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Natural Background Geochemistry and Statistical Analysis of Selected Soil Profiles, Sediments, and Bandelier Tuff, Los Alamos, New Mexico

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NATURAL BACKGROUND GEOCHEMISTRY AND STATISTICAL ANALYSIS OF SELECTED SOIL PROFILES, SEDIMENTS, AND BANDELIER TUFF, LOS ALAMOS, NEW MEXICO

Revision Date: September 28, 1995

by

Patrick Longmire, CST-7; David Broxton, EES-1; and Steven Reneau, EES-1
Editors

EXECUTIVE SUMMARY

The investigations compiled in this draft report describe elemental background concentrations for 24 analytes in soils, sediments, and the Bandelier Tuff at Los Alamos National Laboratory. Results of these investigations form the basis for statistical analysis for risk and screening analysis for the Environmental Restoration Project and are required as part of the RCRA corrective action process developed by the US Environmental Protection Agency (EPA). These investigations included studies of geochemistry, soil characterization, stratigraphy, and geomorphology. These investigations were conducted in support of the Resource Conservation and Recovery Act (RCRA) Facility Investigation for Los Alamos National Laboratory. Results of these investigations have relevance to all Laboratory field units and operable units.

The Wilcoxon rank sum test and box plots are used to determine if there is a significant chemical difference between soil horizons, sediments, and mapping units of the Bandelier Tuff. Values of upper tolerance limits (UTLs) in soils, sediments, and the Bandelier Tuff for naturally-occurring metals, nonmetals, and radioisotopes of K, Th, and U (excluding sediments) at the Laboratory are presented.

Approximately 250 background soil samples have been collected adjacent and within the Laboratory boundary. Soil samples were partially digested using HNO_3 and completely digested using HF, providing total element concentration, prior to analysis following EPA SW846 methods. Total element concentrations in 75 soil samples were also determined by x-ray fluorescence and instrumental and delayed neutron activation analysis. Background-elemental concentrations in soils on the Pajarito Plateau vary with parent material, the degree of soil development, and other factors. Well-developed soils containing B horizons have higher concentrations of trace elements than weakly developed soils found on the Pajarito Plateau. The B horizons in background soils generally contain higher concentrations of iron hydroxides, clay minerals, and trace elements relative to A and C horizons. No

additional Laboratory background data are needed for B horizons (134 samples) present on mesa tops; however, we recommend additional characterization of A and C horizons because a small number of samples (<30) are present in the data set for mesa top soils. We recommend that additional soil samples be collected and characterized from A, B, and C horizons for slope and canyon bottom soils.

Several soil profiles characterized on mesas at TA-63 and TA-67 contain anomalous concentrations of U within the several A horizons. These horizons apparently have received wind-blown U that possibly was derived from Laboratory firing sites. These U data collected from the A horizons at TA-63 and TA-67 are not included in the background-elemental data set for the Laboratory.

An initial 16 background sediment samples have been collected from Ancho Canyon and Indio Canyon at Technical Area 39. Systematic variations in elemental background concentrations in sediments occur between different geomorphic settings and different particle sizes. The lowest concentrations of most elements occur within coarse, well sorted sands in active stream channels and the concentrations of most analytes generally increase with decreasing particle size characterized by larger surface areas. These differences indicate that the best comparison of potentially contaminated sediments to background should utilize the most comparable subset of the Laboratory background data set. Analyte concentrations in sediments are generally lower than those associated with B horizons in soils, but are comparable to elemental concentrations within A and C horizons. We recommend that additional background sediment samples be collected and chemically characterized from several canyons at the Laboratory representative of the different geologic-geomorphic conditions.

A total of 251 bulk rock samples was collected to characterize the chemistries of bedrock units on the Pajarito Plateau. Total element concentrations were determined for 208 samples by x-ray fluorescence and 38 samples by instrumental and delayed neutron activation analysis to determine the chemical variability of the bedrock units. Based on these analytical methods, a representative suite of 106 samples was selected for analysis by EPA SW846 methods, using HNO_3 digestion techniques, for their leachable concentrations of inorganic analytes. The spatial coverage and population size of background chemistry samples for the Bandelier Tuff are considered adequate for defining background screening values for units Qbt 1g, Qbt 1v, Qbt 2, and Qbt 3 of the Tshirege Member. These tuffs are the most widespread rock units on the Pajarito Plateau and make up the bedrock at the majority of the Laboratory's potential release sites. No additional background data are needed for these units. We recommend additional characterization of Qbt 4 because so few samples of this unit are included in the present data set. Preliminary background screening data are presented for pre-Tshirege rock units (tephras and volcanoclastic sediments of the Cerro Toledo interval, the upper part of the

Otowi Member of the Bandelier Tuff, and dacitic lavas of the Tschicoma Formation); we recommend that these data be supplemented by local background data on an as needed basis.

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NATURAL BACKGROUND GEOCHEMISTRY AND STATISTICAL ANALYSIS OF SELECTED SOIL PROFILES, LOS ALAMOS, NEW MEXICO

by

Patrick Longmire, CST-7; Eric McDonald, EES-1; Randy Ryti, Neptune and Company, Inc.; Steven Reneau, EES-1; and Paula Watt, Univ. of New Mexico

ABSTRACT

During 1993, fourteen soil profiles were characterized and sampled to enlarge the background-elemental database (Longmire et al., 1995) for Los Alamos National Laboratory (hereafter referred to as the Laboratory). Prior to chemical analyses, soil samples are partially digested primarily using HNO_3 at pH 1, which provides element concentrations in acid-soluble solid phases such as calcium carbonate, solid organic matter, clay minerals, and ferric hydroxides. Aliquots of the same soil samples are also completely digested using HF, providing total element concentrations. These soil digestion procedures provide a comparison of elements incorporated within the primary silicate minerals (total digestion) with those elements concentrated in surface coatings formed during soil genesis (partial digestion). Analytical methods consisted of inductively coupled plasma spectroscopy, atomic absorption, and ion chromatography. In addition, several soil properties, including texture, bulk density, organic matter, cation exchange capacity, and extractable iron oxides, were analyzed using standard soil characterization techniques.

Approximately 250 background soil samples have been collected adjacent and within the Laboratory boundary. These samples have been analyzed for 24 metals and non-metals relevant to the Environmental Restoration Project. No additional Laboratory background data are needed for B horizons (134 samples) present on mesa tops; however, we recommend additional characterization of A and C horizons because a small number of samples (<30) are present in the data set for mesa top soils. We recommend that additional soil samples be collected and characterized from A, B, and C horizons for slope and canyon bottom soils.

Background-elemental concentrations in soils on the Pajarito Plateau vary with parent material, the degree of soil development, and other factors. Well-developed soils have higher concentrations of trace elements than weakly developed soils found on the Pajarito Plateau. The B horizons in background soils generally contain higher concentrations of iron hydroxides, clay minerals, and trace elements relative to A and C horizons. In addition, variations in soil-elemental concentrations are related to climate, topography, and to the parent

materials, which include alluvial fan deposits, sheet wash material, colluvium, wind-blown sediment, El Cajete pumice, and the Bandelier Tuff.

Soil profiles characterized on mesas at TA-63 and TA-67 contain anomalous concentrations of U within the several A horizons. These horizons apparently have received wind-blown U that possibly was derived from Laboratory firing sites. These U data collected from the A horizons at TA-63 and TA-67 are not included in the background-elemental data set for the Laboratory. The B and C horizons are less affected by the anthropogenic U and these horizons generally have U concentrations similar to other background soil horizons reported by Longmire et al. (1995).

Comparisons of site data to background data are needed as part of the Resource Conservation and Recovery Act (RCRA) corrective action process developed by the US Environmental Protection Agency (EPA). The Wilcoxon rank sum test and box plots are used to determine if there is a significant chemical difference between soil horizons. Results of statistical analyses, including calculation of a horizon-specific upper tolerance limit (UTL) for each element, are presented in this report. The UTL is equal to the mean plus the standard deviation multiplied by k-factors (one-sided normal tolerance factors), using the 95th percentile at 95% confidence. For elements that are normally distributed without any data transformation and the elements that are normally distributed after a square root transformation, UTLs were calculated using the following equation:

$$UTL_{0.95,0.95} = \text{mean} + \text{standard deviation}^* \, k_{0.95,\,0.95}.$$

The k-factor is dependent on the number of background samples. The UTLs for log-normally distributed elements are estimated by a simulation process. The calculated UTL results were screened to ensure that the estimated UTLs were not artifically inflated due to a small sample size. Site data greater than the UTL-calculated threshold value are considered to exceed the normal maximum background concentration for a particular element. Values of UTL in soils, including A, B, and C horizons, for naturally-occurring metals, nonmetals, and radioisotopes of K, Th, and U at the Laboratory are presented below.

Analyte	Soil Horizon A	B	C	All Data
Aluminum	26600	43600	38700 *	38700
Antimony	0.5	1	ND	1
Arsenic	6.99	8.12	6.58	7.82
Barium	263	321	286	315
Beryllium	1.41	1.91	1.95 *	1.95
Cadmium	1.4	2.7	ND	2.7
Calcium	4030	6480	5930	6120
Chlorine	25.0	78.2	170	75.9
Chromium	19.3 *	19.0	17.0	19.3
Cobalt	31.0	14.8	41.2	19.2
Copper	30.7 *	29.2	22.2	30.7
Iron	18100	21800	18500	21300
Lead	28.4	22.3	21.9	23.3
Magnesium	3460	4480	4610 *	4610
Manganese	1000	673	463	714
Mercury	ND	0.1	0.1	0.1
Nickel	12.2	16.0	13.3	15.2
Potassium-TOTAL	33200	33400	41800	35000
Potassium	3070	3420	3410 *	3410
Selenium	0.7	1.3	1.7	1.7
Sodium	602	798	2680	915
Sulfate	42.7	249	712	317
Tantalum	ND	ND	ND	ND
Thallium	0.4	1	0.6	1
Thorium	13.3	15.0	12.3	14.6
Thorium-TOTAL	20.5	22.7	25.3	22.6
Uranium	1.87 *	1.72	1.36	1.87
Uranium-TOTAL	5.10	5.34	6.58	5.45
Vanadium	42.8	42.0	32.0	41.9
Zinc	47.1	51.5	50.8 *	50.8

* Values were trimmed to the all data UTL to eliminate inflated UTLs.
ND = Not detected. Units are mg/kg.

INTRODUCTION

Determining environmental impacts to surface waters, groundwaters, soils, sediments, and bedrock (Bandelier Tuff) at the Laboratory requires knowledge of background-elemental chemistry of geological and hydrological media. Background media are defined as soils, sediments, rocks, surface waters, and groundwaters unaffected by Laboratory operations. Longmire et al. (1995) reported initial background elemental concentrations in selected soils and the Bandelier Tuff. Broxton et al. (this report) provide additional background elemental data for the Bandelier Tuff. Statistical and geochemical comparisons of background samples with contaminated or non-background samples are needed to identify and evaluate environmental contamination. The purpose of the soil characterization studies presented in this report is to determine the nature and variability of background-elemental concentrations and soil parameters within different soil horizons for a variety of soil profiles at the Laboratory, enlarging the earlier database of Longmire et al. (1995).

During 1993, fourteen soil profiles were characterized and sampled to determine background-elemental concentrations and their relation to soil characteristics (Watt, 1995, McDonald, upublished). One hundred and thirty-nine soil samples were submitted for chemical analyses using methods approved by the USEPA, Laboratory, and Soil Survey Staff (1981). Soil samples were analyzed for both total element and partial element concentrations by digesting soil samples using hydrofluoric acid (HF) and nitric acid (HNO_3), respectively.

Geochemical characteristics of soils on the Pajarito Plateau vary widely and are related to local variations in parent material, topography, soil age, surficial processes, climate, and vegetation. The sites of detailed soil sampling and analysis in this study were chosen to provide chemical data for soils not sampled previously and to evaluate the physical and chemical variability in soils in several soils series previously described by Nyhan et al. (1978). Soil characterization data for these soils reported in Watt (1995) are presented in detail in this report. These soils formed in a wide variety of geomorphic settings and the setting of each sample site was described to provide a better understanding of controls on the variations in soil development.

This investigation contributes to the Environmental Restoration (ER) Project, by providing additional background-elemental data that can be used in conjunction with screening action levels (SALs) in risk-assessment calculations for different contaminants. These background-elemental data are useful in developing sampling and remediation strategies at sites, to understand processes controlling contaminant transport, and to distinguish between contaminated and non-contaminated media. These data may also be used to establish cleanup levels for sites to be remediated. Recommendations are

provided for sample collection, sample preparation and analyses, and statistical and geochemical intepretation of soils data.

This report (1) summarizes results of soil characterization studies conducted by Watt (1995) and McDonald (upublished data); (2) describes analytical and statistical methods used to define and characterize background chemical (analyte) distributions in soils; (3) discusses soil development (pedogenesis) and soil chemistry relationships; and (4) describes how these background data may be statistically compared to the background-elemental data set for soils provided by Longmire et al. (1995) and to non-background (potential release site) or contaminant analytical data. In addition, this report addresses characterization studies outlined in the Laboratory's Hazardous and Solid Waste Amendments (HSWA) permit, Task III (Facility Investigation), Section A. (Environmental Setting), Number 2. (Soils), Items a, b, f, g, i, k, l, m, p, and q.

SAMPLING SITES AND METHODS

Sampling Sites

Fourteen soil profiles at seven different areas were described in the field and soil samples were collected for chemical analyses. The soil sample sites included mesa tops (TA-51, TA-63, TA-67), a canyon bottom (Ancho Canyon (AC-1), and fans and colluvial slopes in the western part of the Laboratory (Water Canyon (WC), TA-16). Vegetation ranges from Ponderosa pine forests in the wetter, western part of the Laboratory to pinon-juniper woodland in the drier, central part (Table 1, Figure 1). The parent materials for the soils included weathered and eroded Bandelier Tuff, alluvium partially derived from Tschicoma dacite in the Sierra de los Valles, wind-blown dust, and El Cajete pumice. All sites were within the soil mapping area of Nyhan et al. (1978), and include six of their thirteen soil series, although the sample sites were not necessarily typical of soils within each series as described by Nyhan et al. (1978).

Descriptions of soil samples are provided in Table 2. Areas selected for detailed soil characterization described by Watt (1995) and McDonald (unpublished data), with the number of soil profiles, include: Site 1, TA-39 in Ancho Canyon near State Route 4 (one profile: AC-1); Site 2, Water Tanks along State Route 501 (two profiles: TA-16-1, -2); Site 3, TA-16 along West Jemez Road near intersection of State Route 4 and State Route 501 (west gate) (one partial soil profile: LA-4); Site 4, TA-51 (one soil profile); Site 5, TA-63 (four soil profiles: 1A, 2, a, c); Site 6, TA-67 at the proposed Mixed Waste Disposal Facility (MWDF) (five soil profiles: E1, E1-2, E3, W1, W5); and site 7, Virgin Mesa (southwest of Jemez Springs and west of the confluence of the Jemez River and the Rio Guadalupe). Although complete soil profiles were described, only a subset of samples were submitted for background geochemistry (LA-4,

Table 1. Summary of Soil Sample Sites.

Sample Site	Technical Area	Elevation (ft)	Vegetation	Topographic Setting	Surficial Material
1. Ancho Canyon	TA-39	6270	Ponderosa pine	canyon bottom	Holocene alluvium (last 5000 years)
2. Water Tanks Trench	TA-16	7750	Ponderosa pine	base of scarp	pre- El Cajete to late Holocene colluvium
3a. Water Canyon, (north)	TA-16	7560	Ponderosa pine	base of scarp	Holocene colluvium over fan
2b. Water Canyon,(south)	TA-16	7580	Ponderosa pine	old fan	Pleistocene alluvium
4. Mesita del Buey	TA-51	7020	piñon-juniper	mesa top	thin post El Cajete (?) soils
5a. Pajarito Road, Trench 1	TA-63	7200	grass	mesa top	thick pre and post (?) El Cajete soils
5b. Pajarito Road, Trench 5-1	TA-63	7200	grass	mesa top	thin post El Cajete (?) soils
5c. Pajarito Road, Trench 5-2	TA-63	7200	grass	mesa top	thin post El Cajete (?) soils
5d. Pajarito Road, Trench 5-3	TA-63	7200	grass	mesa top	thin fracture fill
6a. Pajarito Mesa, Trench E1	TA-67	7240	Ponderosa pine	mesa top	pre- and post El Cajete soils
6b. Pajarito Mesa, Trench E3	TA-67	7210	Ponderosa pine	mesa top	pre- and post El Cajete soils
6c. Pajarito Mesa, Trench W1	TA-67	7250	Ponderosa pine	mesa top	pre- and post El Cajete soils
6d. Pajarito Mesa, Trench W5	TA-67	7290	Ponderosa pine	mesa top	pre- and post El Cajete soils
7. Virgin Mesa, Jemez Springs			Ponderosa pine	mesa top	

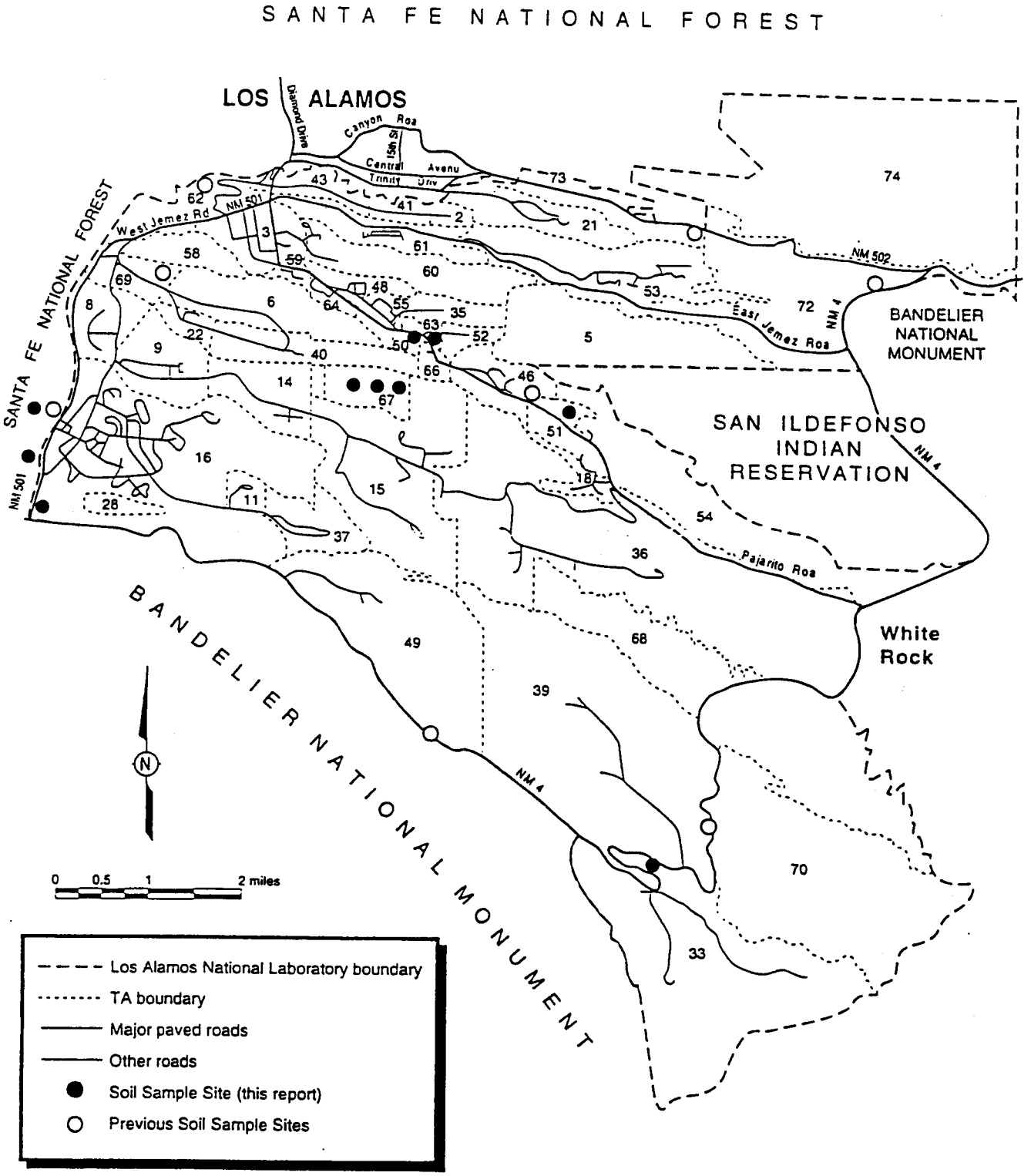

Fig. ~~4~~ 1. Map of Los Alamos National Laboratory showing soil sample sites.

TA-67-E1, TA-63-2). Several soil samples were collected from each horizon (termed colocated sample) at several sites. These localities allowed partial sampling of various degrees of soil development that occurs on the Pajarito Plateau and an evaluation of the variability in soil characteristics and chemistry within several soil series previously described by Nyhan et al. (1978). At each location, soil samples were collected at different depths (0 to 354 cm) corresponding to the different soil horizons and weathered Bandelier Tuff.

Field Methods and Soil Characterization

Soils were described and sampled from exposures in trenches, sides of drainage channels, and road cuts. For each soil horizon, a single, representative bulk sample of approximately one kilogram (kg) was collected. Field descriptions were made according to guidelines and standard procedures for characterizing soils described in Birkeland (1984) and Soil Survey Staff (1981). Collection and analysis of soil geochemical and morphological data were based on these vertically stratified samples. Soil samples were analyzed at the Quaternary Laboratory at the Department of Earth and Planetary Sciences, University of New Mexico, for chemical and physical properties. Procedures for these analyses are contained in Watt (1995), Soil Survey Staff (1981), and Methods of Soils Analysis (American Society of Agronomy, 1986). Soil horizons were classified and characterized according to their texture, consistency (wet/dry), particle-size distribution, color, clay-size content, calcium-carbonate content, organic-carbon content, soil pH, cation exchange capacity (CEC), citrate-bicarbonate-dithionite extraction for iron oxides and iron oxyhydroxides, oxalate extraction for iron oxyhydroxides, and bulk density (Watt, 1995; Watt and McFadden, 1992). Soil samples were passed through a 2.0 mm (20 mesh) sieve to remove pebbles and roots. Soil samples were either air-dried or dried in a forced-air circulation oven at 105°C for 24 hours. All equipment was cleaned and sterilized between each sample preparation.

Sample Digestion and Analytical Techniques

The elements antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), chromium (Cr), lead (Pb), manganese (Mn), mercury (Hg), thorium (Th), and uranium (U) are of primary concern to the ER Project because numerous potential release sites (PRSs) and solid waste management units (SWMUs) at the Laboratory may contain elevated concentrations of these elements. Other elements and compounds of secondary importance to the ER Project include aluminum (Al), cadmium (Cd), calcium (Ca), cesium (Cs), chlorine (Cl), cobalt (Co), copper (Cu), iron (Fe), magnesium (Mg), potassium (K), selenium (Se), sodium (Na), strontium (Sr), sulfate (SO_4^{2-}), tantalum (Ta), thallium (Tl), titanium (Ti), vanadium (V), zinc (Zn), and zirconium (Zr). Radioactive isotopes were not

Table 2. Soil Sample Location and Soil Horizon Collected During Soil Background Investigation.

SOIL PROFILE	SAMPLE NUMBER	SOIL HORIZON
Ancho Canyon		
(1)	2080	A2
	2082	Bw1
	2083	Bw2
	2084	Bw3
	2081	Btb
	2085	Bwb
	2088	Ckq
	2087	C'
	2086	C
TA-16 South-1		
	2090	Bt4b
	2091	Bt5b
	2092	Bt6b
	2093	Bt7b
	2094	Bt8b
	2095	Bt9b
	2089	BCb
TA-51		
	2096	BA
	2098	Bw
	2097	BC
TA-63		
	2099	Bwb

SOIL PROFILE	SAMPLE NUMBER	SOIL HORIZON
TA-63a		
	2114	A2
	2150	Colocated
	2115	Bw1
	2151	Colocated
	2152	Bw2
	2116	CB
	2153	Colocated
	2117	fracture fill
TA-63c		
	2118	A1
	2154	Colocated
	2119	A2
	2120	Bw1
	2155	Colocated
	2121	Bw2
	2122	Bw3
	2156	Colocated
TA-63-1A		
	2100	A1
	2101	A2
	2104	Bw
	2103	Bth
	2102	Btb

Table 2. Soil Sample Location and Soil Horizon Collected During Soil Background Investigation.

SOIL PROFILE	SAMPLE NUMBER	SOIL HORIZON
TA-63-2		
	2113	Bw
	2149	Colocated
	2107	Bth
	2144	Colocated
	2108	Bthk
	2145	Colocated
	2109	Btk1
	2146	Colocated
	2110	Btkb1
	2147	Colocated
	2111	Btkb2
	2148	Colocated
	2105	Btb1
	2142	Colocated
	2106	Btb2
	2143	Colocated
TA-16 Water Tanks Trench, TA-16-2		
	2124	Bt1b2
	2209	Colocated
	2126	Bt2b2
	2210	Colocated
	2127	Bt3b2
	2211	Colocated
	2128	Bt4b2
	2125	Bt2
	2214	Colocated

SOIL PROFILE	SAMPLE NUMBER	SOIL HORIZON
TA-16, Water Tanks Trench, TA-16-2 (con't)	2212	Colocated
	2129	Bt5b2
	2213	Colocated
TA-16, Water Tanks Trench, TA-16-1		
	2135	C1b1a
	2112	C2b1a
	2134	C3b1a
	2130	Bt1b1b
	2215	Colocated
	2208	Bt1b1c
	2123	Colocated
	2131	Bt2b1b
	2216	Colocated
	2132	Bt2b1c
	2217	Colocated
	2133	Bt3b1c
	2218	Colocated
TA-16 South-2		
	2137	Ap
	2139	Bt1
	2140	Bt3
	2141	Bt4
	2138	BC
	2136	2C

Table 2. Soil Sample Location and Soil Horizon Collected During Soil Background Investigation.

SOIL PROFILE	SAMPLE NUMBER	SOIL HORIZON
TA-67 E1-1		
	2159	A
	2160	BA
	2163	Bw
	2161	Bt1
	2162	Bt2
	2158	2Bwb
	2157	2BCb
TA-67 E3		
	2172	A
	2164	2BAb1
	2167	2Bt1b1
	2168	2Bt2b1
	2165	2BC1b1
	2166	2BC2b1
	2169	3Bt1b2
	2170	3Bt2b2
	2171	3Bt3b2

SOIL PROFILE	SAMPLE NUMBER	SOIL HORIZON
TA-67 W1		
	2186	A1
	2219	A2
	2189	A3
	2190	BA
	2188	Bw1
	2192	Bt1
	2193	Bt2
	2187	Btkb
	2194	E/Bb
	2191	Bt/CR
TA-67 W5		
	2183	A
	2184	BA
	2175	2Bt1b1
	2176	2Bt2b1
	2177	2Bt3b1
	2173	2BC1sb1
	2174	2BC2sb1
	2178	2BAb2
	2179	3Btb2
	2181	4CBt1b3
	2182	4CBt2b3
	2180	4C1b3
	2185	4C2b3

Table 2. Soil Sample Location and Soil Horizon Collected During Soil Background Investigation.

SOIL PROFILE	SAMPLE NUMBER	SOIL HORIZON
TA-67E1-2		
	2199	Btkb1
	2203	Bt1b1
	2195	Bt2b1
	2196	Bt3b2
	2197	Btk1b2
	2198	Btk2b2
	2202	E/Btb1
	2201	E/Bt2b1
	2200	CR
Virgin Mesa		
	2204	BA
	2205	Bt
	2206	Bw
	2207	CB

analyzed in this investigation because the Laboratory (Group ESH-18) performs annual sampling of soils and sediments in background (equivalent to fallout activities of radionuclides) and facility areas for these constituents. It is possible that additional sampling of background soils for radionuclides will be conducted in the future.

Following sample preparation, soil samples were submitted to CST-9 for chemical analyses using EPA-SW846 methods and other analytical techniques available at the Laboratory. These include inductively coupled plasma mass spectrometry (ICPMS), inductively coupled plasma emission spectroscopy (ICPES), electrothermal vapor atomic absorption (ETVAA), cold vapor atomic absorption spectroscopy (CVAA), and ion chromatography (IC) analyses. Chemical data obtained for this investigation are stored and are available at the facility for information management analysis and display (FIMAD). Table 3 provides a listing of each analyte and appropriate analytical techniques. The procedures used for these analyses are described in detail in EPA (1986), Gautier and Gladney (1986), and Gladney et al. (1980, 1981). Quality assurance was provided by concurrent analysis of different National Institute of Standards and Technology (NIST), EPA, and United States Geological Survey (USGS) reference materials described by Gladney et al. (1981). Quality control samples including duplicates and spiked samples were analyzed at frequencies specified by the U.S. EPA (1987).

Soil samples were analyzed for total-element concentrations following complete digestion using concentrated HF, $HClO_4$, and HNO_3 (LANL Method EI 143, digestion ((total)/-soils, sludges, and sediments). Aliquots or splits from the same samples were also digested using concentrated HNO_3, HCl, and H_2O_2 (EPA Method 3050A) and were analyzed for the same elements using EPA-SW846 methods, including ICPES, ICPMS, IC, and ETVAA. In all instances, element concentrations from HNO_3 digestion are less than the total-element concentrations. The lowest detection limits for specific elements and species using ICPES, ICPMS, IC, and ETVAA were 0.08 (Be) , 0.12 (Ta), 12 (sulfate), and 0.3 (As) ppm, respectively (see Table 8). Precision values for Be, Ta, sulfate, and As were ±10%, ±10%, ±10%, and ±20%, respectively. Precision values for all of the other elements were ±10%.

Element leaching from soils is evaluated by comparing analytical results from HNO_3 digestion to those obtained from HF digestion. Large differences in concentrations of the total element and HNO_3-digested samples suggest that minimal redistribution of elements from primary silicates to secondary surface coatings has occurred and most of the element is chemically bound or tied up within the primary silicate minerals. Small differences in element concentrations between HNO_3-digested samples and total-element analyses suggest that elements have been largely mobilized and concentrated on surfaces and/or coprecipitated with acid-soluble phases including ferric hydroxide, ferric

TABLE 3. EPA-SW846 and LANL Analytical Techniques Used in LANL Background Soil Investigation.

Element	Technique	Element	Technique
Al	ICPES	Mg	ICPES
As	ETVAA	Mn	ICPES
Ba	ICPES	Na	ICPES
Be	ICPES	Ni	ICPES
Ca	ICPES	Pb	ICPES
Cd	ICPES	Sb	ICPES
Cl	IC	SO_4	IC
Co	ICPES	Ta	ICPMS
Cr	ICPES	Tl	ICPMS
Cu	ICPES	Th	ICPMS
Fe	ICPES	U	ICPMS
K	ICPES	V	ICPES
		Zn	ICPES

ICPES, inductively coupled plasma emission spectroscopy
ICPMS, inductively coupled plasma mass spectrometry
IC, ion chromatography
ETVAA, electrothermal vapor atomic absorption spectroscopy

oxyhydroxide, calcium carbonate, solid organic matter, and clay minerals such as smectite and kaolinite. Many trace and major elements, including Al, Ba, Na, K, U, and Th, are structurally incorporated within primary mineral lattices and amorphous solids (primarily glass). Subsequently, HF digestion of a sample results in higher concentrations for some elements relative to a partial digestion using HNO_3. Other trace elements, including As and Be, are mainly concentrated on surfaces of soil particles, consisting of clay minerals and ferric oxyhydroxide-ferric hydroxide (termed iron oxides) in well-developed soils, through adsorption processes. Under these circumstances, HF and HNO_3 digestions yield similar analyte concentrations. Therefore, the type of digestion (extraction) of environmental samples strongly influences analytical results. Consistent and appropriate digestion procedures should be used to allow comparability of data.

GEOMORPHIC SETTINGS AND GENERAL SOIL HORIZONS

The soils sampled in this investigation include a range of geomorphic settings and ages, both of which influence soil development and soil chemistry. Most sampled soils are collected from mesa tops in the central portion of the Pajarito Plateau, and are developed in a variety of materials that can include components of locally weathered Bandelier Tuff, the ca. 50-60,000 yr old El Cajete pumice (Reneau et al., 1995), and wind-blown sediment. The strongest soil development, and the highest concentrations of most trace elements, are found in soils that are older than the El Cajete pumice. Other geomorphic settings sampled in this study are colluvial slopes at the base of the Pajarito fault scarp, a young stream terrace on the eastern Pajarito Plateau, and an old alluvial fan on the western Pajarito Plateau. Elevations of the study sites range from 6270 to 7750 ft, and vegetation includes both Ponderosa pine forest and pinon-juniper woodlands (Table 1).

