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An unusually energetic basaltic phreatomagmatic eruption: Using deposit characteristics to constrain dilute pyroclastic density current dynamics

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ABSTRACT

Multiple, highly erosive base surges of the Table Rock Complex tuff ring (TRC2), Oregon, produced dune-bedded deposits with crest to crest bedform wavelengths up to 200 m, which are amongst the largest ever recognized in the deposits of pyroclastic density currents. Here we use bedform wavelength, surmounted obstacles, and a large chute-and-pool feature to estimate near-source velocities (118–233 m s^{-1}), lower-bound velocities at radial distances of 1.6, 2 and 4.7 km from source (34, 29 and 20 m s^{-1}, respectively), and corresponding column collapse heights (up to 2.8 km). This paper represents one of the few studies that attempt to quantify flow characteristics, such as emplacement velocities at different distances from source, eruption column collapse height, and eruptive energy, based on deposit characteristics.

1. Introduction

Dilute pyroclastic density currents (PDCs) represent one of the most dangerous and destructive phenomenon associated with explosive volcanism. They can occur in all types of explosive eruptions and are characterized as unsteady, density-stratified, turbulent gas-particulate flows (Valentine, 1987; Wohletz, 1998). Due in part to the wide range of initial conditions associated with dilute PDC generation (e.g., initial current velocity, current depth, sediment concentration, grain size distribution), a wide range of bedforms have been documented. Deposits include high-angle and low-angle dunes, symmetrical, asymmetrical, upstream (regressive) and downstream (progressive) migrating dunes, chute-and-pool structures, trough cross bedding, pinch-and-swale structures, planar strata, and massive deposits that frequently display reverse grading (Moore, 1967; Fisher and Waters, 1970; Waters and Fisher, 1971; Crowe and Fisher, 1973; Wohletz and Sheridan, 1979; Fisher and Schmincke, 1984; Sohn and Chough, 1989; Wohletz, 1998; Nemeth et al., 2001; Brand and White, 2007; Brand et al., 2008; Brand and Clarke, 2009).

Sediment transport, deposition and the controls on bedform morphology and migration within dilute PDCs remain poorly understood (e.g., Hand, 1974; Valentine, 1987; Sequeiros, et al., 2009; Spinewine, et al., 2009). However, several important relationships have been documented relating deposit characteristics to conditions in the basal portion of the current by comparing the deposits of dilute PDCs with their subaqueous equivalent, turbidity currents. The deposits of turbidity currents (turbidites) and dilute PDCs are remarkably similar, suggesting the emplacement dynamics of the two flows may be similar despite the differences in ambient and interstitial fluid (water versus air; e.g., Kneller and Buckee, 2000). For example, there is clear evidence in both environments that current velocity is a controlling factor in bedform morphology and migration. Bedform wavelengths are observed to increase with increasing negative slope in dilute PDC deposits, suggesting that bedform wavelength is a function of the flow velocity (Crowe and Fisher, 1973; Fisher and Schmincke, 1984). Similarly, bedforms found in turbidity current deposits associated with higher flow velocities, such as in channels, tend to have longer wavelengths and commonly appear to migrate upstream (e.g., Stromboli Canyon, Kidd et al., 1998; and the El Julan and Icod wave fields, Canary Islands, Wynn et al., 2000; Wynn et al., 2002). Finally, Morris et al. (1998) observed that turbidite bedform wavelengths of what the authors interpret as antidunes, upstream-migrating bedforms that develop under supercritical flow conditions, decrease with distance from source down fan, which they associate with an increase in sediment concentration, decrease in velocity, decrease in flow thickness, or a combination of the three. This same trend has been noted in the dune-bedded deposits of dilute PDCs (Wohletz and Sheridan, 1979; Brand and White, 2007).

Well-exposed bedforms resulting from dilute PDCs thus lend insight into dynamic emplacement conditions. Unfortunately, the broad extent of many dilute PDC deposits, coupled with complex topography, makes

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observation and interpretation difficult (e.g., lateral blasts, Druitt, 1992; the 1982 El Chichon eruption, Sigurdsson et al., 1987). However, PDCs from mafic hydrovolcanic eruptions, such as those discussed in this paper, tend to produce less extensive deposits (run-out distances of 1–6 km) and are emplaced on simpler topography, making detailed study more feasible. Such studies may lend insight into larger eruptions that produce currents emplaced by fundamentally similar processes. To this end, features of the TRC2 dilute PDC deposits (Brand and Clarke, 2009) are used to estimate current thickness, velocity and criticality at several distances from source and to constrain column collapse height.

