Scoria cone construction mechanisms, Lathrop Wells volcano, southern Nevada, USA

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ABSTRACT

Scoria cones are commonly assumed to have been constructed by the accumulation of ballistically ejected clasts from discrete, relatively coarse-grained Strombolian bursts and subsequent avalanching such that the cone slopes are at or near the angle of repose for loose scoria. The cone at the hawaiitic Lathrop Wells volcano, southern Nevada, contains deposits that are consistent with these processes during early cone-building phases; these early deposits are composed mainly of coarse lapilli and fluidal bombs and are partially welded, indicating relatively little cooling during flight. However, the bulk of the cone is composed of relatively fine-grained (ash and lapilli) planar beds with no welding, even within a few tens of meters of the vent. This facies is consistent with deposition by direct fallout from sustained eruption columns of relatively well-fragmented material, primarily mantling cone slopes and with a lesser degree of avalanching than is commonly assumed. A laterally extensive fallout deposit (as much as 20 km from the vent) is inferred to have formed contemporaneously with these later cone deposits. This additional mechanism for construction of scoria cones may also be important at other locations, particularly where the magmas are relatively high in volatile content and where conditions promote the formation of abundant microlites in the rising mafic magma.

Keywords: scoria cone, Strombolian, fallout, basalt.

INTRODUCTION

Scoria cones are commonly inferred to have been constructed from the deposits of Strombolian eruptions, which are characterized by intermittent bursts of gas and mainly coarse-grained pyroclasts as large gas bubbles rise to the top of a slow-moving or stationary magma column (e.g., see Wood, 1980; Head and Wilson, 1989; and Riedel et al., 2003). A much-cited (e.g., Fisher and Schmincke, 1984; Vespermann and Schmincke, 2000) model for this type of activity and resulting cone construction was developed by McGetchin et al. (1974). In the McGetchin et al. (1974) model, pyroclasts are ejected during bursts from a vent at a range of angles from vertical to ~25° off vertical. Each clast follows a ballistic trajectory, depositing a ring around the vent with a rounded rim that represents the distance of maximum deposition. As the ring builds with successive bursts, it forms a sharp-rimmed cone that becomes oversteepened with respect to the angle of repose of the loose deposits (assuming they are nonwelded), resulting in grain avalanching both on the outer cone slopes and the inner slopes of the crater. The cone continues to grow upward and outward through a combination of ballistic emplacement and grain avalanching until eruptions cease. During this growth phase, the vent is commonly blocked by avalanched pyroclasts such that subsequent bursts partly re-eject previously erupted material.

The McGetchin et al. (1974) model predicts deposits composed mainly of bombs and lapilli. Bombs will be commonly fluidal in shape (e.g., ribbon and spindle bombs) and surface texture. Lapilli-sized pyroclasts (scoria) will range from fluidal to angular (the latter representing pieces of previously erupted larger clasts that were broken on impact or during grain avalanching and recycling in the vent) to, in some cases, rounded (reflecting ball milling–like processes of recycled brittle clasts in the vent). Bedding structures will be dominated (except in deposits from the earliest phase of cone building) by features associated with grain avalanching—e.g., irregular bedding contacts and lenses of coarse, inversely graded clasts. Bursts that are particularly rich in magma clots, such that the accumulation rate of material on the cone slopes is rapid enough that clasts are able to weld, will produce some zones of welded bombs or spatter (also called agglutinate), particularly in areas close to the vent; this also reflects a short ballistic flight time that limits cooling and solidification of clasts before deposition. Coarse bombs might roll down the cone slopes to deposit in a ring or coarse apron around the base. Deposits beyond a cone formed by the McGetchin et al. (1974) model would be limited to thin, highly localized beds of ash and fine lapilli due to the paucity of fine material associated with true Strombolian activity and the lack of a sustained eruption column (see Vergniolle and Mangan, 2000).

