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HOLOCENE FIRE-RELATED ALLUVIAL CHRONOLOGY AND GEOMORPHIC IMPLICATIONS IN THE JEMEZ MOUNTAINS, NEW MEXICO

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by

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THESIS

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ABSTRACT

In fire-prone areas, the geomorphic effects of fire are influenced by fire frequency and severity (i.e. fire regime) and can play a significant role in hillslope evolution. In the Jemez Mountains, tree-ring fire history reconstructions indicate that low-severity fire regimes characterized the ~300 years before Euroamerican settlement, and that human impacts contributed to increased fire severity in recent years. However, other work in the western USA has revealed past episodes of severe fire in similar forest types, therefore, Holocene fire regimes in the Jemez Mountains may also have varied. This work utilized fire-related alluvial fan deposits to assess fire activity, severity and geomorphic response to fire over millennial timescales. It was found that fire activity in the study area may have been influenced by shifts in climate, such that frequent, low-severity fires are promoted by less variable climatic conditions, whereas severe fire may be more likely in forest stands that underwent longer-term wetter than average conditions followed by severe drought. In particular, peaks in fire-related sedimentation occur during severe regional multidecadal droughts around 1800 and 375 calendar years BP. The study area likely experienced somewhat more severe fire events during the parts of the late Holocene than during the period of the pre-Euroamerican tree-ring record.

The study area also displays evidence of slope aspect controls on weathering and slope form. These differences may influence the processes and spatial distribution of fire-related erosion and sedimentation in the study area. Morphometric analysis of north and south-facing alluvial fan basins show no clear differences in fan depositional process

among these aspects. However, it was found that north-facing alluvial fans are dominated by fire-related sedimentation (77% of stratigraphic thickness measured), but fire-related deposits only make up 39% of the total thickness of south-facing fans. Therefore, it may be that with much greater exposed bedrock and sparser vegetation, south-facing slopes generate substantial runoff and sediment in the absence of fire, whereas denser vegetation and thicker colluvium mean that north-facing slopes produce relatively little fan sedimentation unless impacted by fire. Overall, fire is clearly an important control on geomorphic process in the Jemez Mountains.

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INTRODUCTION

The Jemez Mountains have produced severe fires during modern times which have had broad effects on the forest ecosystem and increased threats to human structures. Climate in the western USA (e.g., Meyer et al., 1992; Pierce et al., 2004; Bigio et al., 2010) and human impacts on forest structure in the Jemez Mountains, such as livestock grazing and fire suppression (e.g., Allen, 2001), have both been implicated as dominant causes of unusually high fire severity in recent times. However, other work in the western USA suggests that a change in fire regime, over millennial timescales, is not unprecedented and therefore, although humans have impacted the Jemez Mountains, climate may also be influencing fire regime (Meyer et al., 1992; Pierce et al., 2004; Frechette and Meyer, 2009).

Fire regime includes the spatial pattern, frequency and severity of wildfires. However, for this work factors such as severity and frequency are most applicable in defining and discussing fire regime. Fire severity is a qualitative indicator of the effects of fire on an ecosystem, including fuel type, soil conditions before a fire, energy released during the fire, and the subsequent visible effects after a fire. As a general comparison, fuel for low-severity fires may only include duff and grasses, but severe fires may encompass fuel types ranging from duff to canopy material.

Although the Jemez Mountains have been inhabited in the prehistoric Southwest, it is unlikely that humans played much of a role in altering fire regime on a large scale before the 1880s (Allen, 2002). In the study region, modern humans introduced domestic livestock which tended to keep fine fuel and ladder fuel loads down (Covington and Moore, 1994) but likely avoided saplings. This allowed saplings to grow denser thickets than before, introducing a forest structure which could promote a laddering effect and severe fire. Human efforts to suppress natural fire led to the maturity of these denser forest stands and ultimately an increase in ladder fuels in areas where livestock do not frequent, therefore altering forest structure from open park-like conditions to denser, overgrown thickets (Covington and Moore, 1994; Swetnam and Baisan, 1996)

As a result of recent severe fires in the Jemez Mountains, it has been suggested that efforts should be made to reduce recent human impacts and reintroduce low-severity fire in order to restore ponderosa pine forests to a more natural fire regime, based on current climate (Allen et al., 2002; Swetnam and Baisan, 1996). Tree-ring fire scar chronologies for the Jemez Mountains suggest that frequent, low-severity fires have been dominant over severe fires for the most recent ~400 years, the extent of the scar record (Allen, 2001; Touchan et al., 1996). However, tree-ring fire scar records tend to favor the recording of low-severity fires, due to the likelihood that an individual tree is more likely to survive these events, while also recording the occurrence of fire, as opposed to severe fires which may destroy the tree and therefore, a clear record of severe fire activity. Additionally, Allen et al. (2008) obtained a fire history for the Jemez Mountains over 15,000 years from bog cores, however, due to complications associated with interpreting the bog core results, they suggest focusing primarily on relative changes in fire episode frequency from bog cores. Therefore, a method such as alluvial chronology (e.g., Meyer et al., 1995), which can provide results with moderate resolution on a millennial timescale, may allow the present to be better compared to the past.

Fire is a well-known geomorphic agent in mountain regions (e.g., Shakesby and Doerr, 2006). In the Jemez Mountains, fire has been responsible for accelerated hillslope erosion and alluvial fan sedimentation, especially after severe fires (e.g., Allen, 2001, Cannon et al., 2001) including the 2002 Lakes Fire in the study area (Jemez Watershed Group, 2005). Slope aspect has also been noted as a potentially important spatial control on fire frequency (e.g., Taylor and Skinner, 2003; Heyerdahl et al., 2001) and hillslope processes in the southwestern USA (Burnett et al., 2008). The study area (Figure 1) displays Douglas-fir dominated north-facing slopes that are generally less steep than ponderosa pine dominated south-facing slopes, which suggest that slope aspect may influence post-fire erosion and sedimentation patterns in the Jemez Mountains.

Therefore, it is important to study the relationship between climate, fire regime (e.g. fire frequency and severity) and geomorphic processes over millennial timescales, in order to better understand the natural variability of fire regime and geomorphic response in the absence of major human impacts. Although the primary purpose of this work is to provide a baseline survey to fill the gaps in knowledge previously discussed, this work aims to do so by testing the following hypotheses. It is hypothesized that climate variations have caused episodes of severe fire activity and enhanced geomorphic response to fire in the late Holocene, independent of significant human influence. Additionally, it is hypothesized that, independent of larger climate controls, north-facing slopes have denser forest stands with fewer, more severe fires, and a thicker cover of erodible weathered material, therefore promoting post-fire debris flows. Additionally, it is hypothesized that steeper south-facing slopes are characterized by less weathered and commonly exposed bedrock, open ponderosa pine stands, less severe fires, and smaller but more frequent sedimentation events dominated by more dilute flows, even in the absence of fire.

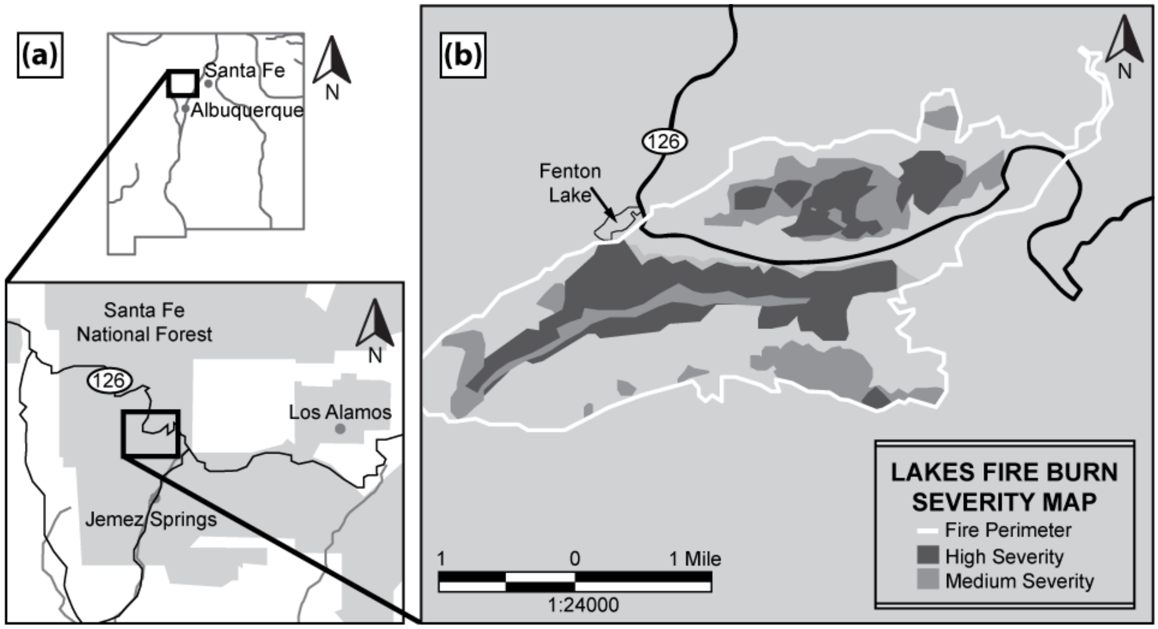

Figure 1. (a) The Lakes Fire area is located in the Santa Fe National Forest, New Mexico. Location of the study area within New Mexico and the Santa Fe National Forest is indicated by the red rectangles. (b) Lakes Fire burn severity map which shows the outline of the Lakes Fire burned area (Adapted from a burn severity map provided by Craig Allen, USGS, from the BAER Imagery Support program).

STUDY AREA

GEOLOGY AND GEOMORPHOLOGY

The Jemez Mountains volcanic field makes up a topographically distinct region in north-central New Mexico. This large edifice lies at the southern tip of the Rocky Mountains, west of the San Juan Basin and Colorado Plateau. However, the long-term, large-scale building of this edifice beginning ~15 Ma is likely associated with regional zones of crustal weakness within the boundaries of New Mexico: the western margin of the Rio Grande rift and the Jemez lineament (Price, 2010). The Jemez Mountains are located at the intersection of these two relatively linear zones and were built by eruption styles ranging from passive basaltic eruptions to extremely explosive silicic eruptions (Price, 2010). The study area is situated west of the Valles Caldera (Figure 1). The main canyon in the study area is an unnamed drainage around 5 km long which lies between Barley Canyon and Lake Fork Canyon, and contains Highway NM 126. This unnamed canyon will hereby be referred to as "NM 126 Canyon". All three canyons drain into the Rio Cebolla, with the main canyon draining first into Fenton Lake, and they display a similar general morphology. Within these canyons and the three other canyons to the north, south-facing slopes were found to be 5° steeper than north-facing slopes, on average (Paulo de Sa' Rego, 2012, personal communication).

Although the main canyon contains six mapped tributaries 0.6 to 1.8 km long, many of the study sites are located within unmapped tributaries with ephemeral flow. Based on observations over 2011, during most of the year, only the axial channel of the main canyon is active and likely achieves the majority of its dry season flow through base flow. The axial channel floodplain is only 130 m at its widest and there is a high likelihood that alluvial fan and floodplain deposits interfinger extensively in the main canyon.

The bedrock underlying the study area (Figure 2a) is composed of upper (Tshirege member) and lower (Otowi member) Bandelier tuff which were deposited 1.2 Ma and 1.6 Ma respectively (Kelley et al., 2004). These deposits were formed during two large explosive eruptions in which ignimbrites blanketed the landscape with hundreds of meters of rhyolitic ash-flow tuff (Kelley et al., 2004). A series of smaller eruptions in between these two major ones produced deposits called the Cerro Toledo rhyolites (Price, 2010), but they are not well exposed in the field area. The Bandelier tuff consists mainly of rhyolitic ash-flow tuff containing 15 – 20% phenocrysts of sanidine and quartz, and other minor constituents, and may be more welded in upper flow units (Kelley et al., 2004). Bandelier tuff, being primarily composed of silica, which may be either amorphous or devitrified to form secondary minerals, will most likely weather to amorphous clays or secondary silicates and may form Andisol soils.

In the study area, colluvium mantled slopes display morphology ranging from small talus wedges or fans at the base of steep bedrock cliffs to thicker colluvial cover completely mantling bedrock on gentler slopes, which provides a sediment source for alluvial fans. As a result of recent fire activity in the study area, hillslopes locally display rills where vegetation has not recovered and some alluvial fans display evidence of deposition and (or) channel incision and cutting of fan toes. Incised channels locally cut into hillslope colluvium, exposing the alluvial-colluvial boundary. In some areas, scoured material has been redeposited at the intersection between an older fan toe and the alluvial floodplain, forming a small, younger fan at the toe of a larger, older fan. Compared to

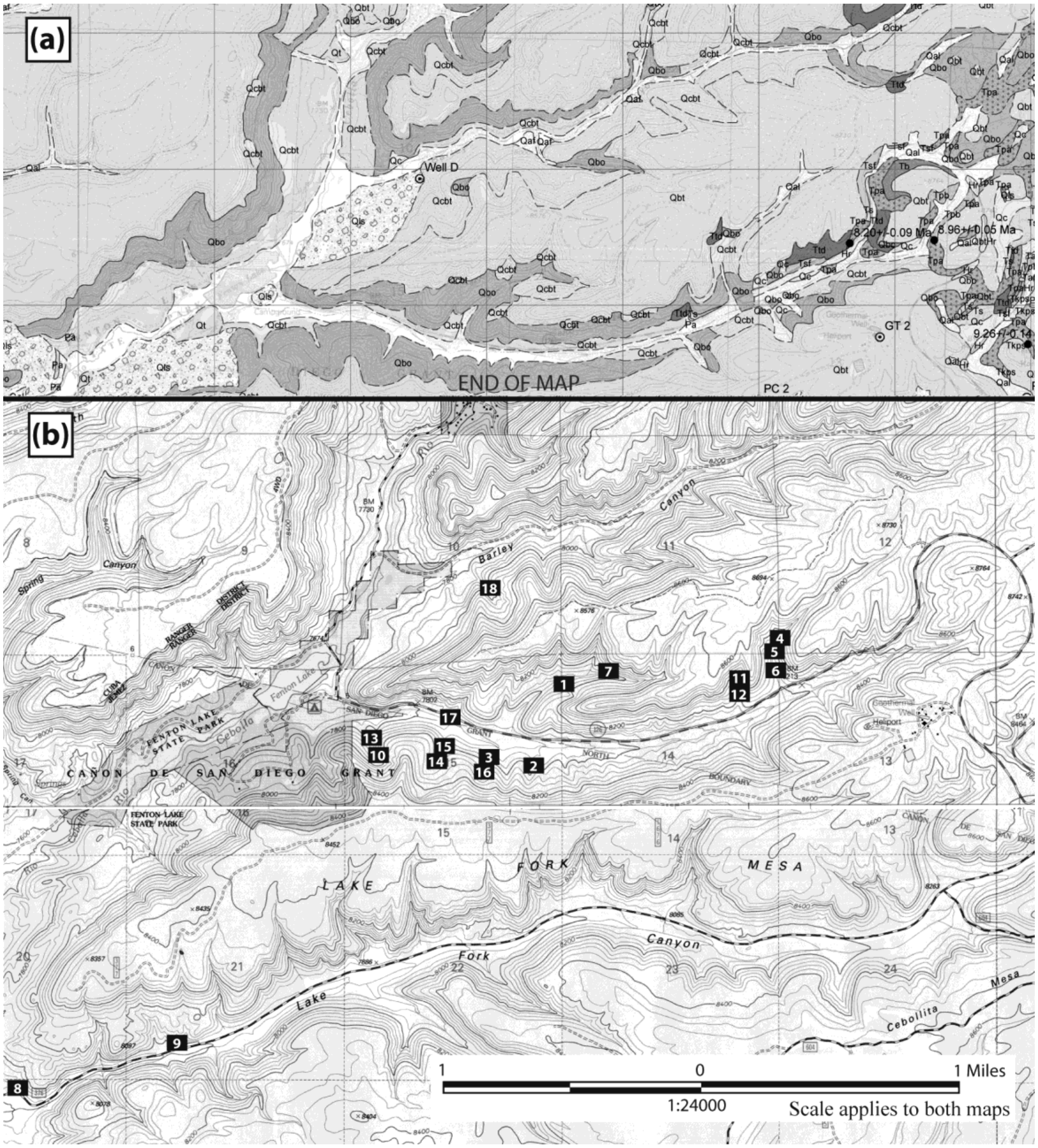

Figure 2. (a) Geologic map showing a portion of the Lakes Fire burned area (Kelley et al., 2004). Geologic units of interest include, Qcbt: Bandelier Tuff colluviums and related hillslope deposits, Qls: Landslide deposit (middle Pleistocene to Holocene), Qt: Terrace deposits (middle Pleistocene to Holocene), Qbt: Upper Bandelier Tuff (Tshirege Member, middle Pleistocene), and Qbo: Lower Bandelier Tuff (Otowi Member, early Pleistocene). (b) Shaded topographic map of the Lakes Fire area with Station locations marked by black rectangles.

alluvial fan morphology in areas flanking the study area (e.g., Barley Canyon and Lake Fork Canyon), which have not experienced recent fire activity, incision and redeposition is unique. Both a scoured primary alluvial fan and the secondary fan at its base may be mantled by cobble and boulder lobes with an abundance of unvegetated sediment at the surface, which sets these fans apart from fans without recent post-fire activity which retain most of their vegetation and feature small, likely ephemeral, channels.

FOREST COMPOSITION

The forest cover of the Jemez Mountains ranges from pure ponderosa pine (*Pinus ponderosa*) stands to mixed conifer forests that include mainly Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and Engelmann spruce (*Picea engelmanni*),), and local aspen (*Populus tremuloides*) stands (Allen et al., 1996; Touchan et al., 1996). Although species distribution may have shifted over time, it is likely that this assemblage of species has not changed significantly in composition over the ~5000 years studied in this work (Anderson et al., 2008). In this study area, in general, ponderosa pine dominates south aspects above drainages and aspen and Douglas-fir dominate valley bottoms and north aspects above drainages (Figure 3) (Craig Allen, personal communication, 2010).

MODERN CLIMATE AND FIRE SEASON

The following climate patterns in the Jemez Mountains are reviewed by Touchan et al. (1996). Precipitation ranges from 300 mm to 900 mm at low and high elevations respectively. Yearly precipitation is bimodal with maxima in the winter (December – January) in the form of snow, and summer (July – August) in the form of rain from convective storms. The source of moisture in the winter originates in generally east-moving storms from the Pacific Ocean. In the summer, moisture originates from the Gulf of Mexico and is transported by a southeasterly wind pattern and accounts for forty

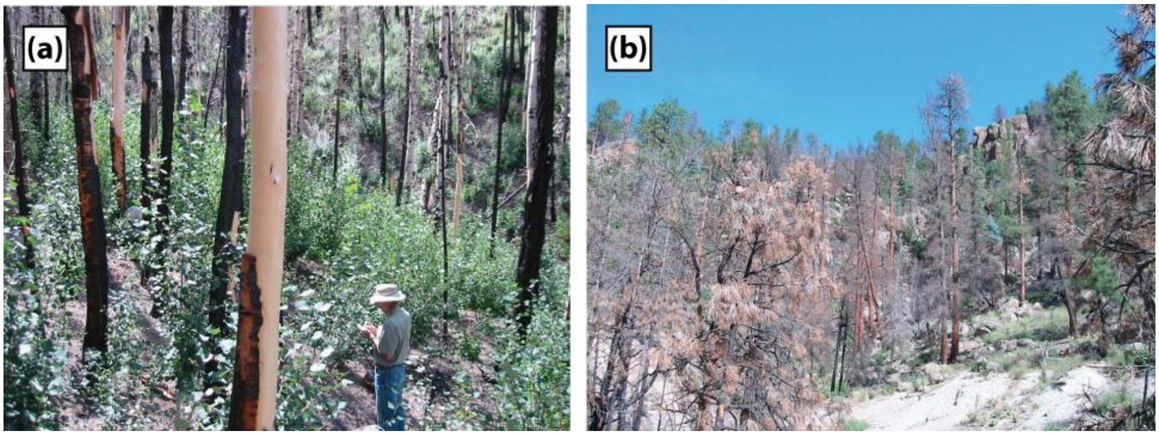

Figure 3. (a) Douglas-fir and aspen dominate valley bottoms and north aspects above drainages. (b) Ponderosa pine dominates south aspects above drainages. Both photos courtesy of Craig Allen, 2010.

percent of total annual precipitation. The typical modern fire season extends from April to September, with June being the peak month for fires. In the southwestern USA (hereafter referred to as the Southwest), around 75% of fires originate through lightning strikes (Allen, 2001).

METHODS

SEDIMENTOLOGY AND STRATIGRAPHY OF FIRE-RELATED DEPOSITS

Alluvial fans tend to be dominated by deposits of infrequent catastrophic events, separated by lesser deposits laid down by processes acting more frequently on the fans (Blair and McPherson, 1994). Fan deposits in small mountain tributaries tend to consist of debris-flow, hyperconcentrated-flow, and streamflow deposits (e.g., Meyer and Wells, 1997). Since fires tend to promote runoff-generated debris flows and flash floods that carry burned material from soil surfaces on steep slopes, abundant macroscopic angular charcoal will be preserved within the deposit as well as finer charred litter or ash which can give the matrix of a deposit a darker color (Cannon, 2001; Meyer and Wells, 1997). Additionally, burned surfaces, preserved in alluvial fan deposits, can provide a record of fire as well as suggest the likelihood that the overlying deposit occurred shortly after a fire event. These thin layers of charred material represent the burned litter at the surface (hereafter referred to as a burned surface). Therefore, it is possible to date charcoal fragments within fire-related deposits or burned surfaces from stratigraphic sections of an alluvial fan. In this way, a history of fire activity occurring within the watershed which feeds the alluvial fan is recorded by post-fire geomorphic response. To infer depositional processes and the likelihood that deposits were fire-related, the following characteristics were visually estimated in the field for deposits within a stratigraphic section (as in New, 2007; Frechette and Meyer, 2009): charcoal content, angularity, size and distribution; gravel percentage, maximum clast size and clast angularity; deposit sorting and structure; matrix color and texture; and unit contact and soil boundary distinctiveness and topography. Field characteristics are reported in Appendix 1.

Meyer et al. (1995) characterize the likelihood that a deposit is fire-related based on the following criteria. The most likely is a debris-flow deposit containing abundant coarse, angular charcoal, especially if the matrix is also ash-rich or if the deposit overlies a burned surface. Probable fire related deposits in Meyer at al. (1995) are those which do not contain abundant charcoal, but overlie a burned soil surface or where hyperconcentrated-flow and streamflow deposits contained abundant angular charcoal. Possible fire related deposits in Meyer at al. (1995) are those which contain abundant charcoal, but the degree of rounding suggests that the material may be reworked.

Based on characteristics of fire-related alluvial fan deposits, it may also be possible to estimate the severity of associated fires (e.g., Pierce et al., 2004). While low-severity fire events can add fine ash to the hillslope and destroy sediment anchoring by grasses and shrubs, increasing runoff and sedimentation, severe fires may destroy sediment anchoring by trees as well, leave even more erodible ash on the surface, and may cause an overall increase in runoff and sedimentation following a fire (Shakesby and Doerr, 2006). Based on these differences, severe fire events may be inferred by the presence of a large depositional response following the fire event and low-severity fire events may be inferred by a small depositional response. Therefore, in order to assess potential patterns in the magnitude of post-fire sedimentation response, "large" fire-related events are defined arbitrarily as debris-flow or hyperconcentrated-flow deposits thicker than 50 cm, which contain abundant coarse angular charcoal. In this study, I consider the possibility that this type of deposit is a proxy for severe fire in the associated drainage basin. Deposits of "small" fire-related events do not meet the above criteria but include abundant charcoal or overlie a burned surface, and may indicate deposition in response to lower-severity fires. Some deposits bridge these classifications, and some interpretations were made on a case-by-case basis. The utility and significance of these classifications is considered in the Discussion section.

Constructing fire records from alluvial fan deposits can be difficult due to the nature of fan construction. There is always the chance that fire-related deposits may subsequently be eroded, removing a record of fire in the alluvial-fan record. Additionally, since deposition on an alluvial fan is not uniform over the entire fan surface, either laterally or distally (Meyer and Wells, 1997; Blair and McPherson, 1994), it is likely that recent incision exposes only some fraction of past deposits. Therefore, where possible, multiple stratigraphic sections have been examined for each alluvial fan. The result is a composite record of fire-related sedimentation based on 18 total stratigraphic sections, including one within the main valley arroyo.

Modern Analogs of Fire-Related Deposits

Although the previously reviewed characteristics of fire-related deposits provide a general framework for identifying them within alluvial stratigraphic sections in the Lakes Fire burned area, local variations may cause deposits in this area to deviate from these general characteristics. Therefore, it is necessary to identify and describe modern fire-related deposits generated by the Lakes Fire in order to adapt current fire-related facies models (e.g., Meyer and Wells, 1997; Cannon, 2001) and aid in the identification of fire-related deposits within the stratigraphic section.

Since the Lakes Fire occurred during recent times when human impacts may have had a large impact on fire regime and therefore fire-related sedimentation, some spatial and stratigraphic characteristics of the deposits may not be generally representative of fire-related deposits in the past. However, the Lakes Fire occurred within the normal fire season (Touchan et al., 1996). Also, the parent material for deposits should be similar to past deposits and characteristics of a particular depositional process observed in the deposits should be similarly displayed in past deposits. Additionally, fire severity ranged from medium to high and some watersheds experienced greater burn severity and a larger depositional response than others. These deposits were similar to fire-related deposits described by Meyer and Wells (1997) and Cannon (2001), however, in some cases deposits have most likely been reworked or depleted in fines after deposition. Recent deposits in these respective watersheds have been compared to those within stratigraphic sections in order to better identify fire-related deposits.

DATING OF FIRE-RELATED DEPOSITS

In order to determine fire history, charcoal was collected from alluvial fan deposits and radiocarbon dated in order to estimate the age of the deposit which contained it. However, charcoal within a deposit may not always be an accurate indicator of deposit age, especially if the charcoal has been reworked from an older deposit. Additionally, since ponderosa pine and Douglas fir may live to be over 500 years old, it is possible that the preservation of charred inner rings may give a dated charcoal fragment an age much older than the deposit which contains it. In order to minimize error caused by dating the inner ring of an old tree, needles, seeds and cones have been dated whenever possible. However, some unavoidable error may be associated if significant time has elapsed between the death of the plant and the date of the fire (Gavin, 2001). Following New (2007), charcoal fragments have been sampled from deposits consisting of 1 – 25% (or more) charcoal and stored in plastic bags with surrounding sediment, paying particular attention not to crush or touch the samples. A total of 54 samples were chosen for dating.

Sample pre-preparation for 50 samples was performed at the Quaternary Laboratory at the University of New Mexico and at the Accelerator Mass Spectrometry (AMS) Lab at the University of Arizona. Pre-preparation involves removal of modern organic material such as rootlets and soil from the sample using forceps and a scalpel followed by the standard acid-base-acid method to further remove impurities from the sample. These pretreated samples were subsequently taken to the AMS lab at the University of Arizona for combustion and radiocarbon analysis. A total of 4 samples of the 54 were partially pretreated at UNM and shipped to Beta Analytic for analysis. Radiocarbon ages were converted to calibrated calendar years using the CALIB 6.0 software program (Stuiver and Reimer, 1993) and the INTCAL04 calibration curve (Reimer et al., 2004). Data has been reported as suggested in Stuiver and Polach (1977).

GRAIN SIZE ANALYSIS AND PROCESS CLASSIFICATION

In order to investigate what processes transport sediment after fires and whether slope aspect plays a part in the characteristics of fire-related sedimentation, depositional processes were classified by comparing field observations and the results of grain size analysis.

Sample Selection and Analysis

One or more samples from each distinguishable deposit (fire-related or non-fire related, including modern analogs) were chosen to represent the deposit for all material smaller than -4 phi (16 mm), resulting in the grain size analysis of 117 samples. Some deposits may not have clearly defined boundaries, therefore where applicable several samples were analyzed from one deposit, especially if a deposit contained significant textural or structural variation. An effort was made in the field to take grain size samples with a volume of at least 500 cm^3 (around half a quart) in most cases.

All samples were sieved through standard -4, -2, -1, 0, 1, 2, 3, and 4 phi sieves (Wentworth scale) following the American Society for Testing and Materials (ASTM) standard D422. Due to the fact that samples often represent the deposit matrix, the coarse fraction percentage (percentage of clasts larger than 2 mm) have been estimated based on field observations, not by sieving in the lab. These estimations are reported in Appendix 1 but were not used to alter any grain size analysis results. Where a sample contained some part larger than 2 mm in lab sieving, this information was used as a comparison to clast-size percentage values chosen for clasts larger than 2 mm in the field.

Deposits with a coarse fraction less than 45% were chosen to be analyzed by laser diffractometry in order to determine the relative percentage of silt and clay. It was presumed that these deposits would have a higher percentage of fines after preliminary sieving of > 2 mm clasts and that further division of silt and clay after sieving of sand-sized clasts may aid in classifying the depositional process associated with the deposit. Of 117 total samples, 61 were chosen to be analyzed by laser diffractometry. These samples were sieved through at least -4, -2, and -1 phi at the UNM Quaternary Lab and the remaining fraction of each sample was sent to the Environmental Soil Analysis Laboratory at the University of Nevada, Las Vegas, where they were analyzed from 0 to 10 phi at one-phi intervals.

After sieving and laser diffractometry, results were graphed as cumulative percentages versus phi. Values such as % gravel, % sand, % fines (silt and clay), graphical standard deviation (GSD, a measure of sorting; Folk, 1974), median, and graphical mean (Folk, 1974) were calculated.

Process Classification

Although in reality flow processes make up a spectrum, for the purposes of this work deposits are classified as either debris-flow, hyperconcentrated-flow, streamflow or cobble lobe (as part of a debris flow or hyperconcentrated flow) deposits. As a framework for classifying deposits, graphs and classification criteria from Meyer and Wells (1997) are considered predominantly, although Cannon et al. (2001) and Cannon (2001) are also considered. Based on characteristics of modern analogs in the study area, this criteria is reasonable. For information related to the classification of each deposit, see deposit descriptions in Appendix 1.

SLOPE ASPECT AND GEOMORPHOLOGY

In order to determine whether slope aspect influences fire-related sedimentation, characteristics of basins as well as streams and alluvial fans with generally north and south-facing source areas, were compared.

Basins and Streams

Characteristics such as basin area and aspect, stream length and relief ratio were determined for the 10 applicable basins within the study area. Measurements of length, area and elevation were made using Terrain Navigator by Maptech. Stream length was determined through visual estimate of upper and lower stream margins from aerial photos after the 2002 Lakes Fire. Basin dimensions for basin area were assessed using a topographic map of the study area. Relief ratio was calculated as the total relief divided by the length of the main basin channel, extended to the basin divide along the single longest tributary.

Alluvial Fans

In order to assess whether slope aspect influences the dominance of a depositional process, fan stratigraphy is compared for alluvial fans with north and south-facing source areas. Since deposits may not always have clearly defined boundaries it is difficult to reliably compare alluvial fan stratigraphy on north and south-facing fans except by the relative amount that each depositional process type contributes to fan-building. This is the summed thicknesses of a deposit type divided by total thickness of deposits studied from a particular slope aspect. This analysis was performed for all deposits described as well as for fire-related deposits only, as a separate analysis. Additionally, given sparser vegetation and a greater area of exposed runoff-generating bedrock, it is hypothesized that south-facing slopes will tend to generate more frequent, smaller, and more dilute flow events (i.e., potentially more well-sorted deposits) than north-facing slopes, even when not burned. Recurrence intervals of fire-related sedimentation and range of sorting for north and south-facing slopes are also compared.

RESULTS

STRATIGRAPHY

A total of 18 stratigraphic sections (stations) were described. Charcoal samples were dated at 11 of these (Figure 4). All but 3 of the stations are located in NM 126 Canyon (Figure 2) and 8 and 9 stations were located on roughly north and south-facing slopes, respectively, with 1 station located within the valley arroyo. Proximal, medial and distal fan locations were numbered 5, 5, and 7 respectively. Modern analogs of fire-related sedimentation were described at 3 locations in the main canyon. Detailed descriptions of each station, including modern analogs, are located in Appendix 1.

