

**Soil Pedogenesis, Erosion, and Prehistoric Agriculture
on the Pajarito Plateau**

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The mesa top alluvial and loess derived soils of the Pajarito Plateau in north-central New Mexico are some of the oldest and best developed in the region (McFadden et al. 1996; Watt 1996). Deeply reddened and clay enriched, the soils appear to have formed under stable conditions over the last one hundred thousand years.

For much of the last millennium these soils have been utilized by the human occupants of the Plateau. The longest and most intensive use was by Puebloan farmers who made much of the Plateau their home between A.D. 1150-1550 (Hill et al. 1996; Powers and Orcutt 1999; Preucel 1988). Practicing areally extensive slash-and-burn agriculture, the Pueblos successfully farmed the mesa tops and canyon bottoms for 400 years. Many aspects of Puebloan agricultural ecology, including drought tolerant corn varieties, micro-climatic constraints, moisture and soil control features, and risk reduction buffering strategies have been the subject of careful study, and are relatively well known (Bradfield 1971; Fish and Fish 1984; Hack 1942; Toll 1995; Wills 1988).

In contrast, few substantive studies of soils have been conducted from a geoarcheological perspective, despite a growing body of detailed soil data gathered by soil scientists and geomorphologists. This paper attempts to examine soil properties and landscapes within a portion of Bandelier National Monument, to determine their possible relationship with, and impact upon prehistoric agriculture. Based on recent archeological survey data from the monument, it is clear that Pueblos initially farmed a narrow band of mesa top elevations, extending from 1920 to 2042m (6300-6700') (Orcutt 1999). As population expanded and competition for resources increased, a broader range of elevations (1859-2195 m [6100-7200']) were farmed. Puebloan preference for intermediate elevations has been attributed to constraints imposed by high evapotranspiration rates at low elevations, as well as short (and often unpredictable) frost-free season length at high elevations. The role that

soils may or may not play in selection of field locations along this 336 m elevational gradient is largely unknown.

In order to address the question of what role soil variability plays in altitudinal field selection at Bandelier, the profiles and properties of soils in a sample of five soil pits are described. Based on soil property and landscape data recovered at each location, I identify and evaluate: 1) differences in soil profile development and the processes responsible for soil formation; 2) the effects of state factors, including climate, organic constituents, topography, parent materials, and time, on soils, and; 3) what bearing the observed soil differences may have had on Puebloan selection of agricultural fields.

The Soil Profile Sample

Soil property and landscape data were recovered from five soil profile pits previously excavated (and left open) by Charles Hibner of the Natural Resources Conservation Service (NRCS) as part of an on-going study of soils within Bandelier National Monument. It was initially hoped that six soil pits could be excavated at 61 m (200') intervals extending from 1890 to 2195m (6200 to 7200'), along the crest of one of the long southeast-trending mesa tops within Bandelier. But, the reluctance of park staff to approve excavation of a new series of pits, project time constraints, and the possible early onset of cold winter weather, dictated use of the existing NRCS pits.

The five pits selected were chosen to adhere to the original sample design insofar as possible, but the resulting elevation range begins and ends 30m (100') higher, and the elevational differences between the pits range from as little as 45m to 120m (147 to 395'), with the largest gap extending from 2042 (6700') to 1922m (6305') (Table 1). The NRCS examined several soil profiles within this low elevation range, but because the "pits" were essentially bedrock exposures with only a few centimeters of alluvial sediment, I elected not to map them.

While the four uppermost pits are positioned along major ridges of Burnt Mesa, the mesa above the north rim of Frijoles Canyon, the fifth is on the

lower Potrero del Rito, the first mesa south of Frijoles Canyon (Figure 1). Although all of the profiles are in apparently arable soils, one (Pit 1) is situated on a moderately steep slope unlikely to have been utilized for agriculture. Known archeological sites are present within 25-75m of the remaining four sites.

The effects of these sample modifications are probably minor. But, the relatively poor preservation of soils below 6700,' while instructive in itself, increases the difficulty of evaluating soil variability in the lower half of the elevation range. More significant still is the small size of the sample in general. In a more detailed study it would be highly desirable to excavate a number of pits within each of the dozen or more soil series so far identified by NRCS.