Many scoria cones are associated with appreciable fallout deposits that might be several meters thick near the cone and gradually thin over distances of many kilometers (e.g., Segerstrom, 1950; Self, 1976; Heiken, 1978; Luhr and Simkin, 1993; Hooten et al., 2001) and/or have been historically observed to include periods of sustained, ash-rich eruption columns that reach kilometers into the atmosphere (see review by Riedel et al., 2003). The occurrence of sustained eruption columns indicates an additional process, not accounted for by McGetchin et al. (1974), that might influence scoria cone construction—i.e., deposition of material by fallout from a sustained

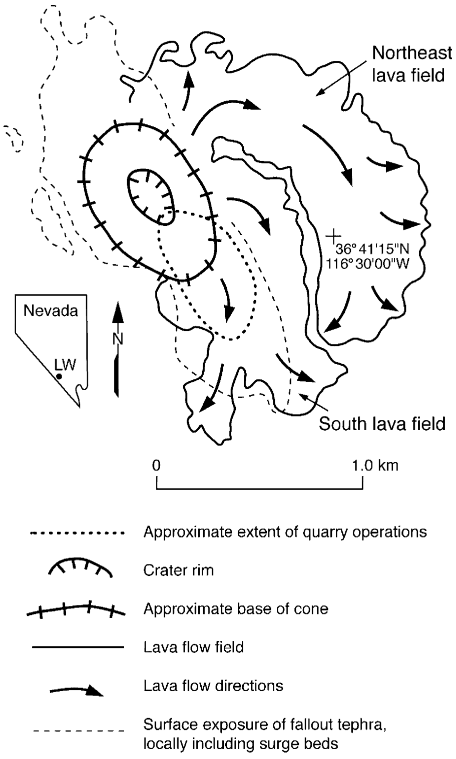

Figure 1. Geologic map showing main features of Lathrop Wells volcano.

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column instead of (or in addition to) deposition by direct ballistic emplacement. In this paper we describe deposits within the scoria cone of the Lathrop Wells volcano, southern Nevada, that record both construction mechanisms.

Lathrop Wells Volcano

The 75–80 ka Lathrop Wells volcano (Fig. 1; Heizler et al., 1999) is composed of hawaiite (Vaniman et al., 1982) with an initial dissolved water content as high as 4.6 wt% (Nicholis and Rutherford, 2004). It consists of the following: (1) an ~140-m-high scoria cone, (2) two aa lava flow fields, one of which vented from the early cone and flowed south-southeastward (south lava field, Fig. 1), while the later one flowed initially northeastward from the cone and then wrapped toward the south (northeast lava field, Fig. 1), and (3) a scoria lapilli and ash-fallout deposit that might have extended as far as 20 km north of the cone (Bechtel SAIC Company, 2004). A local sequence of pyroclastic surge deposits northwest of the cone is interbedded with the fallout deposits; the surge deposits compose <0.03% of the total volume of eruptive products and appear unrelated to any deposits in the cone. The total volume of eruptive products is ~0.09 km^3 (cone, 0.02 km^3; lavas, 0.03 km^3; fallout, 0.04 km^3; Bechtel SAIC Company, 2004). Physical volcanological aspects of the volcano have been touched on by several authors (e.g., Crowe et al., 1983; Crowe, 1986; Wohletz, 1986; Doubik and Hill, 1999; Bechtel SAIC Company, 2004); here we focus only on the cone and the two distinct cone-building facies it preserves.

Early (Lower) Cone Facies

The early cone facies is massive to weakly bedded, dipping northward at ~20° where it was exposed on the cone's southeast flank by quarrying between 1999 and 2002; some of the bedding is vaguely lenticular over scales of meters and shows some inverse grading, typical of grain-avalanche beds. Grain size includes minor coarse ash, but is dominated by lapilli and bombs in the centimeter- to decimeter-size range (Fig. 2A). Some ribbon and spindle bombs reach a meter in length. Individual clasts have shapes ranging from