Exposures ranged from 1.3 to 3.5 m and deposits ranged from debris flow to streamflow, with sorting values ranging from 0.9 GSD to 4.7 GSD (see Figure 5 for cumulative curves). Debris-flow deposits tend to be very poorly sorted, lacking apparent sedimentary structure and appearing massive. They range in maximum grain size from fine pebble to boulder and in matrix sorting from 2.1 to 4.7 GSD with an average of 3.5 GSD. Debris-flow deposits with better sorting tend to either be associated with a cobble lobe or are associated with sample(s) from the same depositional sequence which have a more poorly sorted matrix. Hyperconcentrated-flow deposits tend to be poorly sorted and may contain structure such as weak imbrication, grading or bedding, clast orientation parallel to the flow direction or very minor scour-fill structure. They range in maximum grain size from granule to boulder and in matrix sorting from 1.8 to 3.2 GSD with an average of 2.4 GSD. Hyperconcentrated-flow deposits with matrix sorting values over 3.0 GSD tend to also show other diagnostic features such as weak bedding and low-angle scour-fill structure. Stream-flow deposits tend to show imbrication, grading, bedding, or

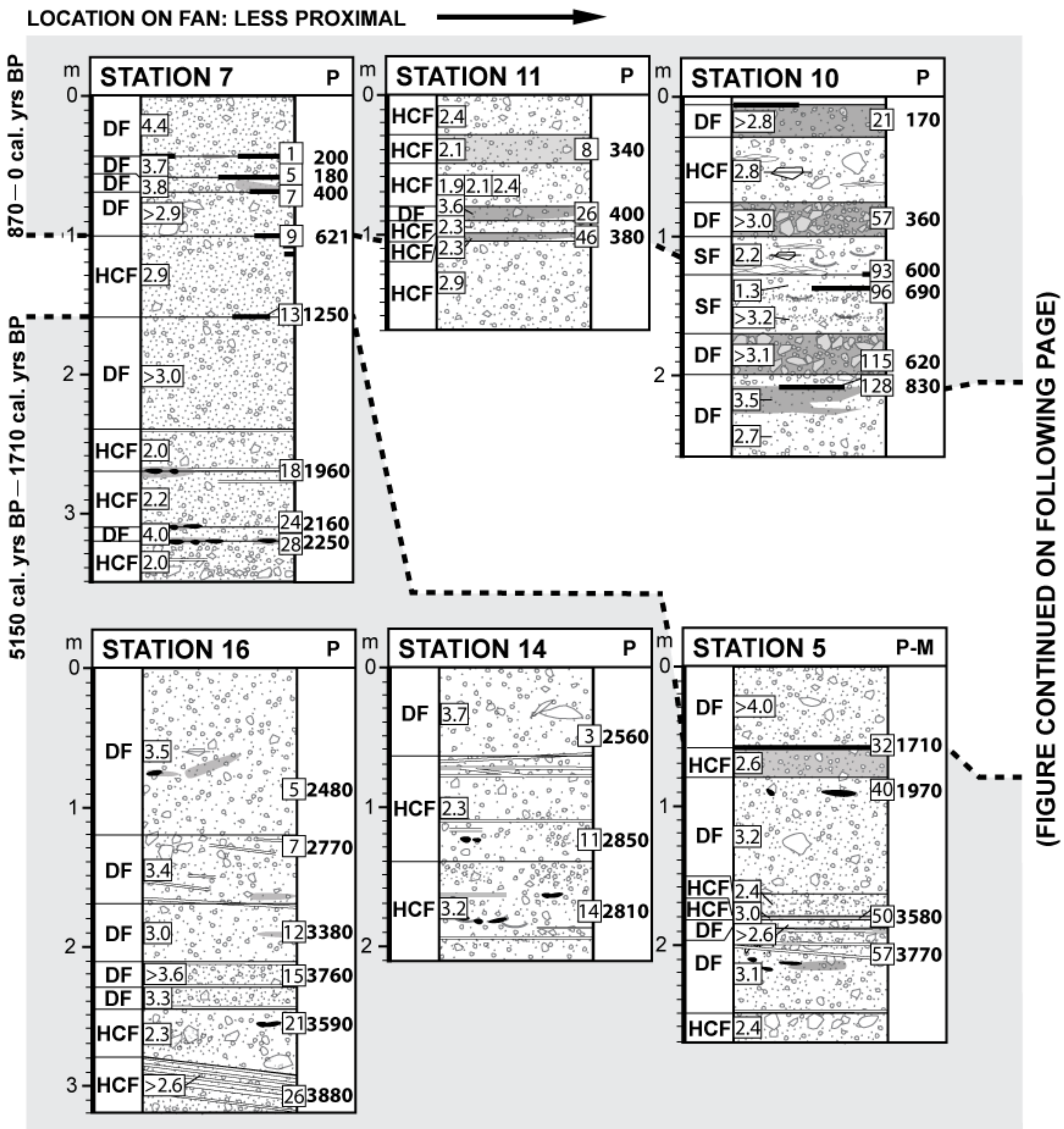

Figure 4. Stratigraphic and date information for dated stations. Stations are arranged by approximate fan location along the horizontal axis and grouped by date ranges listed on the vertical axis. Although the arrangement of stratigraphic sections provides some visual grouping of time periods, the periods delineated by dashed lines are guidelines for convenience only, especially because undated basal deposits in the upper line of sections may not have been deposited between 1710-870 al. yr BP (weighted average range). Furthermore, the stratigraphic sections are simplified, but display significant structural and textural changes as well as deposit boundaries and presence and location of charcoal. (Figure caption continued of following page)

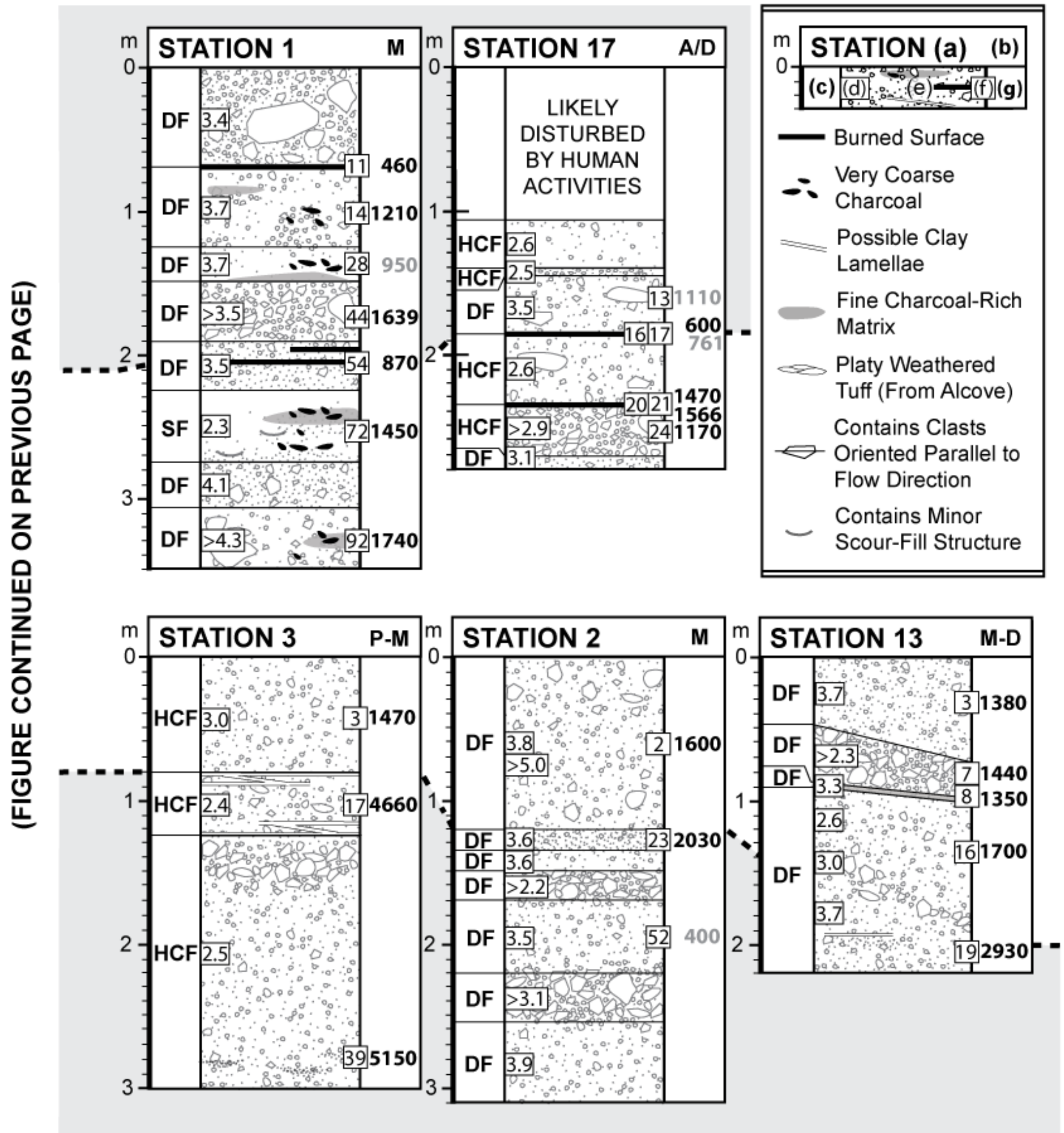

Figure 4. (continued): The following correspond to areas identified on the key: (a) station number; (b) fan location, where "P" refers to proximal, "M" refers to medial and "D" refers to distal; (c) deposit classification, where "DF" refers to debris flow, "HCF" refers to hyperconcentrated flow and "SF" refers to streamflow; (d) sorting value for the associated deposit in graphical standard deviation (Folk, 1974); (e) observable texture which takes into account, the general range of clast sizes from fine fraction (unmarked space) to boulder-sized material, clast orientation, general structure, and notably distinct areas of charcoal content and form; (f) sample identifier associated with the date displayed, where, for example, sample "1" in Station 7 would have the official sample name, 11-7-1; (g) weighted average date associated with adjacent sample identifier, in cal yr BP, where grey colored dates represent those dates which have been removed from analysis.

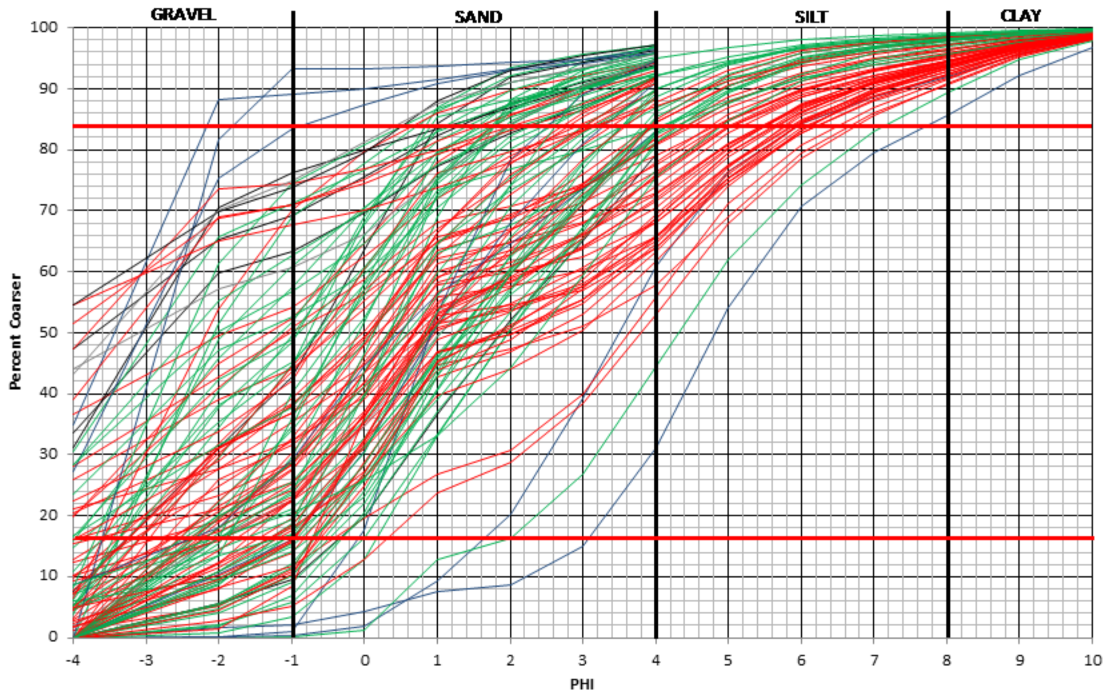

Figure 5. Cumulative percentages of sediment size for each phi value used in lab analysis for each deposit. Debris flow and hyperconcentrated flow deposits are plotted in black. Debris flow deposits are plotted in red, hyperconcentrated flow deposits are plotted in green and streamflow deposits are plotted in blue.

weak scour-fill structure. They range in maximum grain size from fine pebble to boulder and in sorting from 0.9 to 2.3 GSD with an average of 1.8 GSD. Better sorted streamflow deposits are associated with weak bedding and scour-fill structure. Only one streamflow deposit (in Station 8) contains clasts larger than pebble size, a few cobbles and boulders, but weak coarse and fine layering is apparent among the cobbles and boulders. This suggests that the larger clasts may have originally been deposited by another process and matrix was later reworked by streamflow processes. In general, there is not much of a correlation between maximum or mean grain size and depositional type (Figure 6).

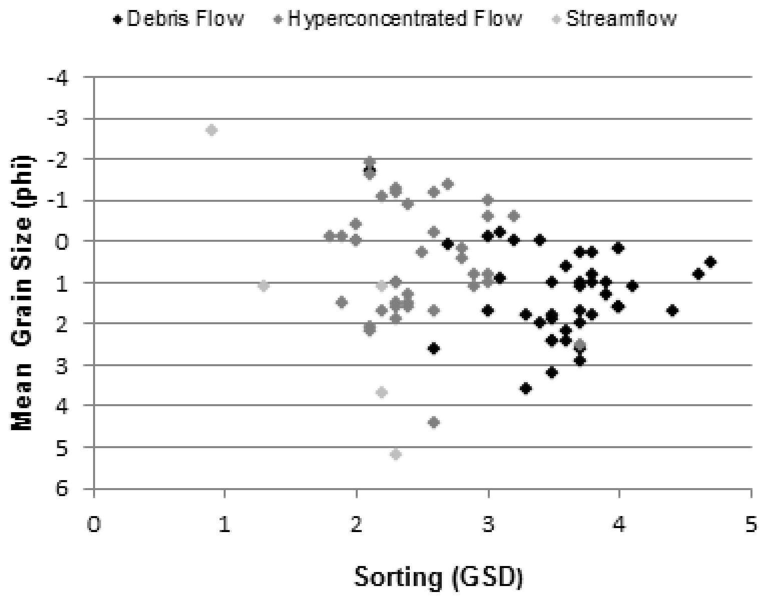

Figure 6. Mean grain size versus sorting (in graphical standard deviation) of 86 samples with quantifiable sorting values out of a total of 117 samples analyzed.

Deposits inferred to be fire-related were either debris-flow or hyperconcentrated-flow deposits, however, two were streamflow deposits either associated with a burned surface or abundant, very coarse, angular charcoal fragments. Some stations contained deposits with a dark matrix due to an abundance of fine charcoal and most of these deposits are inferred to be fire related. However, the majority of fire-related deposits either contained coarse, angular charcoal within the deposit, or were associated with a burned surface. In at least one case (Figure 4, Station 13, 0-90 cm), multiple distinguishable deposits with differing characteristics, but all possibly associated with the same fire event (based on charcoal dates within the deposits), were recorded. Burned surfaces were usually well preserved where exposed, although at least one burned surface showed some evidence of reworking (i.e., Station 1, around 2 m from top) or partial erosion (e.g., Figure 4, Station 7, in several places). The most reliably identifiable burned surfaces are located at proximal-fan stations (8 total), compared with medial-fan sites (3 total) and distal-fan sites (none recorded). Station 7, a proximal-fan site, contains five clearly identifiable burned surfaces within a single station. It is possible that burned surfaces are more likely to be preserved quickly near the top of the fan due to proximity to erodible hillslope material post-fire. However, both proximal and distal fan sites showed evidence of potential reworking or a significant number of unclear deposit boundaries as well. Although deposit boundaries were often more clear in medial-fan sites, some deposit boundaries were difficult to distinguish in sites located near the proximal-medial boundary (Stations 4 and 5).

Also of note, were thin (< 1 cm), irregular, often slightly orange, "resistant layers" (Figure 7), which were present at many of the stations. These layers usually project out from the front of the channel wall a few millimeters beyond the surrounding deposit. One of these layers was analyzed in more detail and compared to the surrounding deposit, and was found to contain around the same percentage of gravel, 20% less sand size material and 20% more silt and clay size material than the surrounding deposit. These layers are often discontinuous, but many extend horizontally over a meter in length or cross other resistant layers at angles less than 45°. Some have been found at observable deposit margins, but many others have been found in very thick, visually homogeneous deposits, although after grain-size analysis many of these resistant layers lay between sediment of notably different sorting. They are often found roughly parallel to the fan surface, but at Station 13 (Figure 4) resistant layers were found to cross-cut other structural features. Therefore, based on these characteristics it is possible these resistant layers are clay lamellae, which may be the result of clay translocation and deposition as the carrying

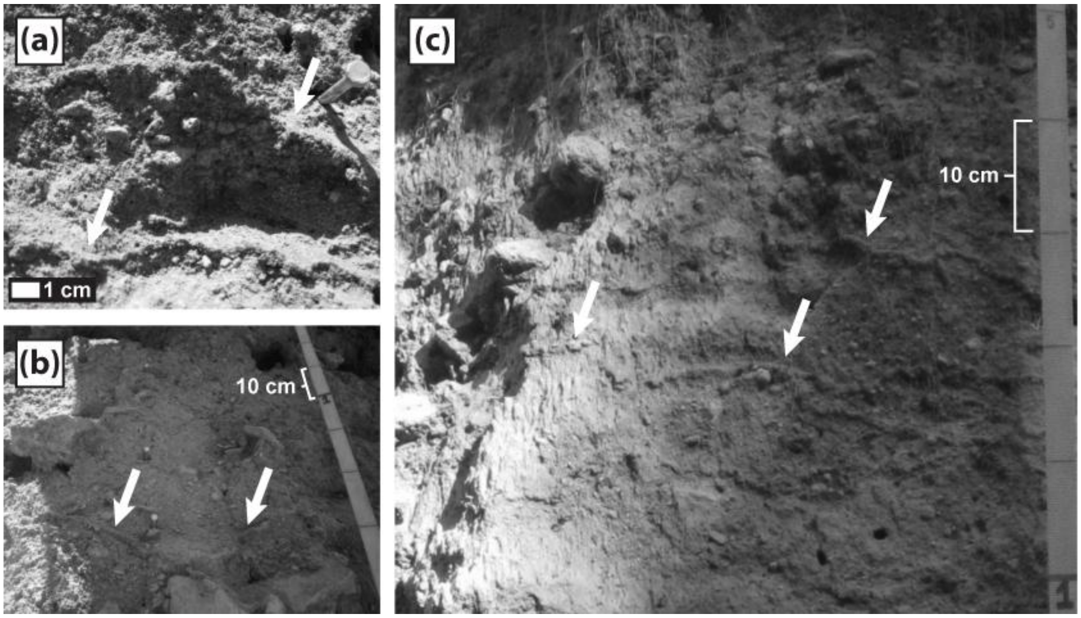

Figure 7. “Resistant layers” which may possibly be clay lamellae.

capacity of soil water reduces with the drying of a wetting front (Rawling, 2000). They also could conceivably form preferentially at boundaries where deposit texture changes, either within a deposit or between deposits (Rawling, 2000). Although potential errors are obvious in using possible clay lamellae to infer rough deposit boundaries, grain size analysis results generally agree with the boundaries delineated (see Figure 4 for examples).

Cannon et al. (2001) investigated post-fire erosion and sedimentation in the Jemez Mountains, and suggested that wood ash may be important in providing an elevated amount of fine material to post-fire debris flows. Although their work investigated multiple flows following the Cerro Grande Fire in 2000, they only obtained grain size information for one debris flow.

In this thesis work, fire-related and non-fire related deposits had average values of 3.1 GSD and 2.9 GSD, respectively. Among fire-related deposits, debris-flow deposits make up 59% of deposits, in terms of individual events, and 57% of thickness. Among non-fire related deposits, debris-flow deposits make up 38% of deposits, in terms of individual events, and 53% in terms of thickness. Therefore, despite the fact that an elevated fines percentage was also used in this thesis as a component of debris flow classification, sorting values for fire-related deposits versus non-fire related deposits do not indicate that fire-related deposits are necessarily more poorly sorted. However, a slightly larger percentage of debris-flow deposits were classified as fire related. Therefore, wood ash may contribute to debris flow generation post-fire.

By thickness, debris-flow deposits make up 51% of proximal stations, 77% of proximal-medial stations, 63% of medial stations and 50% of distal stations. Therefore, proximal-medial and medial stations had a slightly higher percent thickness of debris-flow deposits than proximal or distal stations, but the difference is not significant. However, average sorting does increase from proximal to medial fan locations by 0.6 GSD and decreases from medial to distal fan locations by 0.3 GSD. These values are not greatly different, although based on the small size of most of the fans, it is reasonable to imagine that many flows, especially poorly-sorted flows, may be slightly more likely to be exposed near the medial-fan since this location strikes a balance between fan surface area and likely deposit thickness.

RADIOCARBON DATES

The 54 radiocarbon dates (Table 1) span a time period from 0 cal yr BP to around 5300 cal yr BP, with the oldest charcoal sampled around 280 cm below the top of the station (Figure 4).The approximate depth of samples dated and their weighted average calibrated

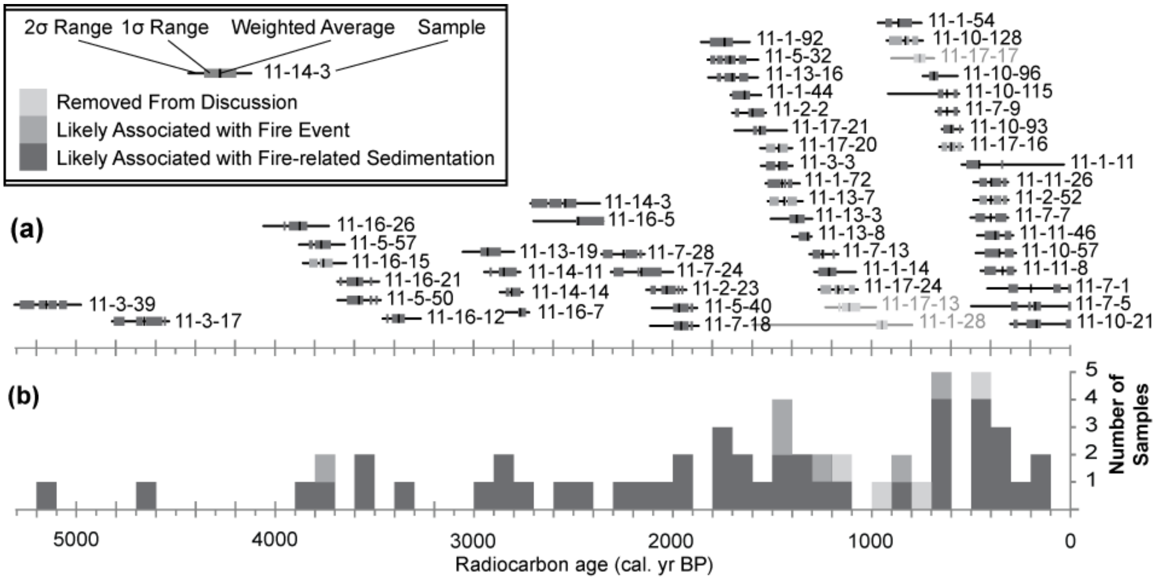

Figure 8. (a) Plot of all sample ages. 1 sigma ranges: rounded up to nearest ten cal yr BP; only ranges greater than ten displayed; 2 sigma ranges: rounded up to nearest ten; only gaps and bars greater than 100 cal yr BP displayed. (b) The number of weighted average ages which fall into each 100 yr interval, where dates on the cusp have been rounded up into the next higher bin. Bar heights represent the total number of samples contributing to the corresponding bin, with bar color changes corresponding to the number of samples of each type which make up the total. Color changes in (a) and (b) represent the same sample type.

ages are displayed in Figure 4. For each sample, 1σ ranges, 2σ ranges and weighted averages are displayed in Figure 8 along a timeline.

The weighted averages calculated in this work provide an estimate of the central point of a calibrated radiocarbon date, based on the probability distribution for each sample. These weighted averages are calculated as the sum of the multiplied probability density function and corresponding year, where the sum of the probability density function for all years is equal to 1. Although this method provides a single-value estimate of age from a probability distribution, the resulting weighted average age calculated may actually have a low probability value in some cases.

Station 7 contains the greatest number of dates, 8 total, which span from 2250 to 200 cal yr BP (weighted average). Five dates are from confidently identified burned surfaces. However, Station 3 contains the longest span of time recorded, between 5150 and 1470 cal yr BP (weighted average), from 3 samples over approximately 3 m. The youngest age for each section (near the tops of sections) span from 2560 to 170 cal yr BP (weighted average) and the oldest age for each section (near the bottoms of sections) are much more variable, spanning from 5150 to 380 cal yr BP (weighted average).

Table 1. Radiocarbon Samples, Locations, ^{14}C and Calibrated Ages and Notes

Station	Sample Number	Lab Code	$\delta^{13}C_{PDB}$ (‰)	^{14}C Age (BP)	1σ age range (cal. yr BP)	2σ age range (cal. yr BP)	Deposit Interpretation (sample from within deposit unless otherwise noted)
1	**11-1-11**	AA95854	-24.3	421±38	342-346 462-516	32-363 365-376 428-530	Associated with burned surface underlying a large debris flow which is likely fire-related
1	**11-1-14**	AA95855	-23.2	1267±39	1176-1265	1084-1112 1122-1286	Large debris flow which is probably fire-related
1	**11-1-28**	AA95856	-25.1	1035±39	922-977	803-809 830-855 905-1015 1023-1055	Small debris flow which is probably fire-related
1	**11-1-44**	11-1-44Beta	-24.3	1730±30	1575-1576 1605-1639 1642-1695	1560-1710	Small debris flow which is possibly fire-related
1	**11-1-54**	AA95857	-25.4	971±52	797-871 897-932	745-750 764-968	Associated with reworked burned surface associated with a large debris-flow which is probably fire-related
1	**11-1-72**	AA95858	-22.1	1549±40	1392-1423 1430-1444 1457-1516	1355-1527	Large streamflow which is probably fire-related
1	**11-1-92**	AA95859	-20.8	1806±41	1703-1814	1614-1679 1683-1828 1847-1862	Large debris flow which is probably fire-related
2	**11-2-2**	AA95888	-22.4	1688±37	1542-1619 1674-1687	1526-1695	Large debris flow which is probably fire-related
2	**11-2-23**	AA95889	-22.2	2057±38	1951-1960 1971-1978 1986-2063 2085-2105	1926-2125	Small debris flow which is probably fire-related
2	**11-2-52**	AA95890	-23.8	343±36	318-344 345-394	310-486	Large debris flow which is

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					424-464		probably fire-related
3	**11-3-3**	AA95882	-20.5	1593±38	1417-1468 1485-1526	1395-1557	Large hyperconcentrated flow which is likely fire-related
3	**11-3-17**	AA95883	-23.6	4118±42	4536-4542 4549-4556 4568-4650 4671-4700 4759-4807	4525-4744 4747-4821	Small hyperconcentrated flow which is probably fire-related
3	**11-3-39**	AA95884	-22.2	4499±50	5051-5090 5097-5143 5156-5193 5212-5287	4975-5017 5031-5310	Large hyperconcentrated flow which is possibly fire-related
5	**11-5-32**	AA95860	-22.1	1787±46	1627-1666 1691-1742 1754-1784 1792-1811	1569-1585 1592-1824	Associated with burned surface underlying a large debris flow which is possibly fire-related
5	**11-5-40**	AA95861	-22.1	2013±38	1901-1911 1922-1999	1879-2060 2089-2101	Large debris flow which is possibly fire-related
5	**11-5-50**	AA95862	-25.1	3344±41	3486-3501 3506-3523 3555-3637	3472-3645 3656-3687	Small hyperconcentrated flow which is possibly fire-related
5	**11-5-57**	AA95863	-24.6	3500±40	3720-3804 3807-3832	3645-3659 3686-3878	Large debris flow which is possibly fire-related
7	**11-7-1**	AA95841	-24	220±39	-1-11 149-186 270-305	-2-32 84-87 93-96 109-111 137-223 256-318 394-424	Associated with burned surface underlying a small debris flow which is probably fire-related
7	**11-7-5**	AA95842	-22.3	206±40	-1-13 148-188 198-211 269-299	-2-33 72-115 135-225 253-311	Associated with burned surface underlying a small debris flow which is probably fire-related
7	**11-7-7**	AA95843	-22	352±39	320-379 387-391 427-477	314-496	Associated with burned surface underlying a small debris flow which is probably fire-related
7	**11-7-9**	11-7-9Beta	-23	670±30	567-585 647-668	560-599 631-675	Associated with burned surface underlying a small debris flow which is probably fire-related
7	**11-7-13**	AA95844	-23.9	1326±41	1185-1203	1176-1305	Associated with burned surface

Table 1. Radiocarbon Samples, Locations, ^{14}C and Calibrated Ages and Notes

Station	Sample Number	Lab Code	$\delta^{13}C_{PDB}$ (‰)	^{14}C Age (BP)	1σ age range (cal. yr BP)	2σ age range (cal. yr BP)	Deposit Interpretation (sample from within deposit unless otherwise noted)
					1242-1251 1255-1296		underlying a large hyperconcentrated flow which is probably fire-related
7	**11-7-18**	AA95845	-22.8	2009±42	1898-1913 1919-1998	1874-2063 2085-2106	Associated with string of coarse charcoal underlying a small hyperconcentrated flow which is probably fire-related
7	**11-7-24**	AA95846	-21.6	2148±48	2057-2159 2171-2177 2247-2300	2001-2210 2223-2309	Associated with string of coarse charcoal underlying a small hyperconcentrated flow which is probably fire-related
7	**11-7-28**	AA95847	-23.8	2268±56	2161-2168 2178-2243 2301-2345	2140-2357	Associated with discontinuous burned surface underlying a small debris flow which is probably fire-related
10	**11-10-21**	AA95848	-24.6	187±38	-1-18 145-215 267-287	-2-34 71-116 133-228 252-304	Small debris flow which is likely fire-related
10	**11-10-57**	AA95849	-25	285±44	292-330 359-429	153-168 282-477	Small debris flow which is probably fire-related
10	**11-10-93**	AA95850	-24.3	592±39	546-564 590-640	536-654	Associated with discontinuous burned surface underlying a small streamflow which is probably fire-related
10	**11-10-96**	AA95851	-26.3	747±39	665-699 703-710 718-722	572-578 652-737	Associated with burned surface underlying a small streamflow which is probably fire-related
10	**11-10-115**	AA95852	-23.6	672±38	565-588 643-671	556-606 625-681	Small debris flow which is probably fire-related
10	**11-10-128**	AA95853	-22.4	903±38	770-803 808-831 852-906	738-915	Associated with burned surface underlying a small debris flow which is probably fire-related
11	**11-11-8**	AA95879	-22.1	273±36	159-162 286-320 378-427	0-4 152-169 281-336 348-459	Small hyperconcentrated flow which is likely fire-related
11	**11-11-26**	AA95880	-23	336±41	316-341 347-399 405 421-461	307-487	Small debris flow which is likely fire-related
11	**11-11-46**	AA95881	-23.3	299±36	300-330 360-369 370-429	289-344 345-466	Small hyperconcentrated flow which is likely fire-related
13	**11-13-3**	AA95874	-23	1491±37	1339-1407	1304-1418 1464-1511	Large debris flow which is likely fire-related

Table 1. Radiocarbon Samples, Locations, ^{14}C and Calibrated Ages and Notes

Station	Sample Number	Lab Code	$\delta^{13}C_{PDB}$ (‰)	^{14}C Age (BP)	1σ age range (cal. yr BP)	2σ age range (cal. yr BP)	Deposit Interpretation (sample from within deposit unless otherwise noted)
13	**11-13-7**	AA95875	-25.5	1536±37	1376-1420 1434-1439 1469-1514	1351-1521	Large debris flow which is likely fire-related
13	**11-13-8**	AA95876	-26.7	1457±37	1310-1370	1299-1403	Large debris flow which is likely fire-related
13	**11-13-16**	AA95877	-23.7	1779±38	1620-1673 1687-1739 1758-1776	1574-1579 1603-1819	Large debris flow which is likely fire-related
13	**11-13-19**	AA95878	-23.2	2820±40	2865-2965	2803-2818 2844-3064	Large debris flow which is likely fire-related
14	**11-14-3**	AA95885	-24.9	2478±39	2475 2486-2550 2556-2618 2633-2705	2365-2414 2433-2717	Large debris flow which is possibly fire-related
14	**11-14-11**	AA95886	-22.2	2755±39	2787-2877 2914-2916	2772-2946	Large debris flow which is probably fire-related
14	**11-14-14**	AA95887	-22.9	2706±39	2766-2807 2816-2844	2750-2872	Large debris flow which is probably fire-related
16	**11-16-5**	AA95864	-22.8	2412±39	2353-2487 2645-2650	2346-2541 2591-2615 2636-2698	Large debris flow which is likely fire-related
16	**11-16-7**	AA95865	-22.4	2639±39	2741-2779	2721-2812 2816-2844	Small debris flow which is probably fire-related
16	**11-16-12**	AA95866	-22.7	3155±40	3351-3409 3425-3441	3267-3291 3322-3461	Small debris flow which is likely fire-related
16	**11-16-15**	AA95867	-22.9	3488±41	3705-3778 3788-3828	3642-3666 3681-3866	Small debris flow which is probably fire-related
16	**11-16-21**	AA95868	-24.8	3356±40	3511-3518 3557-3642 3666-3681	3480-3544 3547-3689	Large hyperconcentrated flow which is possibly fire-related
16	**11-16-26**	AA95869	-21.7	3582±40	3836-3926 3949-3960	3725-3753 3759-3795 3819-3984 4055-4056	Small hyperconcentrated flow which is probably fire-related
17	**11-17-13**	AA95870	-23.2	1181±37	1060-1148 1157-1171	981-1036 1046-1181 1208-1231	Small debris flow which is likely fire-related
17	**11-17-16**	AA95871	-25.5	609±36	553-568 583-611 620-649	544-657	Associated with a burned surface underlying deposit containing sample 11-17-13
17	**11-17-17**	11-17-17Beta	-25.6	850±30	730-787	689-797	Associated with a burned surface

Table 1. Radiocarbon Samples, Locations, ^{14}C and Calibrated Ages and Notes

Station	Sample Number	Lab Code	$\delta^{13}C_{PDB}$ (‰)	^{14}C Age (BP)	1σ age range (cal. yr BP)	2σ age range (cal. yr BP)	Deposit Interpretation (sample from within deposit unless otherwise noted)
						818-821 870-898	underlying deposit containing sample 11-17-13
17	**11-17-20**	AA95872	-23.9	1593±37	1417-1468 1485-1526	1398-1555	Associated with a burned surface underlying a small hyperconcentrated flow deposit which is probably fire related
17	**11-17-21**	11-17-21Beta	-24	1660±30	1528-1572 1581-1602	1422-1432 1441-1460 1514-1628 1656-1664 1665-1691	Associated with sample burned surface as 11-17-20
17	**11-17-24**	AA95873	-25.5	1238±36	1091-1107 1135-1162 1167-1187 1200-1259	1070-1265	Large hyperconcentrated flow which is likely fire related

SLOPE ASPECT AND GEOMORPHOLOGY

As mentioned previously, within several of the canyons in this region, south-facing slopes were found to be 5° steeper than north-facing slopes, on average (Paulo de Sa' Rego, 2012, personal communication). This difference in hillslope gradient with aspect may be evidence for other aspect differences as well, such as differences in microclimate, characteristics of colluvium, and the characteristics of fire-related sedimentation.

Estimations of recurrence intervals associated with fire related events suggest that they tend to occur around every 377 years on average on north-facing slopes and 270 years on south-facing slopes. Recurrence intervals were calculated as follows. The total age range of each station was divided by the most likely range of fire events which may have been recorded by the station, resulting in a "minimum" and a "conservative" recurrence interval for each station. These two recurrence intervals were then averaged, resulting in one recurrence interval for each station. The recurrence intervals for north-facing and south-facing stations were then averaged, resulting in the values presented above.

In thickness, fire-related deposits make up 57% of all alluvial fan deposits analyzed. North-facing alluvial fans were dominated by fire-related deposits, which totaled 77% of the total thickness of all stratigraphic sections in north-facing basins. South-facing alluvial fans were dominated by non-fire related deposits, with fire-related deposits making up 39% of the total thickness of all stratigraphic sections in south-facing basins.

The field data was analyzed in terms of the amount that each depositional process type contributes as a fan-building process on north and south aspects and results are listed in Table 2. Taking into account all stratigraphic sections from either slope aspect, neither aspect is dominant in a particular process type by more than 10% thickness. Additionally, when sorting values for deposits are graphed according to slope aspect (Figure 9), no distinctive trends are apparent. By aspect, average sorting values for fan deposits with north and south-facing basins are 3.0 GSD and 2.9 GSD, respectively.

Morphometric analysis (Table 3) suggests that on average, south-facing slopes tend to have longer basin and stream lengths, even if the two largest basins are removed from the average. Taking all basins into account, south-facing basins tend to have a larger average area and total relief. However, without the two largest basins, average basin areas and total relief on both aspects are comparable. Although average relief ratio for north-facing basins is slightly larger than for south-facing basins, relief ratios of both aspects are generally comparable, although south-facing basins contain more exposed bedrock cliffs.

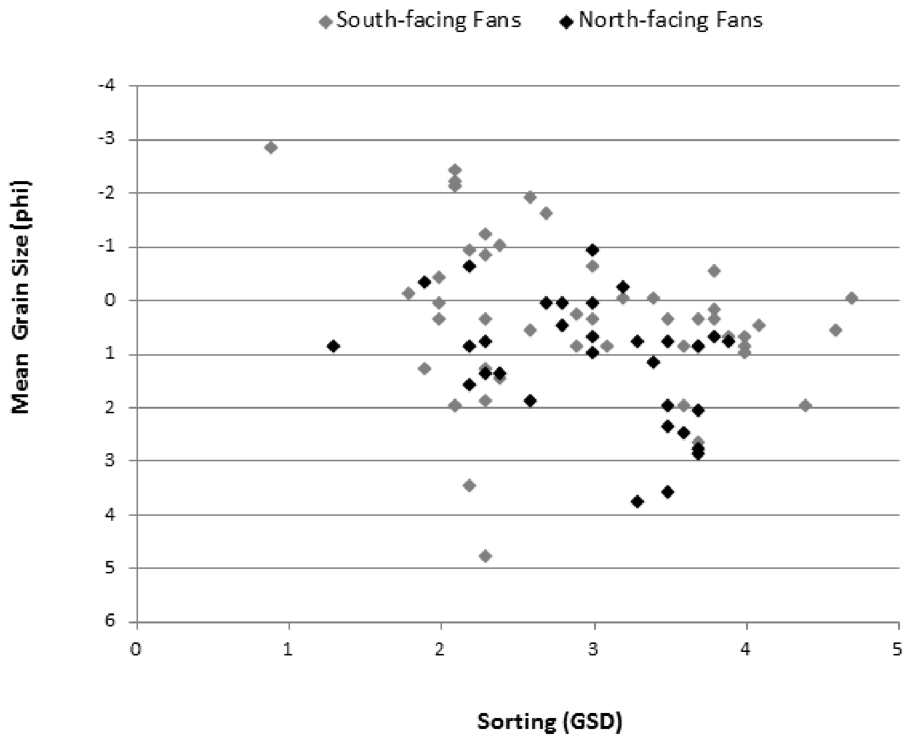

Figure 9. Deposit sorting (in graphical standard deviation) compared to mean grain size (in phi) for north-facing and south-facing aspects.