Site 1. Ancho Canyon, TA-39

The Ancho Canyon sample site is a stream-cut bank that exposes Holocene alluvium below a 2.4 m high terrace. The site was mapped as part of the Totavi series by Nyhan et al. (1978). Ancho Canyon above this point entirely drains the Tshirege Member of the Bandelier Tuff, and the source for sediments is thus eroded tuff plus other material contained within eroded soils (such as wind-blown sediment and El Cajete pumice). Sedimentary layers exposed in this bank include both relatively well-sorted coarse sands and gravels that represent channel deposits, and poorly-sorted mixtures of pumice-rich sand, silt, and clay that represent floodplain deposits (Figure 2: sketch of general stratigraphy + radiocarbon dates). Radiocarbon analyses of charcoal

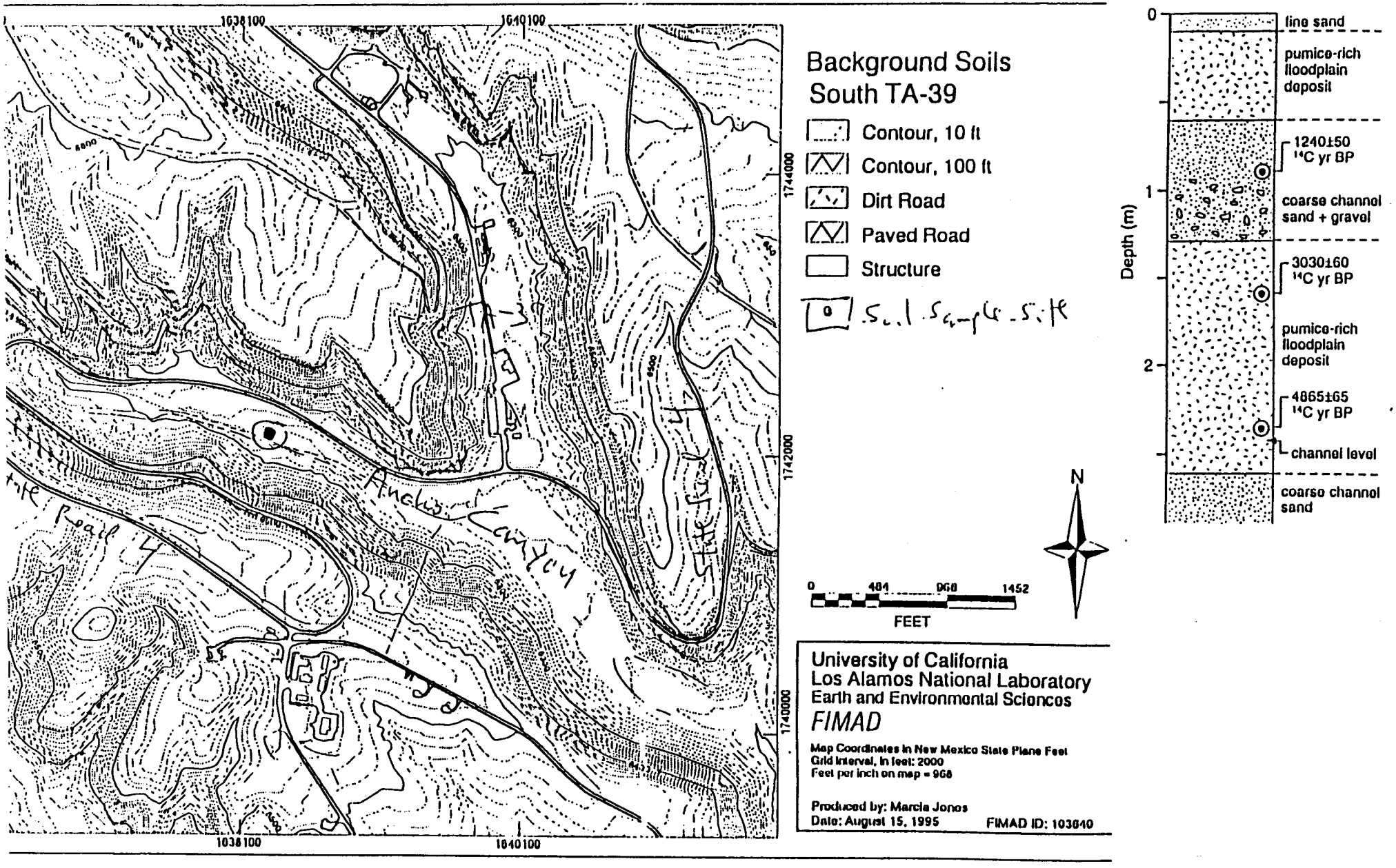

Fig. 2. Map showing location of soil sample site in Ancho Canyon.

fragments collected from these sediments indicate ages of 3000 to 5000 ^{14}C yrs for a buried floodplain deposit at depths of 1.6 to 2.4 m, and an age of about 1200 ^{14}C yrs for an overlying channel deposit at a depth of 0.9 m. This sample site may be representative of many canyon-bottom sites at the Laboratory, particularly in canyons that originate on the Pajarito Plateau and entirely drain Bandelier Tuff, although the chemistry will probably vary with the age of the sediments.

Site 2. Water Tanks Trench, TA-16

The sample site is south of Canon de Valle at the base of the Pajarito fault scarp, in a trench excavated as part of paleoseismic investigations (Figure 3, location map; Wong et al., 1995). The trench exposed a sequence of colluvial deposits of varying age and degree of soil development, and also a pure layer of El Cajete pumice (Figure 4: sketch of trench stratigraphy). One soil profile from this trench, above the pumice, was previously analyzed and is presented in Longmire et al. (1995). In this study, two colluvial layers beneath the pumice were sampled farther west in two locations. The lowest colluvial layer has pedogenic features associated with strong soil development indicating a relatively longer period of soil development than the other colluvial layers exposed in the West Jemez Road trenches. The site was mapped as part of the "Rock Outcrop-Pines-Tentrock Complex" by Nyhan et al. (1978). This pit exposed 1.7 m of fine-textured Holocene colluvium or fan sediment that was derived from a possible fault scarp and deposited on top of a stream terrace derived from Water Canyon. Radiocarbon analyses of charcoal from similar deposits in nearby pit TP2 yielded ages of 8000 to 9500 ^{14}C yrs from depths of 0.5 to 1.0 m (Wong et al., 1995), and the TP1 deposit is probably similar in age.

Site 3. TA-16 South

The sample site south of Water Canyon is a roadcut exposure of an old alluvial fan along West Jemez Road and along the southwest side of TA-16 (Figure 5: location map), that was mapped as part of the Pogna series by Nyhan et al. (1978). The alluvium includes clasts of Tschicoma Formation dacite eroded from the Sierra de los Valles, and the strong soil development indicates that this may be one of the oldest deposits exposed along West Jemez Road, although its age is unknown.

Site 4. Mesita del Buey, TA-51

The Mesita del Buey sample site was a trench excavated by EES-15 as part of hydrological investigations on mesa tops at the Laboratory (Figure 6).

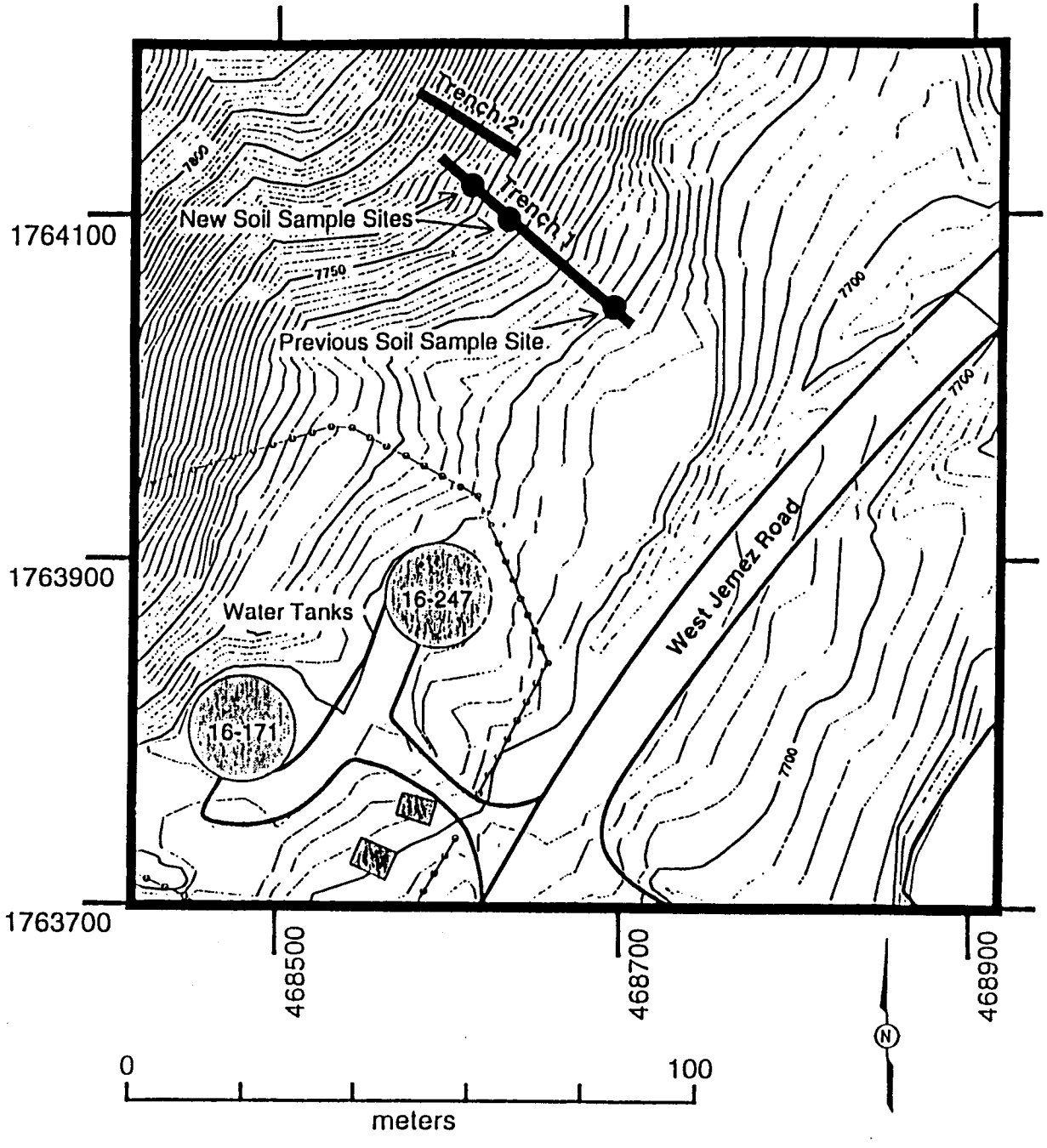

Fig. 3. Sketch of Water Tanks trench at sample sites. Horizontal axis indicates trench distance (m). Modified from Wong et al. (1995).

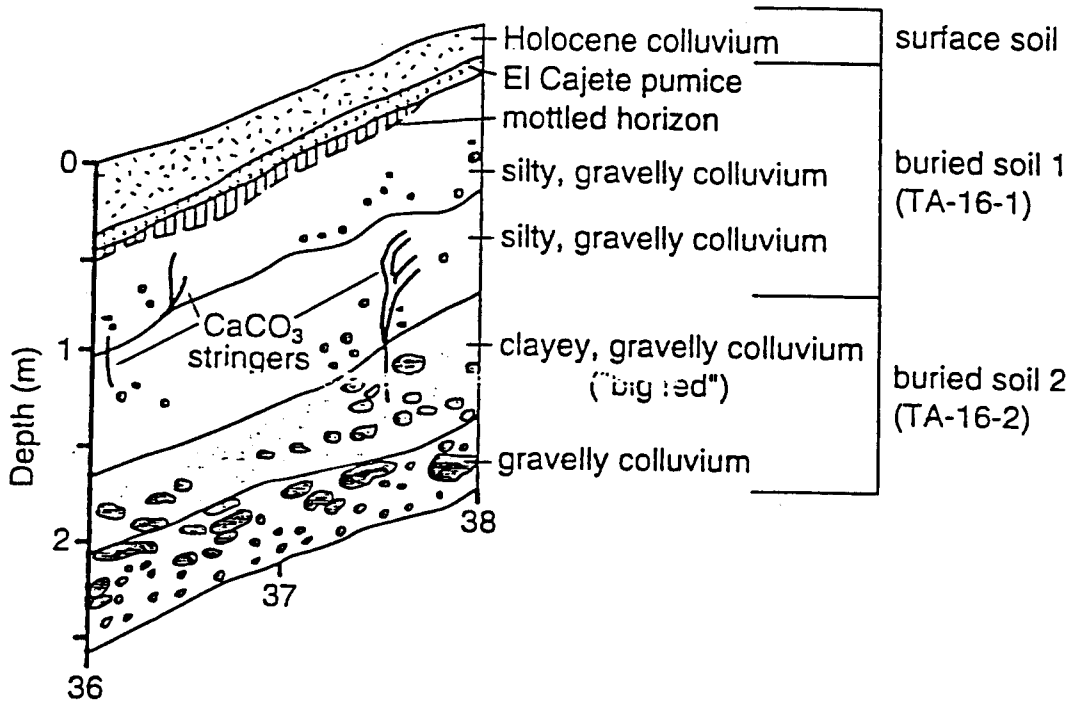

Fig. 4. Map showing location of Water Tanks trenches and sample sites of this report and of Longmire et al. (1995). ~~Topographic base, with 2 foot contours, from FIMAD.~~

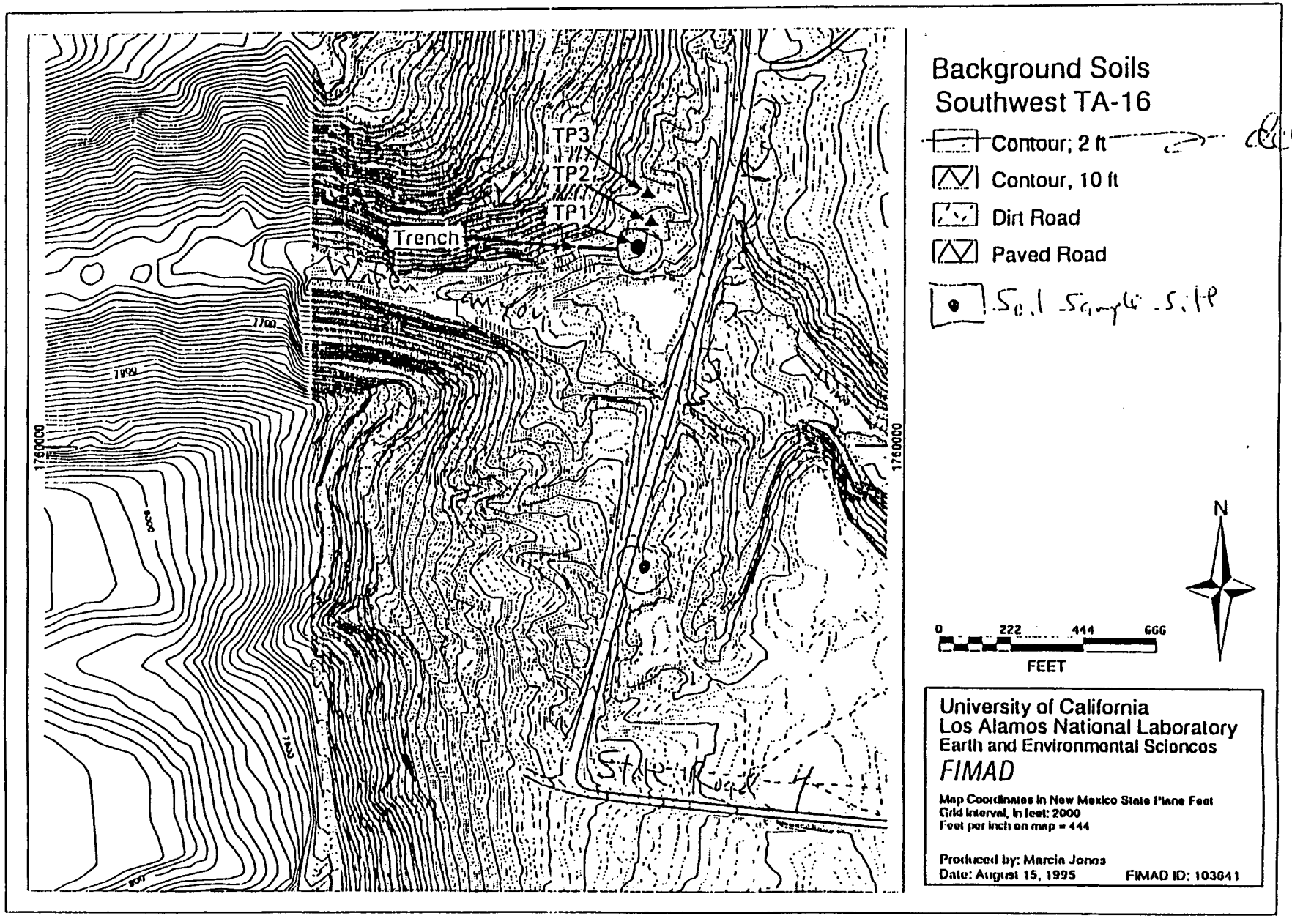

Fig. 5. Map showing location of Water Canyon (TA-16 south) sample sites.

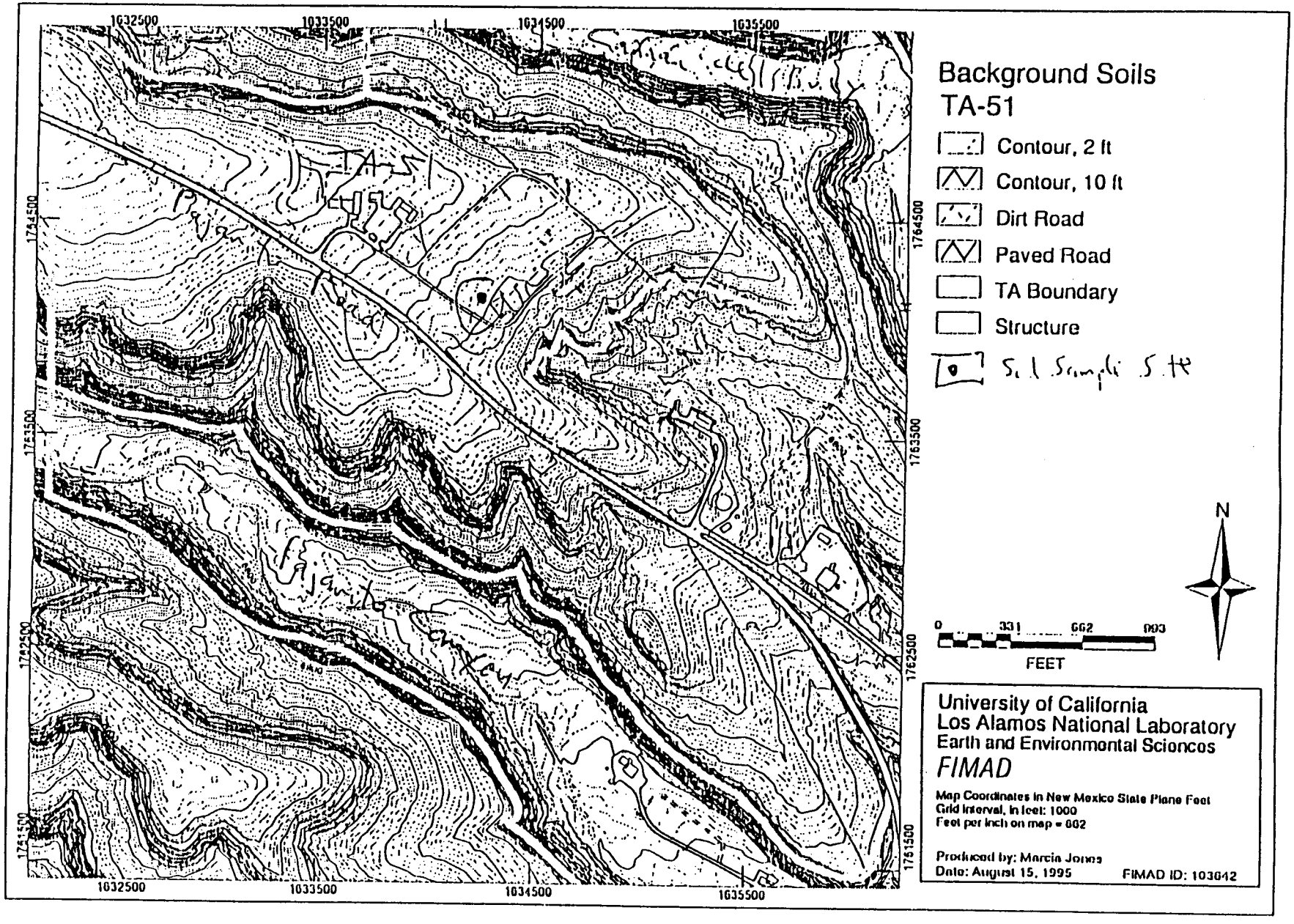

Fig. 6. Map showing location of soil sample site on Mesita del Buey at TA-51.

The soils on the mesa were mapped as part of the Hackroy series by Nyhan et al. (1978). The sampled soil is relatively thin, (* m thick), and may include deposits that both pre-date and post-date the El Cajete pumice.

Site 5. Pajarito Road, TA-63

Four soil profiles were sampled on the mesa top at TA-63 and vicinity near Pajarito Road from a series of trenches excavated to evaluate potential faulting (Figure 7: location map; Kolbe et al., 1995). Sampled soils on the mesa top were mapped as either the Nyjack series (trench 1) or the Hackroy series (trench 5) by Nyhan et al. (1978). The soils and stratigraphy at the Pajarito Road sites are distinctly different from that on Pajarito Mesa, only about 1 km to the south, particularly in the absence of the El Cajete pumice. Soils at TA-63 are generally thinner (0.5-0.7 m thick), and may in general represent Holocene deposits, although a lower clay-rich horizon is usually present that may indicate remnants of Pleistocene soils. One of the sample sites in trench 1 is from a 2.3 m thick deposit that filled a shallow mesa-top drainage, and includes an older, buried deposit that is inferred to pre-date the El Cajete pumice (Kolbe et al., 1995). The range in soil characteristics and soil chemistry present in the TA-63 samples, in combination with the other mesa top sites in this study and in Longmire et al. (1995), may encompass most of the variability that exists on mesa tops in the central part of the Laboratory.

Site 6. Pajarito Mesa, TA-67

Five soil profiles were sampled on Pajarito Mesa in the central part of the Laboratory from a series of trenches excavated to evaluate potential faulting (Figure 8: location map; Kolbe et al., 1994; Reneau et al., 1995). Sampled soils on the mesa top were mapped as mostly the Nyjack series by Nyhan et al. (1978), although a small area of the Frijoles series was also mapped. Sample sites were chosen to include a range of stratigraphic units and soil characteristics as exposed in the trenches, and the sampled soils range from 1.3 to 2.3 m thick. The general stratigraphic units present include old soils that were buried by the El Cajete pumice, a typically disrupted (bioturbated) pumice layer, and overlying deposits that range in age from at least 30,000 yrs to less than 1000 yrs old (Figure 9: sketch of stratigraphy; Kolbe et al., 1994; Reneau et al., 1995). The fine-grained texture of much of the material overlying the pumice indicates that it includes a substantial component of wind-blown sediment, and the soils underlying the pumice probably represent some mixture of locally weathered tuff and wind-blown sediment. The trench W1 sample site is in an area of relatively thin and poorly-developed soils; the trench E3 sample site is in an area where relatively strong soil development is present below the El Cajete pumice; and the trench E1 sample site is at the site where pre-El Cajete soils

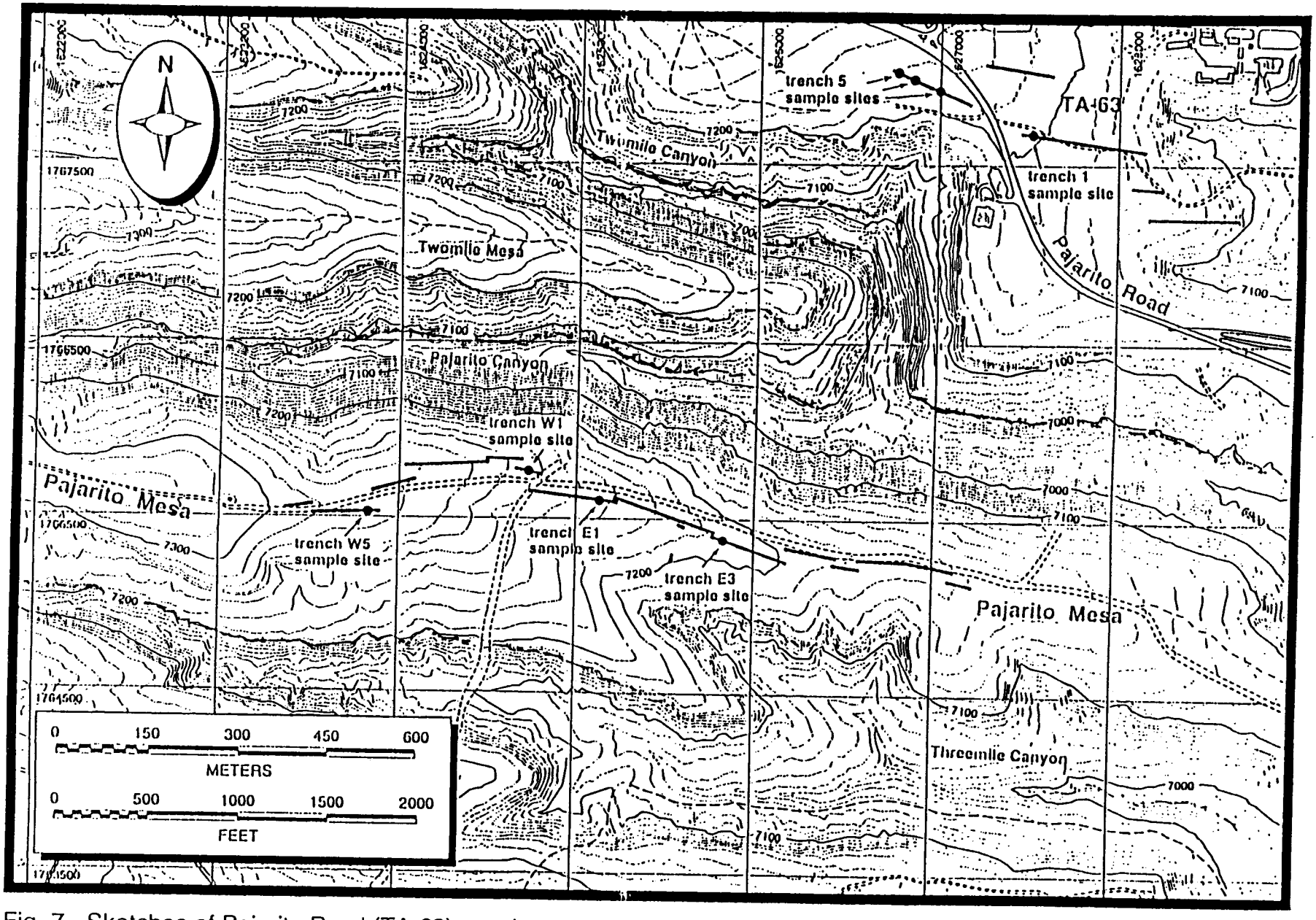

Fig. 7. Sketches of Pajarito Road (TA-63) trenches at sample sites. Horizontal axis indicates trench distance (m). Modified from Kolbs et al. (1995).

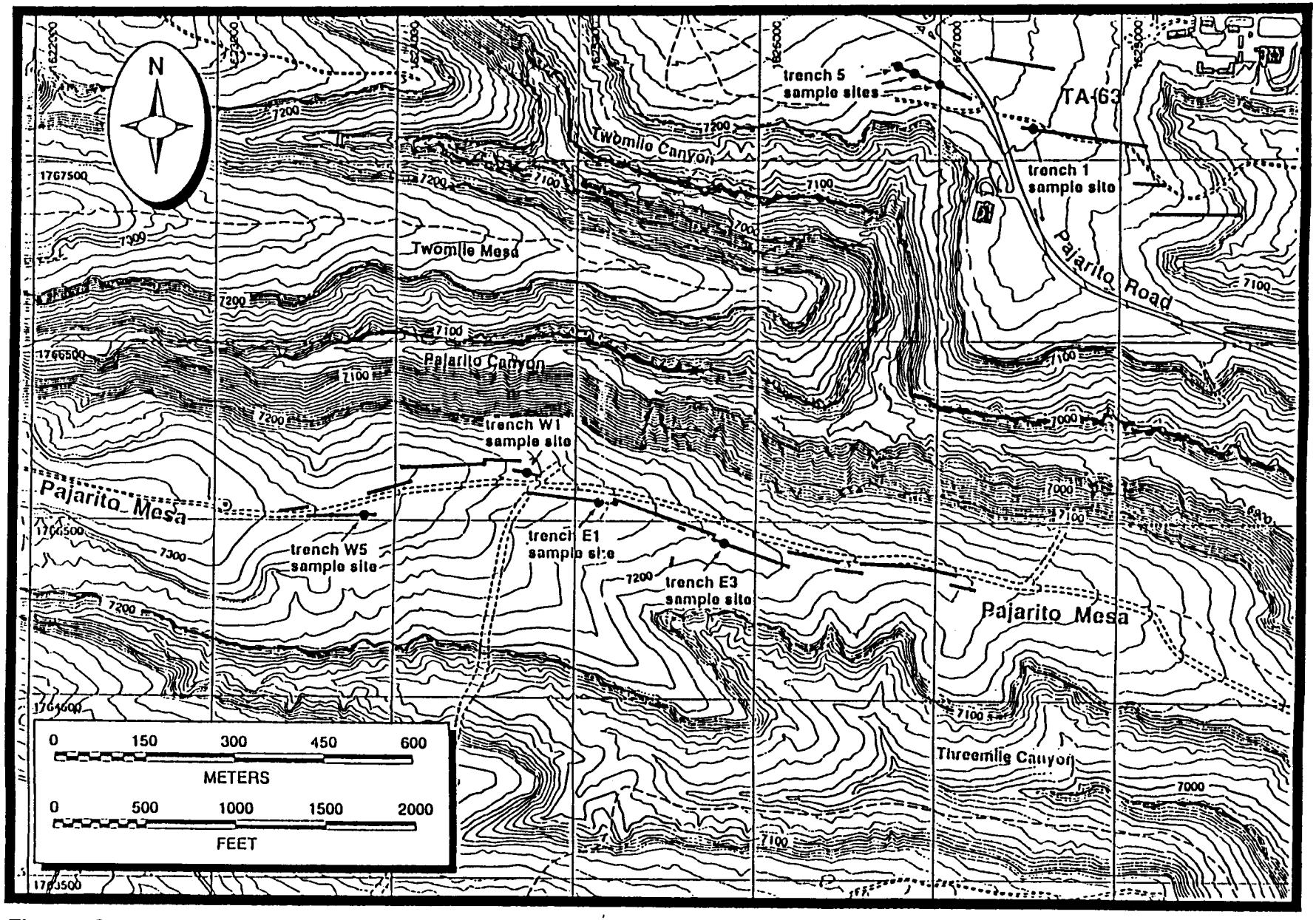

Fig. 8. Sketches of Pajarito Mesa (TA-67) trenches at sample sites. Horizontal axis indicates trench distance (m). Modified from Kolbe et al. (1994).

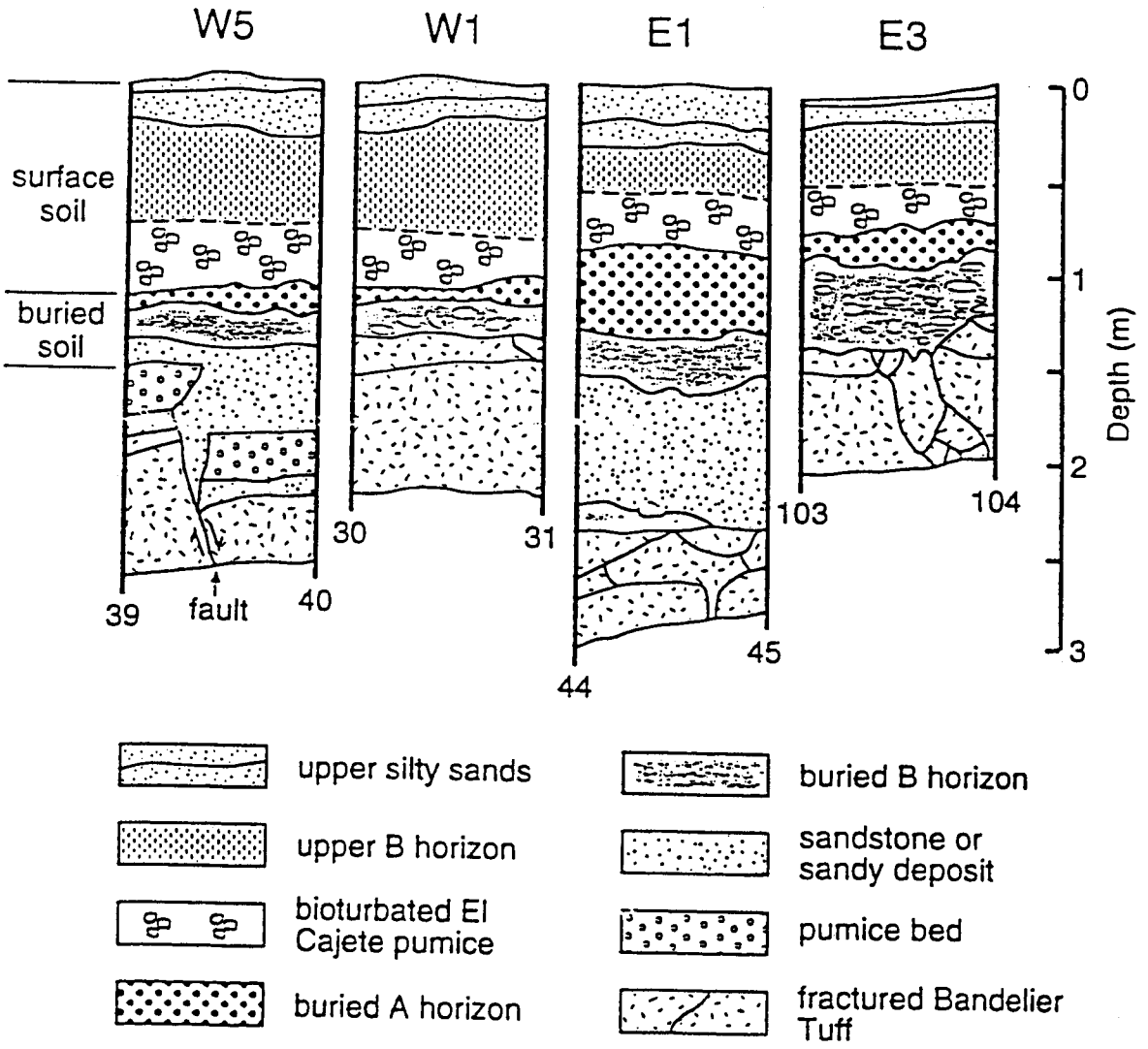

Fig. 9. Map showing stratigraphy at Pajarito Mesa and at TA-67. Modified from Kolbe et al. (1994).

are thickest, including multiple buried soils. At the remaining site, in trench W5, old pre-El Cajete pumice-rich alluvial beds underlie the sampled soil.