Recording of soil properties was performed following the methods and attributes used by Birkeland (1999: 348-359). In addition to general site information, the depth, horizon, color, structure (type, grade, size), percentage of gravel, consistence, texture, clay films (amount, distinctness, location), boundaries, carbonate effervescence, and root characteristics were noted for each horizon. One or more color prints were taken of each profile. Because of partially frozen soil conditions at one pit (Pit 1), samples of each horizon were taken, and attributes requiring soil malleability were made after the sediments had thawed.

Soil Horizons and Soil Development Processes

Although Pajarito Plateau mesa tops preserve old, well developed soils in some locations, Reneau and McDonald (1996) and Watt (1996) have recently emphasized the rarity of stable landscape positions, stressing that many soils "have been partially stripped or buried by younger deposits, forming complex, superimposed soil profiles" (Reneau and McDonald 1996:16). Because the horizons and soil properties identified in the soil pits examined in the present study typify these complex characteristics, the presence of a distinctive geological sediment, the El Cajete Pumice, dated between 50,000-60,000 ka, provides a convenient contextual marker for ordering discussion of

mesa top soil horizons between different soil pedons (Reneau et al. 1996; Self et al. 1988; Watt 1996). Therefore, discussion of differences in profile development and of processes responsible for soil genesis is framed in three gross time groups: 1) relatively recent, post-El Cajete soils (< 50,000-60,000 ka); 2) intermediate El Cajete age materials (ca. 50,000-60,000 ka), and; 3) older, pre-El Cajete deposits (> 50,000-60,000). With further respect for simplicity, horizon description is undertaken collectively in the interest of brevity, although individual soil profile horizons and their properties are shown in Tables 2 through 6. Table 7 summarizes the horizons for all five soil profiles with respect to the El Cajete age groups.

Post El Cajete Horizons

As shown in Table 7, all of the profiles display recent, relatively poorly developed O, A, or Bw surface horizons. O horizons are thin and limited to locations with Ponderosa pine, although much of their visibility appears to be due to organic carbon deposits resulting from recent wild and controlled fires. A horizons are lighter, although organic matter is visibly present, and most display little discernable structure. Bw horizons show weak structure, but little evidence of reddening due to oxidation. A and Bw soils overlying El Cajete pumice contain high percentages of lapilli and ash that appear to reflect upward bioturbation, and to a lesser extent, slope erosion. The complete absence of gravel sized clasts in horizons not associated with El Cajete deposits suggest that the parent materials of these surficial soils are eolian dust and fine erosional slopewash (Reneau and McDonald 1996; Watt 1996).

Because of their weak development, and because these surficial soils either appear to lie unconformably over the El Cajete (where it is present), or over relatively well-developed Bt horizons, Reneau and McDonald (1996:73) suggest that these post-El Cajete soils are late Holocene in age (the degree of development is similar to Pajarito alluvial soils dated to 1.2 to 1.4 ka). They also believe that they are separated from earlier deposits by intervals of mesa top soil erosion.

Relatively poorly developed, buried Bt horizons in one soil profile (Pit

3) show weak structure and a few, faintly visible colloid coats indicative of clay illuviation. The translocated clay in these horizons argues for a longer period of formation, and based on comparison with dated, mesa top Bt soils exhibiting similar time dependent characteristics, an estimated age range of mid-Holocene to late Pleistocene may be reasonable (Reneau and McDonald 1996: 60). The position of these weak Bt soils directly over the Tshirege member of the Bandelier Tuff indicates that this 2108m (6916') location, the El Cajete pumice and earlier buried soils were completely stripped during an indeterminate period (or periods) of surface instability.

El Cajete Horizons

El Cajete pumice deposits are present in two of the five soil pits (Pits 2 and 4) and provide a simple and distinctive means of separating recent, relative weakly developed horizons from earlier well developed buried horizons.

The thickness of the El Cajete ash and lapilli sheet deposit varies with location, probably as a result of erosion (Reneau and McDonald 1996: 73). In the two pits sampled, it ranges in thickness from less than 50 cm to 90+cm.

