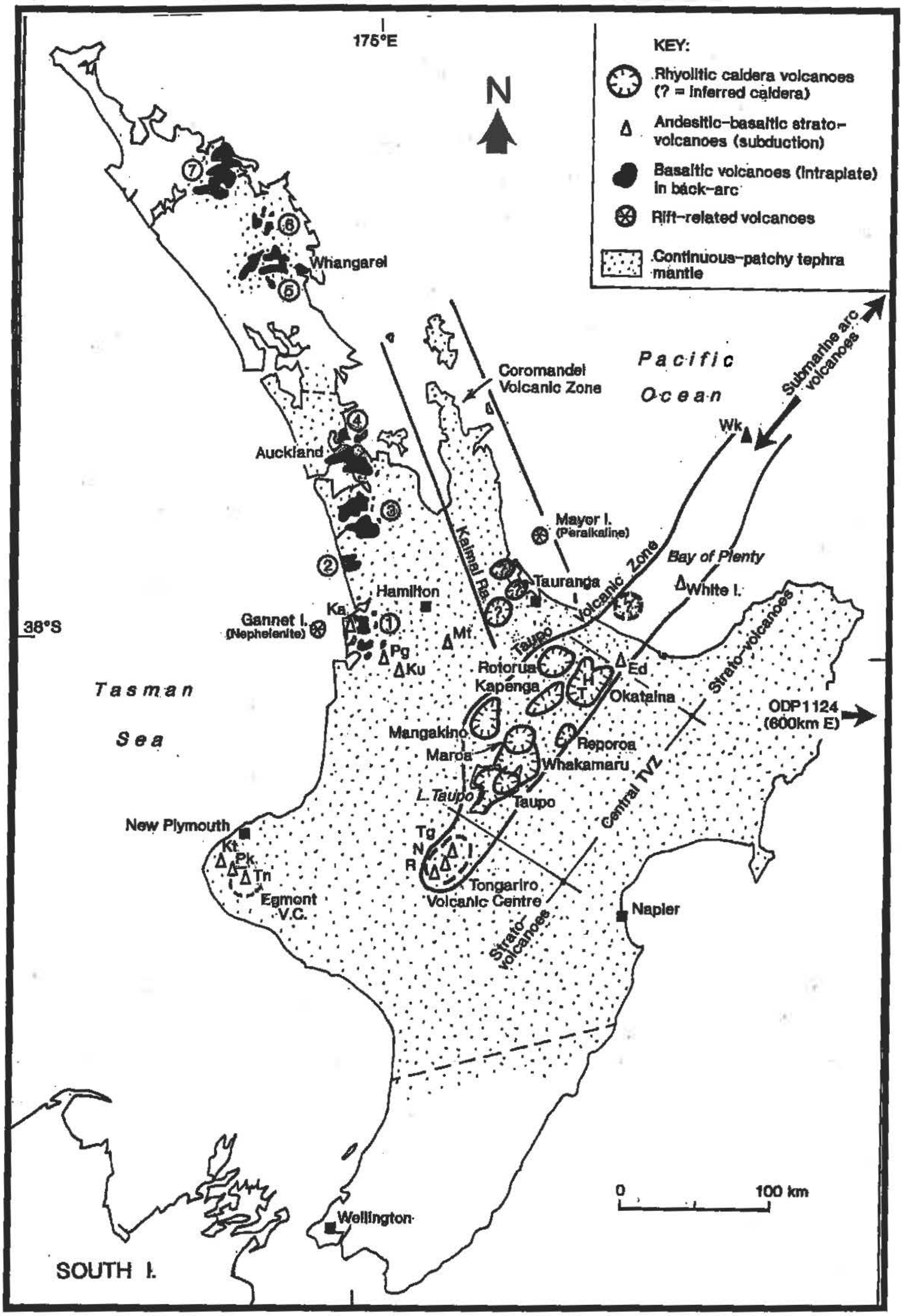

Figure 1: *Major volcanoes of North Island active since c. 2.5 Ma and generalised distribution of pyroclastic deposits. Back-arc, intraplate volcanic fields: 1, Okete; 2, Ngatutura; 3, South Auckland; 4, Auckland; 5, Whangarei; 6, Puhipuhi; 7, Kaihohe-Bay of Islands. Subduction-derived stratovolcanoes (examples only): Ka, Karioi; Pg, Pirongia; Ku, Kakepuku; Mt, Maungatautari; Ed, Edgecumbe (Putauaki); Tg, Tongariro; N, Ngauruhoe; R, Ruapehu; Kt, Kaitake; Pk, Pouakai; Tn, Taranaki (Egmont). Wk, 'Whakatane volcano', is one of the submarine arc volcanoes. T and H represent Tarawera and Haroharo volcanoes, respectively, within the Okataina volcanic complex. Mainly after Briggs et al. (1994), Wright (1994), and Wilson et al. (1995a).*

central TVZ is the largest and most frequently active rhyolitic magmatic system on Earth (Houghton et al., 1995). The sizes of eruptions range from about 0.01 km^3 to 500 km^3, with the smallest known rhyolitic events comparable in size to many basaltic and andesitic events (Wilson et al., 1995a).