Site 7. Virgin Mesa, Sandoval County

One soil profile was sampled on Virgin Mesa southwest of Jemez Springs and west of the Jemez River and Rio Guadalupe confluence. This area was selected as a regional background site for the Jemez Mountains consisting of soil forming on the Tshirege Member of the Bandelier Tuff. Soils at this site have not been mapped by Nyhan et al. (1978). Analytical results from Virgin Mesa are used in this report as are data collected from the other sites within and adjacent to the Laboratory.

CHARACTERIZATION OF BACKGROUND SOILS

General Soil Parameters

This section presents a summary and discussion of soil characterization results reported by Watt (1995). Results of this and other studies (Longmire et al., 1995) show that Laboratory soils have extreme diversity and spatial variability in their physical and chemical properties and in vertical stratification. A summary of these soil parameters is presented in this report (Table 4) and in Watt (1995).

Soil Horizons

Soil consists of layers or horizons of mineral and/or organic matter of variable thicknesses that parallel the land surface and which differ from the parent material in their morphological, physical, chemical, and mineralogical properties and their biological characteristics (Joffe, 1949; Birkeland, 1984; Soil Survey Staff, 1975). In general, soils form nearly ubiquitous cover across the land surface and their formation largely results from physical, chemical, and biological transformations that occur over time along the boundary between the atmosphere, biosphere, and lithosphere. The general characteristics of a soil at any given point in the landscape will primarily reflect the five major factors that control soil formation: parent material (i.e. substrate soil has formed in), vegetation, topographic position (i.e. slope and aspect), climate, and time. Soils across the Laboratory are spatially highly variable and complex due to the diversity of topography, the complex history of landscape evolution, and variation in the ages of soil parent material.

Soil horizons at the Laboratory generally are unconsolidated and largely consist of O, A, B, E, and C horizons. An O horizon is characterized by surface

Table 4. Summary of physical and chemical soil characterization properties.

Soil Number	Horzon	Depth (cm)	Sand (% wt.)	Silt (% wt.)	Clay (%wt.)	Gravel (% wt.)	Bulk Density (g/cm3)	Organic Carbon (% wt.)	CEC (meq/100g)	Carbonate (% wt.)	pH	Dithionite Fe2O3 (%wt.)	Oxalolate Fe2O3 (%wt.)
AC-1	A1	0 - 4	75.1	17.5	7.4	4.30		1.75	5.44		5.5	0.44	0.42
	A2	4 -- 12	88.4	8.5	3.1	6.50		0.47	2.70		5.7	0.48	0.31
	Bw1	12 -- 27	47.5	43.2	9.3	9.10	1.12	2.00	11.56		5.4	0.60	0.35
	Bw2	27 -- 56	65.9	26.0	8.1	13.00		0.83	9.82		6.9	0.53	0.38
	Bw3	56 -- 69	88.3	8.4	3.3	4.60		0.46	3.68		6.8	0.47	0.22
	C	69 -- 90	92.9	4.8	2.3	7.80		0.61	3.19	1.1	6.8	0.32	0.34
	Ckq	90 -- 109	93.7	5.0	1.3	40.60		0.74	3.03	0.47	6.6	0.28	0.32
	C'	109 -- 130	95.3	4.0	0.7	11.00		0.56	2.88		6.8	0.26	0.17
	Bwb	130 -- 151	66.1	23.6	10.3	21.30		1.05	9.73		7.0	0.49	0.43
	Btb	151 -- 175	63.6	27.0	9.4	27.10		0.71	12.35		7.0	0.44	0.44
TA-16-S-1	Bt4b	94 -- 110	22.2	41.0	36.9	9.70	1.68	0.52	27.45		6.3	0.85	0.18
	Bt5b	110 -- 134	25.2	55.7	19.1	12.10	1.62	0.23	19.56		6.5	0.82	0.22
	Bt6b	134 -- 186	29.1	56.7	14.2	11.00	1.62	0.41	19.49		6.5	0.76	0.19
	Bt7b	186 -- 234	30.2	45.7	24.1	28.90	1.65	0.18	17.02		6.6	0.84	0.19
	Bt8b	234 -- 264	32.4	51.8	15.8	11.40	1.60	0.18	14.11		6.5	0.79	0.19
	Bt9b	264 -- 354	21.1	64.5	14.4	4.60	1.59	0.22	13.39		6.3	0.81	0.20
	BCb	354 -- 281+	25.7	58.0	16.4	2.10		1.12	9.33		6.7	0.78	0.25
TA-51	A	0 -- 3	26.0	56.5	17.6	2.90		17.30	43.04		6.4	0.80	0.41
	BA	3 -- 6	13.8	66.6	19.6	0.60		6.97	27.30		6.0	0.86	0.51
	Bw	6 -- 18	18.6	49.8	31.6	3.70		4.86	25.20		6.0	0.96	0.64
	BC	18 -- 25	31.7	45.1	23.2	21.80		8.13	28.95		6.2	1.01	0.60
TA-63a	A	6 -- 12	26.5	57.9	15.6	2.40	1.33	1.79	9.85		5.7	1.08	0.26
	Bw1	12 -- 25	27.4	54.9	17.7	1.10	1.50		10.86		5.7	1.09	0.32
	Bw2	25 -- 35	26.2	53.6	20.2	3.50	1.53	1.21	11.05		5.8	0.99	0.26
	CB	35 -- 47											
	FF	110 -- 111											
TA-63c	A1	0 -- 10	22.1	66.9	11.1	2.10		5.22	14.35		6.1	0.96	0.23
	A2	10 -- 14	22.4	60.3	17.3	0.50	1.45	2.59	12.24		6.1	1.02	0.27
	Bw1	14 -- 36	25.5	62.6	12.0	0.30	1.42	1.60	8.57		6.0	1.00	0.29
	Bw2	36 -- 49	34.5	54.1	11.4	0.60	1.40	1.95	7.66		5.9	0.99	0.27
	Bw3	49 -- 57	38.0	46.0	16.0	1.70	1.48	2.62	8.92		6.0	0.96	0.27
	FF	80 -- 81										1.41	0.27
	FF	110 -- 111										0.83	0.19

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Soil Number	Horzon	Depth (cm)	Sand (% wt.)	Silt (% wt.)	Clay (%wt.)	Gravel (% wt.)	Bulk Density (g/cm3)	Organic Carbon (% wt.)	CEC (meq/100g)	Carbonate (% wt.)	pH	Dithionite Fe2O3 (%wt.)	Oxalolate Fe2O3 (%wt.)
TA-63-1A	A1	0 -- 5	17.7	68.8	13.5	1.00	1.28	3.00	10.94		5.8	0.92	0.55
	A2	5 -- 19	15.2	65.4	19.4	2.20	1.38	1.24	10.93		6.2	1.09	0.71
	Bw	19 -- 40	14.0	62.9	23.2	3.60	1.58	0.77	13.40		6.8	1.00	0.77
	Bth	40 -- 66	19.8	51.7	28.5	9.20	1.63	0.41	19.00		6.8	0.89	0.67
	Btk1	66 -- 72	21.3	56.8	21.9	1.90	1.65	0.45	21.26	6.09	7.0	0.72	0.47
	Btk2	72 -- 77	16.6	54.2	29.2	2.00	1.65	0.45		6.59	7.1	0.81	0.38
	Btb	77 -- 87+	8.4	49.0	42.6	2.30		0.75		3.93	7.1	0.95	
TA-63-2	Bw	8 -- 26	14.7	55.0	30.3	0.00		1.02	11.24		6.1	1.17	0.37
	Bth	26 -- 40	17.8	56.9	25.3	10.90		0.34	16.34		6.5	1.19	0.37
	Bthk	40 -- 53	20.6	59.0	20.3	5.50		0.49	22.05	0.34	7.2	1.09	0.43
	Btk1	53 -- 60	23.9	59.3	16.8	2.30	1.58	0.44	19.66	4.4	7.3	0.95	0.27
	Btk2	60 -- 65	22.4	49.4	28.2	1.70		0.41	15.45		7.3	1.02	0.22
	Btkb1	65 -- 88	11.0	53.0	36.0	4.30		0.37	21.90		7.2	1.19	0.30
	Btkb2	88 -- 118	9.3	59.9	30.8	7.10		0.42	20.40		7.0	1.06	0.34
	Btb1	118 -- 150	15.7	59.8	24.5	8.80	1.61	0.39	22.68		7.0	1.19	0.49
	Btb2	150 -- 174	26.4	45.3	28.3	8.10		0.30	15.55		7.1	0.98	0.33
TA-16-WT-1	C1b1a	100 -- 111	36.5	54.9	8.6	75.06		0.85	6.46		7.0	0.58	0.16
	C2b1a	111 -- 116						0.46	8.38		6.7	1.41	0.47
	C3b1a	116 -- 153	35.8	50.3	14.0		1.83	0.58	6.44		6.6	0.92	0.11
	Bt1b1b	153 -- 170	33.5	41.5	25.0	25.00	1.72	0.03	15.15		6.6	1.03	0.12
	Bt2b1b	170 -- 199	39.9	36.6	23.5		1.70	0.31	13.81		6.6	0.93	0.10
	Bt1b1c	199 -- 210	40.3	34.9	24.8			0.15	11.35		6.6	0.96	0.09
	Bt2b1c	210 -- 235	43.1	31.3	25.6	62.0[illegible]		0.52	2.17		6.5	0.89	0.13
	Bt3b1c	235 -- 256	42.8	31.3	25.8	44.2[illegible]		1.00	13.22		6.5	0.85	0.13
TA-16-WT-2	Bt1b2	256 -- 269	32.6	28.5	38.9	61.8[illegible]	1.74	1.55	22.66		6.9	0.99	0.13
	Bt2b2	269 -- 304	23.2	26.7	50.1	45.2[illegible]	1.65	0.59	15.35		7.2	1.13	0.16
	Bt3b2	304 -- 331	37.8	27.0	35.3		1.72	0.42	29.46		7.2	0.92	0.13
	Bt4b2	331 -- 364	43.7	15.5	40.8	63.5[illegible]	1.79	0.85	19.92		7.0	0.89	0.15
	Bt5b2	364 -- 394	45.4	12.5	42.1			0.43	24.92		7.1	0.91	0.08
TA-16-S-2	Ap	0 -- 8	34.0	54.3	11.7	23.0[illegible]		1.37	6.47		5.0	0.65	0.24
	Bt1	8 -- 21	20.7	40.9	38.4	35.8[illegible]		0.92	17.54		5.7	0.93	0.20
	Bt2	21 -- 39	22.7	67.3	10.1	2.7[illegible]		0.73	17.19		6.9	1.05	0.32
	Bt3	39 -- 70	22.2	58.3	19.5	5.3[illegible]		0.47	18.03		7.1	0.89	0.26
	Bt4	70 -- 107	21.1	60.5	18.4	5.1[illegible]		0.40	20.83		7.1	0.91	0.25
	BC	107 -- 159	27.8	46.2	26.0	9.70		0.18	23.38		6.8	0.81	0.19

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Soil Number	Horzon	Depth (cm)	Sand (% wt.)	Silt (% wt.)	Clay (%wt.)	Gravel (% wt.)	Bulk Density (g/cm3)	Organic Carbon (% wt.)	CEC (meq/100g)	Carbonate (% wt.)	pH	Dithionite Fe2O3 (%wt.)	Oxalolate Fe2O3 (%wt.)
	2C	159 -- 187	76.3	15.3	8.4	56.0		0.22	8.65		7.0	0.35	0.24
TA-67-E1-1	A	0 -- 7	25.6	61.0	13.4	4.60		1.89	9.73		5.8	0.84	0.20
	BA	7 -- 15	28.4	57.9	13.7	5.80	1.25	1.79	9.29		5.7	0.84	0.18
	Bw	15 -- 38	23.7	56.8	19.6	2.30	1.18	1.28			6.0	0.95	0.20
	Bt1	38 -- 50	16.0	63.4	20.7	1.40	1.49	1.82	11.09		6.2	0.99	0.24
	Bt2	50 -- 62	19.7	60.3	20.1	1.50	1.54	0.64	15.74		6.5	1.05	0.21
	2Bwb	62 -- 98	23.5	57.3	19.2	5.40		0.97	15.71		6.9	0.98	0.19
	2BCb	98 -- 108	33.9	52.4	13.7	9.00	1.11	1.39	13.02		6.7	0.84	0.15
TA-67-E-2-1	E/Blb1	108 -- 117	32.8	58.2	9.0	1.30		1.78	11.86		7.4	0.94	0.15
	E/Bt2b1	117 -- 124	30.7	52.1	17.2	4.20		0.21	13.32		7.5	0.80	0.17
	Bt1b1	124 -- 139	27.6	48.8	23.7	0.90		0.41	15.59		7.2	1.11	0.16
	Bt2b1	139 -- 165	30.5	49.2	20.3	1.70		0.49	13.39		7.2	1.26	0.19
	Blkb1	165 -- 195	41.6	43.0	15.5	6.30		1.08	10.65		7.3	0.98	0.22
	Blk1b2	195 -- 222	39.6	23.8	36.6	1.40		0.49	14.54		7.3	0.89	0.17
	Blk2b2	222 -- 252	40.3	39.9	19.8	10.50		0.31	14.82		7.3	0.91	0.17
	Bt3b2	252 -- 272	55.8	26.2	18.0	7.50		0.23			7.3	1.07	0.15
	CR	272+	74.6	20.0	5.4	7.90		0.97			7.1	0.50	0.22
TA-67 E3	A	0 -- 14	20.3	52.2	27.5	4.00	1.36	0.86	7.79		6.1	0.91	0.28
	2BAb1	14 -- 22	15.2	55.7	29.1	4.90	1.55	1.27	17.06		6.1	1.12	0.31
	2Bt1b1	22 -- 40	16.1	59.5	24.5	16.30	1.56	0.73	19.85		6.5	1.17	0.34
	2Bt2b1	40 -- 50	28.1	54.3	17.6	11.10	1.25	0.42	17.90		7.1	0.98	0.28
	2BC1b1	50 -- 57	30.2	57.0	12.8	10.00	1.19	0.94	15.47		6.9	0.90	0.30
	2BC2b1	57 -- 67	35.0	52.6	12.4	10.40	1.23	0.20	18.15		7.0	0.94	0.29
	3Bt1b2	67 -- 76	34.0	55.0	10.9	5.90	1.24	0.47	36.35	1.67	7.2	0.84	0.24
	3Bt2b2	76 -- 87	33.1	51.4	15.6	2.20	1.76	0.03	32.53	1.4	7.5	1.02	0.22
	3Bt3b2	87 -- 101	34.0	43.8	22.3	8.50	1.75	0.27	24.41		7.2	1.08	0.30
TA-67 W1	A1	0 -- 6	35.5	51.8	12.7	6.80		3.37	11.04		5.3	0.83	0.15
	A2	6 -- 13	26.7	60.4	12.9	10.30		2.00	11.94		5.9	0.85	0.16
	A3	13 -- 23	27.4	56.7	15.9	11.20		1.65	12.45		6.2	0.89	0.18
	BA	23 -- 39	24.6	57.9	17.5	10.50	1.16	0.99	12.18		6.3	0.92	0.17
	Bw1	39 -- 65	19.8	47.3	32.9	14.00	1.12		11.31		6.4	0.97	0.23
	Bt1	65 -- 86	19.8	67.1	13.1	4.60	1.27	0.87	12.46		6.6	1.09	0.21
	Bt2	86 -- 109	28.7	55.4	16.0	18.10	1.25	1.16	12.58		6.7	0.99	0.16
	E/Bb	109 -- 120	33.6	59.7	6.8	4.90		0.23		0.71	7.3	0.93	0.11
	Btkb	120 -- 142	58.7	0.0	41.5	1.20		0.88	10.30	1.11	7.1	0.82	0.18
	Bt/Cr	142 -- 163	63.4	25.6	11.0	0.80		0.58	16.78		7.3	0.92	0.13

Table 4. Summary of physical and chemical soil characterization properties.

Soil Number	Horzon	Depth (cm)	Sand (% wt.)	Silt (% wt.)	Clay (%wt.)	Gravel (% wt.)	Bulk Density (g/cm3)	Organic Carbon (% wt.)	CEC (meq/100g)	Carbonate (% wt.)	pH	Dithionite Fe2O3 (%wt.)	Oxalolate Fe2O3 (%wt.)
TA-67 W5	A	0 -- 8	28.6	58.2	13.2	6.60	1.19	1.97	13.81		6.2	0.75	0.18
	BA	8 -- 26	21.0	59.5	19.5	1.60	1.28	1.10	11.84		6.7	0.88	0.19
	2Bt1b1	26 -- 44	18.2	59.2	22.5	3.30	1.32	1.10	14.33		7.0	1.01	0.25
	2Bt2b1	44 -- 59	18.7	60.8	20.4	32.10	1.41	0.87	17.65		6.7	1.07	0.22
	2Bt3b1	59 -- 79	32.4	51.9	15.7	22.10	1.27	1.05	21.94		7.6	0.89	0.19
	2BC1sb1	79 -- 107	39.2	30.7	30.1	18.40	1.04	0.37	30.18	0.9	7.3	0.84	0.19
	2BC2sb1	107 -- 124	45.3	41.1	13.7	35.70	1.09	0.43	30.08	1.23	7.4	0.77	0.21
	3BAb2	124 -- 136	34.9	57.1	8.0	4.30	1.73	0.43	15.13		7.6	0.63	0.16
	3Btb2	136 -- 145	32.3	46.1	21.6	14.40	1.61	0.31	32.00		7.2	0.61	0.14
	4CBt1b3	145 -- 168	70.1	14.5	15.4	0.10	1.38	0.42	17.26		7.4	0.42	0.09
	4CBt2b3	168 -- 186	72.6	12.7	14.7	23.10		0.51	22.76		7.6	0.42	0.11
	4C1b3	186 -- 194	73.6	11.5	15.0	46.80		0.37	25.31		7.3	0.59	0.13
	4C2b3	194 -- 211	72.0	11.9	16.1	66.30		0.93	37.88		7.7	0.63	0.15

accumulation of organic material overlying a mineral soil (Birkeland, 1984). O horizons in Laboratory soils are generally thin (~1-3 cm) and largely consist of poorly decomposed pines needles, leaves, twigs, and other forest litter. An A horizon accumulates humified organic matter mixed with a much larger fraction of minerals. A horizons occur at the surface or below an O horizon. A horizons can also occur as thin disturbed soils horizons with minimal amounts of humified organic matter. Such horizons are common where surface activity (i.e. grazing, overland traffic) has compacted upper soil horizons or reuslted in partial strpping of the original A horizon.

The B horizon underlies an A horizon and shows little or no evidence of the original rock structure or sediment (Birkeland, 1984). The B horizon will often contain increases in phyllosilicate clay minerals, iron oxyhydroxides, organic coatings . These geochemically reactive phases may concentrate major and trace elements. The development of the B horizons is strongly influenced by illuvial processes relative to A or C horizons and primarily reflects the downward translocation of organic compounds, clay minerals, clay- and silt-sized particles, and other physical and chemical substances that have leached through and/or from the O and A horizons. B horizons in soils at the laboratory display a wide range of features and degrees of development. B horizons largely display characteristics resulting from several primary soil forming processes and types of illuvial material. Laboratory soils consists of (1) weakly developed B horizons ('w' subscrip, Table 4) that have minimal changes in physical and chemical properties relative to the parent material, (2) Clay-rich B horizons that have resulted in an increase in clay-sized material over time ('t' subscript, Table 4), and (3) B horizons that have been influence by the accumulation of calcium carbonate ('k' subscript, Table 4). B horizons can also form as transitional horizons (ie. BA, BC, Table 4) sharing physical and chemical attributes common to either A or C horizons.

Incipient E horizons are found in some Laboratory soils. E horizons are soil horizons that have been primarily influenced by strong leaching conditions where downward and/or lateral translocation of soil water has resulted in the partial removal of clay-sized material and coatings of iron oxides.

The C horizon is a subsurface horizon lacking properties of A and B horizons but may include minimal alteration of the parent material such as accumulation of silica and calcium carbonate, mineral alteration through oxidation and reduction processes, and gleying (Birkeland, 1984). C horizons are wide spread at the Laboratory consisting of slightly altered- and non-altered parent materials. Several soils across the Laboratory have R horizons. The R horizon consists of consolidated bedrock underlying soil horizons and is usually highly fractured but has undergone minimal chemical alteration.

Soil Stratigraphy

An important characteristic of many of the soils reported here, as well as across the Laboratory, is the complex soil stratigraphy that has resulted from one or more soils profiles that have been superimposed upon pre-exisitng (ie older) soil profiles. Complex soil profiles consists of a surface soil that may partially overlap underlying and now buried soils. Buried soils, when recognized, are described in a similar fashion to surface soils, but are denoted by the subscript "b" (Table 4). These types of soils are common in geomorphic environments where landscapes are episodically unstable over long periods of time, and in enviroments where eposidic additions of new sediment can be deposited across an exisitng soil and landscape.

The common occurrence of buried soils across the laboratory (Figures 2, 4 and 9) is particularly revelant to spatial variability of background geochemistry and to the transport and fate of numerous contaminants found at the Laboratory. First, B horizons of buried soils typically have the strongest degree of horizon development, including the highest concentrations of iron oxides and clay-sized material (Table 4). As a result, the proximity of these buried soil B horizons will directly influence the fate and transport of any surface and subsurface contaminants. In addition, where these horizons have been re-exposed at the surface due to recent erosion or excavations the degree of B horizon development may influence local background geochemistry.

Primary and Secondary Solid Phases and Parent Material

Variations in soil-elemental concentrations are related both to chemical characteristics of a particular soil horizon and to parent material. Primary major minerals and solid phases found in the Bandelier Tuff include tridymite, quartz, feldspar, and glass (Broxton et al., 1995). Minor and trace minerals consist of smectite, hornblende, mica, hematite, magnetite, kaolinite, allanite, chevkinite, and gypsum. Primary major minerals, secondary soil minerals, and solid organic matter occur within soil profiles sampled and characterized during this investigation. Secondary soil minerals include aluminum oxides, iron oxides, smectite, illite, kaolinite, calcite, gypsum, and manganese oxides. Some of the more important secondary soil phases with their associated trace elements include: Fe and Al oxides (Be, B, P, V, Mn, Ni, Zn, Mo, As, Se, U); Mn oxides (P, Fe, Co, Ni, Zn, Mo, As, Se, Pb); calcium carbonates (As, Se, P, V, Mn, Fe, Co, Cd, U); illites (B, V, Ni, Co, Cr, Cu, Zn, Mo, As, Se, Pb); smectites (B, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Pb, U); and organic matter (Al, V, Cr, Mn, Fe, Ni, Cu, Zn, Cd, Pb, U) (Sposito, 1989). These trace elements are chemically associated with solid phases through adsorption and coprecipitation reactions.

The Bandelier Tuff contains varying amounts of glass (0-88 wt%) (Broxton et al., 1995), which is the most soluble silicate phase and is of great

importance as a parent material. The fine size and glassy nature of the particles, as well as the high porosity and permeability of the Bandelier Tuff and related sedimentary deposits, enhance weathering and physicochemical and biological interactions in soils. Detailed mineralogical characterization of the soils found on the Pajarito Plateau will provide useful information regarding the stability of these trace minerals.

Clay-Size Material

The occurrence of clay-rich horizons are particularly relevant to the transport and fate of numerous inorganic and organic contaminants found at the Laboratory. Variation in clay-sized material (less than 2 micrometers) is significant within the soils (Figure 10) and subsequently, the extent of contaminant mobility varies depending on the presence of geochemically reactive phases, including clay minerals, iron oxides, solid organic matter, and carbonate minerals. Clay-rich horizons typically alter the local hydrologic environment by providing low permeability and low hydraulic conductivity zones, increasing the water-holding capacity of the horizon and contributing to an overall increase in the degree of chemical weathering (Sposito, 1989; McBride, 1994).

Clay-size material in all the soil samples ranges from 0.7 weight percent (wt%) (AC-1) within a C horizon to 50 wt% (TA-16-2) within a Bt horizon (Table 4). The content of clay-size material can also vary significantly throughout any one soil profile (Table 4; Figures 11-14). This size fraction, however, is heterogeneous in mineralogy and does not entirely consist of phyllosilicate clay minerals. The clay-size fraction is characterized by the smallest particle diameters having relatively large surface areas, which is an important factor in controlling the extent of adsorption of trace elements (Sposito, 1994).

Heterogeneity in the clay-size material (either vertically within one soil or spatially among different soils) can reflect variations in parent material, age, topography, eolian input, and degree of chemical weathering (Longmire et al., 1995; Birkeland, 1984; Sposito, 1989; and McBride, 1994). Clay minerals may be concentrated in B horizons resulting in an increase in clay content relative to the original parent material by downward translocation of material from overlying horizons and by *in situ* formation of clay minerals due to mineral weathering and transformations occurring within the soil environment. Clay minerals may form in Laboratory soils from the enrichment of Al_2O_3 and depletion of SiO_2 from hydrolysis reactions involving glass and framework silicates. Authigenic and translocated kaolinite and smectite are observed in soils and fracture fill material at the Laboratory (Davenport, 1993). The clay mineralogy may be related to original composition or stratification of the parent material. Clay-sized material (as well as sand- and silt-size material) can be added to the soils from atmospheric additions of dust. Spatial variability in the content of clay-sized material can also

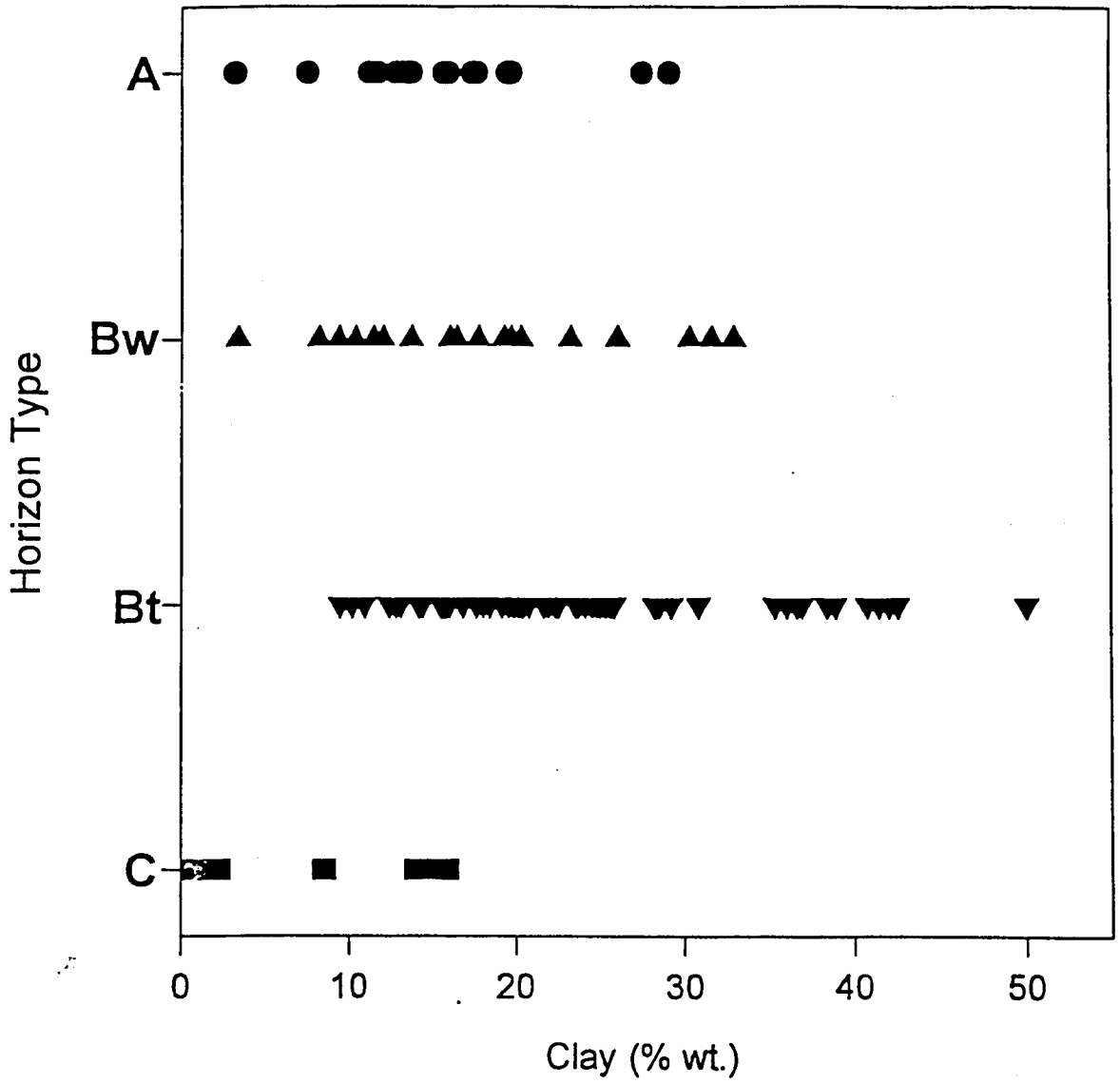
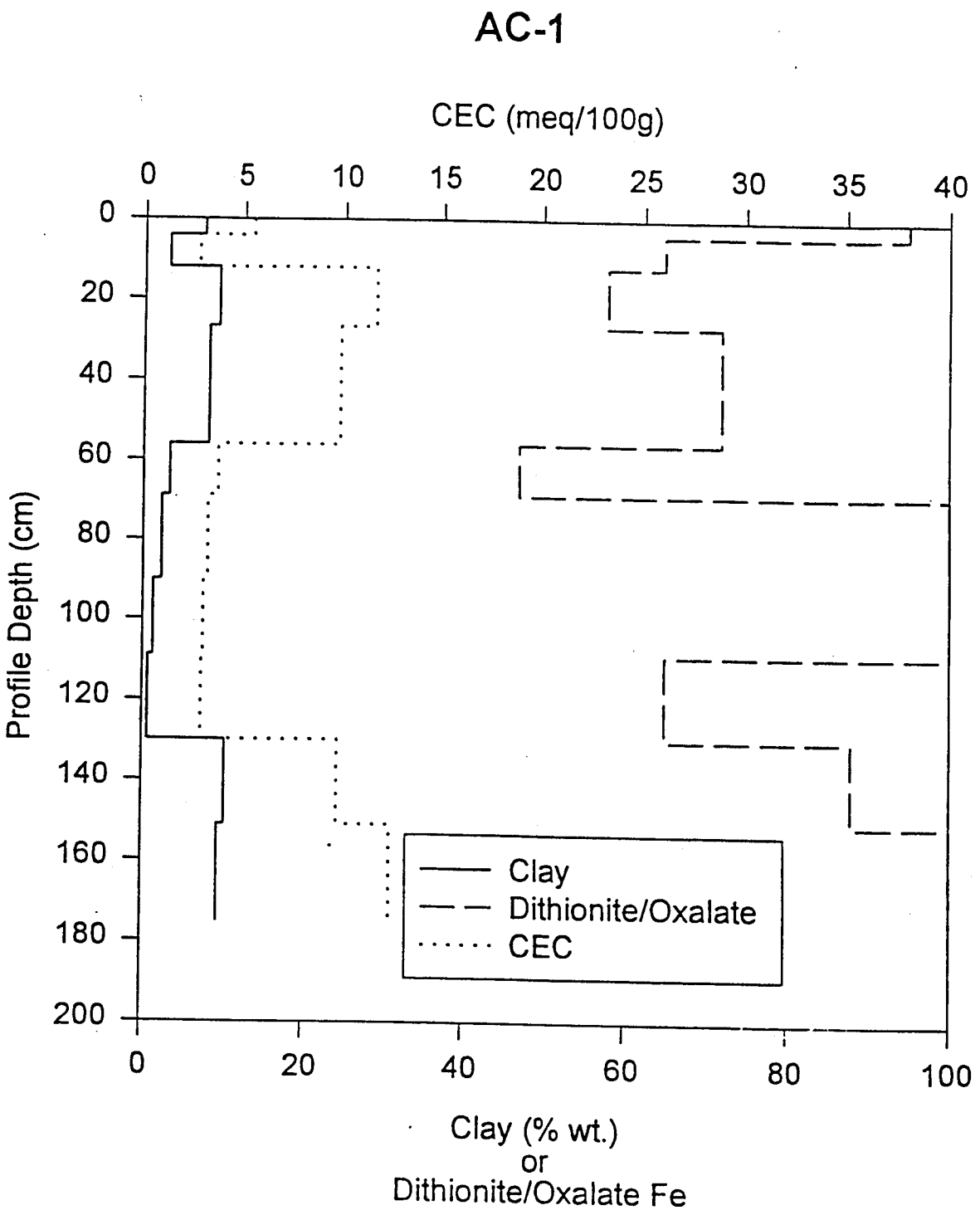


Figure 10. Variation in % wt. clay contents for dominant genetic soil horizons.