Table 2. Percent Thickness of Deposits Associated with North and South-Facing Fans

	Cobble Lobe (Debris Flow)	**Debris Flow**	**Cobble Lobe (Hyper-concentrated Flow)**	**Hyper-concentrated Flow**	**Streamflow**
	FIRE-RELATED DEPOSITS				
North-facing Slopes	2	54	0	42	3
South-facing Slopes	0	63	0	32	5
	ALL DEPOSITS				
North-facing Slopes	4	51	1	41	3
South-facing Slopes	0	58	0	38	4

Table 3. Morphometric Analysis

Stations Within Basin	Basin Aspect	Basin Length (m)	Stream Length (m)	Basin Area (km^2)	Min. Relief (m)	Max. Relief (m)	Total Relief (m)	[1]Relief Ratio
10, 13	NW (341°)	557	367	0.145	2377	2537	161	0.29
14, 15	N (6°)	574	364	0.175	2436	2523	87	0.15
3, 16	N (9°)	338	197	0.048	2438	2503	66	0.19
2	N (6°)	320	192	0.047	2438	2528	91	0.28
18	NW (316°)	560	396	0.162	2438	2560	122	0.22
AVERAGE		**470**	**303**	**0.115**			**105**	**0.23**
1, 7	SW (249°)	1841	1858	0.873	2438	2620	183	0.10
11, 12	S (181°)	599	499	0.067	2499	2606	107	0.18
4, 5, 6	SW (221°)	1707	1663	0.539	2499	2666	167	0.10
8	SW (204°)	524	366	0.138	2322	2439	117	0.22
9	S (178°)	667	239	0.116	2395	2499	104	0.16
AVERAGE		**1068**	**925**	**0.347**			**136**	**0.15**

[1] Relief ratio was calculated as the total relief divided by the length of main basin channel extended to the basin divide along the single longest tributary.

DISCUSSION

STRATIGRAPHY AND FIRE HISTORY

Choosing Dates for Analysis

Radiocarbon dating of *in situ* charcoal provides an estimate of deposit age and associated fire events. However, in some cases, older *in situ* charcoal may overlie younger charcoal, in opposition to relative ages defined by superposition. This condition is commonly referred to as an age inversion and may occur when a sample has been reworked from an older deposit or if errors associated with inbuilt age are large. Even if a sample is associated with an age inversion, it may still provide valuable evidence of a fire event, without additional data related to fire-related sedimentation. However, these samples were only used in analysis if their age distribution curves significantly overlapped that of a more reliable date. Out of the 54 samples dated, 4 were deemed unusable for analysis due to age inversion, possible reworking and lack of distribution overlap with another more reliable sample. Out of the 50 remaining samples, 7 were associated with age inversion and may have been reworked from an older deposit, but significantly overlapped the distribution of a more reliable sample, therefore providing evidence to suggest that a fire event may have occurred at that time. The remaining 43 samples provide a reliable set of dates for analysis of fire-related sedimentation.

Removed or Limited Dates

The 4 dates completely removed from analysis are 11-1-28, 11-2-52, 11-17-13 and 11-17-17 and are discussed in more detail in Appendix 2. In Station 1, sample 11-1-28 was removed due to age inversion, possible reworking and lack of distribution overlap with another more reliable sample (Figure 8). In Station 2, sample 11-2-52 was removed due to the anomalously young date with respect to stratigraphic position and other dated samples in the section (Figure 4). In Station 17, sample 11-17-13 was removed due to age inversion compared to all other dates in the section, and although its date distribution overlaps that of 11-17-24, it does not significantly overlap another more reliable sample associated with fire-related sedimentation (Figure 8). Sample 11-17-17 was removed for the same reason. Again, these dates have been completely removed from analysis. However, samples which are associated with age inversion, but significantly overlap the distribution of a more reliable sample (therefore providing evidence to suggest that a fire event may have occurred at that time) will be combined with fire-related sedimentation results to provide a curve representing possible fire activity. However, samples only associated with fire-related sedimentation will also be displayed by a separate cumulative curve (Figure 10).

There are 7 dates associated with samples, 11-1-14, 11-10-128, 11-13-7, 11-16-15, 11-17-16, 11-17-20 and 11-17-24, which have been removed from fire-related sedimentation results, but still represent valuable evidence of fire. They are included in fire-activity results due to the fact that they significantly overlapped the distribution of a more reliable sample, even though they are associated with age inversions and may have been reworked from an older deposit. The corresponding samples which have overlapping distributions (especially 1σ intervals) with the 7 samples in question can be identified on Figure 8. The probability distributions for the resulting 50 ages were summed to produce a cumulative probability curve representing changes in relative fire activity over time (Figure 10).

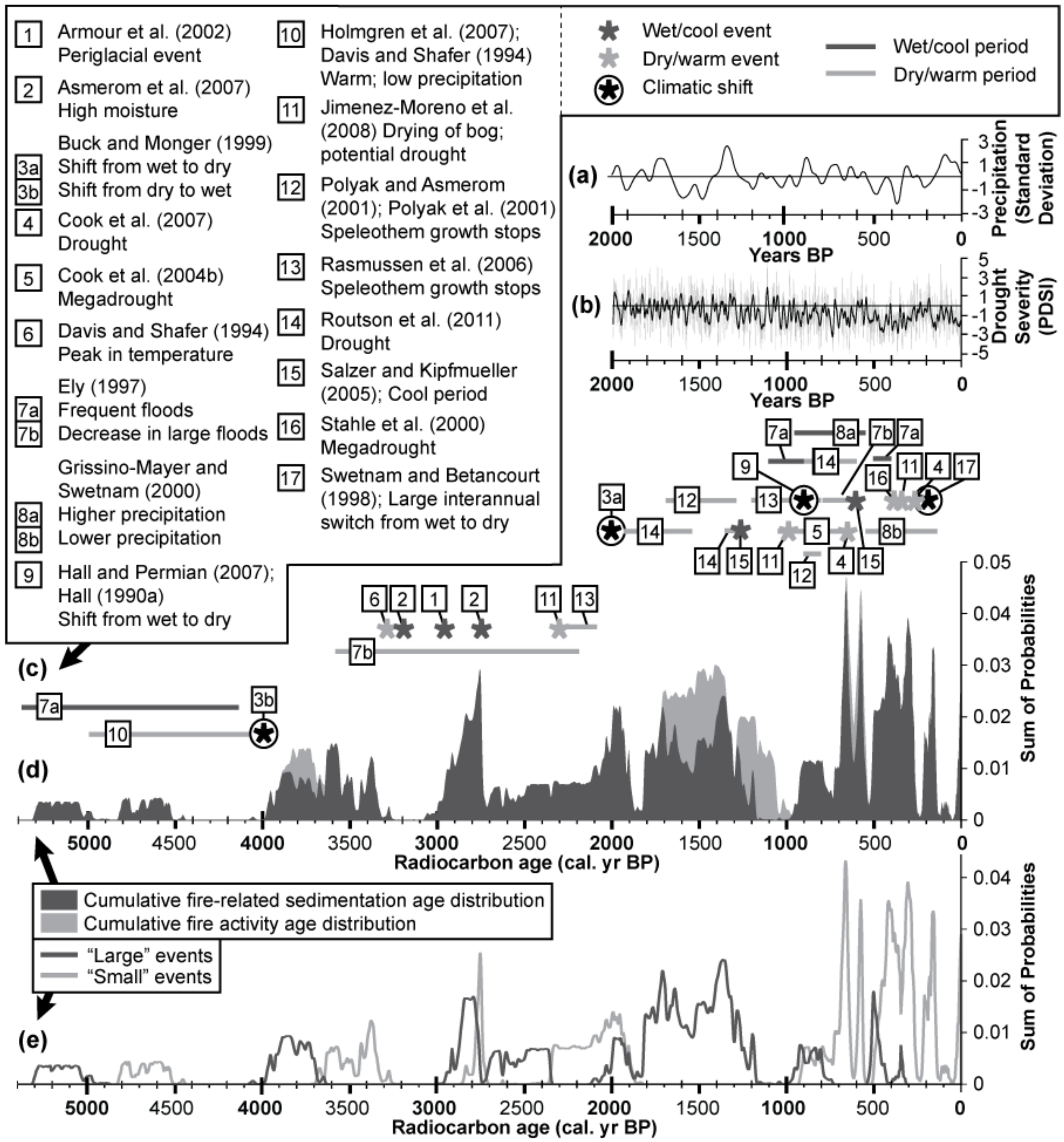

Figure 10. Probability distributions representing ^{14}C-dated fire-related sedimentation and fire activity events compared to paleoclimate records. The paleoclimate record at (a) represents a 100-year smoothing spline fit through a reconstruction of precipitation (from tree-ring records) for northwestern New Mexico, smoothed by a 100-year spline in units of standard deviation (Grissino-Mayer, 1996). Negative precipitation values indicate relatively dry conditions, while positive values indicate relatively wet conditions. The paleoclimate record at (b) represents average Mean Palmer Drought Severity Index (PDSI) for the four grid points surrounding the Jemez Mountains (Cook et al. 2004a). The grey line represents the summer PDSI reconstruction and the black line represents the 20-year low-pass filtered version of the reconstruction. Negative PDSI values indicate dry conditions, while positive values indicate wet conditions. Paleoclimate records at (c) are inferred to represent cool and/or wet periods or events, warm and/or dry periods or events or a shift in climate from dry to wet or vice versa. Cumulative probability distributions at (d) represent all applicable individual distribution curves and cumulative distribution curve for samples which could be reliably associated with a deposit. Cumulative probability distributions at (e) represent cumulative distribution curves for small and large events.

Analysis of Fire-Related Sedimentation

After consideration of possibly unsuitable sample ages, the remaining 43 samples provide a reasonably reliable set of dates for analysis of fire-related sedimentation. Therefore, individual probability distribution curves for samples which could be reliably associated with a deposit were summed to produce a cumulative probability curve representing the relative probability of fire-related sedimentation occurrence over time (Figure 10). Based on this cumulative probability (Figure 10) and number of samples supporting fire activity (Figure 8), peaks in fire activity occurred around 2850-2750 cal yr BP, 2050-1950 cal yr BP, 1700 cal yr BP, 1400 cal. yr BP and multiple peaks occurred between 700-150 cal yr BP.

As discussed previously, severe fire events may be inferred by the presence of a large depositional response following the fire event and low-severity fire events may be inferred by a small depositional response. In the study area, as discussed previously, although many deposit boundaries are clearly distinguishable, some areas may produce such similarly textured deposits that deposit boundaries may be difficult to distinguish, promoting a bias in defining deposits as “large”, due to apparent thickness, even though they may represent several depositional events. Although the depositional response to a severe fire event may result in multiple deposits of similar texture, it is unavoidably difficult at times to assess the relative size of response to a fire event. However, a range of deposit thicknesses are represented in the dated sections and the following criteria was used conservatively to infer the size of the corresponding fire event.

“Large” fire-related events are defined as debris-flow or hyperconcentrated-flow deposits thicker than 50 cm that contain abundant coarse angular charcoal. I tentatively consider these deposits as proxies for higher-severity fires. Deposits of "small" fire-related events do not meet the above criteria, but nonetheless include abundant charcoal or overlie a burned surface, and are considered proxies for lower-severity fires. Based on the cumulative probability curve for large events (Figure 10), peaks in severe fire activity occurred around 1350 and 1700 cal yr BP. For low-severity events, a peak occurs around 2750 cal yr BP and multiple significant peaks between 700 – 150 cal yr BP. Based on these curves, although the determination of large and small events involves substantial uncertainty, the period between 2900 and 1200 cal yr BP appears to be dominated by severe events and the period between 800 cal yr BP and present appears to be dominated by small events.

In agreement with the cumulative curve for low-severity events (Figure 10), deposits between 870 cal yr BP to present (weighted average range) tend to be less than 50 cm (Figure 4). However, in Station 11, over 50 cm of hyperconcentrated-flow to debris-flow material may have been deposited following a fire between 490 – 150 cal yr BP (based on rounded 2σ ranges from Figure 8), with matrix charcoal lightening with decreased depth in the section. However, these deposits could also have been the result of three separate fire events during this time period, based on the alternating darkening and lightening of sediment. The best record close to Station 11 which could be used for comparison is a burned surface, overlain by a very small debris-flow deposit, in Station 7 which significantly overlaps the 1σ and 2σ ranges of these dates. Partially eroded burned surfaces are common during this time period, and in Station 7 it is still possible the debris-flow deposit overlying the compared burned surface may have been eroded. Although the 1σ ranges overlap less than the 2σ ranges (Figure 8) a burned surface in

Station 1, overlain by a large debris-flow deposit, may correspond to the same fire event as the deposits in Station 11, if they correspond to the same fire event. Therefore, it is difficult to assess whether around 400 cal. BP, a large or small response to fire was recorded, however, the general period of interest is still dominated by small deposits, and likely, lower-severity fire events, insofar as deposit thickness can be used as a measure of severity in this study area.

As above, based on Figure 4, it is apparent that dated deposits between 1710 – 870 cal yr BP (weighted average range) tend to be 50 cm or greater and therefore may represent severe events. As discussed previously, deposit boundaries may be difficult to distinguish between similarly textured deposits, however, the deposit thicknesses are not unreasonable for single deposits. Of particular note, Station 13 displays multiple distinct deposits which may, based on the overlap of dates, have been related to the same fire event (sample identifiers 3, 7 and 8). Taken separately, only the upper most deposit would be considered a large deposit, and taken together, the group also represents a large deposit. Therefore, the general period of interest is still dominated by large deposits, and possibly, severe fire events, insofar as these large deposits represent approximate depositional response following severe events.

Also based on Figure 4, between 5150 and 1710 cal yr BP (weighted average) it is likely a range of thicknesses is recorded and no particular dominance in inferred fire severity, although it is increasingly difficult at times to delineate deposit boundaries and therefore determine deposit thickness. However, it is notable that as deposit age increases, relative to previous time periods, the occurrence of possible clay lamellae increase, further suggesting these structures may have required a sufficient time to form and may indeed be clay lamellae.

Other work (outlined in Rawling, 2000) has suggested that increased development time may promote a stronger expression of lamellae. However, further evidence to support soil formation, such as the accumulation of organic material (possible A horizon) at the top of a deposit, were not noted in sediment below the top 20 cm in most sections, although some do not even show darkening, due to organic accumulation, at the inferred deposit top. Soils may not have been significantly developed or they may have been eroded away.

Fire Events

Due to the small size of the study area, it is possible that an individual fire event may be recorded at multiple stations. Although it is difficult to infer individual fire events, based on the possible sampling and radiocarbon dating errors discussed previously, single fire events or several events close together may result in several or more clustered sample ages. Since the dates presented in this work do show some clustering of weighted averages and 1σ and 2σ ranges (Figure 8), the possibility of overlapping records from single or contemporaneous fire events is considered.

When considering clusters of dates, a weighted-average age provides a single-value measure of age, but it is the least reliable as a standard of comparison between deposits and should only be considered along with 1σ and 2σ ranges. Although comparing 1σ ranges increases the probability that grouped samples are associated with the same fire event, it also increases the possibility that the groupings over-estimate the number of fire events interpreted, due to the fact that 1σ represents minimum error.

Although 2σ ranges are more reliable, more samples may be grouped to support fewer fire-events than the number which may have actually taken place. Therefore, discussion of date clustering as evidence of a single fire event is limited to conservative speculation as supplementary analysis alongside analysis of the cumulative curves.

Based on the number of samples contributing to the cumulative distributions between 5300 and 2800 cal yr BP, only a few time periods contain enough large enough clusters of sample ages to suggest the possibility that these clusters represent single or contemporaneous events recorded in multiple locations. Based on clustering of parameters discussed above it is possible that between 3800 and 3700 cal yr BP, one severe fire event may be recorded and around 3600 cal. yr BP, one low-severity event may be recorded. Also, between 3000 – 2700 cal yr BP and 2000 – 1900 cal yr BP, one fire event may be recorded during each period. Additionally, between 1860 – 1070 cal yr BP, between 3 and 5 severe fire events may be recorded, although five severe events recorded over 600 years is unlikely. Finally, between 970 cal yr BP and present, between 4 and 6 low-severity fire events may have been recorded. However, in Station 10, due to the presence of one distinct, likely fire-related debris flow and two overlying burned surfaces which all have ages which lie between a total 1σ range of 670 – 550 cal yr BP and 2σ range of 680 – 540 cal. yr BP (both σ ranges in this case have been rounded to nearest tenth), it is likely these are three separate events which occurred between 680 and 540 cal yr BP (see Appendix 2 for a more detailed discussion). Therefore, between 1000 cal yr BP and present, between 5 and 7 low-severity fire events may have been recorded.

Based on the average number of fire events over the intervals analyzed, the rounded recurrence interval for 1860 – 1070 cal yr BP is 200 yrs and for 970 cal yr BP to present is160 yrs. Although the error inherent in this analysis has been discussed and though these intervals are not too dissimilar, it is possible that recorded fire events in the last 1000 years may have been more frequent than in period between around 1900 and 1000 cal yr BP which would agree with the different relative fire frequencies expected between severe and low-severity fire regimes.

FIRE, SEDIMENTATION AND CLIMATE

Climate influences fire activity on interannual to centennial scales through complex changes in forest type, structure and fuel moisture. Short term climate change can result in fuel moisture changes, which can affect fire ignition in different ways for different forest types. Longer-scale climatic changes can shift entire ecotones, possibly changing the dominant fire regime altogether. Therefore, although current forest type, structure, and fire activity may provide baseline information, they may not reflect past conditions.

The study area currently contains both mixed-conifer and ponderosa pine stands and has likely been dominated by both forest types over the late Holocene (Anderson et al. 2008), with aspect playing a strong role in type as previously noted. However, rapid ecotone shifts in the Jemez Mountains, in recent times, favoring more xeric species at higher elevations than normal, has been associated with warming (Allen and Breshears 1998). Since mixed-conifer stands favor more mesic conditions that ponderosa pine stands it is possible that moister or drier conditions could have caused one or the other to dominate the study area in the past. This is of particular importance due to the fact that different forest types respond to fire ignition in different ways.

It has been suggested, based on historical accounts, that ponderosa pine stands in the Southwest should have a naturally open, park-like structure (Covington and Moore, 1994). In open ponderosa pine stands, it has been suggested that wet years can build up ladder fuels and promote fire, with an average of a two year lag (Swetnam, 1990; Touchan et al., 1996, Swetnam and Baisan, 1996; Allen et al., 1995). Additionally, fire-scar records indicate that frequent, low-severity fires have been dominant over severe fires for the most recent ~400 years (Allen, 2001; Touchan et al., 1996), coincident with accounts of open ponderosa pine structure (Allen, 2001). However, in the western US, it has been suggested that even in open ponderosa-pine stands, multidecadal wet intervals followed by prolonged severe drought, may result in large canopy fires (i.e., severe fire, Pierce and Meyer, 2008).

Unlike ponderosa-pine stands, mixed-conifer stands tend not to show a relationship between fire and precipitation in preceding years (Swetnam, 1990; Touchan et al., 1996) and it has been suggested that decreased canopy fuel moisture is a more important factor in initiating fires for this forest type. Mixed-conifer stands may also produce an understory structure and composition which is not as conducive to the spread of surface fires and may sustain fires at a lower frequency than ponderosa-pine stands (Swetnam and Baisan, 1996). Therefore, based on this information it is possible that frequent, low-severity fires are more likely supported by less variable climatic conditions and open forest structure whereas less frequent, severe fire may be more likely to initiate in thicker ponderosa-pine stands or unusually dry mixed-conifer stands, both of which are supported by longer-scale wetter than average conditions followed by drought.

Although conditions which favor fire initiation are important, it is also necessary to consider conditions which support a distinctive fire regime over time. It was found that after severe fires in Southwestern ponderosa-pine forests within the last century, most areas recovering from severe burns developed a structure which made them vulnerable to further severe fire, either through the development of high densities of young trees or samplings, or through a shift to a slightly different vegetation regime which was also susceptible to severe fire (Savage and Mast, 2004). They suggest in the event that severe fire produces a recovery stand which is vulnerable to further severe fire, this cycle may continue until the seed source is exhausted. In only a few cases Savage and Mast (2004) found that forest structure became more open as a result of severe fire, promoting future low-severity fire in the decades following. Therefore, although multiple recovery pathways are possible following a severe burn, distinctive climatic shifts may alter forest structure and fire regime for decades or longer through fire.

Fire histories suggest that regional precipitation changes can affect the timing and characteristics of fires in the Jemez Mountains (Allen et al., 1995; Touchan et al., 1996) and Southwest in general (Swetnam, 1990; Swetnam and Baisan, 1996; Grissino-Mayer and Swetnam, 2000). The most important control on climate at the annual to interdecadal scale in the Southwest is the El Niño Southern Oscillation or ENSO (Swetnam and Bentancourt, 1998). El Niño and La Niña events tend to correspond to reduced fire activity and peak fire years, respectively, due to changes in average precipitation and seasonal variability (Swetnam, 1990; Swetnam and Bentancourt, 1998). Longer timescale oscillations such as the Pacific Decadal Oscillation (PDO) and the Atlantic Mutidecadal Oscillation (MDO) modulate the strength of ENSO events in the Southwest and may account for mutidecadal variations in fire regime (Frechette and Meyer, 2009). Additionally, drought is an important climatic condition in the Southwest and in general has been linked to elevated fire activity (Pierce and Meyer, 2008). Therefore, over the period considered in this work, droughts recorded in the Southwest, persisting over decades to centuries, could potentially influence fire activity in the Jemez Mountains.

Although alluvial chronology only provides centennial-scale resolution of possible fire activity for a study area, it does provide an important historical perspective. It is applicable for considering the natural range of variability of fire activity in comparison to the climatic factors discussed previously. The results discussed below provide a 5300 year record of fire occurrence in the study area can be partitioned into three separate periods, based on the inferred dominant fire regime (Figure 10): 5300 – 1900 cal yr BP, 1900 – 1000 cal yr BP and 1000 cal yr BP to present.

5300 – 1900 years BP

In general, the period from 5300 to 1900 years BP in the study area is one in which both low-severity and severe fire events may be recorded. Records of fire activity from 5300 to 3000 years BP in the study area are not as well supported as records closer to present, where more dates are available to support the likelihood of fire activity. However, this part of the record will still be considered in this discussion for the purposes of considering the entire record, especially two periods with a significant probability of fire-related sedimentation, 2850 – 2750 cal yr BP and 2050 – 1950 cal yr BP.

Two samples indicate fire activity between 3700 and 3900 cal yr BP, possibly of high severity. Around 100 years prior to this time, paleoclimate records suggest an end to dry, warm conditions in southern New Mexico and central Arizona (Rasmussen et al., 2006; Buck and Monger, 1999; Davis and Shafer, 1994), and the beginning of wetter conditions in northern Mexico (Holmgren et al., 2007; Castiglia and Fawcett, 2006). Subsequently, between 3650 and 3550 cal yr BP, a minor peak in fire-related sedimentation is indicated by two samples, one of which suggests low-severity fire. Paleoclimate records imply drier conditions at this time in Arizona and southern Utah (Ely, 1997).

As mentioned previously, two significant periods of fire activity fall between 2850 and 2750 cal yr BP and 2950 – 2000 cal yr BP. The period between 2850 and 2750 cal yr BP is supported by 4 samples which record the possibility of low-severity and/or severe fire activity. Paleoclimate records suggest that this peak in fire activity occurs during an extended dry period in southern Utah (Ely, 1997). Within 100 years prior to and after this peak, relatively cold or wet periods are recorded, including a periglacial event in northeastern New Mexico (Armour et al., 2002) around 2800 ^{14}C yr BP, corresponding to a calibrated weighted average age of ~2940 cal yr BP (Appendix 3). Following the fire activity, an inferred peak in wet conditions in southern New Mexico is recorded around 2700 years BP (Asmerom et al., 2007). The period between 2950 and 2000 cal yr BP is supported by 3 samples which record the possibility of low-severity and/or severe fire activity. Paleoclimate records suggest a shift from wet to dry conditions around 2000 years BP in northern Mexico (Buck and Monger, 1999). Although other records suggest preceding and following conditions may have been warm and/or dry (Figure 10), they do not significantly overlap this peak in fire activity.

As a fire history comparison, Pierce et al. (2004) suggest the period from 3000 to 2800 cal yr BP may have been cool and wet due to a relative minimum in fire-related sedimentation for their study area in central Idaho. The presented fire record (Figure 10) suggests severe fire events between 2850 and 2750 cal yr BP, following a peak in cool, wet conditions (Asmerom et al., 2007) and coincident with a periglacial event (Armour et al., 2002).

In general, fire activity appears to be associated with climatic shifts during this period, particularly shifts in precipitation. Although it is difficult to make assertions regarding fire severity and climate during this period, it is possible that severe fire may be associated with wetter conditions and low-severity fire activity may be associated with dry conditions.

1900 – 1000 years BP

The period from 1900 to 1000 years BP in the study area is dominated by severe fire activity. Two peaks in probability of fire-related sedimentation occur over this period at roughly 1700 cal yr BP and 1350 cal yr BP. Including charcoal dates associated with an age inversion, the probability of fire activity over this period remains high between 1700 and 1350 cal yr BP, with a separate minor peak between 1300 and 1200 cal yr BP. The fire activity recorded is supported by a total of 15 samples.

During this period, persistent warm and dry conditions are suggested in southern Colorado and New Mexico at different times which when combined, extend over almost the entire period (1950 – 1550 years BP and 1350 – 1250 BP: Routson et al., 2011; 1700 – 1300 years BP: Polyak and Asmerom, 2001; Polyak et al., 2001). The period of aridity between 1950 – 1550 years BP recorded by Routson et al. (2011) contains a megadrought between 1828 – 1778 years BP with the driest period centered around 1787 years BP. Both peaks in fire-related sedimentation recorded by this work (Figure 10) occur within a decade of the severe drought, 1828 – 1778 years BP, and the 1350 – 1250 period of aridity recorded by Routson et al. (2011).

Other paleoclimate records for this time period vary in interpretation and relevance to the fire record. Of the paleolake records compiled by Castiglia and Fawcett (2006) for the Southwest, none show significant lake levels between ~1600 – 1400 cal yr BP. Additionally, tree-ring precipitation reconstructions from west-central New Mexico show persistent dry conditions from 1650 – 1450 years BP (Grissino-Mayer, 1996). However, major peaks in fire-related sedimentation also correspond roughly with peaks in precipitation in this tree-ring record, as well as a peak in flood activity in the Southwest at 1350 years BP (Hardin et al., 2010), suggesting that perhaps wetter periods promoted fuel buildup conducive to higher severity fires, and (or) that heavier precipitation promoted fire-related sedimentation. Finally, PDSI records (Figure 10) suggest that a gradual shift occurred around 1000 yr BP from relatively wet to relatively dry conditions. This shift may have promoted a change in fire regime to a more fuel-limited system promoting low-severity events. This is supported by the results, which show the expected shift in fire-regime from a period dominated by severe activity to one dominated by low-severity activity.

Although paleoclimate records seem to conflict for this time period, records show a combination of extensive droughts (Routson et al., 2011), general aridity (Polyak and Asmerom, 2001; Polyak et al., 2001, Castiglia and Fawcett, 2006) and wetter conditions on average, relative to the following millennia, according to PDSI records. This suggests that during non-drought years, ladder fuels may have accumulated promoting fire activity during droughts, due to reduced fuel moisture, and severe fires may have become more likely. Fire-related sedimentation may have also been favored due to average wetter conditions following the drought periods that may have promoted severe fire activity.

Considered along with the fact that El Niño frequency increased between ~2150 – 1450 years BP (Conroy et al., 2008), it may be that climatic variability was large enough to sustain a high-severity fire regime during this period. Additionally, within this approximately 900 year time period there may have been deposits stemming from low-severity fires that were lost due to erosion by high-severity fire-related sedimentation events.

1000 years BP to Present

In general, the period from 1000 years BP to present in the study area is one marked by a dominance of low-severity fire activity, which may have also occurred at a relatively high-frequency, based on short-term, high resolution fire histories of the Jemez Mountains (e.g., Swetnam and Baisan 1996). A minor period of increased probability lies between 900 and 800 cal yr BP, supported by 2 samples. Significant periods of fire activity occur between 700 – 575 cal yr BP (5 ages) and 525 – 275 cal yr BP (7 ages). Fire activity over the last 200 years of the record most likely occurred during one of two major peaks, 225 – 125 cal yr BP and 25 cal yr BP to present (3 ages). However, significant uncertainty is associated with the relative magnitude of peaks between ~400 years BP to present and their association with an actual fire event, due primarily to the fact that the radiocarbon calibration curve representing the past ~300 cal BP is shaped such that there is a greater likelihood that a single radiocarbon date (with standard error) will intersect the calibration curve in multiple places, with those places also being further apart temporally than most other parts of the calibration curve (Reimer et al., 2004).

Although many paleoclimate records show generally drier conditions over the most recent 1000 years BP, in the Southwest some have recorded notable droughts, shifts in climate and periods that may have been wetter than average. Precipitation shifts become more frequent during this period, relative to the previous 1000 years (Grissino-Mayer 1996; Figure 10). Additionally, El Niño frequency increased between ~850 – 650 years BP and between ~100 years BP to present (Conroy et al., 2008). Salzer and Kipfmueller (2005) also report high decadal and multi-decadal scale variability in temperature and precipitation, near the Four Corners area, during the Medieval Warm Period (1050 – 650 years BP, Cook et al., 2007; Lamb, 1977) and Little Ice Age (400 – 100 years BP, Lamb, 1977).

In general, significant peaks in possible fire-related sedimentation during this period occur close to records of drought which overlie records of warm, dry intervals, or shifts in climate from wet to dry conditions. Periods in which severe fire-related sedimentation response was recorded in conjunction with low-severity fire-related sedimentation response, occur close to records of frequent flooding and short-term cool conditions in southern Utah and northern Arizona (Ely, 1997; Salzer and Kipfmueller, 2005).

Fire-related sedimentation between 900 and 800 cal. yr BP overlaps the Medieval Warm Period from 1050 to 650 cal. yr BP (Cook et al., 2007; Lamb, 1977). Other paleoclimate records also suggest warm, dry conditions at 1200 – 800 years BP in southern New Mexico (Rasmussen et al., 2006), and at 900 – 800 years BP in southern New Mexico (Polyak and Asmerom, 2001; Polyak et al., 2001), as well as four major megadroughts within the interval 1050 – 650 years BP in the western USA (Cook et al., 2004b), and the drying of a bog surface at 1000 years BP in northeastern New Mexico (Jimenez-Moreno et al., 2008). Also during this period, Ely (1997) records a decline in the frequency of extreme floods in Arizona and southern Utah from 800 to 600 years BP, and a shift from moist to drier conditions is recorded at 1000 ^{14}C years BP (912 cal. yr BP, weighted average, Appendix 3) in Oklahoma and Texas (Hall and Permian, 2007; Hall,1990). However, a mixed-severity response may have been recorded over this period, possibly involving a range of depositional response from low-severity to severe.

Fire-related sedimentation between 700 and 575 cal yr BP also overlaps the late Medieval Warm Period and transition to the early Little Ice Age (Cook et al., 2007; Lamb, 1977). Other paleoclimate records during this time suggest warm, dry conditions at 900 – 600 years BP in southern Colorado (Routson et al., 2011), a decrease in large floods at 800 – 600 years BP in Arizona and southern Utah (Ely, 1997), and a severe multidecadal drought around 670 – 650 years BP in a broad region centered on the Four Corners area (Cook et al., 2007). However, generally higher precipitation in west-central New Mexico is also recorded between 950 – 550 years BP (Grissino-Mayer and Swetnam, 2000) as well as a brief cool period around 600 years BP in southern Utah and northern Arizona (Salzer and Kipfmueller, 2005).

Fire-related sedimentation between 525 and 275 cal yr BP occurs when paleoclimate records suggest warm, dry conditions between 550 and 140 years BP in west-central New Mexico (Grissino-Mayer and Swetnam, 2000), and a possible switch from wetter conditions to drier conditions. Frequent floods are recorded at 500 – 400 years BP in Arizona and southern Utah (Ely 1997), with peaks in flood activity in the Southwest at 480 and 350 years BP (Hardin et al., 2010), which may also correlate with a possible mixed-severity response in the study area, if the same was true for the Jemez Mountains. Following this recorded increase in flooding, a megadrought was recorded around 375 years BP in the Southwest (Stahle et al., 2000), corresponding to a major peak in fire-related sedimentation in the study area. Other droughts were also recorded at 350 years BP in northeastern New Mexico (Jimenez-Moreno et al., 2008) and at 285 – 280 years BP over much of the western USA (Cook et al., 2007). A shift from wet to dry may also have promoted a mixed-severity response, or if fire activity occurred before this shift, increased flooding may have promoted a mixed-severity response in a low-severity fire regime.

Lastly, although records are difficult to correlate in the most recent 400 years BP, due to the limitations of radiocarbon dating, possible fire-related sedimentation between 225 and 125 cal yr BP would have occurred near a very large shift in interannual precipitation recorded at 202 – 203 years BP from PDSI records for the southwest US (Swetnam and Bentancourt, 1998).

Mentioned previously, it has been suggested that El Niño frequency generally increases during the last 400 years of the fire record (Conroy et al., 2008; Salzer and Kipfmueller, 2005). Although Grissino-Mayer and Swetnam (2000) propose a dry period from 550 to 140 years BP, Ely (1997) records a period of enhanced and frequent precipitation between 500 years BP and present. These records overlap the Little Ice Age period (400 – 100 years BP) which is generally considered to be a cool period over the Northern Hemisphere (e.g. Mann et al. 2008), but may also be marked by high variability in interannual temperature (Salzer and Kipfmueller, 2005). The occurrence of fire events and fire related-sedimentation suggests climatic variability, and the expression of a low-severity fire regime in the study area may correlate to a generally cooler and effectively wetter Little Ice Age that promoted the growth of grasses and other fine surface fuels (Pierce et al., 2004).

Some fire records for this period (1000 yr BP to present) agree with the record presented as well. Meyer et al. (1995; Yellowstone National Park, WY) also suggest a major peak in fire-related sedimentation around 850-800 cal yr BP, coincident with the western US megadrought between1050 – 650 years BP (Cook et al., 2004b). Pierce et al. (2004; central Idaho) also infer severe fire during the Medieval Warm Period and low-severity fire during the Little Ice Age. Additionally, Frechette and Meyer (2009; Sacramento Mountains, NM) show a major peak in fire-related sedimentation coincident with the Four Corners area megadrought between 670 – 650 years BP (Cook et al., 2007). The Jemez Mountains study area also shows a peak in low-severity fire-related sedimentation at that time (Figure 10), in agreement with severe drought conditions. Finally, Frechette and Meyer (2009) and Bigio et al. (2010; San Juan Mountains, CO) suggest low-severity fire and infer higher climatic variability during 500 – 100 cal. years BP and 300 – 150 years BP, respectively. Although the record presented here does not record any severe fire events from 300 years BP to present, Bigio et al. (2010) and Margolis and Balmat (2009; north-central NM) each suggest some mixed-severity to severe fire activity during this period.

