APPENDIX E

Three L Canyon Soil Geomorphic Units

This document describes soil analyses in Three L Canyon and surrounding area conducted by Jed Frechette.

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Three L Canyon Soil Geomorphic Units

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The informal soil geomorphic units described in this report are defined based on field descriptions of soils at 23 locations in the vicinity of Three L Canyon, Sacramento Mountains, NM (Figure 1). Soil horizon designations and descriptive terms follow those of the Soil Survey Division Staff (1993), and Birkeland (1999). Stages of pedogenic calcium carbonate morphology follow those of Gile et al. (1966) and Birkeland (1999).

Vegetation is variable throughout the area and appears to be strongly correlated with aspect. Douglas fir (*Pseudotsuga menziesii*) is the dominant canopy species. Ponderosa pine (*Pinus ponderosa*) is also common and is codominant or dominant at drier locations where alligator juniper (*Juniperus deppeana*) and piñon pine (*Pinus edulis*) are also present. Southwestern white pines (*Pinus strobiformis*) are also plentiful, particularly on wetter slopes. Various oak species (*Quercus* sp.) are also a common component of the understory throughout the area.

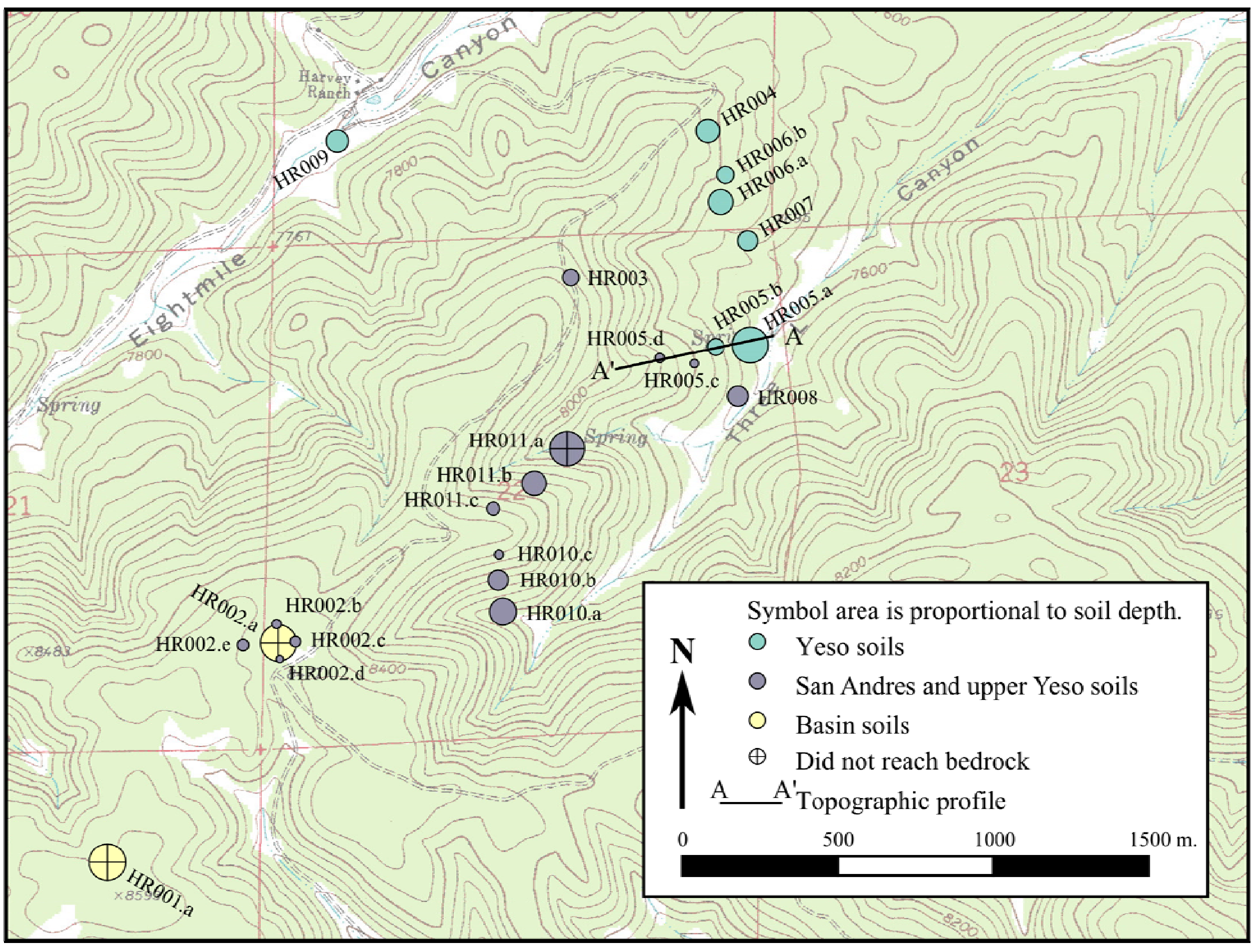

Figure 1: Locations and thicknesses of described soil stratigraphic sections.

Soil geomorphic units

Observed differences between the three informal soil geomorphic units described in this report are primarily attributed to differences in parent material. Slopes underlain by resistant carbonate rocks of the Permian San Andres formation and upper Yeso formation are detachment limited with soils consisting of thin A horizons that mantle the surface and fill fractures in the largely unaltered bedrock. In contrast, slopes underlain by less resistant rocks of the Yeso formation are commonly transport limited with better developed soil profiles that extend into, and may significantly alter, the underlying bedrock. These characteristics are modified locally by the effects of topographic position and aspect controlled microclimate. A third soil stratigraphic unit is found in closed basins along ridge tops. This unit records an extended period of surface stability and soil development followed by increased sediment deposition and cumulic soil development in more recent times. Some hill slope soils also suggest a similar history. Finally, although they were not examined during this study, valley floors in the study area are underlain by several meters of fan and valley fill alluvium. These deposits are likely similar to the complex alluvial deposits, often with Mollisol like soils, described in the adjacent Peñasco valley by Frechette (2007)