Figure//. Profile distribution of cation exchange capacity (CEC), % wt clay, and ration of oxalate to dithioninte extractable Fe oxides.

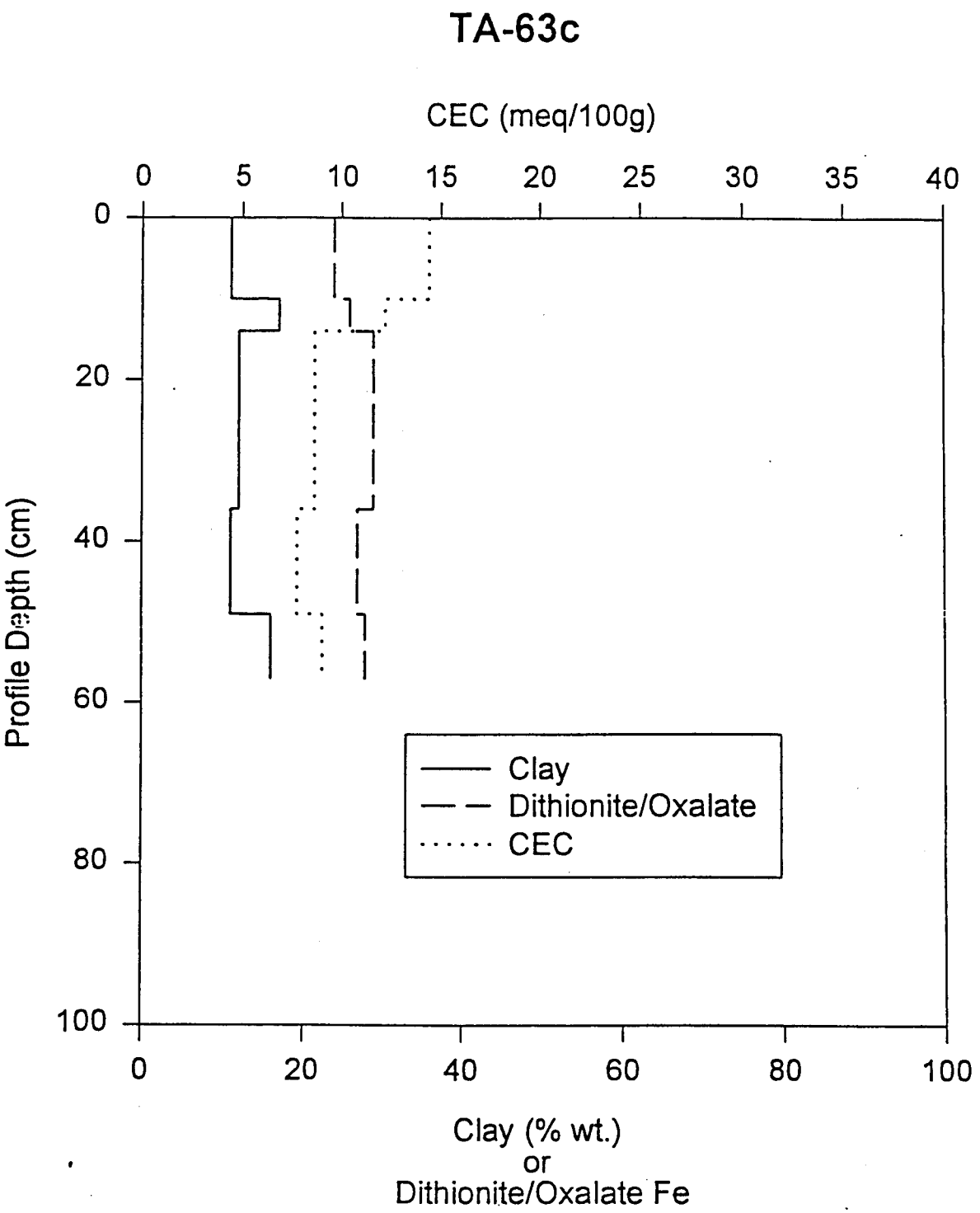


Figure 12. Profile distribution of cation exchange capacity (CEC), % wt clay, and ration of oxalate to dithioninte extractable Fe oxides.

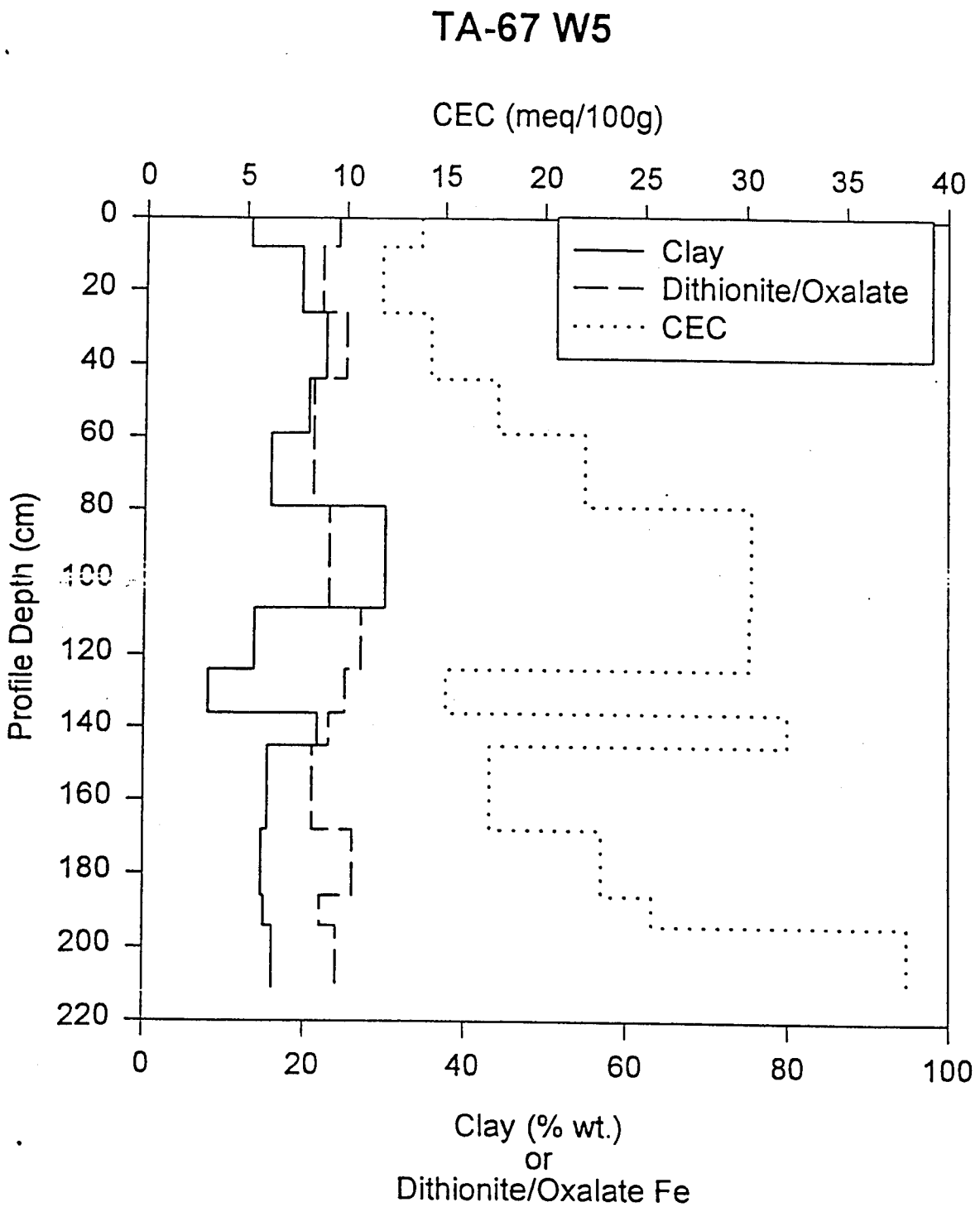


Figure B. Profile distribution of cation exchange capacity (CEC), % wt clay, and ration of oxalate to dithioninte extractable Fe oxides.

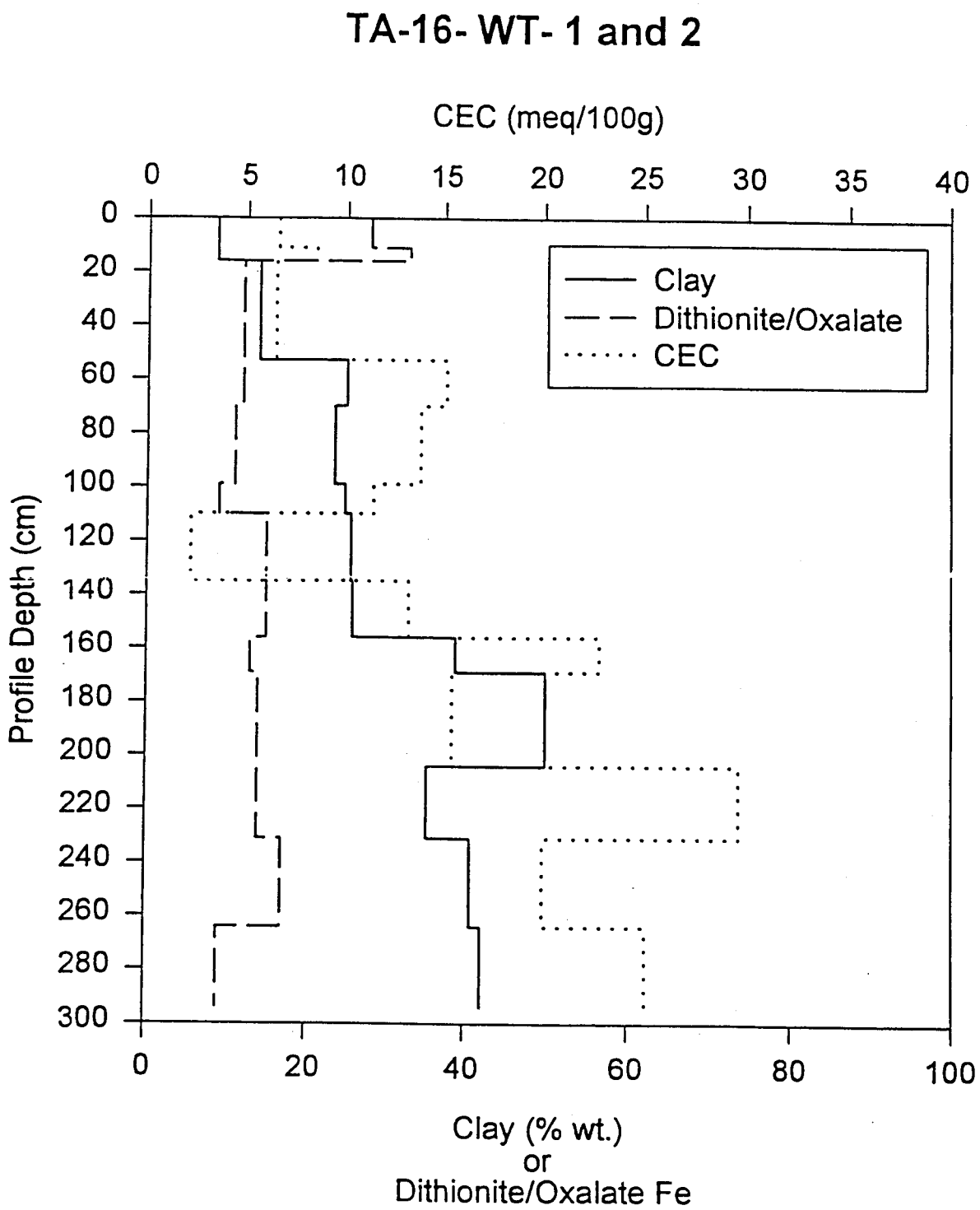


Figure 14. Profile distribution of cation exchange capacity (CEC), % wt clay, and ration of oxalate to dithioninte extractable Fe oxides.

be due to variations in the clay content of the parent material. Such variations in clay content frequently occur in soils derived from colluvial or alluvial deposits.

Soil pH

Laboratory-determined soil pH values range from 5.0, for a sample obtained from an A horizon (WC-1) to 7.6 for two samples collected from B and C horizons at (TA-67 W1; Table 4). Solid organic carbon, possibly present as humic and fulvic acids, is concentrated in A horizons containing carboxylic acids that deprotonate under moderately acidic (4.5) conditions (Thurman, 1985; Stevenson, 1994). Other organic acids with pka ($-\log_{10}$ dissociation K for the acid) values ranging from 3 to 7 may also control soil pH within the A horizons. This deprotonation results in acidic pH conditions within A horizons. In addition, enhanced biological activity in A horizons produces a high partial pressure of CO_2 gas, which reacts with soil-pore water and thereby decreases soil pH (Drever, 1988). Soils that have higher pH values (7.0-8.2) can be primarily attributed to the presence of calcium carbonate (Bk) horizons (Table 4). Soil pH is an important parameter that controls precipitation-dissolution (Lindsay, 1979)and adsorption-desorption reactions (Sposito, 1984), which is addressed in the section on trace element geochemistry.

Calcium-Carbonate Content

Calcium carbonate content of the soils is variable, ranging from 0.1 wt% in a Bt2b1 horizon at TA-67 W5 to 6.6 wt% in a Btk2 horizon at TA-63-1A (Table 4). Most soil horizons have no measurable calcium carbonate. Most of the calcium carbonate found in soils in the southwestern US and on the Pajarito Plateau probably originates from wind-blown or atmospheric sources (Gile et al., 1966; Watt and McFadden, 1992). Carbonate chemistry is important in controlling soil pH; in providing active adsorption sites for anionic and cationic adsorbates; providing ligands for metal complexing, especially for uranyl (U(VI)) (Langmuir, 1978; Brookins, 1988); in enhancing the stability of smectite characterized by a high cation exchange capacity (CEC); and in controlling hydraulic conductivity. Calcium carbonate is an important adsorbent for cations (Cd^{2+}, Zn^{2+}, Mn^{2+}, Co^{2+}, Ni^{2+}, Ba^{2+}) and anions (PO_4^{3-}, SeO_3^{2-}, and possibly $UO_2(CO_3)_2^{2-}$), where solution pH and calcium carbonate concentration are the most important factors controlling adsorption processes (Zachara et al., 1993).

Cation Exchange Capacity

Cation exchange capacity (CEC) in the sampled soils ranges from 2 to 43 milliequivalents/100 grams soil (meq/100 g) (Table 4), which is reflective of the different types and amounts of clay minerals and variations in organic matter conent in these soils. Because B horizons generally have the highest clay mineral content, they also generally have the highest CEC (Figures 11-14). Higher CEC values are associated with 2:1 (octahedral: tetrahedral layers) clay minerals such as smectite or mixed-layer smectite, whereas the lower CEC values are representative of 1:1 clay minerals including kaolinite (Sposito, 1989; McBride, 1994). Clay minerals with higher CEC values are geochemically more reactive (larger surface area) than those with lower CEC values. Clay minerals and other adsorbents with larger surface areas have higher adsorption capacities compared to clay minerals with smaller surface areas (Sposito, 1984, 1989; McBride, 1994).

Solid Organic Carbon

Solid organic carbon (SOC) content ranges from 0.03 to 17.3 wt% for soil samples characterized during this investigation (Table 4). Values greater than about 1.5-2 wt% are unlikely in soils formed in semi-arid environments and under forest conditions (Sposito, 1989; Soil Survey Staff, 1981). High values of SOC reported here and in Watt (1995) are probably a result of laboratory error. The measured SOC content typically is highest in the A horizons where accumulation of humified organic matter is a dominant soil process. In general, soil profiles described on mesa tops at higher elevations with cooler temperatures tend to have higher SOC content than soil profiles described in Ancho and Water Canyons at lower elevations.

Bulk Density

Measured soil bulk density ranges from 1.04 g/cm^3 (TA-67 W5) to 1.79 g/cm^3 (TA-16-2; Table 4). Bulk density is generally higher for Bt horizons and gravel-rich horizons and lowest for weakly developed Bw horizons and A horizons.

Extractable Iron Oxyhydroxides

Results of oxalate and dithionite Fe extractions performed on soil samples collected during this investigation are provided in Table 4. Dithionite extraction largely removes all iron oxide coatings ($Fe(OH)_3$) including well developed crystalline forms (α-FeOOH, Fe_2O_3) whereas the oxalate extraction

largely removes amorphous forms of iron oxides, including amorphous $Fe(OH)_3$ and magnetite (Fe_3O_4) largely associated with poorly crystalline forms of iron oxide (i.e. ferrihydrite) (Schwertmann and Taylor, 1989).

Iron removed from Laboratory soils during the oxalate extraction (reported as mean wt% Fe_2O_3) ranges from 0.09 wt% in a Bt2b1b horizon at TA-16-2 to 0.77 wt% in a Bw horizon at TA-63-1A (Table 4). Iron removed from Laboratory soils during the dithionite extraction (reported as mean wt% Fe_2O_3) ranges from 0.26 wt% in a C' horizon (AC-1) to 1.41 wt% in a C2b1a horizon (WC-2; Table 5). Several fracture fillings sampled at TA-63 contained 0.83 to 1.41 wt% Fe_2O_3 using the dithionite extraction method (Table 4).

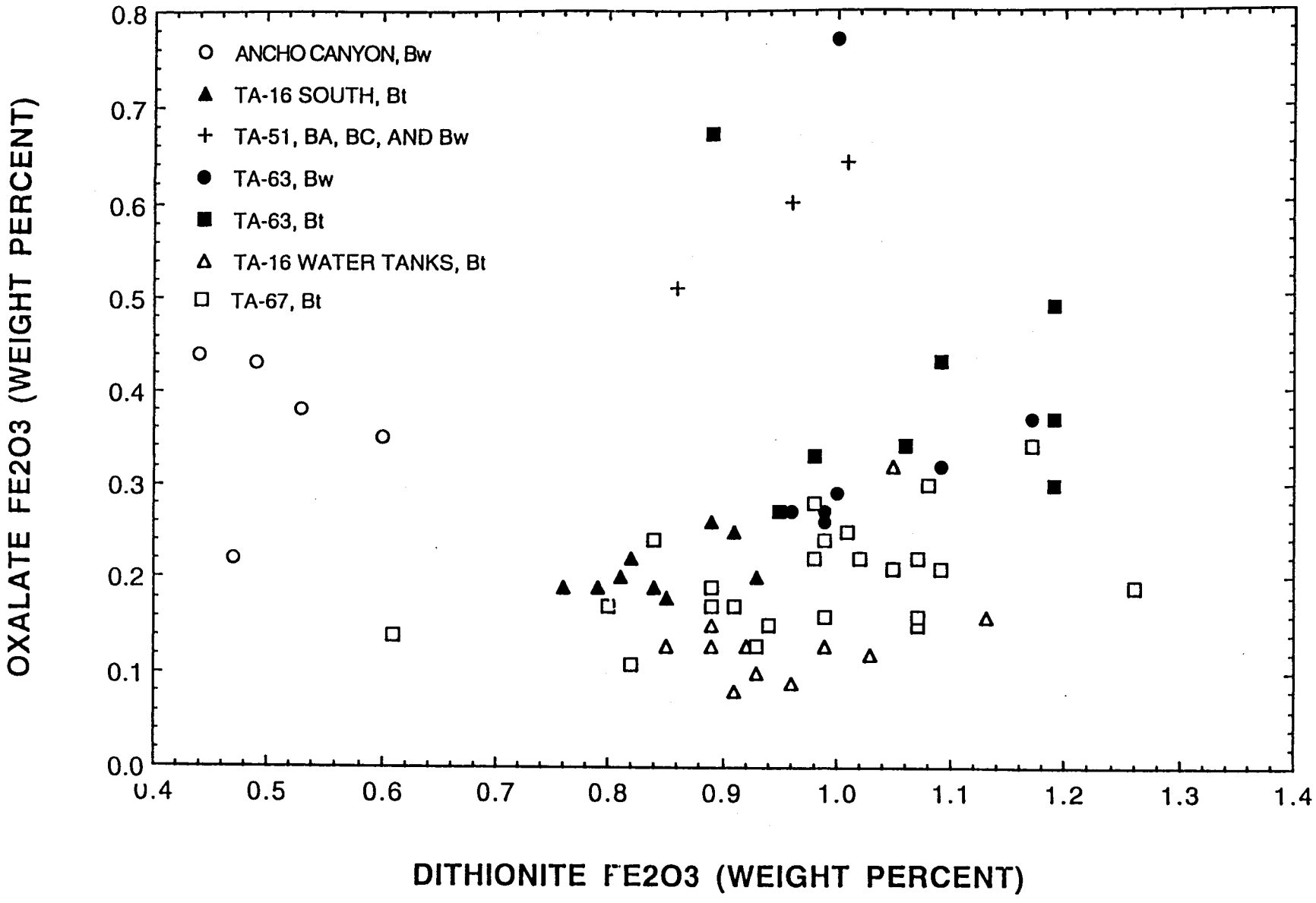
Oxalate- and dithionite-extracted Fe makes up varying percentages of the total Fe in soil samples collected during this investigation. Higher percentages of Fe were extracted from well-developed soil profiles containing one or more B horizons than from the less developed-soils (Table 4), indicating a greater abundances of iron oxides and iron oxyhydroxides in the well-developed soils. The ratio of dithionite/oxalate extractable iron oxides generally represents the relative proportions of amorphous forms of iron oxides with better developed, cystalline forms of iron oxides. With time and increased degrees of soil formation, poorly crystalline forms of Fe oxides are transformed into more developed crystalline forms. In general, weakly developed soil Bw horizons have higher quantities of amorphous froms of iron oxides relative to more developed soil Bt horizons (Figures 11-14).

Figure 15 shows distributions of dithionite- and oxalate-extracted Fe (reported as Fe_2O_3) for different B horizons characterized during this investigation. Soil samples collected from Ancho Canyon are chemically distinct from the mesa top soils. The Ancho Canyon soils have a greater percentage of oxalate-extracted Fe, mainly consisting of amorphous $Fe(OH)_3$, with lower concentrations of dithionite-extracted Fe relative to the mesa top soils. The mesa top soils, however, contain higher amounts of dithionite-extracted Fe, suggesting that higher concentrations of crystalline Fe oxide (Fe_2O_3) and Fe oxyhydroxide (α-FeOOH) occur in these more developed soils. In general, samples collected from the Bt horizons contain lower percentages of oxalate-extracted Fe than do samples collected from the Bw horizons.

GEOCHEMISTRY OF SELECTED TRACE ELEMENTS

Trace-element geochemistry of each soil profile (associated with the < 2mm soil fraction) varies as a function of soil age, mineralogy of soil and parent material, the amount and composition of eolian dust and other forms of aerosols, degree of chemical weathering, and hydrology. General discussions of the geochemical characteristics of trace elements are provided by Longmire

FIGURE 15. B HORIZONS, BACKGROUND SOILS, LOS ALAMOS.



et al. (1995). This section focuses on geochemical distributions of As, Be, Fe, U, and Th within A, B, and C horizons.

Concentration distributions, including minimum, arithmetic mean, and maximum, for several analytes (elements) within A, B, C horizons are shown in Figures 16, 17, and 18, respectively. Analytical results of soil samples digested by HNO_3 prior to chemical analyses, using EPA-SW846 analytical methods (3050), are shown in these figures. Concentration units are ppm for the elements shown in Figures 16, 17, and 18 excluding Al and Fe, which are reported as wt%. The number of samples collected from each horizon varies and most samples were collected from B horizons (n=111) during this investigation, which are geochemically important because of element enrichment. Smaller numbers of samples were collected from the A (n=17) and C horizons (n=16). Concentrations of most of the elements are log-normally distributed in the soil horizons and the log-normal mean is greater than the arithmetic mean. Ranges in element distribution can exceed a factor of ten for most of the elements plotted on Figures 16, 17, and 18. These figures can be used to compare element concentration ranges with site-specific soil data, provided that the local soil horizon(s) is known.

Figure 19 shows mean-element concentrations (HNO_3 digestion) within A, B, and C horizons for Laboratory soils. In general, the B horizons contain higher concentrations of most trace elements (Al, As, Ba, Be, Cr, Fe, Ni, Th, Tl, and V) relative to A and C horizons. This trace-element enrichment within B horizons is most likely due to the presence of geochemically-reactive phases, primarily clay minerals and iron oxides. The A horizons sampled during this investigation contain higher concentrations of Co, Pb, and U (anthropogenic) relative to the B and C horizons, and the C horizons have higher concentrations of Tl relative to the A and B horizons.

Arithmetic mean and ranges for analyte concentrations (HF and HNO_3 digestions) within A, B, and C horizons are provided in Table 5. Generally, these data agree well with soil data reported from other sources summarized in Tables 6 and 7, including Longmire et al. (1995), Ferenbaugh et al. (1990) for Sigma Mesa on the Pajarito Plateau, and Schacklette and Boerngen (1984) for many different locations in the United States. Laboratory soils contain higher concentrations of Th and U (Table 6) relative to other soils listed in Tables 6 and 7, which is a result of local parent material at the Laboratory derived from U- and Th-rich volcanic rock. Anthropogenic sources of U from firing sites, however, apparently contribute to elevated U concentrations within A and several B horizons at TA-51, TA-63, and TA-67 (Table 5). Laboratory soils generally fall within the range of elemental concentrations reported elsewhere in the United States (Schacklette and Boerngen,1984, Table 7), although the mean values for Laboratory soils are higher for some elements.

FIGURE 16. A HORIZONS, BACKGROUND SOILS, LOS ALAMOS.

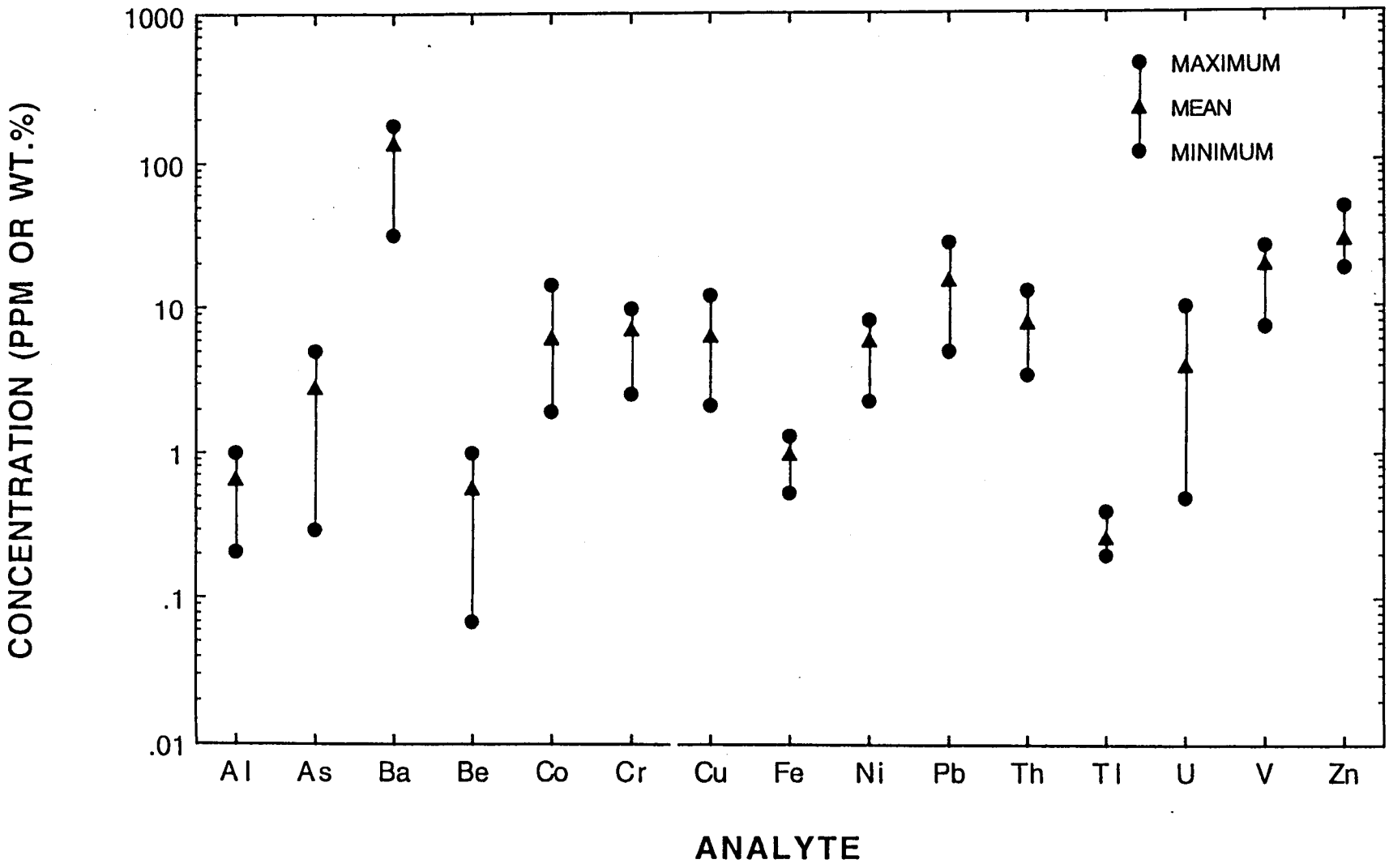


FIGURE 17. B HORIZONS, BACKGROUND SOILS, LOS ALAMOS.

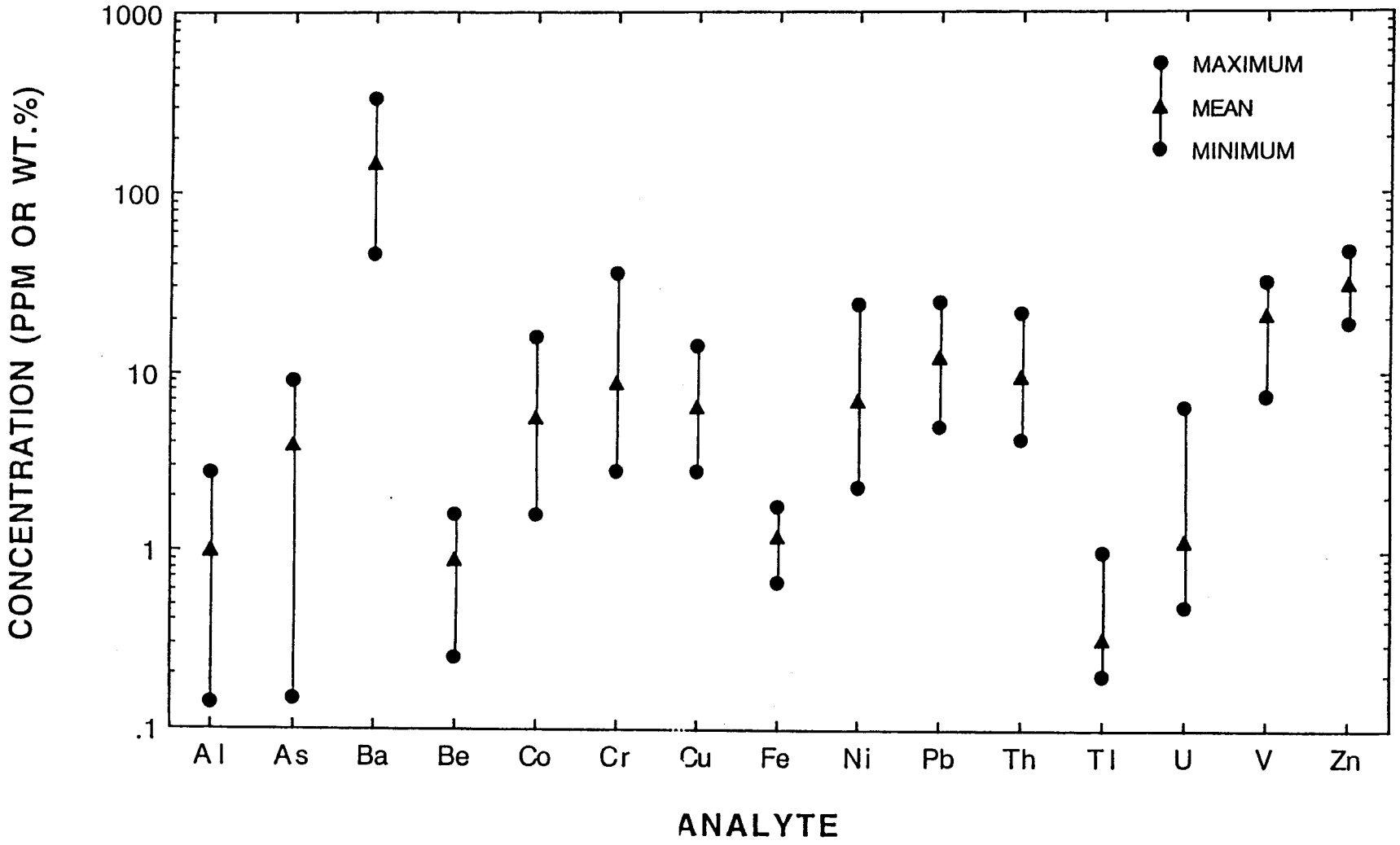


FIGURE 18. C HORIZONS, BACKGROUND SOILS, LOS ALAMOS.