Large-scale Patterns in Fire Regime

Based on past work (i.e., Savage and Mast, 2004) and the results presented here, there likely exists an interplay between climate and forest type in the Jemez Mountains, where climatic shifts may cause a shift in forest type or structure such that a new fire regime is promoted which may be unique compared to the past. It may be that regardless of minor climatic change, after a new regime is established this regime may tend to reinforce a forest structure which promotes this particular fire regime. As suggested above, severe fire may produce a recovery forest structure which promotes further severe fire, and low-severity fire may clear open spaces of saplings, therefore promoting an open forest structure more likely to support low-severity fires. These fire regimes could possibly persist for decades or longer in this self-reinforcing pattern under even variable climatic conditions, until conditions shift enough to perhaps allow the dominant fire regime to change (e.g., millennial-scale climatic changes such as the large scale PDSI shift around 1000 years BP or cycles such as the PDO and MDO which may modulate the strength of ENSO events in the Southwest). For example, a low-severity regime may persist until unusually wet or quiescent conditions allow ladder fuels to grow to the point when the structure becomes at risk for crown fire. Once established, a high-severity regime may persist until the ponderosa pine (or other recovery species associated with the ponderosa pine forest assemblage) seed source is reduced heavily or exhausted, allowing the landscape to persist with an open structure promoting low-severity fires. This possible model of behavior may account for the apparent switch to a severe-fire regime around 1900 years BP and the apparent switch to a low-severity fire regime around 800 years BP. Although it is likely during both periods a range of fire severity occurred, dominant fire severity may have been influenced by self-reinforcing patterns between climate forest structure and fire severity.

CONCLUSIONS

FIRE HISTORY

In summary, the period from 5300 – 1900 years BP does not appear to be dominated by a particular fire regime and general fire activity appears to be associated primarily with shifts in precipitation, although it is difficult to make assertions during this period. However, the period from 1900 to 1000 years BP contains major peaks in fire activity, coincident with persistent warm and dry conditions in the Southwest. Both peaks in fire activity during this period occur within a decade of a megadroughts and a period of aridity. However, major peaks in fire-related sedimentation also correspond roughly with peaks in precipitation as well as a peak in flood activity in the Southwest, suggesting that perhaps wetter periods promoted fuel buildup conducive to higher severity fires, and (or) that heavier precipitation promoted fire-related sedimentation. Finally, PDSI records suggest that a gradual shift occurred around 1000 yr BP to drier conditions. This shift may have promoted a change in fire regime to a more fuel-limited system promoting low-severity events. This assertion agrees with the following period, from 1000 years BP to present, which is marked by a dominance of low-severity fire activity. Although many paleoclimate records show drier conditions over this period, some have recorded notable droughts, shifts in climate and periods that may have been wetter than average. In general, significant peaks in possible fire-related sedimentation during this period occur close to records of drought which may also overlie records of warm, dry intervals, or shifts in climate from wet to dry conditions. Also, precipitation shifts appear to become more frequent during this period, relative to the previous 1000 years. The occurrence of fire events and fire related-sedimentation also suggests climatic variability, and the expression of a low-severity fire regime in the last ~500 years of the record may correlate to a cooler but not necessarily wetter, Little Ice Age.

Therefore, fire activity in the study area may have been influenced by shifts in climate with fire regime possibly influenced by relatively warmer or cooler conditions on average. In particular, peaks in fire-related sedimentation occur during regional, severe droughts recorded at 1828-1778 years BP (Routson et al., 2011) and 375 years BP (Stahle et al., 2000). It is possible that frequent, low-severity fires are more likely supported by less variable climatic conditions whereas severe fire may be more likely to initiate in forest stands which underwent longer-scale wetter than average conditions followed by drought. Additionally, climatic shifts may cause shifts in forest type or structure, which may be unique compared to the present and may influence fire regime over various timescales. In relation to modern fire events, although it is not apparently unusual for the study area to be characterized by severe fire events during parts of the record presented, modern severe fires in the Jemez Mountains appear anomalous compared to the previous 1000 years.

SLOPE ASPECT AND GEOMORPHOLOGY

Sedimentation events following a fire make up a 57% of the total thickness of all alluvial fan deposits analyzed, although the potential for bias toward exposures with fire-related sedimentation must be considered. However, it is likely that, fire has an important influence on hillslope erosion and fan sedimentation in the Jemez Mountains.

It was found that north-facing alluvial fans are dominated by fire-related deposits, which made up 77% of the total thickness of alluvial fans). South-facing fans appear to be dominated by non-fire related deposits, since fire-related deposits make up 39% of the total thickness of fans. Although no particular flow process (fire-related or otherwise) dominates either slope aspect, it may be that sedimentation more commonly the result of fire than other factors, on north-facing slopes. North-facing slopes may have a thicker cover of relatively permeable, weathered colluvium, anchored by a thicker, mesic forest structure, which may not be as susceptible to erosion unless these slopes are impacted by fire, which greatly increases surface runoff generation. South-facing slopes may produce substantial runoff and sedimentation during intense storms even in the absence of fire, due to sparser vegetation, a thinner cover of colluvium and more exposed bedrock.

The findings of this study clearly show that fire is an important geomorphic agent in the study area. Additionally, although north and south-facing fans are not dominated by a particular sediment transport type, there is nonetheless strong evidence that north-facing slopes have a moister microclimate which affects the processes of erosion and sedimentation in a unique ways relative to south-facing slopes.

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APPENDICIES

Appendix 1. Deposit Characteristics & Applicable Grain Size Information for Classification

Appendix 2. Select Station Notes and Drawings

Appendix 3. Outline of Paleoclimate and Fire History References

APPENDIX 1. DEPOSIT CHARACTERISTICS & APPLICABLE GRAIN SIZE INFORMATION FOR CLASSIFICATION

List of Abbreviations

LS – loamy sand
SL – sandy loam
S – sand
SiL – silt loam
sr – subrounded
sa – subangular
ang – angular
char – charcoal
gran – granule
peb – pebble
cob – cobble
bldr – boulder
resistant layer – possible clay lamellae; generally coat tops of clasts but also under clasts
PWT – platy weathered tuff
DF – debris flow
DF CL – debris flow cobble lobe
HCF – hyperconcentrated flow
HCF CL - hyperconcentrated flow cobble lobe
SF – stream flow
Poss. – Possibly fire related
Prob. – Probably fire related
Likely – Likely fire related
FR – fire related

STATION: MA 1 (Modern Analog 1; fan toe, W channel wall)						LAT: 13 S 0345925		LONG: 3972250	DATE: 6/17/2011
Depth (cm)	**Thick. (cm)**	**Lower Contact**	**Texture (fine/coarse) & % >2mm (from field obs.)**	**Max. b-axis**	**Charcoal**	**%Gravel/Sand/Silt+Clay (from lab)**	**Structure**	**Process**	**Sample #s**
				Sorting (GSD)		**Color (Dry)**			**Samples Dated**
				Clast Shape					**Grain Size Samples**
0	20	abrupt planar; slightly irregular	LS, up to coarse sand coarse fraction: gran-peb; cobble: 60%	cobble	very few ang. Char >2mm; some sr-ang char < 2mm	69.2/24.8/6	no apparent clast orientation of bedding; clast-supported	DF CL	1
-to-	-to-			>2.7					
10	n/a		%>2mm: 80	sr-sa		10YR/6/2			1
10	0	clear, very irregular	LS, up to coarse sand coarse fraction: gran-very fine peb	fine pebble	rare sa char >2mm; few sr char <2mm	0.4/60.5/39.1	alternating coarse sand-gran layers and very fine layers; fining upwards in some layers; layers <1cm-3cm thick	SF	2
-to-	-to-			2.2					
50	50		%>2mm: 3	sr-sa		7.5YR/5/2			2
50	100	very abrupt, slightly irregular	S, up to coarse sand; coarse fraction: (100cm): gran-fine peb; coarse fraction: (50cm): gran-peb; cob-bldr:50%	boulder	(50cm) no char >2mm and very few ang char <2mm; (100cm) same as at 50 cm	44.6/52.6/2.9	interfingering deposits in top 50-70 cm: no clast orientation of imbrication; moderate bedding; 70-105 cm: lenses of peb within low-angle scour-fill structure; weak clast orientation parallel to surface and weak imbrication	HCF	3, 4
-to-	-to-			2.3					
105	50		%>2mm: 25-75	sr-sa		7.5YR/5/2			3
105	25	clear, irregular	LS, up to coarse sand coarse fraction: gran-peb	pebble	char-layer (duff) at top 1-5cm	dark brown locally under duff lenses – possible weak A horizon (7.5YR/4/2)	weak lenses of peb; no bedding; weak clast orientation of peb parallel to surface	HCF	5, 6
-to-	-to-			2					
130	n/a		%>2mm: 50	sr-ang		120cm: 7.5YR/5/2			6
130	?	not exposed	SL, up to coarse sand coarse fraction: gran-fine peb	coarse pebble	fine, char-rich area at 140cm; irregular char with reddened sediment at 150cm	darkened sediment: 10YR/4/2	no bedding or clast orientation	DF	7, 8
-to-	-to-			4					
180	?		%>2mm: 25	sr-ang		7.5YR/5/2			7

STATION: MA 2
(Modern Analog 2; debris fan at base of channel)

LAT: 13 S 0345894 | LONG: 3971832 | DATE: 6/17/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process	Sample #s / Samples Dated / Grain Size Samples
0	240	based on observ-ed bottom of lobe	LS, up to coarse sand coarse fraction: gran-peb; cobble: 50% bldr: 10%	boulder	no char >2mm; common ang char <2mm	42.7/53.6/3.7	crude surface imbrication; no apparent clast orientation or bedding; many surface cob-bldr parallel to surface	**DF CL**	1,2
-to-	-to-			2.2					
40	n/a		%>2mm: 80	sr-ang		10YR/5/2			1

STATION: MA 3 (Modern Analog 3; matrix run-out)	LAT: 13 S 0345790	LONG: 3971893	DATE: 6/17/2011

Depth (cm)	**Thick. (cm)**	**Lower Contact**	**Texture (fine/coarse) & % >2mm (from field obs.)**	**Max. b-axis** / **Sorting (GSD)** / **Clast Shape**	**Charcoal**	**%Gravel/Sand/Silt+Clay (from lab)** / **Color (Dry)**	**Structure**	**Process**	**Sample #s** / **Samples Dated** / **Grain Size Samples**
0	0.3	based on obser-ved bottom run-out	LS, up to coarse sand coarse fraction: gran-peb; cobble: 50% cob <5%	cobble	no char >2mm; few ang char <2m	44.6/52.6/2.9	possible bedding <1cm, but difficult to see; coarse clasts tend to be on the surface (appear to be “sitting” on top of matrix), so crude surface-parallel orientation of peb-cob	**DF**	1
-to-	-to-			>4.2					
3-15	15		%>2mm: 30-35	sr-ang		7.5YR/6/2			1

STATION: 1
(mid-fan channel wall)

LAT: 13 S 0346034 | LONG: 3972325 | DATE: 6/1/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
0	70	abrupt, irregular	LS, up to coarse sand coarse fraction: 30%, gran-peb, 20% peb-bldr	boulder	local ang char up and down section (fine-very coarse), especially at the bottom of the deposit	37.9/50.9/11.2	darker top around 20cm thick; 7.5YR/5/2; organic material and fine char; clast-matrix support, no clast orientation or bedding	**DF (likely)**	1, 2
-to-	-to-			3.4					
70	n/a		%>2mm:50	sa-ang		5YR/6/1			2
70	55	abrupt, irregular	LS, up to coarse sand coarse fraction: gran-peb	pebble	see structure; lower 30cm contains abundant 4-6mm ang char	22.7/42.9/34.4	70-80cm: continuous layer of fine-coarse char 82-84cm: lens of fine char, ~30cm long. In general, alternating coarse-fine layers from top to bottom: char, fine, coarse, char, coarse, fine-coarse, coarse, very coarse	**DF (prob.)**	3-22
-to-	-to-			3.7					11, 14
125	n/a		%>2mm: 25	sa-ang		10YR/5/2			13
125	25	abrupt, irregular	LS, up to coarse sand coarse fraction: gran-peb	pebble	abundant coarse char up and down section and distinct char layers <1cm with 1-3cm ang char	11.4/46.4/42.2	darker layer: 10YR/4/2 Top and bottom darker with fine char (4-6c thick), and coarse-fine layer in between	**DF (prob.)**	23-39
-to-	-to-			3.7					28
150	n/a		%>2mm: 5	sa-ang		7.5YR/6/2			30
150	40	abrupt, irregular	LS, up to coarse sand coarse fraction: gran-coarse peb	boulder	minor small 1-2mm ang char	54.1/35.5/10.4	matrix-supported; no clast orientation or bedding. Deposit overlies burned surface or char-rich grey deposit in much of the channel wall near the section	**DF (poss.)**	40-51
-to-	-to-			>3.5					44
190	n/a		%>2mm: 55	ang		10YR/6/2			51
190	20	abrupt, irregular	LS, up to coarse sand coarse fraction: gran-peb	pebble	discontinuous char burned surface at 200cm	30.2/47.8/22.1	rough fining-up from bottom 20cm; irregular top ~10-15cm interbedded char layer, layer of granule and finer discontinuous up/down stream	**DF (prob.)**	52-66
-to-	-to-			3.5					54
225	35		%>2mm: 40	sa-ang		10YR/6/2			66

STATION: 1 (continued) (mid-fan channel wall)	LAT: 13 S 0346034	LONG: 3972325	DATE: 6/1/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
225	50	abrupt, irregular	LS, up to very coarse sand coarse fraction: gran-peb	fine pebble	2 char layers: 245 cm (2cm thick) with dark matrix; at 265cm (10 cm thick)	2.1/29.1/68.8	top 20-25cm is very fine with 1-2, 1-5cm gran layer (discontinuous); bottom 20cm marked by scour-fill and <=2mm size material	**SF (prob.)**	67-82
-to-	-to-			2.3					72
275	n/a		%>2mm: 30	sa-ang		7.5YR/7/2			81
275	40	clear, very irregular	LS, up to very coarse sand coarse fraction: gran-peb	boulder	few, slightly rounded <3cm	28.4/44.3/27.3	no bedding or matrix support; deposit overlies darkened layer with charcoal	**DF**	83-89
-to-	-to-			4.1					
305	n/a		%>2mm: 40	sa-ang		7.5YR/7/2			89
305	45	not exposed	LS, up to coarse sand coarse fraction: gran-peb	cobble	abundant fine char <3cm, some >3cm near top of layer	44/36.7/19.3	matrix supported; some darkened lenses (fine char?)	**DF (prob.)**	90-105
-to-	-to-			>4.3					92
350	n/a		%>2mm: 30	sa-ang		10YR/6/2			105

STATION: 2 (mid-fan channel wall) | LAT: 13 S 0345896 | LONG: 3971752 | DATE: 6/2/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
0 -to- 120	120 / n/a	clear, irregular	SL, up to very coarse sand coarse fraction: gran-coarse peb; %>2mm: 30	cobble; pebble below 50cm / 3.8 / sa-ang	abundant angular char, some >2mm, many <2mm	7: 19.7/46/34.3 18: 36.8/31.4/ 31.8 / 7.5YR/5/2	no bedding; crude clast orientation parallel to flow direction; matrix supported; top 70cm more poorly sorted	**DF (prob.)**	1-15, 18 / 2 / 7, 18
120 -to- 135	15 / n/a	abrupt, irregular	SL, up to very coarse sand coarse fraction: gran-peb; %>2mm: 40	pebble / 3.6 / sa-ang	abundant ang char <2mm	27.7/58.5/ 13.8 / 10YR/5/3	no bedding or apparent clast orientation; matrix-clast supported	**DF (prob.)**	16, 17, 19-23 / 23 / 19
135 -to- 150	15 / n/a	abrupt, irregular	SL, up to very coarse sand coarse fraction: gran-peb; %>2mm: 20-25	coarse pebble / 3.6 / sa-ang	common ang char <2mm	17.6/45.7/ 36.6 / 10YR/5/2	no bedding; matrix supported; no apparent clast orientation	**DF**	24-35 / / 35
150 -to- 170	20 / n/a	abrupt, irregular	SL, up to very coarse sand coarse fraction: gran-cob; %>2mm: 65-70	cobble / >2.2 / sa-ang	common <2mm char in fine fraction	9.6/69.5/20.8 / 7.5YR/5/2	some cobble oriented parallel to surface/flow direction; discontinuous fines layer <2mm, under parallel-oriented cobbles	**DF CL**	36-40 / / 39
170 -to- 220	50 / n/a	clear irregular	SL, up to very coarse sand coarse fraction: gran-peb; %>2mm: 20	pebble / 3.5 / sa-ang	abundant ang char, common >2mm, abundant <2mm	13.9/50.2/36 / 10YR/4/2	no bedding or apparent clast orientation; matrix supported	**DF (prob.)**	41-55 / 52 / 55

STATION: 2 (continued)
(mid-fan channel wall)

LAT: 13 S 0345896 LONG: 3971752 DATE: 6/2/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
220 -to- 255	35 -to- n/a	clear irregular	LS, up to very coarse sand coarse fraction: 40% cob, 30% gran-peb %>2mm: 70	coarse cobble >3.1 sa-ang	common <2mm char with slight rounding	63.3/28.8/8 7.5YR/6/2	possible crude parallel clast orientation (to flow direction); no bedding; possible imbrication of cobbles; could be debris levee or surface lag, similar to modern cobble lobes on fans and levees	**DF CL**	56-64 63
255 -to- 310	n/a -to- n/a	not exposed	LS, coarse fraction: gran-peb %>2mm: 20-30	coarse pebble 3.9 sa-ang	minor (few) <2mm char, very few >2mm with minor rounding	23.1/49/27.9 7.5YR/6/2	no bedding or clast orientation	**DF**	65-78 77

STATION: 3 (upper-fan channel wall) | LAT: 13 S 0345557 | LONG: 3971778 | DATE: 6/7/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
0	50	abrupt, irregular, defined by top of fine layer	SL, up to coarse sand coarse fraction: gran-fine cob	coarse pebble-fine cobble	common-abundant ang char > and < 2mm	21/63.3/15.7	A horizon from 0-40cm (10YR/4/2); no apparent clast orientation or bedding; matrix-clast supported. Cumulative grain-size curve appears similar to others in this section, as well as other HCF curves.	**HCF (likely)**	1-5, 7-16
-to-	-to-			3.0					3
80	100		%>2mm: 50	ang		7.5YR/5/2			19
80	0	abrupt, irregular, defined by bottom of fine layer	SL, up to coarse sand coarse fraction: gran-pebble (with a few cob)	cobble	abundant ang char < 2mm; some ang char >2m	12.1/71.2/ 16.7	poorly sorted deposits interfingering fine <1cm layer; crude clast orientation parallel to flow direction	**HCF (prob.)**	6, 17-31
-to-	-to-			2.4					17
125	30		%>2mm: 45	sr-ang		10YR/5/2			30
125	120	not exposed	LS, up to coarse sand coarse fraction: gran-cob	cobble	abundant ang char < 2mm; some ang char > 2mm	15.5/67/17.5	layer may be composed of many <50cm deposits, but difficult to identify boundaries; 130-160: up to 70% coarse fraction: with ang cob; 160-250: 40% coarse fraction: with few cob, mainly gran-peb; 250-300: gran-peb with crude scour-fill structure	**HCF (poss.)**	32-51
-to-	-to-			2.5					39
300	n/a		%>2mm: 40-60	sr-ang		10YR/5/2 – 10YR/6/2			51

STATION: 4 (mid- upper fan channel wall) | LAT: 13 S 0347694 | LONG: 3972607 | DATE: 6/9/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
0	155	abrupt, irregular, defined by top of resistant layer	SL, up to coarse sand coarse fraction: 40%, gran-peb with 5% bldr	cobble-boulder	common ang char <2mm; very few ang char >2mm	50.9/28.1/21	possible A horizon from 0-50cm (up to 100cm): 30cm (10YR/4/2), 70cm (10YR/4/2); no bedding or clast orientation; more gran-peb rich in pats of bottom 10cm; matrix supported	**DF**	1-15
-to-	-to-			>4.4					
155	n/a		%>2mm: 40-45	sr-ang		105cm: 10YR/5/2			15
155	25	abrupt, irregular, defined by top of resistant layer	155-163cm: LS, up to coarse sand; coarse fraction: 70% gran-peb	pebble	some rounded <2mm; none >2mm	69/27.6/3.3	155-163cm: normally graded (peb-gran), crude imbrication; 163-170cm: normally graded (peb-gran), possible crude imbrication; 170-180cm: no grading or clast orientation	**HCF**	16
-to-	-to-			2.1					
180	n/a		%>2mm: 70	sr-ang		10YR/5/2			16
180	30	abrupt, irregular	LS, up to coarse sand; coarse fraction: 25% gran-peb, 25% cob-bldr	cobble	many ang char <2mm; none>2mm	29.6/65.5/4.8	no bedding or apparent clast orientation	**HCF**	17-27
-to-	-to-			1.8					
210	n/a		%>2mm: 50	sr-ang		7.5YR/6/2			27
210	40	clear, irregular	fine ortion: SL, up to coarse sand; coarse fraction: gran-peb, 59% cob	pebble	common ang char <2mm; very few ang char >2mm	28: 35.3/36.3/28.4 30: 70.1/24.3/5.6	alternating coarse and fine layers: coarse layers: peb-sand, clast supported, some alternating peb and course sand lenses; fine layers: peb-mud, matrix supported, no clast orientation, local rare grading (peb layer on gran layer), irregular boundaries between layers	**DF**	28-31, 33-34
-to-	-to-			4.6					
250	n/a		%>2mm: 40-65	sr-ang		10YR/5/3			28, 30

STATION: 4 (continued)
(mid- upper fan channel wall)

LAT: 13 S 0347694 | LONG: 3972607 | DATE: 6/9/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
250	25	clear, irregular	LS, up to coarse sand; coarse fraction: gran-peb	pebble	common rounded char <2mm; very few ang char >2mm	28.6/47.8/ 23.6	no bedding or clast orientation	**DF**	32, 35-43
-to-	-to-			3.8					
275	n/a		%>2mm: 45	rounded-sa		10YR/5/2			45
275	?	not exposed	LS, up to coarse sand; coarse fraction: 50% gran-peb, 10% cob-bldr	boulder	few rounded char <2mm; none >2mm	57.3/37.3/5.4	no bedding or clast orientation; clast supported	**HCF**	44
-to-	-to-			2.7					
300	n/a		%>2mm: 60	rounded-sa		10YR/6/2			44

STATION: 5 (mid- upper fan channel wall)						LAT: 13 S 0347685	LONG: 3972584	DATE: 6/14/2011	
Depth (cm)	**Thick. (cm)**	**Lower Contact**	**Texture (fine/coarse) & % >2mm (from field obs.)**	**Max. b-axis**	**Charcoal**	**%Gravel/Sand/Silt+Clay (from lab)**	**Structure**	**Process (Fire relation)**	**Sample #s**
				Sorting (GSD)		**Color (Dry)**			**Samples Dated**
				Clast Shape					**Grain Size Samples**
0	60	abrupt, irregular, defined by fines and burn layer	SL, up to coarse sand; coarse fraction: gran-peb	pebble	very few sa char >2mm; few sa char <2mm	50.2/34.2/15.6	possible A horizon (0-50cm): at 20cm (10YR/3/2); no clast orientation or bedding	**DF (poss.)**	1-16
-to-	-to-			>4					
60	n/a		%>2mm: 15	sr-ang		55cm: 7.5YR/5/2			16
60	20	clear to broken lensoid, defined by change in sorting	LS, up to coarse sand; coarse fraction: gran-peb	coarse pebble-fine cobble	discontinuous burn surface on top; very few sa char >2mm; many sa char <2mm	44.7/50/5.3	more peb-gran supported in bottom 5cm; more fines at top; no clast orientation or bedding	**HCF**	17-34
-to-	-to-			2.6					32
80	n/a		%>2mm: 65	sa-ang		7.5YR/4/2			20
80	80	abrupt but disconti-nuous, defined by top of resistant layer	SL, up to coarse sand; coarse fraction: gran-peb, <5% cob	cobble	char-rich layer at 155 and 110cm; many sr-ang char >2mm; abundant sr-ang char <2mm	39.2/49.1/11.7	distinct orange layer above burned surface at 110cm (7.5YR/5/3); discontinuous resistant layer marking upper surface of smaller depositional events within layer; sorting changes but internal contacts are very difficult to distinguish; cob layer at base probably deposited behind bldr; generally no bedding or clast orientation	**DF (poss.)**	35-44, 46
-to-	-to-			3.2					40
160	110		%>2mm: 65	sr-ang		7.5YR/5/2			46
170	0	abrupt, roughly planar	LS, up to coarse sand; coarse fraction: gran-peb	pebble	no char >2mm; some rounded char <2mm	49.5/43.9/6.6	some clasts orientated parallel to flow direction on north side of layer; separated from overlying deposit by discontinuous resistant layer	**HCF**	45, 47, 48
-to-	-to-			2.4					
180	10		%>2mm: 85	sr-ang		7.5YR/5/2			45

STATION: 5 (continued)
(mid- upper fan channel wall)

LAT: 13 S 0347685 LONG: 3972584 DATE: 6/14/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
180	0	abrupt, roughly planar	LS, up to coarse sand; coarse fraction: very coarse sand-gran	granule	layer darkened by fine char; no char >2mm; very abundant sr-ang char <2mm	40.1/43.6/ 16.4	may be a resistant surface layer or very thin runout; fine peb layer <1cm below	**HCF (poss.)**	49, 50
-to-	-to-			3					50
181	1		%>2mm: 20	sr		10YR/4/2			49
181	0	abrupt, disconti-nuous, defined by top of resistant layer	LS, up to coarse sand; coarse fraction: gran-peb	cobble	no char >2mm; some sr char <2mm	76.2/17.4/6.3	deposit eroded into by layer (80-160cm); clast supported; no bedding or clast orientation	**DF CL**	51, 52
-to-	-to-			>2.6					
185	10		%>2mm: 80	sr-ang		7.5YR/5/2			52
185	65	abrupt, defined by resistant layer	LS, up to coarse sand; coarse fraction: gran-peb	pebble	very few ang char >2mm; abundant ang char <2mm	25.2/59.1/ 15.8	continuous and discontinuous resistant layers within deposit marking smaller depositional events within layer; no grading or clast orientation	**DF (poss.)**	53-77
-to-	-to-			3.1					57
250	n/a		%>2mm: 50	sa-ang		7.5YR/5/3			77
250	?	not exposed	LS, up to coarse sand; coarse fraction: gran-peb	cobble	very few ang char >2mm; few ang char <2mm	17/69.9/13.1	cobbles in top 10cm with peb-fine fraction below; no clast orientation	**HCF**	78
-to-	-to-			2.4					
270	n/a		%>2mm: 20	sa-ang		7.5YR/6/2			78

<table>
<tr><td colspan="7">STATION: 6
(down-fan channel wall)</td><td>LAT: 13 S
0347680</td><td>LONG:
3972454</td><td>DATE: 6/14/2011</td></tr>
<tr><th rowspan="3">Depth (cm)</th><th rowspan="3">Thick. (cm)</th><th rowspan="3">Lower Contact</th><th rowspan="3">Texture (fine/coarse) & % >2mm (from field obs.)</th><th>Max. b-axis</th><th rowspan="3">Charcoal</th><th>%Gravel/Sand/Silt+Clay (from lab)</th><th rowspan="3">Structure</th><th rowspan="3">Process (Fire relation)</th><th>Sample #s</th></tr>
<tr><th>Sorting (GSD)</th><th rowspan="2">Color (Dry)</th><th>Samples Dated</th></tr>
<tr><th>Clast Shape</th><th>Grain Size Samples</th></tr>
<tr><td>0</td><td>90</td><td rowspan="3">abrupt, disconti-nuous, irregular, defined by resistant layer</td><td rowspan="2">SL, up to coarse sand; coarse fraction: gran-peb, 10% cob</td><td>cobble</td><td rowspan="3">few sr char >2mm; some sr char <2mm</td><td rowspan="2">28.7/55.7/15.6</td><td rowspan="3">possible A horizon between 0-50cm (20cm: 7.5YR/4/2); no bedding or clast orientation; matrix supported</td><td rowspan="3">DF</td><td>1, 2</td></tr>
<tr><td>-to-</td><td>-to-</td><td>4</td><td></td></tr>
<tr><td>90</td><td>n/a</td><td>%>2mm: 35</td><td>sa-ang</td><td>80cm: 10YR/5/2</td><td>1</td></tr>
<tr><td>90</td><td>100</td><td rowspan="3">clear, disconti-nuous, irregular, defined by resistant layer and sorting change</td><td rowspan="2">SL, up to coarse sand; coarse fraction: gran-peb, <5% cob</td><td>cobble</td><td rowspan="3">some sr char <2mm</td><td rowspan="2">19.4/23.3/57.3</td><td rowspan="3">crude clast orientation parallel to flow direction for some deposits within layer; layer consists of possibly ~7 deposits of similar sorting; no grading or imbrication; many abrupt, irregular discontinuous resistant layers (more orange colored); more cobbles at the top of the deposit</td><td rowspan="3">HCF</td><td>3-5</td></tr>
<tr><td>-to-</td><td>-to-</td><td>>2.8</td><td></td></tr>
<tr><td>190</td><td>n/a</td><td>%>2mm: 45</td><td>sa-ang</td><td>10YR/6/2</td><td>5</td></tr>
<tr><td>190</td><td>?</td><td rowspan="3">not exposed</td><td rowspan="2">no texture defined; coarse fraction: gran-peb, 50% cob</td><td>cobble</td><td rowspan="3">no apparent char</td><td rowspan="2">38.4/43.6/18</td><td rowspan="3">possibly multiple layers defined by resistant layers (~4 layers); crude imbrication at 90cm and crude clast orientation parallel to flow throughout; matrix-supported; no grading</td><td rowspan="3">DF</td><td>6</td></tr>
<tr><td>-to-</td><td>-to-</td><td>>3.5</td><td></td></tr>
<tr><td>?</td><td>n/a</td><td>%>2mm: 75</td><td>sa-ang</td><td>10YR/6/2</td><td>6</td></tr>
</table>

STATION: 7 (upper-fan channel wall) | LAT: 13 S 0346491 | LONG: 3972407 | DATE: 6/16/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis	Sorting (GSD)	Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab)	Color (Dry)	Structure	Process (Fire relation)	Sample #s	Samples Dated	Grain Size Samples
0 -to- 45	45 -to- n/a	defined by disconti-nuous burned layer	LS, up to coarse sand; coarse fraction: gran-peb; %>2mm: 25	pebble	4.4	sa	few sa char >2mm; common ang char <2mm; burned surface at 0cm	24.2/40.4/35.4	7.5YR/6/2	no apparent clast orientation; possible small burned surfaces above 45cm, but difficult to observe; some lenses lacking fines but no apparent grading; possible crude scour-fill	**DF (prob.)**	2		2
45 -to- 60	15 -to- n/a	defined by disconti-nuous burned layer	LS, up to coarse sand; coarse fraction: gran-peb; %>2mm: 35	pebble	3.7	sr-sa	burned surface at 45cm; very few sr char >2mm; some sr char <2mm	27.4/47.8/24.8	7.5YR/6/2	no apparent clast orientation or bedding	**DF (prob.)**	1,3,4	1	4
60 -to- 70	10 -to- n/a	defined by disconti-nuous burned layer	LS, up to coarse sand; coarse fraction: gran-peb; %>2mm: 45	coarse pebble	3.8	sa-ang	discontinuous burned surface at 60cm; very few ang char >2mm; common sa char <2mm	28.5/49/22.5	7.5YR/6/2	no apparent clast orientation or bedding	**DF (prob.)**	5,6	5	6
70 -to- 100	30 -to- n/a	defined by disconti-nuous burned layer	LS, up to coarse sand; coarse fraction: 40% gran-peb, 0-50% cob; %>2mm: 40-90	cobble	>2.9	rounded-sa	discontinuous char layer at 70cm; common sa char >2mm; abundant sa char <2mm	52.3/41.9/5.7	7.5YR/6/2	no apparent clast orientation or bedding; local accumulations of cobbles, where accumulated cobbles may be up to 50% of sediment	**DF (prob.)**	7,8,9	7, 9	8
100 -to- 160	60 -to- n/a	defined by disconti-nuous burned layer	LS, up to coarse sand; coarse fraction: gran-peb; %>2mm: 20	pebble	2.9	sr-ang	discontinuous char layer at 100cm; some angular char >2mm; abundant ang char <2mm	18.6/62.5/18.8	7.5YR/6/2	some rough bedding of gran-coarse peb and coarse sand-fine peb (both contain fine fraction); no apparent clast orientation; a few local fine char layers at 110 and 130cm	**HCF (prob.)**	10, 11, 12		12

STATION: 7 (continued) (upper-fan channel wall) | LAT: 13 S 0346491 | LONG: 3972407 | DATE: 6/16/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
160	80	abrupt, irregular, defined by resistant layer	LS, up to coarse sand; coarse fraction: gran-peb	coarse pebble	discontinuous char layer at 160cm; some ang char >2mm; abundant ang char <2mm	22.5/60/17.5	some discontinuous resistant layers (more than drawn) but unable to map across station; no apparent clast orientation within station	**DF**	13, 14, 15
-to-	-to-			>3					13
240	n/a		%>2mm: 50%	sa-ang		7.5YR/6/2			14
240	30	abrupt, irregular, defined by resistant layer	LS, up to coarse sand; coarse fraction: gran-peb	pebble	few ang char <2mm	34.6/60.2/5.2	some peb-rich areas and also some discontinuous resistant layers (irregular); no apparent clast orientation or imbrication	**HCF (poss.)**	16, 17
-to-	-to-			2					
270	n/a		%>2mm: 45	sr-ang		7.5YR/6/2			17
270	40	clear, irregular, defined by roughly continu-ous char layer	LS, up to coarse sand; coarse fraction: gran-peb	pebble	very few ang char >2mm; few ang char <2mm; local large ang char in top 3cm	48.5/43.6/7.9	top and bottom: 1cm thick normally graded with resistant fine layers on top (fine to gran sized material); middle of the deposit shows discontinuous resistant layers with deposit showing crude normal grading to no grading	**HCF (prob.)**	18-22
-to-	-to-			2.2					18
310	n/a		%>2mm: 45	ang		7.5YR/6/2			22
310	10	defined by disconti-nuous char layer	LS, up to coarse sand; coarse fraction: gran-peb	fine pebble	abundant large ang char in top 5cm (discontinuous); few ang char >2mm; some ang char <2mm	22.4/45.8/31.8	no apparent clast orientation or bedding or imbrication	**DF (prob.)**	23-25
-to-	-to-			4					24
320	n/a		%>2mm: 30	sa-ang		7.5YR/6/2			25
320	?	no exposed	texture not analyzed; coarse fraction: 15-45% gran-peb, 0-60% cob	cobble	possible discontinuous burned surface in top 5cm; few sr char <2mm	24/69.7/6.3	bottom 20cm: 50% cobble; above lies gran-peb with possible crude normal grading and local cobbles; no apparent clast orientation; some discontinuous resistant layers	**HCF**	26-29
-to-	-to-			2					28
?	n/a		%>2mm: 45-75	sr-ang		7.5YR/6/2			29