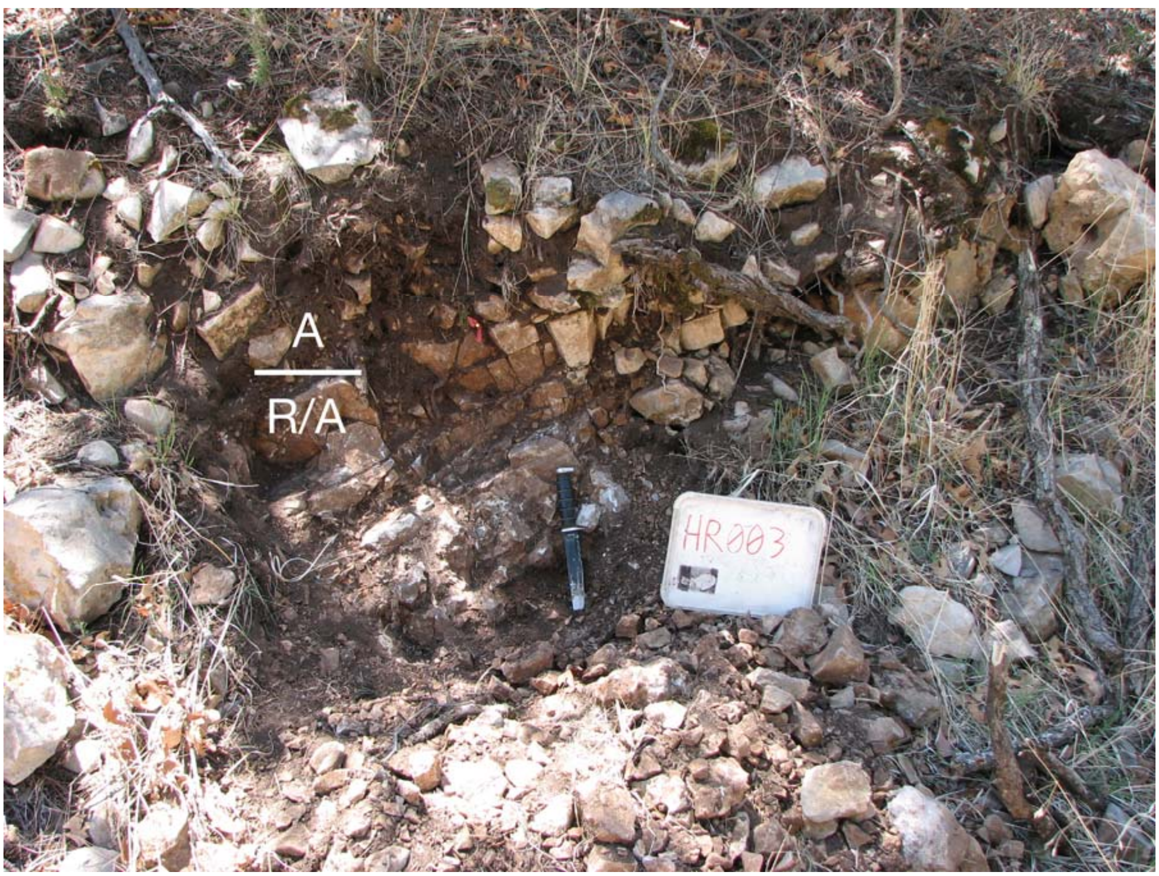

Figure 2: Soil profile HR003. This road cut exposure was one of the few locations where more than a few centimeters of R/A horizon could be exposed.

San Andres and upper Yeso soils

The soils in this unit cover the majority of the study area and roadcuts at HR003 (Figure 2) and

HR011.c provided the best exposures. They occupy a variety of topographic positions and are associated with a number of vegetation types. The unifying characteristic of these soils is that they are formed in resistant carbonate rocks of the San Andres and upper Yeso formations. Although carbonate dissolution is clearly a factor, bedrock weathering appears to proceed primarily by physical processes that result in subangular to angular blocks that litter the surface and form the parent material for this unit. Soils are generally thin their distribution is patchy and they are intermixed with low relief outcrops of fractured bedrock.

Table 1: Soil data for Entisol-like soil at HR003.

Horizon	Depth, cm	Dry color	% Gravel	Texture
A	0-30	7.5YR 4/3	30	Cobbly silt loam
R/A	30-85	7.5YR 4/3	>50[a]	Cobbly silt loam

[a]Interlocking angular blocks resulting from weathering of parent material.

The A over R/A profile described at HR003 and shown in Figure 2 and Table 1 is typical of these deposits. Fine-fraction textures were consistently silt loams and loams. Textures of loamy sand and sandy loam were recorded at two sites, however, in both cases the sandy texture was attributed to high concentrations of twig, bark, and need fragments. Textures of the mineral fractions were probably closer to a loam or silt loam in both horizons. Horizons were brown to dark brown and typically exhibited weak to moderately developed very fine to medium granular texture. Gravel content varied from 1 to 30 % and consisted of subangular to subround gravel to cobble size limestone blocks. Weakly hydrophobic A horizons were observed at several locations, however there is little evidence that this hydrophobicity is continuous.

