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Temporal and spatial climatic controls on Holocene fire-related erosion and sedimentation, Jemez Mountains, New Mexico

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ABSTRACT

In the Jemez Mountains, tree-ring data indicate that low-severity fires characterized the 400 yr before Euro-American settlement, and that subsequent fire suppression promoted denser forests, recent severe fires, and erosion. Over longer timescales, climate change may alter fire regimes; thus, we used fire-related alluvial deposits to assess the timing of moderate- to high-severity fires, their geomorphic impact, and relation to climate over the last 4000 yr. Fire-related sedimentation does not clearly follow millennial-scale climatic changes, but probability peaks commonly correspond with severe drought, e.g., within the interval 1700–1400 cal yr BP, and ca. 650 and ca. 410 cal yr BP. The latter episodes were preceded by prolonged wet intervals that could promote dense stands. Estimated recurrence intervals for fire-related sedimentation are 250–400 yr. Climatic differences with aspect influenced Holocene post-fire response: fire-related deposits constitute 77% of fan sediments from north-facing basins but only 39% of deposits from drier southerly aspects. With sparser vegetation and exposed bedrock, south aspects can generate runoff and sediment when unburned, whereas soil-mantled north aspects produce minor sediment unless severely burned. Recent channel incision appears unprecedented over the last 2300 yr, suggesting that fuel loading and extreme drought produced an anomalously severe burn in 2002.

Introduction

The Jemez Mountains host a diverse ecosystem, highly valued natural resources, and important cultural, recreational, and scientific sites. All have been directly impacted by severe fires within recent decades, and the associated erosion and sedimentation generate additional concerns (Orem and Pelletier, 2015). These severe and extensive fires have been attributed to human activities following Euro-American settlement that increased forest densities, including livestock grazing, logging, and fire suppression (e.g., Allen et al., 2002). In the interior western USA, however, warming climate and earlier spring snowmelt have also contributed to increased burn area and fire severity, and are the dominant factors in high-elevation and northern Rocky Mountain forests (e.g., Meyer et al., 1992; Pierce et al., 2004; Westerling et al., 2006; Bigio et al., 2010).

Documentation of fire and erosion over long timescales can provide insights into the influence of past climates on these phenomena, under limited human impacts. Tree-ring fire-scar chronologies have provided high-resolution records of low-severity fire in the Jemez Mountains over the past ca. 400 yr (Touchan et al., 1996; Allen, 2001; Allen et al., 2008), and charcoal content in bog sediments has shown broad relative changes in fire activity over the past 8000 yr (Allen et al., 2008; Anderson et al., 2008). However, further Holocene-scale records are needed to understand long-term climatic influences on fire, in particular high-severity fires (i.e., those with high soil burn severity; Parsons et al., 2010). Such fires often result in major hillslope and channel erosion, and debris-flow and flash-flood sedimentation on alluvial fans (Meyer and Wells, 1997; Cannon, 2001). Therefore, we developed a chronology of fire-related alluvial fan sedimentation over the last 4000 yr to test whether climate variations promoted the occurrence of severe fire and enhanced erosion and sedimentation (e.g., Meyer et al., 1995), and whether recent fires are anomalous in their severity and geomorphic effects.

An important consideration in understanding relations among Holocene fire, climate, and erosion in the study area is whether contrasts in microclimate with aspect could result in significant differences in fire and erosional response. Drier south-facing (equatorward) slopes are dominated by open ponderosa pine stands, with generally thin soils and substantial areas of exposed bedrock. In contrast, north-facing (poleward) slopes feature denser mixed-conifer forests that are more susceptible to infrequent high-severity fires (Allen et al., 1995), but also have a thicker, largely continuous mantle of soil and colluvium that can absorb runoff when unburned. Given these contrasts, the nature of Holocene fire-related sedimentation and its relation to climate may differ substantially with aspect. We address these questions by comparing the depositional processes and timing of fire-related

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sedimentation in north-facing and south-facing basins, as well as the relative proportion of fire-related deposits identified in alluvial fans from both aspects.

Study area

The Jemez Mountains in north-central New Mexico stand as a broad range surrounding a central caldera complex, which formed over two major periods of volcanic activity in the last two million years (Doell et al., 1968; Izett et al., 1981). Mesas capped by 1.15 Ma welded Bandelier Tuff slope gently away from the Valles Caldera rim and are incised by narrow canyons (Fig. 1). This variably welded, rhyolitic ash-flow tuff underlies slopes in the study area (Kelley et al., 2004) and tends to weather to predominantly silt to pebble-sized sediment, along with larger clasts up to boulder size. The study area covers about 4.5 km^2 (450 ha) between about 2370 and 2670 m elevation, and is centered on an unnamed drainage west of the Valles Caldera, between Barley Canyon and Lake Fork Canyon. This 5-km-long canyon contains New Mexico Highway 126, and is herein termed “NM 126 Canyon”. The study area lies within the perimeter of the August 2002 Lakes Fire, which burned at moderate to high severity and was spurred by exceptionally severe summer drought conditions in northern New Mexico (http://droughtmonitor.unl.edu/mapsanddata/maparchive.aspx, accessed 30 August 2015).