STATION: 8 (fan channel wall) | LAT: 13 S 0341999 | LONG: 3969408 | DATE: 6/20/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
0	0	abrupt, curved but smooth. Truncat-es other layers	SL, up to coarse sand; coarse fraction: gran-peb	pebble	matrix darkened by char; very few ang char >2mm; abundant ang char <2mm	60.9/31.8/7.3	no bedding, clast orientation or imbrication; matrix-clast supported	**HCF (FR)**	1-4
-to-	-to-			2.6					
130	130		%>2mm: 55	ang		10YR/2/2-10YR/4/2			1
0	65	abrupt, irregular disconti-nuous, defined by resistant layer	SL, up to coarse sand; coarse fraction: gran-peb, <5% fine cob	coarse pebble-fine cobble	no char >2mm; few ang char <2mm	71.2/22.4/6.4	possible weak A horizon from 0-20cm; possible bedding, but not continuous; no apparent clast orientation or imbrication; matrix supported	**HCF**	5, 6
-to-	-to-			>2.6					
65	n/a		%>2mm: 50	sr-ang		7.5YR/3/1-10YR/5/2			5
65	10	abrupt, irregular disconti-nuous, defined by resistant layer	SL, up to coarse sand; coarse fraction: gran-peb, <5% fine cob	coarse pebble-fine cobble	no char >2mm; some sa-ang char <2mm	83.5/12.3/4.2	bottom 5cm marked by low-angle bowl structure (scour?), with clast orientation parallel to flow direction	**SF**	7
-to-	-to-			>1.6					
75	n/a		%>2mm: 55	sr-ang		10YR/3/2-10YR/6/3			7
75	10	abrupt, irregular disconti-nuous, defined by resistant layer	LS, up to coarse sand; coarse fraction: gran-peb, <5% cob	cobble	no char >2mm; common sr-ang char <2mm	89.1/7.4/3.4	10 cm thick total; matrix poor; shows week imbrication and possible weak clast orientation parallel to flow direction	**SF**	8
-to-	-to-			>0.9					
85	n/a		%>2mm: 70	sr-ang		10YR/3/2-10YR/5/3			8
85	20	abrupt, irregular disconti-nuous, defined by resistant layer	SL, up to coarse sand; coarse fraction: gran-peb	coarse pebble	no char >2mm; abundant ang char <2mm	74.5/21.3/4.2	possibly multiple layers but also possibly shows weak normal grading	**HCF**	9
-to-	-to-			2.1					
105	n/a		%>2mm: 80	sr-ang		10YR/3/2-10YR/5/2			9

STATION: 8 (continued)
(fan channel wall)

LAT: 13 S 0341999 | LONG: 3969408 | DATE: 6/20/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
105	10	abrupt, irregular disconti-nuous, defined by resistant layer	SL, up to coarse sand; coarse fraction: gran-peb, mostly peb ~10cm, <10% cob-bldr	cobble-bldr	no char >2mm; common ang char <2mm	93.2/2.8/4	weak normal grading; contains bldrs and cobs within a peb-clast supported flow	**SF**	10
-to-	-to-			0.9					
130	30		%>2mm: 90	ang		10YR/4/2-10YR/6/2			10
130	?	not exposed	LS, up to coarse sand; coarse fraction: gran-peb, <10% cob	cobble	rare ang char >2mm; some sr-ang char <2mm	62.7/28.9/8.3	no apparent clast orientation or bedding; not well exposed; 5-10cm thick area of crude normal grading; 2-3 gran-peb layers, 30cm thick total	**HCF**	11
-to-	-to-			>3					
160	n/a		%>2mm: 55	sr-ang		10YR/3/2-10YR/6/2			11

STATION: 9
(fan channel wall)

LAT: 13 S 0343264 LONG: 3969703 DATE: 6/20/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
0	60	clear, irregular	SL, up to coarse sand; coarse fraction: gran-peb, 10% cob	cobble	rare ang char >2mm; rare sa-ang char <2mm	45.1/47/7.9	no clast orientation, bedding or imbrication; matrix-supported	**HCF**	1
-to-	-to-			3					
60	n/a		%>2mm: 40-50	sr-sa		10YR/3/2-10YR/5/2			1
60	<10	clear, irregular	LS, up to coarse sand; coarse fraction: gran-peb	pebble	no char >2mm; some sa-ang char <2mm	51.7/44.1/4.2	moderate imbrication and clast orientation parallel to flow direction; clast supported	**HCF**	2, 3
-to-	-to-			2.3					
80	20		%>2mm: 65	sr-ang		10YR/3/2-10YR/5/2			3
80	80	not exposed	SL, up to coarse sand; coarse fraction: gran-peb, <5% cob	cobble	no char >2mm; common sa-ang char <2mm	38.2/34.7/27.1	May be composed of multiple layers but unable to determine contacts; generally no clast orientation or imbrication	**DF**	4, 5
-to-	-to-			4.7					
160	n/a		%>2mm: 40	sr-ang		10YR/3/2-10YR/5/2			4

STATION: 10
(upper-fan channel wall)

LAT: 13 S 0344766 LONG: 3971821 DATE: 6/22/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis	Charcoal	%Gravel/Sand/Silt+Clay (from lab)	Structure	Process (Fire relation)	Sample #s
				Sorting (GSD)		Color (Dry)			Samples Dated
				Clast Shape					Grain Size Samples
0	0	abrupt-clear, irregular	SL, up to coarse sand; coarse fraction: gran-peb, 40% cob-bldr	boulder	rare ang char >2mm; some ang char <2mm	67.7/22.1/10.2	very crude clast orientation parallel to flow direction; crude imbrication of surface cobbles; generally clast supported; no apparent bedding; truncates other layers; forms a channel under rock-overhang scoured bedrock channel	**DF**	1-3
-to-	-to-			>3.6					
130	100		%>2mm: 30-70	sr-sa		7.5YR/3/2-7.5YR/5/2			1
10	0	abrupt, irregular	SL, up to coarse sand; coarse fraction: gran-peb	pebble	many ang char >2mm; abundant ang char <2mm	70.9/22.2/6.9	char-rich matrix (fines) giving deposit a dark color; partially charred duff at 10cm; possible crude clast orientation parallel to flow direction; color becomes lighter in upper portion of deposit; possible weak bedding; no imbrication; matrix supported	**DF (likely)**	char/duff layer: 4-8 main layer: 9-28
-to-	-to-			>2.8					21
30	30		%>2mm: 50	sa-ang		10YR/2/1-10YR/3/2			28
30	0	abrupt, irregular	SL, up to coarse sand; coarse fraction: gran-peb, <5% cob	cobble	many ang char >2mm; abundant ang char <2mm	34/57.1/8.9	roughly interfingering PWT and grey (from abundant charcoal) fines-rich layer; crude clast orientation parallel to flow direction in non-PWT layers; some mixing or interfingering; clast-matrix supported	**HCF**	29-49
-to-	-to-			2.8					
90	50		%>2mm: 55	sr-sa		10YR/2/2-10YR/4/2			43

STATION: 10 (continued) (upper-fan channel wall)	LAT: 13 S 0344766	LONG: 3971821	DATE: 6/22/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
75	10		texture not analyzed; coarse fraction: gran-peb	pebble	very few ang char >2mm (some very coarse though); common ang char <2mm	74.6/17.4/8.1	fine, char-rich matrix; deposit becomes more fines-rich further back into the alcove and coarsens up again on the other side of the alcove; possible bedding in fines-rich area; no apparent clast orientation; matrix supported		50-70
-to-	-to-	abrupt, irregular		>3				**DF (prob.)**	57
110	40		%>2mm: 55	ang		10YR/2/1-10YR/3/2			70
110	20		coarse layer/fine layer; LS/SL; up to ocarse sand; coarse fraction: gran-fine peb/very coarse sand-gran	fine pebble/granule	rare/abundant ang char >2mm; few/abundant ang char <2mm	16.2/74.9/8.9	roughly interfingering PWT and grey (from abundant charcoal) fines-rich layer; minor scour-fill structure in non-PWT layer with ang clasts; interfingering less rough than in 20-90cm		71-91
-to-	-to-	abrupt-clear, irregular		2.2				**SF (prob.)**	
145	40		%>2mm: 55/5	sa-ang/sr-sa		10YR/2/2/10YR/2/1-10YR/5/2/10YR/4/2			87
145	20		LS, up to coarse sand; coarse fraction: gran-peb	pebble	very few sr-ang char >2mm; common sr-ang char <2mm; 2 burned surfaces: 130cm & 140cm (discontinuous)	98: 1.1/93.6/5.3 99: 29.2/53.7/17.1	alternating coarse and fine layers with more clast rounding than above layer; some low-angle scour and fill		91-100
-to-	-to-	abrupt-clear, irregular		>3.2				**SF**	93, 96
165	55		%>2mm: 50	sr-ang		7.5YR/3/2-7.5YR/5/2			98, 99
165	0		SL, up to coarse sand; coarse fraction: gran-peb	coarse pebble	very few ang char >2mm; common ang char <2mm	71/19.8/9.2	fine char-rich matrix with dark color; clast supported; no bedding or clast orientation; thins downstream to char layer; very fines rich		101-121
-to-	-to-	abrupt, irregular		>3.1				**DF (prob.)**	115
200	30		%>2mm: 55	sa-ang		7.5YR/2.5/1-10YR/4/2			121

STATION: 10 (continued)
(upper-fan channel wall)

LAT: 13 S 0344766 | LONG: 3971821 | DATE: 6/22/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
200	60	not exposed	LS, up to coarse sand; coarse fraction: gran-peb, <5% cob	cobble	some ang char >2mm; abundant ang char <2mm; char-rich layer at 215cm; abundant ang char above 230cm	133: 32.7/59/8.3 141: 11.6/44.3/ 44.1	coarse and fine layer mixing and alternation in upper portion (local crude scour-fill) with massive poorly sorted deposit under fine layer at 230cm; no sorting or clast orientation	**DF (poss.-prob.)**	122-141
-to-	-to-			133: 2.7 141: 3.5					128
260	n/a		%>2mm: 40	sr-ang		10YR/2/2-10YR/4/3			133, 141

STATION: 11 (upper-fan channel wall)						LAT: 13 S 0347432	LONG: 3972212	DATE: 8/3/2011	
Depth (cm)	**Thick. (cm)**	**Lower Contact**	**Texture (fine/coarse) & % >2mm (from field obs.)**	**Max. b-axis**	**Charcoal**	**%Gravel/Sand/Silt+Clay (from lab)**	**Structure**	**Process (Fire relation)**	**Sample #s**
				Sorting (GSD)		**Color (Dry)**			**Samples Dated**
				Clast Shape					**Grain Size Samples**
0	30	abrupt; slightly irregular	LS, up to coarse sand; coarse fraction: gran-peb	pebble	rare ang char >2mm; few ang char <2mm	18.4/71.6/10	no apparent clast orientation, bedding or imbrication	**HCF**	1-3
-to-	-to-			2.4					
30	n/a		%>2mm: 35	sr-sa		7.5YR/3/2-10YR/5/2			3
30	10	abrupt; slightly irregular	SL, up to coarse sand; coarse fraction: gran-peb	pebble	abundant ang char >&< 2mm	5.8/77/17.2	no apparent clast orientation, bedding or imbrication	**HCF (likely)**	4-19
-to-	-to-			2.1					8
50	20		%>2mm: 30	sr-sa		10YR/2/2-10YR/4/2			14
50	30	abrupt; slightly irregul-ar; disconti-nuous	SL, up to coarse sand; coarse fraction: gran-peb	pebble	few sr char > 2mm; some sr char <2mm	21: 3.3/78/18.7 22: 6.8/82.5/10.7 23: 15/70/14.9	no apparent clast orientation, bedding or imbrication; coarse pebble coarse pebbles orientated with a axis parallel to vertical surface of bldr	**HCF**	20-23
-to-	-to-			21: 2.1; 22: 1.9; 23: 2.4					
80	n/a		%>2mm: 20	sr-sa		10YR/3/2-10YR/6/2			21, 22, 23
80	10	abrupt; slightly irregul-ar; disconti-nuous	SL, up to coarse sand; coarse fraction: gran-peb	pebble	abundant ang char >&< 2mm	32.3/52.8/15	no apparent clast orientation, bedding or imbrication; coarse pebble coarse pebbles orientated with a axis parallel to vertical surface of bldr	**DF (likely)**	24-34
-to-	-to-			3.6					26
90	n/a		%>2mm: 30	sr-sa		10YR/2/2-10YR/4/2			32
90	8	abrupt; slightly irregul-ar; disconti-nuous	LS, up to coarse sand; coarse fraction: gran-peb	pebble	few ang char >2mm; abundant ang-sr char <2m	9.1/73.6/17.3	no apparent clast orientation, bedding or imbrication	**HCF**	35-38
-to-	-to-			2.3					
98	n/a		%>2mm: 25	sr-sa		10YR/3/2-10YR/5/2			38

STATION: 11 (continued) (upper-fan channel wall) | LAT: 13 S 0347432 | LONG: 3972212 | DATE: 8/3/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
98	7	abrupt; slightly irregul-ar; disconti-nuous	SL, up to coarse sand; coarse fraction: gran-peb	pebble	abundant ang char >&< 2mm	11.4/74.8/ 13.8	no apparent clast orientation, bedding or imbrication	HCF (likely)	39-49
-to-	-to-			2.3					46
105	n/a		%>2mm: 30	sr-sa		10YR/2/2- 10YR/4/2			44
105	65	not exposed	LS, up to coarse sand; coarse fraction: gran-peb	coarse cobble	few ang char >2mm; common ang char <2mm; a few in layer around 1cm	24.7/64.1/ 11.3	no apparent clast orientation, bedding or imbrication	HCF	50-60
-to-	-to-			2.9					
170	n/a		%>2mm: 35	sr-ang		10YR/3/2- 10YR/5/2			52

STATION: 12 (fan channel wall) LAT: 13 S 0347423 LONG: 3972187 DATE: 8/4/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
0 -to- 80	80 -to- n/a	abrupt-clear, slightly irregul-ar; possibly disconti-nuous	LS-SL, up to coarse sand; coarse fraction: gran-peb, <10% bldrs %>2mm: 20-25	boulder 3.6 sr-sa	2 discontinuous areas with darkened matrix at 50cm an 75cm; no char >2mm; rare sr-ang char <2mm	18.6/47.3/34.2 7.5YR/3/2-7.5YR/5/2	no apparent clast orientation, bedding or imbrication; weak clast orientation parallel to flow direction; clast-matrix support; local granule-rich areas and pebble-poor areas; may represent multiple flows or local texture differences within single event	**DF**	1-10 9
80 -to- 100	20 -to- 20	abrupt-clear, slightly irregular	LS-SL, up to coarse sand; coarse fraction: gran-peb, <5% cob %>2mm: 10-50	cobble 3.8 sr-sa	none-few char >2mm; some-common sr-ang char <2mm	43.7/37.4/19 10YR/3/2-10YR/5/2	local texture differences very distinct – most likely represents multiple events; bedding difficult to distinguish; weak clast orientation parallel to flow direction; no apparent imbrication; local fines-rich areas and gran-rich areas as well as pebble-poor areas; also local cob-coarse pebble rich areas.	**DF**	11-15 13
100 -to- 210	110 -to- n/a	not exposed	LS, up to coarse sand; coarse fraction: gran-peb %>2mm: 45	coarse pebble 25: 3.7; 26: 3.9 sr-sa	irregular and discontinuous char-rich layer in top half of deposit; rare sr char >2mm only at 170cm; some char <2mm elsewhere; irregular line of char with dark matrix at around 120cm	25: 27.7/48.3/24 26: 31.7/44.1/24.2 10YR/4/3-10YR/6/2	appears massive but some distinct orange resistant laers (possible bedding planes) in lower half; very weak grading at 180cm down, 170cm across – several set of coarse and fine layers	**DF**	16-30 25, 26

STATION: 13 (fan channel wall) | LAT: 13 S 0344708 | LONG: 3971906 | DATE: 8/6/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
0	40	abrupt, slightly irregular	SL, up to coarse sand; coarse fraction: gran-peb	coarse pebble	abundant coarse ang char >&< 2mm	18.1/43.6/ 38.3	weak A horizon <50cm thick (20cm: 10YR/3/2); appears massive; no apparent bedding or imbrication; possible weak clast orientation parallel to flow direction; local small lenses of peb/gran-rich sediment; matrix supported	**DF (likely)**	1-4
-to-	-to-			3.7					3
100	90		%>2mm: 30	sr-sa		10YR/2/2-10YR/4/2			2
40	10	abrupt, slightly irregular	SL, up to coarse sand; coarse fraction: gran-peb	cobble	abundant coarse ang char >&< 2mm	73.7/23.5/2.7	many clasts oriented parallel to flow direction or imbricated; no apparent bedding; truncates layer below; clast-matrix supported	**DF CL** (based on coarse matrix) **(likely)**	5-7
-to-	-to-			>2.3					7
110	50		%>2mm: 80	sr-sa		10YR/3/2-10YR/5/2			6
90	<5	abrupt, roughly planar, disconti-nuous	SiL, up to coarse sand; coarse fraction: gran-peb	fine pebble	darkened matrix possibly due to fine char; some ang char >2mm; abundant-common ang char <2mm	5/47.9/47	deposit is so thin it is difficult to determine structure; no apparent bedding, clast orientation or imbrication	**DF (prob.)**	8-10
-to-	-to-			3.3					8
110	10		%>2mm: 10	sr-sa		2.5YR/2.5/1-10YR/3/2			10
90	140	not exposed	SL, up to coarse sand; coarse fraction: gran-peb	coarse pebble	abundant ang char >&< 2mm at 140cm; however, see individual samples for char content	12: 36.8/55/8.2 15: 10.9/58.4/ 30.7 20: 22.4/46.4/ 31.3	bedding and multiple processes/events likely, but contacts are difficult to distinguish; local gran-rich areas and discontinuous resistant layers; some highly angular cob/peb layers	**DF (likely)**	11-20
-to-	-to-			12: 3; 15: 2.6 20: 3.7					16, 19
230	n/a		%>2mm: 30-55	sr-sa		2.5YR/3/2-10YR/5/2			12, 15, 20

STATION: 14 (upper-fan channel wall) | LAT: 13 S 0345252 | LONG: 3971909 | DATE: 8/7/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis	Sorting (GSD)	Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab)	Color (Dry)	Structure	Process (Fire relation)	Sample #s	Samples Dated	Grain Size Samples
0 -to- 65	60 -to- n/a	abrupt, slightly irregular, defined by resistant layer	LS, up to coarse sand; coarse fraction: gran-peb, <10% cob %>2mm: 35	coarse cobble	3.7	sr-sa	common ang char >&< 2mm	25.5/62.3/ 12.2	10YR/3/2-10YR/5/2	appears massive; weak clast orientation and imbrication; discontinuous line of peb/cob may indicate separate events; matrix supported	**DF (poss.)**	1-3	3	2
65 -to- 140	75 -to- n/a	abrupt, clear, slightly irregular, defined by texture change	LS, up to coarse sand; coarse fraction: gran-peb %>2mm: 25	pebble	2.3	sr-sa	common ang char <2mm; few char >2mm	16.9/73/10.1	10YR/3/2-10YR/5/2	many continuous intersecting resistant layers (slightly orange); texture and structure similar in deposit; circular resistant layer at 110cm; no apparent clast orientation or imbrication	**HCF (poss.)**	4-13	11	5
140 -to- 210	60 -to- n/a	not exposed	LS, up to coarse sand; coarse fraction: gran-peb %>2mm: 25-50	pebble	3.2	sr-sa	none-abundant ang char >2mm; common-abundant char <2mm; char concentrations at 170cm and darkened layer at 195cm	37.8/54.9/7.3	10YR/3/2-10YR/5/2	fine and coarse alternating layers; structure indicates low-angle scour-fill; coarse layers typically gran-peb; fine layers contain <2mm gran; also pebble-rich areas present, not associated with scour-fill structures	**HCF (prob.)**	14-26	14	24

STATION: 15 (fan channel wall) — LAT: 13 S 0345256 — LONG: 3971945 — DATE: 8/7/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
0	50	abrupt, slightly irregular disconti-nuous, defined by resistant layer and texture change	LS, up to coarse sand; coarse fraction: gran-peb, <10% cob	cobble	some-abundant ang char >2mm; common sr-ang char <2mm	52.5/39.7/7.7	appears massive; matrix supported; moderate clast orientation parallel to flow direction; weak imbrication; possibly multiple events; no bedding apparent	**HCF (FR)**	1-3
-to-	-to-			>3.3					
50	n/a		%>2mm: 45	sr-sa		10YR/3/2-10YR/6/3			2
50	40	abrupt, slightly irregular disconti-nuous, defined by resistant layer and texture change	LS, up to coarse sand; coarse fraction: gran-peb, 25% cob and bldr	boulder	few sr-ang char > 2mm; abundant ang char <2mm	25.6/64.2/10.3	matrix supported; moderate clast orientation parallel to flow direction; weak imbrication; possibly multiple events; possibly multiple events; common discontinuous resistant layer and pebble rich clusters	**HCF**	4-8
-to-	-to-			2.8					
100	50		%>2mm: 50	sr-sa		10YR/3/2-10YR/6/3			5
100	50	not exposed	SL, up to coarse sand; coarse fraction: gran-peb, 5-10% cob	cobble	common ang char >2mm; some ang char <2mm	10.1/75.2/14.7	matrix supported; very weak clast orientation parallel to flow direction; no imbrication; possibly multiple events; possibly multiple events; some weak discontinuous resistant layers	**HCF (FR)**	9, 10
-to-	-to-			2.2					
150	n/a		%>2mm: 40-45	sr-sa		10YR/3/2-10YR/6/3			10

STATION: 16 (upper-fan channel wall)	LAT: 13 S 0345547	LONG: 3971728	DATE: 8/10/2011

Depth (cm)	**Thick. (cm)**	**Lower Contact**	**Texture (fine/coarse) & % >2mm (from field obs.)**	**Max. b-axis / Sorting (GSD) / Clast Shape**	**Charcoal**	**%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)**	**Structure**	**Process (Fire relation)**	**Sample #s / Samples Dated / Grain Size Samples**
0	110	abrupt, slightly irregular disconti-nuous	SL, up to coarse sand; coarse fraction: gran-peb	pebble	abundant ang char >2mm; abundant ang char >2mm	16.1/47.8/ 36.1	possible A horizon in upper 30cm (20cm: 10YR/4/2; 40cm: 10YR/5/2); appears massive; weak clast orientation parallel to flow direction and imbrication; no apparent bedding but a few very fine discontinuous resistant layers; matrix supported	**DF (likely)**	1-5
-to-	-to-			3.5					5
120	n/a		%>2mm: 25	sr-sa		60cm: 10YR/3/2-10YR/5/2			2
120	50	abrupt, planar-slightly irregular	LS, up to coarse sand; coarse fraction: gran-peb; 5-10% cob	coarse pebble-fine cobble	common ang char >2mm; abundant ang char >2mm	15.7/52.9/ 31.3	many discontinuous resistant layers; cobble-rich in upper portion, but matrix of consistent texture; possible weak clast orientation parallel to flow direction, but also clasts perpendicular to flow direction; matrix supported	**DF (prob.)**	6-10
-to-	-to-			3.4					7
170	n/a		%>2mm: 30-35	sr-sa		10YR/3/2-10YR/5/2			8
170	40	abrupt, planar-slightly irregular	LS, up to coarse sand; coarse fraction: gran-peb	pebble	abundant ang char >2mm; common ang char >2mm	8.5/65.6/26	no clast orientation or imbrication; generally matrix supported; local minor clast support; local cob-peb rich areas; very few very fine discontinuous resistant layers	**DF (likely)**	11-13
-to-	-to-			3					12
210	n/a		%>2mm: 30	sr-sa		10YR/3/2-10YR/6/2			13
210	20	abrupt, planar-slightly irregular	LS, up to coarse sand; coarse fraction: gran-peb	pebble	common-abundant ang char >2mm; common-abundant ang char >2mm	42/45.2/12.8	possible weak clast orientation parallel to flow direction; no imbrication; generally matrix supported; local minor clast support; local cob-peb rich areas; very few very fine discontinuous resistant layers	**DF (prob.-likely)**	14-16
-to-	-to-			>3.6					15
230	n/a		%>2mm: 30	sr-sa		10YR/4/2-10YR/6/2			16

STATION: 16 (continued) (upper-fan channel wall) | LAT: 13 S 0345547 | LONG: 3971728 | DATE: 8/10/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
230	15	abrupt, planar-slightly irregular	LS, up to coarse sand; coarse fraction: gran-peb	pebble	common sr-ang char >2mm; common sr-ang char >2mm	15.8/54.7/29.5	no clast orientation or imbrication; generally matrix supported; local minor clast support; local cob-peb rich areas; very few very fine discontinuous resistant layers	DF	17-19
-to-	-to-			3.3					
245	n/a		%>2mm: 30	sr-sa		10YR/3/2-10YR/6/2			19
245	45	abrupt, planar-slightly irregular	LS, up to coarse sand; coarse fraction: gran-peb, 0-60% cob	fine cobble	some sr char >2mm; common-abundant sr-ang char >2mm	10.2/72.8/17	possible local weak clast orientation parallel to flow direction; no imbrication; generally matrix supported; local minor clast support; local cob rich areas (>50% cob); very few very fine discontinuous resistant layers	HCF (poss.)	20-23
-to-	-to-			2.3					21
290	n/a		%>2mm: 25-85	sr-sa		10YR/3/2-10YR/6/2			23
290	30	not exposed	LS, up to coarse sand; coarse fraction: gran-peb	pebble	common ang char >2mm; abundant ang char >2mm	24: 16.7/63.9/19.4 *25: 17/44.7/38.2	alternating 1-5cm; thick resistant layer and peb-rich layers; no apparent low-angle scour-fill structure; very weak clast orientation parallel to flow direction; clast-matrix support; no imbrication	HCF (prob.)	24-27
-to-	-to-			3.7					26
320	n/a		%>2mm: 20-50	sr-sa		10YR/3/2-10YR/5/2			24, *25

* Sample represents resistant layer aka, possible clay lamellae

STATION: 17 (arroyo channel wall) | LAT: 13 S 0345175 | LONG: 3972133 | DATE: 8/11/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
40	40	abrupt, gener-ally planar	LS, up to coarse sand; coarse fraction: gran-peb	pebble	>2mm: rare ang char; <2mm: few-some ang char	n/a	no apparent soil development; some coarse and fine layers but no apparent clast orientation; matrix supported; may show some grading topped with a fine layer in portions of the section.	**NOT ANALYZIED (LIKELY MODERN)**	1-6
-to-	-to-			n/a					
80	n/a		%>2mm: 10	sr-sa		10YR/3/2-10YR/6/2			
80	25	abrupt, gener-ally planar, slightly irregular	LS, up to coarse sand; coarse fraction: gran-peb	pebble	>2mm: few ang char; <2mm: common ang char	n/a	appears massive; possible weak clast orientation parallel to flow direction; no apparent imbrication or bedding; clast-matrix supported; some pebble rich areas – not common though	**NOT ANALYZIED (LIKELY MODERN)**	7-8
-to-	-to-			n/a					
105	n/a		%>2mm: 45	sr-sa		10YR/2/1-10YR/5/1			
105	35	abrupt, slightly irregular -slightly wavy	SiL, up to coarse sand; coarse fraction: gran-peb	pebble	>2mm: few ang char; <2mm: some ang char	0.1/44.5/55.4	appears massive but some mixing with the layer below over the bottom 1/4-1/2; possible x-axis scour in west portion; possible bedding (may just be weathering o fine deposit); no clast orientation or imbrication	**HCF**	9-10
-to-	-to-			2.6					
140	n/a		%>2mm: <1	sr-sa		10YR/3/1-10YR/5/1			9
140	<1	abrupt, slightly irregular	LS, up to coarse sand; coarse fraction: gran-peb	pebble	>2mm: few ang char; <2mm: some ang char	28.8/66.2/4.9	no apparent bedding, clast orientation or imbrication; clast supported, but local matrix support	**HCF**	11-12
-to-	-to-			2.5					
145	5		%>2mm: 45	sr-sa		10YR/3/1-10YR/5/2			11

STATION: 17 (continued) (arroyo channel wall) | LAT: 13 S 0345175 | LONG: 3972133 | DATE: 8/11/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
145	40	abrupt, generally planar-slightly irrengular	SL, up to coarse sand; coarse fraction: gran-peb, 5-10% cob	cobble	>2mm: abundant ang char; <2mm: abundant ang char	10.4/55.6/34	appears massive; no apparent clast orientation, bedding or imbrication	**DF (likely)**	13-15
-to-	-to-			3.5					13
185	n/a		%>2mm: 30-35	sr-sa		10YR/3/1-10YR/5/1			15
185	50	abrupt, generally planar-slightly irregular	L, up to coarse sand; coarse fraction: gran-peb	coarse pebble-fine cobble	>2mm: some-common ang char; <2mm: some ang char; charred duff layer 1-3cm thick at top	14.2/68.4/17.4	local linear pebble-rich areas; rare weak clast orientation parallel to flow direction; no imbrication; clast-matrix supported	**HCF (prob.)**	16-19
-to-	-to-			2.6					16, 17
235	n/a		%>2mm: 10	sr-sa		10YR/3/1-10YR/5/1			18
235	50	abrupt, generally planar	S-LS, up to coarse sand; coarse fraction: gran-peb, 20% cob	cobble	>2mm: abundant ang char; <2mm: abundant ang char; charred duff layer 0-3cm thick at top	56.7/40.3/3.1	weak imbrication and clast orientation parallel to flow direction; no apparent bedding; matrix supported; imbricated towards arroyo downstream	**HCF (likely)**	20-24
-to-	-to-			>2.9					20, 21, 24
270	n/a		%>2mm: 65	sr-sa		10YR/4/1-10YR/5/1			22
270	10	not exposed	LS, up to coarse sand; coarse fraction: gran-peb	pebble	> 2mm: none-rare; <2mm: rare-few ang char	44.6/47/8.5	no apparent clast orientation or imbrication; 0-1cm fines-rich layer in east portion of exposed layer at top; no grading; clast supported	**DF**	25-26
-to-	-to-			3.1					
280	n/a		%>2mm: 50	sr-sa		2.5YR/4/2-2.5YR/6/2			26

STATION: 18 (fan channel wall)	LAT: 13 S 0345522	LONG: 3973102	DATE: 8/12/2011

Depth (cm)	Thick. (cm)	Lower Contact	Texture (fine/coarse) & % >2mm (from field obs.)	Max. b-axis / Sorting (GSD) / Clast Shape	Charcoal	%Gravel/Sand/Silt+Clay (from lab) / Color (Dry)	Structure	Process (Fire relation)	Sample #s / Samples Dated / Grain Size Samples
0	60	abrupt, slightly irregular	LS, up to coarse sand; coarse fraction: gran-peb, <5% cob	fine cobble	>2mm: few ang char; <2mm: some sr-ang char	48.9/44.8/6.3	no clast orientation or imbrication; no apparent bedding but multiple events possible; matrix supported	**HCF**	1-3
-to-	-to-			3					
60	n/a		%>2mm:50	sr-sa		10YR/3/2-10YR/5/2			2
60	10	abrupt, slightly irregular	LS, up to coarse sand; coarse fraction: gran-peb	coarse pebble	>2mm: few ang char; <2mm: abundant ang char	60.7/34/5.3	moderate clast orientation parallel to flow direction and weak imbrication; no apparent bedding; clast-matrix support	**HCF CL**	4, 5
-to-	-to-			>3					
70	n/a		%>2mm: 55	sa-ang		10YR/3/2-10YR/5/2			4
70	20	abrupt, slightly irregular	S-LS, up to coarse sand; coarse fraction: gran-peb	pebble	>2mm: some ang char; <2mm: some ang char	36.1/59.8/4.1	mainly semi-spherical grains but elongate grains show weak clast orientation parallel to flow direction; no bedding or imbrication; clast supported; weak upward fining	**HCF (FR)**	6, 7
-to-	-to-			1.9					
90	n/a		%>2mm: 55	sr-sa		10YR/4/2-10YR/6/2			7
90	15	abrupt, slightly irregular	LS, up to coarse sand; coarse fraction: gran-peb, 10% cob	cobble	>2mm: none-rare <2mm: some sr-ang char	74.9/20.6/4.4	weak-moderate imbrication and clast orientation parallel to flow direction; no apparent bedding; clast supported	**HCF CL**	8, 9
-to-	-to-			>2.2					
105	n/a		%>2mm: 70	sa-ang		10YR/3/2-10YR/5/2			8
105	25	not exposed	SL, up to coarse sand; coarse fraction: gran-peb,	pebble	>2mm: none; <2mm: abundant sr-ang char	20.5/55.1/24.4	clast-matrix supported; peb-rich areas semi-lens shaped; no apparent grading or imbrication or clast orientation	**DF**	10, 11
-to-	-to-			3.5					
130	n/a		%>2mm: <5-40	sr-sa		10YR/4/2-10YR/6/2			10

APPENDIX 2. SELECT STATION NOTES AND DRAWINGS

SELECT STATION NOTES

STATION 1

Introduction

Station 1 lies just north of a side tributary, along the side of a large channel, at the middle-toe of a south-facing alluvial fan. One of the main considerations in this area is the possibility, because of the large drainage area, that some deposition may be from the main channel and some from the adjacent side tributary. This location has potential for different depositional types (i.e., due to different travel distances and processes involved) and reworking of sediment through the main channel.

Dates

6 dates were taken from this section and all show a normal progression with depth except 2 dates associated with the samples:

- **11-1-14**, 1210 cal. yr BP weighed average(total 1σ range: 1176-1265 cal. yr BP); large charcoal fragment; single fragment from fine-grained deposit.
- **11-1-28**, 950 cal. yr BP weighed average (total 1σ range: 922-977 cal. yr BP); single fragment with a high rootlet density, from fine-grained deposit.
- **11-1-44**, 1639 cal. yr BP weighed average (total 1σ range: 1575-1695 cal. yr BP)

Characteristics are compared to the underlying dated sample:

11-1-54, 870 cal. yr BP weighed average (1 σ: 797-932 cal. yr BP); seed pod, needles and twig from fine fine-charcoal rich layer.

Discussion

Based on dates, stratigraphic relationships and deposit characteristics, it is most likely that 11-1-14 and 11-1-28 are reworked charcoal from older fire events which were temporarily stored upstream.

11-1-28 comes from a very reliable source but is most likely not from the same fire event as 11-1-54, due to only slightly overlapping 1 σ range with 11-1-54 (see Appendix 4 and 5). Therefore, 11-1-28 is removed from the fire-related sedimentation results. Due to the fact that 11-1-28 does not significantly overlap another recorded fire event, it is also not considered in fire-event results.

11-1-14 is most likely reworked and not from the same fire event as 11-1-28 or 11-1-54 due to non-overlapping 1 σ ranges and stratigraphic age reversal. Therefore, 11-1-14 was removed from the fire-related sedimentation results. However, due to the fact that 11-1-14 does significantly overlap another recorded fire event (see Appendix 4 and 5), it is considered in fire-event results

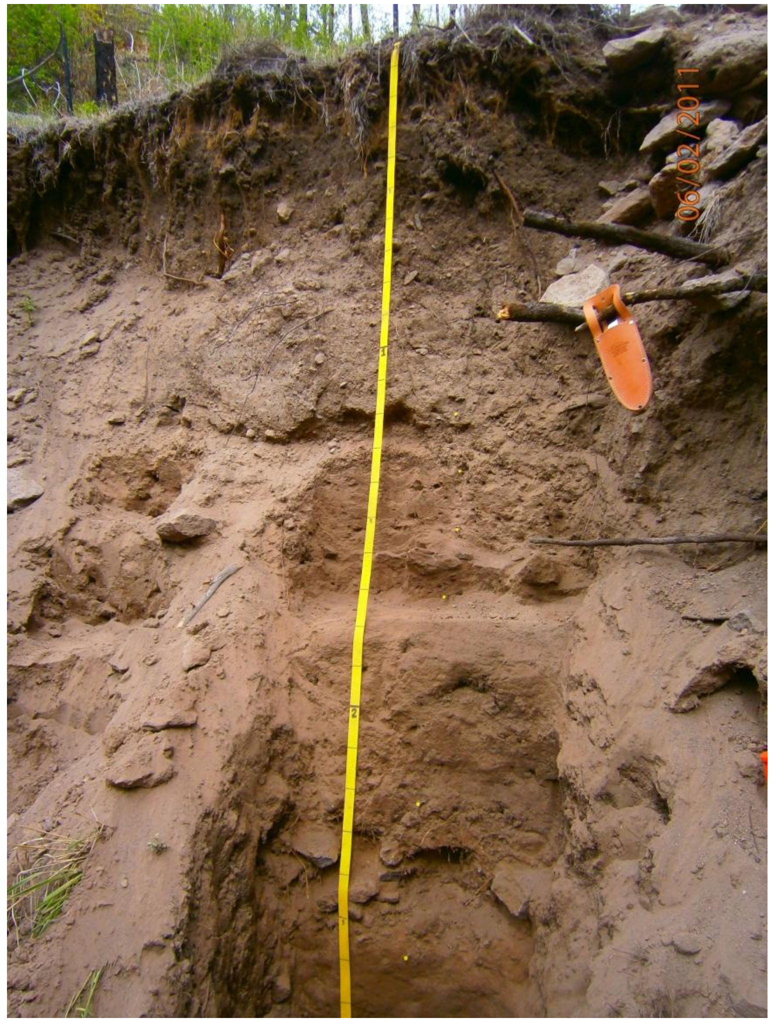
11-1-44 is most likely reworked. Therefore, it was removed from the fire-related sedimentation results. However, due to the fact that 11-1-14 does significantly overlap another recorded fire event (see Appendix 4 and 5), it is considered in fire-event results.

