Possible Role of Eolian Sediment in the Genesis of Bouldery Debris-Flow Deposits on the Lower Flanks of Ute Mountain, Northern Taos Plateau Volcanic Field, New Mexico

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CHAPTER I

Introduction

Runoff produced by high-intensity rainfall events on steep slopes in alpine to semiarid areas of the western United States locally generates stream flows, hyperconcentrated flows, and debris flows (for example, Meyer and Wells, 1997; Cannon, 2001; Godt and Coe, 2007). The flow properties of these water-sediment mixtures vary chiefly with sediment concentration, size, and sorting (Costa, 1984; Pierson and Costa, 1987). Stream flows are fully turbulent Newtonian flows (water-sediment mixtures) that exhibit flow behavior unaffected by the low concentration of sediment in transport (Meyer and Wells, 1997; Pierson and Costa, 1987). Hyperconcentrated flows are non-Newtonian flows that appear to flow like a liquid but exhibit low yield strength (resistance to flow) and dampened turbulence, owing chiefly to abundant sediment in transport (Pierson and Costa, 1987). Sediment transported by both stream flow and hyperconcentrated flow moves as separate components carried in suspension by fluid lift and in traction by fluid drag (Costa, 1984), and it can be selectively deposited as a result of decrease in velocity or flow depth (Bull, 1972). Stream-flow deposits commonly are poorly to well sorted, clast supported, and crudely stratified (for example, Meyer and Wells, 1997). Hyperconcentrated-flow deposits have sorting and bedding characteristics intermediate between those of stream-flow and debris-flow deposits (for examples, Pierson and Costa, 1987; Meyer and Wells, 1997), and they commonly consist of poorly sorted granules to boulders in an abundant sandy matrix low in silt- and clay-sized particles (Meyer and Wells, 1997; Cannon, 2001). Debris flows, in contrast, are non-Newtonian flows composed of intergranular fluid and high concentrations of sediment that move as a single phase and exhibit considerable yield strength. They can travel long distances on low slopes and do not separate into solid and liquid phases at the time of deposition (Costa, 1984). Debris-flow deposits commonly are unsorted to very poorly sorted and matrix supported, and they lack internal stratification (for example, Meyer and Wells, 1997).

Fan Deposits at Ute Mountain

Coalescing fan deposits of three age groups form an extensive (about 40 km^2) piedmont apron (or bajada) that surrounds Ute Mountain, the northernmost intermediate-composition volcano of the Taos Plateau volcanic field (fig. I–1). The fan apron commonly is about 0.5–3 km wide, has average slopes of about 2.5°–5.5°, and is slightly incised by a network of shallow ephemeral stream channels that radiate outward from Ute Mountain. Younger fan deposits (unit Qf3) are more extensive on the east and southeast sides of Ute Mountain, whereas intermediate-age and older fan deposits (units Qf2 and Qf1, respectively) are more extensive on the southwest side (fig. I–2). Stage I and II carbonate morphology on clasts in younger fan deposits suggests that these deposits accumulated during the Pinedale and Bull Lake glaciations (Machette, 1985, table 2). These fan deposits probably formed under pluvial climatic conditions associated with these glaciations, which occurred about 12 to >30 ka and 120–170 ka, respectively (Pierce, 2004, and references cited therein). Older fan deposits locally overlie higher, older stream alluvium (unit Qao1). These latter deposits predate major downcutting of the Cañon del Rio Grande, which is interpreted to have occurred after about 440 ka (chapter G and field trip day 3, this volume).

Ute Mountain, which rises to an elevation of about 3,080 m, consists of eroded monolithologic dacite domes, flows, and spires that are locally cut by radial dikes. Clasts (granule-sized and larger particles) in the fan deposits are composed of dacite eroded from Ute Mountain as well as a minor amount of olivine andesite eroded from several small outcrops that locally protrude through the fan deposits near the base of Ute Mountain. These lithologies weather chiefly by physical processes, which produce only a minor amount of sand-sized and finer particles that can be incorporated into the matrix of debris-flow and other surficial deposits.

