Field Investigations of Soils at TA-19, TA-26, TA-73 and TA-0, SWMU Aggregate 0-D and 015

Leslie D. McFadden
Geoprofile, Inc.
229 Horton Ln. NW
Albuquerque, NM 87114

Abstract

Field based investigations of the general soil-geomorphic characteristics were carried out at TA-19, -26, -73, -0, Aggregate 0-D and -016 in order to provide information for utilization in ongoing and anticipated LANL ERP activities at these sites. These investigations show that soils exhibiting diverse morphologic character, varying ages, and relations to landforms characterize these sites. A review of recent and ongoing soils studies also shows that soil textural, chemical, and mineralogical characteristics may profoundly influence the migration and/or retardation of a variety of potential contaminants initially placed in direct contact with soils, or that encounter soils during subsurface percolation or discharge. Soil-geomorphic relations also provide important insights into recent site erosion, deposition or other surficial processes that must be considered as part of environmental assessment of a given site and remediation; and, the planned geomorphic mapping activities at each site, as well as other associated activities (e.g., geophysical survey, site sampling) are accordingly appropriate and necessary with respect to identification of significant soil relations at each site. Specific and general recommendations in consideration of important findings regarding the possible impacts of soil development of the nature of contaminant behavior at various sites are provided to help guide sampling and analysis activities during ERP investigations outlined in the RFI Work Plan for Operational Unit -1071.

1.0 Introduction

1.1 Purpose

The purposes of this report are to: (1) describe the general characteristics of soils present in the areas TA-19, TA-73, and TA-26 and at selected SWMUs in OU-1071 (TA-0, SWMU Aggregate 0-D, 016) and (2) discuss the implications of these investigations for

anticipated activities associated with the Los Alamos National Laboratory (LANL) Environmental Restoration Project (ERP) investigations; and (3) propose recommendations for ERP activities associated with ongoing and planned future investigations at these sites (specifically TA-19, -26, and -73) detailed in the RFI Work Plan for Operable Unit - 1071 (Aldrich and others, 1992) as they apply to and assist in the development of surface and subsurface sampling and evaluation of data gained through various field examinations and subsequent laboratory analyses of sampled materials. This report is provided in fulfillment of Task A as outlined in Appendix B of Subcontract 9-LV3-6489F -1 and Task B as outlined in Appendix B of Subcontract 9-LC2-Z8609-1.

1.2 Previous and Other Ongoing Soil Studies at LANL

Until 1991, major investigations of soils in the area of LANL primarily were chiefly those conducted by J. Nyhan and his colleagues (Nyhan and others, 1978). These investigations resulted in compilation of a general soil map of the region and an accompanying report that depicted identified location of soil series and other soil-mapping units that were defined on the basis of field studies. The mapped area, however, did not include the majority of the townsite area of OU-1071. Also, the report presented morphological data for some the soils, but not laboratory data (e.g., textural, mineralogical, chemical analyses). Other investigations conducted by LANL researchers have involved some limited studies of soils, but did not focus on aspects of soil genesis, soil-landscape relations, or soil-stratigraphy. McFadden (unpublished report, 1992) compiled a summary of results of Nyhan's soils investigations as well as other soil investigations in the region surrounding the Pajarito Plateau that provide important information relevant to the study and interpretations of soils in the LANL area. Part of this report was included in Aldrich and others (1992).

The most recent formal investigations of soils in the LANL area include those of Watt and McFadden(1993); Watt and others (1994); Eberly and others (1994); and McDonald and others (1994). Watt's research focusses on studies of the characteristics of soils in different geomorphic settings in order to provide a basis for assessing the influence of soil properties on the movement of radionuclides and other trace elements potentially released in the environment due to various LANL activities since early 1940s. These studies have been conducted in close collaboration with several LANL researchers and have been largely supported through LANL funding sources. Eberly's

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

research focus on genesis of oldest, most well developed soils on the geomorphic surface formed on the youngest parts of the 1.2 My-old Bandelier Tuff, to determine primary factors influencing the genesis of the soils. Part of this study also provides data that enables assessment of the possible relations between such soils and development and evolution of joints and joint-filling materials that occur in the tuff bedrock present beneath the soil. This study was conducted in close collaboration with B. Wilcox (EES-15, J 495, LANL) who is studying rates and processes of surface runoff and shallow subsurface flow in the LANL region. McDonald's work focuses on geologically recent geomorphic activity on the Pajarito Plateau as indicated by soil stratigraphic and soil geomorphic relations. This ongoing study is also being supported through LANL funding sources.

Although these studies were often not conducted specifically in areas that contain SWMUs and were conducted at sites presumed to be "uncontaminated" (largely in order to provide important "background" data), the data and conclusions from these studies are highly relevant to the understanding of soils observed at SWMUs in OU-1071 (as well as in other SWMUs throughout LANL), because the soils can be shown to have formed in similar landscape settings represented by those that occur in the sites discussed in this report. Consequently, the latter soils can be interpreted through comparison to and contrast with these analogous soils.

2.0 Methods of Investigation

Soils described in this report were examined in natural exposures, roadcuts, small pits. Soils were described according to conventional procedures used by American soil scientists. A Munsell Soil Color Chart was used to determine soil color, dilute hydrochloric acid was used to determine the presence or absence of calcium carbonate, a hand ocular was used to identify clay films.

3.0 Results

3.1 TA-19

3.1.1 Introduction

The former TA-19 (East Gate Laboratory) is now part of TA-72 and is located in Santa Fe County east of the Los Alamos Airport. Detailed descriptions and maps of this site, including its physical characteristics (including climate, geology, hydrology), history, and

nature and possible extent of contamination are included in the RFI Work Plan for Operable Unit-1071 (Aldrich and others, 1992). There are three SWMUs identified at TA-19, including 19-001, 19-002, and 19-003, and an area of concern, C-19-001.

3.1.2 Observations

C-19-001 is present on an erosional remnant of the Pajarito Plateau (often referred to as Los Alamos Mesa), which is underlain principally by the Tshirege Member of the Bandelier Tuff. The remnant, oriented approximately east-west, is about 50 to 60 m in width, and C-19-001 is located in the center of the remnant. Approximately 10 to 15 % of the ground surface is characterized by outcrops of tuff bedrock. The remaining area of the surface is mantled by moderately well developed soils that range from only a few cm to at least 30 cm thick. In general, soils are very thin or absent within a few meters of the edge of the surface remnant, where the outfall location associated with drain lines associated with 19-001 and 19-003 occur. A small pit was excavated on the surface to expose a soil profile on the surface. The soil was 40 cm thick, but may have been somewhat thicker prior to occupation of the site and site-related activities (ie., construction, road-building and transportation). The soil exhibited the following field characteristics: The upper 5 cm of the soil consists of slightly hard (dry), pale brown (10YR 6/3) noncalcareous (noneffervescent) material (probably a sandy loam) which lies below a weakly developed gravelly lag. From 5 to 30 cm, a horizon that exhibits characteristics of an argillic horizon (a Bt horizon that has a substantial amount of illuvial clay) is present; subhorizons were not identified within this thickness interval. This horizon consists of hard (dry), brown (10YR 5/3), strong subangular blocky, noncalcareous (noneffervescent) material (possibly a sandy clay loam). The horizon also has common fine tubular pores and exhibits dark organic and mineral-rich coatings (organoargillans) on some ped faces. The horizon contains locally small subrounded clasts of volcanic tuff. At a depth of about 30 cm, the soil is in abrupt contact with altered volcanic tuff. The tuff contains small pockets of dark, clay-rich material of unknown origin, and grades to a relatively fresh unaltered state at a depth of a 40 cm. No calcium carbonate was observed in the pit.

