The 1800a Taupo eruption: "Ill wind" blows the ultraplinian type event down to Plinian

B.F. Houghton[1], R.J. Carey[1,2], and M.D. Rosenberg[3]
[1]Geology and Geophysics, University of Hawai'i, Honolulu, Hawaii 96822, USA
[2]CODES, School of Earth Science, University of Tasmania, Hobart, Tasmania 7001, Australia
[3]Wairakei Research Centre, GNS Science, Taupo 3384, New Zealand

ABSTRACT

The most powerful category of explosive volcanic eruptions, called "ultraplinian," was proposed in 1980 on the basis of the distribution of a single pyroclastic fall product of one phase of the 1800a Taupo eruption in New Zealand. Dispersal data, a measure of the "footprint" of the deposit, were used subsequently to estimate eruption plume heights of 50–51 km, more than 10 km higher than observed or estimated for any historical Plinian eruption. Today, this unit remains the only deposit to have met the rigorous ultraplinian dispersal criteria, and it is an important and widely cited exemplar in physical volcanology. The earlier study was based on total thicknesses for the entire bed and grain-size data across that full thickness. We have now subdivided this bed into 26 subunits and measured their individual thicknesses and selected maximum clast sizes. Our data show that the apparent large footprint of this bed is an artifact of a previously unrecognized shift in the wind field during the eruption, rather than extreme eruptive vigor. Our study demonstrates the dangers of applying full-thickness approaches to even seemingly uniform fall deposits. The results throw into some doubt the need for the term ultraplinian, at least for this deposit. With the revision of plume heights for the Taupo ultraplinian, a height range of 35–40 km may be practical for use as an upper limit for source parameters in models of transport and dispersal of volcanic ash.

INTRODUCTION

Rigorous classifications of explosive eruptions, especially sustained ones, are dependent on proxies for "intensity," a parameter defined by mass or volume eruption rates (Walker, 1973; Pyle, 1989; Bonadonna and Costa, 2013). There are few direct measurements of instantaneous mass or volume flux for even very small explosive eruptions. An alternative for those eruptions that are observed is to calculate time-averaged rates, arrived at by measuring total mass or volume of ejecta and total eruption duration. For unobserved or pre-historical eruptions, researchers deduce time-averaged eruption rates from the geometry of the deposits, that is, rates of thinning (from thickness or isomass data) and fining (size of largest particles, isopleth data, at every site), which scale with mass discharge.

Both approaches, *a priori*, calculate time-averaged fluxes. The consequences of this are minimized if the parent event is steady, i.e., eruptive conditions and the wind field are relatively constant during an eruption or eruption phase. However, if mass eruption rate waxes and wanes, the effect is to reduce the calculated eruption rate to a value below the peak discharge rate. We show here that the previously undocumented effects of a changing wind field (Fig. 1A) on estimated plume height and eruption intensity are equally dramatic.

Walker (1980) used "full-thickness" data to propose that unit 5 of the 1800a eruption of Taupo volcano (the Taupo Lapilli Member) in New Zealand represented an extremely high eruption rate for steady eruptions, defining a new end-member class called ultraplinian. By full-thickness, we mean isopachs constructed from thicknesses measured across the entire unit and isopleths derived from size data for the largest clasts collected over the entire thickness of the deposit at each site. By recognizing and mapping 26 subunits, we show that previously undetected wind shifts from west-northwest to southwest during the eruption resulted in major overestimates of the deposit thinning and pyroclast fining rates, and thus dispersive power. The characteristics of individual subunits do not meet Walker's ultraplinian criteria, and suggest the eruption was merely a strong, but not atypical, Plinian event.

THE TAUPO ERUPTION

The 1800a eruption is the youngest event at Taupo volcano in the central Taupo Volcanic Zone (Figs. 1B and 1C). It is globally the second largest eruption in the past 2000 yr, and probably the most powerful worldwide in the past 5000 yr (Wilson and Walker, 1985). It is notable for a great diversity of explosive eruptive styles, and the extreme mass discharge rates inferred for unit 5, the Taupo Lapilli, and unit 6, the climactic Taupo ignimbrite (Wilson and Walker, 1985).