Although the El Cajete is largely unaltered, three El Cajete deposits were identified as buried Bt or Btk horizons due to the presence of distinctive reddish yellow lamellae containing translocated clay and iron (Fe) (Birkeland 1999: 113-114). Within Pit 2, the upper El Cajete Bt horizon exhibits numerous lamellae 5-10 cms apart and about 5 mm thick. Underneath this is a single very thick lamellae that was identified as a Btk horizon. A single lamellae is also present in the lower portion of the Btk horizon of Pit 4. In both of the lower El Cajete Btk horizons, a relatively strong effervescent reaction to diluted HCl indicates the build-up of precipitated calcium carbonate. As Birkeland (1999: 113-114) notes, lamellae appear to become more frequent with time, and may reflect the depth of seasonal water penetration, changes in sediment grain size, clay flocculation due to the presence of salts, or aluminum (Al) or iron released during weathering.

Finally, inspection of the upper portions of the El Cajete in both pits shows heavy bioturbation, and in Pit 4, the pinkish chroma of the lapilli

suggest oxidation. With the exception of bioturbation, slight oxidation, and the much more obvious clay and iron accumulations displayed in the lamellae, the El Cajete appears to be unaltered volcanic ash.

Pre-El Cajete Horizons

Well developed, buried Bt horizons distinguished by minor differences in color, structure, texture, and accumulations of clay films are present in three soil pits, and may be present in a fourth where the base of the El Cajete was never reached (Pit 4). The most strongly developed sequence of buried Bt soils was encountered in Pit 1 where four sequent horizons display strong evidence of clay illuviation in the form of distinct clay film coatings and bridges. In comparison, the frequency, distinctness, and location of clay films in Bt and Btk horizons underlying the El Cajete pumice in Pit 2, indicate substantially less clay translocation. Probably this difference reflects the relative youngness of the Pit 2 buried Bt and Btk horizons, since the El Cajete pumice cap, would if anything increase overlying soil permeability, and therefore promote more rapid accumulation of illuviated clay and calcium carbonate precipitate. While the bottom-most Btk layer in Pit 2 lies directly on the Tshirege Member of the Bandelier Tuff, this moderately developed soil is clearly substantially younger than the 1.22 ma age of the tuff, suggesting an substantial intervening hiatus. Unfortunately the position of the lowest Pit 1 Bt layer in reference to the Bandelier Tuff is unknown, because excavation in the pit was halted before bedrock was reached.

What is probably the oldest buried Btk horizon was encountered in Pit 5, on the lower end of the Potrero del Rito. Exhibiting both pronounced rubification and prominent clay films, this horizon is underlain by a Bk layer which produced the strongest calcium carbonate reaction of any soil tested. Both of these buried soils are well developed, and exhibit strong time dependent characteristics, suggesting that they may approach the ages of the older buried soils described by McFadden et al (1996) and Watt (1996).

In general, these Bt and Btk horizons, with evidence of structure, some reddening, clay illuviation, and the presence of calcium carbonate, suggests

development during extended periods of landscape stability, potentially extending over 100 ka or more.

Soil State Factors

Disentangling the relative importance of the five soil state factors (time, climate, topography, organic constituents, parent material) (Jenny 1941; Birkeland 1999: 141-144) in the five soil profiles is exacerbated by the difficulty of holding any one factor constant. Perhaps the least dynamic of the five elements are the parent materials, although these change from post El Cajete (reworked volcanic materials and eolian dust) to El Cajete to pre-El Cajete (reworked volcanic alluvium, colluvium, and sheet wash) (McFadden et al. 1996; Watt 1996).

While topography is constant at a gross level, position on mesa tops appears to be a significant factor in soil presence or absence, as well as depth. Soils are frequently stripped near canyon edges, lower elevations tend to have shallow soil pedons, and slope, aspect and buried geomorphic features such as fans are undoubtedly also responsible for additional variation (McFadden et al. 1996; Watt 1996; Reneau and McDonald 1996).