Deep trenches would be required to expose the nature of soil development at depths greater than 0.5 meters at this site. However, certain aspects of soil development can be generally evaluated owing to the recent exposure of tuff below the surface related to trail-

building activity where a trail descends from the surface to the canyon. The construction activities, that appear to have involved some blasting, expose numerous fractures (joints) in the tuff that extend to a depth of several meters below the surface, and where not oriented parallel to the slope, extend at least 2 to 3 meters from the slope face. Although joints exposed in natural cliff-dominated upper slopes do not contain any material (open joints), joints exposed by human activity contain several types of materials. In contrast to the soils on the surface, calcium carbonate coats the walls of several of the fractures. The carbonate is up to several millimeters thick and occurs on fractures exhibiting vertical to subhorizontal orientations. At a depth of several meters below the surface, the joints are up to 15 cm thick, and the joint-filling material also includes carbonate as well as reddish clay. These materials exhibit features (lamination, platy structure) that resemble weak stratification that is oriented generally parallel with the joint wall. The thickness of some joints increases significantly with shallower depth. One joint observed in this area is almost a meter thick near the surface and is 50 cm thick at a depth of approximately 3 meters. This joint contains massive, slightly indurated calcium carbonate and large, blocky coarse clasts of tuff.

The hillslopes immediately below the mesa surface are generally steep, cliff dominated slopes that have formed in an indurated part of the ash flow unit. Further downslope, the slope is underlain by a less indurated volcanic tuff; consequently, the slope angle is significantly shallower. On the north-facing slope, above Pueblo Canyon, at this slope position, poorly sorted, locally boulder colluvium locally mantles the slope. A shallow pit excavated in these materials shows that the soil is very weakly developed, exhibiting the following field properties: The horizon in the uppermost 20 cm is light brownish gray color (10YR 6/2), soft (dry), weakly granular and non effervescent loamy sand containing many fine roots. These characteristics indicate that this is a transitional AC horizon that overlies the C horizon in the parent material colluvium that is an additional 20+ cm thick, composed of light gray (10YR 7/1) non effervescent, locally bouldery to granule-rich coarse sand with common medium roots.

Further downslope, slope angle diminishes, and the thickness of slope-mantling colluvial deposits appears to generally thicken. Also, small drainages are locally incised a few meters into some of the slope deposits. Field observations suggest that this colluvium generally grades to fluvial deposits that underlie terraces associated with Pueblo Canyon. A soil exposed in this colluvium exhibits the

following characteristics based on very limited observations: the uppermost 10 cm is tentatively identified as an A horizon, soil material between 10 to 40 cm depth exhibits weak subangular blocky structure, indicating the presence of a Bw horizon. Below this depth, the soil parent material (C horizon) consists of loamy sand. The soil is noncalcareous.

3.1.3 Discussion and Summary

Soils on the surface of the tuff, in the area of C-19-001 are interpreted to be the remnants of once much thicker and well developed soils that are present on geomorphically more stable parts of the Pajarito Plateau. Such soils are as thick as 100 cm and have reddish, clay rich Bt horizons. The presence of subrounded clasts in Bt horizon strongly suggests that much of the soil developed mostly in alluvial deposits and not directly in the tuff itself. This relationship can be observed unambiguously at sites in TA-69, where the shape of the deposit (lens shape reflecting broad channel geometry), and the nature of base of deposit (abrupt contact with very weakly weathered tuff) reflect the alluvial origin of the soil parent materials. The TA-19 site once was part of more extensive mesa that characterized by significantly less local relief; presumably these were the conditions that favored deposition of such sediments. However, as Pueblo Canyon and other large tributaries became deeply incised in the Pajarito Plateau, sites such as TA-19 became far less geomorphically stable, subject to increasing erosion by sheet wash, or perhaps periodically rilling, stripping of soils as low-order tributaries became established below the increasingly isolated remnants of the mesa and on the mesas themselves.

Below the cliffs, the degree of soil development in colluvial deposits indicates that the soils have formed in relatively young colluvium, probably of late Holocene age. The basis for this age estimate is provided by radiocarbon dating of soils formed in alluvial deposits that occur just below the plateau surface near the E.G. and G. facility that is located only a few km from TA-19. These deposits yield radiocarbon ages of over 4000 years B.P. and exhibit soils with stronger development (McDonald and others, 1994) than the colluvial soils observed at TA-19; so it can be inferred that since conditions of soil development are not substantially different, the colluvial soils observed at TA-19 must be somewhat younger than the alluvial soils. The soils further downslope, however, are more well developed, showing that they are slightly older age than the

soils further upslope. However, it is unlikely to be much older than Holocene in age given the overall weaker degree of soil development as compared with soils developed in deposits of Pleistocene age (such as the El Cajete Ash Fall, or older alluvial terraces in the LANL area).

The material that fills some of the fractures in bedrock exhibits characteristics that suggest that some of the material has been derived from soils developed in the materials that overlie the tuff and not by alteration of the tuff itself by throughflowing water. The research of D. Davenport (1994) and P. Eberly (unpublished laboratory reports), utilizing detailed microscopic examination of thin sections of the material and fracture wall tuff and chemical and mineralogic analyses, strongly support this interpretation. The precise mechanisms of genesis of these materials, timing of its deposition, as well as the reasons for deposition of the compositionally different joint-filling materials, however, are unclear. However, the presence of course, angular material in the upper parts of some fractures is suggestive of periods of rapid infilling of fractures that became abruptly wider, whereas the finely laminated morphology of clay, carb suggest deposition over a much longer period of time in much more restricted, narrower, joints not directly subjected to surficial processes of erosion.

3.2 TA-26

3.2.1 Introduction

The former TA-26, located within the present boundaries of TA-73, is located near the east end of a finger of Los Alamos Mesa bounded by Los Alamos and Pueblo Canyons. The area considered for environmental studies as part of the LANL ERP is designated as the D-site, and includes several SWMUs: 26-001, 26-002a, b, and 26-003. For detailed descriptions of site physical and historical characteristics, refer to Aldrich (1992).

3.2.2 Observations

In many respects, the geologic and geomorphic character of TA-26 are similar to those at TA-19, although the slopes subject to disposal of waste materials face south, rather than north as is the case at the former TA. Reconnaissance investigations on the mesa surface indicate that it has been heavily disturbed due to extensive construction, roadbuilding, and excavation activities. Several small pits were excavated in the area of the former vault. These pits

revealed about 3 to 4 cm of loose, loamy sand that contained occasional fragments of quartzite, which is clearly lithologically exotic to this site. In some cases, this material directly overlies indurated volcanic tuff; however in other cases, it overlies up to 10 cm of reddened, clay-rich material inferred to be remnants of the Bt horizon. In some cases, the uppermost materials seem to be mixed, perhaps the result of reworking and bulldozing of the soils associated with construction activities at the site. Thus, good exposures of the soils formerly present in the area of the remains of the vault at TA-26-1 could not be found. However, an excellent exposure of what is mostly the original mesa surface occurs on the north side of State Highway 502, located approximately 100 meters east of TA-26-1. Geomorphologically this site is analogous to the area of the vault, and accordingly many aspects of the soils originally present (which may now be either buried or possibly stripped during active occupation and use of the site) are likely to be similar.