Primary vs. Side Tributary Deposition

Although a few of the deposits within this section appear very fine grained, they are actually very poorly sorted and most likely represent debris flows, possibly a watery tail. The upper deposit, between 45-60 cm, displays layers of alternating coarse-fine sediment, so accumulation of small flows is likely. These fine-grained flows contain pebble-rich areas and fine charcoal-rich areas (usually associated with large coarse charcoal). There is a marked difference in the appearance of these deposits compared to other very coarse-grained debris flow deposits. It is possible that the more fine grained (although very poorly sorted) deposits originated in the main channel, not the adjacent tributary or hillslope (where more coarse-grained deposits may have originated). Therefore, charcoal in the fine-grained layers is more likely to have been reworked.

STATION 2

Introduction



Station 2 lies along a west channel wall on the mid-toe portion of a north-facing alluvial fan. Deposits in this section tend to alternate between cobble/boulder lobes and finer, matrix-runout type flows.

Dates

All dates show a normal date progression with depth, except the lowest date associated with 11-2-52. Due to this date being anomalously low, it is removed from the dates. Either there is an error in the dating process for this sample or a sampling error. Both are possible but it is important to note that a talus cone of sediment eroded off of the channel wall is located right next to where the samples were taken. The section was cleared and the channel wall was dug into to sample, so it’s possible that 11-2-52 was actually sampled from talus. Since this layer is poorly sorted it may have been difficult to distinguish a boundary.

STATION 3

Station 3 lies along a west channel wall on the middle portion of a north-facing alluvial fan. All dates show a normal progression of date with depth.

STATION 7

Introduction

Station 7 lies along a west channel wall on the upper portion of a south-facing alluvial fan. On the east wall, facing the station, alluvium has been completely removed and the channel wall is composed of bedrock. Due to the short distance a flow would need to travel to be deposited at this station, it is likely that these flows are characteristic of flows which may have been generated on the hillslope, rather than the channel, for this drainage area. Burned surfaces mark boundaries near the top of the section but below 150 cm it's difficult to tell where deposit boundaries lie. Structures which are likely pedogenic clay lamellae may be indicators of deposit boundaries, as well as "lines" of coarse charcoal.

Dates

All dates show normal progression of date with depth. The top 2 dates are likely separate fire events (due to the presence of burned surfaces) but have highly overlapping distribution curves. It is possible that, due to deposit characteristics, 3 fire events may have occurred between 400 and 1250 cal. yr BP (not including the events dated at 400 and 1250 cal yr BP). 11-7-24 and 11-7-28 may also be from the same event, due to highly overlapping 1σ intervals and deposit characteristics.

STATION 10

<u>Introduction</u>

Station 10 lies at top of fan directly under bedrock channel/overhang on a north-facing alluvial fan. The deposits are located under the protected side of the bedrock alcove which shows evidence of having been filled almost to the ceiling and then extensively eroded with only a relatively small amount of sediment remaining along the inside of the alcove. Near the outer edge of the section, on the outside of the alcove, grasses and trees grow. There are two bedrock channels, one main channel centered over the alcove (~5m high from bottom fill and ~ 7m deep) and one small channel directly over a scoured/filled (e.g., paleochannel) feature in the section. The main channel is likely to be older but both could have supplied material to the alcove over the years. However, the majority of the deposits are continuous across the section (i.e., on either side of the scour/fill feature) and therefore contribution by the smaller channel is likely to be recent.

Based on the site location, a few location-specific factors should be noted. Due to the presence of PWT (partially weathered tuff) in the section, weathering, erosion and deposition of tuff from the sides and ceiling of the alcove can provide insight into event timing and surface stability. Although rain events will allow water to enter cracks and promote weathering at the crack terminus,

Looking into the alcove at section. Note the paleochannel at the right –hand edge.

The primary bedrock channel is shown on the left and the secondary one, on the right. Again, note the paleochannel.

cracks are most likely to be developed, and PWT dislodged, through freeze-thaw. Wet years/decades may produce more tuff weathering and deposition but dislodgement is more likely in the winter or after a storm event, not during a flow. If PWT became dislodged during a flow it would most likely not be perfectly aligned with the flow direction and may also be in smaller pieces. Therefore, PWT layers which form thick layers parallel to the flow, and were most likely deposited over time, have been identified within the section (see section drawing).

Apart from PWT, the area near the entry to the alcove is more likely to provide conditions which support grass and small tree growth, if enough quiescence is provided. If duff is deposited in the alcove it’s most likely to accumulate near the entry edges of the alcove or below the bedrock channels in the overhang, although this duff is also likely to be eroded away quickly. The way this alcove fills and erodes is likely to be unique based on energy gain/loss through a 5+m drop from the hillslope above. Watery events will likely erode material in the alcove through energy gained through the drop, whereas debris flows & hyperconcentrated flows will likely act more like wet concrete flowing and dropping from the chute of a concrete truck. Sediment laden flows will likely lose a l ot of energy upon impact with the alcove floor, both through scouring and clast impact within the flow. The drop likely results in material being pushed into a mound/dam around the impact site, much like the raised edge of a cow paddy or the structure which forms when wet concrete drops from a chute. The raised edge is likely broken eventually near the channel area and material continues to flow, but the raised edge likely remains in some form. After an erosive/depositional event, such as after a fire, it will likely take time for the middle of the "cow paddy" to fill with smaller flows and for material to be deposited on the top of the outer edge (i.e., the section mapped). If it takes a long enough time to deposit material there (i.e., through many depositional/erosive events) grasses many grow or PWT may accumulate. Therefore, this section will record relatively major events which supply material quickly to the alcove edge and material deposited after the "cow paddy" has become a shelf (likely with a small channel).

Dates

6 dates were acquired for this station which display an expected date progression with depth, except for 3 dates ranging from 600-690 cal. yr BP weighted average:

- 11-10-93, 600 cal. yr BP weighted average (total 1σ range: 546-640 cal. yr BP); needles.

- 11-10-96, 690 cal. yr BP weighted average (total 1σ range: 665-722 cal. yr BP); single twig.
- 11-10-115, 620 cal. yr BP weighted average (total 1σ range: 565-671 cal. yr BP); single twig.

Discussion

All three sources should be accurate due to the reliability of the samples sources. Due to the three points of intersection at relatively high probability areas on the distribution curves for 11-10-93 and 11-10-115, it's possible they are from the same event. However, due to the depositional characteristics and stratigraphy (see below), it is much more likely these are three separate events which occurred within a 150-200 yr time period (546-722 cal. yr BP, the lowest and highest 1 σ age for the three dates).

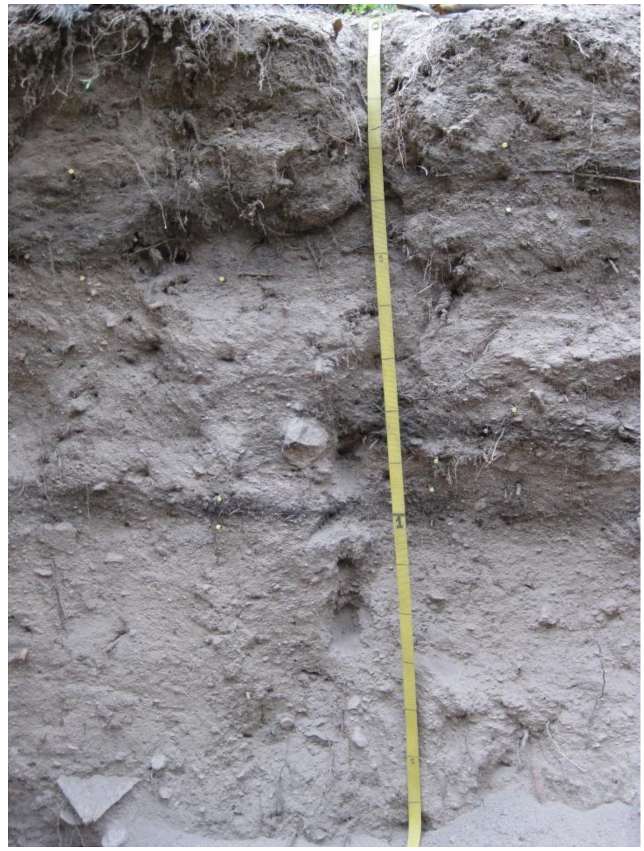
Stratigraphy (bottom to top)

Below the 830 cal. yr BP weighted average (11-10-128; total 1σ range: 770-906 cal. yr BP) duff layer at 210 cm, debris flow deposits interfinger with fine grained, charcoal-rich areas within the deposit. Above the charred duff layer is 10 cm of deposition below the first charcoal-rich debris-flow deposit. This debris-flow deposit makes up part of 60-70 cm of deposition during, after and between three likely fire events within the same 150-200 yrs. The weighted average ages for these events (samples 11-10-93, 11-10-96, 11-10-115) are not "in order" but the 1σ ranges for both 11-10-93 and 11-10-96 overlap 11-10-115, but not each other. These have been interpreted as three separate events. First, a 40 cm thick "small" fire-related debris flow was deposited and then small pulses of sediment were likely added (i.e., coarse-fine layer with some grain rounding and low-angle scour-fill) making up 20-30 cm of deposition. This material was added fast enough such that grasses and PWT did not accumulate. However, enough time passed for some, likely grasses, to accumulate at 140 cm and burn. This event may have either been a small grass fire (with the alcove acting as a fire break) or could have occurred on a highly charred hillslope which would not have been able to support a large fire. 20 cm of material was deposited above (coarse-fine) and then another period of stability lasted such that another grass/duff surface formed, burned, and a significant layer of PWT accumulated on top. This whole period of three events lasted, 1 σ, from 546-722 cal. yr BP.

After the last grass fire discussed above and before the next fire-related debris-flow event (360 cal. yr BP weighted average; total 1σ range: 292-429 cal. yr BP; 11-10-57), 20 cm of sediment was deposited. At the deposit base there are some fine charcoal-rich areas, possibly associated with the last grass fire, as well as significant layers of PWT. Then, at 360 cal. yr BP weighted average (11-10-57), another "small" debris flow event, matrix-charcoal rich, was deposited. In between it and a 170 cal. yr BP weighted average (total 1σ range: 0-287 cal. yr BP; 11-10-21) deposit is a 50 cm thick layer made up of at least 2 deposits separated by small PWT layers. Above a "small" charcoal-rich debris-flow deposit lays a deposit dated at 170 cal. yr BP weighted average(11-10-21). On top of this deposit lies a charred duff layer which spans the depth of the alcove, suggesting a significant period of quiescence. Over the entire top of the section lies a debris-flow deposit which has scoured and filled a channel in older layers; both the charred duff layer and the debris flow deposit are likely to be associated with the 2002 Lakes Fire.

STATION 11

Introduction



Station 11 lies on the east mid-channel wall of a south-facing alluvial fan. Based on the proximity to bedrock (see sketch on drawing) this location may produce distinct deposits developed through runoff with upland sediment, gaining a lot of energy and turbulence in dropping potentially more than 20 m before travelling less than 15 m to the channel. It could be that this produces some reworking/inconsistent flows, which could explain deposit morphology (discontinuous over short distances).

Dates

Its likely 11-11-26 (400 cal. yr BP weighted average, total 1σ range: 316-461 cal. yr BP) and 11-11-46 (380 cal. yr BP weighted average, total 1σ range: 303-429 cal. yr BP) are associated with the same fire event, since they come from similarly structured deposits, close together, and their 1σ intervals considerably overlap. Due to the overlapping 1σ intervals of 11-11-8, 11-11-26 and 11-11-46 there is a possibility that they are all associated with same fire event. However, the total 1σ range for 11-11-8 also overlaps 11-7-5, 11-7-1 and 11-10-57, so it may be from a more recent fire event.

East bank and exposed bedrock near Station 11.

STATION 13

Introduction

Station 13 lies along a west channel wall on the mid-toe portion of a north-facing alluvial fan. Several deposits within this section display steeper slopes than the fan surface slope. This may have been due to the presence of a minor channel which intersected the main channel, which was scoured following the 2002 Lakes Fire. However, no clear indication of terracing is noted.

Dates

All dates show a normal progression of date with depth except the date associated with:

- **11-13-7**, 1440 cal. yr BP weighted average, total 1σ range: 1376-1514 cal. yr BP); bark.
- Which is compared to the samples associated with deposits above and below it:
- **11-13-3**, 1380 cal. yr BP weighted average, total 1σ range: 1379-1407 cal. yr BP); charcoal fragment(s)
- **11-13-8**, 1350 cal. yr BP weighted average, total 1σ range: 1310-1370 cal. yr BP); twigs and needles

Discussion

The deposit which is associated with 11-13-7 is distinct from the flows above and below it, which have overlapping total 1σ ranges and likely correspond to the same fire event. Based on the irregular, locally scoured contact between the flow associated with 11-13-7 and the flow below it, it is likely that this flow is capable of scouring underlying deposits and that 11-13-7 is actually a reworked piece of charcoal. Therefore, it is suggested that the deposits associated with 11-13-3, 11-13-7, and 11-13-8 are all associated with the same fire event.

Therefore, 11-13-7 is removed from the fire-related sedimentation results. However, due to the fact that 11-13-7does significantly overlap other recorded fire events (see Appendix 4 and 5), it is considered in fire-event results. 11-13-3, 11-13-7, and 11-13-8 combined should be considered a large response to a fire event, and therefore a large fire-related sedimentation event.

STATION 14

Introduction

Station 14 lies along a west channel wall on the upper portion of a north-facing alluvial fan. This section contains abundant possible clay lamellae and often it is difficult to distinguish deposit boundaries.

Dates

Based on deposit characteristics and highly overlapping total 1σ ranges, it is likely that 11-14-11 and 11-14-14 are associated with the same fire event, even though their ages show a minor abnormal progression of date with depth.

STATION 16

Introduction

Station 16 lies along a west channel wall on the upper portion of a north-facing alluvial fan. This section contains debris-flow and hyperconcentrated-flow deposits and abundant possible clay lamellae.

Dates

All dates show a normal progression of date with depth except the date associated with:

- **11-16-15**, 3760 cal. yr BP weighted average, total 1σ range: 3705-3828 cal. yr BP); single fragment of charcoal.

Which is compared to the samples associated with deposits above and below it:

- **11-16-12**, 3380 cal. yr BP weighted average, total 1σ range: 3351-3441 cal. yr BP); outer rings of single charcoal fragment
- **11-16-21**, 3590 cal. yr BP weighted average, total 1σ range: 3511-3681 cal. yr BP); several rings of one large twig.

Discussion

It is most likely that 11-16-15 is a reworked piece of charcoal. Therefore, 11-16-15 was removed from the fire-related sedimentation results. However, due to the fact that 11-16-15 does significantly overlap another recorded fire event (see Appendix 4 and 5), it is considered in fire-event results.

STATION 17

Introduction

Station 17 is located in an arroyo which contains running water most of the year. The site is also at the toe of a side-tributary, south-facing alluvial fan.

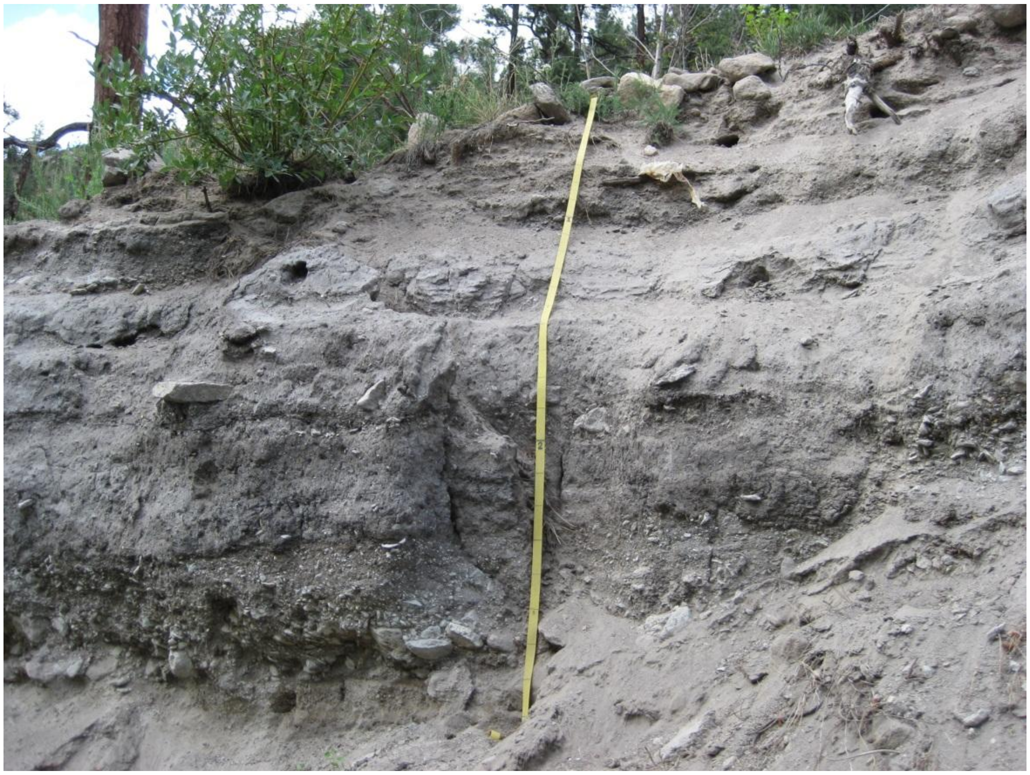
Dates

None of the dates in this section follow an expected date progression with depth:

- **11-17-13**, 1110 cal. yr BP weighted average (total 1σ range: 1060-1171 cal. yr BP); 2 charcoal fragments
- **11-17-16**, 600 cal. yr BP weighted average (total 1σ range: 553-649 cal. yr BP); charred leaves
- **11-17-17**, 761 cal. yr BP weighted average (total 1σ range: 730-787)
- **11-17-20**, 1470 cal. yr BP weighted average (total 1σ range: 1417-1526 cal. yr BP); charcoal fragment
- **11-17-21**, 1566 cal. yr BP weighted average (total 1σ range: 1528-1602)
- **11-17-24**, 1170 cal. yr BP weighted average (total 1σ range: 1091-1259 cal. yr BP); charcoal fragment

Discussion

11-17-13 does not follow an expected date progression with depth and due to the fact that 11-17-13 does not significantly overlap another reliably recorded fire event, it is not considered in fire-event results or fire-related sedimentation results.



11-17-16 and **11-17-17** come from an organic rich, possible detrital organic/char layer containing charred and uncharred bark, twigs, fibrous "clods" (may be filled with grasses) and leaves (removed for dating). Most of the leaves had 10-20% loss on each leaf, which suggests that they were charred in place and buried quickly. No obvious coatings were noted. Although leaves cannot be scraped before dating, all precautions were taken to clean them as well as possible. Although these sample dates do not follow an expected date progression with depth, due to the fact that 11-17-16 does significantly overlap another recorded fire event (see Appendix 4 and 5), it is considered in fire-event results. 11-17-17 does not and is not considered in fire-event results. Both 11-17-16 and 11-17-17 are removed from the fire-related sedimentation results.

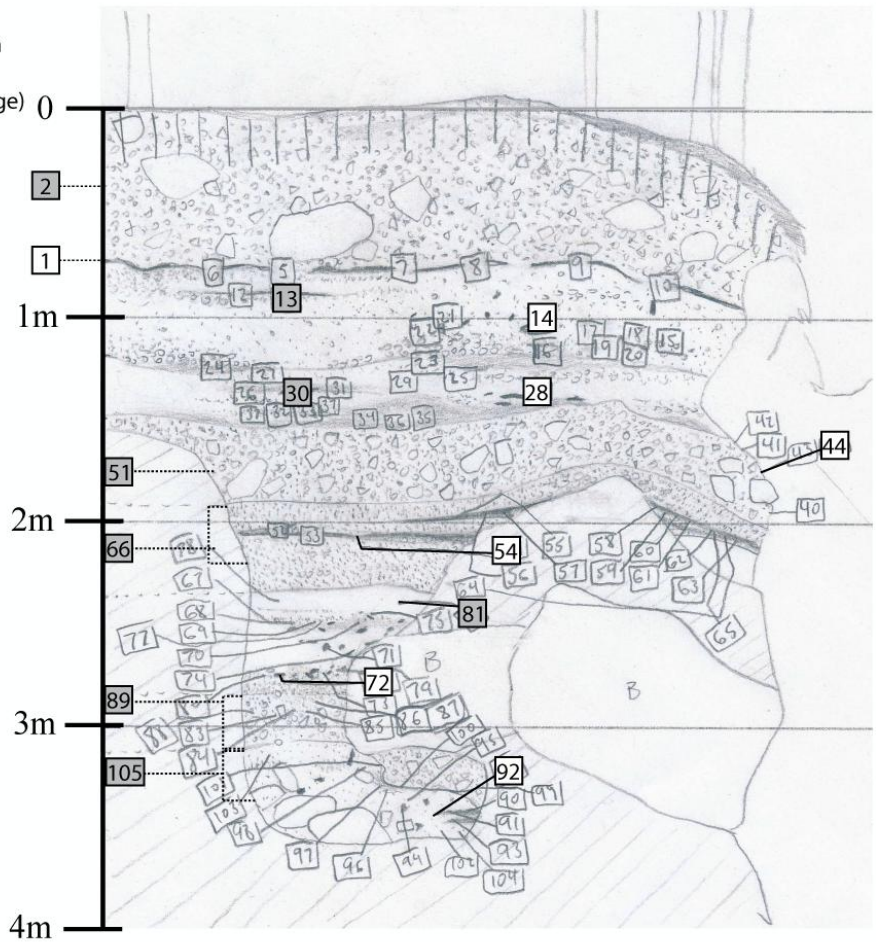
11-17-20 and **11-17-21** come from a burned surface/duff layer. Sample contains dark sediment with abundant charcoal (as opposed to uncharred material) with bark, twigs and wood fragments but no visible leaves. Although these sample dates do not follow an expected date progression with depth, due to the fact that 11-17-20 and 11-17-21 do significantly overlap other recorded fire events (see Appendix 4 and 5), it is considered in fire-event results. However, 11-17-20 and 11-17-21 are removed from the fire-related sedimentation results. Although both samples overlap different recorded fire events, it is likely they are actually associated with the same fire event.

11-17-24 likely came from the adjacent fan. The matrix of this deposit contains a higher than normal concentration of fibrous material/larger rootlets (mainly uncharred but some may be charred), along with abundant fine charcoal. It could have mobilized from the hillslope rather than channel sediment. Its grain-size distribution is different than other flows, more clast supported, which further suggests hillslope mobilization. Although this sample date does not follow an expected date progression with depth, due to the fact that 11-17-24 does significantly overlap another recorded fire event (see Appendix 4 and 5), it is considered in fire-event results. However, 11-17-24 is removed from the fire-related sedimentation results.

STATION DRAWINGS

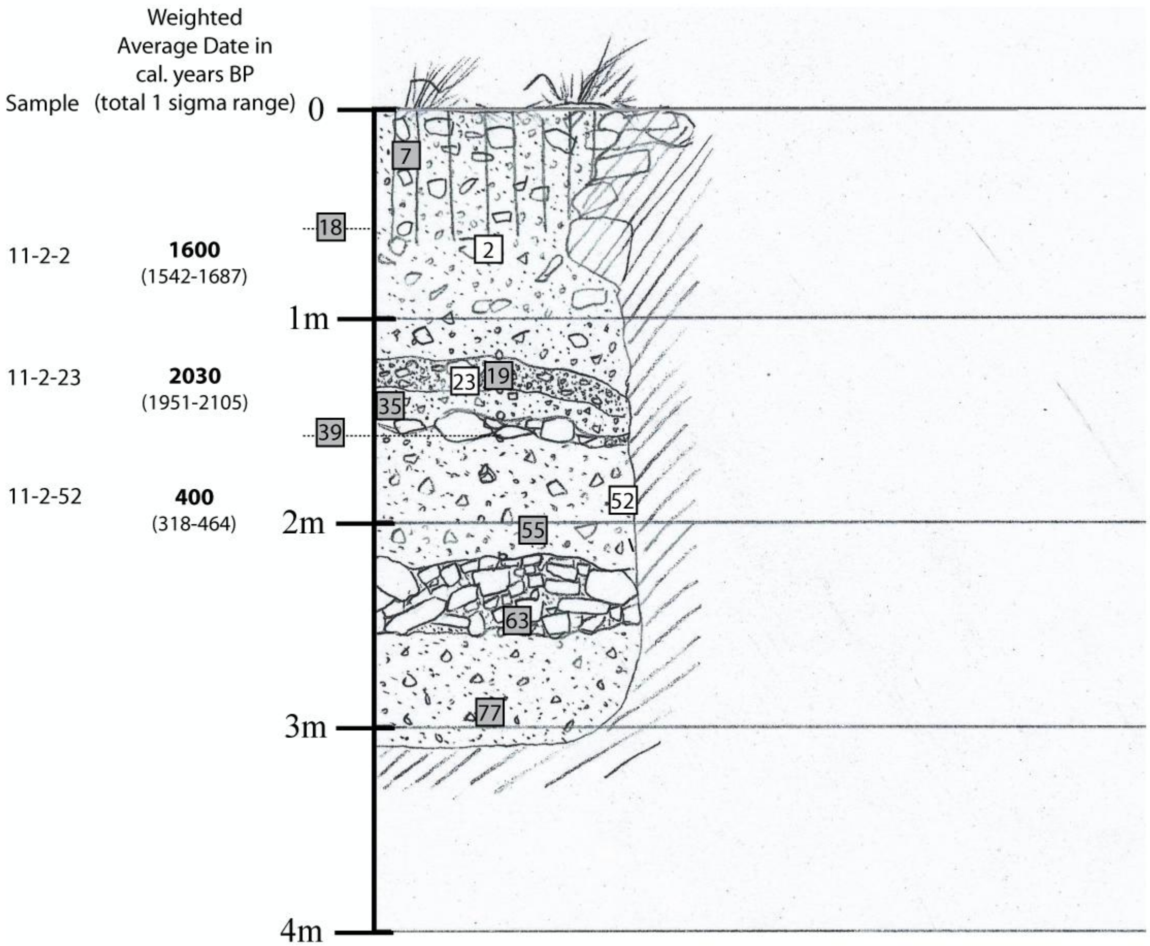
STATION: **1**	(south-facing slope, mid-fan channel wall)		SECTION: N/A
LAT: 13 S 0346034	LONG: 3972325	DATE: 06/01/2011	WORKER: EF

Sample	Weighted Average Date in cal. years BP (total 1 sigma range)
11-1-1	**460** (342-516)
11-1-14	**1210** (1176-1265)
11-1-28	**950** (922-977)
11-1-44	**1639** (1575-1695)
11-1-54	**870** (797-932)
11-1-72	**1450** (1392-1516)
11-1-92	**1740** (1703-1814)



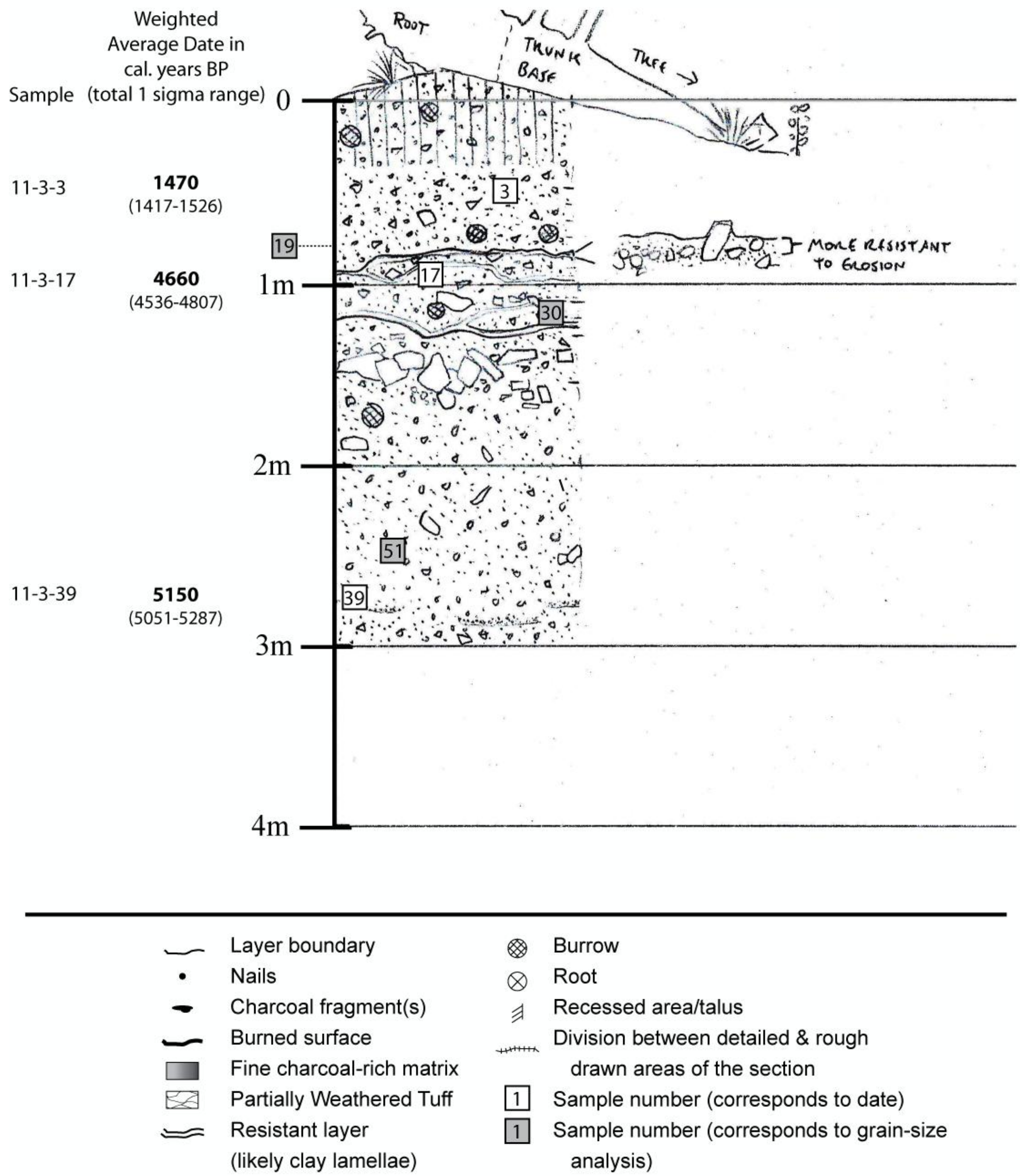
- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- 1 Sample number (corresponds to date)
- 1 Sample number (corresponds to grain-size analysis)

STATION: **2**	(north-facing slope, mid-fan channel wall)		SECTION: N/A
LAT: 13 S 0345896	LONG: 3971752	DATE: 06/02/2011	WORKER: EF

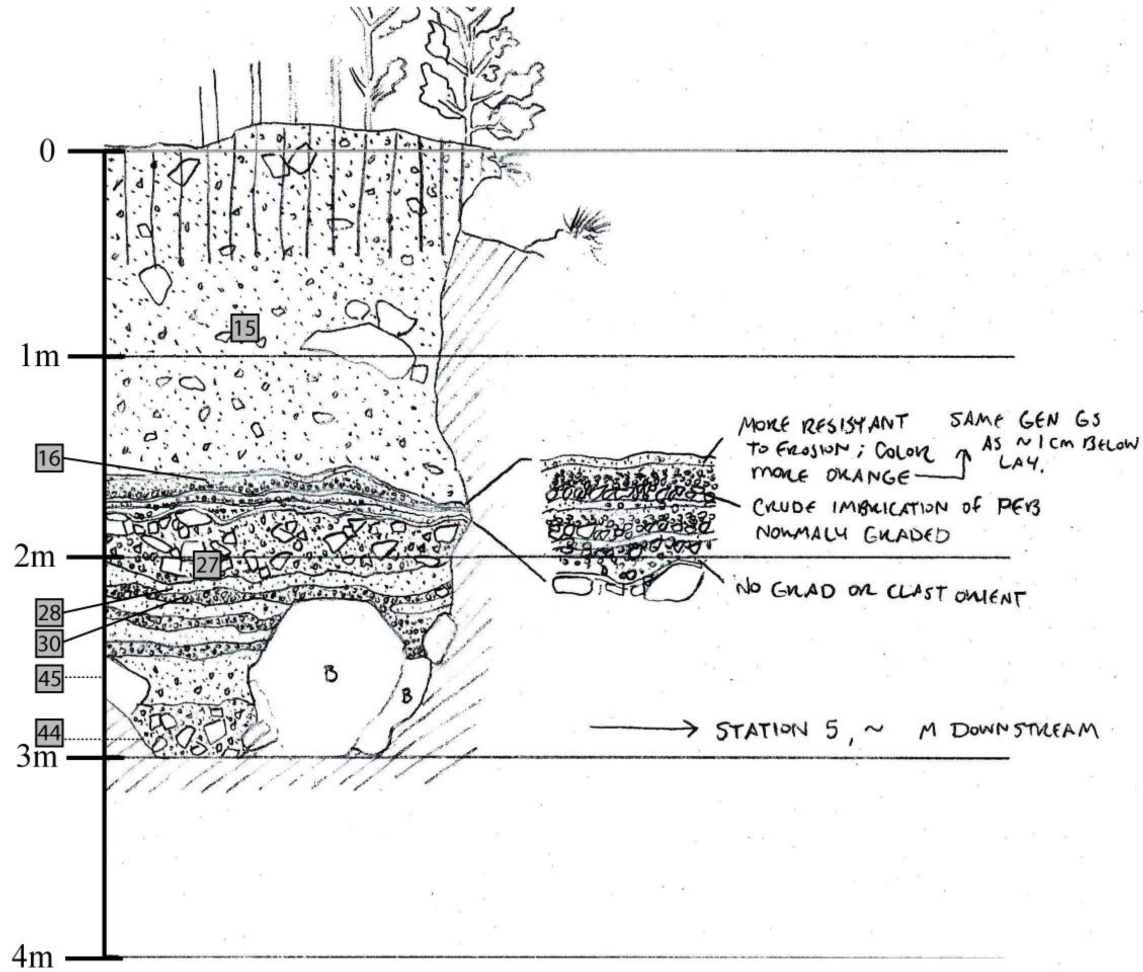


- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- 1 Sample number (corresponds to date)
- 1 Sample number (corresponds to grain-size analysis)

STATION: **3**	(north-facing slope, upper-fan channel wall)		SECTION: N/A
LAT: 13 S 0345557	LONG: 3971778	DATE: 06/07/2011	WORKER: EF