Possible caldera structures of Quaternary age have been provisionally identified recently in the Tauranga and Kaimai Range regions of the southern CVZ (Wilson et al., 1995a; Brathwaite and Christie, 1996; Briggs et al., 1996; Lowe et al., in press a) and a submarine caldera volcano has been identified in offshore Bay of Plenty (Fig. 1; Davey et al.,1995). A series of eight large (50–260 km^3 in volume), submerged stratovolcanoes along the southern Kermadec frontal arc to the northeast of North Island have also been investigated (Gamble et al., 1993; Wright, 1994). The submarine 'Whakatane volcano' marks the northern extremity of continental TVZ (Wright, 1994; Fig. 1).

Techniques used recently in dating lavas and pyroclastic deposits (both ignimbrites and tephra-fall materials) include K-Ar (on whole rock or feldspar or hornblende separates), Ar-Ar (single-crystal laser fusion on feldspar separates), fission-track (using both the isothermal plateau method on glass or the external detector method on zircon), ^{14}C (high-precision liquid scintillation spectrometry or accelerator mass spectrometry) and palaeomagnetic methods (see below).

Tephrostratigraphy: post-65 ka deposits

Tephrostratigraphic work in New Zealand has expanded in recent years in conjunction with the new volcanological work, and also with important advances in geochronological techniques. The pyroclastic eruptives from the central TVZ dating back to 65 ^{14}C ka have been well documented (e.g. Froggatt and Lowe, 1990; Wilson, 1991, 1993; Wilson et al., 1992; Alloway et al., 1994; Lowe and Hogg, 1992, 1995; Carroll et al., 1997), both at proximal and distal localities (e.g. Pillans and Wright, 1992; Carter et al., 1995; Wilson et al., 1995c; Eden and Froggatt, 1996; Lowe et al., 1999). New tephrostratigraphic and petrological studies on deposits associated with stratovolcanoes of Mt Egmont (Alloway et al., 1995; Price et al., 1999) and Tongariro Volcanic Centre (e.g. Donoghue et al., 1995a, 1995b, 1997, 1999; Cronin et al., 1996a, 1996b; Donoghue and Neall, 1996; Hobden et al., 1996; Lecointre et al., 1998; Nagakawa et al., 1998; Nairn et al., 1998) have been published.

Key palaeoenvironmental tephra marker beds identified include the Kaharoa (0.65 ka), Taupo (1.85 ka), Tuhua (6.2 ka), Konini (10.15 ka), Waiohau (12 ka), Rerewhakaaitu (14.7 ka), Kawakawa (22.6 ka) and Rotoehu (65 ka) tephras (Newnham et al., 1999b). These and other tephras have been used widely as tephrochronological markers in a range of disciplines and environments (e.g. see Lowe, 1990, 1995; Alloway et al., 1992; Berryman, 1992; Pillans et al., 1993; Kennedy, 1994; Carter et al., 1995; McGlone, 1995; Newnham et al., 1995; Berryman et al., 1998; Eden and Page, 1998; Lowe and Hendy, 1998; Newnham and Lowe, 1999; Newnham et al., 1999b; Newnham and Lowe, in press) including, most recently, archaeology (Wilmshurst, 1997; Lowe et al., 1998, in press b; Newnham et al., 1998a, 1998b). Some also provide a potential means of linking high-resolution tree-ring and ice-core records (e.g. Baillie, 1996; Lowe and Higham, 1998).