At the highway soil exposure site, a Bt horizon that is approximately 60 cm thick is present. The uppermost few dm have probably been removed due to roadbuilding activities and/or erosion, so the original nature of the A horizon cannot be evaluated. The Bt horizon is noncalcareous and exhibits brown (7.5YR 5/3) color and well developed subangular blocky structure. These attributes, considering the hard dry consistence, indicate a relatively high clay content and suggest that the horizon would probably qualify as an argillic horizon. The Bt horizon also contains subrounded clasts composed of volcanic tuff that have a strong brown (7.5YR 5/6) color, which contrasts with the typically much less reddened, pale color of the unweathered volcanic tuff, showing that these clasts have been oxidized during soil development. The lower boundary of the Bt horizon is abrupt, in contact with the Bandelier Tuff. Locally the lowest part of the Bt horizon apparently has the highest clay content observed throughout the Bt horizon and is associated with angular blocky structure. In addition, this part of the Bt horizon contains dark mottles of unknown origin. The uppermost part of the volcanic tuff is altered as indicated by reddened colors and the tuff is strongly jointed. Some of the joints contain calcium carbonate.

South of the area of the former vault, approaching the canyon walls, the area of exposed bedrock increases significantly. The increased areal exposure of bedrock can be attributed to natural erosional processes; however at one site, the overlying material had clearly been stripped, presumably through some type of bulldozing activity. The purpose of the activity may have been to provide a supply of fill material that subsequently was shoved over the side of

the canyon to bury downslope waste materials which are described in more detail later in this section. The stripping exposes the joints in bedrock, which in many cases are filled with calcium carbonate. In some areas the bedrock surface also is coated by calcium carbonate. Joints located 6 to 10 meters from the canyon rim are a maximum of 2 cm thick, contrasting with the wider diameter of joints observed at the canyon wall here and the joints observed at TA-19.

At the east side of TA-19, a small gully with an east-west orientation is present, thereby draining runoff away from the canyon walls located immediately south of this site. Such drainages are important to note, as their presence demonstrates that not all surface erosion generates runoff directed towards the nearest cliffs; rather, much sediment drains toward the east, a situation observed in the area of the E.G. and G. site, where several meters of alluvium have accumulated in similarly oriented but larger channels that have yet to descend to elevations significantly lower than the mesa surface.

The area of canyonside disposal (26-001) is located immediately on a bench formed in less indurated materials that is present beneath the steep cliffs formed in a more indurated unit of an ash flow tuff. At this site, numerous man-made materials cover parts of the slope, some exposed by erosion of fill material presumably intended to bury these materials. Reconnaissance along the bench revealed an area below a large powerline not subject to these disposal activities. This site exhibits features similar to those that existed in the disposal area previous to dumping, etc. at the site. Here, the bench is mantled by a largely fine grained colluvial mantle that contains occasional coarse angular blocks of indurated volcanic tuff. The fine grained colluvium consists of non effervescent, light brownish gray (8.75YR 6/2) loamy sand. The thickness of these materials is up to 10 cm, and no discernable soil development in the unit was recognized. Near the lip of the bench, bedrock is exposed in which several, large, open joints are present.

3.2.3 Discussion and Summary

As at TA-19, soils on the mesa are inferred to have been much thicker and more extensive in the past, but processes of natural erosion have eliminated much of the soil and in some places all of the soil, exposing volcanic bedrock. More recently, human activities have resulted in removal and/or modification of the surface soils due to a variety of activities, although in many areas, much of the soil is still extant, albeit significantly thinner. The lack of soils near the canyon

rims is attributed to natural erosional processes, and as described above, the presence of materials filling joints in the bedrock is hypothesized to be directly related to the former presence of soils above the joints.

In marked contrast to the geomorphic character of the north-facing slopes at TA-19, the south-facing slopes at TA-26 are generally much steeper and consequently harbor considerably less colluvial material, at least on the uppermost 30 to 50% of the canyon walls. What colluvium is present is quite thin, restricted to deposition on lithologically controlled benches of limited areal extent. The lack of soil development in the colluvium shows that it is quite geologically young (latest Holocene), demonstrating that storage on such benches is rather transient. This soil-geomorphic contrast presumably reflects largely site aspect, which influences the degree and magnitude of diurnal heating of the soils and, consequently, soil moisture regimes and processes and intensities of mechanical/chemical weathering. These differences in turn result in different magnitudes of production and nature of colluvial materials on the slopes that reflect relatively xeric conditions on south-facing slopes and more mesic conditions in north-facing slopes.

3.3 TA-73

3.3.1 Introduction

TA-73 includes current and former operational structures located in what is now the facilities associated with Los Alamos Airport. It also includes a former landfill used by the DOE and Los Alamos County. As with TA-19 and TA-26, TA-73 is located on Los Alamos Mesa east of the city of Los Alamos. It is bounded by Pueblo Canyon on the north, and DP Canyon on the south. The physical, geological, and historical characteristics of TA-73 are described in detail in Adrich and others (1993). TA-73 includes several SWMUs, including TA-73-001a,b,c,d, -002,-003,-004a,b,c, -005, and -006. In addition, it includes an area of concern, C-73-001,-002,-003, and-004.

3.3.2 Observations

In the area of 73-001c (at the east end of the runway), a few small gullies have formed a few meters beyond the eastern terminus of the asphalt runway. The material exposed in the gully is light brown (7.5YR 6/3) noncalcareous, slightly gravelly sandy loam. The

gravel consists of angular volcanic tuff. Soil development is not present in this material and fragments of ceramic materials, such as tile, show that this material is some type of artificial fill. North of this area, closer to the canyon rim, several types of materials are present partly buried within the exposed surficial materials, including fragments of concrete, asphalt, and gravel composed of exotic lithologies (ie., not volcanic tuff), also showing that this material is artificial fill.

A fence has been constructed near the canyon rim above Pueblo Canyon; presumably it encircles the entire airport facility. Approximately 10 meters before the airport boundary fence is encountered (still within the airport), the fill terminates and the Bandelier tuff is exposed. Locally, as at TA-19 and TA-26, pockets of clay rich, reddish brown (5YR 4/4) material is present above the tuff bedrock, which are remnants of the Bt horizons of formerly thicker soils developed on the mesa top. The advanced degree of development of these soils is shown by the strong subangular blocky structure of the soil material as well as the presence of many moderately thick clay films on the bedrock surface. A road is present immediately adjacent to the fence and within the airport. Excavation of the road exposes the bedrock to a about a depth of one meter, which is slightly weathered. On some parts of the bedrock surface, lichen colonization is present and some lichen thalli are moderately large. Also in this general area, trash (rebar, styrofoam, cans, paper, concrete fragments, rubber, plastic) is found everywhere lying directly on the bedrock surface.

At the eastern end of the airport, the character of the exposed surficial materials (crushed Bandelier Tuff and admixed asphalt) shows an artificial fill extends to within 3 meters of the boundary fence. The toe of the fill materials is characterized by a relatively steep slope; observations here indicate that the fill is at least 2 meters thick, at other locations the fill may be at least 4 meters thick. The mesa surface beyond the boundary fence slopes approximately 10 degrees to the east towards a small tributary canyon. Thus, the thickness of the fill at this location appears to be the result of fill emplacement designed to enable lengthening of airport runway. The fill material is cut by numerous gullies, and rusted sections of pipe and locally concrete fragments are exposed at the surface.