A horizon thicknesses varied significantly as a function of slope position, and perhaps to a lesser extent aspect. The thickest horizons were found in footslope setting such as HR010.a and HR011.a (Figure 1). Cumulic deposition of upslope material at these locations is strongly indicated by the relatively homogeneous A horizons, exceeding 50 cm in thickness that were observed. In contrast the thinnest soils are present near ridge crests where erosional processes dominate and A horizon thicknesses rarely exceed 20 cm. Backslope soil thicknesses are intermediate and appear to be more variable as a result of vegetation controlled microtopogr態, e.g. colluvium accumulation behind trees and logs. Data from the HR010-HR011 toposequence suggest that soils on wetter, more densely vegetated, North facing slopes are thicker than soils on drier more sparsely vegetated South facing slopes. This is consistent with observations of other slopes in the area and the current understanding of the relationships between aspect and geomorphology (Kirkby et al., 1990; Burnett et al., in press).

The R/A horizons are characterized by interlocking carbonate blocks transitioning to fractured bedrock with depth. The fine material filling these fractures shares the same texture and color as the overlying A horizons. Due to the difficulty of manually digging soil pits in this material most pits were completed within a few centimeters of encountering the first interlocking limestone blocks. As a result the depth to which these filled fractures extend into the bedrock is not well constrained. Based on road cut exposures, however, it appears that most fractures close up rapidly with depth. Therefore, it seems unlikely that much A horizon material penetrates more than a meter or two into the bedrock, even though the underlying fracture networks are probably much more extensive.