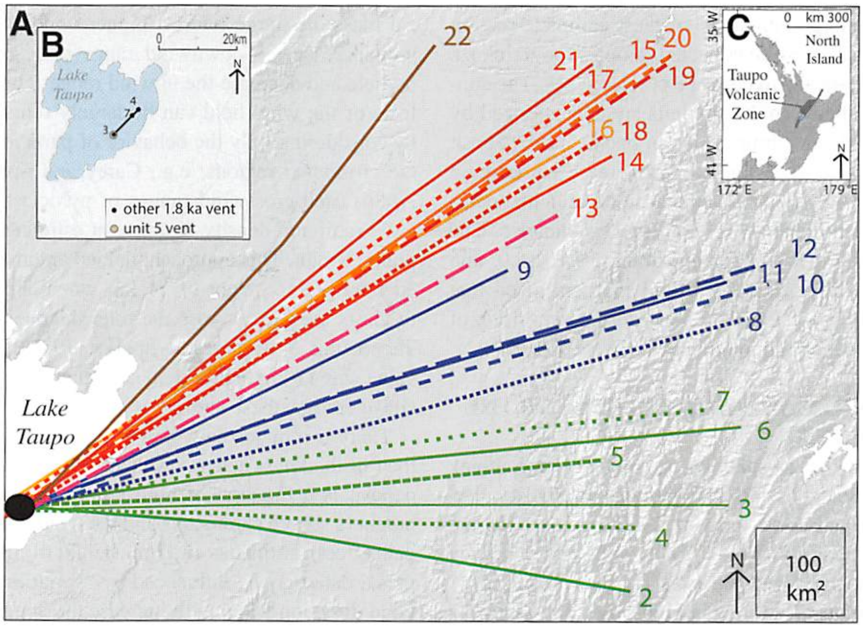

Figure 1. Dispersal axes for subunits of Taupo Lapilli Member (unit 5), New Zealand. A: Dispersal axes shown are derived from isopach maps drawn for 21 of the 26 subunits mapped in this study. These were derived using elongation of isopach sets, as shown in the Data Repository (see footnote 1). They show general progression from west-northwest to southwest with time. This shift has the effect of greatly increasing the "footprint" of the deposit, giving a misleading impression of dispersive power. Large black dot is inferred unit 5 vent. B: Map showing location of 10-km-long Taupo eruption fissure. Large gray dot is newly inferred vent for unit 5. Small black dots are previously mapped vents for units 3, 4, and 7. C: Location of Lake Taupo within Taupo Volcanic Zone (dark gray shading).

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The eruption products are mapped as seven units, equating with seven contrasting eruption phases. The eruption occurred from at least three vents on a 10-km-long northeast-southwest fissure (Fig. 1B) along the eastern shoreline of Lake Taupo (Smith and Houghton, 1995). Unit 5, the topic of this study, is a widespread lapilli fall (5.8 km^3 dense-rock equivalent [DRE]), erupted coevally with at least 11 small, weak pyroclastic density currents. After phase 5, the explosive volcanism culminated in the generation of unit 6, the 12.1 km^3 (DRE) highly energetically emplaced Taupo ignimbrite (Wilson, 1985).