In the area of the airport where four hangars are present, 0.1 mile east of the terminal and near 73-001a and d, virtually all of the surface is covered by asphalt or fill material, preventing examination of soils. Approximately 100 to 150 meters east of the

easternmost hangar, however, an area bordered by the airport boundary fence that was subject in the past to excavation activities is present. Here the fill, which appears to consist largely of crushed Bandelier Tuff, is exposed immediately overlying the Bandelier Tuff itself. Also a linear structure, perhaps a former leach line or outfall related to a septic system, is present, excavated in the tuff and extending to the rim of Pueblo Canyon. A good exposure of the residual, reddened Bt horizon locally overlying the tuff is present as well as carbonate- and reddish clay-infilled joints. Some pale, light-colored material that does not effervesce upon exposure to dilute hydrochloric acid occurs in the joints. The composition of this material is not known.

Below the rim of Pueblo Canyon, the slopes exhibit characteristics generally similar to those observed at TA-19. Locally moderately thick colluvial deposits in which weakly developed soils are present occur below the steep cliffs that mark the uppermost part of the indurated part of the ashflow. The colluvium appears to grade to fluvial terraces present above the main stream of Pueblo Canyon.

3.3.3 Discussion and Summary

In general, many aspects of the soil-geomorphic relations observed at TA-73 resemble those observed at TA-19 and TA-26. However, a much broader part of Los Alamos Mesa occurs here in contrast to the mesa widths associated with the former TAs. Accordingly, it is very likely that much thicker soil remnants are present in the landscape now largely covered by artificial fill or other materials, unless it was mostly stripped before burial by the fill. The presence of small rills and gullies in the exposed fill and the presence of fill material exposed on bedrock exposed beyond the fill margin clearly show that the fill has been subject to erosion and modification by surface water. The presence of lichen on bedrock outcrops near the canyon rim indicates the stability of these sites insofar as surface erosion is concerned, as lichen can only form in a stable subaerial environment. Nevertheless, the presence of colluvially mantled north-facing slopes below the rim show that significant removal of materials from the upper parts of the bedrock dominated, steep slopes has occurred recently. This material is temporarily stored as colluvium on lower, more less steep hillslopes; however, the presence of weakly developed soils in the colluvium indicate a relatively young age for this material and that storage times of colluvium on the slope do not exceed more than a few

thousand years, and is probably even less than this. The abundance of colluvium on the northfacing slopes at TA-73 and TA-19 in comparison with the lesser amounts on the generally steeper southfacing slopes observed at TA-26 strongly suggests aspect-related, geomorphologically distinct slope-forming processes are an important factor in the LANL area.

As at TA-19 and TA-26, joints in the tuff observed at TA-73 are filled with materials such as carbonate and reddish clay-rich sediment. As suggested previously, these materials are not largely the result of chemical weathering of the adjacent fracture walls, but instead reflect the transport of pedogenic materials from overlying soils into the subjacent joints. Joints exposed on unmodified outcrops on cliff walls are often open; however, these joints may well have been filled with either clay, carbonate or other material prior to exposure at the surface and removal of material by surface flow or sapping.

3.4 TA-0, SWMU Aggregate 0-D

SWMU Aggregate 0-D includes SWMUs 0-0011 (a,c,d, and e) and Area of Concern C-0-020(see Aldrich and others, 1992). The areas are located in Rendija and Bayo Canyons. These areas represent chiefly either known or suspected mortar impact areas.

3.4.1 TA-0-011a

3.4.1.1 Introduction

TA-0-011a is located east of the Sportsmen's Club firing range in Rendija Canyon. Soil-geomorphic observations were focussed at several sites designated 00-1201 to 00-1218. Most sites are located on the south side of Rendija Canyon road, but a few sites were also located on the north side of the road. The locations of these sites, flagged and staked by a team of environmental scientists, were made on the basis of geomorphic mapping and surface sampling plans described in Aldrich and others (1992).

3.4.1.2 Observations

Site 00-1202: Very recent fluvial deposits are present at this site that have accumulated in an approximately 1.5 meter deep, recently formed gully. These materials consist of brown (10YR 5/3) poorly sorted, noncalcareous, nongravelly loamy sand (very slightly

sticky and slightly plastic wet consistence). A moderately well developed soil was exposed in the walls of the gully at this site, showing the nature of soil developed in the valley fill deposit that is present over much of the area of this site. The uppermost 50 to 75 cm of the gully wall consists to massive, nonstratified material inferred to be agriculturally mixed, stirred A and upper B horizon materials. Below these deposits, undisturbed BA and Bt horizons are present. The total thickness of these two horizons is at least 75 cm deep. The presence of rounded clasts of volcanic tuff show that the parent material of the soil is alluvial gravelly sand. The BA horizon exhibits light brown (7.5YR 6/4) color. The Bt horizon is even redder, exhibiting a light reddish brown color (5YR 6/4) color as well as having hard dry consistence and sticky plastic consistene of a clay loam. Dark coatings on some ped faces indicate the presence of mangans (manganese rich pedogenic material).

Site 00-1203: This site occurs in a broad swale in the valley floor. The valley deposits appear to grade to the walls of Rendija Canyon. The materials in the broad swale have a brown color (7.5YR 5/2) indicating the presence of at least some organic materials that produce the observed darker color.

Site 00-1204: This site occurs in a broad, erosional swale the maximum depth of which is approximately 0.5 meter. Sediment in the swale is slightly sticky, slightly plastic loamy sand that is slightly redder than the swale sediment observed at 00-1203.

Site 00-1205: This site occurs in a 1.2 to 1.5 meter deep gully that has formed in the valley fill alluvium. The gully fill is a sandy loam. Up the gully bottom, the gully depth increases. The gully wall consists of locally coarser, angular material, inferred to represent colluvial material derived from local valley slopes.

Site 00-1206: This site occurs in a 10 meter wide, approximately 1 meter deep swale.

Site 00-1207: This site occurs in a 10 meter wide, approximately 0.5 meter deep swale. The swale-filling sediment is loose, loamy material that contains many fine roots.

Site 00-1208: This site occurs in a broad swale eroded in valley fill alluvium.

Site 00-1209: This site occurs in an approximately 2 meter deep, 4 meter wide gully that appears to have been modified or at least partly excavated by human activity. A large pine, estimated to be at least 50 years old, is growing in the channel.

Site 00-1210: This site, located about 20 meters down channel from site 00-1209, is present in a 2-to-3 meter-deep gully. The gully at this location is oriented approximately parallel to axis of Rendija Canyon. Exposure of materials in gully wall demonstrate the presence of older, bouldery valley alluvial-fill unit. A boulder exposed on gully floor exhibits lichen growth cover. Large pines grow on the channel bottom.

Site 00-1211: This site, located about 20 meters down channel from site 00-1210, occurs in the same gully as the latter site.

Site 00-1212: This site, located about 30 meters down channel from site 00-1211, is located in the same gully as the latter site. The floor of the gully at 00-1212 is approximately 5 meters wide. A 5 meter tall juniper has germinated in the channel, and a large ponderosa pine is growing a foot above the base of the channel. A small, discontinuous channel system occurs on the gully floor, which is covered by a thin layer of pine needles. Boulders in the channel are covered by lichen.