Tephrostratigraphy: pre-65 ka deposits

Major advances in tephrostratigraphy and tephrochronology have been made on the pre-65 ka Quaternary silicic tephra beds that occur in terrestrial sedimentary sequences (e.g. in Wanganui Basin: Carter and Naish, 1998a; Kidnappers Group, Hawke's Bay: Shane et al., 1996a) and in marine cores, where they have been dated using fission-track techniques, Ar-Ar, luminescence and amino-acid racemisation methods. Examples of such work include earlier papers by Nelson et al. (1985), Froggatt et al. (1986) and Black et al. (1988). More recent studies have been reported by Black (1992), Kohn et al. (1992), Alloway et al. (1993), Berger et al. (1994), Kimber et al. (1994), Shane et al. (1994, 1995, 1996a, 1996b), Naish et al. (1996, 1997, 1998), Palmer and Pillans (1996), Pillans et al. (1994, 1996), Seward and Kohn (1997) and Lowe et al. (in press a). The veracity of the dating has been testable in some cases by independent magnetostratigraphy, marine oxygen isotope (MOI)-derived orbital tuning, coccolith biostratigraphy and aminostratigraphy (e.g. Pillans et al., 1994, 1996; Naish et al., 1996, 1998; Bowen et al., 1998; Carter and Naish, 1998a, 1998b). Key tephra marker beds identified include Rangitawa (0.35 Ma), Potaka (1 Ma), which is associated with the Jaramillo Subchron and Pakihikura (1.63 Ma) tephras (Newnham et al., 1999b).

Further work dating and correlating the older, distal

Quaternary tephra beds is underway in the Bay of Plenty (Briggs et al., 1996; Manning, 1996), Hamilton (Waikato) (Lowe et al., in press a) and Auckland regions (Newnham et al., 1999a) and on the c. 140 macroscopic tephra layers, some up to 0.9 m thick, recorded in cores from ODP Site 1124 that date back to c. 11 Ma (Carter et al., 1999; Fig. 1). This core and others including Site 1123 provide a long record of North Island volcanism that is potentially able to be dated very accurately using magnetostratigraphy, biostratigraphy and, critically, MOI-based orbital tuning (Carter et al., 1999; Newnham et al., 1999b).

Correlation techniques

A major advance in tephra characterisation and hence correlation techniques has been the use of the electron microprobe to analyse volcanic glass. This work began in New Zealand with Froggatt (1983) and has since been widely adopted (e.g. Lowe, 1988a, 1988b; Eden et al., 1992; Froggatt, 1992; Shane and Froggatt, 1992; Pillans, 1994; Eden and Froggatt, 1996; Manning, 1996; Shane et al., 1996b; Donoghue et al., 1999; Lowe et al., 1998, 1999). Analyses of Fe-Ti oxides, first undertaken in 1970 (Kohn, 1970), have also been used to fingerprint tephras, in part using major and trace element compositions but more recently via estimates of eruption temperature and oxygen fugacity (e.g. Lowe, 1988a; Cronin et al., 1996c; Donoghue and Neall, 1996); a detailed study on Fe-Ti oxides and tephra correlation was reported by Shane (1998). Analyses of ferromagnesian minerals (e.g. pyroxenes, amphiboles) by electron microprobe are being used as well (e.g. Lowe, 1988a; Froggatt and Rogers, 1990; Cronin et al., 1996c; Donoghue and Neall, 1996). Statistical techniques including discriminant function analysis to aid correlation are well established (e.g. Stokes and Lowe, 1988; Stokes et al., 1992; Shane and Froggatt, 1994; Cronin et al., 1996b, 1996c, 1997a).

Volcanic hazards and impacts

The growing dossiers on the eruption histories of the North Island volcanoes have led to an increasing appreciation of the potential volcanic hazards and impacts posed by these volcanoes (e.g. Dibble et al., 1985; Clarkson, 1990; Allen and Smith, 1994; Bebbington and Lai, 1996; Cronin et al., 1997b; Johnson et al., 1997; Houghton, 1998; Pyle, 1998; Lowe and de Lange, 1998; Giles et al., 1999; Newnham et al., 1999a). The potential magnitude of these hazards was highlighted by the relatively minor AD 1995–1996 Ruapehu eruptions that generated considerable problems, including the disruption of aviation (e.g. many airports were closed, including Auckland International Airport for three nights), serious disruption to electricity generation and transmission in central North Island, damage to crops and the killing of livestock (Houghton et al., 1996; Newnham et al., 1999a).

Conclusions

This short review has summarised just some aspects of important tephrostratigraphic and tephrochronologic work and related volcanological studies, undertaken in New Zealand in recent years. Such research demonstrates the key role that tephras play in volcanological and palaeoenvironmental research in New Zealand and elsewhere: (1) tephra deposits resulting from large-scale eruptions provide stratigraphic marker beds that assist in correlating sequences in both terrestrial and marine environments and in linking such sequences; (2) they provide mineralogical components for numerical dating and hence a means for independently testing dates based on biostratigraphy, magnetostratigraphy and MOI-based orbital tuning; and (3) they provide a comprehensive record of volcanism, especially in distal environments because proximal, near-vent deposits may be complex and 'incomplete' with successive eruptive events tending to destroy or bury antecedent deposits.

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