PERALKALINE IGNIMBRITE SEQUENCES ON MAYOR ISLAND, NEW ZEALAND

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ABSTRACT

The peralkaline ignimbrite deposits on Mayor Island do not readily conform to the idealised sequence of pyroclastic flows due to their distinctive grading of lithic clasts. Possibly, a unique occurrence is an inverse grading of lithic clasts in a flow unit. Evidence suggests that some pyroclastic flows may be of such high density and poor expansion that they do not separate into the normal ground-hugging flow and overriding ash cloud components. It appears that such flows are a result of a combination of high viscosity and low water content of Mayor Island peralkaline magmas, and abnormal conditions at the vent at the time of discharge, such as a parasitic vent discharging ignimbrites while contemporaneous plinian-type pumice eruptions occur from the main vent.

INTRODUCTION

Mayor Island is an extinct, isolated peralkaline rhyolite volcano lying near the edge of the continental shelf about 26 km offshore in the Western Bay of Plenty, North Island, New Zealand (Fig. 1). The peralkaline character of Mayor Island contrasts markedly with the nearby calc-alkaline Taupo Volcanic Zone and it is thought that its location records the impingement of a tensional rift on the continental crust of the North Island (1).

The island consists of a composite volcanic cone that is built up of pumiceous pyroclastics and thick comendite lava flows. The pyroclastics presently form a thick mantle over much of the

S. Self and R. S. J. Sparks (eds.), Tephra Studies, 337–345.

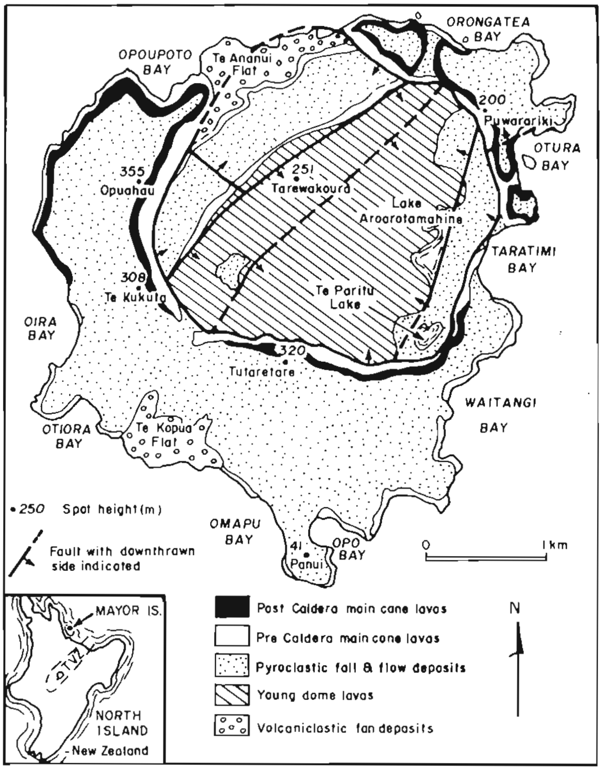

Figure 1. Geology map of Mayor Island. Inset shows regional location of Mayor Island with regard to the North Island, New Zealand and the Taupo Volcanic Zone (TVZ).

island (Fig. 1) as well as being interbedded with the lava flows. Pyroclastic flow deposits form the bulk of the pyroclastic sequences (2) and thin, incipient to non-welded ignimbrites are most noteworthy.

Ignimbrite eruptions commonly pass through a sequence of phases which produce a characteristic sequence of deposits. Sparks et al. (3) first constructed an idealised depositional flow-unit model characterising the main phases of a pyroclastic flow and Fisher (4) has subsequently expanded this model from his observations on the Bandelier Tuff sequence. Thus, the idealised sequence (Fig. 2A) now consists of a ground surge deposit (layer a), a pyroclastic flow unit (layer b), an ash cloud surge unit (layer c) and a thin unit capping the sequence called a tephra fallout unit (4) or a co-ignimbrite ash (5) (layer d).