Climate and organic constituents are closely intertwined, since the types of flora and fauna contributing to the formation of the mesa top soils are closely related to changes in climatic conditions. Reneau and McDonald (1996) argue that periods of relative stability and instability may be related to different climatic regimes, and more specifically that late Pleistocene conditions are replaced in the early Holocene by a drier regime with intense summer rainfall. This may have triggered unstable conditions in which well-developed mesa top soils were eroded, resulting in rapidly aggrading canyon bottom alluvial deposits.

Because parent materials, topography, organic constituents, and climate all change over the time span represented by the Bandelier soils, it is difficult to argue that the properties of the described soils are strictly a result of time-dependent development. Although the more diagnostic attributes -- reddening, clay illuviation, Fe accumulation, and calcium carbonate

development -- are time driven, it seems likely that the relative development of these features is influenced by variability in other factors.

Agriculture on the Higher and Lower Mesas

Agriculture on the higher mesa tops does not appear to be severely constrained by soils. Three of the four profiles above 2042m (6700') display deep, well-drained, sandy or clayey loams. The lower altitudes present a different picture. Although the sample of lower altitude soils is limited, making it impossible to discuss in any rigorous fashion how soils may or may not have effected Puebloan agriculture below 1920m (6300'), the data do provide some significant clues--clues that can inform future, more focussed investigation. Reneau et al. (1996) argue that old, well developed soils have been eroding for much of the Holocene, leaving the mesa tops stripped bare to the tuff bedrock in many eastern portions of the plateau. These eastern mesa tops are also the mesas lowest in elevation. As some of the NRCS pits revealed, soils in these areas are frequently limited to a few centimeters of slopewash overlying tuff, or in more stable locations (such as Pit 5) to a shallow A horizon, directly overlying a highly clayey and probably agriculturally undesirable Btk. There are patches of arable soils at lower elevations, but in comparison to the greater extent of such soils at middle and higher elevation locations, it is clear that factors other than temperature and precipitation contributed to the Pueblo preference for farming at higher altitudes.

Conclusion

In sum, the soils represented in the sample of soil pits investigated present a complex history of soil development, punctuated by periods of instability, that may extend over the last 100,000 years, and which can be divided into post-El Cajete, El Cajete period, and pre-El Cajete deposits. Although the properties displayed by the soils are primarily time-dependent, other soil factors, including climate, organic constituents, topography, and parent materials cannot be held constant. Climatic and biotic changes almost certainly occurred at the close of the Pleistocene and beginning of the

Holocene, and these may be responsible for Holocene intervals of instability and erosion. Recent Holocene erosion of soils on lower elevation mesa tops is particularly pronounced and has, in combination with climatic limitations, made these areas less desirable for prehistoric Puebloan agriculture.