Site 00-1201: This site is located on the valley floor surface that has a 2 to 3 degree slope on the north side of Rendija Canyon Road. The site appears to have been forested at one time, as pine woodland exists only 10 meters north of this site, which is covered by weeds. The uppermost few cm is inferred to be a mixed, agriculturally modified Ap horizon which overlies a Bt horizon with light brown (7.5YR 6/4) colors.

Site 00-1217: This site is located in a small, first-order drainage formed in the hillslope present just north of the stable valley floor surface on which site 00-1201 is located. This slope formed due to incision of the main channel of Rendija Canyon through the main valley-filling alluvial deposits. The material in the drainage is recently accumulated dark sediment, containing abundant organic litter.

Site 00-1216: The site is located in a 2-to-3-meter-deep first-order drainage line, approximately 10 meters from 00-1217

(horizontally, along slope). Material in the drainage floor is light brown (7.5YR 6/4) and contains some organic materials, and has less clay than the much older alluvial fill material that underlies the slopes in which the drainage line is eroded. The latter material is brown (7.5YR 5/4). Also, large pines, estimated to be at least a few decades old, grow in (and probably germinated in) the drainage lines.

Site 00-1215: This site is located near the base of a first-order drainage in which 00-1216 is located, and about 3 to 4 meters topographically above the tread of a terrace associated with what presumably is the main channel draining Rendija Canyon. A small pit excavated at this site revealed a one-centimeter-thick O horizon, a 10-centimeter-thick C horizon, and a 10-centimeter-thick darkened material, tentatively identified as a buried ABb horizon. The ABb horizon, in comparison to overlying C horizon, exhibits more clay rich consistence.

Site 00-1218: This site is located at the toe of the toe of the slope formed by incision of main channel into the main valley fill of Rendija Canyon, topographically about one meter above the tread of the low terrace associated with the main channel. A small pit shows that a cumelic A horizon is forming the the sediments accumulating at the site.

Site 00-1214: This site characteristics here are similar to those described at 00-1218. Here, however, pedogenically unmodified materials (C horizon) are present.

Site 00-1213: This site is located near the base of a first-order drainage in the hillslope that rises above the main channel of Rendija Canyon. The material is gravelly (cobbles to granules) loamy sand, overlain by a 1 centimeter, conifer-needle-rich gravelly lag. Some larger boulders are present in the drainage that are covered extensively by lichen.

3.4.1.3 Discussion and Summary

Site investigations indicate five major soil-geomorphic settings characterize areas where sampling activities have been conducted: (1) Thin (< 20 cm thick) pedogenically unmodified very recent fine-grained sediment deposited in shallow swales or channels inset into Holocene (?) fluvial deposits or into an older Pleistocene gravelly to

bouldery fluvial/debris flow deposit. (samples 00-1202,-1203,-1207,-1208, -1209)

(2) Very thin (<2 -3 cm?) very recent pedogenically unmodified fine-grained sediment deposited in shallow swales or in broad channels inset into Holocene (?) fluvial deposits or in an older Pleistocene gravelly to bouldery fluvial/debris flow deposit. The latter deposit is variably pedogenically modified, ranging from weakly to strongly pedogenically modified (locally residual remnants of an reddish clay-rich argillic horizon). (00-1204,-1205,-1206,-1210,-1211,-1212)

(3) residual moderately to strongly developed soil on an older Pleistocene (?) gravelly fill terrace surface, possibly partly modified by agricultural activity. (00-1201)

(4) Thin (<10cm) thick very recent pedogenically modified fine-grained sheetwash sediment derived from erosion of deposits underlying the Pleistocene (?) fill terrace that have accumulated in 1st-order drainages on moderately steep hillslopes. (00-1217,-1216,-1215,-1213).

(5) Organic-rich, fine-grained cumulic A horizon formed in toeslope deposits that have accumulated at the base of moderately steep hillslopes formed on remnants of the Pleistocene terrace. (00-1218,-1214).

Sediments in low-relief swales may be derived from both upswale positions, or from swale slopes directly above sample sites. Dark colors of many swale deposits is attributable to erosion of sediment from source areas in which organic material accumulation in surface A (and rarely O) horizons are present.

3.4.2 TA-0-011e

3.4.2.1 Introduction

TA-0-011e is located in Rendija Canyon on the opposite side of the channel and a few tenths of a mile upchannel from the Sportsmen's Club. Several sites for sampling and subsequent laboratory analyses were located in 0-011e, either in the channel itself, or in first-order channels formed in the south-facing slopes above the canyon, or in colluvial materials that mantle these slopes.

3.4.2.2 Observations

Site 00-1225: This site is located in a second- or possibly third-order channel that occurs just below the foot of the steep south-

facing slopes above Rendija Canyon. The sampled material is pedogenically unmodified channel material consisting of gravelly sand.

Site 00-1224: This site is located about 100 meters up-channel from 00-1225. The sample environment is the same as that noted for 00-1225.

Site 00-1223: This site is located on a first- or possibly second-order drainage line on the slopes that lie immediately below the steep cliffs above Rendija Canyon. The sampled material is recently deposited colluvium. One adjacent slope of the drainage is underlain by weakly stratified steeply dipping, unwelded tuffaceous materials that are apparently graded to or near the present canyon floor. These are either minimally modified colluvial materials, or some sort of primary air fall material that filled the canyon. The opposite slope is mantled by coarse colluvial boulders of Bandelier Tuff.

Site 00-1222: This site is located about 100 meters below the steep cliffs of the south-facing canyon walls of Rendija Canyon. The sampled materials are pedogenically unmodified interboulder sandy granule matrix that contain few roots.

Site 00-1221: This site is located on the same slope as that on which 00-1222 is located. The sampled materials are granules and sandy colluvial materials deposited on the upslope side of larger colluvial boulders. Some grasses, cacti, and small woody plants are growing at or in the vicinity of this site that has resulted in the development locally of a very weak, thin A (Ochric) horizon with many fine roots.

Site-00-1226: This site is located in the active channel in which sites 00-1225 and 00-1224 are located, but about 50 or more meters downchannel of those sites. The sampled material is gravelly sand very recently deposited in the channel.

3.4.2.3 Discussion and Summary

Site investigations indicate two major soil-geomorphic settings characterize areas where sampling activities have been conducted:

(1) Second or possibly third order channels in which pedogenically unmodified, gravelly sandy sediment has recently accumulated. (00-1225,-1224,-1226).

(2) Recently deposited, pedogenically modified angular gravelly to sandy colluvium deposited in swales on steep hillslopes present below steep cliffs formed in the more resistant members of the Bandelier Tuff.

3.4.3 TA-0-011d

3.4.3.1 Introduction

TA-0-011d is located just east of San Ildefonso Dr., approximately a tenth of a mile north of Diamond Drive. A few sites were located for subsequent sampling and analysis as described in Aldrich and others (1992).

3.4.3.2 Observations

A few sites were selected for sampling that were located in a small channel that drains the primarily south-facing slopes. The channel materials consist of pale, poorly sorted loose channel sediment that ranges in thickness from a few cm to as much as 10 cm. This material overlies a substantially darker layer, here inferred to be an A (Ohric) horizon.