Most of the ignimbrite sequences on Mayor Island show the

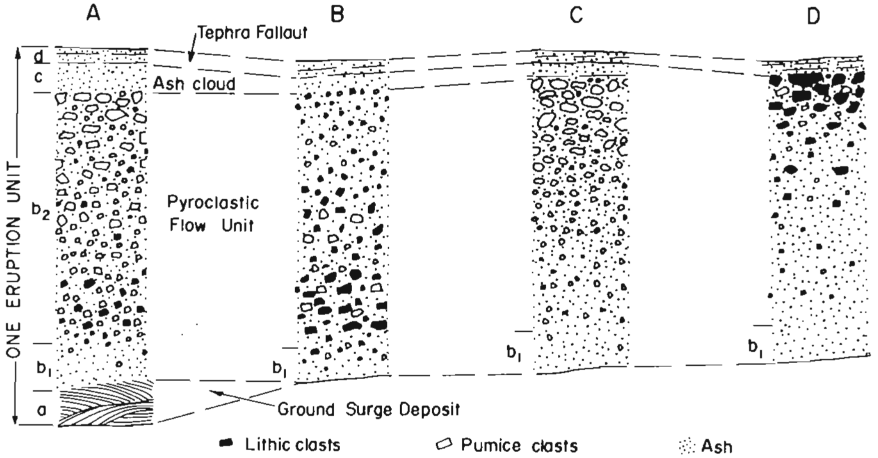

Figure 2. Ignimbrite sequence on Mayor Island. A. The complete ideal sequence (after Fisher (4)). The pyroclastic flow unit includes layers b_1 and b_2, with an underlying ground surge deposit (layer a), an ash cloud deposit (layer c) and a tephra fallout deposit (layer d). B. Lithic fragment-rich flow unit with normal grading. Ground surge unit absent. C. Pumice fragment-rich flow unit with inverse grading. Boundary between layers b_1 and b_2 becomes obscure. Ground surge unit absent. D. Lithic fragment-rich flow unit with inverse grading. Ground surge and ash cloud units are absent.

same succession of units noted by Fisher (4) in his expanded model but significant differences occur in grading and in the amount and size of clasts of different composition in layer b. Therefore, additional comments are presented to explain the distinctive features seen in these Mayor Island peralkaline ignimbrites.

MAYOR ISLAND IGNIMBRITES

Ignimbrite sequences on Mayor Island that record a single pyroclastic flow eruption are usually less than 5 m thick and the main body of the ignimbrite flow unit (layer b) is normally unwelded, or sometimes incipiently welded. The major types of ignimbrite flow sequences on Mayor Island are schematically summarized in Fig. 2. The complete idealised sequence (Fig. 2A) occurs only in a succession of ignimbrites outcropping in the caldera wall at the northern end of Te Paritu Lake.

Ground surge units in Mayor Island sequences are usually less than 1 m thick, are well stratified with common low-angle cross-bedding, and, even though they show considerable variation in grain size and sorting between beds, are mostly fine grained. When a ground surge unit is present it passes gradationally upwards into the main flow unit into a conspicuously fine grained layer b_1 which coarsens upwards into layer b_2. Layers b_1 and b_2 make up the bulk of the ignimbrite sequences and together they are normally less than 4-5 m thick, with layer b_2 being about one tenth of that thickness.

As in the idealised sequence, ash cloud units (layer c) sometimes immediately overlie the main flow units on Mayor Island. Fisher (4) describes layer c as consisting of 0.5 to 1 m long lenses that are up to 5 cm thick, and are well bedded and sometimes cross-bedded. However, the layer c ash cloud deposit in most of the Mayor Island ignimbrite sequences are mostly massive and occur as very extensive beds that thicken and thin laterally (Fig. 3). They are finer grained and slightly better sorted than layers b_2.

Tephra fallout deposits (layer d), commonly named by others (5) as co-ignimbrite ashes, sometimes overlie and top the ignimbrite sequences (Fig. 3). They are typically very fine vitric ash beds and, of the few samples analysed, 50 per cent is normally finer than 4.75ϕ (0.37 mm). Sometimes these units, which are generally up to 10 cm thick, show a poorly developed shower bedding.

The main body of the flow sequence is layer b_2 and in the Mayor Island ignimbrites it is this layer that shows considerable variation from the idealised model (Fig. 2). Ideally layer b_2 is relatively homogeneous and poorly sorted with ash and blocks co-existing in the rock (3). Pumice clasts generally show an inverse grading where both size and proportion of clasts increases upwards to the top of layer b_2, while lithic fragments show a normal grading with the larger lithic clasts concentrated at the base of layer b_2 (Fig. 2A). The Mayor Island ignimbrites show that if the pyroclastic flow was depleted in either one of the two components in the coarser sized grades, then the resultant layer b_2 shows a normal grading because of a dominance of lithic clasts (Fig. 2B) or an inverse grading because of a dominance of pumice clasts (Fig. 2C).

