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Syn-depositional substrate deformation produced by the shear force of a pyroclastic density current: An example from the Pleistocene ignimbrite at Monte Cimino, northern Lazio, Italy

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Abstract

Substrate deformation by pyroclastic density currents is very sparsely described in the literature. The rare occurrence of syn-depositional substrate deformation suggests that special circumstances are required to transmit shear from the base of a pyroclastic density current into the deposited ignimbrite and the substrate. One example of a substrate deformed by a pyroclastic density current is found at the base of the Pleistocene ignimbrite at Monte Cimino, central Italy. A series of reverse faults that offsets the basal contact were produced by the shear force of the pyroclastic current during deposition of the ignimbrite. The faults formed on the vent-facing side of a palaeo-slope that strikes sub-parallel to the flow direction of the pyroclastic current. Fault offsets suggest motion was parallel to the flow direction of the pyroclastic current, rather than down-slope. We propose that these faults resulted from fluctuations in the shear force of the pyroclastic density current as it was channelled down a palaeovalley. The lower flow boundary, which separated the deposited ignimbrite and the substrate from the moving pyroclastic density current, momentarily stepped down into the substrate, so that the upper 0.5 m of the substrate and about 1.5 m of the deposited ignimbrite became incorporated into the current. This momentary coupling of the current and the substrate induced reverse faulting in the substrate and the deposited portion of the ignimbrite. Deposition appears to have been ongoing during the formation of these faults, as well as afterward. Following the formation of the faults, the lower flow boundary seems to have been quickly re-established above the faults (approximately 1.5 m above the base of the ignimbrite), allowing deposition to continue without further deformation of the substrate.

Keywords: Cimino; ignimbrite; Italy; palaeotopography; pyroclastic density current; substrate deformation

1. Introduction

In the thousands of studied ignimbrites, there are very few documented examples of substrate deformation produced by pyroclastic density currents. It appears that the vast majority of deposition from pyroclastic

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currents does not involve the exertion of significant shear on the substrate, and thus only rarely do these currents produce deformation in the pre-volcanic surface. Given the observable destructive power of these phenomena and the predominance of plastic substances such as soil as substrates, it is surprising that so few examples of substrate deformation are described. Although the lack of descriptions of substrate deformation at the bases of ignimbrites may reflect a lack of observations rather than a true absence of these features, it is more likely that shear coupling between the base of a pyroclastic flow and the substrate is rare. The few examples in the literature are generally documented with only a brief description, some have a photo or figure, but discussion of their geneses is generally absent. The mechanisms of transmitting shear forces across the lower flow boundary of a pyroclastic current remain poorly understood. This paper documents and describes one example of syn-depositional substrate deformation produced by a pyroclastic current, and discusses its origin and implications.

Pyroclastic density currents may modify the pre-existing ground surface by erosion (e.g., Wilson and Walker, 1985; Sparks et al., 1997), loading due to deposition (e.g., Cole et al., 1993), or deformation by impact or shear (e.g., Sparks et al., 1985). These erosional and deformational features give evidence for the powerful nature of pyroclastic currents and provide insights to their interior structure. Pyroclastic density currents are presently understood to be diverse in nature, however they have some basic unifying characteristics. The currents have an upper low-particle-density, fully turbulent ash cloud, which may grade down into a higher-particle-concentration, less turbulent portion of the flow (Sparks, 1976). The lowest part of the flow is thought to have the highest particle concentration, which may suppress turbulence (Valentine, 1987). The 'lower flow boundary' (Branney and Kokelaar, 2002), 'boundary layer' (Valentine, 1987; Buesch, 1992) or 'hindered settling zone' (Druitt, 1992) is thought to be characterized by increased particle concentration and decreased turbulence just above the depositional interface. Within this zone, particles are thought to travel by saltation, rolling, and sliding, as well as by suspension within the current (e.g., Calder et al., 2000; Branney and Kokelaar, 2002). A velocity gradient probably occurs through this zone, from the deposit or substrate, which are at rest, increasing upward through the aggrading deposit to the moving pyroclastic density current (Valentine, 1987; Branney and Kokelaar, 2002). Miller and Smith (1977) suggested that the lower flow boundary may act as a "cushion" to the pyroclastic density current, increasing the flow mobility and allowing it to locally move upslope and overrun some topographic barriers. While there is no universally accepted understanding of the exact nature of this basal flow zone, it seems clear that there is a separation between particles moving in the pyroclastic density current and those that have been deposited. This separation prevents the deposited material from being re-entrained. Following the usage in Branney and Kokelaar (2002), we refer to this separation of moving and non-moving particles as the "lower flow boundary".

The basal contact of the "peperino tipico" (PT) ignimbrite surrounding Monte Cimino, 65 km northwest of Roma, central Italy (Fig. 1), is well exposed along cliffs incised through the ignimbrite, giving ample evidence of the nature of the basal contact. In only one location does the basal contact appear to have been purely depositional, with fine carbonised leaf imprints preserved on the pre-volcanic surface (Fig. 2). In other areas, the basal contact of the ignimbrite shows more dynamic interaction between the pyroclastic current and the substrate, most commonly in the form of pre-depositional scour (erosion). More rarely, the basal contact displays syn-depositional deformation structures, such as faults and injection structures that involve the basal layers of the ignimbrite as well as the pre-volcanic substrate. This paper focuses on a series of syn-emplacement reverse faults exposed in one locality at the base of the PT ignimbrite and considers the implications for pyroclastic density current flow dynamics.

2. Geologic setting

Central Italy was uplifted and deformed by the Apennine orogeny during the Miocene (Malinverno and Ryan, 1986; Doglioni, 1991; Faccenna et al., 2001), and subsequently, during the Pliocene, underwent extension, producing a series of northwest trending grabens (Barberi et al., 1994). These basins were intermittently flooded by the sea and filled by clay, sand, and gravel of Messinian to Pliocene age, these being in excess of 800 m thick in the study area (Barberi et al., 1994). Sedimentation corresponded to local subsidence events, and continued intermittently through the Pliocene into the early Pleistocene (about 1.5 Ma). Since that time, the region has been undergoing uplift (Calamita et al., 2004, and references therein). Volcanism in the region began in the early Pliocene, during the waning stages of subsidence and marine sedimentation.

Since the middle Pliocene (about 3.5 Ma, Serri et al., 1993), central Italy has been the focus of profuse volcanic activity (Conticelli and Peccerillo, 1992). Two magmatic provinces have been described, which overlap in space