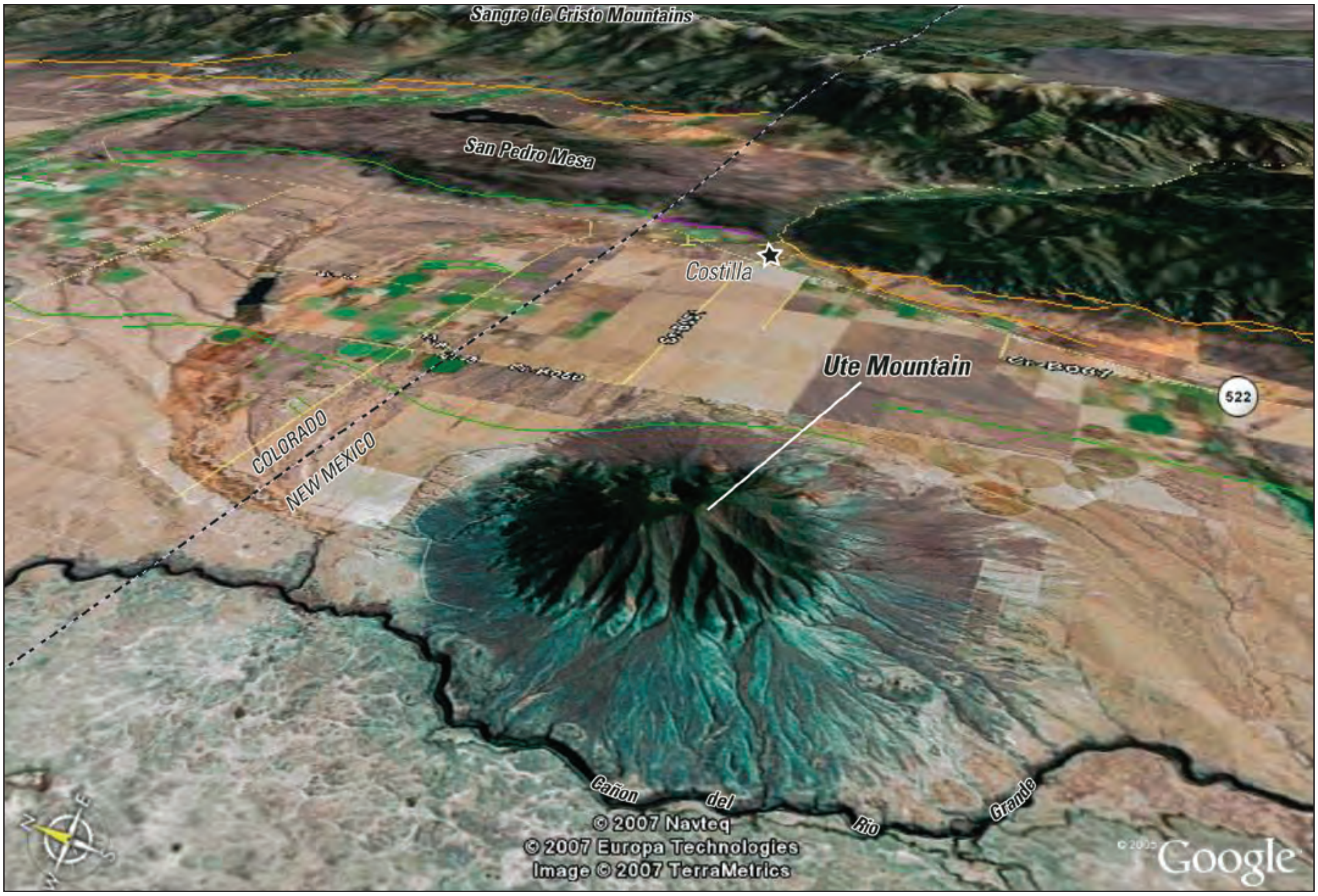

Figure I–1. Oblique aerial view toward the east-northeast of Ute Mountain and adjacent area. Image was obtained from Google Earth. For scale, the distance along the Colorado–New Mexico state line between the Rio Grande and the western margin of San Pedro Mesa is 19 km. Superimposed orange and green lines show locations of mapped faults at the base of San Pedro Mesa and the Sangre de Cristo Mountains. Any use of product, trade, or firm names is for informational purposes only and does not imply endorsement by the U.S. Government.