Ignimbrite units at Omapu Bay have originated from a small parasitic cone in south Opo Bay and, except for a unit exposed near the base of the sequence at north Omapu Bay, they show inverse grading of pumice fragments (Fig. 3). This succession of ignimbrites also shows an up sequence enrichment of pumice clasts with a coincident impoverishment of lithic clasts. The exceptional unit at north Omapu Bay differs in that layer b_2 contains a predominance of accessory lithic fragments which show an inverse

Figure 3. Several flow units of nonwelded inverse graded ignimbrite that were erupted from a parasitic vent to the right of the photograph. Lowermost and second from top units have recessive tephra fallout units at their top. Note the massive, laterally extensive layer c in the subdivided unit. North Omapu Bay.

grading (Fig. 2D), sometimes with blocks up to 75 cm in diameter at the top of the layer. The finer juvenile components of this unit are essentially glass shards and crystals so that its particle size distribution is much the same as the other types of layer b_2 except that about 20 per cent of the particles are coarser than -4ϕ (16 mm). But, unlike the other ignimbrite sequences, the sequence containing inverse graded lithic clasts in layer b_2 does not have an overlying ash cloud layer, and commonly only has a very thin tephra fallout layer.

INTERPRETATION

Many ignimbrites are now considered to result from deposition from the collapsed part of a vertical eruption column (4,6,7) and it appears to be the process involved in the formation of Mayor Island ignimbrites. Firstly, the presence of layers a through d in some ignimbrites on Mayor Island indicates the same column collapse sequence envisaged by Fisher (4). Secondly, the shower bedding and extreme enrichment of fine vitric material in the tephra fallout layers suggests almost complete differentiation of fragment sizes and compositions probably only possible in the upper reaches of a vertical eruption column. Therefore, a vertical explosion occurred initially and subsequent collapse of the eruption column concentrated the larger vitric fragments, crystals and lithic fragments in the collapsing part of the column because of their greater densities.

Ground surge deposits are considered, because of their associated occurrence with ignimbrites, to be the result of an outwardly moving surge cloud or "ash hurricane" (8) that accompanies or precedes the main pyroclastic flow. Sparks *et al.* (3) suggest that the ground surge deposit spreads laterally more widely and for less distance distally over the terrain than the associated pyroclastic flow which may be confined to valleys. Thus, the absence of ground surge components in most of the Mayor Island ignimbrites (Fig. 2B-D) suggest that either ground surges did not separate from the main flows or the ground surges had a limited extent and the main flows extended beyond that limit. A complete absence of any ground surge units in the many outcrops of these ignimbrites suggests the former is more likely.

The fine grained basal layer b_1 of ignimbrites differs from layer b_2 only in that it lacks any large fragments. Sparks *et al.* (3) consider it to result from a regime of the pyroclastic flow from which the large fragments are excluded probably due to high shear and grain dispersive forces near the base of the flow.

In the ideal situation, evidence suggests that pyroclastic flows are high-concentration dispersions that move in a laminar flow similar to debris flows (6) and in the main flow body the pumice clasts would have a lower density than the enclosing matrix, and lithic fragments would have a higher density. Thus, if the matrix is only slightly expanded it behaves as a homogeneous fluid phase (3), so that the pumice clasts would literally float to the top while the lithic fragments would sink with the largest grains sinking the furthest. Therefore, the pumice clasts show an inverse grading (Fig. 2A and C) while the lithic clasts show a normal grading (Fig. 2A and B).

Before interpreting the mechanisms involved in the genesis of the inverse graded lithic fragment-rich ignimbrite on Mayor Island it is best to first consider the mechanisms of formation of layers c and d. Pyroclastic flows generally segregate into two main parts (9), a ground-hugging pyroclastic flow and an overriding ash cloud. The ground-hugging flow forms layers a and b, the bulk of any flow sequence, and the overriding ash cloud deposits thinner, finer grained layers c and sometimes d on top. A detailed description of the genesis of layer c from the ash cloud is recorded by Fisher (4) but, briefly, the normally discontinuous, thin lenses form when the body of the pyroclastic flow decelerates and deposition occurs from turbulent vortex cells that continue to sheer across the top.