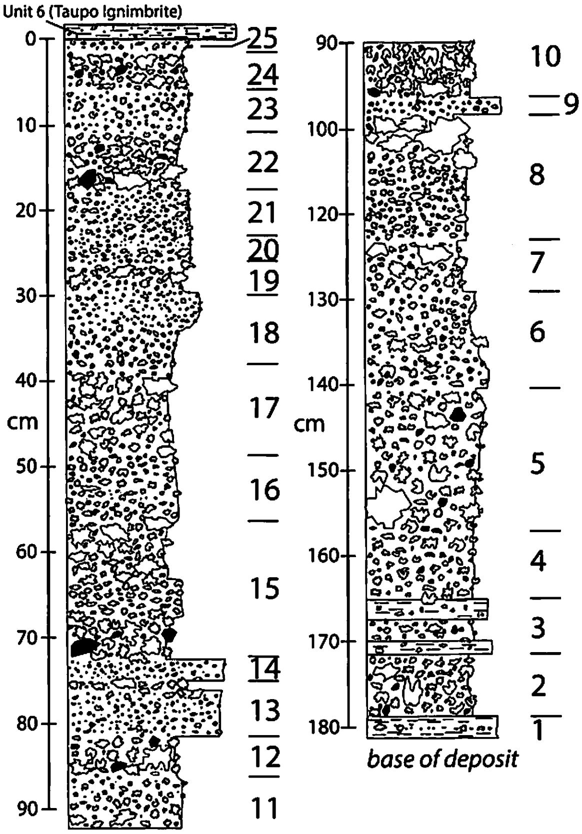

Figure 2. Stratigraphic log for unit 5 at site 25 km northeast of vent, showing 25 subunits recognized in this study; unit 26 is not preserved at this site. Juvenile pumice is in white; wall-rock clasts (mostly older rhyolitic lava) are in black. Note particularly the finer-grained subunits (e.g., 1, 9, 14) interpreted to represent weaker pulses of the sustained eruption column.

SUBDIVISION OF UNIT 5

Unit 5 is a lapilli fall that is markedly coarser than the other 1800a and earlier fall deposits, including Plinian unit 2. It extends more than 220 km downwind to beyond the eastern coast of New Zealand (Healy et al., 1964). Previous studies chose not to subdivide unit 5, while noting the presence of two centimeter-thick finer layers in the sequence (Walker, 1980). In sections in the south, the largest pyroclasts are near the base of the deposit; in the north, the coarsest clasts are always near the top of the sequence. This unexpected observation prompted us to re-examine the internal stratigraphy of unit 5. Working at closely spaced sections we were able to define 26 subunits in the Taupo Lapilli. We measured thicknesses at 149 sites, and collected the five largest pumice and wall-rock clasts for the nine best-defined subunits (2, 5, 10, 12, 14, 15, 19, 20, and 22) where they were exposed. At the thickest complete section (Fig. 2), we also collected samples for grain-size analysis and to describe pumice types. The contacts between the subunits are characterized by significant, abrupt shifts in one or more deposit characteristics, including: increase or decrease in grain size or in abundance of stretched pumice, and changes in wall-rock abundance. The finer-grained intervals (subunits 9, 14, 20, and 21) are particularly useful markers given that unit 5 was eroded variably during deposition of unit 6, the Taupo ignimbrite (Walker, 1980).

DISPERSAL AND INTENSITY FOR THE SUBUNITS

Of the 26 subunits, subunit 1 is a complex sequence of fall and pyroclastic density current beds, and subunits 23, 24, 25, and 26 are too poorly preserved to be well constrained by isopachs. Dispersal axes for the remaining 21 subunits are plotted in Figure 1A. They show an overall progressive shift from 100° to 045° with time, which we interpret as the consequence of a southward shift in wind direction.

The dispersal of pyroclasts of given sizes and densities is used to estimate the height of eruption plumes and mass fluxes, empirically calibrated by data from well-observed eruptions (Carey and Sparks, 1986; Wilson and Walker, 1987). Clasts disperse due to diffusion and advection by wind. Under identical wind conditions, a higher eruption plume (due to a higher mass eruption rate) will lift a given clast higher, and transport it farther from the vent. For identical mass discharge rates, a higher wind speed will increase the downwind range of a given particle and decrease the upwind range. The effects of the wind field can be largely removed by considering only the behavior of particles in the crosswind regions; e.g., Carey and Sparks (1986) used crosswind ranges of pyroclasts of fixed radii and density to arrive at estimates of plume height. This approach yielded an unprecedented plume height of 51 km when applied to clasts averaged across the total thickness of Taupo unit 5 (Carey and Sparks, 1986). The value was 17 km higher than any other example considered by these authors.