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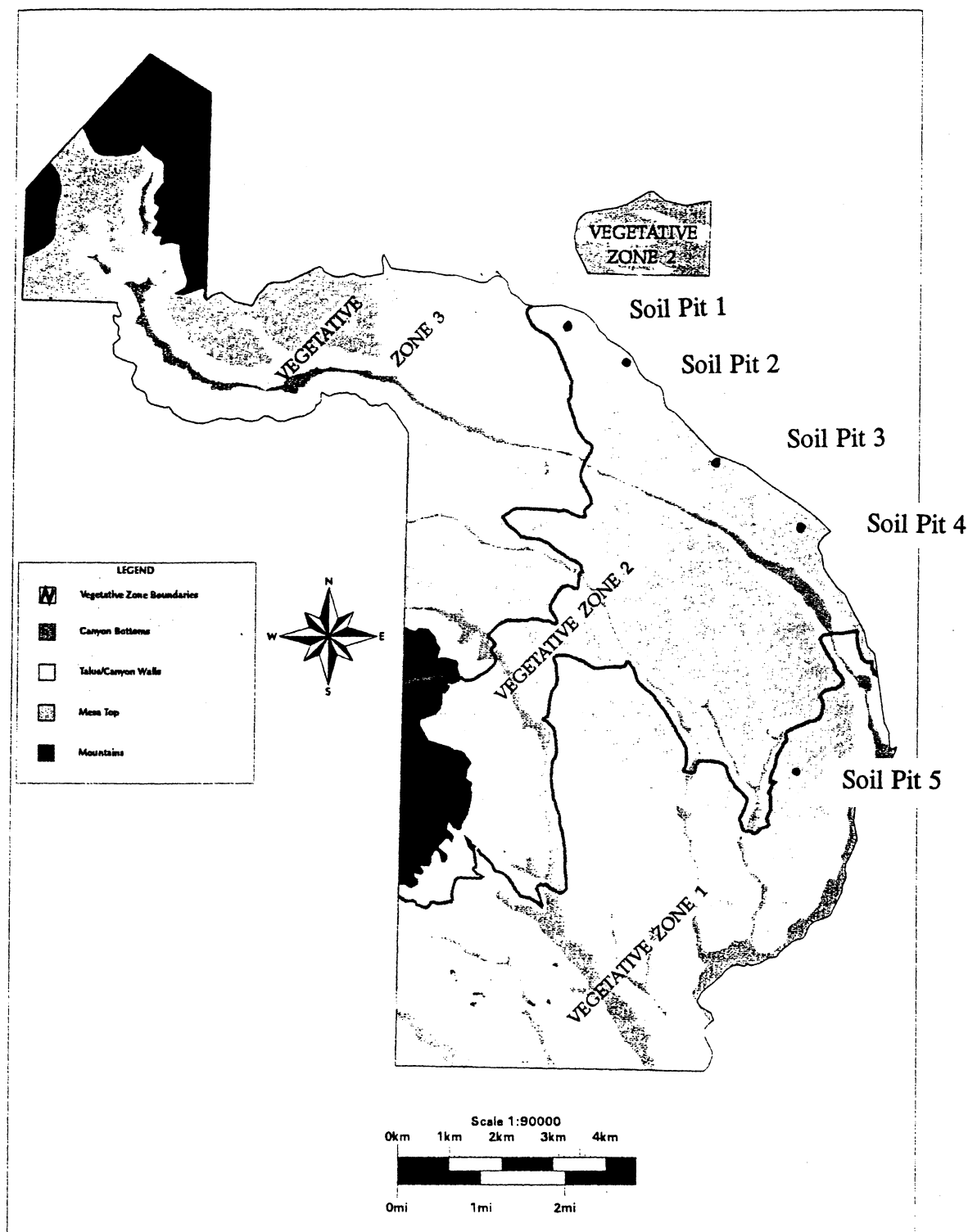


Figure 1. Five Soil Pit Locations in Bandelier National Monument

Table 1. Soil Pit Elevation, Landform and Slope.

Pit #	Elevation meters (feet)	Primary Landform	Secondary Landform	Slope (est.)
1	2232 (7322)	mesa top	ridge slope	15%
2	2187 (7175)	mesa top	ridge slope	5%
3	2108 (6916)	mesa top	ridge center	2%
4	2042 (6700)	mesa top	ridge slope	5%
5	1922 (6305)	mesa top	ridge center	1%

Table 2. Soil Horizons and Soil Properties for Soil Pit # 1.

Soil Pit # 1 . Location . Described by R. Powers .

Date 11/29/00 . Time 11:30 . Elevation 7322 . Slope 15% . Aspect N .

Vegetation Ponderosa pine, Gambel oak, grasses .

Parent reworked volcanic alluvium and sheetwash, dust. Geomorphic Surface mesa slope .

Depth (cms)	Hor- izon	Color moist/ dry	Struct- ure	Gra- vel	Consistence			Text- ure	Clay Films	Bound- aries
					Wet	Moist	Dry			
2-0	0	7.5YR4/1	-	-	-	-	-	-	-	abrupt smooth
0-15	2Bt1 b	7.5YR5/3	weak, granular coarse	0%	sticky; very plastic		hard to very hard	silty clay	common distnct coats and bridges	clear wavy
15-34	2Bt2 b	7.5YR5/3	weak, granular coarse	0%	sticky; very plastic		hard to very hard	sandy clay loam	many, distnct coats and bridges	grad- ual, smooth
34-75	2Bt3 b	7.5YR5/3	moderate sub- angular blocky	0%	sticky, very plastic		hard	sandy clay loam	many, distnct coats and bridges	clear wavy