Layer c in Mayor Island ignimbrites are unlike those noted by Fisher (4), in that they are in more extensive, thicker lenses and are massive. This suggests that grain support and dispersive mechanisms were continually high in a poorly expanded, turbulent cloud so that deposition occurred en masse only after cessation of the cloud movement. It is also envisaged that the ash cloud was not detached but remained intimately associated with the main flow unit (see later).

The final phase of any ignimbrite eruption is the fallout of fine grained ejecta that elutriates from the upper regions of the ash cloud and/or settles from the vertical explosion column (3). Thus, layer d is the residual material left after all coarser and heavier material has been deposited and it is consequently enriched in vitric ash.

An important consideration in interpreting the inverse graded lithic fragment-rich ignimbrite is that its sequence does not contain an ash cloud layer c. This suggests that either an overriding ash cloud was detached from the flow proper and moving on a different flow path, so that it was deposited elsewhere on the island or even out at sea, or that the ash cloud did not separate from the flow. It is proposed that the latter is more applicable, in that other ignimbrite sequences on Mayor Island normally contain an ash cloud layer c and there is no evidence in other locations to suggest the former case. Therefore, it is conceived that this ignimbrite was deposited from a very poorly expanded pyroclastic flow that flowed in a laminar fashion similar to subaqueous debris flows whereby the lithic clasts are "buoyed up" by strong shear forces set up in a highly concentrated matrix and the tendency for smaller particles to fall downward between the larger particles (kinetic sieve mechanism) would enhance the displacement of the larger particles towards the surface (10). The cessation of lateral movement of the flow resulted in deposition en masse probably after the internal shear stress no longer exceeded the yield strength of the flow (11) and the volatiles separated from the solids after deposition by transpiration or percolation. Furthermore, the presumed absence of an overriding ash cloud suggests that when a shower bedded layer d is present in these ignimbrites, it results directly from fallout from the vertical eruption column.

MAGMA AND VENT CONDITIONS

Sparks et al. (7) and Wilson et al. (12) have demonstrated that the formation of ignimbrites from collapsing columns depends on the magmatic gas content, vent velocity and vent radius.

Mayor Island peralkaline magmas had relatively low water content (13) and therefore, low magmatic gas content since water is a major gas component. This low gas content allied with the considerable viscosity of peralkaline magmas (14) may have caused some decrease from the normal fluidisation of ignimbrite flows, both internally and in their interaction with the atmosphere. Similarly, these factors would have ensured continual slow emission of volatiles from the fragments in the flow so that turbulence could be maintained throughout the flow's motion.

Many of the ignimbrite units mentioned here have been discharged from a parasitic cone on the southern edge of Opo Bay. This parasitic vent was emitting ignimbrites while plinian-type pumice eruptions were being contemporaneously discharged from the main central vent on the island (2). The effect this had on the ignimbrite eruptions is incalculable but it may have caused a slight reduction in their mass output rate and escape velocity at the vent.

The greater number of lithic fragments in the lower ignimbrite units at Omapu Bay suggests that the parasitic vent at south Opo Bay was enlarging during its early phases of activity. The increasing vent size probably caused decreased velocities in the later ignimbrite eruptions.

Thus, the combination of all these factors appears to have caused a marked decrease in the explosivity of some eruptions on Mayor Island so that eruption column heights were comparatively low and ground surge components did not always form. Thus, resultant pyroclastic flows would have been poorly inflated so that overriding ash clouds did not separate but remained attached to the main ignimbrite flow. Continual turbulence caused by the volatiles emitted from the fragments in the underlying flow appears to have induced the massive ash cloud (layer c) deposits.

The paucity of pumice in the inverse graded lithic fragment-rich ignimbrite suggests that its magma had a very low gas content and that there were few magmatic fragments from which volatiles could be emitted. Furthermore, the abundance of accessory lithic fragments that would have originally been cool would have further lowered the temperature of this flow (15) and the result was a very poorly inflated flow from which an ash cloud did not evolve.

Therefore, it appears that the difference in the Mayor Island ignimbrite sequences from the idealised model is a combined result of the peralkalinity and low gas content of magmas, and some abnormal conditions of the vent at the time of discharge.

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