Table 2 Soil data for cumulic Entisol-like soil at HR010.a

Horizon	Depth, cm	Dry color	% Gravel	Texture
A	0-40	7.5YR 4/3	15	Gravelly silt loam
Bk	40-83	7.5YR 4/3	15	Gravelly silt loam
R/Bk	83-98	7.5YR 5/4	>50[a]	Cobbly silt loam

[a]Interlocking angular blocks resulting from weathering of parent material.

Despite the abundant source of carbonate provided by the San Andres and Yeso formations little carbonate accumulation was observed in these soils. Weak Bk horizons were observed overprinting cumulic A horizons in the thickest soils at HR010.a (Table 2) and HR011.a. In both soils, however, carbonate accumulation was minor and features associated with development of the original A horizon dominated. Minor amounts of soil carbonate were also observed surrounding limestone clasts, suggesting rapid in-situ weathering and reprecipitation. The lack of carbonate accumulation is not surprising given the fairly wet climate of the Sacramento Mountains and the likely young age of these soils. The almost complete lack of carbonate in most of these soils, however, does suggest that the fine mineral fraction must originate from another source, most likely eolian dust. An eolian source is also consistent with the high silt concentrations that were observed.

The generally poor development of soils within this unit can be attributed to the underlying bedrock's resistance to weathering. Although soils may achieve significant thicknesses locally all available evidence indicates most thickening occurs due to erosion and transport of material from upslope locations rather than from in-situ weathering. The fine fraction's general lack of carbonate also argues against in-situ weathering. These observations suggest that although bedrock characteristics exert a strong physical control on this unit, soil formation is largely independent of the underlying bedrock's chemical properties.

Infiltration rates in this unit are likely to be high. Although many soils are thin and their distribution is patchy the loose to weakly coherent generally loamy texture is likely to encourage infiltration. Infiltration rates are likely to be enhanced further by the tortuous flow paths typical of the rocky and debris littered surface of this unit. Although slight hydophobicity was observed at some sites it seems unlikely that it is strong enough and widespread enough to have any significant impact on infiltration rates. If surficial fractures are well connected to more extensive fracture networks at depth precipitation falling on this unit may be rapidly transmitted to the groundwater system.

Yeso soils

This unit consists of soils forming in less resistant rocks of the Yeso Formation and is less widespread within the study area than the San Andres and upper Yeso soils. In contrast to the San Andres soils, which show little evidence of in-situ alteration and weathering, B horizons are common in this unit. Slopes underlain by this unit are generally smooth with few, if any, clasts resting on the surface. Bedrock outcrops are rarely observed, except in road cuts, and soils are often thicker and better developed than San Andres soils in similar topographic positions.

The contact with the San Andres soils is complex and irregular. This can be attributed to both the gradational nature of the depositional contact between the Yeso and San Andres formations and recent geomorphic disruptions, e.g. slumping of San Andres blocks. For example, site HR004 is within the mapped perimeter of the San Andres Formation, however, it was included in the Yeso soils because it is forming in a yellow siltstone typical of the Yeso Formation and has a Bw horizon similar to other soils in this unit. An outcrop of Galisteo equivalent sandstone was observed in the roadbed 40 vertical feet above HR004 and limestone outcrops are present both above and below the site so it is clearly very close to the Yeso/San Andres contact.

A horizons in Yeso soils are generally similar to those of the San Andres soils with brown silt loams being most common. A slightly wider range of textures was observed, one A horizon had a texture of loamy sand and another had a texture of silt. Very fine to medium granular structure was often more strongly developed in the Yeso soils and gravel was typically absent. Similarity to the San Andres soils is not surprising given environmental similarities and likely downslope transport of San Andres soil material and mixing with Yeso soils.

Unlike the San Andres soils, B horizons are common in this unit. Bw horizons were most common and could be identified by a lightening in color and in some case weak to moderately developed subangular blocky structure. All Bw horizons had silt loam textures. Reddish Bt horizons were observed at HR005.a and HR006.b. Both horizons had moderately developed very fine subangular blocky structure and textures of silty clay loam. Distinct clay coatings and bridges covered 5-25 % of the described surface. Soil samples were collected from all horizons at HR005.a.