NM 126 Canyon trends east–west, with largely north- and south-facing sideslopes, and contrasts in slope characteristics with aspect are striking. On average, south-facing slopes are about 5° steeper than north-facing slopes in this and adjacent valleys (Paulo de Sa' Rego, written communication, 2012) an asymmetry apparent in the map of Poulos et al. (2012) and noted elsewhere in the region where soil moisture plays a strong role in bedrock weathering (Burnett et al., 2008). Steep exposed bedrock is more common on rugged south-facing slopes, which typically display a thin and discontinuous colluvial cover. Storm runoff from bedrock surfaces can entrain abundant sediment from colluvium at cliff bases, a process termed the “firehose effect” (e.g., Melis et al., 1994). A thicker, more continuous soil and colluvial mantle characterizes north-facing slopes, which have a generally smooth, curvilinear form. Ephemeral tributaries draining both canyon sides have built small alluvial fans on the main valley floor, and most fan feeder channels also contain alluvial fill. These alluvial sediments include fire-related deposits that are the primary focus of this study. After the 2002 Lakes Fire (Fig. 1), hillslopes locally displayed rills, and some alluvial fans and channels underwent major post-fire deposition and (or) incision that exposed stratigraphy. The incised channel in lower NM 126 Canyon reveals an alluvial fill at least 3 m thick.

Forest cover in the Jemez Mountains ranges from pure ponderosa pine (*Pinus ponderosa*) to mixed-conifer stands that include mainly Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and Engelmann spruce (*Picea engelmannii*), with local aspen groves (*Populus tremuloides*) (Allen et al., 1995; Touchan et al., 1996). In the study area, ponderosa pine dominates south aspects, and mixed-conifer and aspen stands cover north aspects, as is widely observed in the Jemez Mountains (Allen et al., 2008). The study area has likely seen a broadly similar distribution of tree species over the late Holocene (Anderson et al., 2008). A rapid upward shift of the ponderosa pine to piñon-juniper ecotone in the Jemez Mountains during the severe

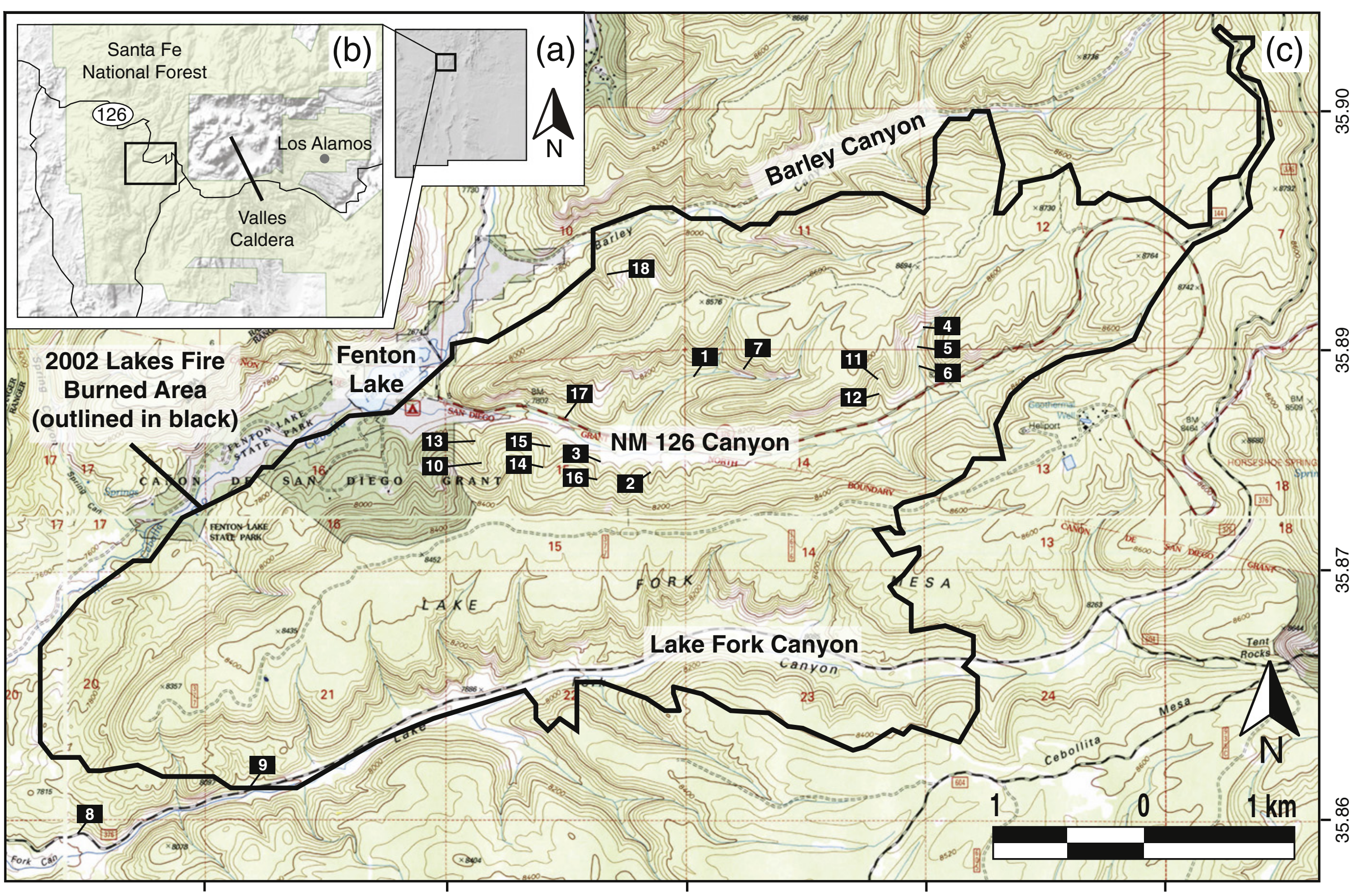

Figure 1. Study area maps showing (a) location of map in b within New Mexico, USA, (b) location of the study area within the Santa Fe National Forest west of the Valles Caldera, and (c) topographic map of the study area from USGS Seven Springs and Jemez Springs 7.5 minute quadrangles; contour interval 40 ft (12.2 m). Station locations are indicated by numbered black boxes.