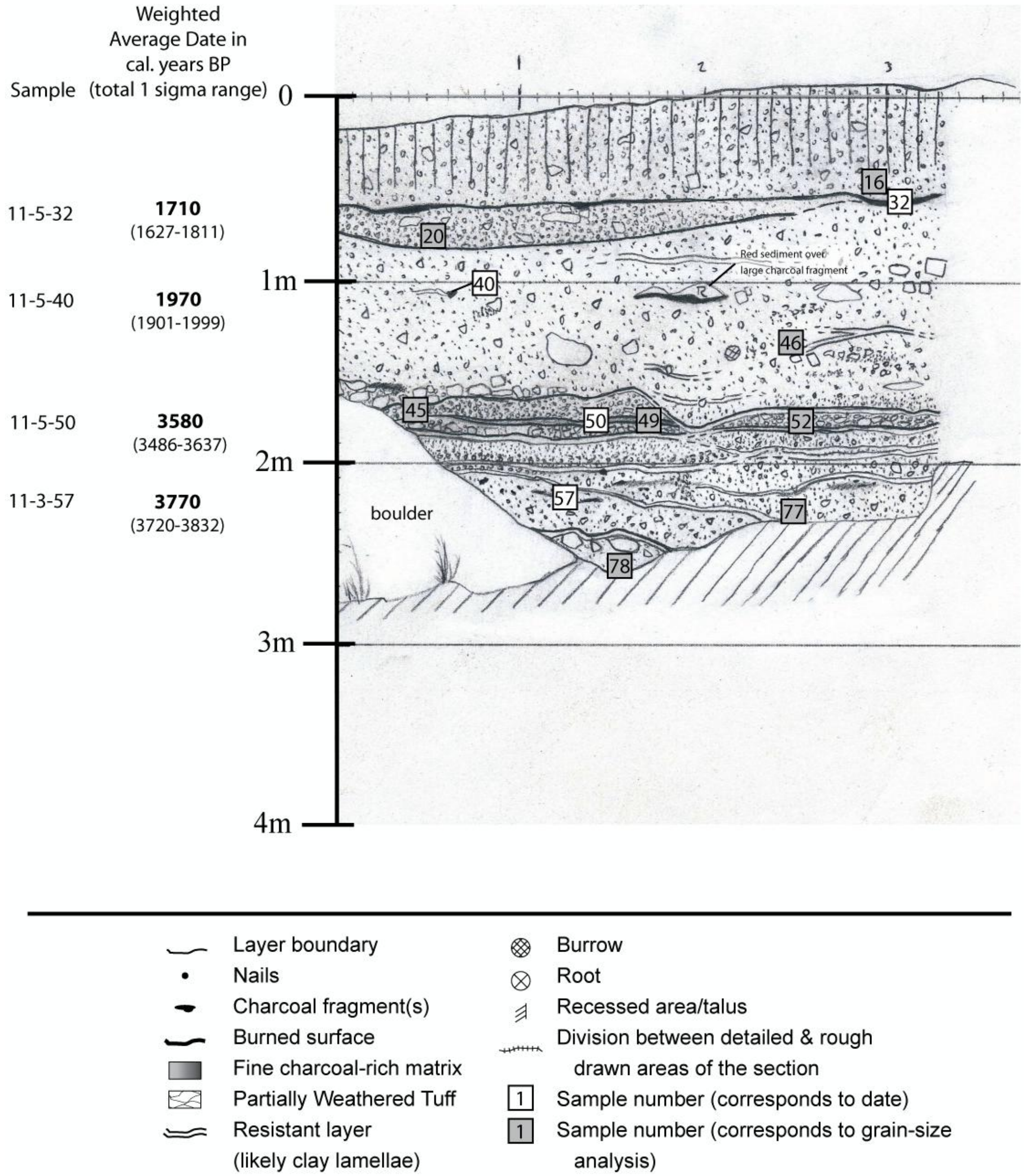


STATION: **4** (south-facing slope; mid/upper-fan channel wall)	SECTION: N/A		
LAT: 13 S 0347694	LONG: 3972607	DATE: 6/9/2011	WORKER: EF

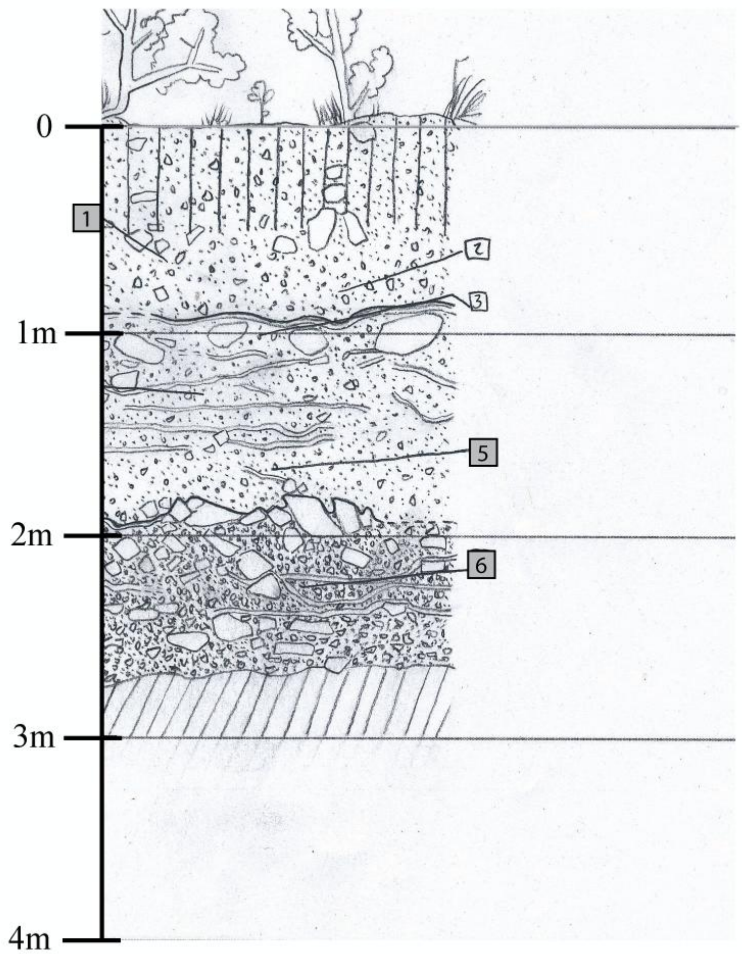


- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- 1 Sample number (corresponds to grain-size analysis)

STATION: **5** (south-facing slope, upper-mid fan channel wall)	SECTION: N/A		
LAT: 13 S 0347685	LONG: 3972584	DATE: 06/13/2011	WORKER: EF



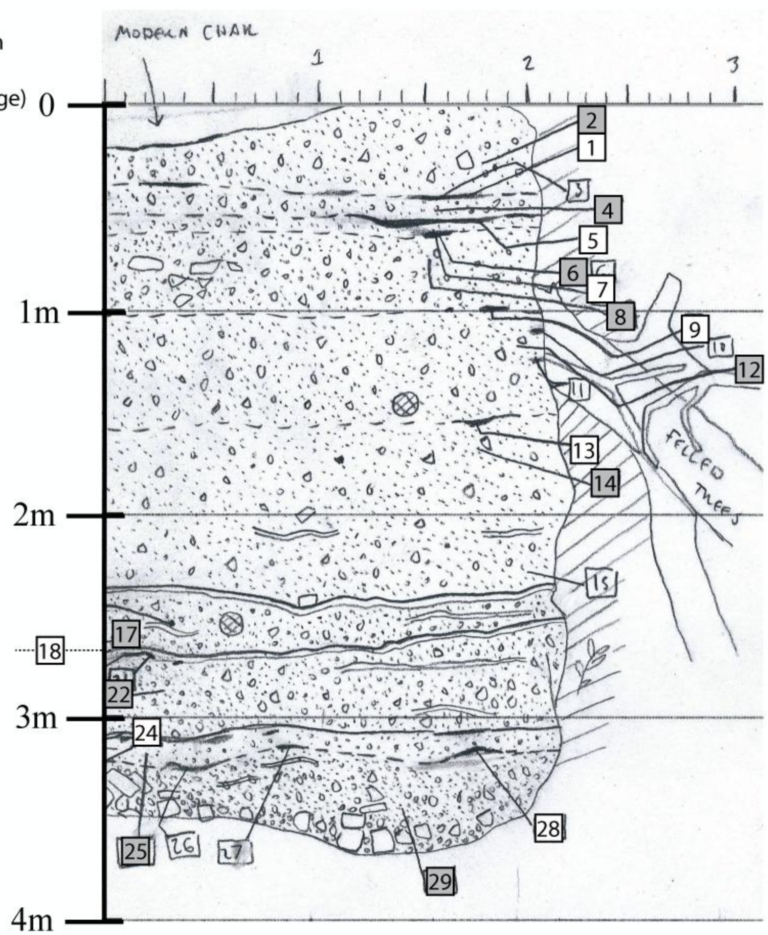
STATION: **6**	(south-facing slope; lower-fan channel wall)	SECTION: N/A
LAT: 13 S 0347680	LONG: 3972454 DATE: 6/14/2011	WORKER: EF



Layer boundary
Nails
Charcoal fragment(s)
Burned surface
Fine charcoal-rich matrix
Partially Weathered Tuff
Resistant layer (likely clay lamellae)
Burrow
Root
Recessed area/talus
Division between detailed & rough drawn areas of the section
1 Sample number (corresponds to grain-size analysis)

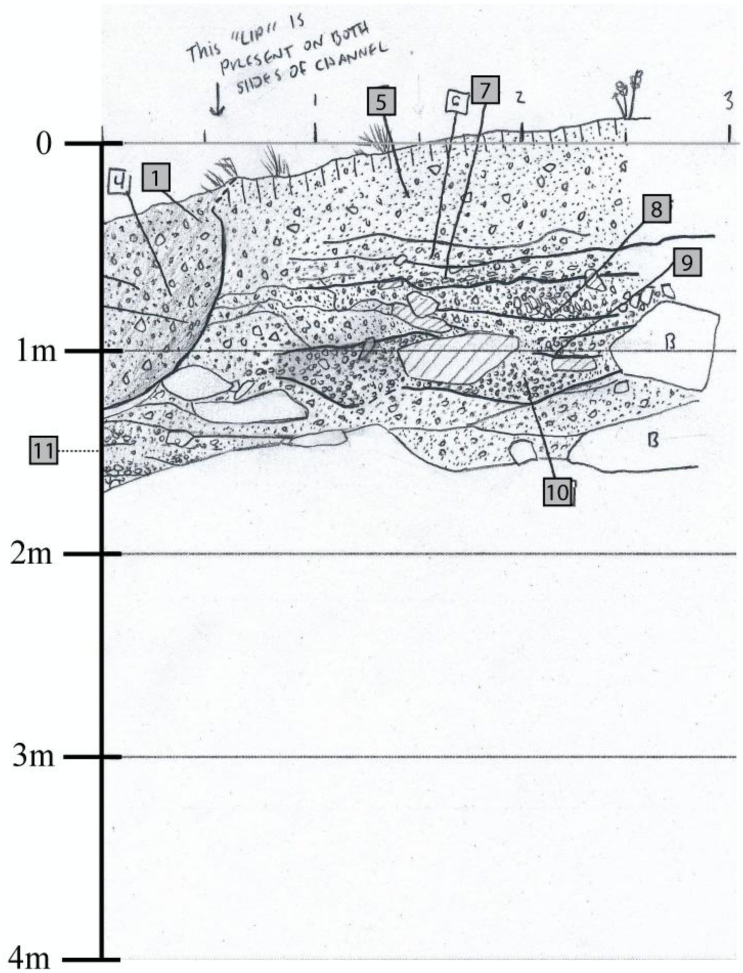
STATION: **7**	(south-facing slope, upper-fan channel wall)		SECTION: N/A
LAT: 13 S 0346491	LONG: 3972407	DATE: 06/16/2011	WORKER: EF

Sample	Weighted Average Date in cal. years BP (total 1 sigma range)
11-7-1	**200** (0-305)
11-7-5	**180** (0-299)
11-7-7	**400** (320-477)
11-7-9	**621** (567-668)
11-7-13	**1250** (1185-1296)
11-7-18	**1960** (1898-1998)
11-7-24	**2160** (2057-2300)
11-7-28	**2250** (2161-2345)



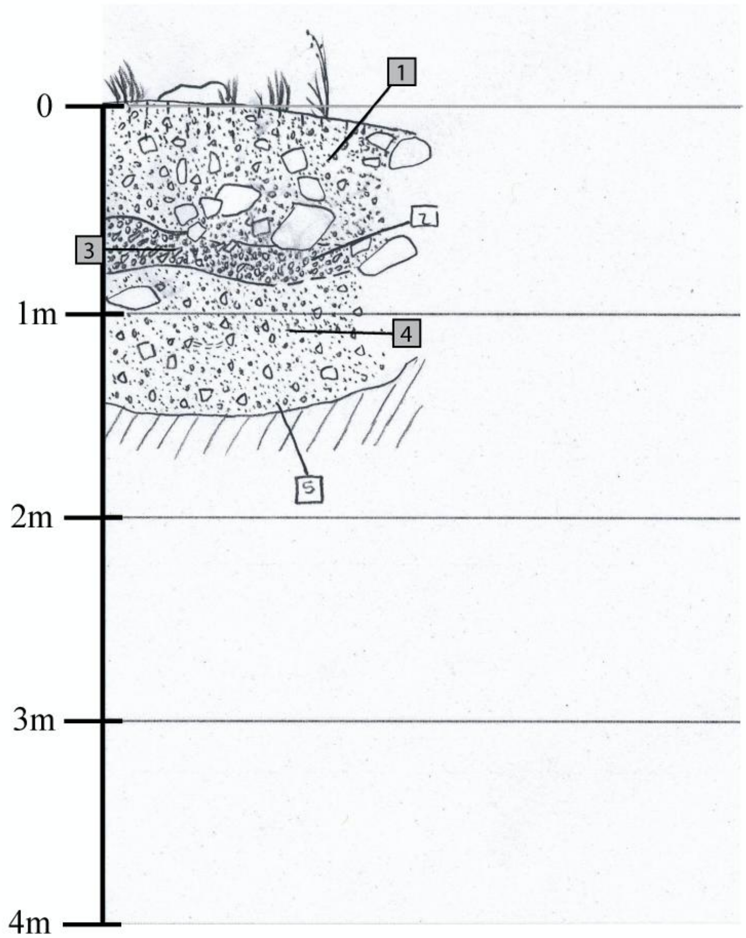
- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- Sample number (corresponds to date)
- Sample number (corresponds to grain-size analysis)

STATION: **8**	(south-facing slope; lower-fan channel wall)	SECTION: N/A
LAT: 13 S 0341999	LONG: 3969408	DATE: 6/20/2011 — WORKER: EF



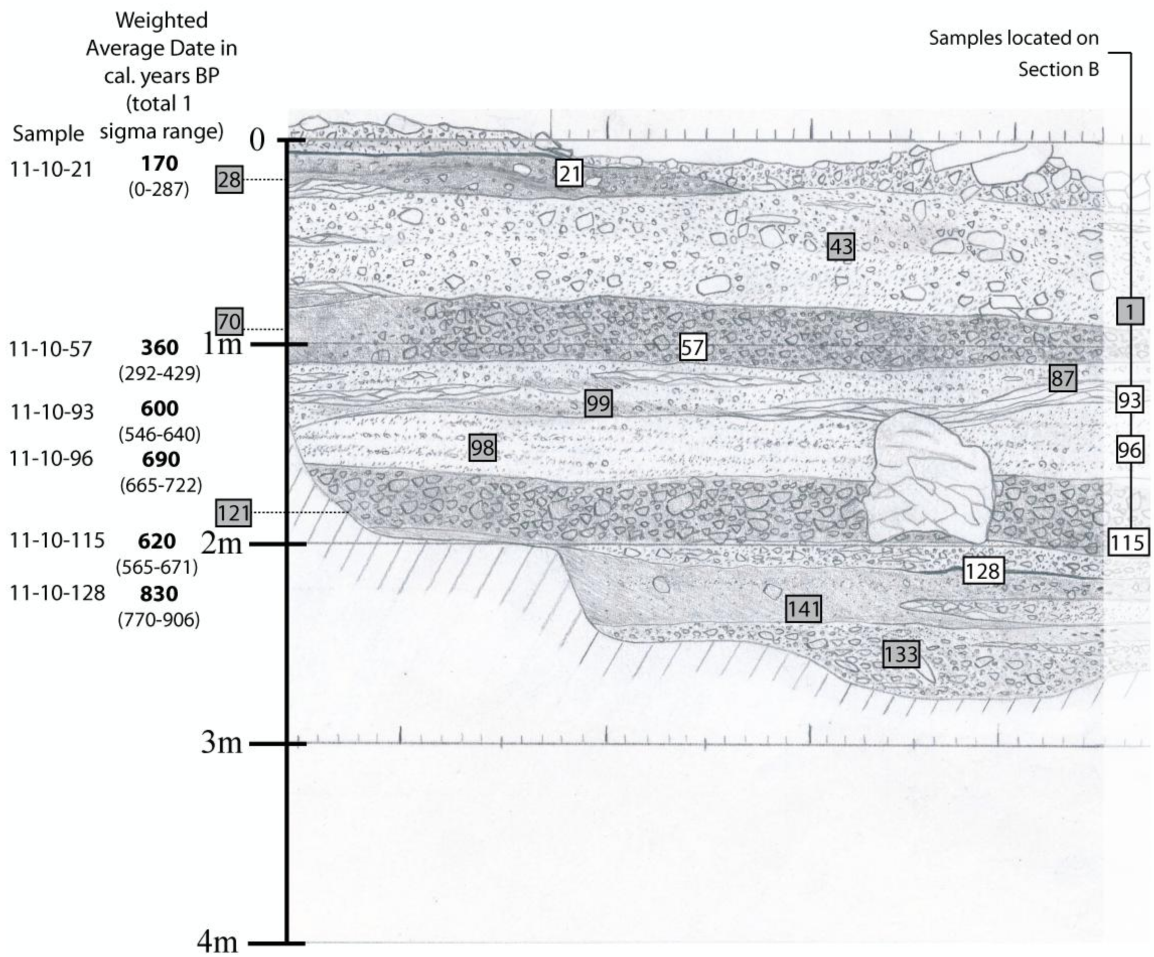
- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- Sample number (corresponds to grain-size analysis)

STATION: **9**	(south-facing slope; lower-fan channel wall)	SECTION: N/A
LAT: 13 S 0343264	LONG: 3969703	DATE: 6/20/2011	WORKER: EF



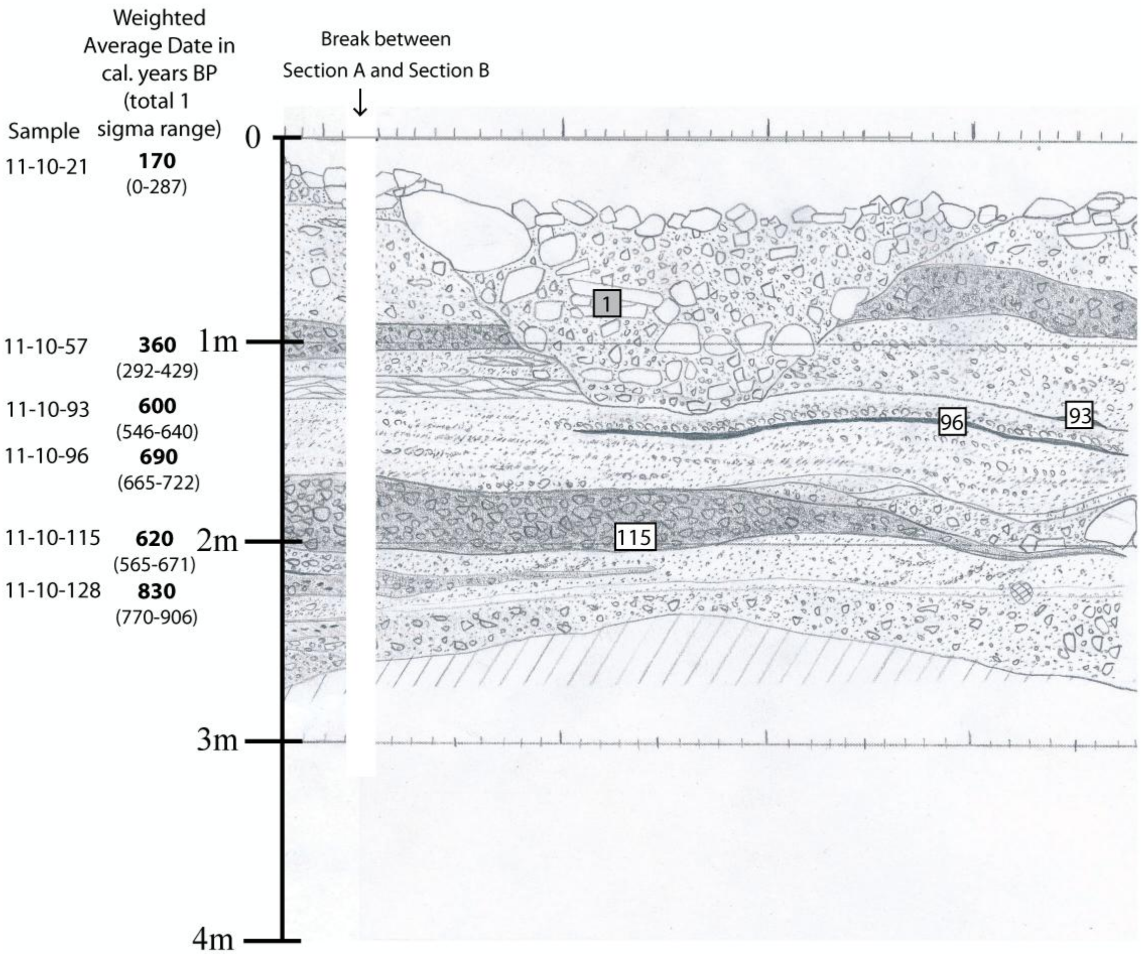
Layer boundary
Nails
Charcoal fragment(s)
Burned surface
Fine charcoal-rich matrix
Partially Weathered Tuff
Resistant layer (likely clay lamellae)
Burrow
Root
Recessed area/talus
Division between detailed & rough drawn areas of the section
Sample number (corresponds to grain-size analysis)

STATION: **10**	(north-facing slope, near top of fan)		SECTION: A
LAT: 13 S 0344766	LONG: 3971821	DATE: 06/21/2011	WORKER: EF



Layer boundary
Nails
Charcoal fragment(s)
Burned surface
Fine charcoal-rich matrix
Partially Weathered Tuff
Resistant layer (likely clay lamellae)
Burrow
Root
Recessed area/talus
Division between detailed & rough drawn areas of the section
Sample number (corresponds to date)
Sample number (corresponds to grain-size analysis)

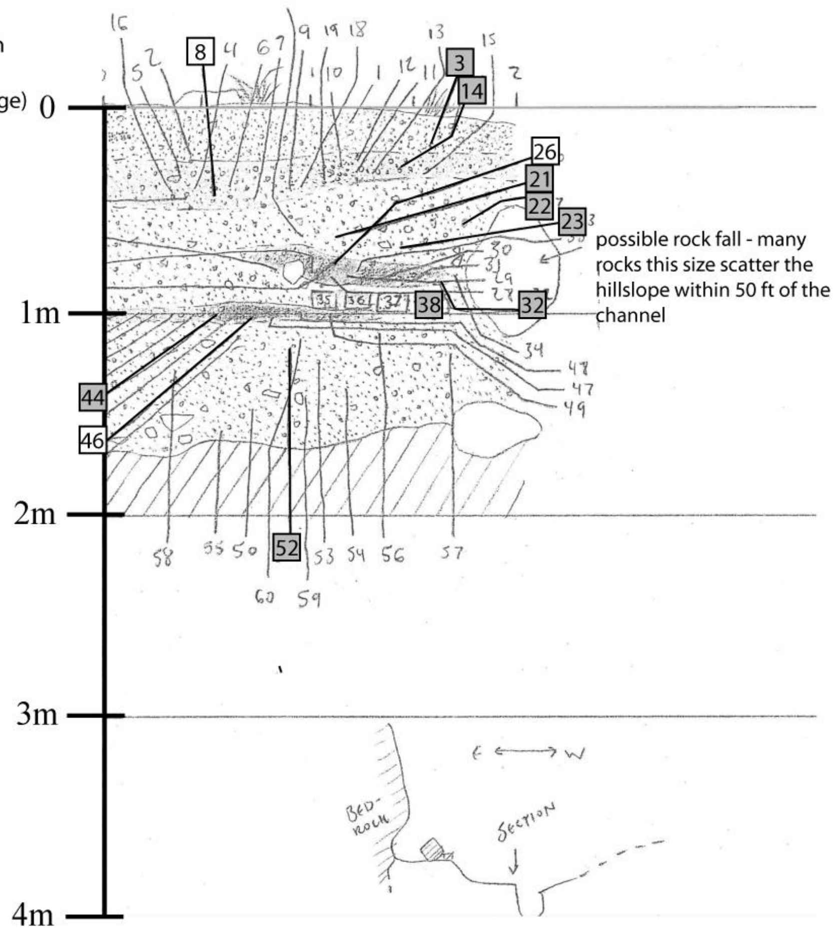
STATION: **10** (north-facing slope, near top of fan)			SECTION: B
LAT: 13 S 0344766	LONG: 3971821	DATE: 06/21/2011	WORKER: EF



- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- 1 Sample number (corresponds to date)
- 1 Sample number (corresponds to grain-size analysis)

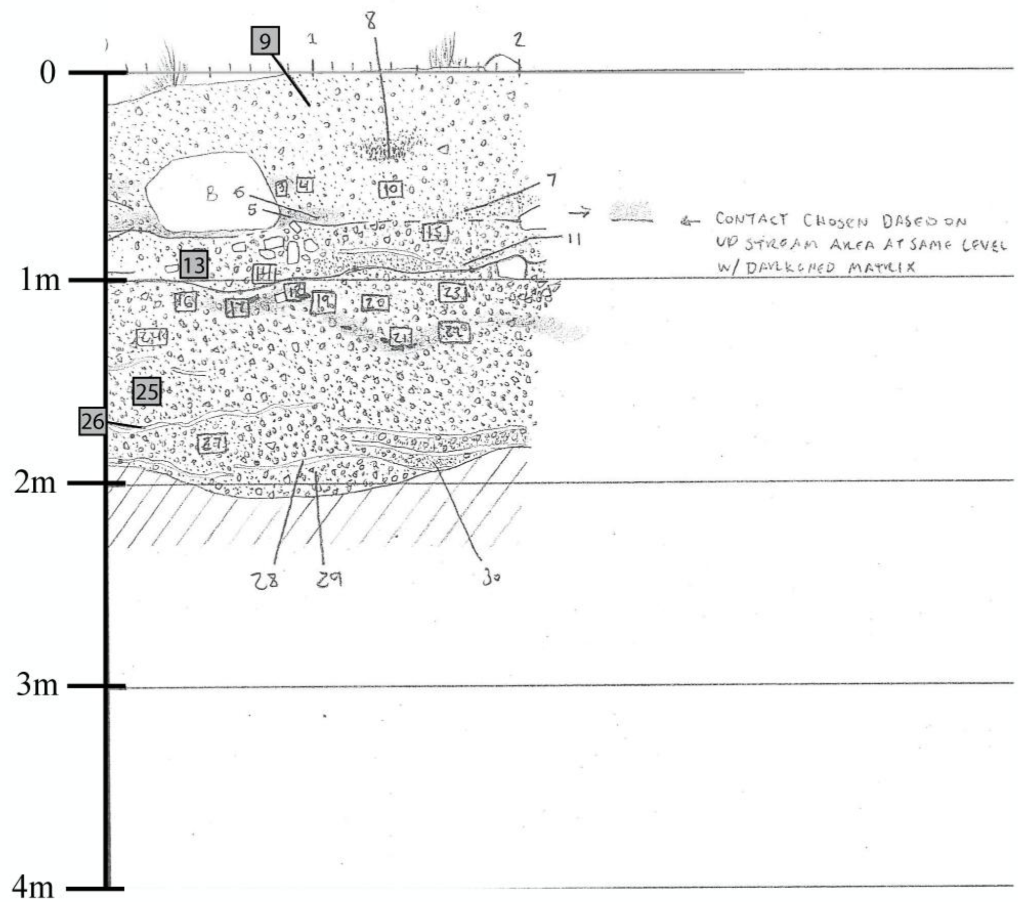
STATION: **11**	(south-facing slope, upper-fan channel wall)	SECTION: N/A
LAT: 13 S 0347432	LONG: 3972212	DATE: 08/03/2011 WORKER: EF

Sample	Weighted Average Date in cal. years BP (total 1 sigma range)
11-11-8	**340** (159-427)
11-11-26	**400** (316-461)
11-11-46	**380** (303-429)



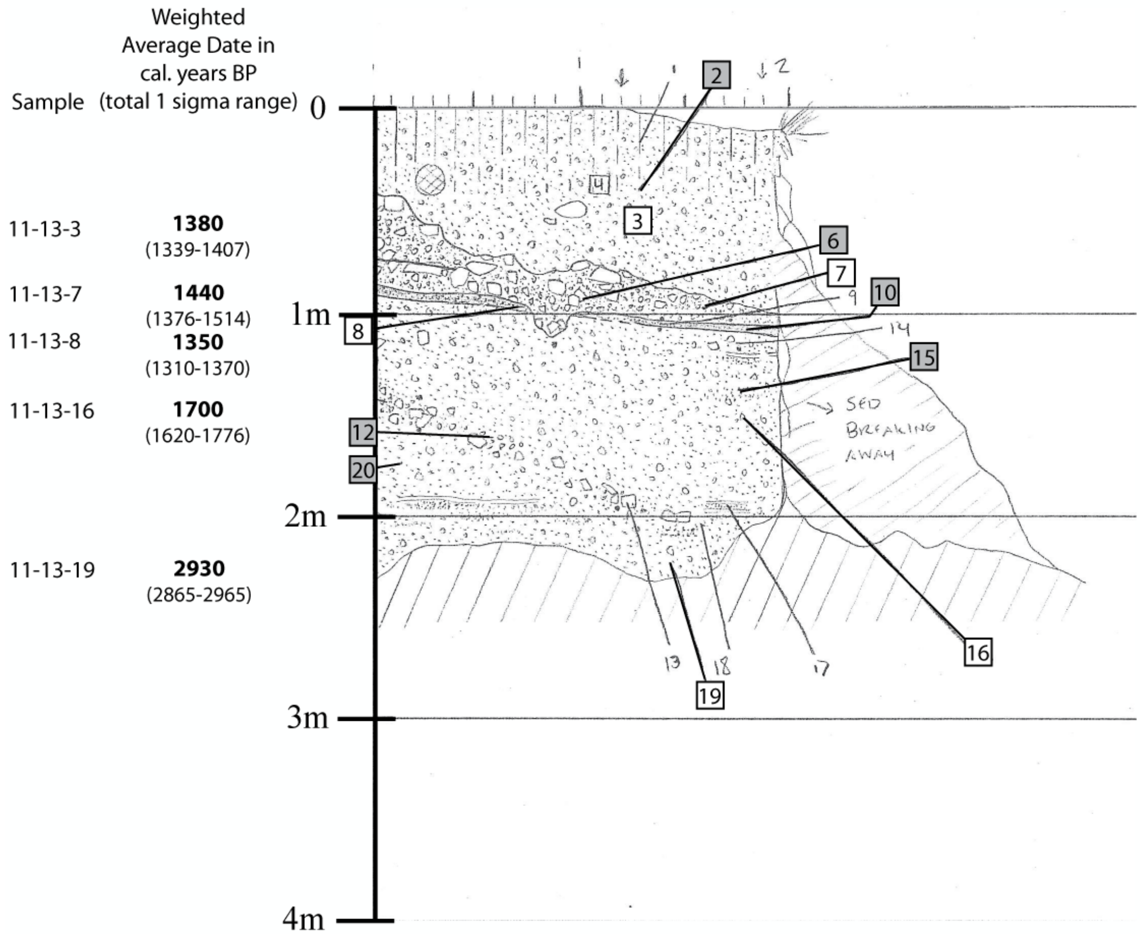
- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- Sample number (corresponds to date)
- Sample number (corresponds to grain-size analysis)

STATION: **12**	(south-facing slope; lower-fan channel wall)	SECTION: N/A
LAT: 13 S 0347423	LONG: 3972187 DATE: 8/4/2011	WORKER: EF



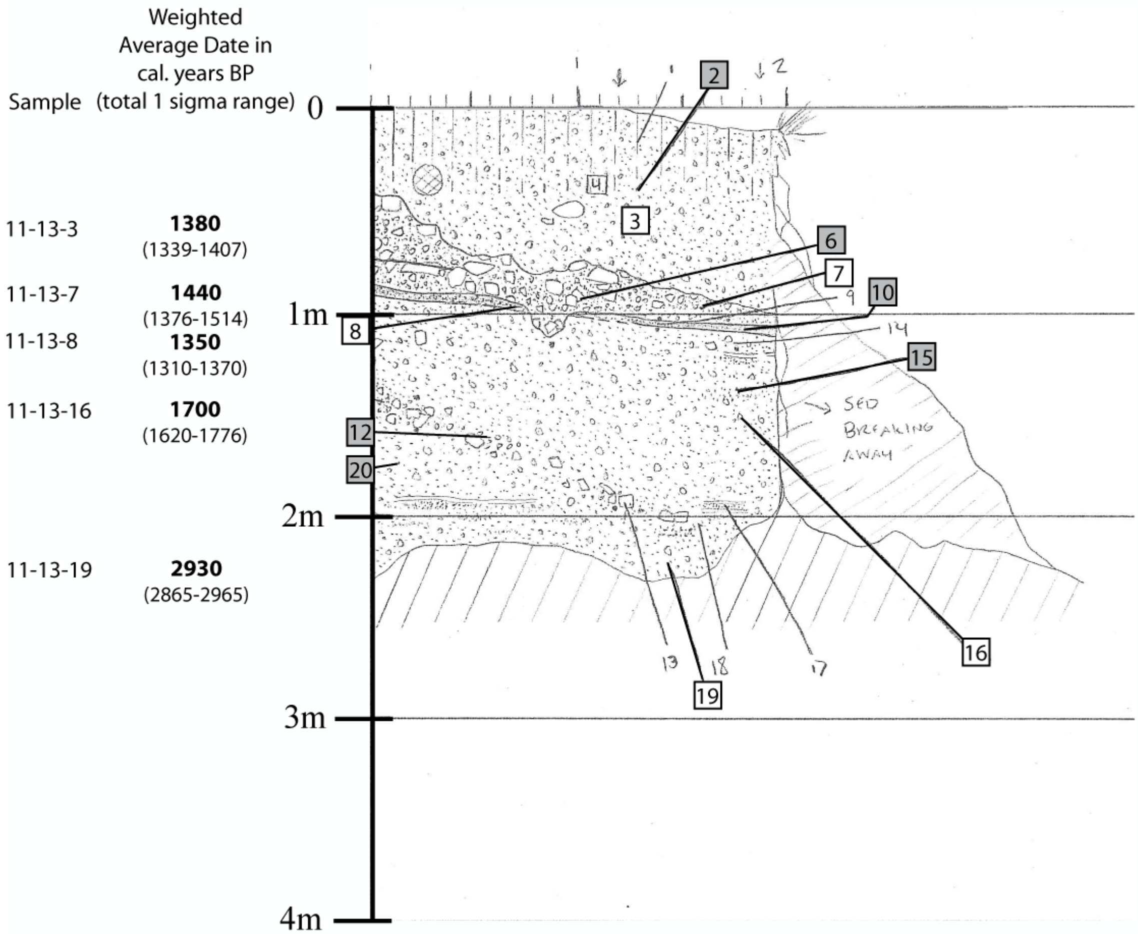
- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- 1 Sample number (corresponds to grain-size analysis)

STATION: **13** (north-facing slope, lower-fan channel wall)	SECTION: N/A
LAT: 13 S 0344708 LONG: 3971906 DATE: 08/06/2011	WORKER: EF



- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- 1 Sample number (corresponds to date)
- 1 Sample number (corresponds to grain-size analysis)