Depth (cms)	Hor- izon	Color moist/ dry	Struct- ure	Gra- vel	Consistence			Text- ure	Clay Films	Bound- aries
					Wet	Moist	Dry			
		7.5YR6/4								
75- 105	2Bt4 b		weak, granular coarse	0%	sticky, very plastic		very hard	sandy clay loam	common, distnct coats and bridges	cont- inues below bottom of pit
		7.5YR6/3								

Comments:

O -- Dark gray organic layer with carbon and partially decomposed roots, pine needles, twigs, etc., probably from 1977 La Mesa Fire.

2Bt1b -- Bioturbated layer with numerous small rootlets.

2Bt2b--Brown, slightly reddened horizon containing more sand, but with distinct clay illuviation. Frequent rootlets from 1.0 mm to 15.0 mm.

2Bt3b--Light brown horizon with moderate sub-angular blocky structure with distinct clay illuviation. Differs from 2Bt2b primarily in color and structure. Some rootlets.

2Bt4b--Light brown horizon with weak, coarse granular structure with distinct clay illuviation. Differs slightly from 2Bt3b in color and structure. Few small rootlets. No effervescence in any of the Pit #1 horizons.

Table 3. Soil Horizons and Soil Properties for Soil Pit 2.

Soil Pit # 2 . Location Zone 13 381734E, 3964110N . Described by R. Powers .
 Date 11/17/00 . Time 3:20 PM . Elevation 7175' . Slope 2-8% (est) . Aspect SW .
 Vegetation Ponderosa pine, Gambel oak, shrubs, and grasses .
 Parent Material El Cajete pumice, reworked volcanic alluvium and sheet wash, dust .
 Geomorphic Surface dissected mesa top .

Depth (cms)	Hor- izon	Color moist/ dry	Struct- ure	Grav el	Consistence			Text- ure	Clay Films	Bound- aries
					Wet	Moist	Dry			
0-5	O	10YR2/1	massive	25%	slightly sticky; non- plastic	very friab le	-	sandy loam	none	abrupt smooth
5-33	A	10YR3/1	weak, sub- angular blocky; fine	50%	non- sticky; non- plastic	very friab le	-	loamy sand	none	clear, smooth
33-52	A2	10YR4/3	massive	50%	non- sticky; non- plastic	loose	-	sand	none	clear, irregu lar

Depth (cms)	Hor- izon	Color moist/ dry	Struct- ure	Grav el	Consistence			Text- ure	Clay Films	Bound- aries
					Wet	Moist	Dry			
52-93	2Bt1 b	7.5YR8/1	single, fine to very coarse	75%	non- sticky; non- plastic	loose	loose	sand	few, distinct coats	abrupt smooth
93-96	2Bt2 b	7.5YR6/6	single fine to very coarse	75%	non- sticky; non- plastic	loose	loose	sand	many distinct coats bridges	abrupt smooth
96- 108	3Bt1 b	10YR6/3	massive	<10%	slightly sticky, slightly plastic	friable	-	sandy loam	few, faint pores	clear smooth
108- 142	3Btk 2b	7.5YR5/4	weak, sub- angular blocky, coarse	<10%	sticky, plastic	firm	-	sandy clay loam	common, distinct pores	abrupt smooth
142+	R	-	-	-	-	-	-	-	-	-

Comments:

O--Black surface horizon with carbon from La Mesa fire (?), with higher percentage of silt and clay with pumice sand. Numerous small rootlets less than 1 mm diameter.

A--Very dark gray, thick horizon with large proportion of El Cajete pumice sand and gravel.

Largely granular but with a few sub-angular blocky peds. Small rootlets throughout. Bioturbation of underlying 2Bt1b has resulted in upward movement of pumice.

A2--Brown, with some silt and clay content, although dominated by pumice sand. Coarse pumice has been moved upward by bioturbation of underlying 2Bt1b layer. Small rootlets throughout. Lower boundary is irregular due to bioturbation.