The contrast between the Yeso and San Andres soils is clearly demonstrated by the differences observed along transect A-A' (Figure 3). Although HR005.b and HR005.c occupy similar backslope positions they have markedly different soil profiles. Not only is soil depth greater at HR005.b, but the addition of a Bw horizon suggests that soil forming processes are occurring more rapidly than downslope transport. This trend is accentuated at HR005.a where soil depth is nearly 150 cm and a thick Bt horizon has developed. The translocation of clay and deposition of clay films within the Bt horizon indicates significant water movement through this horizon. Given the footslope position of this site throughflow may be enhanced relative to other slope positions, however, the other site where a Bt horizon was observed, HR006.b, is located near the crest of a small ridge. Additional work is required to determine how soil volume is partitioned between material transported from up slope, material produced by in-situ weathering, and material moving vertically through the soil profile. Nonetheless, soil development at this site is in striking contrast to HR011.a, which is in a similar topographic position and has a similar thickness but consists almost entirely of cumulic A horizons overprinted by very weak pedogenic modification.

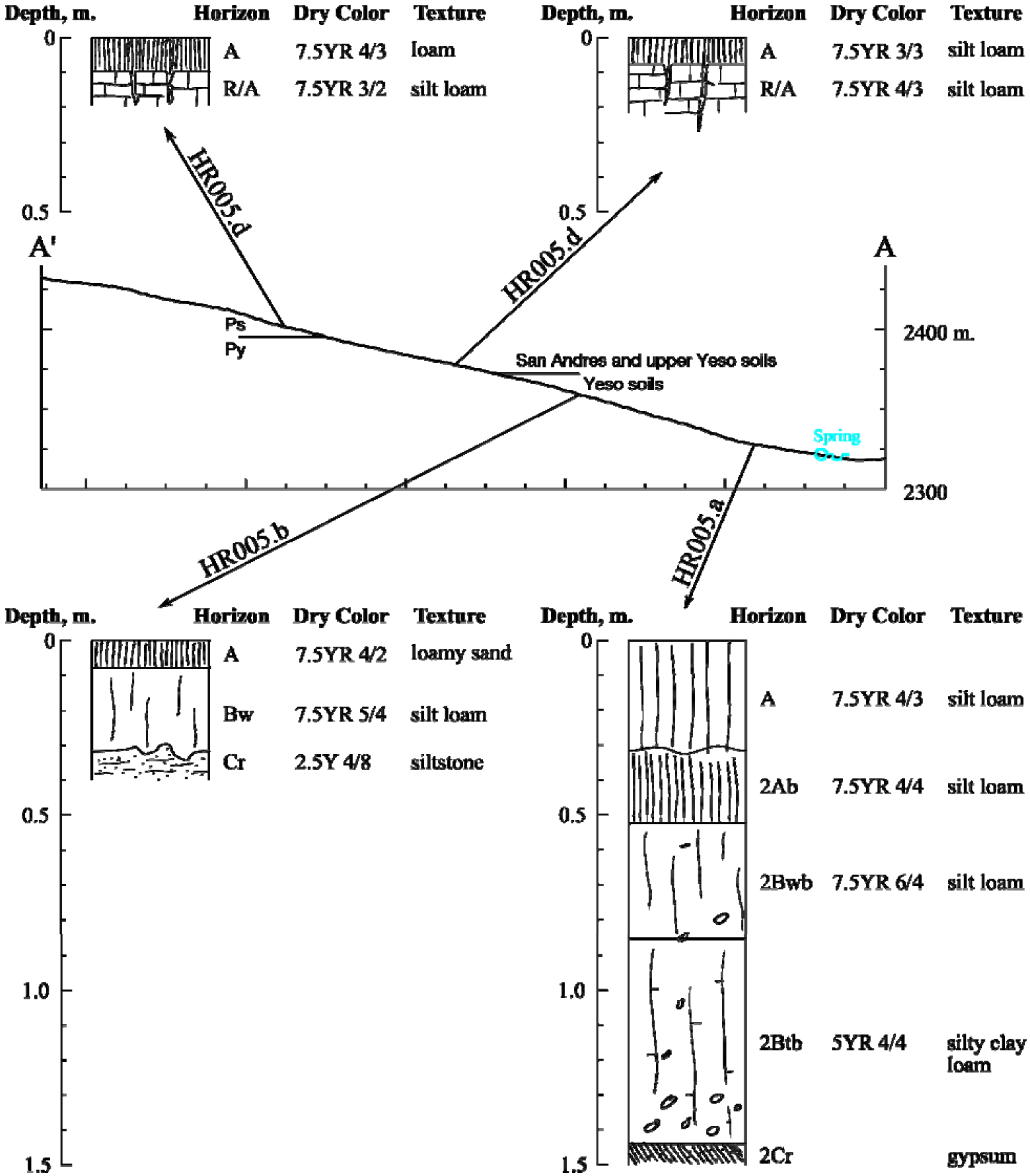

Figure 3: Toposequence completed up slope of lower spring in Three L Canyon. Soil profile locations were projected to profile line A-A' (Figure 3) orthographically. The topographic profile was extracted from a 10 m DEM after interpolating to 2.5 m with a regularized spline. The elevation of the contact between the San Andres and Yeso Formations is based on Hallet, 2007.

Although the relationship between the well developed buried soil profiles and current climatic conditions is unclear the presence of Bw horizons in most of the active soil profiles strongly suggests that in-situ weathering and soil development continues throughout the area covered by this unit. Sites HR005.b (Figure 3) and HR006.a (Figure 4) provide examples of more typical soils within this unit that consist of A and Bw horizons that transition gradually into the underlying bedrock, siltstone at both of these locations. Limited exposures prevent estimates of C horizon thicknesses, however, alteration may continue to a significant depth.

Similar to the San Andres soils infiltration rates are likely to be high due to the weakly coherent generally loamy textures of A horizons within this unit. However, due to thicker soil profiles and the lack of preferential flow paths along fractures, soil water residence time may be greater in this unit. This leads to the potential for higher evapotranspiration rates in areas covered by this unit relative to adjacent areas covered by San Andres soils.