There is a major flaw, however, in the use of the full-thickness data set. The dispersal of a fall deposit is a function of both eruption column height (a source parameter) and the wind field (a path effect). Estimates of plume height from dispersal data may be influenced by "variations in wind direction which will increase the apparent crosswind range (of a particle) and thus overestimate column height" (Carey and Sparks, 1986, p. 120). Maximum clast sizes at individual sites reflect the progressive shift in dispersal, that is, the coarsest clasts were sampled from the base of the sequence in the south and at the top of the sequence in the north. The largest clasts used to construct the Walker (1980) isopleth contours are therefore not strictly time equivalent at each site; they came from different subunits for different parts of the dispersal area, and were erupted at different times. The new subunit isopleth data show that the footprint of each isopleth contour is much larger for the combined full-thickness data than for data from any one subunit (Fig. 3). Plume heights for the coarse-grained subunits, calculated after Carey and Sparks (1986), range from 31 to 37 km (Table DR1 in the GSA Data Repository[1]), values much more in accordance with the range of 34–41 km observed or recorded for the strongest historical Plinian eruptions (Williams and Self, 1983; Rosi et al., 2001).

INTERPRETATION OF FINER-GRAINED INTERVALS

There are two possible interpretations of the finer-grained subunits (9, 14, 20, and 21). They may represent periods of lower mass discharge and thus weaker dispersive power. Alternatively, minor ingress of water from Lake Taupo into the vent could have boosted the fragmentation of the magma. Fine subunits are both more weakly dispersed and also more strongly wind attenuated than coarser intervals, and calculated plume heights for subunits 14 and 20 are 25 km and

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[1] GSA Data Repository item 2014144, supplementary notes and figures describing methods and showing isopach and isopleth data for selected subunits, is available online at www.geosociety.org/pubs/ft2014.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

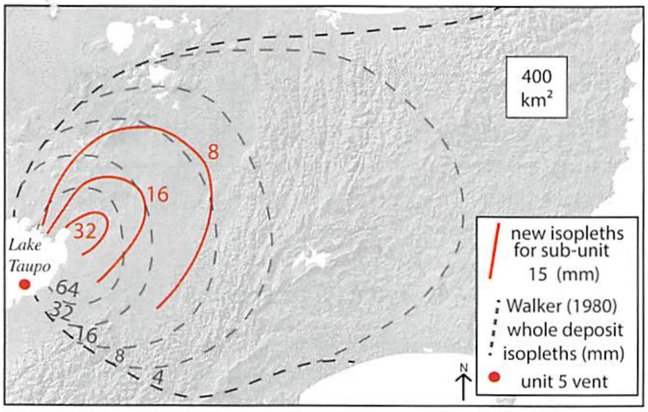

Figure 3. Juxtaposition of isopleths for subunit 15 against full-thickness isopleths of Walker (1980). Isopleths for subunit 15, and all other subunits, enclose much smaller areas than full-thickness isopleths, leading to marked reduction in inferred column heights and hence mass discharge rates during eruption.

26 km, respectively. As a contrast, near-circular isopachs of the preceding phreatoplinian falls (units 3 and 4) reflect the ability of "wet" (water-rich) plumes to propagate cross- and upwind (Smith and Houghton, 1995). We therefore suggest that the entire unit 5 eruption was "dry" and that the finer intervals reflect minor brief drops in mass eruption rate and plume height.

NEW INFERENCES FOR VENT POSITION

A vent position for unit 5 has not previously been constrained. Dispersal axes of units 3 and 4 showed that neither was erupted from the original vent proposed for the entire eruption. Instead, vent position migrated ~10 km northeastwards between the two eruptive phases (Smith and Houghton, 1995). Our unit 5 dispersal axes converge on a southwestern site and strongly suggest that the locus of eruption shifted again after unit 4, back to, or near, the vent(s) active during eruption of unit 3. This is perhaps not a surprise given the pumiceous nature of both units 3 and 5 and the contrasting dominance of dense, partially outgassed clasts in unit 4 (Houghton et al., 2010). Our data are insufficient to detect any minor shift in position during the eruption of unit 5.