2Bt1b-- White, unaltered El Cajete pumice gravel (2 to 10 mm clasts), with coarse sand (>2mm) grains. Displays numerous thin (5 mm thick) lamellae composed of sand and gravel clasts that are coated on the bottom and sides with clay and Fe. The bands are horizontal and are spaced 5 to 10 cms apart. In places this horizon is disturbed by bioturbation almost to its bottom. Rootlets are again present.

2Bt2b--Reddish yellow, very thin layer of pumice at the base of the El Cajete that reflects the coating of pumice gravel and sand clasts with clay and Fe.

3Bt1b-- Pale brown buried soil of sandy loam with virtually no gravel particles. Translocated clay is present, but clay films in pores are difficult to see. Some small rootlets present.

3Btk2b--Brown, buried soil of silty clay loam that directly overlies the Tshirege Member of the Bandelier tuff. Layer exhibits definite rubification. Clay films in pores are distinct. Strong effervescence was noted on the underside of Bandelier tuff clasts (45 x 25 x 25 mm) interspersed throughout the layer. Some small rootlets present.

R- Probable Tshirege Member of Bandelier Tuff.

Table 4. Soil Horizons and Soil Properties for Soil Pit # 3.

Soil Pit # 3. Location Zone 13, 383342E, 3962649N. Described by R. Powers.

Date 11/18/00. Time 12:55. Elevation 6916'. Slope 2-12%. Aspect SW.

Vegetation Pinyon pine, juniper, and grasses.

Parent Material reworked volcanic alluvium and sheet wash, dust. Geomorphic Surface mesa top.

Depth (cms)	Horizon	Color moist/dry	Structure	Gravel	Consistence			Texture	Clay Films	Boundaries
					Wet	Moist	Dry			
0-13	A	7.5YR3/2	massive	<10%	slightly sticky, plastic	very friable	-	sandy clay loam	none	clear smooth
13-42	Bw	7.5YR4/3	moder. sub- angular blocky, medium	0	slightly sticky, plastic	friable	hard	clay loam	none	clear smooth
42-82	2Btk1 b	7.5YR4/3	weak, sub- angular blocky, medium	0	slightly sticky, plastic	friable	hard	clay loam	very few, faint coats	grad. irreg.

Depth (cms)	Hori- zon	Color moist/dry	Struct- ure	Gravel	Consistence			Text- ure	Clay Films	Bound- aries
					Wet	Moist	Dry			
82-90	2Btk2 b	7.5YR4/3	weak, sub- angular blocky, medium	<10%	non- sticky, slightly plastic	friab le	-	sandy loam	very few, faint coats	clear wavy
90+	R	-	-	-	-	-	-	-	-	-

Comments:

A--Dark brown, no clear evidence of organic material, small rootlets are common.

Bw --Brown, but slightly reddened clay loam, but clay films not clearly visible. Some soft pockets of soil appear bioturbated.

2Btk1b--Brown clay loam with few faint colloid coats. Soft pockets of soil appear bioturbated. Small rootlets present. Very slight effervescence.

2Btk2b--Brown sandy loam with intermixed Bandelier tuff clasts (80 x 80 x 60 to 35 x 25 x 20 mm) with strong effervescence.

R--Bandelier tuff bedrock.

Table 5. Soil Horizons and Soil Properties for Soil Pit # 4.

Soil Pit # 4 . Location Zone 13, 384590E, 3961597N . Described by R. Powers .
 Date 11/18/00 . Time 4:00 . Elevation 6700' . Slope 5% . Aspect NE .
 Vegetation Ponderosa pine, juniper, sparse grass .
 Parent Material El Cajete pumice, dust . Geomorphic Surface low hill on mesa top .