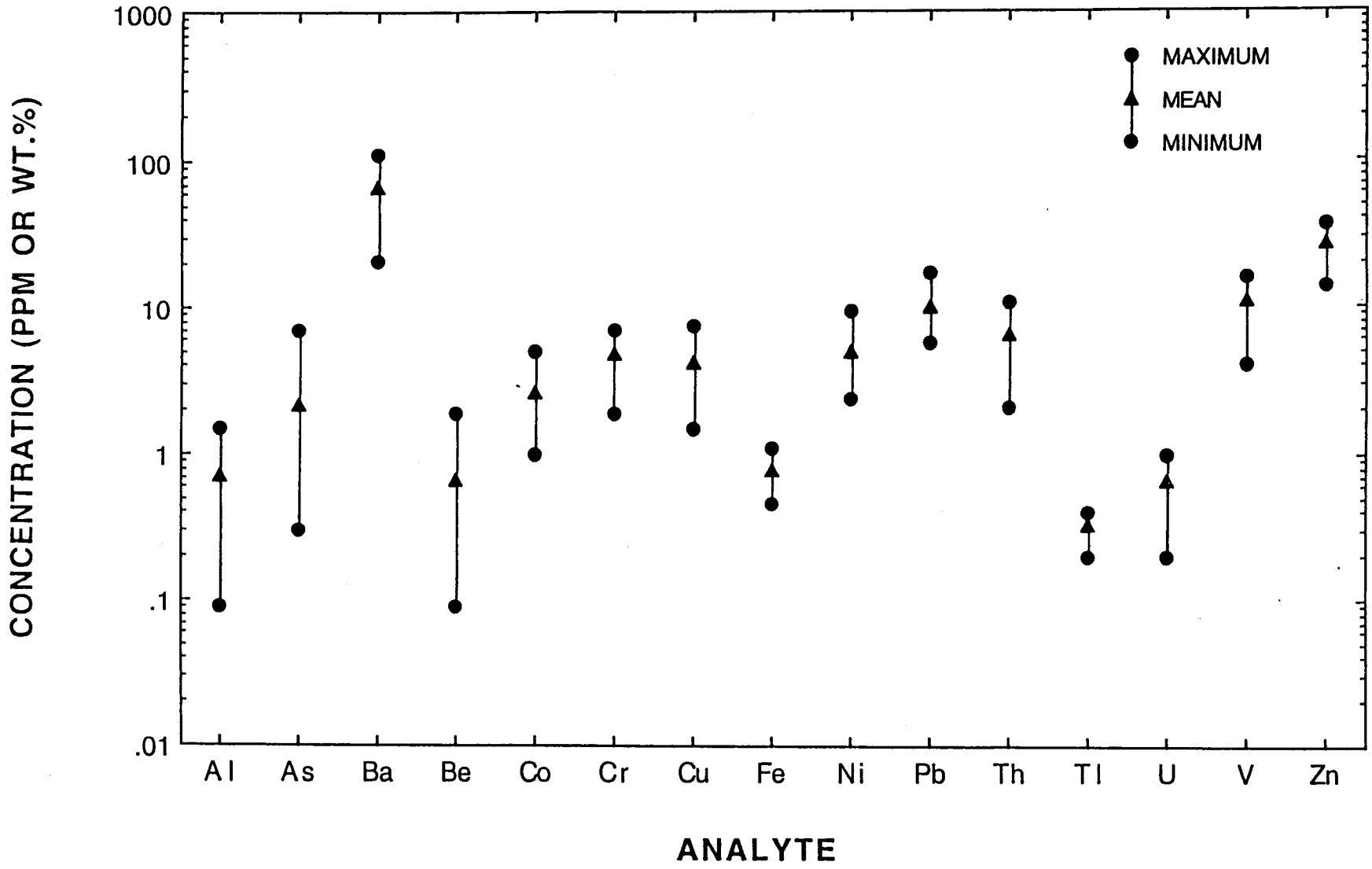


FIGURE 19. MEAN CONCENTRATIONS, BACKGROUND SOILS, LOS ALAMOS.

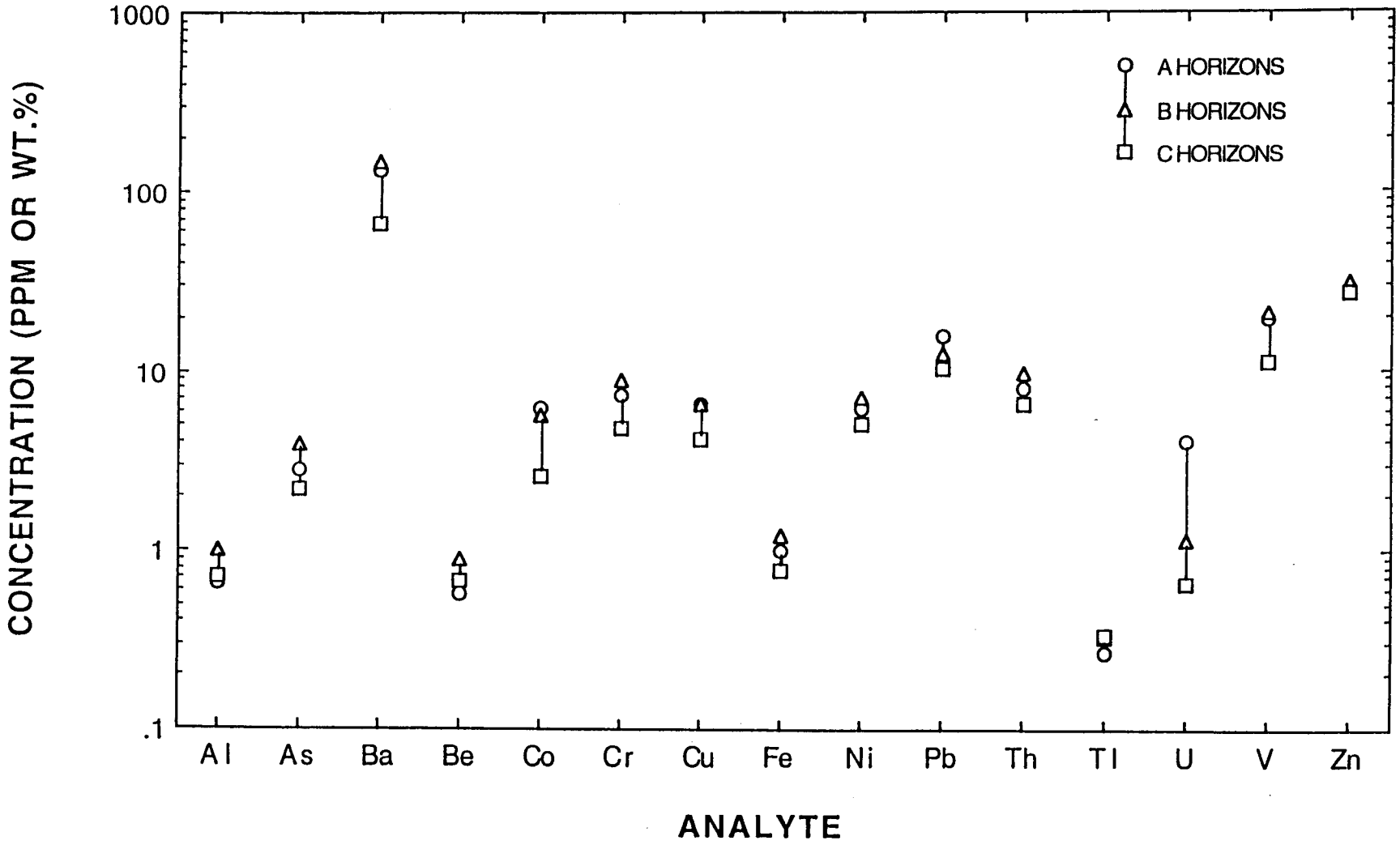


TABLE 5. Background Elemental Concentrations in A Horizons at Los Alamos, NM.

	Nitric Acid Dissolution (EPA-SW846)			Hydrofluoric Acid Dissolution		
Element[a]	Number of Samples	Mean	Range	Number of Samples	Mean	Range
Al (wt.%)	16	0.65	0.21- 1.00	14	4.92	2.10 - 6.30
Sb	3	0.37	0.20 - 0.50	16	0.92	0.50 - 0.92
As	14	2.76	0.30 - 5.00	14	8.20	0.90 - 18.0
Ba	16	134	32.0 - 180	14	549	200 - 650
Be	16	0.59	0.07 - 1.00	14	2.02	1.40 - 2.40
Cr	16	7.22	2.50 - 9.80	14	23.1	5.50 - 31.0
Co	16	6.16	1.90 - 14.0	14	10.1	0.79 - 13.0
Cu	16	6.44	2.10 - 12.0	14	9.83	1.90 - 17.0
Fe (wt.%)	16	0.99	0.54 - 1.30	14	1.76	1.30 - 2.30
Pb	16	15.3	5.00 - 37.0	14	24.6	7.50 - 37.0
Mn	16	439	240 - 950	14	523	370 - 680
Ni	13	6.06	2.30 - 8.30	13	9.56	4.40 - 13.0
Tl	12	0.27	0.20 - 0.80	16	0.69	0.20 - 0.80
Th	16	7.83	3.50 - 12.8	17	14.5	8.50 - 22.6
U	17	3.97	0.50 - 9.90	15	8.11	3.00 - 17.7
V	16	19.1	7.40 - 26.0	14	47.4	15.0 - 62.0
Zn	16	28.1	18.0 - 47.0	14	49.4	41.0 - 58.0

[a]Data are reported in parts per million (ppm) unless otherwise noted.

TABLE 5. Background Elemental Concentrations in B Horizons at Los Alamos, NM.

	Nitric Acid Dissolution (EPA-SW846)			Hydrofluoric Acid Dissolution		
Element[a]	Number of Samples	Mean	Range	Number of Samples	Mean	Range
Al (wt.%)	111	0.98	0.14- 2.70	107	5.70	2.00 - 8.10
Sb	16	0.41	0.20 - 1.00	111	0.97	0.30 - 2.60
As	94	3.87	0.30 - 9.00	105	10.1	0.50 - 25.0
Ba	111	148	46.0 - 340	106	519	220 - 810
Be	111	0.89	0.25 - 1.60	105	2.32	1.30 - 2.32
Cr	106	8.90	2.80 - 36.0	106	24.8	11.0 - 46.0
Co	111	5.64	1.60 - 16.0	106	9.14	2.30 - 25.0
Cu	111	6.54	2.80 - 14.0	106	9.90	3.00 - 20.0
Fe (wt.%)	111	1.20	0.68 - 1.80	106	2.09	1.40 - 3.60
Pb	110	12.3	5.00 - 25.0	106	22.4	7.60 - 47.0
Mn	110	362	150 - 1,000	107	489	260 - 1,600
Ni	108	6.95	2.30 - 24.0	104	12.4	4.00 - 43.0
Tl	72	0.32	0.20 - 1.00	112	0.76	0.50 - 1.30
Th	112	9.53	4.20 - 21.6	111	16.5	10.0 - 27.6
U	112	1.13	0.50 - 6.40	112	4.01	1.00 - 11.9
V	111	20.8	7.40 - 32.0	106	50.4	23.0 - 69.0
Zn	110	31.3	19.0 - 47.0	107	60.0	26.0 - 130

[a]Data are reported in parts per million (ppm) unless otherwise noted.

TABLE 5. Background Elemental Concentrations in C Horizons at Los Alamos, NM.

	Nitric Acid Dissolution (EPA-SW846)			Hydrofluoric Acid Dissolution		
Element[a]	Number of Samples	Mean	Range	Number of Samples	Mean	Range
Al (wt.%)	14	0.71	0.09-1.50	13	5.02	2.60 - 7.40
Sb	0	-	-	15	0.63	0.30 - 1.20
As	13	2.17	0.30 - 7.00	13	8.92	3.00 - 14.0
Ba	14	66.7	21.0 - 110	13	278	150 - 620
Be	12	0.67	0.09 - 1.90	13	2.67	1.00 - 4.40
Cr	14	4.79	1.90 - 6.90	13	13.9	4.90 - 31.0
Co	14	2.60	1.00 - 4.90	13	5.12	1.90 - 12.0
Cu	14	4.19	1.50 - 7.30	13	4.56	1.00 - 8.80
Fe (wt.%)	14	0.78	0.47 - 1.10	13	1.45	0.91 - 2.20
Pb	9	10.1	5.60 - 17.0	13	20.1	4.40 - 30.0
Mn	14	194	82.0 - 440	13	348	200 - 550
Ni	7	4.99	2.40 - 9.20	13	7.61	2.30 - 17.0
Tl	3	0.33	0.20 - 0.40	15	0.64	0.30 - 1.00
Th	14	6.55	2.10 - 10.3	15	14.4	7.80 - 19.0
U	14	0.66	0.20 - 1.00	15	3.77	1.70 - 4.90
V	14	10.9	4.00 - 16.0	13	26.2	9.00 - 44.0
Zn	14	26.8	14.0 - 37.0	13	57.8	33.0 - 76.0

[a]Data are reported in parts per million (ppm) unless otherwise noted.

TABLE 6. Background Elemental Concentrations in Soils at Los Alamos, NM (Longmire et al., 1995).

	Nitric Acid Dissolution (EPA-SW846)			INAA or DNAA (Uranium Only)		
Element[a]	Number of Samples	Mean	Range	Number of Samples	Mean	Range
As	72	4.9	0.5 - 13.6	67	5.04	1.20 - 10.81
Ba	72	176	24 - 730	75	459	125 - 829
Be	72	1.23	0.18 - 4.00		-	-
	75	[b]2.37	1.00 - 4.40			
Co	72	15.2	5.5 - 34	75	7.14	0.44 - 23.35
Cr	72	12.2	1.9 - 37.0	74	34.74	2.03 - 71.07
Cu	67	6.6	0.6 - 16.0		-	-
Fe (wt.%)	72	1.51	0.33 - 3.60	75	2.37	1.09 - 4.86
Ni	70	10.3	2.0 - 28.0		-	-
Pb	69	16.7	4.0 - 37.0		-	-
		[b]28.36	18.00 - 56.00			
Se	41	0.75	0.30 - 2.40		-	-
Th	72	7.1	0.6 - 15.0	75	16.06	10.09 - 27.30
Tl	40	0.42	0.20 - 0.90		-	-
U	72	0.94	0.20 - 2.40	75	3.41	1.54 - 6.73
V	72	26.6	4.0 - 56.0	72	48.95	11.54 - 113.10

[a]Data are reported in parts per million (ppm) unless otherwise noted.
[b]Hydrofluoric acid used in sample dissolution.

TABLE 7. Elemental Concentrations in Soil.

	Farenbaugh et al. (1990) Sigma Mesa, Los Alamos		Schacklette and Boerngen (1984) Random Locations, USA	
Element[a]	Mean	Range	Mean	Range
Al (%)	5.8	5.3 - 6.7	5.8	0.5 - >10
As	3.9	1.3 - 6.7	5.5	<0.1 - 97
Ba	410	120 - 810	580	70 - 5,000
Be	1.9	1.1 - 3.3	0.68	<1 - 15
Br	1.9	0.40 - 5.7	0.52	<0.5 - 11
Cd (ppb)	170	30 - 520	-	-
Cl	<100	-	-	-
Cr	27	4.2 - 136	41	3 - 2,000
Cu	10	2.0 - 18	21	2 - 300
F	240	50 - 390	280	<10 - 1,900
Fe (%)	1.7	1.0 - 2.6	2.1	0.1 - >10
Hg (ppb)	18	7.0 - 29	46	<10 - 4,600
Mn	510	330 - 840	380	30 - 5,000
Ni	8.9	1.6 - 19	15	<5 - 700
Pb	24	8.0 - 98	17	<10 - 700
Rb	120	90 - 160	69	<20 - 210
Th	-	-	9.1	2.4 - 31
Ti (%)	0.26	0.079 - 0.49	0.22	0.05 - 2.0
U	-	-	2.5	0.68 - 7.9
Zn	54	38 - 71	55	10 - 2,100

[a]Data are reported in parts per million (ppm) unless otherwise noted.

Element concentration distributions resulting from HF and HNO_3 digestions, including minimum, arithmetic mean, and maximum, for several analytes (elements) within A, B, and C horizons are shown in Figures 20, 21, and 22, respectively. Total sample digestion using HF generally results in higher elemental concentrations (maximum, mean, and minimum values) than partial digestion using HNO_3. Concentration ranges for As, Cr, Pb, U, and other analytes in the B horizons using the two digestion procedures overlap to a greater extent than other analytes collected within the A and C horizons. This suggests that these elements have been redistributed within the B horizons, possibly through translocation, precipitation, and adsorption processes, and concentrated in acid-soluble (pH 1) phases such as surface coatings.

Mean concentration ratios (HF/HNO_3 digestion) for several analytes (elements) of soil samples collected from A, B, and C horizons are shown in Figure 23. A higher concentration ratio for a given analyte suggests lesser amounts of leaching with HNO_3 and that an element, for example Al, is primarily concentrated within a silicate phase(s) that does not completely dissolve at pH 1. These phases include feldspars, glass, and other silicate and oxide minerals. Lower concentration ratios for certain elements (Fe, Ni, V) suggest that these elements are concentrated in one or more acid soluble phases such as clay minerals, calcium carbonate, and ferric hydroxide. Lower concentration ratios are observed for Al, Be, As, Ba, Cr and Th within the B horizons relative to the A and C horizons. This suggests that these elements may have been redistributed within the B horizons. Other elements including Pb, U, and Zn have lower concentration ratios within the A horizons relative to the B and C horizons, whereas Cu, Ni, and Tl have the lower concentration ratios in the C horizons. Iron and V are distributed evenly between the A, B, and C horizons and these elements are distributed at a ratio of 2:1.

Different trace elements shown in Figures 16 through 23 are distributed in B horizons possibly by the following processes (Longmire et al., 1995; Sposito, 1984, 1989): (1) trace elements that are concentrated primarily on surfaces of soil particles through chemical weathering, for example As and Be; (2) trace elements that remain concentrated within soil particle matrices consisting of primary minerals (silicates) and glass, for example Ni, Pb, Th, Tl, V, and Zn; and (3) trace elements that are distributed as a combination of processes (1) and (2), for example Ba, Co, Cr, Cu, Pb, and U. Process (1) is due mainly to adsorption of trace elements onto surfaces of clay minerals, iron oxides, solid organic matter, and calcium carbonate, whereas process (2) is dominated by incorporation within primary minerals and volcanic glass (Longmire et al., 1995; Sposito, 1984, 1989). Enrichment of As in soil correlates with soil development, specifically with the formation of B horizons containing iron oxides, clay minerals, and solid organic matter as possible dominant adsorbents (Longmire et al., 1995). Factors controlling extent of element

FIGURE 20. COMPARISON OF SAMPLE DIGESTION USING HF (TOTAL) OR HNO3 WITH ANALYTICAL TECHNIQUES (ICPES (Be, Cr, Pb),AA (As), AND ICPMS (Th, U)), A HORIZONS, LOS ALAMOS.

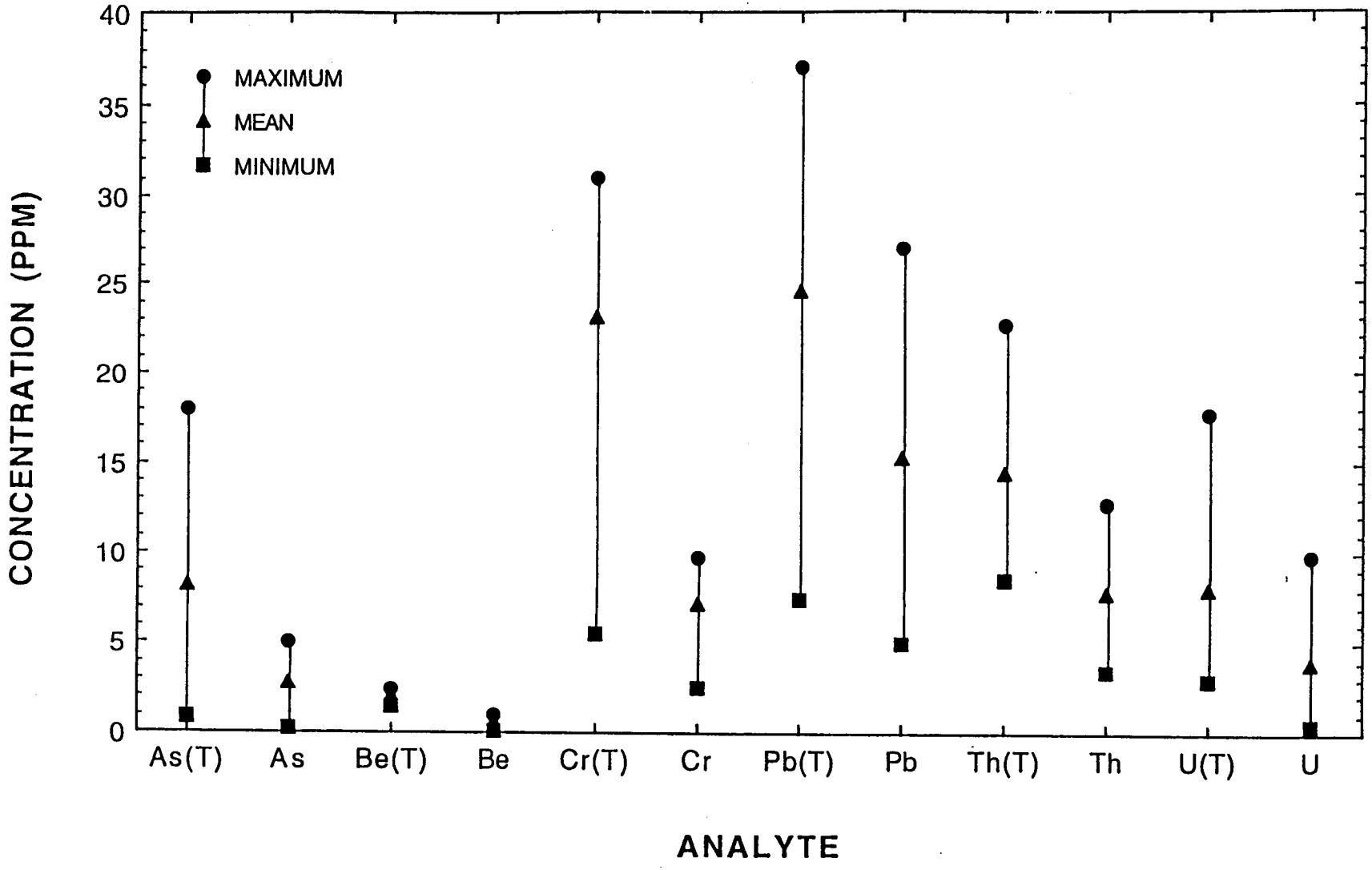


FIGURE 21. COMPARISON OF SAMPLE DIGESTION USING HF (TOTAL) OR HNO3 WITH ANALYTICAL TECHNIQUES (ICPES (Be, Cr, Pb), AA (As), AND ICPMS (Th, U)), B HORIZONS, LOS ALAMOS.

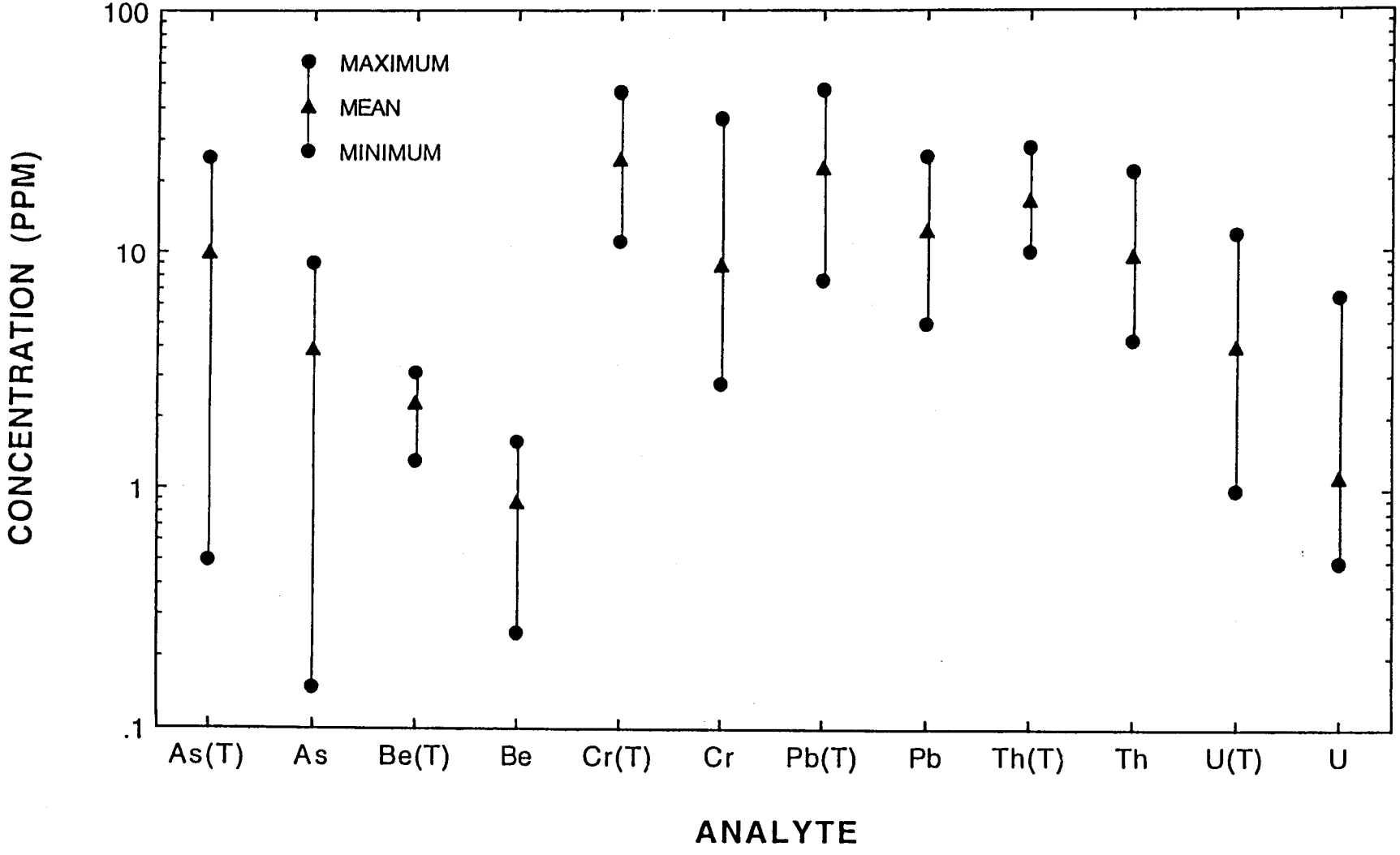


FIGURE 22. COMPARISON OF SAMPLE DIGESTION USING HF (TOTAL) OR HNO3 WITH ANALYTICAL TECHNIQUES (ICPES (Be, Cr, Pb), AA (As), AND ICPMS (Th, U)), C HORIZONS, LOS ALAMOS.

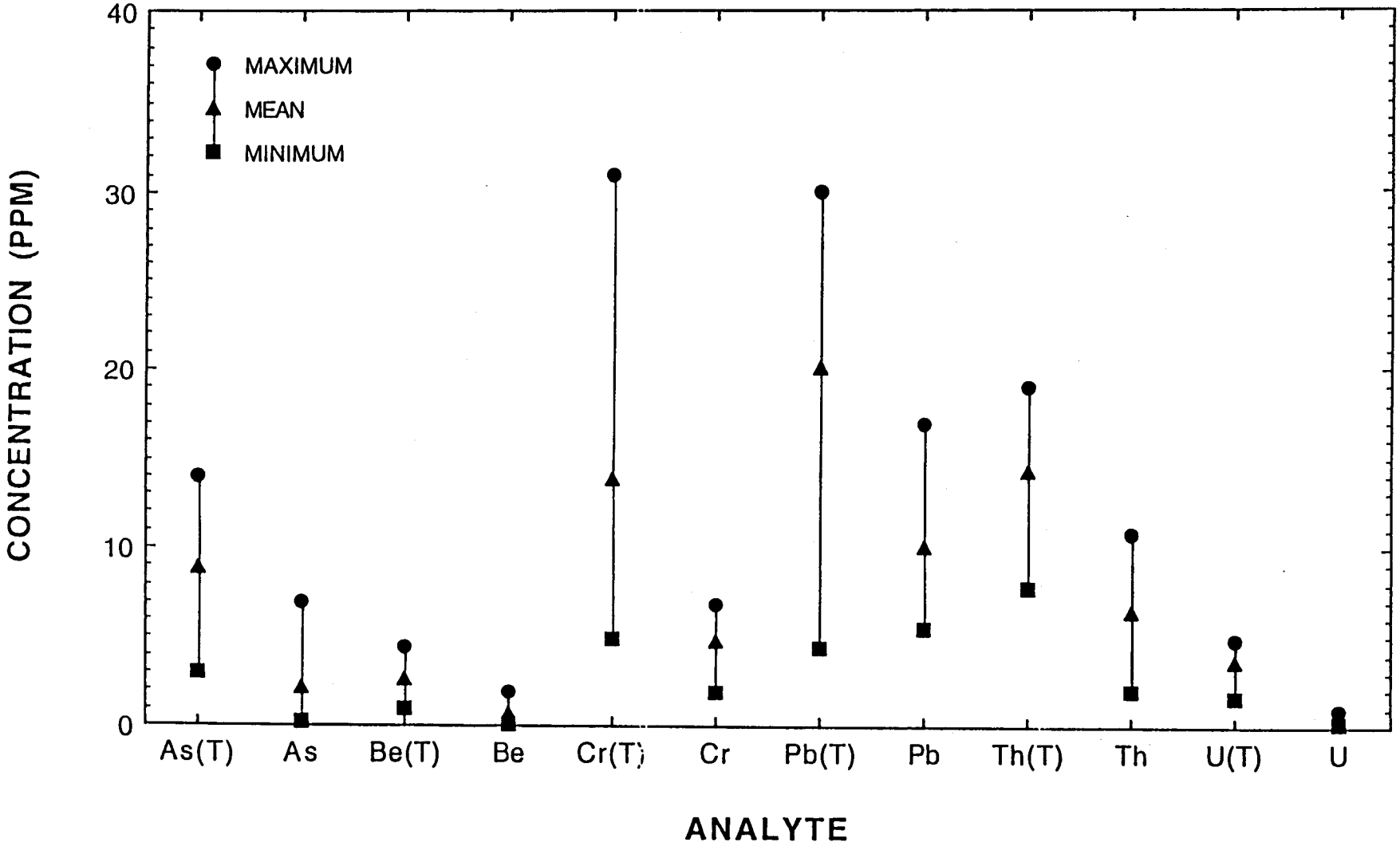
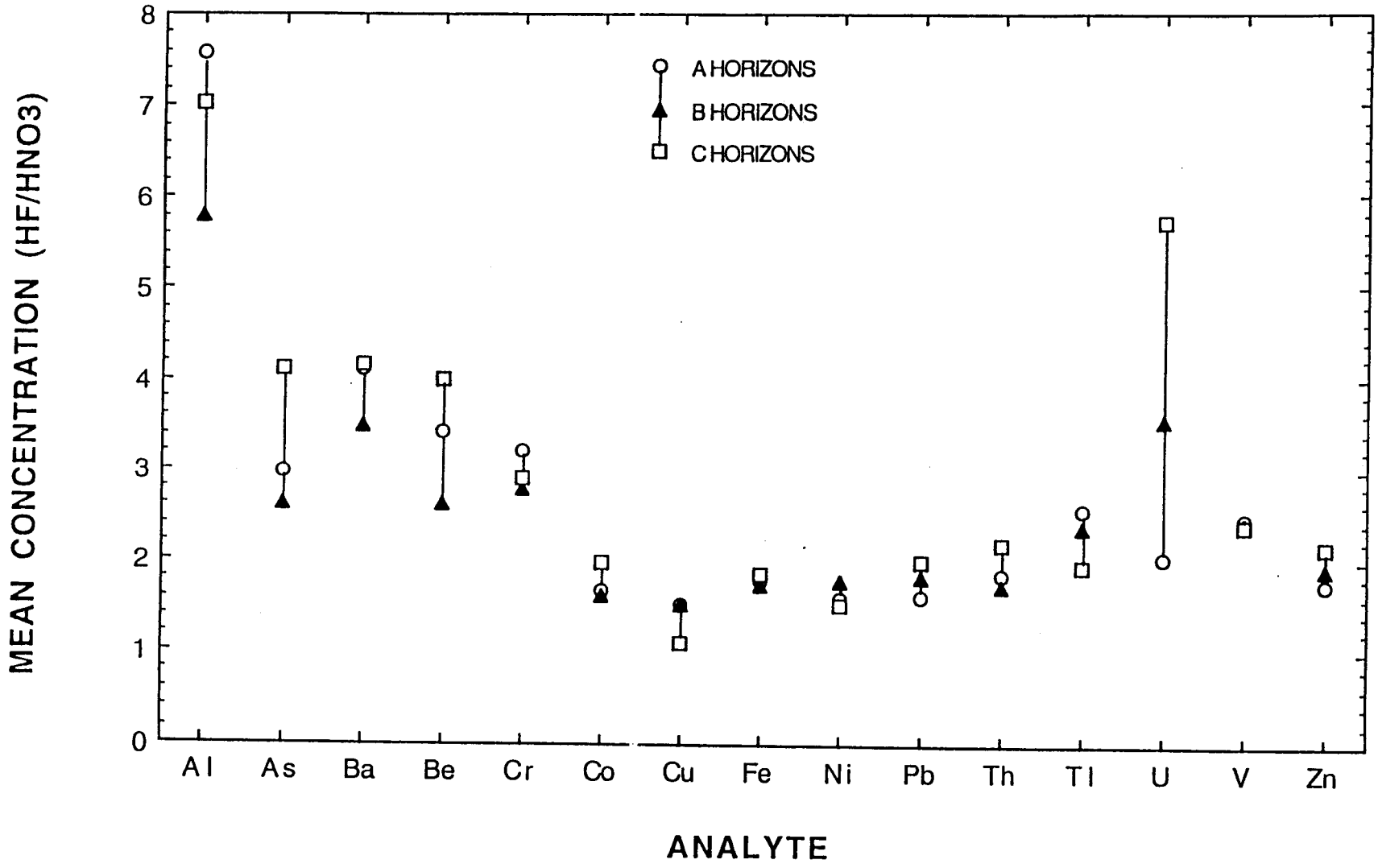


FIGURE 23. A, B, C HORIZONS, BACKGROUND SOILS, LOS ALAMOS.



leaching from primary soil phases include solid-state diffusion, solubility of the host phase, dissolution kinetics, solution flux, pH, Eh, and speciation of the trace element.