3.4.3.3 Discussion and Summary

Site investigations indicate one major soil-geomorphic setting characterizes areas where sampling activities have been conducted: Very recently deposited, pedogenically unmodified pale sandy sediment of variable thickness (2-10 cm thick) which overlies a weak A horizon formed in older channel fill alluvium.

3.5 TA-O-016

3.5.1 Introduction

SWMU 0-016 is an inactive firing range located west of Guaje Pines Cemetery in Rendija Canyon. Physical characteristics and historical attributes of the site are described in Aldrich and others (1992). Several sites were chosen for sampling to document lead

concentrations related to bullet debris according to plans also described in this document.

3.5.2 Observations

One of the sites located in an area that had been determined through previous field studies as being unmodified by activities associated with the firing range is Site 0-1421. A soil at this site was described to provide some data to use to determine potential background concentrations of lead. The soil at this site exposed in a hand-dug pit displayed the following characteristics-- 4 to 0 centimeters: O horizon, composed largely of weakly to moderately decayed pine needles and oak leaves. The amount of mineral material in the horizon is essentially zero at the surface of the horizon, but increases slightly with depth. 0 to 3 centimeters: A horizon, consisting of noncalcareous, light brownish gray (10YR 6/2) fine loamy sand that is very slightly sticky and nonplastic when moistened (wet consistence). The structure is weak coarse granular to medium granular and the horizon contains plentiful fine roots. The lower boundary of horizon is smooth. 3 to 18 centimeters: Bt1 horizon, consisting of light gray (7.5YR 7/2 dry; 7.5YR 5/2 moist) noncalcareous loam (sticky, plastic wet consistence). The horizon contains few granules and pebbles of volcanic tuff, has plentiful fine tubular pores, weak medium subangular blocky structure, and is slightly hard when dry. The lower boundary of the horizon is abrupt and probably smooth. 18 to 25 cm+: Bt2 horizon, consisting of reddish brown (5YR 4/4) noncalcareous clay loam with strong, subangular blocky structure, contains strongly weathered fragments of volcanic tuff.

Site 0-1417: This site is located on a 5 to 10 degree slope, topographically approximately 10 meters below the position of site 0-1421. The soil at this site has a 5 cm-thick O horizon, a weakly developed A horizon, a pale Bt horizon, and a strongly developed Bt horizon at a depth of approximately 20 cm. The parent material of the soil appears to be colluvium.

3.5.3 Discussion and Summary

The soils described at sites 0-1421 and 0-1417 are relatively strongly developed soils. The soil at 0-1421 is probably developed in materials deposited on the tuff in a manner similar to that proposed in descriptions of mesa-top soils described previously in this report.

The soil at site 0-1417, in contrast, formed in materials eroded from the stable summit and redeposited on the slope as colluvium; thus the degree of the development may owe to the possibility that some of the soil material has been inherited from previously extant, well developed soils.

4.0 Ongoing Soil-Geomorphic Studies in the LANL Area

4.1 Introduction

As mentioned in section 1.2 of this report, several soil-geomorphic and soil-genetic studies have been conducted recently or are in progress that provide information critical in the interpretation, analyses and evaluation of soils that occur in TAs described in this report. Accordingly, brief summaries of these studies are included in order to (1) demonstrate the basis for certain conclusions and interpretations noted previously in this report, and to (2) help support recommendations concerning future investigations at these and other SWMUs, given the general applicability of the results of these studies to the larger LANL area.

4.2 Soils of the LANL area: Morphology, Chemical and Mineralogical Composition, and Relation to Contaminant (Trace elements + radionuclides) Behavior in the Pedologic Environment

Twenty two soils in the LANL area have been described as part of a study to document the physical and chemical properties of soils that occur in the landscapes of this region (Watt and McFadden, Watt and others, 1994). Soils were described in diverse climatic and topographic settings and in different types of parent materials and land surfaces of differing ages. Soils were also located in areas with similar properties to those located at past or potential waste disposal sites or in SWMUs identified in LANL reports. Thus, this data enables development of background soil properties to be formulated that can be compared with samples from soils studied in contaminated sites. The field properties of the soils are described at each site enabling field morphology to be characterized and to guide soil horizon based sampling. Laboratory analyses included textural analysis (particle-size distribution), physical analysis (bulk density), and chemical and mineralogical analyses (pH, iron oxide content and mineralogy, clay mineralogy, oxide-element bulk composition, calcite

content, electroconductivity, organic matter content, and cation exchange capacity/exchangable cations).

Data from the uncontaminated sites show that the soil properties of soils in LANL landscapes exhibit significant variability and complexity, an aspect of LANL area soils documented by Nyhan and others (1978). Some soils have formed in alluvial/colluvial parent materials deposited atop the youngest member of the Bandelier Tuff and are quite strongly developed, perhaps having an age as old or older than several hundred thousand years (such as the mesa top soils at TAs 19,26,73). Soils have also formed in much younger deposits, however, including the 0.5 to 1.5ky old El Cajete Ash that locally blankets the Pajarito Plateau, latest Pleistocene/Holocene fine grained loess, or younger fluvial and colluvial deposits in channels and canyons incised into the Pajarito Plateau (such as soils observed at settings identified throughout TA-0). Also, soils have formed at altitudes that range over nearly a thousand feet, which indicates soil development under significantly different climates, as suggested by meteorologic data that exhibits a strong gradient in climate closely correlated with altitude in the LANL area (see Aldrich and others, 1992). Soil formation under such diverse circumstances has resulted in significant ranges in the values of several key soil properties. For example, clay content, much of which is composed of smectitic clays, of soil horizons ranges from less than 3 % to over 63 %, carbonate content ranges from zero to greater than 29 wt. %, and U (IV, VI) content ranges from 2.17 to 6.73 ppm.

Positive correlations exist between many important soil properties and uranium/trace element concentrations. For example, strong correlations between uranium and both organic carbon and carbonate content are recognized. Primary (parent material) uranium in the soils appears to be associated principally with phases present in the volcanic glass component of the parent volcanic tuff. Mobile uranium, however, can be segregated from this immobile uranium through nitric acid leaching. In many soils, a correlation is evident between mobile uranium and cation exchange capacity; in contrast, mobile uranium and dithionite extractable iron (Fe present in ferric oxyhydroxide phases) are not correlated. Mobile uranium is also correlated with pedogenic carbonate or organic carbon content. These correlations demonstrate that sorption, complexation, and coprecipitation are processes acting in soils of the LANL area that control uranium distribution. The ability of a soil to affect the migration of uranium, as well as other trace elements, is strongly influenced by any or all of these processes. Another important conclusion from this study is that it shows that much of the uranium

in many of the "uncontaminated" soils is derived by chemical weathering of the volcanic parent material.

4.3 The Role of Aerosolic Dust and Important Aspects of Parent Material Composition in the Development of Strongly Developed Soils of the Pajarito Plateau

The soil map of Nyhan and others (1978) and the field studies of soils in the areas of TA-19, TA-26, and TA-73, and recent soils investigations in the LANL area summarized in this report show that strongly developed, locally thick soils possessing reddish, clay rich argillic (Bt) horizons are present over much of the Pajarito Plateau. On the basis of several types of evidence, the latter studies conclude that these soils have developed largely in alluvium deposited on top of the Bandelier Tuff and not largely in the tuff itself. This different interpretation strongly affects the interpretation of rates, magnitude and processes of pedogenesis based on chemical and mineralogical data from such soils. For example, numerous studies throughout the western United States show that the incorporation of eolian dust has very strongly impacted various pedogenic processes (Birkeland, 1984). Much pedogenic clay, carbonate, and Fe oxides accumulate in soils directly via entrapment and subsequent profile incorporation of these materials. Correct interpretations of soil-landscape relations and evolution, an important aspect of environmental evaluations largely relying on documentation surficial processes, require recognition of the major factors influencing soil profile evolution.