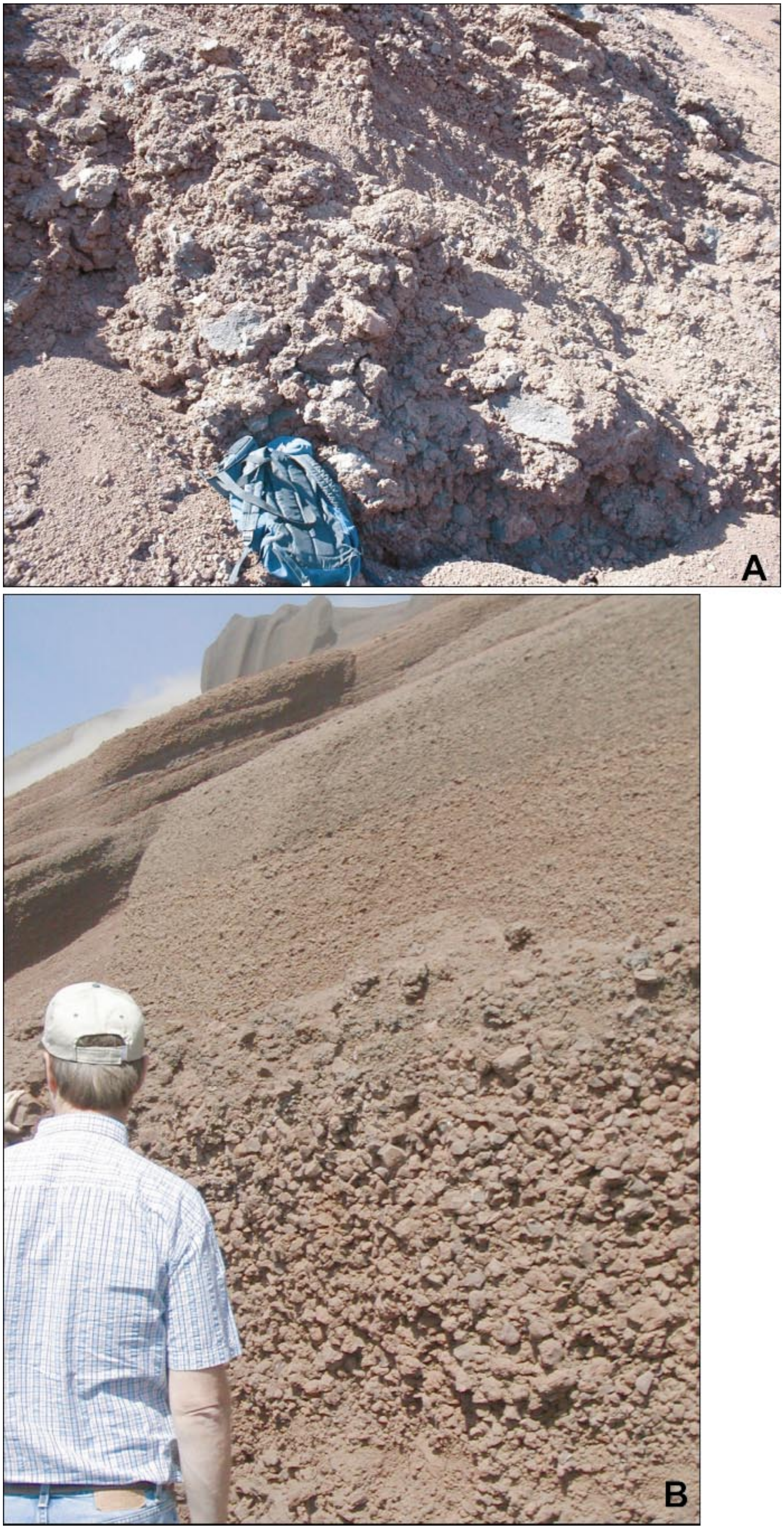

Figure 2. A: Early cone facies, consisting mainly of lapilli and bombs, partly welded, with crude bedding dipping toward right (north). Backpack is ~40 cm tall. Photo by Frank Perry. B: Upper cone facies, showing coarse-lapilli bed that is overlain by finer-grained lapilli beds; latter are well sorted and continuous both laterally and up quarry slope (parallel to original cone surface). Photo by Gordon Keating.

elongate (e.g., ribbons) to irregular to roughly equant and are generally moderately to highly vesicular; most vesicles are several millimeters in size. The deposits are moderately to poorly sorted (on the basis of visual inspection in the field) and are mainly clast supported. In addition, the deposits are partly welded, such that the early cone facies forms an indurated horizon.

Numerous mounds of pyroclastic material on the top of the south lava field all contain abundant fluidal bombs. Most of these mounds are composed of loose material, but a few are composed of weakly to completely welded agglutinate that preserves original bedding. The abundance of fluidal bombs and various degrees of welding is consistent with rafting of material from the early cone by contemporaneous lava effusion from the base of the cone, although a few of these mounds might be remnants of spatter-rich tumuli formed by local lava degassing.