CONCLUSIONS

Our study suggests that full-thickness sampling of pyroclasts, across even relatively massive fall deposits, should be avoided, as it may lead to misleading conclusions. The new data suggest that the effect of a steady shift in wind direction during unit 5 was to expand the apparent areas enclosed by both isopachs and isopleths based on the total fall deposit, leading to a false impression of the dispersive power and mass eruption rate of the eruption phase. Our data also permit accurate location of the source vent in a way that was not feasible using bulk thickness data.

Each subunit of unit 5 is of Plinian intensity, but none meets the ultraplinian criteria proposed by Walker (1980). This result implies that the concept of ultraplinian perhaps needs to be revisited. Potentially the term, if it is to be retained, is better used for the products of extremely voluminous, rather than powerful, eruptions (i.e., magnitude rather than intensity).

The height attained by an eruption plume is modulated by factors linked to the eruption (mass discharge rate, fragmentation efficiency, magma temperature, and volatile content), the volcano (vent and conduit radii and geometry, and volcano height) and meteorological conditions (wind field, atmospheric density, temperature and stratification, and humidity) (Wilson and Walker, 1987; Glaze and Baloga, 1996; Sparks et al., 1997; Herzog et al., 1998; Bonadonna and Costa, 2013). The revision to the estimate for the height of the Taupo plume means that the maximum observed or estimated plume heights cluster at ~35–40 km (Williams and Self, 1983; Sigurdsson and Carey, 1989; Rosi et al., 2001). The fact that, for at least three of these eruptions, further increase in eruption rate culminated in a shift from stable plume to instability and plume collapse (Walker, 1980; Sigurdsson and Carey, 1989; Rosi et al., 2001) suggests that this range represents a practical upper limit that can be used in forecast models for both tephra sedimentation and volcanic plume dispersal (Mastin et al., 2009).

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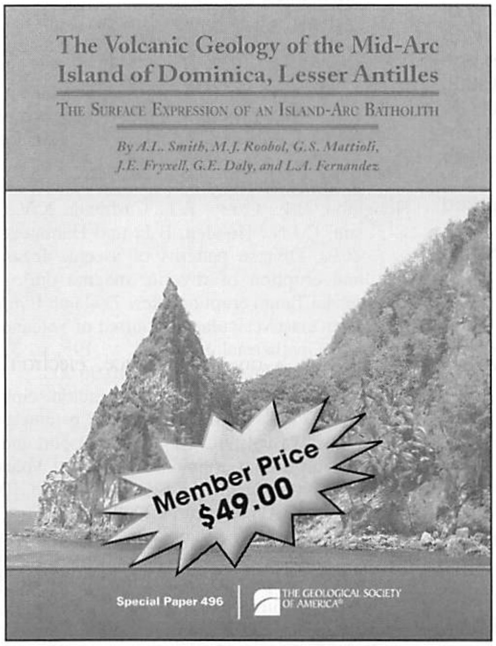
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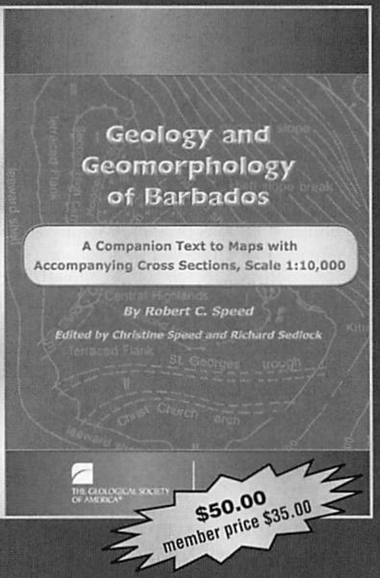
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