Arsenic, Beryllium, and Iron

Figures 24 and 25 are bivariate plots of Fe versus As and Fe versus Be, respectively, within several different types of B horizons characterized during this investigation. Overall, there is a strong correlation between Fe and As and Fe and Be and this correlation is discussed in the statistics section of this report. Soil profiles containing well developed B (Bt) horizons contain higher concentrations of As, Be, and Fe than do weakly developed B (Bw) horizons for mesa top and canyon bottom soils. The soil profile in Ancho Canyon is characterized by lower concentrations of these elements because this soil is less developed relative to the mesa top soils (Watt, 1995). Iron, in the forms of iron oxide, amorphous ferric hydroxide, and ferric oxyhydroxide, is an important soil constituent. In addition to As and Be, other trace elements including Cr, Mn, Ni, and other trace elements correlate well with Fe in the soil profiles characterized in this investigation and soil profiles described by Watt and McFadden (1992) and Longmire et al. (1995). Iron forms several sparingly soluble phases in soil, including $Fe_3(OH)_8$, amorphous $Fe(OH)_3$, and goethite (α-FeOOH), under different oxidation-reduction conditions. These solids are important adsorbents for many metals found at the Laboratory and elsewhere (Leckie et al., 1980; Hsi and Langmuir, 1985; Rai and Zackara, 1984).

Beryllium is an important element at the Laboratory because of its use in detonation of ballistics. Beryllium forms hydroxo complexes ($BeOH^+$, $Be(OH)_2^0$, and $Be(OH)_3^-$) above pH 6 (Rai and Zachara, 1984). There are very little data available on adsorption and precipitation/dissolution reactions of Be at low temperatures. Available thermochemical data suggest that β-$Be(OH)_2$ is moderately insoluble and this phase precipitates rapidly from solution (Rai and Zachara, 1984). There is some evidence that Be adsorption onto soil surfaces (iron oxides and clay minerals) is pH dependent. Column experiments conducted by Alesii et al. (1980) and Korte et al. (1976) show that Be was more strongly attenuated then were Zn, Cd, Ni, and Hg. Korte et al. (1976) suggest that calcareous soils high in clay minerals appear to be effective in Be retention.

Distributions of oxalate- and dithionite extracted Fe versus Be, in B horizons for two geomorphic settings (canyon bottom and mesa tops), are shown in Figures 26 and 27, respectively. Figure 26 shows an overlap of Ancho Canyon and mesa top samples with respect to oxalate-extracted Fe and Be, suggesting that amorphous $Fe(OH)_3$ is present in various concentrations in all soil samples. The correlation of Be with oxalate-extracted Fe is not obvious in

FIGURE 24. B HORIZONS, BACKGROUND SOILS, LOS ALAMOS.

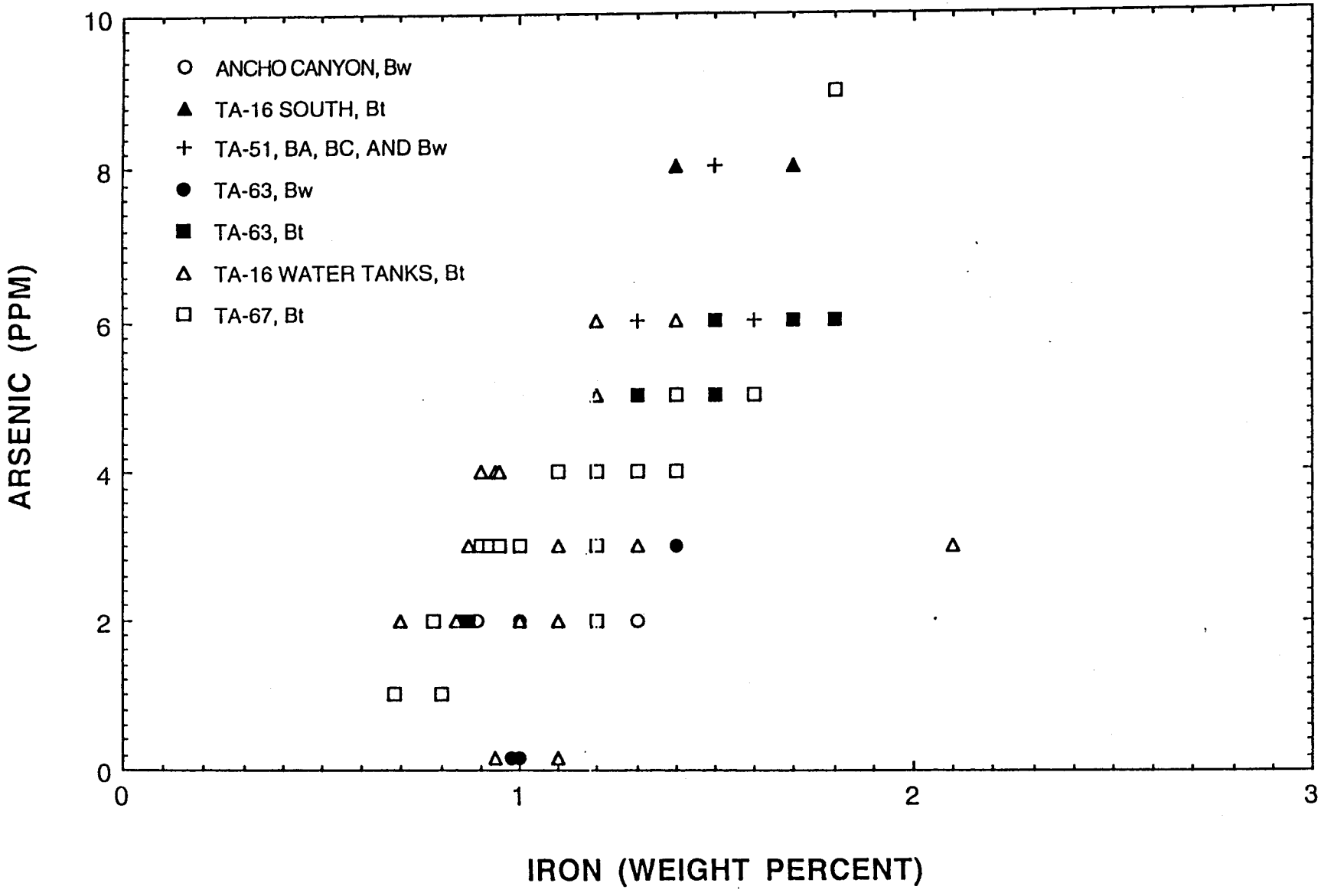


FIGURE 25. B HORIZONS, BACKGROUND SOILS, LOS ALAMOS.

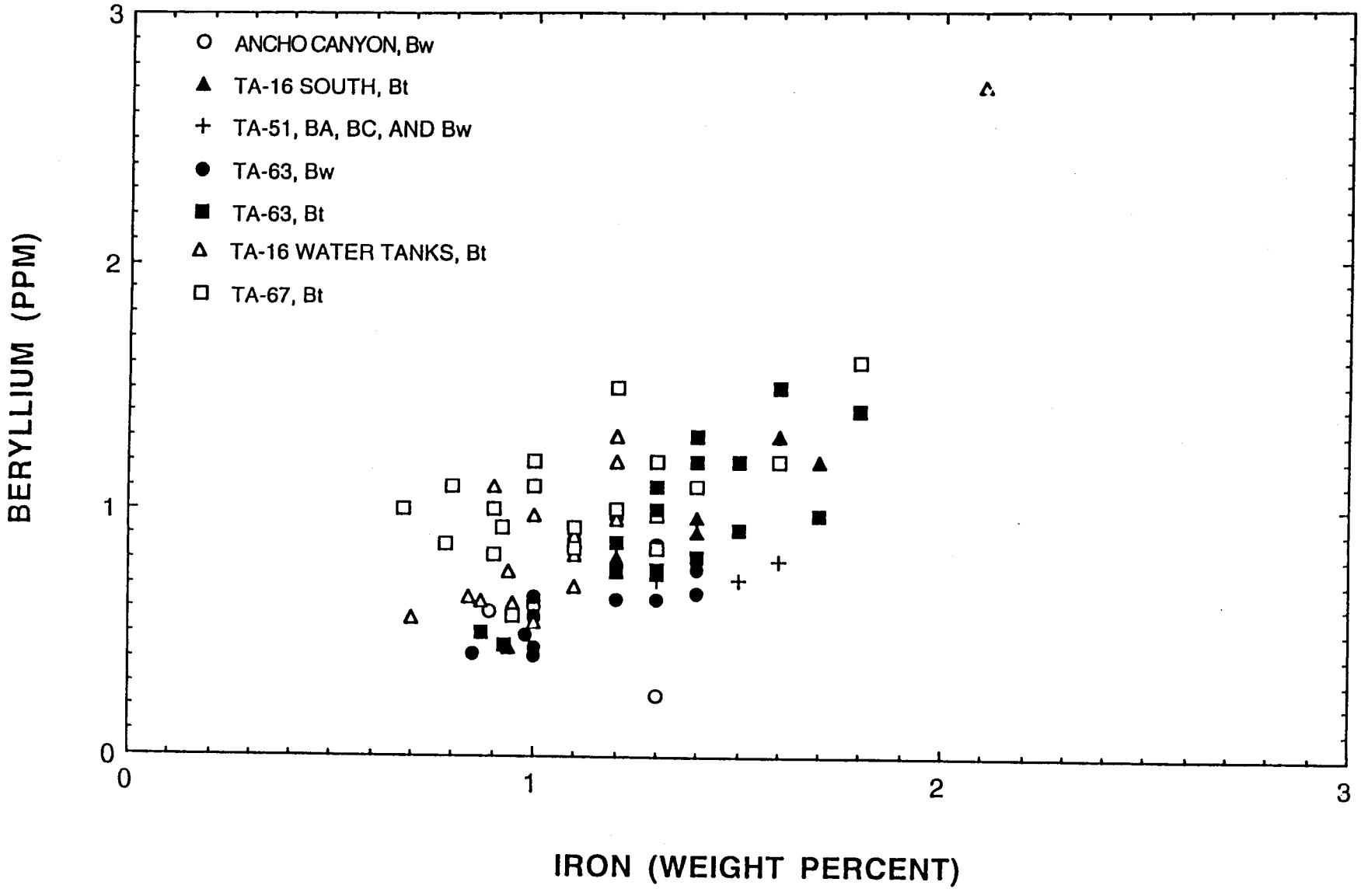


FIGURE 26. B HORIZONS, BACKGROUND SOILS, LOS ALAMOS.

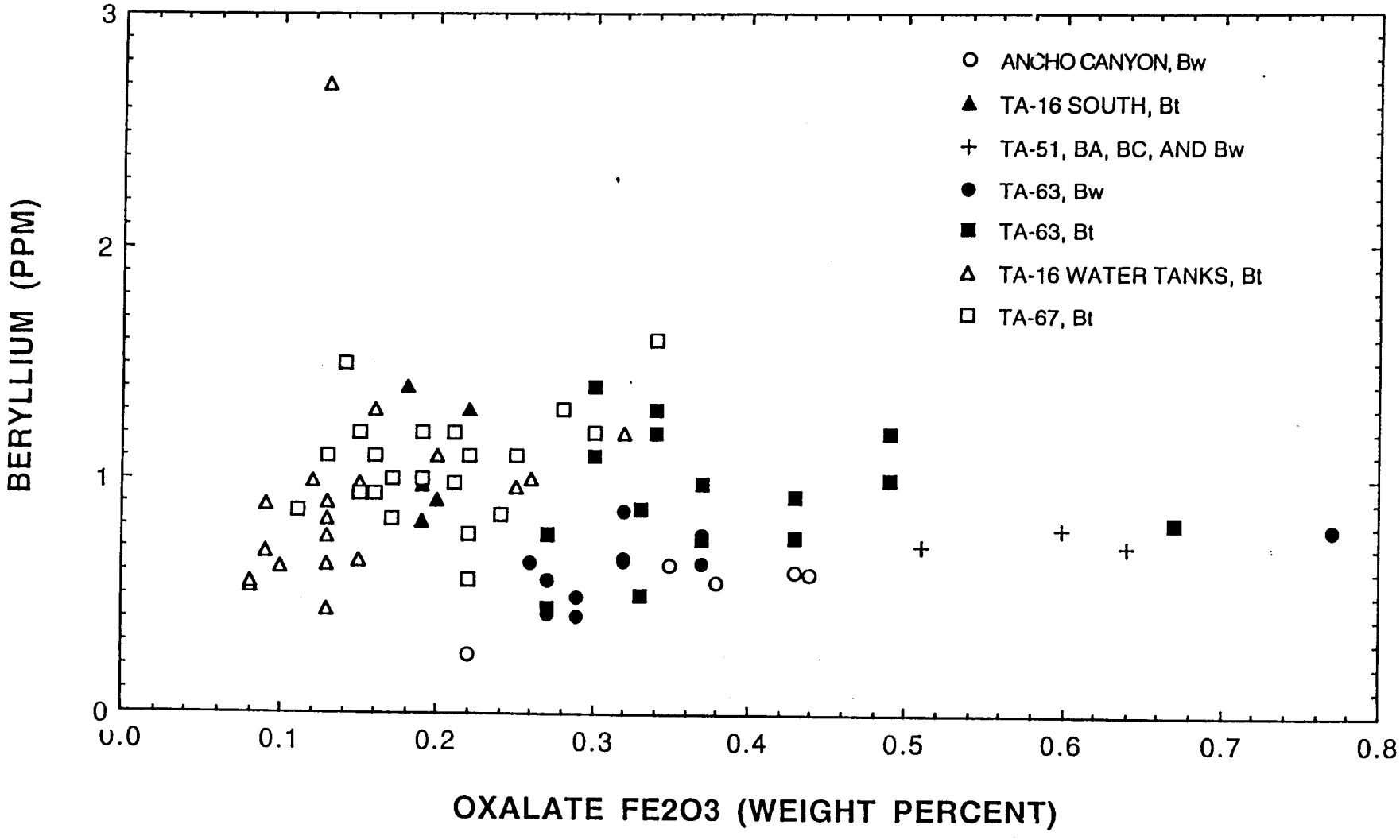


FIGURE 27. B HORIZONS, BACKGROUND SOILS, LOS ALAMOS.

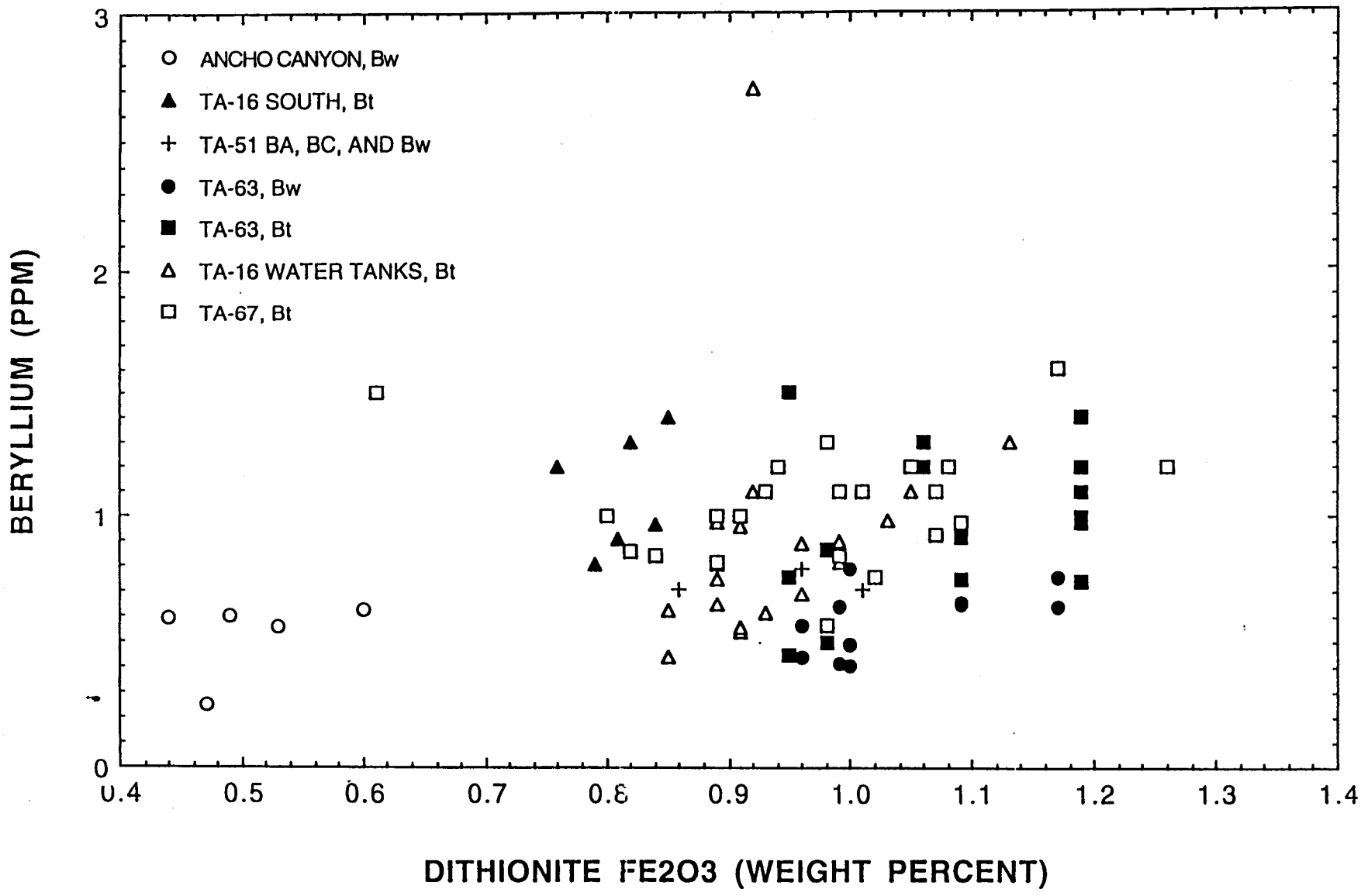


Figure 26 due to complex nature and distribution of amorphous $Fe(OH)_3$. A better correlation of dithionite-extracted Fe with Be for the two different geomorphic environments is shown in Figure 27. Soil samples collected in Ancho Canyon have lower concentrations of Be and dithionite-extracted Fe than do the mesa top samples (Figure 27). This suggests that Be probably is more associated (chemisorption) with goethite and hematite rather than amorphous $Fe(OH)_3$.

Thorium and Uranium

Thorium and U are important actinide elements that occur naturally in the Bandelier Tuff and soils on the Pajarito Plateau, and these elements may also occur above background concentrations resulting from Laboratory activities. An understanding of background elemental distributions of Th and U will provide constraints on the fate and transport of anthropogenic actinides. Thorium is stable in the 4+ valence state and forms hydroxo complexes ($Th(OH)_3^+$ and $Th(OH)_4^o$) above pH 4 in organic-free solution (Langmuir and Herman, 1980). Thorium hydroxo species strongly adsorbed onto iron oxides and clay minerals. Thorium is considered to be less leachable than U in these soils based on thermodynamic considerations and results of experimental data cited in Brookins (1988) and Langmuir and Herman (1980). Under relatively oxidizing conditions, U(VI) forms stable carbonato complexes ($UO_2CO_3^0$, $UO_2(CO_3)_2^{2-}$, and $UO_2(CO_3)_3^{4-}$) in aqueous solutions above pH 6 (Langmuir, 1978; Brookins, 1988). These carbonato complexes adsorb onto surfaces of iron oxides and clay minerals; however, desorption of these complexes under alkaline pH conditions has been demostrated by Tripathy (1984) and Hsi and Langmuir (1985).

Figure 28 shows the total distributions (HF digestion) of Th and U in the Bandelier Tuff (Longmire et al., 1995) and in soils characterized during this investigation. Total Th and U concentrations in soil samples collected from the B and C horizons generally fall within the distribution for the Tshirege Member of the Bandelier Tuff, where tuff mapping unit 1 has the highest concentrations of Th and U followed by mapping units 2 and 3 (Longmire et al, 1995). Concentrations of total Th and U in the soils, excluding the A horizons, overlap with the ranges of these two elements in mapping units 2 and 3 of the Bandelier Tuff.

Several soil samples collected from A and B horizons at TA-63 and TA-67 contain elevated concentrations of U, which may represent aerosol dispersion of U from Laboratory firing sites within TA-67 and TA-15 (Figures 28 and 29). These apparently baised data have been excluded from the background-elemental database for the Laboratory for purposes of calculating

FIGURE 28. BANDELIER TUFF AND BACKGROUND SOILS, LOS ALAMOS.

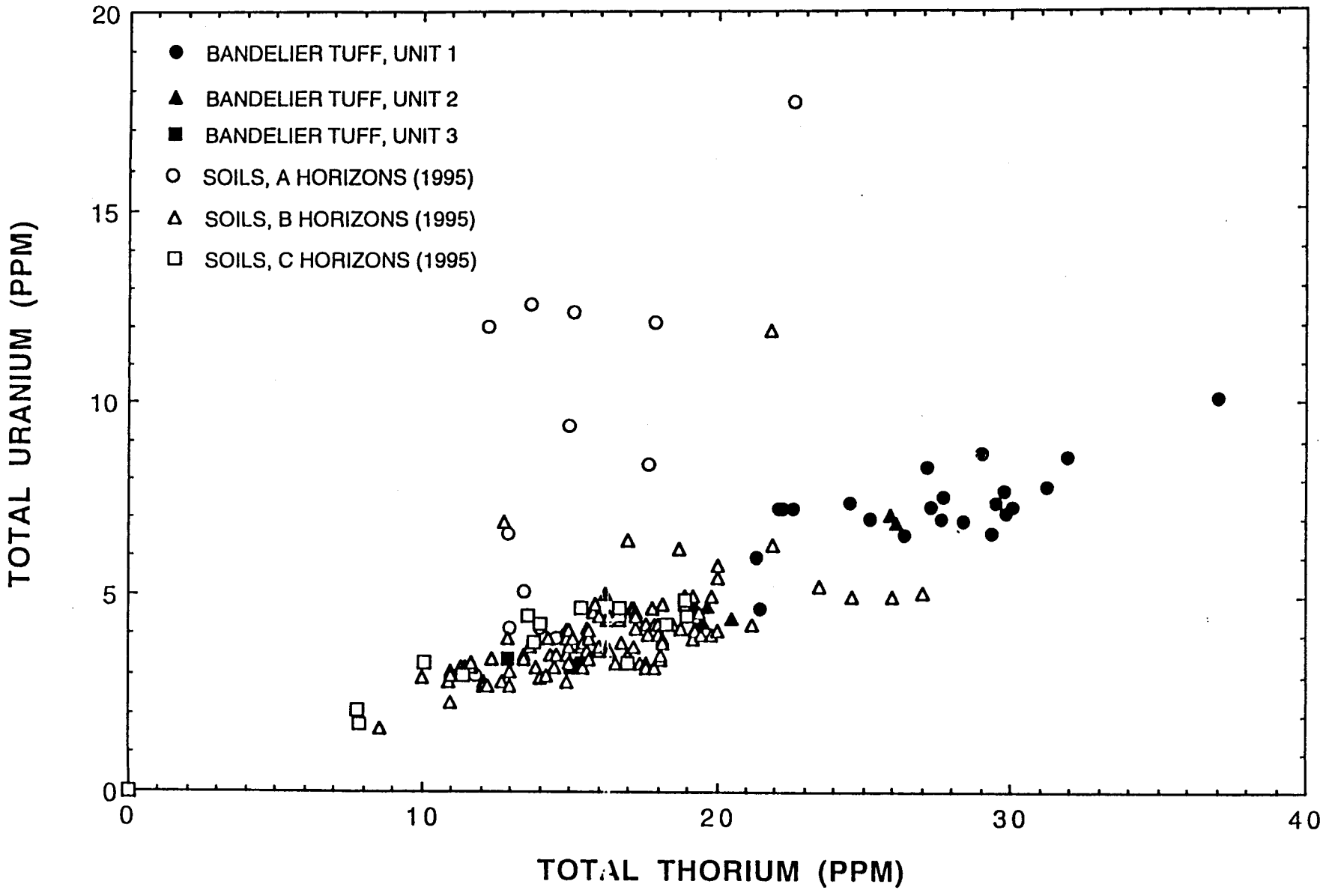
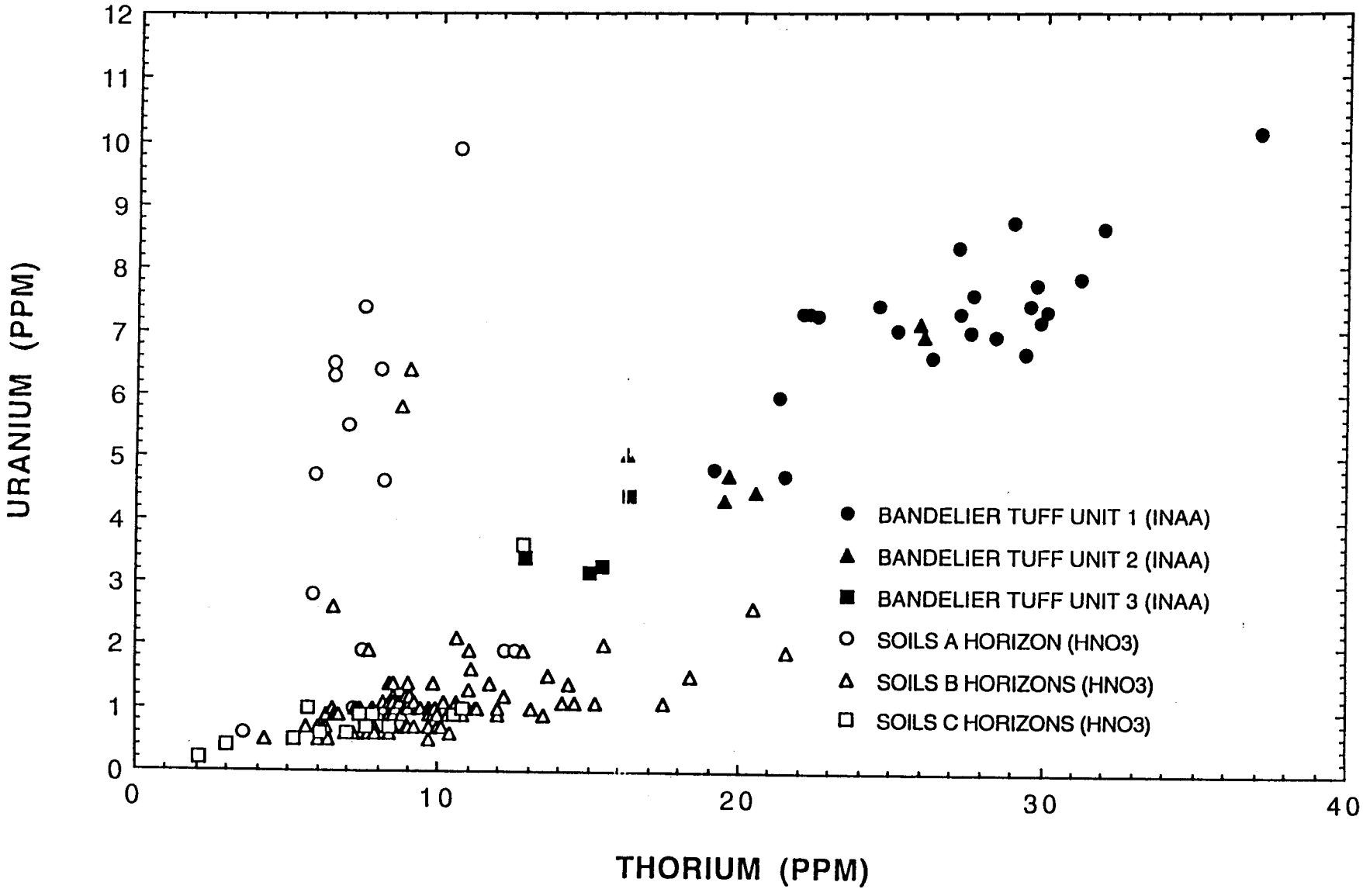


FIGURE 29. BANDELIER TUFF AND BACKGROUND SOILS, LOS ALAMOS.



UTLs; however, they may be useful for determining U concentrations within TA-63, TA-67, and other sites down-wind from firing sites.

Most of the soil samples collected from the B horizons are characterized by significantly higher concentration ratios of total U (Figures 23 and 28) to HNO_3-digested or soluble U (Figures 23 and 29) relative to the A and C horizons. Differences in mass balance between total and soluble U suggest that up to 30% of the soluble U has been mobilized from the primary minerals and possibly redistributed in secondary phases (clay minerals, carbonate minerals, and Fe oxides and hydroxides) within some of the B horizons. Redistribution of soluble U is based on the assumption that Th is not as mobile as U under oxidizing and near neutral pH conditions based on results of geochemical data presented by Langmuir and Herman (1980) and Figure 23 in which Th concentration ratios (HF/HNO_3) within the soil horizons are fairly consistent relative to U. This redistribution also assumes that Th and U are not significantly concentrated in dust.

Figure 30 shows the distribution of total U versus HNO_3-digested U for the A and C horizons. The total U ratio : HNO_3-digested U (projected through the origin on Figure 30) generally is 5:1 (total U $\leq$ 5 ppm; HNO_3-digested U $\leq$ 1 ppm) or less for soil samples collected from the C horizons, which may represent natural background U distributions in soils. This ratio decreases to approximately 2:1 (projected through the origin shown on Figure 30) for samples collected from most the A horizons at TA-63 and TA-67, which suggests that soluble U is present, possibly as anthropogenic U. Anthropogenic U may occur in several redox states over time, including 0, IV, and VI. Prior to U leaching in the soils, U(IV) probably is the dominant valence state within primary phases present in the soils. Uranium (VI) minerals generally are characterized by higher solubilities relative to U(IV) minerals. Increased dissolution of U solids occur as the oxidation state of U increases, which decreases the total U:HNO_3-digested U ratio. Oxidation of U metal to U(VI) minerals is observed at firing sites across the DOE complex. Ebinger et al. (1990) report that schoepite ($UO_3 \cdot 2H_2O$) has been identified on depleted U at the Yuma Proving Ground, Arizona. Studies conducted on the oxidation state and mineralogy of depleted U, using x-ray diffraction on Laboratory soil samples collected from TA-33, also show that schoepite is the dominant U(VI) mineral forming from the oxidation of U metal (personal communication with Pam Gordan, CST-7 on July 25, 1995). Schoepite may be an alteration (oxidation) product of U metal at TA-67 based on these previous studies.

Distributions of U and sulfate within the A and C horizons are shown in Figure 31. Concentrations of sulfate, in which this anion may be derived from dust and subsequently translocated through the soil horizons, range from 11 to 90 ppm within the C horizons. Within the A horizons, sulfate concentrations show a smaller range (6 to 25 ppm) than in the C horizons. Higher

FIGURE 30. A AND C HORIZONS, BACKGROUND SOILS, LOS ALAMOS.