Basin soils

Two soil pits (HR001 and HR002.a) were excavated in closed basins atop the ridge near Three L Canyon's headwaters (Figure 1). Both pits were completed at a depth of 1.5 m without reaching bedrock. Despite being located in separate basins nearly a kilometer apart the stratigraphy at both sites was virtually identical. The stratigraphy described at HR002.a is shown in Figure 5 and will be discussed below. Samples were collected from all horizons at HR002.a.

The profile described at HR002.a consists of a buried profile similar to the buried profiles at HR005.a and HR006.b overlain by a series of cumulic A horizons. The lowest horizon, 4Btb is reddish yellow with moderately developed fine subangular blocky structure and a silty clay loam texture. Prominent clay films cover 25-50 % of the described surface. No gravel is present in this horizon. The age of 4Btb is unknown, however, a large piece of wood was collected from an apparently correlative horizon at HR001 and could be dated using conventional radiocarbon methods. 4Btb is overlain by 3Bwb which is reddish brown, contains 20% gravel, and has more weakly developed clay films and structure. Horizon 3Bwb also has a slightly higher clay content than 4Btb. The uppermost B horizon 2Bwb is similar to 3Bwb, but contains no gravel and has a texture of silty loam. These B horizons are overlain by a series of brown cumulic A horizons with moderately developed medium granular structure. These A horizons are loams and silt loams with no gravel.

Similarities between the basin soil stratigraphy and stratigraphy observed at HR005.a (Figure 3) add support for a geomorphic history characterized by an extended period of landscape stability and soil formation followed by one or more episodes of instability and erosion. The clay accumulation and structural development observed in the basin soils' Bt horizons would have required a significant period of time to develop, suggesting they may be as old as early Holocene or Pleistocene. These features are not as well developed at HR005.a, however, this is not surprising considering its less stable position within the landscape. The erosional event, or events, represented by 3Bwb must have been very severe considering that no other horizons contain gravel and 3Bwb contains clasts with *b*-axis diameters of up to 3 cm at HR002.a and 10 cm at HR001. Precipitation and/or devegetation must have been extreme in order to generate flows capable of transporting clasts of this size to the center of these small, low relief basins.