Fan deposits are locally exposed in small, shallow, widely spaced stream cuts near the lower limit of the fan apron. Grain-size and sorting characteristics of these deposits suggest that they consist of debris-flow deposits along with a subordinate amount of stream-flow (water-laid) deposits within incised channels. Some of the fan deposits probably are hyperconcentrated-flow deposits, because sediment transport at Ute Mountain likely possessed a wide continuum of water-sediment concentrations. Some of the debris-flow deposits on the fan apron probably were eroded by more-fluid late-stage flows and by subsequent sediment-deficient stream flows.

The primary factors that determine flow processes on fans are grain size and areal extent of readily erodable sediment on slopes and in channels (Meyer and Wells, 1997), such as those at Ute Mountain. Much of the sediment in the fan deposits probably was derived from mass-movement deposits on slopes and flash-flood deposits in channels that were mobilized and transported from small (≤1.1 km^2), steep (about 10°–20°) drainage basins on the upper flanks of Ute Mountain by runoff produced by high-intensity and high-volume rainfall events.

Debris-flow deposits near the lower limit of the fan apron commonly consist of unsorted to very poorly sorted, matrix-supported material. Many of the deposits are slightly bouldery and contain abundant cobbles and pebbles; some deposits consist of cobbles and pebbles supported in an abundant sand matrix. Boulders are angular to subangular and commonly 30–90 cm long. Boulders probably decrease in size downslope on the fan apron (Bull, 1972, and references cited therein) and they probably decrease in relative abundance downslope. Clasts make up about 20–70 percent (by volume) of the deposits. Matrix (sand and finer particles) makes up about 30–80 percent (by volume) of the deposits, and it commonly consists of slightly silty to silty, mostly very fine to medium sand and locally very fine to fine sand. These debris-flow deposits form laterally extensive, lobate bodies about 0.5–2 m thick that lack levees. Levees commonly form on debris-flow deposits that have a relatively high content of boulders (Blair and McPherson, 1998; Blair, 1999a); those near the lower limit of the fan may lack sufficient boulders to form levees. In addition, surface features such as levees may have been muted or obscured by subsequent erosion or deposition of sheetwash deposits.

Shallow ephemeral streams generated chiefly by sediment-charged flash floods deposited many of the stream-flow deposits and probably hyperconcentrated-flow deposits. Near the lower limit of the fan apron, stream-flow deposits commonly consist of poorly sorted, clast-supported, nonbouldery to slightly bouldery gravel that contains abundant cobbles and pebbles. Boulders are subangular and commonly 30–50 cm long. Clasts make up about 80–90 percent (by volume) of the deposits. Matrix makes up about 10–20 percent (by volume), and commonly it consists of very slightly silty, very fine to very coarse sand that locally contains abundant granule-sized particles. Deposits of coarse, open-worked gravel, such as sieve deposits (Hooke, 1967) and boulder berms (Costa, 1984) or boulder jams (Blair, 1987), were not observed but may be locally present in the upper part of the fan apron. Debris-flow and other fan deposits are locally mantled by sheetwash deposits a few tens of centimeters thick. These latter deposits consist of pebbly, plastic, silty, mostly fine to medium and locally very fine to fine sand. The matrix of these deposits may be derived in part from eolian sand. Features characteristic of upper-flow regime sheetflood processes, such as stacked gravelly and sandy couplets and up-fan sloping (antidune) deposits (Blair, 1987, 1999b), were not observed.