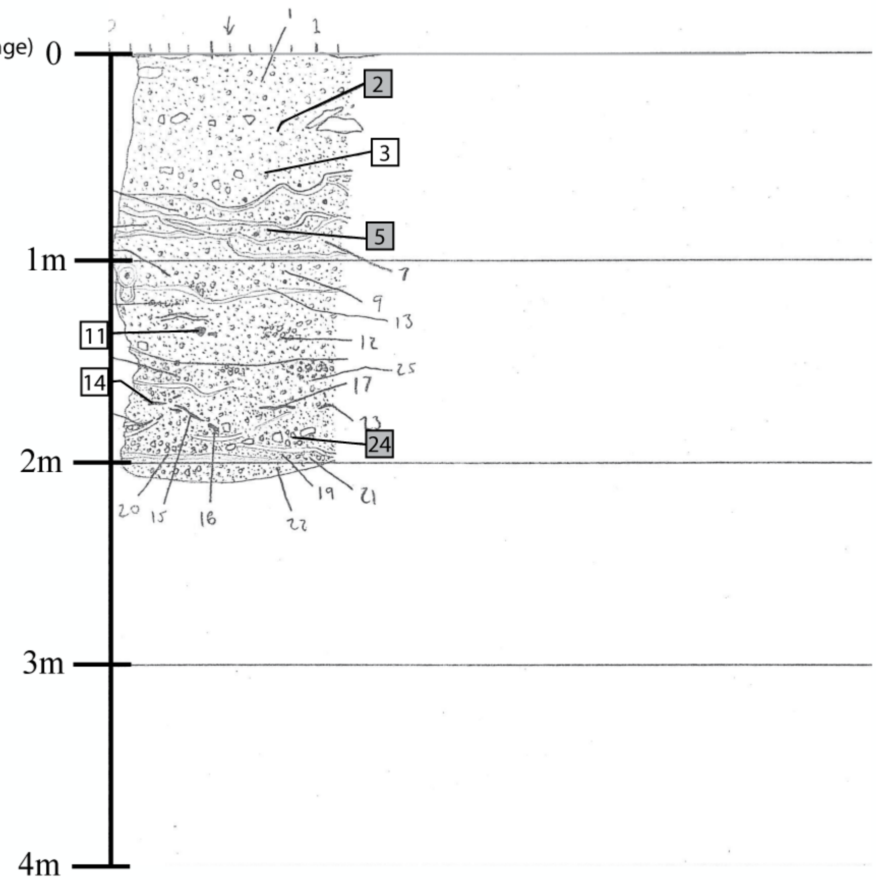
STATION: **13** (north-facing slope, lower-fan channel wall)	SECTION: N/A		
LAT: 13 S 0344708	LONG: 3971906	DATE: 08/06/2011	WORKER: EF



- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- Sample number (corresponds to date)
- Sample number (corresponds to grain-size analysis)

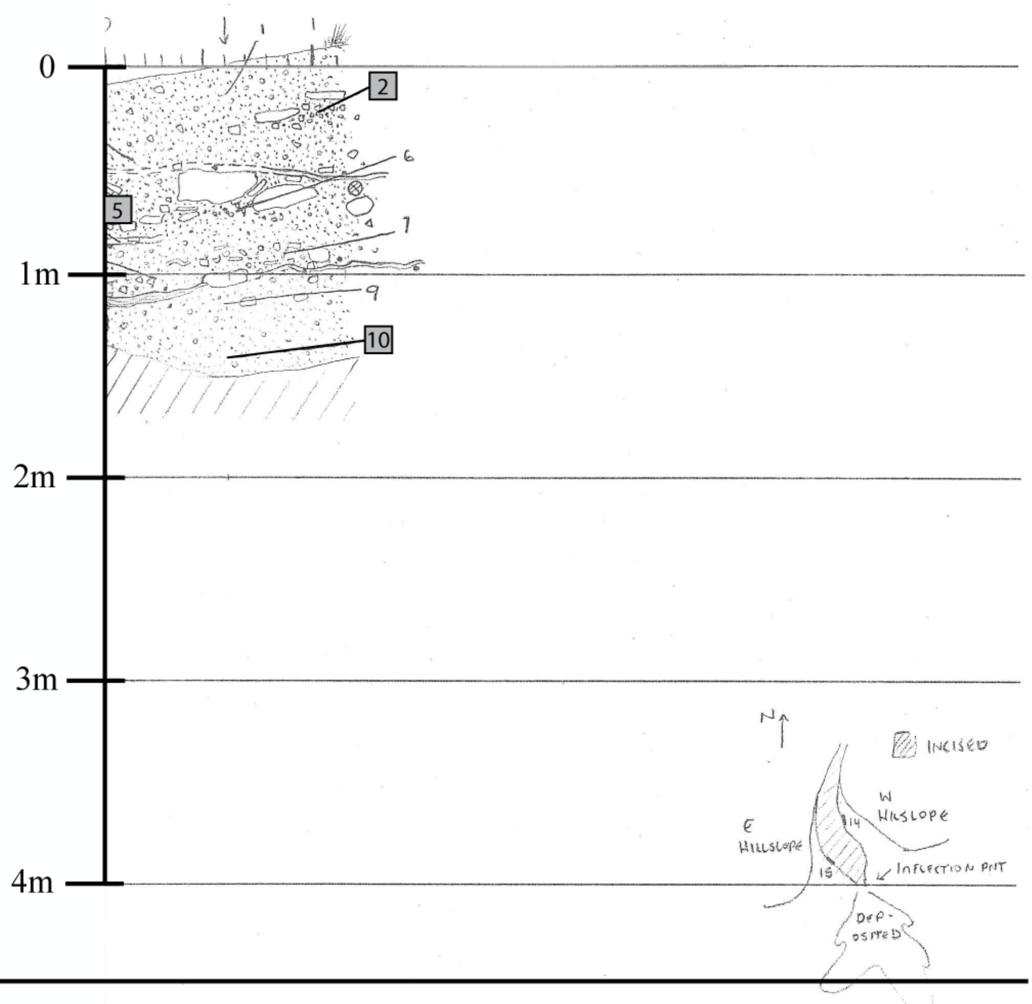
STATION: **14**	(north-facing slope, upper-fan channel wall)	SECTION: N/A
LAT: 13 S 0345252	LONG: 3971909	DATE: 08/07/2011	WORKER: EF

Sample	Weighted Average Date in cal. years BP (total 1 sigma range)
11-14-3	**2560** (2475-2705)
11-14-11	**2850** (2787-2916)
11-14-14	**2810** (2766-2844)



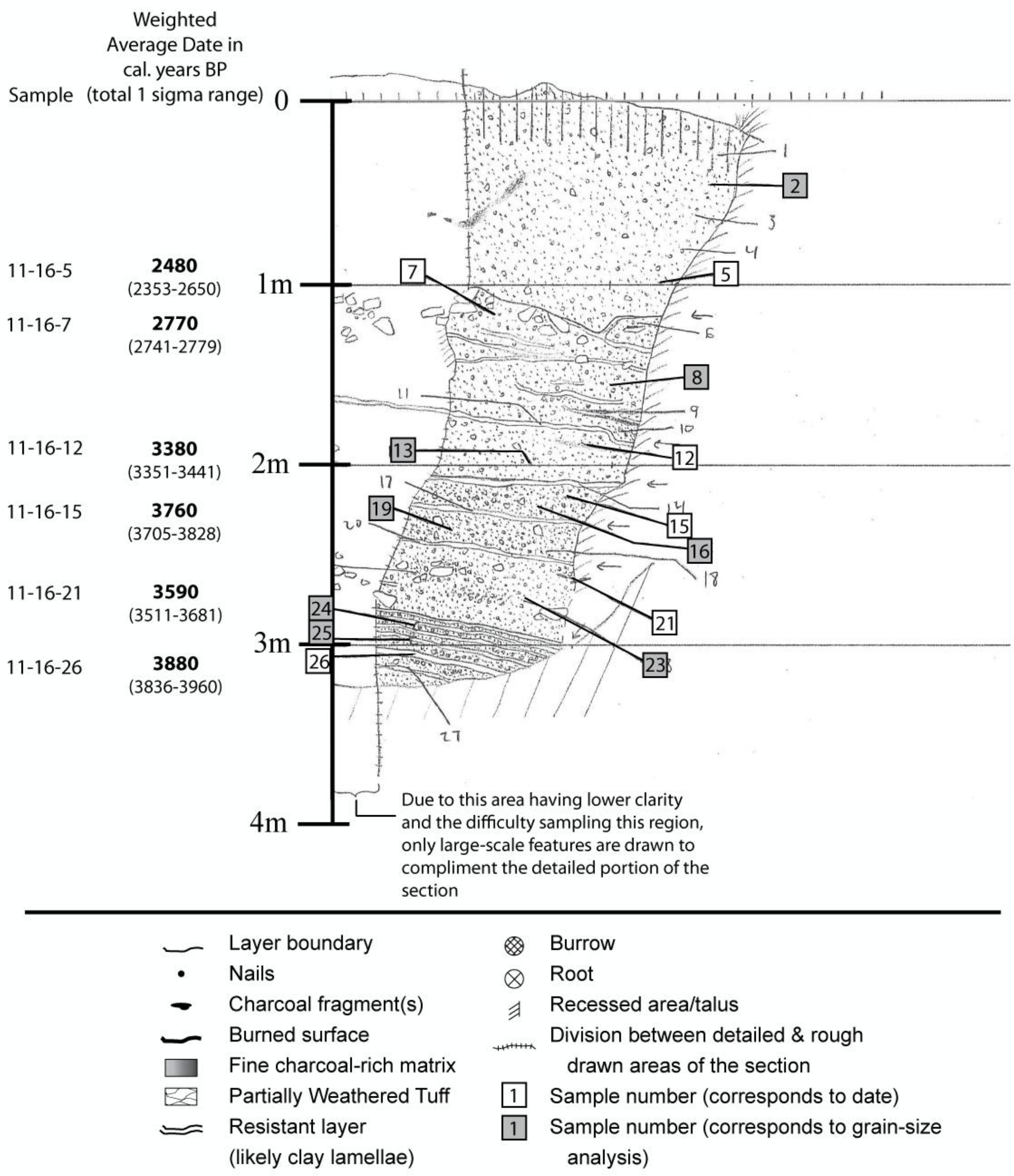
- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- 1 Sample number (corresponds to date)
- 1 Sample number (corresponds to grain-size analysis)

STATION: **15**	(north-facing slope; lower-fan channel wall)	SECTION: N/A
LAT: 13 S 0345256	LONG: 3971945	DATE: 8/7/2011
WORKER: EF		

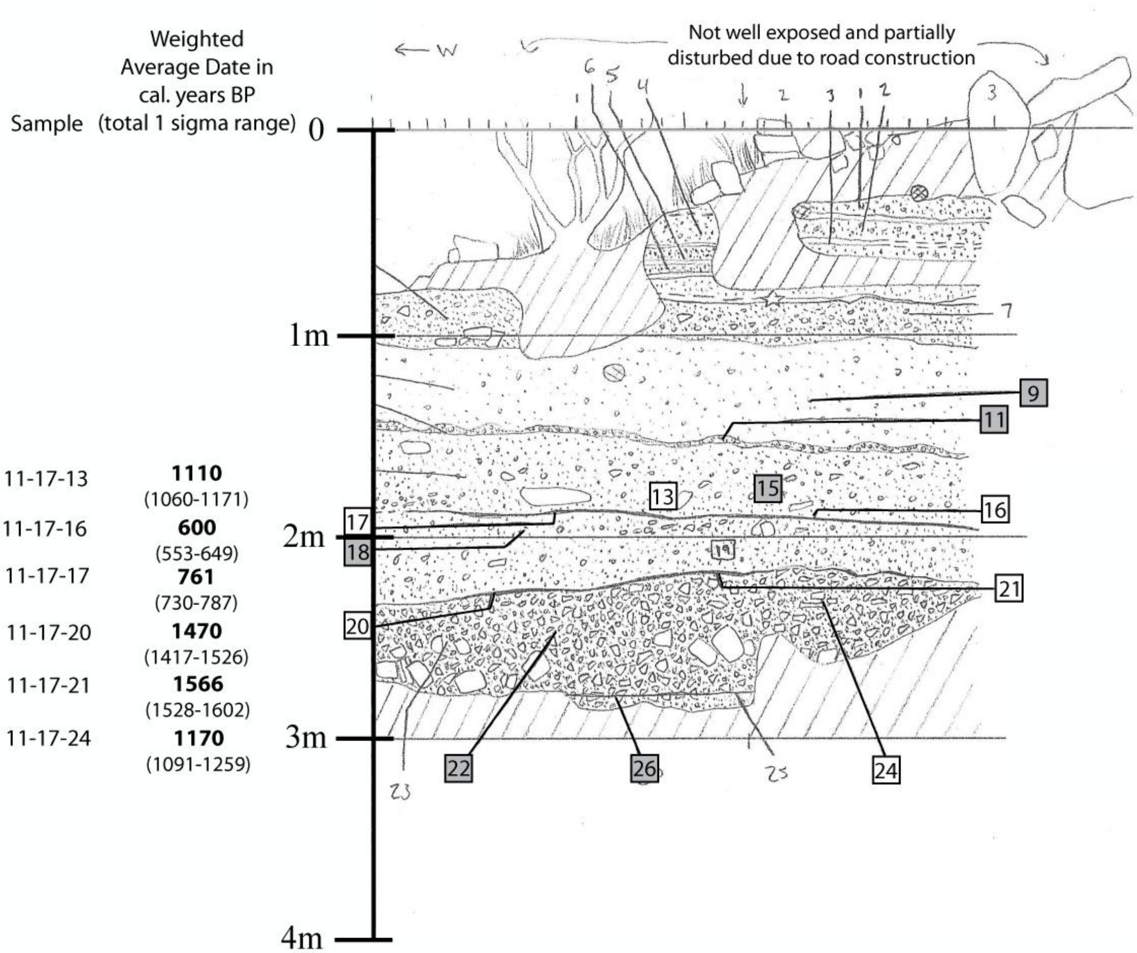


Layer boundary
Nails
Charcoal fragment(s)
Burned surface
Fine charcoal-rich matrix
Partially Weathered Tuff
Resistant layer (likely clay lamellae)
Burrow
Root
Recessed area/talus
Division between detailed & rough drawn areas of the section
1 Sample number (corresponds to grain-size analysis)

STATION: **16** (north-facing slope, upper-fan channel wall)		SECTION: N/A
LAT: 13 S 0345547	LONG: 3971728	DATE: 08/10/2011 WORKER: EF

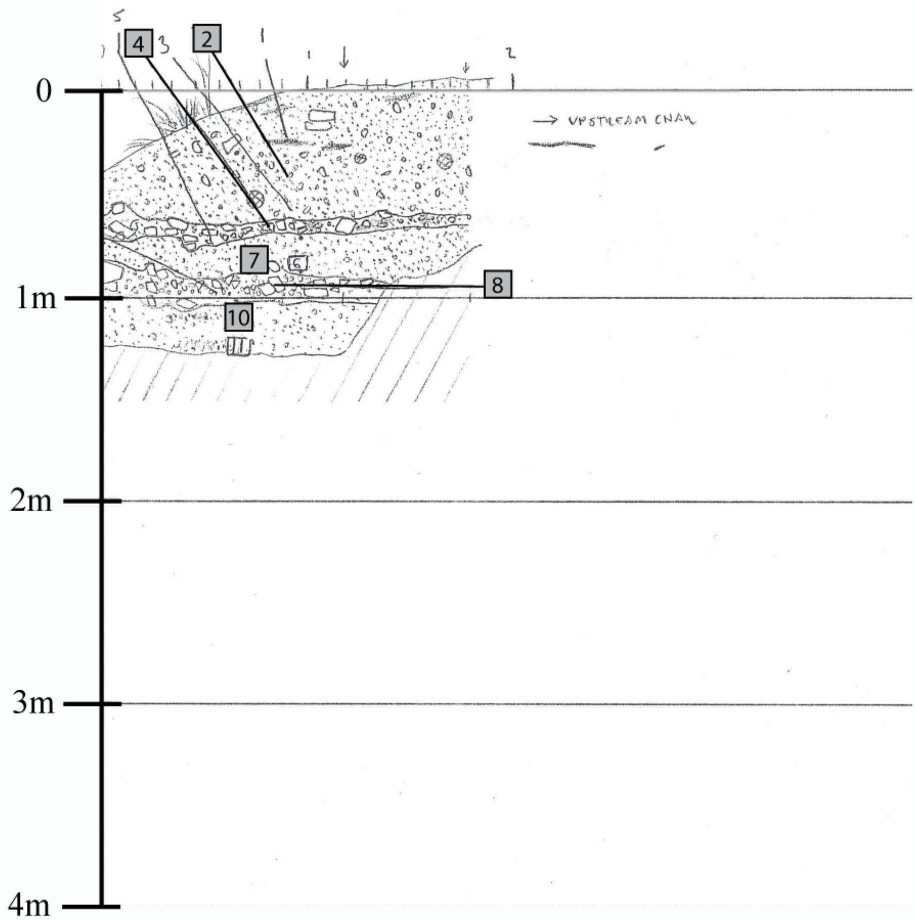


STATION: **17** (arroyo)			SECTION: N/A
LAT: 13 S 0345175	LONG: 3972133	DATE: 08/11/2011	WORKER: EF



- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- 1 Sample number (corresponds to date)
- 1 Sample number (corresponds to grain-size analysis)

STATION: **18** (north-facing slope; lower-fan channel wall)		SECTION: N/A
LAT: 13 S 0345522	LONG: 3973102	DATE: 8/12/2011	WORKER: EF



- Layer boundary
- Nails
- Charcoal fragment(s)
- Burned surface
- Fine charcoal-rich matrix
- Partially Weathered Tuff
- Resistant layer (likely clay lamellae)
- Burrow
- Root
- Recessed area/talus
- Division between detailed & rough drawn areas of the section
- Sample number (corresponds to grain-size analysis)

APPENDIX 3. OUTLINE OF PALEOCLIMATE AND FIRE HISTORY REFERENCES

Records listed from oldest to youngest dated record

Reference	Date(s)	General Interpretation	Discussion	Location
7500-1900 years BP				
PALEOCLIMATE RECORDS				
Holmgren et al. (2007)	8000 – 4000 years BP	Warm and wet	Holmgren et al. suggest, based on other records that, "expanded upper and lower treelines (Fall, 1997), northward expansion of C4 grasses and tropical elements in packrat middens (Van Devender, 1990; McAuliffe and Van Devender, 1998), and climate model output (Rind, 1994; Kutzbach, 1998) all indicate greater-thanmodern summer temperatures and precipitation during the mid-Holocene (ca. 8000–4000 yr BP)."	northern Chihuahuan Desert, Mexico
Hasbargen (1994)	8000 – 2500 years BP	Warm and dry		Stoneman lake, AZ
Menking and Anderson (2003)	5400 14C yr BP (around [a]6169 cal. yr BP, weighted average)	shift from dry to wet	"Eolian landforms in Estancia basin, central New Mexico, record two episodes of extreme drought and low groundwater levels during the middle Holocene (7000–5400 14C yr B.P.), followed by a rise in the water table through the late Holocene."	Estancia basin, central NM
Ely (1997)	5750 – 4150 years BP	Frequent floods (inferred wet period)	"High-magnitude floods were frequent on rivers throughout the region from 5000 to 3600 14C yrs BP (dendrocalibrated age = 3800-2200 BC)…"	Arizona and southern Utah
Davis and Shafer (1994)	5000 – 4000 years BP	relative low in precipitation	"Precipitation was least from 4000 to 5000 yr B.P…"	Montezuma Well, AZ
Holmgren et al. (2007)	5000 – 4000 years BP	general warming and onset of climatic variability	"…ca. 5000–4000 yr BP increasing winter insolation and the onset of modern ENSO variability."	northern Chihuahuan Desert, Mexico
Buck and Monger (1999)	4000 years BP	shift from dry to wet conditions		northern Chihuahuan Desert, Mexico

Reference	Date(s)	General Interpretation	Discussion	Location
7500-1900 years BP				
PALEOCLIMATE RECORDS				
Castiglia and Fawcett (2006)	4000 14C yr	lake high-stand (i.e., inferred wet conditions)	"Reestablishment of a 1190-m-high shoreline centered ca. 4000 14C yr B.P. marks wetter than present conditions, in agreement with other Neoglacial age climate reconstructions of wetter conditions in the southwestern United States (Ely, 1997; Enzel et al., 1989; Polyak and Asmerom, 2001; Waters, 1989)."	Chihuahuan Desert, Mexico
Ely (1997)	3600 – 2200 years BP	Inferred sharp decrease in precipitation	"The periods 3600-2200 BP (2200-400 BC) and 800-600 yrs BP (1200-1400 AD) are marked by sharp decreases in the occurrence of large floods on these rivers."	Arizona and southern Utah
Davis and Shafer (1994)	3400 years BP	relative high in temperature	"Temperature was highest ca. 3400 and 5700 yr B.P…"	Montezuma Well, AZ
Asmerom et al. (2007)	3300 years BP	Inferred peak wet conditions	"…ca. 3300 yr B.P. and in particular at 2700 yr B.P. correlate with increased stalagmite growth (high moisture)…"	Guadalupe Mountains, southern NM
Armour et al. (2002)	2800 14C yr BP ([b]2941 cal. yr BP, weighted average)	periglacial event		Sangre de Cristo Mountains, northeastern NM
Asmerom et al. (2007)	2700 years BP	Inferred peak wet conditions	"…ca. 3300 yr B.P. and in particular at 2700 yr B.P. correlate with increased stalagmite growth (high moisture)…"	Guadalupe Mountains, southern NM
Jimenez-Moreno et al. (2008)	2300 years BP	dry	Drying of the bog surface; potential drought	Sangre de Cristo Mountains, northeastern NM
Rasmussen et al. (2006)	2300 – 2100 years BP	dry	Speleothem growth at at Carlsbad Cavern was arrested around 0.8–1.2 and 2.1–2.3 ka.	Carlsbad Cavern, southern NM
Buck and Monger (1999)	2000 years BP	shift from wet to dry conditions		northern Chihuahuan Desert, Mexico
FIRE HISTORY RECORDS				
Meyer et al. (1995)	7500 yr B.P. and 5500 yr B.P.; 4600-4000 yr B.P	Increased fire-related sedimentation		Yellowstone National Park, WY

Reference	Date(s)	General Interpretation	Discussion	Location
7500-1900 years BP				
FIRE HISTORY RECORDS				
Frechette & Meyer (2009)	5800 – 4200 cal. yr BP	Increase in fire-related sedimentation	Rapid aggradation by charcoal-rich debris flows.	Sacramento Mountains, NM
Frechette & Meyer (2009)	~4200 cal. yr BP	Virtual cessation of fire-related deposition	This work reports virtual cessation of fire-related deposition around 4200 cal. yr BP and slower aggradation and cummulic soil development until 1800 cal. yr BP.	Sacramento Mountains, NM
Toney and Anderson (2006)	4100 – 2620 cal. yr BP	Period dominated by an infrequent, severe fire regime	Work suggests a less frequent, but more intense fires during the period from 4100 to 2620 cal. yr BP.	San Juan Mountains, CO
Meyer et al. (1995)	3500 yr B.P; 3250 – 2800 yr B.P	Minor episodes of fire-related sedimentation		Yellowstone National Park, WY
Pierce et al. (2004)	3000 – 2800 cal. yr BP	Minimum in fire-related sedimentation; cooler, wetter climate	"…maxima in small-event probability (Fig. 2a) in the SFP area generally correspond with prominent minima in fire-related sedimentation in Yellowstone (,350–500, 1,200–1,400 and 2,800–3,000 cal. yr BP), suggesting a regional millennial- scale climatic control. In Yellowstone, these minima in fire-related sedimentation are associated with colder, effectively wetter, climates and increased runoff in streams, including during the Little Ice Age (LIA)12. LIA climate was not uniformly cold in either time or space, but glacial advances occurred at,650–100 cal. yr BP in the northern Rocky Mountains6–8, with colder than present conditions in many Northern Hemisphere localities."	South Fork Payette River area, central Idaho
Bigio et al. (2010)	~2600 cal. yr BP	Period dominated by mix-severity fire regime	This work suggests that a low–moderate and mixed-severity fire regime was dominant during this period.	San Juan Mountains, CO
Bigio et al. (2010)	~2600 cal. yr BP.- present	Large, high-severity fires unlikely	This work suggests that large extensive patches of high-severity fire equivalent to the modern fires in the study area are unlikely to have occurred over the past ~ 2600 cal. yr BP.	San Juan Mountains, CO
Meyer et al. (1995)	2500, 2100	Clustered fire-related sedimentation ages		Yellowstone National Park, WY

Reference	Date(s)	General Interpretation	Discussion	Location
7500-1900 years BP				
FIRE HISTORY RECORDS				
Allen et al. (2008)	2500 cal. yr BP	Relative peak in fire frequency	This work reports evidence for higher fire frequency during the mid-late Holocene, with a relative peak around 2500 cal yr BP.	Jemez Mountains, NM
1900-1000 years BP				
PALEOCLIMATE RECORDS				
Viau et al. (2006)	1900 – 1000 yrs BP	average increasing temperature	Based on the temperature records of Viau et al. (2006), this period is one of average increasing temperature, although significant variation exists compared to the previous 3400 years.	records from across North America
Grissino-Mayer (1996)	1900 – 1000 yrs BP	n/a	five relative peaks and five relative lows in precipitation were recorded	El Malpais National Monument, west-central NM
Routson et al. (2011)	1949 – 1550 BP (~400-1 AD)	period of frequent and prolonged drought	Droughts based on tree ring records. ~1050-1350 AD corresponds with other records which document aridity within the medieval period. Droughts within the 2nd century: 148-173 AD (1802-1777); 122-172 AD (1828-1778); 301-400 (1649-1550).	southern San Juan Mountains, Colorado
Polyak and Asmerom (2001); Polyak et al. (2001)	1700 – 1300 years BP	dry	Speleothem growth at Hidden Cave in southern New Mexico was arrested between ca 1.7–1.3 ka, and after ca 0.9–0.8 ka.	Hidden Cave, southern NM
Hardin et al. (2010)	1350 years BP	Peak in flood activity	Peak in flood activity in the Southwest	Southwest
Routson et al. (2011)	1350 – 1250 BP (700 – 600 AD)	increased aridity	See earlier Routson et al. (2011) records	southern San Juan Mountains, Colorado
Salzer and Kipfmueller (2005)	1267 – 1250 yrs BP	cool	"The coldest period identified was an eighteen year interval from AD 683–700 (1267-1250 yrs BP). The longest cool period was the 35 years from 1330 to 1364 (620-586 yrs BP). The late 20th century 49-year period from 1946 to 1996 is the warmest period identified and also the warm interval with the longest duration."	southern Colorado Plateau (southern Utah and Northern AZ)

Reference	Date(s)	General Interpretation	Discussion	Location
1900-1000 years BP				
FIRE HISTORY RECORDS				
Frechette & Meyer (2009)	1800 – 500 cal. yr BP	Increase in fire-related sedimentation	During this period, fire-related sedimentation increases, but less than first peak (middle Holocene).	Sacramento Mountains, NM
Meyer et al. (1995)	1800, 1200, and 850 yr B.P.	Clustered fire-related sedimentation ages		Yellowstone National Park, WY
Allen et al (2008)	1500 cal. yr BP	Relative peak in fire frequency		Jemez Mountains, NM
Pierce et al. (2004)	1400 – 1200 cal. yr BP	Minimum in fire-related sedimentation; cooler, wetter climate	See notes for 2,800–3,000 cal. yr BP	South Fork Payette River area, central Idaho
1000 years BP to Present				
PALEOCLIMATE RECORDS				
Cook et al. (2007); Lamb, (1977)	1050 – 650 years BP	Medieval Warm Period		
Grissino-Mayer (1996)	1000 yrs BP – present	Precipitation shifts become more frequent	Precipitation shifts recorded by Grissino-Mayer (1996) become more frequent on average during this period, relative to the previous ~1000 years.	El Malpais National Monument, west-central NM
Viau et al. (2006)	1000 yrs BP – present	Increasing temperature	Temperature records show this period to be one in which an increase in average temperature over the preceding ~1000 years is continued	records from across North America
Rasmussen et al. (2006)	1200 – 800 years BP	dry	Speleothem growth at Carlsbad Cavern in southern New Mexico was arrested around 0.8–1.2 and 2.1–2.3 ka	Carlsbad Cavern, southern NM
Ely (1997)	1100 – 900 years BP	Inferred frequent precipitation events	"High-magnitude floods were frequent on rivers throughout the region … with particularly prominent peaks in magnitude and frequency around 1100-900 BP (AD 900-110) …"	Arizona and southern Utah
Cook et al. (2004b)	1050 – 650 years BP	drought	Western US "megadrought epoch"	Western US
PDSI records	1000 BP	Shift in general precipitation trends	A shift occurred around 1000 BP where wet periods are much less frequent and are often at least half the magnitude	Average of four grid points surrounding the Jemez Mountains

Reference	Date(s)	General Interpretation	Discussion	Location
1000 years BP to Present				
PALEOCLIMATE RECORDS				
Jimenez-Moreno et al. (2008)	1000 years BP	dry	Drying of the bog surface; potential drought	Sangre de Cristo Mountains, northeastern NM
Grissino-Mayer and Swetnam (2000)	950 – 550 years BP	wet		El Malpais National Monument, west-central NM
Routson et al. (2011)	900 – 600 BP	period of enhanced drought frequency and duration	See earlier Routson et al. (2011) records	southern San Juan Mountains, Colorado
Polyak and Asmerom (2001); Polyak et al. (2001)	900 – 800 years BP	dry	Speleothem growth at Hidden Cave in southern New Mexico was arrested between ca 1.7–1.3 ka, and after ca 0.9–0.8 ka.	Hidden Cave, southern NM
Hall (1990); Hall and Permian (2007)	1000 ^{14}C years BP ([c]912 cal. yr BP, weighted average)	shift from wet to dry conditions	"The regional down-cutting documented about 1000 14C yrs BP is a response to a broad-based change in climate from comparatively moist to dry conditions …"	OK and TX; Jemez Mountains, NM
Ely (1997)	800 – 600 years BP	Inferred sharp decrease in precipitation	"The periods 3600-2200 BP (2200-400 BC) and 800-600 yrs BP (1200-1400 AD) are marked by sharp decreases in the occurrence of large floods on these rivers."	Arizona and southern Utah
Cook et al. (2007)	670 – 650 years BP	dry	Inferred from drought records	North America
Salzer and Kipfmueller (2005)	620 – 586 years BP	cool	"The coldest period identified was an eighteen year interval from AD 683–700 (1267-1250 yrs BP). The longest cool period was the 35 years from 1330 to 1364 (620-586 yrs BP). The late 20th century 49-year period from 1946 to 1996 is the warmest period identified and also the warm interval with the longest duration."	southern Colorado Plateau (southern Utah and Northern AZ)
Grissino-Mayer and Swetnam (2000)	from 550 – 140 years BP	dry	Below average precipitation in SW; fire frequent	El Malpais National Monument, west-central NM

Reference	Date(s)	General Interpretation	Discussion	Location
1000 years BP to Present				
PALEOCLIMATE RECORDS				
Ely (1997)	500 years BP	enhanced and frequent precipitation	"High-magnitude floods were frequent on rivers throughout the region … with particularly prominent peaks in magnitude and frequency … after 500 yrs BP (AD 1400)."	Arizona and southern Utah
Lamb (1977)	400 – 100 years BP	Little Ice Age		
Stahle et al. (2000)	~375 years BP	mega drought	Tree-ring data indicate that drought lasted from 1559 to 1569, and then returned again in the 1580s." "The reconstructed mean PDSI or precipitation for the 16th century (1500-1600) is lowest in northern Mexico [and] the Southwest…"	Southwest
Jimenez-Moreno et al. (2008)	350 years BP	dry	Drying of the bog surface; potential drought	Sangre de Cristo Mountains, northeastern NM
Cook et al. (2007)	285 – 280 years BP	drought	Inferred from drought records	North America
Swetnam & Betancourt (1998)	202 – 203 years BP	large amplitude switch from wet to dry	"…greatest amplitude of interannual switching from wet to dry; 1747-1748 AD"	Southwest US
FIRE HISTORY RECORDS				
New, 2007; Frechette and Meyer, 2009	1060 – 760 cal yrs BP	MWP; fires more common		Sacramento Mountains, NM
Pierce et al. (2004)	1050 – 650 cal. yr BP	Severe fire and warm conditions	"… intervals of stand-replacing fires and large debris flow events are largely coincident in SFP ponderosa pine forests and Yellowstone, most notably during the 'Medieval Climatic Anomaly' (MCA), 1,050–650 cal. yr BP (ref. 23; Fig. 2b)."	South Fork Payette River area, central Idaho
Frechette & Meyer (2009)	650 cal. yr BP	Peak in fire-related sedimentation; drought	At this time this work records a peak in FRS, corresponding to widespread severe drought in the south-western USA.	Sacramento Mountains, NM

Reference	Date(s)	General Interpretation	Discussion	Location
1000 years BP to Present				
FIRE HISTORY RECORDS				
Touchan et al, 1996	600 yrs BP to present	Low-severity fire regime in ponderosa pine forests and less frequent fire, with some crown fires in mixed-conifer stands	[During the study period] "Ponderosa pine forests were characterized by high frequency, low intensity surface fire regimes. The mixed-conifer stands sustained somewhat less frequent surface fires, along with patchy crown fires."	Jemez Mountains, NM
Allen et al (2008)	500 cal. yr BP	Relative low in fire frequency		Jemez Mountains, NM
Frechette & Meyer (2009)	500 – 100 cal. yr BP	Dominated by low-severity fire events; higher climatic variability	During this period, this work records limited fire-related sedimentation. This is consistent with "Little Ice Age" and frequent low-severity fires (although at least one severe fire during this interval). According to this work, higher climatic variability also likely involved, including multidecadal wet periods resulting in stand density increase followed by droughts, which support fire.	Sacramento Mountains, NM
Pierce et al. (2004)	500 – 350 cal. yr BP	Minimum in fire-related sedimentation; cooler, wetter climate	See notes for 2,800–3,000 cal. yr BP	South Fork Payette River area, central Idaho
Bigio et al. (2010)	Late 1600s to1800s (~300 – 150 years BP)	Period dominated by a frequent low-severity fire regime	This work suggests that a fire regime of frequent, surface fires was present during the late seventeenth to nineteenth centuries.	San Juan Mountains, CO
Margolis & Balmat 2009	265 BP	Date of severe fire	This work reports a (stand replacing) fire within the upper Santa Fe watershed (1685 AD).	North-central NM
Meyer et al. (1995)	within the last 250 14C yr	Minor episode of fire-related sedimentation		Yellowstone National Park, WY
Bigio et al. (2010)	1851 AD (99 yrs BP)	Date of mixed-severity fire		San Juan Mountains, CO
Other Information				
Jenkins et al. (2011)	n/a	n/a	This work reports that fire is an important geomorphological agent at Kendrick Mountain in Northern Arizona, and that fire-related debris-flow sedimentation dominates alluvial deposition in the study area.	Kendrick Mountain, AZ

Reference	Date(s)	General Interpretation	Discussion	Location
Other Information				
Jenkins et al. (2011)	n/a	n/a	This work did not find a clear relationship between regional climatic changes and fire-related debris flow events.	Kendrick Mountain, AZ
Pierce et al., 2004; Frechette, 2007; Pierce and Meyer, 2008	n/a	n/a	These papers suggest a link between fire and increased warmth and/or drought.	Various
Frechette & Meyer (2009)	n/a	n/a	This work suggests that fire contributes a significant amount of sediment to Holocene valleys in the study area.	Sacramento Mountains, NM
Allen et al. (1995)	present	n/a	This work suggests that in modern times low-severity surface fires are the normal.	Jemez Mountains, NM

[a]Dates were calibrated using the *CALIB software using the estimated radiocarbon ages reported and the largest 1σ range reported in Menking and Anderson (2003), ±80 radiocarbon years BP.
[b]Dates were calibrated using the *CALIB software using the estimated radiocarbon ages reported and the largest 1σ range reported in Armour et al. (2002), ±95 radiocarbon years BP.
[c]Date was calibrated using the *CALIB software using the estimated radiocarbon age reported and a conservative error of ± 100 yrs.
* CALIB 6.0 software program (Stuiver and Reimer, 1993) and the INTCAL04 calibration curve (Reimer et al., 2004).