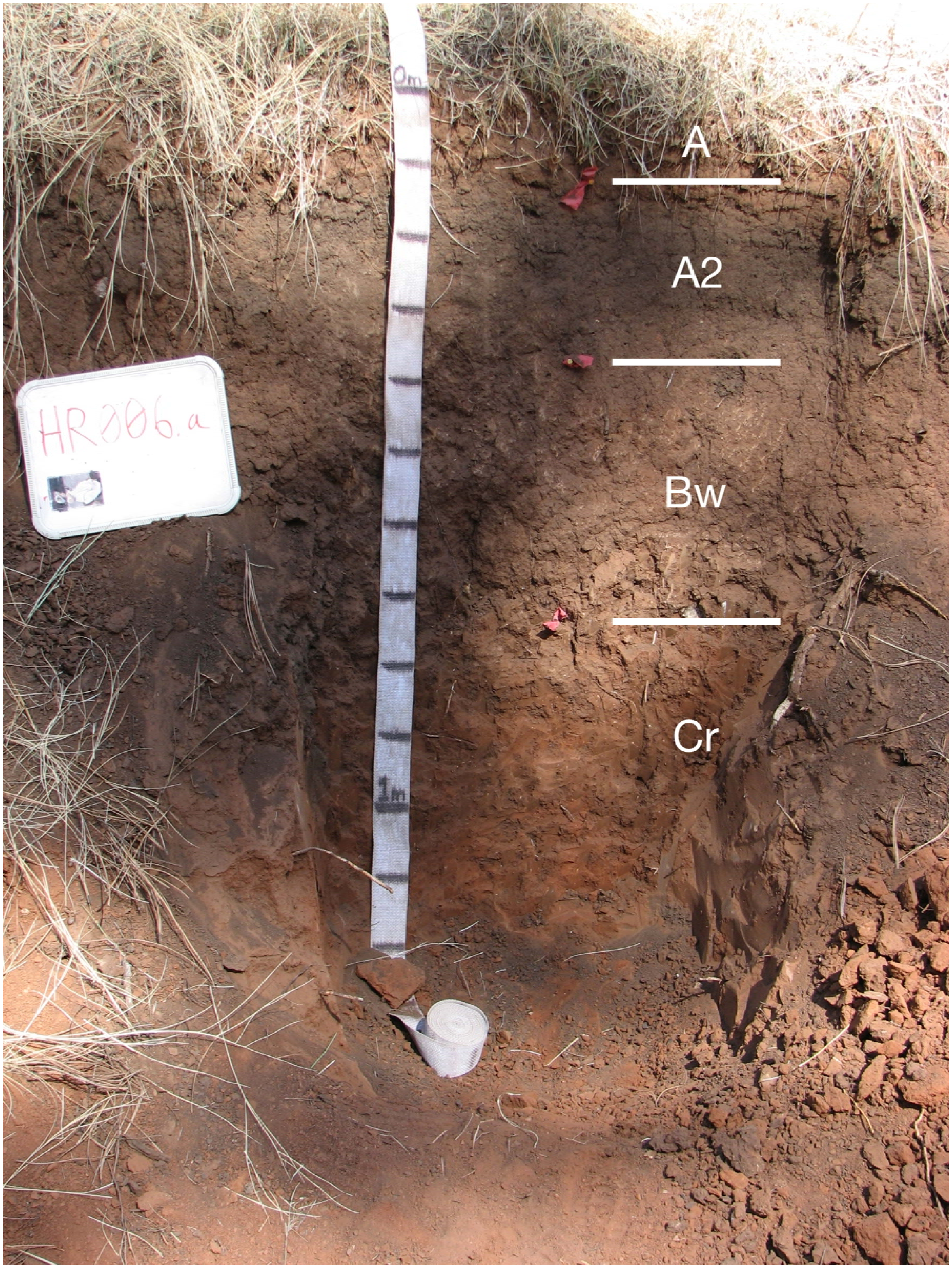

Figure 4: Soil stratigraphic section described at site HR006.a. Horizon A1 is very similar to A2 and forms a small berm that may be related to road construction that exposed this profile.