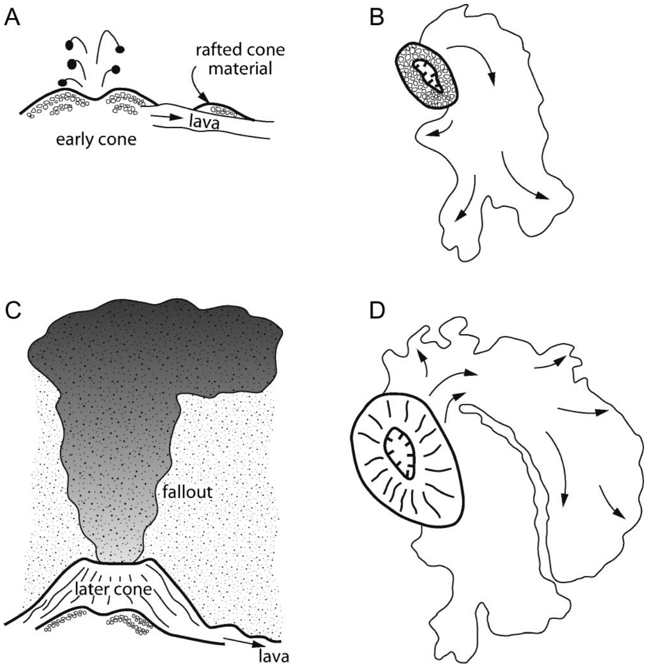

Figure 3. Inferred sequence of events at Lathrop Wells volcano. Early cone building (A) dominated by Strombolian bursts and development of concurrent lava flow (B). Later cone building dominated by fallout from sustained columns (C) and development of northeast lava field (D). This lava field is inferred to be contemporaneous with later cone building because fallout tephra are both beneath and on top of it.

Later (Upper) Cone Facies

Limited exposures of the contact between early and later cone facies are sharp, indicating a rapid change in emplacement and eruption mechanisms. The later cone facies form beds typically ∼10 cm to ∼1 m thick that dip outward from the rim (southeastward) at angles of 30°–32° in lower exposures, but shallow with height to angles of ∼20° near the rim, and then dip inward inside the crater (Bechtel SAIC Company, 2004). Some beds have geometries and features indicative of emplacement by grain avalanching; e.g., they are lenticular over meters of distance (with local evidence for erosion into underlying deposits) and/or have clear reverse grading and clast-supported, coarse lenses typical of granular flows.

Other beds have characteristics that seem to be more typical of direct deposition by fallout from sustained eruption columns. These characteristics include planar top and bottom contacts, good sorting, massive to planar-stratified internal structure, and continuity of beds and their grain size and structure both upward toward the crater rim and horizontally along quarry faces over distances of at least tens of meters (limited by exposure). The coarse lapilli and small block bed in the lower half of Figure 2B is laterally continuous over at least 50 m along the full length of a quarry face, with continuous internal stratification of zones of slightly coarser- or finer-grained clasts consistent with deposition by fallout; local lenses of coarse clasts indicate some concurrent avalanching of large fragments. The finer-grained beds that overlie it are quite continuous and planar, even in detailed internal stratification, as they extend upslope.

Most clasts in the later cone facies are highly vesicular and blocky to elongate in shape, with angular edges. Many of these clasts are likely fragments of recycled coarser clasts that avalanched into the vent and were re-ejected. Compared with the early cone deposits, fluidal bomb shapes are rare in the later cone facies. Grain-size characteristics of individual beds vary from coarse lapilli and bombs to beds that are dominated by small lapilli and ash. Coarser-grained beds have open frameworks. Lithic clasts are sparse, typically $\ll$1% of the volume of individual beds (Bechtel SAIC Company, 2004).

The craters and rims of many scoria cones are characterized by coarse material and abundant welded spatter or agglutinate (e.g., Wood, 1980). In contrast, the deposits at the top and in the crater of the cone at Lathrop Wells volcano are composed entirely of loose scoria ash, lapilli, and small blocks and/or bombs characteristic of the late cone facies. Approximately 6 m below the summit, there is a 40-cm-thick stratified and cross-stratified ash and coarse ash deposit that is sandwiched conformably between massive scoria beds such as those described here, and that pinches out laterally over a distance of ∼40 m. The bedding structures within the ash deposit are indicative of deposition from a weak density current such as a pyroclastic surge (e.g., Valentine and Fisher, 2000). The western rim of the cone and the ground at the base of this sector of the cone are littered with some decimeter-sized blocks that record the final explosive event from the main cone. These blocks are mainly composed of welded fragments of relatively dense, angular basalt breccia and agglutinate, and probably resulted from a late-stage steam explosion that disrupted and ejected part of a solidified conduit plug.