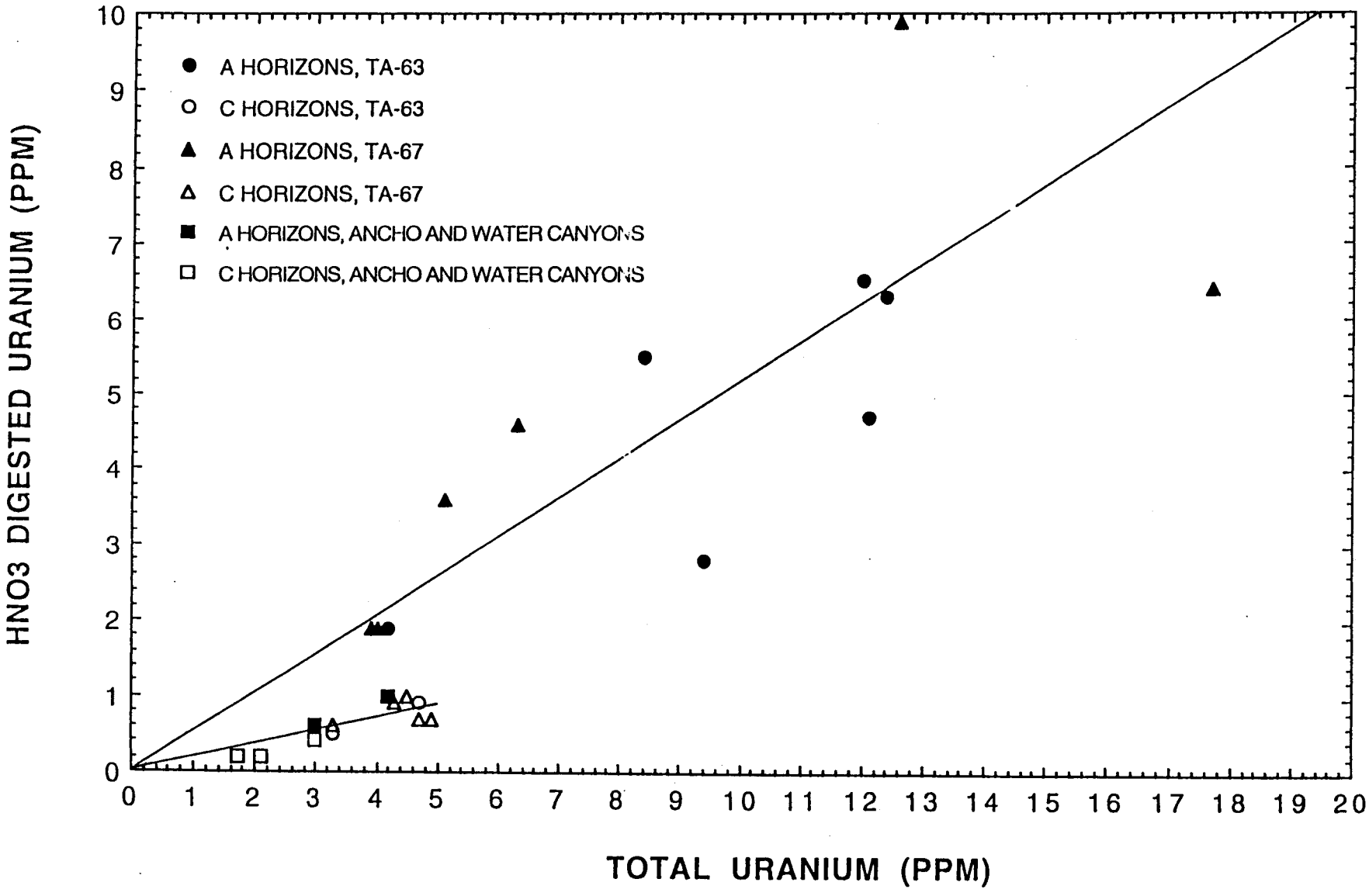
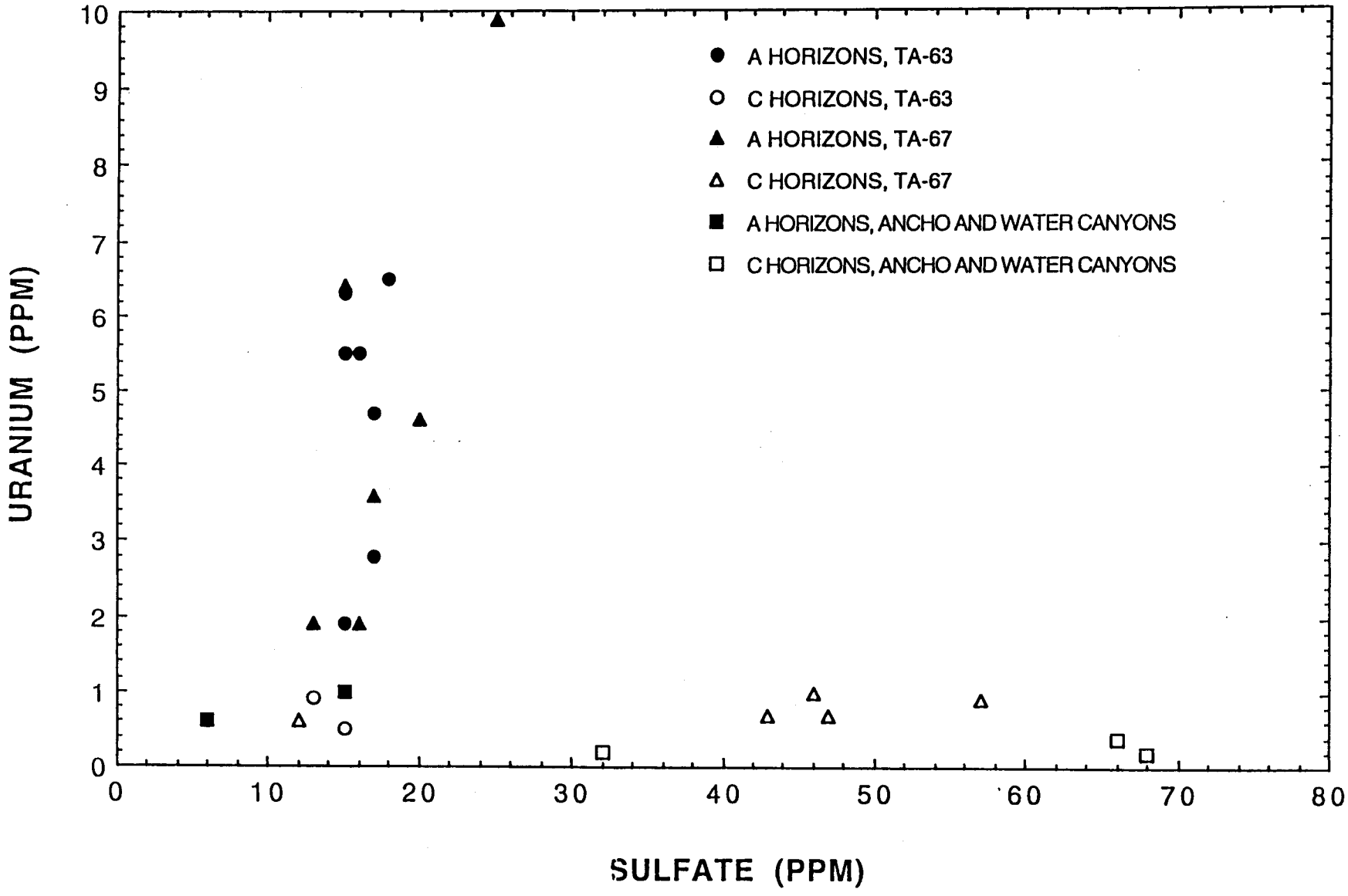


FIGURE 31. A AND C HORIZONS, BACKGROUND SOILS, LOS ALAMOS.



concentrations of U (0.6 to 9.9 ppm) occur in the A horizons than U than in the C horizons (0.1 to 3.6 ppm). Distributions of U and sulfate shown in Figure 31 suggest that these two species do not correlate well with each other and that soluble U is not significantly bound to sulfate minerals such as gypsum ($CaSO_4 \cdot 2H_2O$).

Figure 32 shows the distributions of Fe and U within the A and C horizons. Within the A horizons, these two elements are widely distributed, whereas in the C horizons they are independent of one another. Concentrations of Fe within the C horizons show a smaller range (0.45 to 1.1 wt%) than in the A horizons (0.54 to 1.34 wt%). Solid phases of Fe, possibly consisting of ferrihydrite, amorphous $Fe(OH)_3$, and α-FeOOH, may provide active adsorption sites for soluble U(VI) which may account for the correlation observed between these two elements. Adsorption of U(VI) species onto surfaces of Fe oxides is significant at near neutral pH conditions (Hsi and Langmuir, 1985). Within the A horizons, U may be adsorbed onto solid organic matter, which is more abundant within the A horizons.

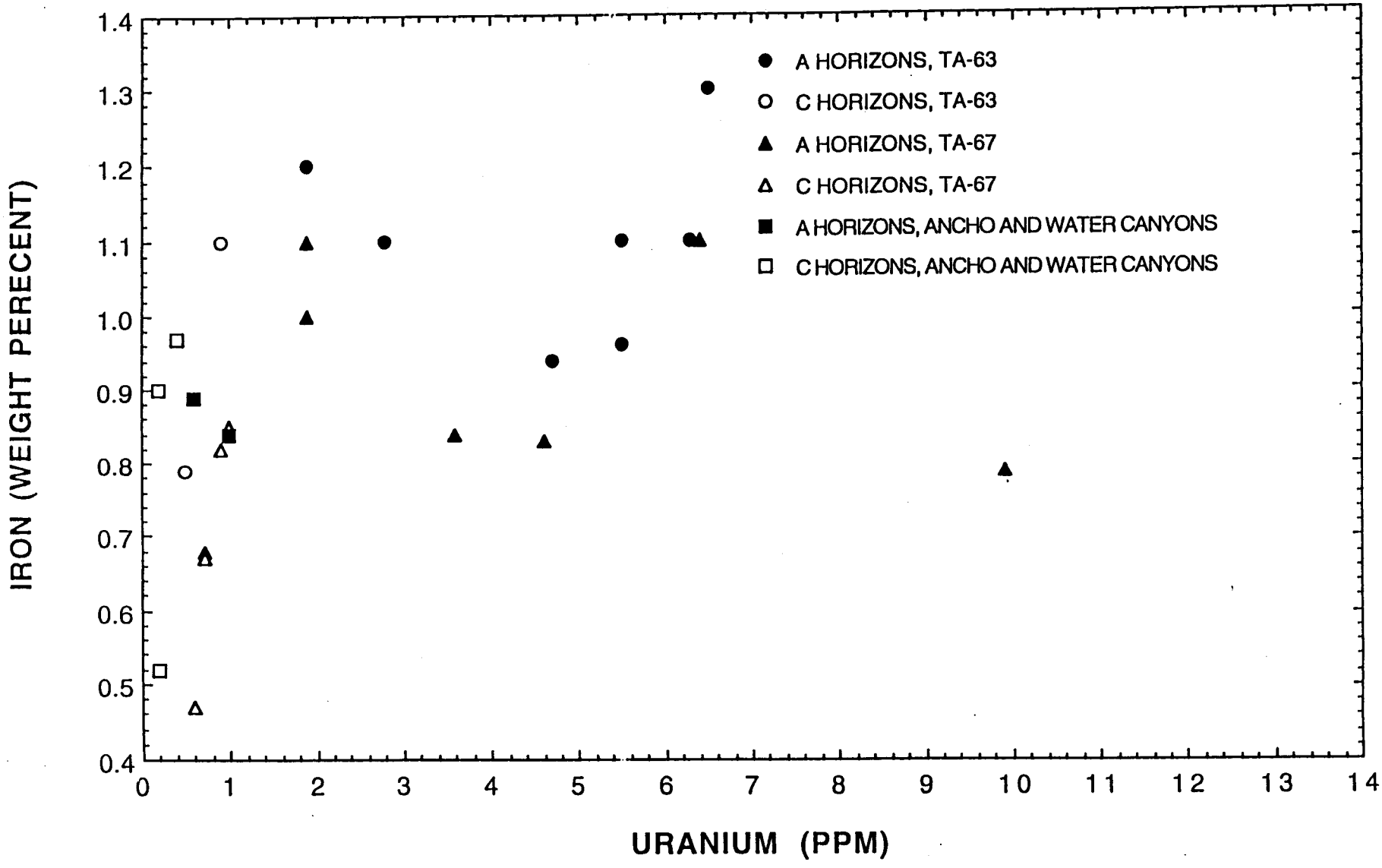
RESULTS AND STATISTICAL ANALYSIS OF BACKGROUND-SOIL DATA

The goal of the statistical analysis of the background soil data is to develop a technically-defensible set of data for ER Project decision-making. The key to technical defensibility is ensuring that the soils represent the natural variation found within the Laboratory's A, B and C soil horizons[1] found in a variety of geomorphic settings. Thus, the background soil samples should not have been impacted by Laboratory operations. The soil samples presented in this report have been collected at sampling locations both within the interior of the Laboratory and along the margins. These new samples are first compared in this study to the original background data presented by Longmire et al. (1995). All data that are statistically and geochemically comparable to the original background soil data are then included in a combined LANL-wide soil background data set.

The primary use of the background data is as a part of the RCRA Facility Investigation screening process ("Screening Assessment Methodology at Los Alamos National Laboratory", LANL ER Project, January 1995, draft). As a part of the RFI process, data for most sites are compared to natural background concentration of inorganics. The background screening value for inorganic analytes is the 95th percentile upper tolerance limit (UTL), which is the 95% upper confidence limit of the 95th percentile of the data distribution. The type of data distribution for each inorganic analyte must be estimated to calculate these UTLs. Thus, the second part of the statistical analysis of the soil data presented

[1] We do not consider background samples collected from calcium carbonate zones or fine fractions due to the small number of samples for these data groups.

FIGURE 32. A AND C HORIZONS, BACKGROUND SOILS, LOS ALAMOS.



in this report is an estimate of the type of data distribution for each inorganic analyte. The last part of the statistical analysis will be to calculate background screening values for each analyte (either UTLs or maximum reported values for infrequently detected analytes). Elements that fail background screening are compared to risk-based screening action levels (SALs) or ecotoxicological screening action levels (ESALs). For most inorganics, the SAL comparison step represents the definitive screening assessment step, which then is the basis for proposing no further action for LANL potential release sites.

The ER Project background assessment team has identified several key elements based on either the potential risk posed by background concentrations or the geochemical properties of the elements. Background concentrations of Al, As, Be, Mn, and U may pose a significant background risk. Aluminum, Fe, and Th are of interest due to their geochemical properties. For these key elements, this report will consider differences in background concentrations correlated to subdivisions of the B soil horizon, and variation between background sampling locations. This information will assist in the technical assessment of the need for site-specific background data for these key elements, and provide the geochemical and statistical basis for the design of site-specific background assessments.

This section considers the data reported by the standard EPA digestion and analysis of inorganics (extraction method 3050 and analysis methods 6010, 7060, and 300.0 [ion chromatography]). Total elemental concentration data are not analyzed, with the exception of K, Th, and U because these data will be used to estimate the abundance of naturally-occurring isotopes of these inorganics. The 3050 digestion is the standard digestion procedure used in target analyte list (TAL) inorganic analyses in support of RFI characterization.

Initial Data Analysis Steps

Some of the inorganic results in the combined background soil data set are reported as less than the detection level (<DL). Table 8 summarizes all values (including laboratory replicates) that were reported for all inorganic analytes in the combined data set. The full data set is presented in Appendix A. To facilitate statistical analysis of the data, all values reported as <DL were replaced by one-half of the detection limit. This replacement approach is recommended in the EPA risk assessment guidance (EPA 1992, 1166). Low detection frequencies analytes (Sb, Cd, Hg, Se, Ta, and Tl) are excluded from the analyses presented in the next two sections of this report.

Table 8. Summary of combined data sets by soil horizons (values in ppm).

	A Horizon						
	Non-detects			Detects			
Analyte	Count	Min	Max	Count	Min	Max	Average
Aluminum	0			25	2100	23000	8332.00
Antimony	22	0.6	5	3	0.2	0.5	0.37
Arsenic	0			23	0.3	5.4	3.12
Barium	0			25	27	190	125.28
Beryllium	0			25	0.07	1.2	0.66
Cadmium	8	0.4	2	1	1.4	1.4	1.40
Calcium	0			25	610	4500	1812.40
Chloride	0			24	8	24	13.33
Chromium	0			25	1.9	16	8.02
Cobalt	0			25	1.9	29	10.10
Copper	1	0.5	0.5	24	1.7	12	5.88
Iron	0			25	3300	16000	10296.00
Lead	1	4	4	24	5	37	16.13
Magnesium	0			25	440	2800	1582.00
Manganese	0			25	140	1100	440.00
Mercury	9	0.1	0.1	0			
Nickel	4	2	2	21	2.3	12	6.64
Potassium	0			25	410	2900	1533.60
Potassium-TOTAL	0			14	20000	26000	22285.71
Selenium	8	0.2	0.3	1	0.7	0.7	0.70
Sodium	0			25	64	660	174.24
Sulfate	1	12	12	23	13	44	22.09
Tantalum	25	0.2	0.9	0			
Thallium	8	0.2	1	17	0.2	0.4	0.25
Thorium	0			25	2	12.8	7.21
Thorium-TOTAL	0			17	8.5	22.6	14.46
Uranium	0			26	0.2	9.9	2.92
Uranium-TOTAL	0			15	3	17.7	8.11
Vanadium	0			25	4.6	35	20.33
Zinc	0			25	14	58	28.64

Table 8 (continued). Summary of combined data sets of soil horizons.

	B Horizon						
	Non-detects			Detects			
Analyte	Count	Min	Max	Count	Min	Max	Average
Aluminum	0			132	1400	62000	12852.27
Antimony	118	0.1	5	16	0.2	1	0.41
Arsenic	5	0.3	0.3	116	0	11.2	4.33
Barium	0			132	46	730	160.04
Beryllium	0			132	0.25	4	1.01
Cadmium	18	0.4	2	3	0.6	2.7	1.93
Calcium	0			132	1100	14000	2989.39
Chloride	0			126	8	246	27.81
Chromium	0			132	2.8	46	10.20
Cobalt	0			132	1.6	22	6.65
Copper	0			132	2.7	16	6.62
Iron	0			132	6800	36000	13237.12
Lead	1	4	4	131	5	30	13.19
Magnesium	0			132	800	10000	2385.61
Manganese	0			131	76	1000	348.15
Mercury	19	0.1	0.1	1	0.1	0.1	0.10
Nickel	3	2	2	129	2.3	30	8.00
Potassium	0			132	680	6900	1855.23
Potassium-TOTAL	0			106	11000	36000	24188.68
Selenium	3	0.2	0.3	19	0.3	1.3	0.74
Sodium	0			132	58	1800	296.32
Sulfate	0			126	9	722	58.79
Tantalum	134	0.2	0.9	0			
Thallium	44	0.2	1	90	0.2	1	0.35
Thorium	0			134	4.2	21.6	9.35
Thorium-TOTAL	0			111	10	27.6	16.53
Uranium	0			134	0.5	6.4	1.10
Uranium-TOTAL	0			112	1	11.9	4.01
Vanadium	0			132	7.4	57	23.05
Zinc	0			131	14	76	33.21

Table 8 (continued). Summary of combined data sets of soil horizons.

	C Horizon						
	Non-detects			Detects			
Analyte	Count	Min	Max	Count	Min	Max	Average
Aluminum	0			24	900	33000	10083.33
Antimony	23	0.2	5	0			
Arsenic	1	0.2	0.2	23	0.3	7	2.63
Barium	0			24	21	410	90.33
Beryllium	2	0.08	0.08	22	0.09	1.9	0.78
Cadmium	10	0.4	0.4	0			
Calcium	0			24	500	87000	5401.67
Chloride	0			24	9	303	44.18
Chromium	0			24	1.9	15	6.10
Cobalt	0			24	1	34	8.32
Copper	1	0.5	0.5	23	0.6	7.3	3.90
Iron	0			24	3300	17000	9020.83
Lead	7	4	4	17	4	24	11.04
Magnesium	0			24	420	7400	1772.50
Manganese	0			24	76	440	193.63
Mercury	9	0.1	0.1	1	0.1	0.1	0.10
Nickel	8	2	2	16	2.4	15	6.68
Potassium	0			24	410	4200	1536.25
Potassium-TOTAL	0			13	26000	35000	29538.46
Selenium	7	0.2	0.3	3	0.3	1.7	0.87
Sodium	0			24	90	1700	523.63
Sulfate	0			24	12	1200	122.83
Tantalum	24	0.12	0.9	0			
Thallium	19	0.125	1	4	0.2	0.6	0.40
Thorium	0			24	2.1	10.8	6.19
Thorium-TOTAL	0			15	7.8	19	14.37
Uranium	0			24	0.2	1.5	0.69
Uranium-TOTAL	0			15	1.7	4.9	3.77
Vanadium	0			24	4	32	13.18
Zinc	0			24	14	57	29.00

Table 8 (continued). Summary of combined data sets of soil horizons.

	All Data						
	Non-detects			Detects			
Analyte	Count	Min	Max	Count	Min	Max	Average
Aluminum	0			181	900	62000	11860.77
Antimony	163	0.1	5	19	0.2	1	0.40
Arsenic	6	0.2	0.3	162	0	11.2	3.91
Barium	0			181	21	730	145.99
Beryllium	2	0.08	0.08	179	0.07	4	0.93
Cadmium	36	0.4	2	4	0.6	2.7	1.80
Calcium	0			181	500	87000	3146.69
Chloride	0			174	8	303	28.07
Chromium	0			181	1.9	46	9.35
Cobalt	0			181	1	34	7.35
Copper	2	0.5	0.5	179	0.6	16	6.17
Iron	0			181	3300	36000	12271.82
Lead	9	4	4	172	4	37	13.39
Magnesium	0			181	420	10000	2193.31
Manganese	0			180	76	1100	340.30
Mercury	37	0.1	0.1	2	0.1	0.1	0.10
Nickel	15	2	2	166	2.3	30	7.70
Potassium	0			181	410	6900	1768.51
Potassium-TOTAL	0			133	11000	36000	24511.28
Selenium	18	0.2	0.3	23	0.3	1.7	0.76
Sodium	0			181	58	1800	309.60
Sulfate	1	12	12	173	9	1200	62.79
Tantalum	183	0.12	0.9	0			
Thallium	71	0.125	1	111	0.2	1	0.34
Thorium	0			183	2	21.6	8.64
Thorium-TOTAL	0			143	7.8	27.6	16.06
Uranium	0			184	0.2	9.9	1.30
Uranium-TOTAL	0			142	1	17.7	4.42
Vanadium	0			181	4	57	21.37
Zinc	0			180	14	76	32.02

The background data set includes samples that have been designated as "collocated" samples, and there are also laboratory replicates included in the combined background soil data set. Collocated samples are a type a field duplicate sample. In this case, the collocated samples were collected from the same trenches next to original sampling for a given soil horizon. Thus, collocated samples may be used to estimate to local sampling variability for inorganic analytes. The duplicate analyses provide an estimate of the analytical measurement variability. The collocated samples have about 1.8 times the variability as the duplicate measurements (based ratio of average normalized variances for the two data groups for both HNO_3 digested and total analyses). Because the duplicate analyses are to some extent providing "redundant" information[2], all laboratory duplicate analyses were averaged to estimate a single value for each sampling location. The duplicate analysis average is used in the statistical analyses. Given the variability observed for collocated samples, these samples are treated as another value for that soil horizon and are retained as separate samples in the statistical analyses.

Graphical Display of Background Data

Two types of plots are presented for graphical display of the background data. "Box plots" (Figures 33-39, 41, 43, 45, 47, 49, 51, 53, and 55) are used to show data differences as a function of grouping variables. "Scatter plots" (Figures 40, 42, 44, 46, 48, 50, 52, and 54) are used to show correlations between pairs of variables (concentrations of inorganic analytes). Either sampling location or the soil horizon is used as a grouping variable in the box plots. The box plots show the actual values (as filled circles) for each soil horizon. The ends of the box represent the "inter-quartile" range of the data distribution. The inter-quartile range is specified by the 25th percentile and 75th percentile of the data distribution. The line within the box plot is the median (50th percentile) of the data distribution and the 10th and 90th percentiles are outside the box plots. Thus the box indicates concentration values for the central half of the data, and concentration shifts can be readily assessed by comparing the boxes. If the majority of the data is represented by a single concentration value (usually the detection limit), the box is reduced to a single line. The dotted line across all of the boxes is the overall average of all data groups represented by the box plots.

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[2]For example, potassium duplicates have a coefficient of variation (CV) of 8%, the collected samples have a CV of 25%, and the CV of all B soil horizon analyses is 49%.

Analysis of Key Inorganics by Soil Subhorizons and Background Sampling Locations

Because the background sampling locations do not have equal (in proportion) representation of the soil subhorizons, a simplistic one-way analysis of location and subhorizon may be misleading. For example, the upper LA Canyon samples (Longmire et al., 1995) do include any A or C horizons (Table 9), and these results should not be directly compared to AC sampling locations, which include one A horizon sample and three C horizon samples. A linear statistical model can be built to determine if there is a significant interaction term between location and soil horizon, but this is beyond the current scope of this report. One simple solution to the location-horizon interaction is to compare the locations that are most similar in the distribution of soil subhorizons. Technical Area-16, TA-63, and TA-67 are the three most similar background sampling locations in the number of samples collected from each horizon. The results for these background sampling locations is presented graphically below.

Similarly, the analysis of soil horizons is also confounded by a possible location-horizon interaction term. As a crude measure of the difference between horizons, a Wilcoxon rank sum test was used to determine if there were statistically significant distribution shifts between the soil subhorizons. The set of six soil subhorizons (A, BA, BC, Bt, Bw, and C) were significantly different for six of the seven key inorganics (Table 10). Aluminum exhibited a marginally significant distribution shift ($p=0.052$, or slightly greater than a significant probability of 0.05). In general, the major elements did not exhibit significant distribution shifts for comparisons among B subhorizons, but the minor elements were significantly different between soil subhorizons (Table 10). The statistical differences of the key inorganics by horizon and location is discussed in more detail below.

Thus, there is a rationale to evaluate soil subhorizons in planning for site-specific background of certain key minor elements. However, it is also important that the key major elements do not exhibit significant differences between soil subhorizons. This observation supports our use of the major element to trace element correlations to assist in evaluating the inclusion of samples into a LANL-wide background data base. These correlations are discussed in the following section of this report.

Table 9. Distribution of the number of samples by soil subhorizon and background sampling location.

Subhorizon	Location AC	LA	TA-16	TA-63	TA-67	TA-69	Subhorizon total
A	1	0	2	7	6	2	18
BA	0	0	0	0	5	0	5
BC	0	1	1	0	5	1	8
Bb	0	0	0	0	1	0	1
BR	0	0	0	0	0	1	1
Bt	1	6	25	16	23	7	78
Bw	4	0	1	12	3	1	21
C	3	0	4	2	5	3	17
Location total	9	7	33	37	48	15	149

Table 10. Summary of the results of the Wilcoxon rank sum test comparison of soil subhorizons.

Analyte	Data groups compared A, BA, BC, Bt, Bw, C	BA, BC, Bt, Bw	Bt, Bw
Aluminum	0.052	0.126	0.765
Arsenic	0.002 *	0.160	0.025 *
Beryllium	<0.001 *	0.005 *	0.001 *
Iron	<0.001 *	0.890	0.860
Manganese	<0.001 *	<0.001 *	<0.001 *
Thorium-total	0.009 *	0.073	0.164
Uranium-total	0.001 *	0.019 *	0.005 *

* These probabilities indicate a statistically significant difference between soil subhorizons. Probabilities less than 0.05 indicate that there is a statistically significant difference between the horizons, and a probability greater than 0.05 indicates that there is no statistically significant difference between the soil horizons. Bb and BR were excluded from the analysis because they were represented by one sample each.

Aluminum by subhorizon and location

Aluminum concentrations are not significantly different between six soil subhorizons (Table 10, Figure 33). There is no significant difference between the B subhorizons. There is little difference in the Al concentration range between TA-16 and TA-67, and the median concentration for TA-63 and TA-67 are similar (Figure 33). Thus, there is little evidence for significant differences between mesa top background sampling locations for Al.

Arsenic by subhorizon and location

The median percentiles (25th to 75th percentile) of the As concentrations are similar for all soil subhorizons except the C horizon (Figure 34). The concentration range for the Bt subhorizon is greater than the other subhorizons, but this could be due to the larger number of samples representing the Bt horizon. There is little difference in the location of the median percentiles of the TA-16, TA-63, and TA-67 background sampling locations (Figure 34). Thus, there is little evidence for significant differences in As concentrations between mesa top background sampling locations.

Beryllium by subhorizon and location

There are statistically significant distribution shifts for Be between groups of soil subhorizons (Table 10, Figure 35). However, the differences in the median percentiles for soil subhorizons are modest, and exhibit slight distribution shifts. There is little difference in the Be median percentiles between TA-16 and TA-63, and the median percentiles of TA-67 are modestly elevated compared to TA-16 and TA-63 (Figure 35). Thus, some Be variation can be attributed to differences between sampling locations.

Iron by subhorizon and location

The median percentiles of the A and C soil horizons for Fe are lower than the median percentiles for the B subhorizons (Figure 36). There is no statistical difference between the B subhorizons (Figure 36, Table 10). There is little difference in the location of the median percentiles of the TA-16, TA-63, and TA-67 background sampling locations (Figure 36). Thus, there is little evidence for significant differences in Fe concentrations between mesa top background sampling locations.

Manganese by subhorizon and location

Although there is considerable overlap in the Mn concentrations represented by the median percentiles of the soil subhorizons (Figure 37), there are statistically significant differences between the major horizon groups (Table 10). There is little difference in the Mn median percentiles between TA-16 and TA-67, and the median percentiles of TA-63 are elevated compared to TA-16 and TA-67 (Figure 37). Thus, there is some variation in Mn concentrations that can be attributed to differences in Mn concentrations between sample locations.

Total thorium by subhorizon and location

The Th median percentiles of the B subhorizons and the C horizon are similar (Figure 38), and there is no statistical difference between the B subhorizons (Table 10). The median percentiles of the background sampling locations are similar, and median values of the mesa top sampling locations (TA-16, TA-63, and TA-67) vary within a narrow range between 15.6 mg/kg and 17 mg/kg (Figure 38). Thus, there is little evidence for significant differences in Th concentrations between mesa top background sampling locations.

Total uranium by subhorizon and location

Uranium median percentile values show that the A and BA horizons are elevated relative to other horizons (Figure 39), and there are statistically significant differences between soil horizons (Table 10). The median percentiles of the BC, Bt, Bw and C horizons are similar (Figure 39). The median percentiles of the mesa top sampling locations are similar, although the 90th percentile of TA-63 and TA-67 are significantly elevated relative to other sampling locations (Figure 39). It may be that the A and BA horizons sampling locations in TA-63 and TA-67 have been impacted by airborne releases from weapons testing in that portion of the laboratory. These data are evaluated in more detail in the following section of the report, to determine if this new background data collected from TA-63 and TA-67 can be added to the existing background data reported in Longmire et al. (1995).

Summary of results by subhorizon and location

The differences between soil horizons tend to be statistically significant, where the B horizon data is typically elevated relative to the A or C soil horizons. If site-specific background data are needed, it may be necessary to consider pedological and chemical differences between B subhorizons for some analytes (Be, Mn, and U). Differences between background sampling locations tend to be less significant when comparing mesa top locations, but there are significant differences between canyon and mesa top sampling locations. In summary, we recommend that the results presented in this section of the report should be considered when assessing the need to collect site-specific background to support risk assessment or a corrective measures study (CMS), but that the LANL-wide data base is expected to be adequate for most screening level decisions.

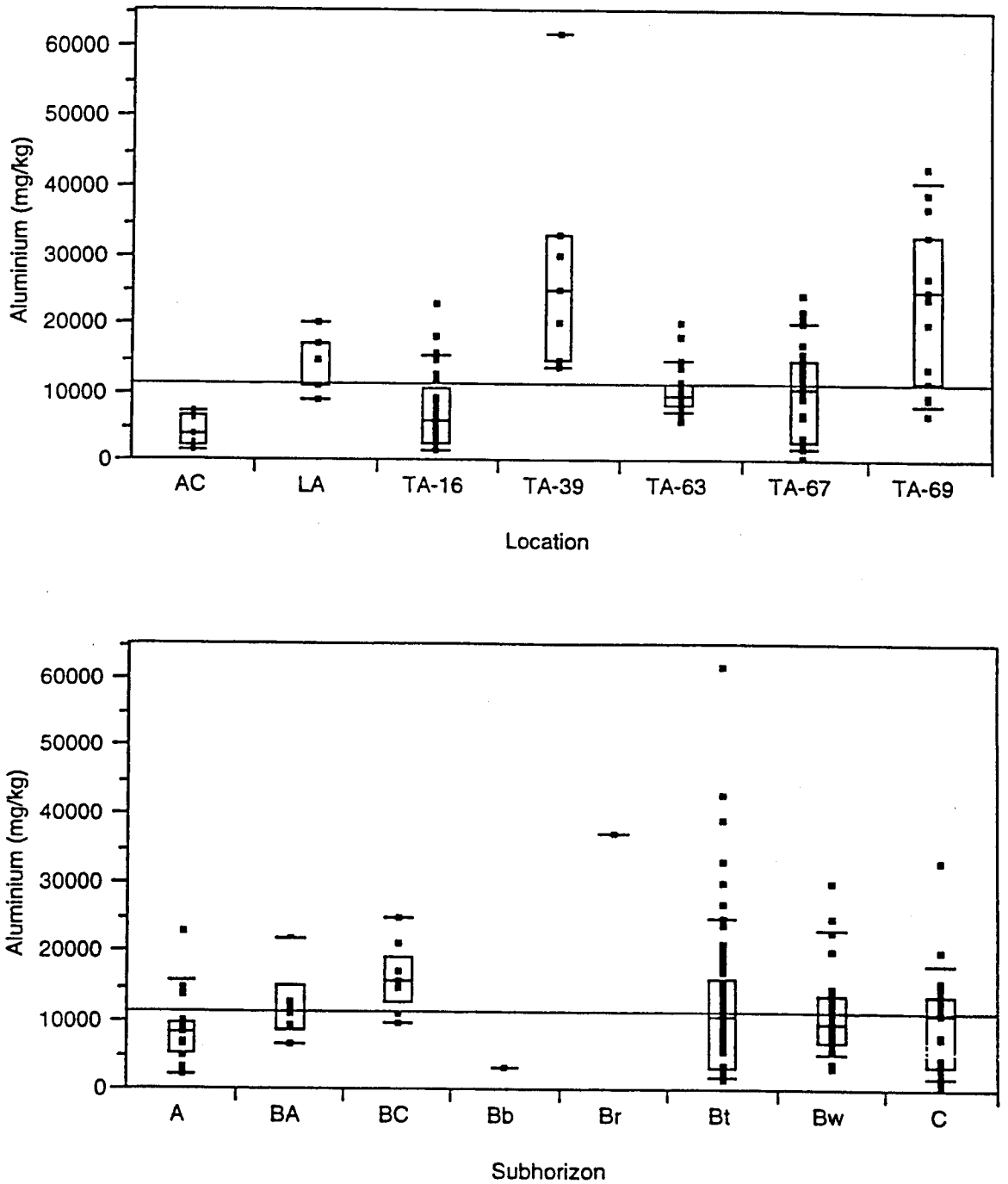

Figure 33. Summary of Al results by soil subhorizon and location.