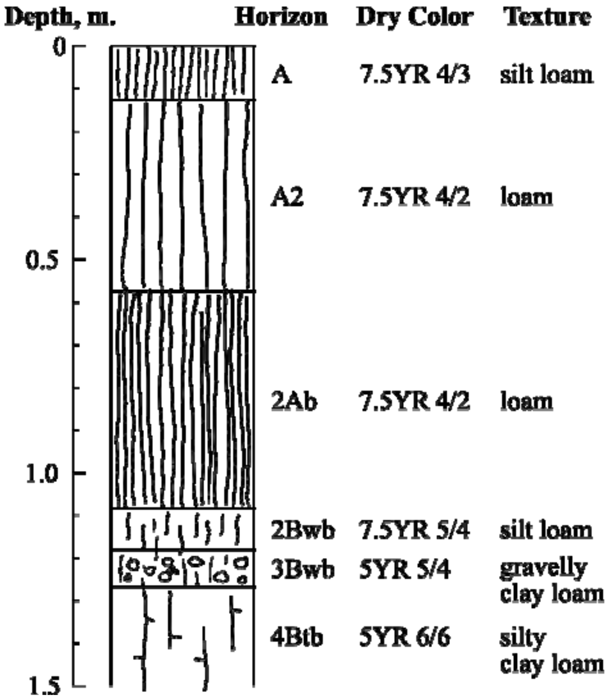

Figure 5: Soil stratigraphic section described at HR002.a.

Although overland flow clearly accumulates in the closed basins of this unit clay rich soil horizons may limit or prevent any significant groundwater recharge. Numerous slickensides were observed within the Bt horizon of the drier HR001 basin. This suggests that although voids may exist under dry conditions they close up following wetting and clay hydration. One other data point can be obtained from the soil moisture observed in pit HR002.a which was located 9.5 m from the edge of a small pond and was completed approximately 1 m below the pond's water surface. None of the horizons within this pit were more than slightly moist, implying a fairly steep water table gradient away from the pond. The presence of the pond at HR002 may be explained by a perched water table resulting from the contrast in hydraulic conductivity between the overlying A horizons and the relatively impermeable B horizons. Although no standing water is present at HR001 similar conditions may develop under wetter conditions.

Summary

Bedrock lithology appears to be the dominant control on soil geomorphic characteristics in this area. In the extensive areas underlain by mechanically resistant carbonate rocks of the San Andres and upper Yeso formations slopes are commonly detachment limited with thin Entisol-like soils that fill bedrock fractures. In contrast areas underlain by more easily weathered facies of the Yeso formation are more likely to be transport limited with thicker Mollisol or Alfisol-like soils. Similar Mollisol-like soils are also found within two closed basins near the headwaters of Three L Canyon. Buried soils preserved in the closed basins and at a few lower Yeso sites suggest an extended period of landscape stability and soil development followed by more recent instability and erosion. Thick clay-rich Bt horizons that developed during this period of stability may have a significant negative impact on groundwater recharge in areas where they are preserved. In contrast, recharge is likely to be highest in areas covered by San Andres and upper Yeso soils due to a permeable surficial cover, tortuous surface flow paths, and a potential direct

connection to subsurface aquifers via fracture networks.

References cited

Birkeland, P. W., 1999. Soils and Geomorphology. Oxford University Press, New York.

Burnett, B.N., Meyer, G.A., and McFadden, L.D. (in press), Aspect controls on hillslope geomorphology and implications for slope evolution, northeastern Arizona: Journal of Geophysical Research - Earth Surface.

Frechette, J. D., 2007, Millennial-scale changes in fan deposition and fire severity in ponderosa pine forests, Sacramento Mountains, New Mexico: Masters Thesis, University of New Mexico, 56 p.

Gile, L. H., Peterson, F. F., and Grossman, R. B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347-360.

Hallet, B., 2007, Preliminary geologic map of the Harvey Ranch quadrangle, Otero County, New Mexico: New Mexico Bureu of Geology and Mineral Resources OF-GM 154, Scale 1:24,000, revised: 08 March 2006, http://geoinfo.nmt.edu/publications/maps/geologic/ofgm/154/documents/Harvey_Ranch_prelim_geo_for_web.pdf.

Kirkby, M.J., Atkinson, K., and Lockwood, J. G.,1990, Aspect, vegetation cover and erosion on semi-arid hillslopes. *in* Vegetation and Geomorphology. ed Thornes, J., John Wiley & Sons, New York, 25-39.

Soil Survey Division Staff, 1993. Soil Survey Manual, 3rd edition. Soil Conservation Service. U.S. Department of Agriculture Handbook 18.