Genesis of Debris-Flow Deposits at Ute Mountain

The dacite and minor andesite bedrock at Ute Mountain weather chiefly by physical processes, which produce mostly granule-sized and larger particles. It is likely that these lithologies contribute only a minor portion of the sand and finer particles (about 30–80 percent by volume) in the debris-flow deposits near the lower limit of the fan apron. We suspect that reworked silty eolian sand and silt-rich eolian sediment (loess) are locally important components of the matrix of the debris-flow deposits at Ute Mountain and that they play a key role in the genesis of these deposits. The matrix of these debris-flow deposits is similar in grain size and mineralogy to that of reworked (slightly pebbly) deposits of eolian sand rich in quartz and feldspar that locally underlie some of the debris-flow deposits near the lower limit of the fan apron. The grain size and mineralogy of the <2 mm-sized fractions of reworked eolian sand are similar to those of deposits of silty sand exposed in small nearby outcrops of the upper Santa Fe Group (fig. I–2). Therefore, it is likely that some or much of the silty sand within and below the debris-flow deposits may be reworked by eolian processes from deposits of silty sand in the upper Santa Fe Group. Thick (>3 m) silt-rich deposits, probably loess reworked by sheet flow, are locally present on slopes above washes near the upper limit of the fan apron. Likewise, these silt-rich deposits may also be derived from deposits of the upper Santa Fe Group. These silt-rich deposits consist of slightly sticky, very plastic, slightly sandy silt that contains a minor amount (≤10 percent by volume) of dacite clasts about 0.5–20 cm long. These deposits likely contribute matrix material to the debris flows as well.

Many field and laboratory studies indicate the importance of silt- and clay-sized particles in the genesis of debris flows (for example, Meyer and Wells, 1997; Cannon, 2001; Godt and Coe, 2007; and references cited in these reports). The amount of fine-grained matrix need not be large; for example, the <2-mm-sized fractions of some debris-flow deposits consist of only about 14–16 percent silt (0.5–0.002 mm) and 0–5 percent clay (<0.002 mm) (Cannon, 2001). Primary or reworked deposits of eolian sediment, such as those at Ute Mountain, (1) would retard infiltration and thus promote storm runoff and overland flow on hillslopes, (2) are easily eroded by runoff-related processes, and (3) could be readily entrained within fluid flows by means of progressive sediment bulking and could serve as fine-grained matrix material that promotes the support and transport of granule- to boulder-sized clasts. Silt- and clay-sized particles derived from eolian sediments would help to sustain high pore-fluid pressures in debris-flow slurries (Iverson, 1997, 2003; Meyer and Wells, 1997). High pore-fluid pressures, in turn, would reduce viscosity and internal friction as well as promote flow mobility (Pierson and Costa, 1987; Iverson, 1997). Sediment entrained by overland flow is a dominant mechanism for initiating debris flows and generating debris-flow deposits in steep terrain of the western United States (for example, Meyer and Wells, 1997; Cannon, 2001; Godt and Coe, 2007), and local debris flows may be a dominant mechanism at Ute Mountain.

In addition, the relatively high moisture-holding capacity of primary or reworked loess may locally promote the development of small, thin (≤1 m), infiltration-triggered landslides and small debris flows at Ute Mountain similar to those investigated by Godt and Coe (2007).