Eberly and others (1994) have developed a constitutive mass balance model to assess the impact of dust accumulation relative to chemical weathering and pedogenesis. To enable such modeling required identification of a chemically immobile constituent for use as a strain indicator. Detailed evaluation of whole rock compositions of the Bandelier Tuff from XRF and INAA analysis provided characterization of the soil parent material. XRF measurements of the less-than-2 mm fraction of soil samples provide soil horizon composition. Analysis of these data assuming only alteration of the Bandelier Tuff indicates that Zr and Al are essentially immobile in the soil. However, these constituents are present in dust, and presuming their incorporation in the soil, it must be the case that they are not immobile in the soil. A two-end-member mixing model for two constituents though to be refractory with respect to chemical weathering was simultaneously solved for the dust fraction and for change in mass during alteration. Elements Ti and Zr were assumed to be refractory. A post-Archeon shale composite composition was

used to represent aerosolic dust. Dust fractions in the soil calculated on the basis of this approach are consistent with particle size distribution analyses of Watt and others (1994). Generally, the data show that Si and alkali element removal is essentially balanced by eolian addition, and Al, Fe, Ti, Zr, Ca, Sr, and Ba are more enriched than indicated by modelling uncorrected for dust addition to the soils. Thus, evaluations of the composition of surficial samples of soils in the LANL region must take into account the admixture of materials incorporated in the soil over time; soil composition cannot be explained by a simple model entailing chemical alteration of Bandelier Tuff.

4.4 Soil-Geomorphic Evidence for Dynamic Landscape Evolution on the Pajarito Plateau

Recently, McDonald and others (1994), as well as those of Watt and others (1994) described above, have conducted soil-geomorphic investigations in several locations in the LANL area. These investigations clearly demonstrate that the Pajarito Plateau is not simply a stable plateau formed 1.2 Ma, subject to progressive weathering and soil development. In contrast, numerous sites display evidence of several periods of erosion and deposition throughout the Pleistocene and during the Holocene. For example, as noted above in several sections, the parent material for most of the soils atop the plateau is alluvium and not the tuff itself. Therefore, prior to incision of the major drainages to form the larger canyons in this region, substantial drainages occurred on the plateau that were characterized by periods of aggradation and stability. During times of stability, soil development occurred. The cycles may have occurred several times in the past 1.2 My; however, only one major cycle has been preserved in the soil-stratigraphic record. Sometime between 0.5 and 1.5 Ka, the El Cajete Ash fall resulted in burial of extensive parts of the plateau as well as major canyon slopes, channels, and other landforms; thick soils have developed in this deposit in the most stable parts of the landscape. In most parts of the LANL area, this unit has been eroded. Most recently, much of the Plateau has been buried by deposition of loess. A weak A/Bw profile in materials as thick as 20 to 30 cm has developed in the nongravelly loess.

Erosion of material from the Plateau surface provides sediment to channels that may accumulate to thicknesses of several meters in small basins located topographically above the steep cliffs of the upper parts of canyon walls. Some of the material may also accumulate as colluvium in the toeslope and footslope positions of

aprons that flank chiefly the north-facing hillslopes of the LANL area. The soils in these deposits exhibit characteristics that suggest a Holocene age for the aggradational events; radiocarbon dating of a few of these deposits yield Holocene ages (McDonald and others, 1994). The ultimate factor ultimately responsible for these erosion-deposition cycles may be climatic changes occurring at several frequencies during the Quaternary, or perhaps other factors are important, such as locally tectonics, volcanic processes, and complex-response dynamics. Nevertheless, the landscape of the LANL area is dynamic, and on a temporal scale ranging from tens of thousands to thousands of years, and perhaps centuries.

4.5 Joints and Joint-Filling Materials in the Bandelier Tuff: Relationship to Soils of the Pajarito Plateau

As noted in sections 3.1, 3.2, and 3.3, and has been noted in other studies of the LANL area, a significant fraction of the numerous joints in the Bandelier Tuff contain reddish clay, calcium carbonate, and occasionally other materials. The recent studies of Davenport (1993) focussed on analysis of the joint-filling materials at one site at LANL based on micromorphologic evidence (conventional microscopy, SEM) XRD data, and other conventional laboratory characterizations. On the basis of this data, Davenport concludes that the ultimate source of these materials are the overlying, well developed soils and that processes of subprofile translocation, not chemical alteration of the joint-wall materials accounts for the composition of the materials. Unpublished studies of Eberly at another site in TA-69 also strongly indicated that such materials are pedogenic in origin. At this site, the joints are both horizontal and subparallel and occur cm to dm from the base of the overlying Bt horizon in the slightly chemically altered tuff.

The precise nature and timing of the filling, as well as exact relationship, of the joints to timing and processes of soil development is not clear. However, as discussed in section, at least some evidence suggests different processes of joint-filling are related to changes in fracture width, availability of materials present above the joints, or perhaps joint orientation. The orientation of joints presumably reflects their origin. Many near vertical joints and intersecting near-vertical joint sets may reflect either flow cooling processes or tectonic processes related to faults that transect the Pajarito Plateau. However, the development of many joints that have orientations subparallel to nearby canyon walls or the ground surface may reflect processes of unloading and pressure release. Filling of shallow,

subhorizontally oriented joints may reflect a dilation driven process of joint expansion as smectitic clay is subjected to alternating shrink-swell cycles coupled with translocation of clay from adjacent Bt horizons. The presence of joints lacking infill material commonly observed in outcrop may be due to processes causing material removal as joint position progressively approaches the surface and is subjected to changes in percolation orientation and intensity. The presence or absence of joint-filling materials, as well as the composition of these materials, may well have significant implications for the depth and magnitude of transport of fluids that reach the vadose zone subsequent to penetration of meteoric water through overlying soils.

5.0 ERP Activities and Soils Investigations: Recommendations

All of the conceptual models that guide investigations of SWMUs in OU-1071 as part of the LANL ERP (Aldrich and others, 1992) include the term "soil" as either a significant secondary source of contamination, an important migration pathway of contaminants, or as a potential contact medium. As the information presented in this report demonstrates, soils in the LANL area are diverse, exhibiting varying degrees of development, composition, and ages; such diversity is observed in TAs that were the primary subject of investigations reported in this study. Soil-landform relations at different sites can be used as an aid in evaluating the relative degree of stability (recent rates and/or processes of erosion, ages of deposits/surfaces) at a given site. The proposed sample plans outlined in Aldrich and others (1992) for investigation of TAs-19,-26, and -73 (as well as SWMUs at other TAs in OU-1071) provide specific directions regarding geomorphic mapping of each site. Such mapping, assisted by and integrated with other planned activities described in this workplan (e.g., geophysical surveys and surface and subsurface sampling) should provide basic data necessary to assist in interpretation of critical aspects of soils encountered during these stages of investigations. Accordingly, these activities are regarded as sufficiently detailed and comprehensive to enable reasonable evaluation of soils encountered during initial investigations of these sites as ER activities progress.