INTERPRETATION AND SUMMARY

The lower, early cone facies exhibits characteristics that are relatively consistent with the McGetchin et al. (1974) model, as depicted in Figures 3A and 3B. It is relatively coarse grained (coarse lapilli and bombs) and contains abundant fluidal bombs that followed individual ballistic paths. The clasts' flight times were not long and the clasts were therefore sufficiently hot to weld upon deposition. There is some evidence for grain avalanching in these deposits, but as described here, the dips we measured on crude bedding interfaces are ∼20°, substantially less than the ∼30°–32° that is associated with grain-avalanche–maintained angle of repose for loose scoria. It is possible that the deposits we observed were produced during the earliest phase of cone building in the McGetchin et al. (1974) model (stage 1 in their Fig. 14).

The upper cone facies seems to record cone-building processes significantly different from the McGetchin et al. (1974) model in that construction was dominated by the accumulation of fallout deposits from sustained, well-fragmented eruption columns (Figs. 3C, 3D). Consistent with one of the fundamental characteristics of fallout, these deposits mantled the cone slopes. On occasion, the slopes would become oversteepened, and there would be minor avalanching to maintain the angle of repose, but most of the deposits are essentially in situ fallout beds. The shallowing of bedding dips upward in the cone is consistent with fallout mantling a cone rim. Localized deposits of weak pyroclastic surges are consistent with very local, partial collapse of ash-rich portions of an eruption column (Taddeucci et al., 2004). The important role of fallout from sustained, finer-grained eruption columns for construction of scoria cones, in addition to the processes described in the McGetchin et al. (1974) model, was discussed in detail by Riedel et al. (2003); the Lathrop Wells cone provides an excellent example where deposit facies and field observations support this broader view of cone construction.

We infer that the tephra fallout blanket that covers some of the terrain around the volcano resulted from the same eruptions as the later cone-building facies. The abundance of tachylite of 22%–77% (compared with sideromelane; Bechtel SAIC Company, 2004) in the ash fraction of these deposits provides a mechanism by which the effective viscosity of the magma is increased by the presence of abundant microlites, relative to pure melt (e.g., see Heiken, 1978). This increased viscosity would cause the basaltic magma to behave in a manner akin to silicic magmas in that the higher viscosity prevents the rise of bubbles with respect to magma as well as coalescence to form larger bubbles, as in pure Strombolian behavior. Instead, the microlite-rich magma results in an abundance of small bubbles (possibly enhanced if the microlites act as bubble-nucleation sites) that produce a highly fragmented eruption column. The resulting finer particle sizes are able to effectively transfer heat with entrained air in the eruption column, promoting a high (on the order of a few kilometers) column from which clasts deposit by fallout after a long flight time that allows for extensive cooling (and hence the absence of welded deposits; recycling of pieces of previously erupted bombs, which we view as minor but has not been quantified, would also provide a source of solidified, cooled clasts that would not weld when redeposited). Microlite growth might reflect cooling of the magma column when the vent was choked by grain avalanches (e.g., Heiken, 1978) and/or by a decrease in magma flow rate (e.g., Taddeucci et al., 2004).

ERUPTIVE TERMINOLOGY

There is some ambiguity in terminology for mafic scoria cone-forming eruptions, and this might partly be the result of application of the term Strombolian to include explosions ''separated by periods of less than 0.1 seconds to several hours'' (Blackburn et al., 1976 p. 429). Explosions separated by less time than a characteristic roll-over time for large eddies near the base of an eruption column will have their individual signals or impulses swamped out by turbulence such that above some height the column will behave as if it had a steady source, therefore, very high explosion frequencies will depart from classical Strombolian behavior and resulting facies. Parfitt (2004) and Riedel et al. (2003) argued that this is a transition toward Hawaiian or sub-Plinian dynamics, depending upon grain size, which in turn relates to clast dispersal and in-flight cooling (i.e., welding or lack thereof). The term violent Strombolian has been used by some in reference to these eruptions, which correctly implies a smaller scale (eruptive volume and eruption column height) than is associated with sub-Plinian eruptions (e.g., Sparks et al., 1997; Arrighi et al., 2001).

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