Acknowledgments

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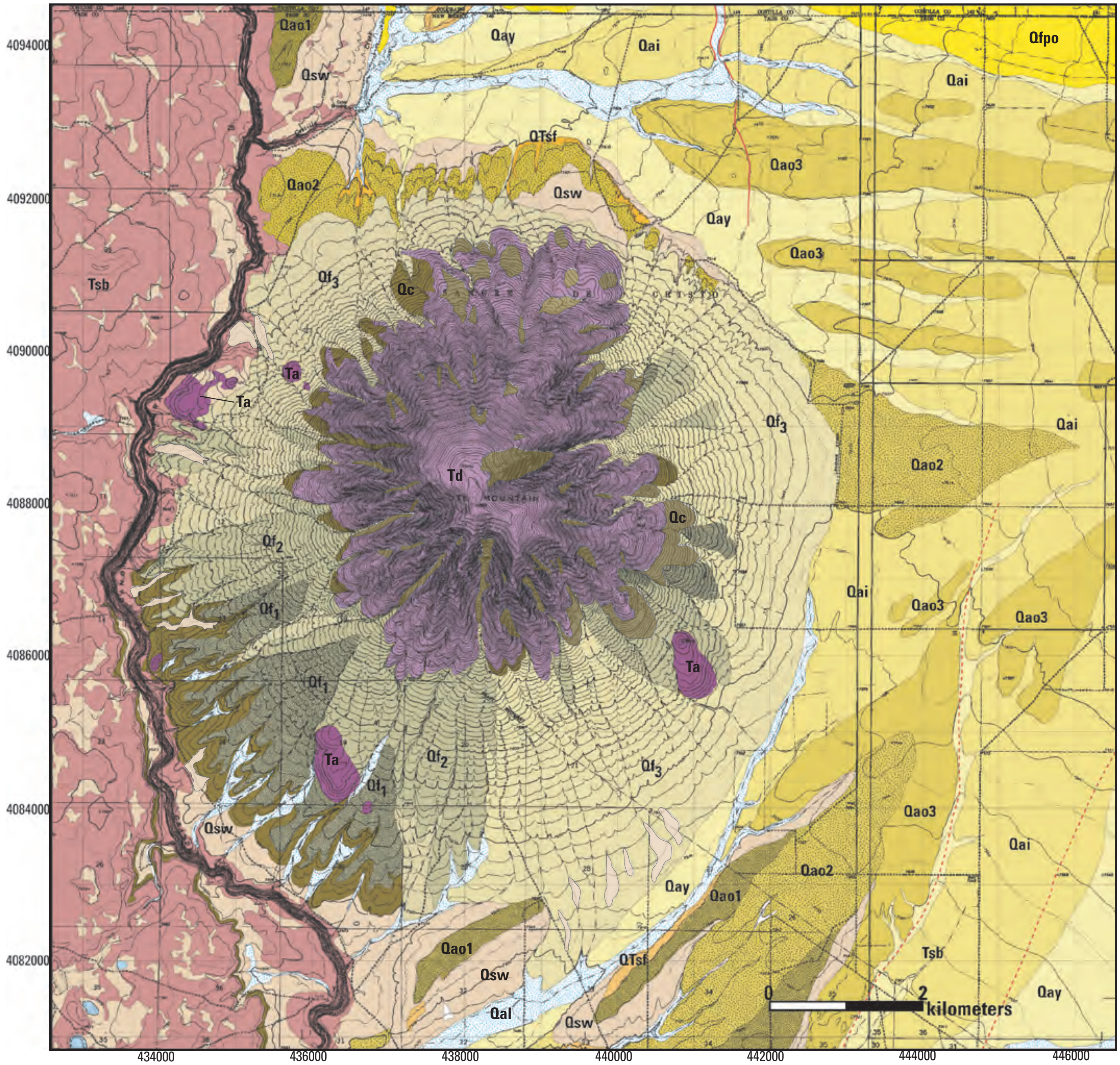

Figure I–2. Generalized geologic map of Ute Mountain and adjacent area. Map units and their known or inferred ages are as follows: Qa, stream alluvium in active channels and flood plains (late Holocene); Qfpo, older flood-plain alluvium (Holocene); Qay, younger stream alluvium (Holocene and late Pleistocene); Qsw, sheetwash deposits (Holocene and late Pleistocene); Qc, colluvium, undivided (Holocene and late Pleistocene); Qf3, younger fan deposits (late and middle Pleistocene); Qai, intermediate-age stream alluvium (middle Pleistocene); Qf2, intermediate-age fan deposits (middle Pleistocene); Qf1, older fan deposits (middle Pleistocene); Qao3, lower older stream alluvium (middle Pleistocene); Qao2, intermediate-height older stream alluvium (middle Pleistocene); Qao1, higher older stream alluvium (middle Pleistocene); QTsf, upper Santa Fe Group (middle Pleistocene to middle (?) Pliocene); Td, dacite (late Pliocene); Tsb, Servilleta Basalt (early Pliocene); Ta, andesite (early? Pliocene). Red lines show locations of known (solid) and inferred (dotted) faults.

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