However, as discussed in detail in this report, many aspects of soil development can clearly affect both migration and sequestration of important contaminants that may have been released at various SWMUs. Given these general as well as other more specific

conclusions regarding soils in the LANL area, the recommendations listed below are proposed with respect to anticipated investigations of SWMUs TA-19,-26,-73 and TA-0 in order to assist in identification, sampling, and subsequent analysis of surficial and subsurface soil materials encountered at these sites.

1. Sampling of surficial materials at SWMUs should be guided by an appreciation of the presence of and degree of development of soils and soil horizons present at a given site. Accordingly, samples of surficial materials should not be taken simply as, for example, a general "0 to 6" sample. Rationale:

- Where strongly developed, Bt horizons are present, the presence of locally clay rich materials may strongly influence potential contaminant migration (largely via surface exchange reactions), if the soils have been exposed to such materials. Surface sampling, accordingly, should be carefully keyed to key soil horizon development in order to permit evaluation of sample compositional data.

- Where calcic horizons (Bk) or organic material-rich soils occur (relatively darkened A horizons), sampling should be guided by careful identification of these horizons, given the affinity of these horizons for elements such as uranium.

- In sampling of channel materials to determine presence/absence of contaminants and assess distance of transport, the channel material should be carefully examined to determine degree of pedogenic modification or to determine if a buried soil is present at a shallow depth. The latter may well be the case in low-order tributaries at many SWMUs. As noted above, even relatively weak pedogenesis can strongly impact chemical composition, behavior of the surficial material. Inadvertent (and inappropriate) sampling of channel material and underlying, buried soil material will significantly affect measured concentrations of many constituents and thereby affect/modify subsequent evaluations.

- Colluvial materials sampled to determine transport of potential contaminants from topographically higher areas should be examined for presence or absence of soil development. The presence of even weak soil development shows that at least centuries of surface stability has occurred, information which will have significant

implications for evaluation of chemical data obtained through ER-related studies.

2. Evaluation of various chemical analysis of samples as part of ER activities should be informed by a basic understanding of pedogenic factors that can strongly influence composition of the material.

Examples:

- High uranium and other trace element contents may be strongly influenced by the sortive character of the soil. This character is strongly related to soil cation exchange capacity, which in the LANL area, is correlated with clay content and organic matter.
- High Arsenic content has been shown recently to be strongly correlated with high extractable Fe content (personal communication, P. Longmire, 1994), a relationship produced by selective sorption on surface sites of such elements; accordingly, As contents above SALs are have been measured that reflect normal processes in soil profiles that result in retention of such elements released by chemical weathering of parent material minerals over long periods of time.

3. Joints, many of which have clay and carbonate present as materials filling part or all of joint space, are present at TA-19, -26, and -73 as well as numerous other sites throughout OU-1071. As noted above, the presence of the joints themselves, their orientation, and the character of the fill has many potentially important implications for interpretation of past geomorphic and geohydrologic evolution of site as well as for future history. Accordingly, these aspects of the joints should be carefully documented when possible during site investigations that include both surface and subsurface studies.

4. At site TA-73, and potentially at other sites, surficial soils have been buried by artificial fill. The presence of such soils will have a profound impact on the migration/retardation of contaminant-bearing fluids originating from fill materials or from deeply infiltrating soil water that encounter these buried soils. Accordingly, where discovered by virtue of site investigation, such soils should be carefully described and sampled on a horizon basis prior to submitting the samples for subsequent laboratory characterization.

5. The degree of development and nature of soil-geomorphic surface/stratigraphic relations at a site provide key insights into the

implications for evaluation of chemical data obtained through ER-related studies.

2. Evaluation of various chemical analysis of samples as part of ER activities should be informed by a basic understanding of pedogenic factors that can strongly influence composition of the material.

Examples:

- High uranium and other trace element contents may be strongly influenced by the sortive character of the soil. This character is strongly related to soil cation exchange capacity, which in the LANL area, is correlated with clay content and organic matter.
- High Arsenic content has been shown recently to be strongly correlated with high extractable Fe content (personal communication, P. Longmire, 1994), a relationship produced by selective sorption on surface sites of such elements; accordingly, As contents above SALs have been measured that reflect normal processes in soil profiles that result in retention of such elements released by chemical weathering of parent material minerals over long periods of time.

3. Joints, many of which have clay and carbonate present as materials filling part or all of joint space, are present at TA-19, -26, and -73 as well as numerous other sites throughout OU-1071. As noted above, the presence of the joints themselves, their orientation, and the character of the fill has many potentially important implications for interpretation of past geomorphic and geohydrologic evolution of site as well as for future history. Accordingly, these aspects of the joints should be carefully documented when possible during site investigations that include both surface and subsurface studies.

4. At site TA-73, and potentially at other sites, surficial soils have been buried by artificial fill. The presence of such soils will have a profound impact on the migration/retardation of contaminant-bearing fluids originating from fill materials or from deeply infiltrating soil water that encounter these buried soils. Accordingly, where discovered by virtue of site investigation, such soils should be carefully described and sampled on a horizon basis prior to submitting the samples for subsequent laboratory characterization.

5. The degree of development and nature of soil-geomorphic surface/stratigraphic relations at a site provide key insights into the

past erosional/depositional history of the site. Important clues to past history of surficial processes, such as recency of dust deposition or most recent period of channel erosion, are provided by soil studies. Accordingly, a general recognition of significance of soils in environmental studies is a useful to guide ongoing investigations at a site; such information may be especially important when integrated with geohydrological information/modelling.

6.0 References

- Aldrich, M. J., Bowers, K. D., Brorby, G. P., Campbell, K., Charles, R. W., Coons, L. M., Filemyr, R., Harrington, C. D., Johnson, P. S., McFadden, L. D., and Stephens, D. B., 1992, RFI work plan for Operable Unit 1071; Los Alamos National Laboratory Report LA-UR-92-810 (M.D.Aldrich, editor and compiler), Los Alamos, New Mexico.
- Birkeland, P. W., 1984, Soils and geomorphology. Oxford University Press.
- Davenport, D., 1993,
- Eberly, P. O., McFadden, L. D., Watt, P. M., Longmire, P., and Broxton, D., 1994, Evaluation of the role of aerosolic dust in the evolution of a soil developed in rhyolitic alluvium atop the Pajarito Plateau, northern New Mexico, U.S.A. Geological Society of America Annual Meeting Abstracts and Programs, 1994.
- McDonald, E. B., Reneau, S. L., and Watt, P. M., 1994, Soil-landscape stability and potential contaminant transport, los Alamos National Laboratory, New Mexico. Geological Society of America Annual Meeting Abstracts and Programs, 1994.
- Nyhan, J. W., Hacker, L.W., Calhoun, T. E., and Young, D. L., 1978, Soil survey of Los Alamos County, New Mexico. LA-6779-MS Informal Report, UC-11. Los Alamos National Laboratory.
- Watt, P., and McFadden, L.D., 1993, Preliminary soil analyses from Los Alamos County. Unpublished Report Submitted to P. Longmire, CST-10 Group, Los Alamos National Laboratory.

Watt, P. ., McFadden, L. D., and Longmire, P., 1994, The impact of soil properties on uranium migration, Los Alamos National Laboratory. Geological Society of America Annual Meeting Abstracts and Programs, 1994.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.