Depth (cms)	Hori- zon	Color	Struct- ure	Gravel	Consistence			Text- ure	Clay Film s	Bound- aries
					Wet	Moist	Dry			
1-0	O	-	-	-	-	-	-	-	-	abrupt smooth
0-19	A	7.5YR3/2	massive	25%	non- sticky non- plastic	very friab le	-	loam y sand	none	grad. wavy
19-37	Bw	7.5YR4/3	weak, sub- angular blocky, coarse	25%	non- sticky non- plastic	friab le	-	loam y sand	none	clear wavy
37-60	2Cox		weak, sub- angular blocky, coarse	25%	non- sticky non- plastic	-	loose	sand	none	clear wavy
		7.5YR7/4								

60- 125	2Btk1 b	massive, very coarse	75%	non- sticky non- plastic	-	loose	sand	none	-
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10YR8/1

Comments:

O -- Very thin surface skin of carbonized pine needles, bark, and charcoal from recent prescribed burn.

A -- Dark brown loamy sand pumice layer. More organic looking than underlying material with Rootlets (2.0 mm and up) are common. Sediment holds face, but no visible peds. Layer is bioturbated.

Bw -- Brown, loamy sand pumice with few, weak peds, no visible clay films. Rootlets are common (2.0 mm up to 4.00 mm). Layer is bioturbated.

2Cox -- Pinkish, largely unaltered El Cajete pumice sand horizon (which barely holds face), with very few weak peds in upper portion of the layer. Layer appears oxidized. Some loamy pockets and color irregularities appear to be due to bioturbation. Many to few rootlets. Lower portion is strongly effervescent.

2Btk1b -- White, unaltered El Cajete pumice sand and gravel ranging in size from 15 mm to 2 cm in diameter. Top 20 cm of horizon are less consolidated and show some signs of bioturbation. Lower portion is undisturbed pumice. At depth of 99 bpgs is a single lamellae of pumice clasts cemented by clay coats and bridges and discolored (on bottoms) by Fe. Layer is strongly effervescent. Few roots are visible below 1.00 m.

Table 6. Soil Horizons and Soil Properties for Soil Pit # 5.

Soil Pit # 5 . Location Zone 13, 384699E, 3956289N . Described by R. Powers .

Date 12/3/00 . Time 1:15 . Elevation 6305 . Slope 1% . Aspect SE .

Vegetation juniper, snakeweed, opuntia, grasses . Parent

72Material reworked volcanic alluvium and sheetwash, dust. Geomorphic Surface mesa ridge.

[illegible]

Comments:

A-- Brown (moist) to light brown (dry) layer with obvious organic material (flecks of carbon) with numerous small rootlets. Very small amount of volcanic gravel (1-2%).

2Btk1b-- Reddish brown (moist and dry) sandy clay horizon exhibiting strongest rubification seen in any of the five pits. Structure grade is probably moderate to strong, but wetness of soil, makes classification difficult. About 1-2% gravels. Some small rootlets present. Shot of HCl produced a strongly effervescent reaction in the bottom portion of the layer.

2Bk1b -- Reddish brown (moist) to pink (dry) loamy horizon with much higher proportion of gravelly material. Gravel size material may represent clasts of Bandelier tuff. Magnification shows numerous angular quartz crystals in sand component. Layer is very hard and has whitened appearance due to presence of calcium carbonate (strong effervescence -- estimated as Stage II).

R -- Bedrock, apparently the Tshirege Member of the Bandelier Tuff.

Table 7. Soil Pit Horizons in Relation to post-El Cajete, El Cajete, and pre-El Cajete Age Deposits.

Depth (cms)	Pit 1	Pit 2	Pit 3	Pit 4	Pit 5
5-0	O			O	
0-5	2Bt1b	O	A	A	A
5-10		A			
10-15					2Btk1b
15-20	2Bt2b		Bw		
20-25				Bw	
25-30					2Bk1b
30-35					
35-40	2Bt3b	A2			
40-45			2Btk1b	2Cox	
45-50					
50-55		2Bt1b			R
55-60					
60-65				2Btk1b	
65-70					
70-75					
75-80	2Bt4b				
80-85			2Btk2b		
85-90					
90-95		2Bt2b	R		
95-100		3Bt1b			
100-105					
105-110					
110-115		3Btk2b			
115-120					
120-125					
125-130					
130-135					
135-140					
140-145		R			

Post El Cajete

El Cajete

Pre El Cajete