2. Table rock complex

The Table Rock Complex (TRC; Pliocene–Pleistocene; Fig. 1) is a well-exposed hydrovolcanic complex in the Fort Rock–Christmas Valley Basin, Oregon (USA), the former location of an extensive, 64-km-long by 40-km-wide, fluctuating Pliocene to Pleistocene lake (Heiken, 1971; Brand and Clarke, 2009; Brand and Heiken, 2009). The complex contains a large tuff cone with a solidified capping lava lake (TRC1), a large, broad tuff ring (TRC2), and at least seven flanking explosion craters (flank vents) with variably preserved tuff rings (Fig. 1c). The exact age of each eruption is unknown; however, the relative timing of each eruption is constrained through the mapping and stratigraphic correlation of Brand and Clarke (2009). The first eruption, TRC1, occurred through a 60–70 m deep lake (approximated by the distance between the freshwater lake sediments and the subaqueous–subaerial contact; Brand and Clarke, 2009). The eruption built a large tuff cone that rose more than 285 m above the lake surface, which ultimately sealed the conduit off from the lake water. As a result the eruption ended with an effusive phase producing a lava lake in the crater, ~365 m above the lake floor (Heiken, 1971; Brand and Clarke, 2009). The outer tuff cone walls have since been eroded, leaving the resistant solidified lava lake as the prominent feature in the complex (Fig. 1c).

The timing of the flank vent eruptions is difficult to constrain as they are generally highly eroded. Most cut through TRC1 deposits and are overlain by TRC2 deposits, suggesting eruption between the two larger events. A geologically-significant time gap occurred between the TRC1 and TRC2 eruptions, as evidenced by up to 50 cm of diatomitic lake deposits between the two eruptive sequences. TRC2 is a 2.7-km-wide tuff ring that violently erupted when magma encountered near-surface groundwater or a shallow lake underlain by saturated playa lake sediments (Brand and Clarke, 2009). Characteristics of the TRC2 deposits (maar-like proximal morphology and evidence for subaerial deposition at low elevation) as described by Brand and Clarke (2009), suggest the lake, if present, had a maximum depth of 15 m in the area of TRC prior to this eruption. This implies a regional drop in the lake level between the TRC1 and TRC2 eruptions (Brand and Clarke, 2009). The topography around the Table Rock Complex is a flat lake bed. Thus we can assume that the pre-eruptive topography for TRC2 was mostly gently sloping (<2°) or flat except for obstacles from the earlier tuff cone (TRC1) and scattered flank vents. The deposits of TRC2, the focus of this paper, are interpreted to be the result of radially-propagating dilute pyroclastic density currents (PDCs; Brand and Clarke, 2009), often referred to as base surges when associated with hydrovolcanic eruptions (e.g., Valentine and Fisher, 2000).

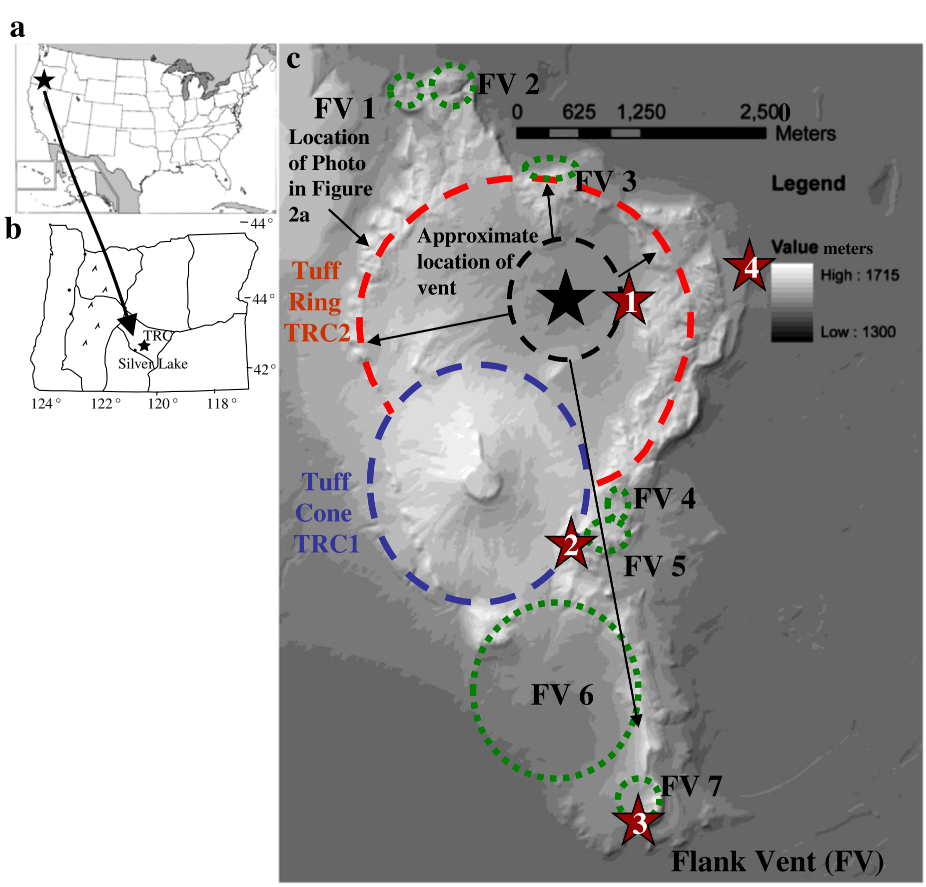

Fig. 1. a and b) Location of TRC. c) DEM of TRC, showing approximate location of vent major eruptive centers (TRC1 and TRC2) and smaller flank vents. The dashed line surrounding a large star represents the estimated location of the TRC2 vent. The smaller, numbered stars are locations referred to in the text.
Modified from Brand and Heiken (2009).