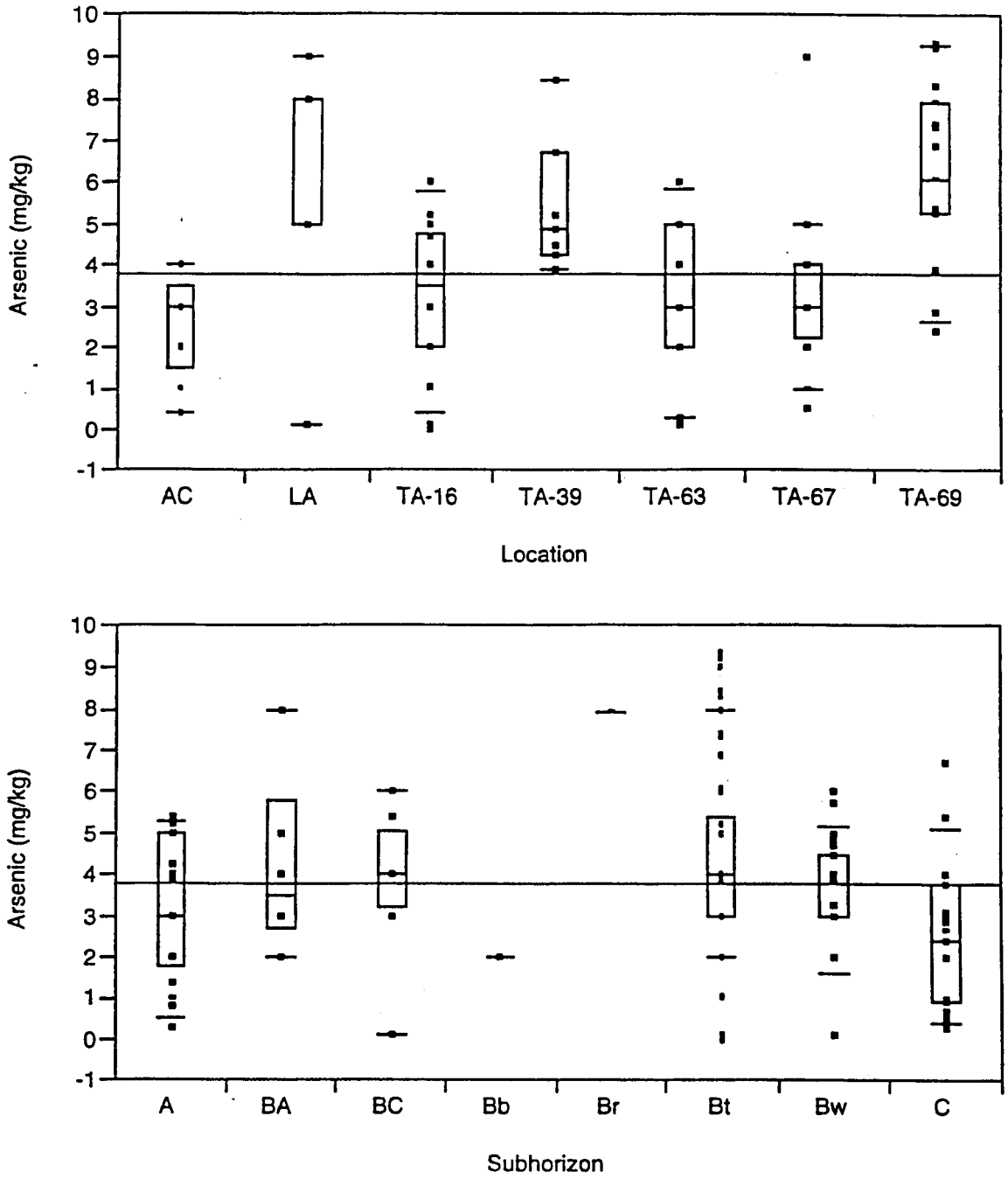

Figure 34. Summary of As results by soil subhorizon and location.

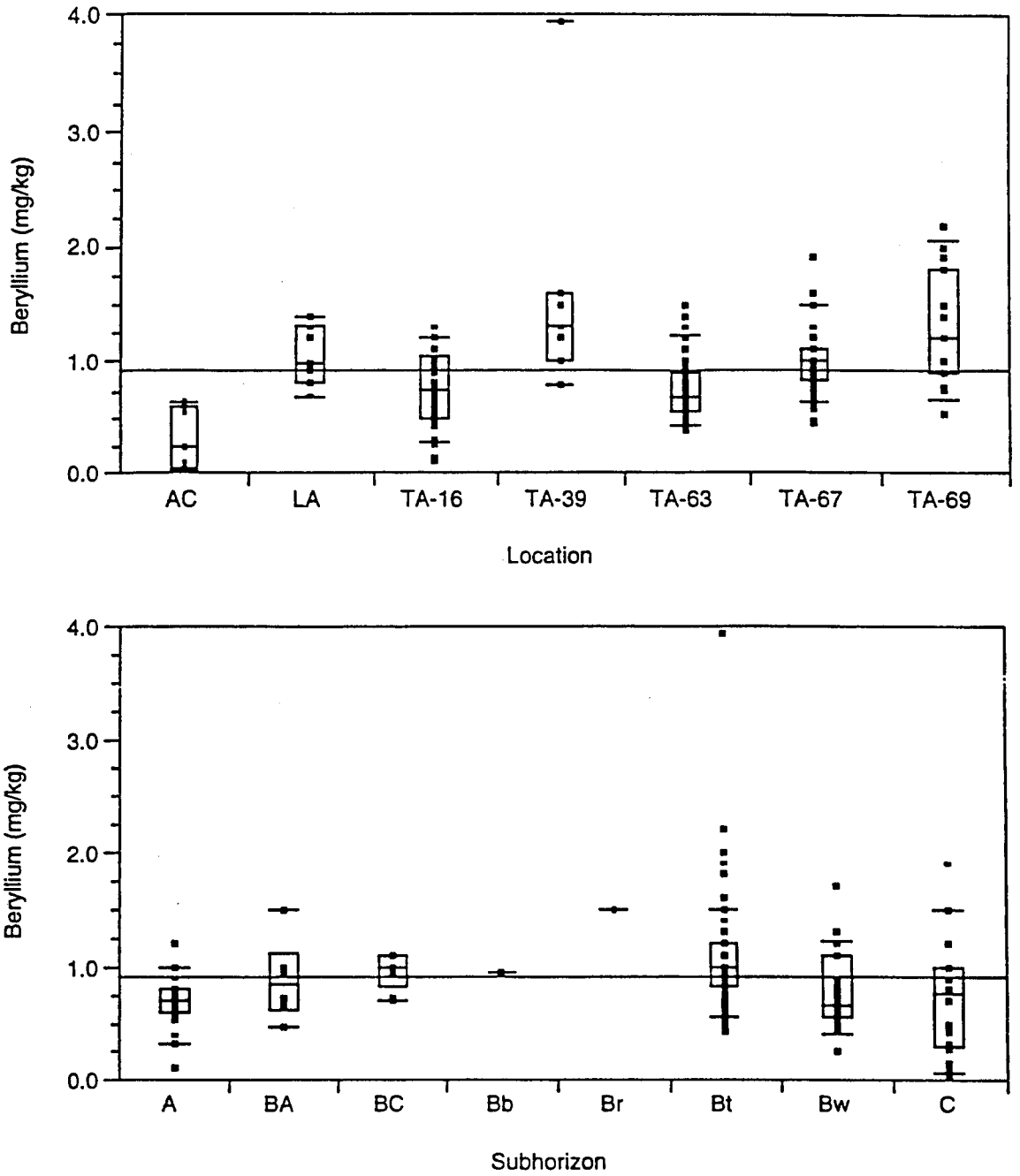

Figure 35. Summary of Be results by soil subhorizon and location.

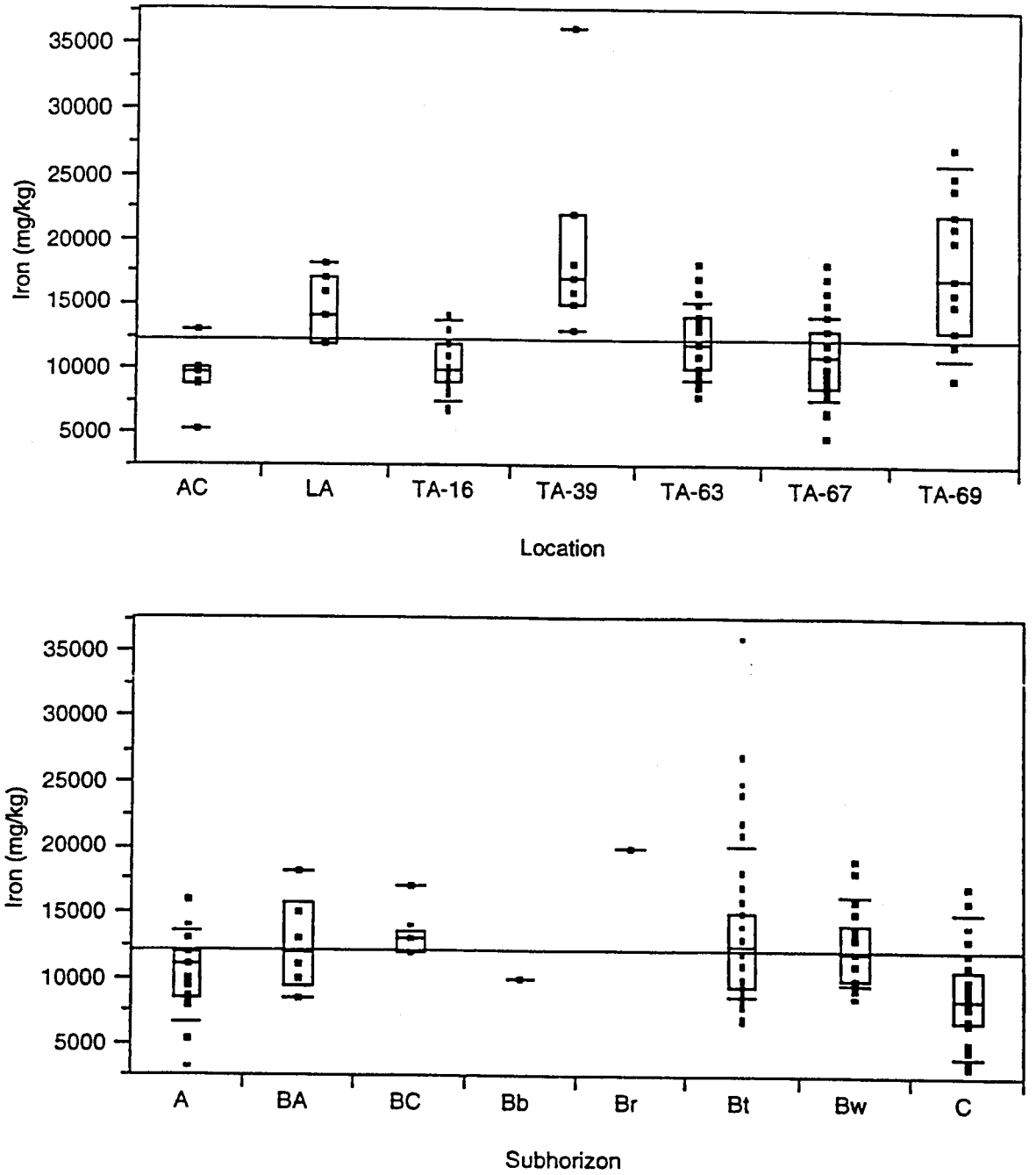

Figure 36. Summary of Fe results by soil subhorizon and location.

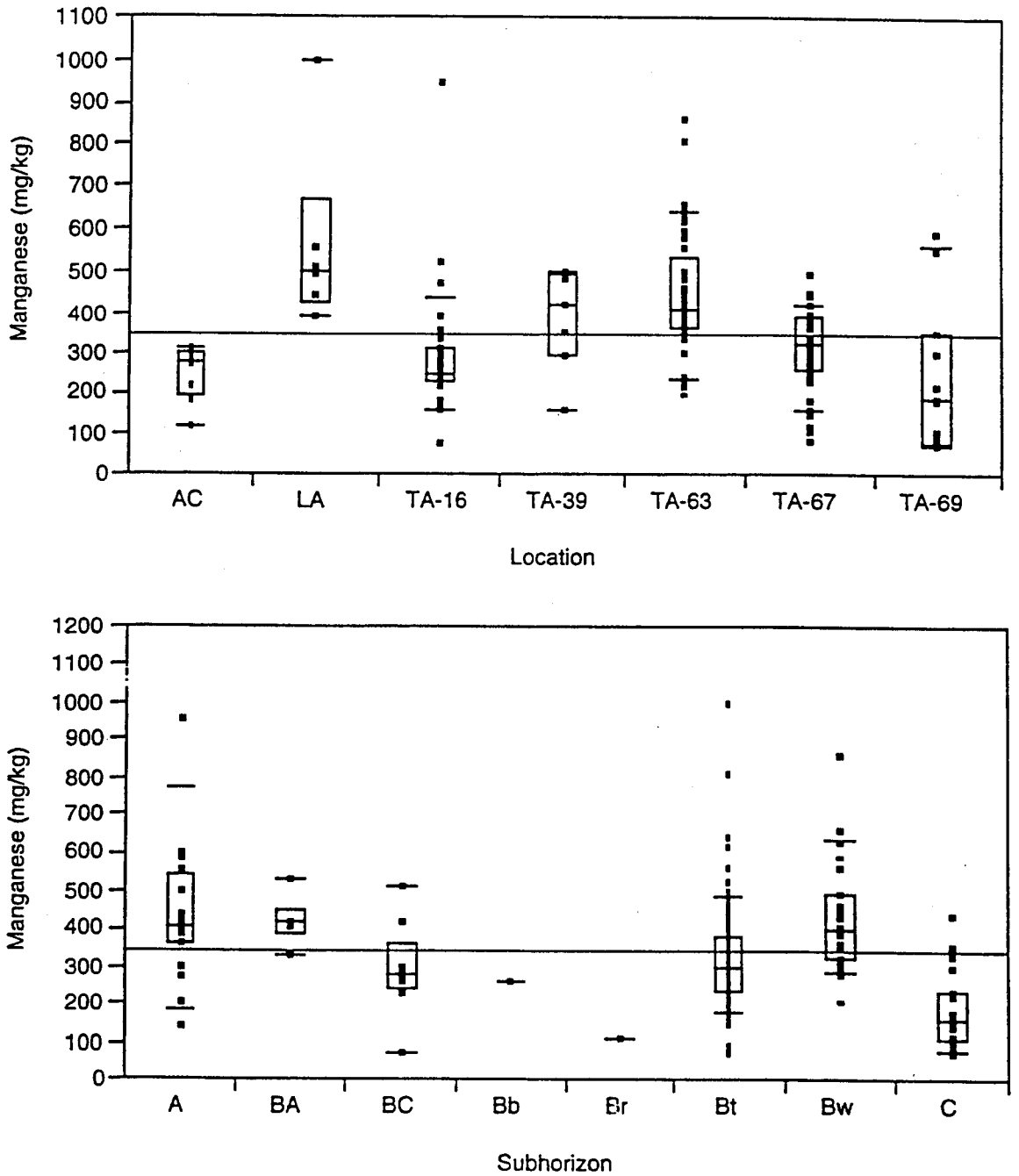

Figure 37. Summary of Mn results by soil subhorizon and location.

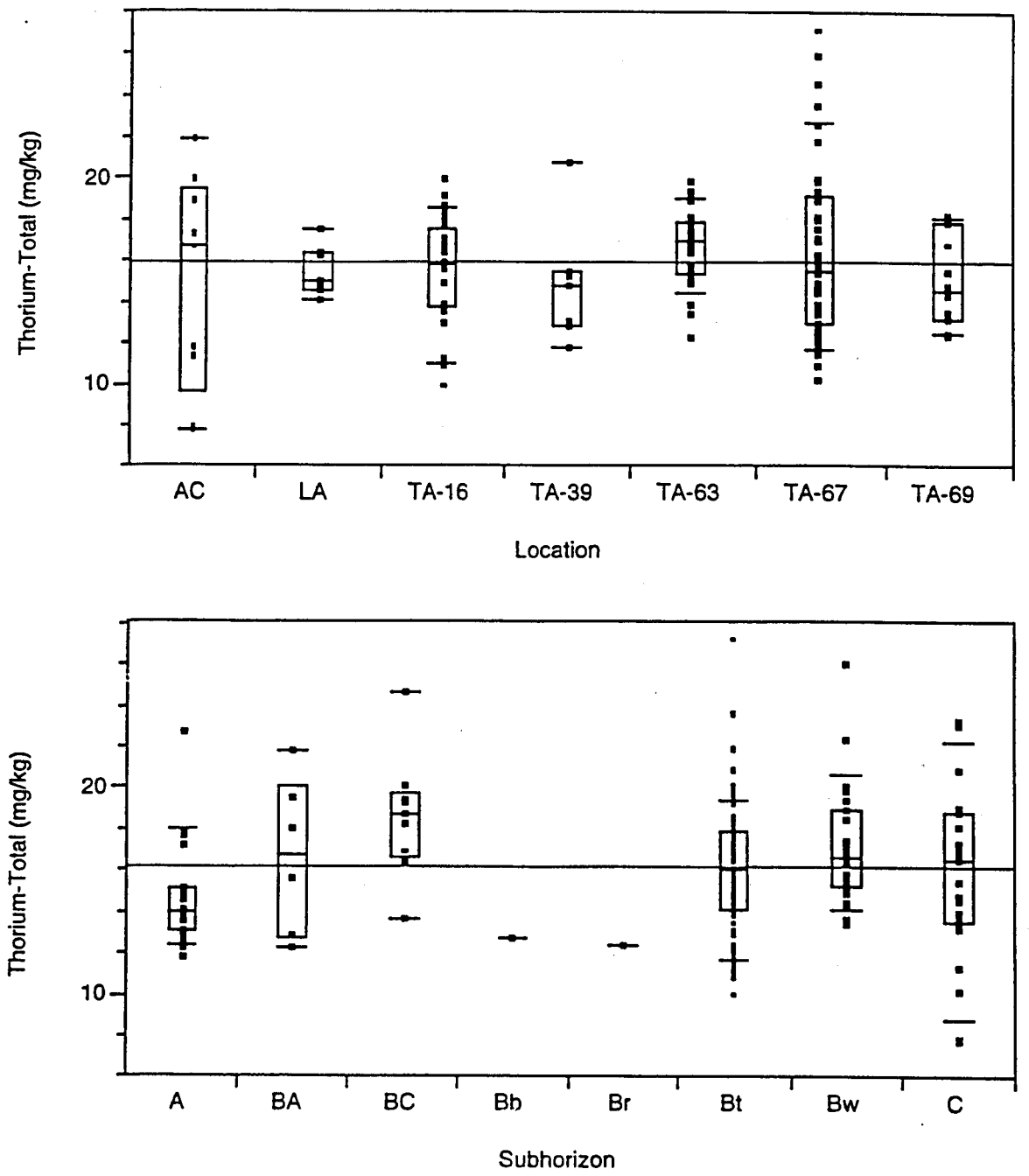

Figure 38. Summary of total Th results by soil subhorizon and location.

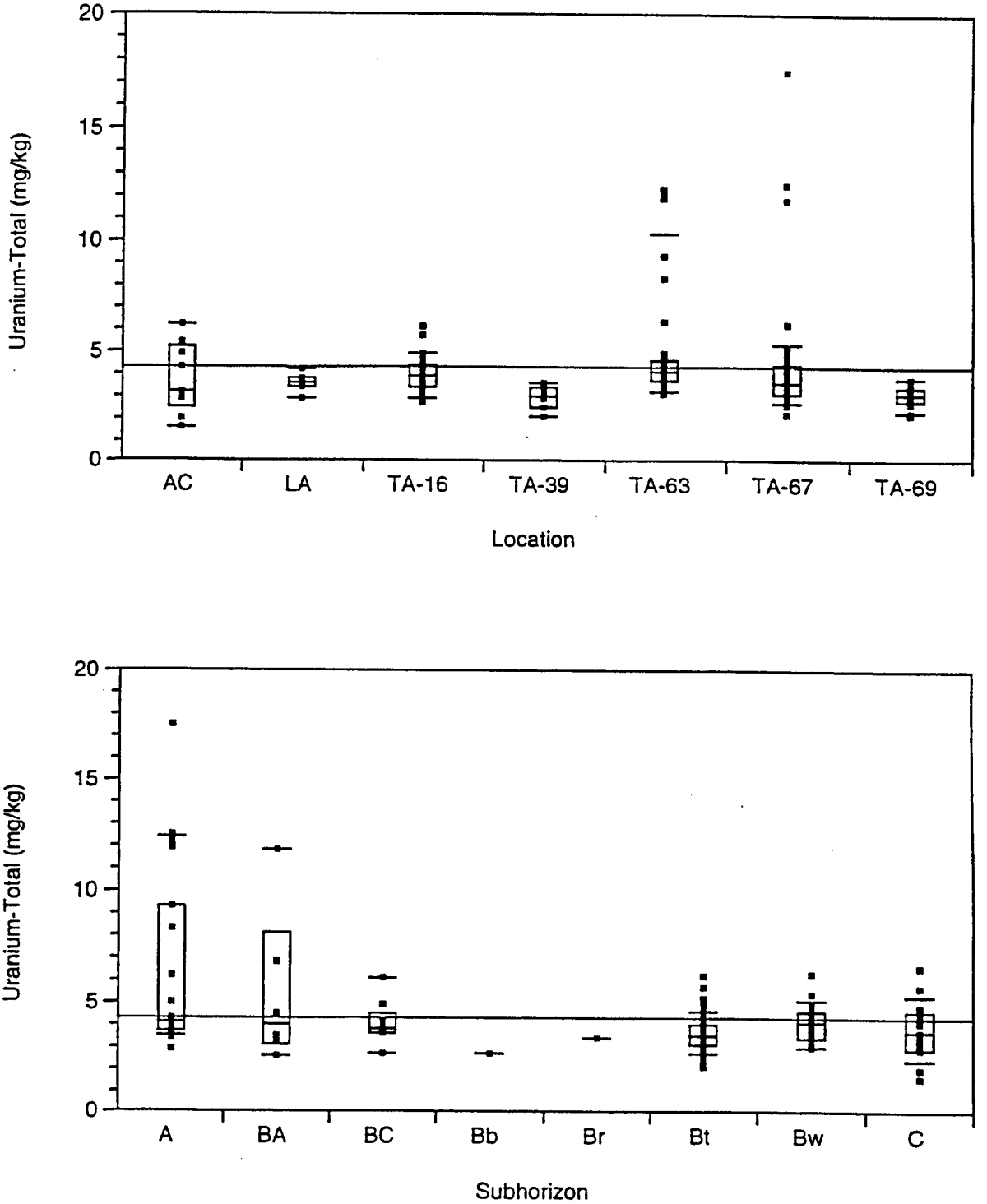

Figure 39. Summary of total U results by soil subhorizon and location.

Comparison of New Background Data to Existing LANL-wide Background Data

The new background soil data set differs in two primary respects from the original LANL-wide background data. First, the new data were mostly sampled at locations within the interior of the Laboratory. Second, the frequency of samples from the A, B and C horizons differed between the two data sets. Many more soils horizons were sampled in this investigation. These factors make a simple distribution or mean comparison of the data sets non-informative. In lieu of sophisticated multivariate or generalized linear model approaches, we decided to use an approach that combined statistics, geochemistry, and risk-based screening values to eliminate "outliers" from the combined data distributions that we inferred to contain contamination from Laboratory activities (i.e., widely dispersed fallout from explosive testing).

The key to this approach is the presence of a significant correlation between the major elements (Al, Fe, and K) and most of the other trace elements in LANL soils. These correlations are summarized in Table 11. The U data were screened for outliers in a different way, and this approach is discussed below. The geochemical basis for this correlation is discussed by Longmire et al. (1995). The first step in our outlier screening process is to calculate the statistical residual from a regression analysis of the trace elements and the minor elements. The regression analysis is performed on the combined data set, where the < detection limit (DL) and laboratory duplicate values are treated as discussed above. Residuals that differ significantly from the distribution of residuals are tentatively classified as outliers. These regression residual outliers are excluded from the combined data set if they meet one or more of the following conditions:

1) The value is also an outlier in its soil horizon group. Preference is given to eliminating outliers from the A horizon, because these outliers may logically be associated with a release associated with Laboratory activities and do not represent natural background concentrations.

2) The HNO_3 digestion result is inconsistent with the total analysis of the same sample. These outliers most likely represent laboratory artifacts, and should not be included in the background data base. Both usually low results and unusually high (i.e., where the HNO_3 results is greater than the total result) may be excluded for this reason.

3) The value would have an unacceptable impact on the estimation of the statistical distribution. For example, an outlier may be an order of magnitude greater than the next largest value, and using this value

would inflate the estimated UTL. Some of these values may represent an undersampled part of the background distribution, but it beyond the scope of this report to estimate statistical properties of every possible background soil type. For example the calcium carbonate horizon has been excluded from these analyses, and only the more broadly distributed soil horizons (A, B, and C) are evaluated.

4) The residual represents a significant fraction of the SAL. Because the SAL comparison represents the step that follows the background comparison in the screening assessment process, this condition helps to place the outlier into a decision-making context. Outliers with residuals that represent a significant fraction of the SAL may be excluded from the LANL-wide background data base.

Our goal in this report is not to definitively determine whether each sample value represents background, but to use a weight-of-evidence approach, described above, to eliminate results that are inconsistent with the majority of the LANL-wide background data. We cannot be certain that some values excluded in this process represent legitimate natural background conditions, but this process is intended to increase the defensibility, and therefore usability, of the LANL-wide background data.

Detection of Uranium Outliers

Uranium outliers were identified in a process similar to other inorganics, with the exception that we used Th as a correlate of uranium. As discussed in trace geochemistry section of this report, the common correlation of Th and U in both the soil and the Bandelier Tuff indicates that most of the B and C soil horizons have been ultimately derived from the Bandelier Tuff. Given this assumption, the Th-U relationship for the Bandelier Tuff can be viewed as a limiting case for relationship between the Th-U for the soils. The correlation plot of Th-U (Figure 40) shows the statistical outliers. Figure 41 shows the data distributions for the A, B, C soil horizons and the Bandelier Tuff. These data distributions show some apparent outliers in the soil data, which are primarily in A horizons soils. All of the values identified on these plots were judged to be true outliers from the background U soil concentration distribution and have been eliminated from the combined LANL-wide background data set. All A horizon samples are from mesa tops in the central part of the Laboratory and indicate widespread, low-level contamination from explosives testing. These excluded U samples are summarized in Table 12.

Table 11. Summary of correlation analysis between "trace" elements and major soil elements of the combined soil background data sets.

Element	Correlation with Aluminum	Iron	Potassium
Aluminum	1	0.870	0.859
Antimony (4)	0.583	0.424	0.538
Arsenic (2)	0.634	0.775	0.568
Barium	0.543	0.535	0.559
Beryllium	0.772	0.777	0.843
Cadmium (1)	0.427	0.487	0.447
Calcium	0.345	0.241	0.400
Chlorine	0.197	0.063	0.195
Chromium	0.742	0.801	0.695
Cobalt	0.268	0.167	0.270
Copper	0.401	0.599	0.412
Iron	0.870	1	0.783
Lead	0.499	0.525	0.482
Magnesium	0.893	0.854	0.906
Manganese (4)	-0.055	0.158	-0.055
Mercury (1)	0.281	0.122	0.322
Nickel	0.703	0.777	0.716
Potassium	0.859	0.783	1
Potassium-TOTAL (3)	-0.393	-0.503	-0.326
Selenium (1)	0.714	0.631	0.548
Sodium	0.545	0.322	0.609
Sulfate	0.305	0.148	0.338
Tantalum	0.017	-0.047	-0.050
Thallium (4)	0.527	0.559	0.425
Thorium	0.263	0.288	0.318
Thorium-TOTAL (3)	0.373	0.219	0.268
Uranium	-0.037	0.006	0.045
Uranium-TOTAL (3)	-0.138	-0.170	-0.096
Vanadium	0.753	0.901	0.673
Zinc (4)	0.614	0.689	0.616

Sample size is 174 with the exception of (1) 39, (2) 157, (3) 171, (4) 173

Table 12. Summary of uranium values excluded from the combined background data set.

Sample ID	Sample location	Soil Horizon	Residual	Excluded	Rationale
FS2100	TA-63	A	5.32	Yes	Greater than tuff regression, A horizon outlier
FS2114	TA-63	A	6.15	Yes	Greater than tuff regression, A horizon outlier
FS2118	TA-63	A	5.11	Yes	Greater than tuff regression, A horizon outlier
FS2119	TA-63	A	1.65	Yes	Greater than tuff regression, A horizon outlier
FS2150	TA-63	A	4.28	Yes	Greater than tuff regression, A horizon outlier
FS2154	TA-63	A	3.54	Yes	Greater than tuff regression, A horizon outlier
FS2159	TA-67	A	5.12	Yes	Greater than tuff regression, A horizon outlier
FS2186	TA-67	A	8.47	Yes	Greater than tuff regression, A horizon outlier
FS2219	TA-67	A	3.31	Yes	Greater than tuff regression, A horizon outlier
FS2096	TA-51	BA	4.48	Yes	Greater than tuff regression, BA horizon outlier
FS2149	TA-63	B	1.41	Yes	Greater than tuff regression
FS2160	TA-67	BA	5.06	Yes	Greater than tuff regression, BA horizon outlier

Detection of Arsenic Outliers

Seven low values were identified by the regression analysis of As (Figure 42). These values are primarily from the B soil horizon (Figure 43). These values are summarized in Table 13, and all were excluded from the combined background data set.

Table 13. Summary of arsenic values excluded from the combined background data set.

Sample ID	Sample location	Soil Horizon	Residual	Excluded	Rationale
FS2089	LA	B	-3.51	Yes	Inconsistent with total result (0.15 vs 16), A horizon outlier
FS2123	TA-16	B	-3.15	Yes	Inconsistent with total result (0.15 vs 17), A horizon outlier
FS2130	TA-16	B	-2.70	Yes	Inconsistent with total result (0 vs 16), A horizon outlier
FS2115	TA-63	B	-2.79	Yes	Inconsistent with total result (0.15 vs 15), A horizon outlier
FS2120	TA-63	B	-2.72	Yes	Inconsistent with total result (0.15 vs 12), A horizon outlier
FS2114	TA-63	A	-3.00	Yes	Large residual, A horizon outlier
FS2118	TA-63	A	-3.00	Yes	Inconsistent with total result (0.3 vs 13), A horizon outlier

Detection of Barium Outliers

One high outlier was identified in the Ba-K correlation plot (Figure 44). This value was a B soil horizon outlier (Figure 45), the HNO_3 digestion result was greater than the total result, and the residual of this outlier represented about 10% of the SAL (532 ppm divided by 5300 ppm). This outlier was excluded from the combined background data set (Table 14).

Table 14. Summary of barium values excluded from the combined background data set.

Sample ID	Sample location	Soil Horizon	Residual	Excluded	Rationale
FS2040	TA-69	B	532	Yes	B horizon outlier, Nitric acid result of 730 > total result of 558.7, Large fraction of SAL

Detection of Beryllium Outliers

No outliers were detected in the Be-K regression analysis.

Detection of Calcium Outliers

One high outlier was identified in the Ca-K correlation plot (Figure 46). This value was a C soil horizon outlier (Figure 47), the HNO_3 digestion result was greater than the total result, and it was nearly an order of magnitude larger than the next highest Ca result (Figure 47). This outlier was excluded from the combined background data set (Table 15). It is interesting to note that this Ca value was two to three times greater than Ca values reported for the $CaCO_3$ soil horizons.

Table 15. Summary of calcium values excluded from the combined background data set.

Sample ID	Sample location	Soil Horizon	Residual	Excluded	Rationale
FS2060	TA-39	C	75 600	Yes	Outlier in C horizon, Nitric acid result of 730 > total result of 558.7, Including the value in the statistical analysis would significantly inflate the UTL

Detection of Chlorine Outliers

No outliers were detected due to a low correlation with the major elements.

Detection of Chromium Outliers

One high outlier was identified in the Cr-Fe correlation plot (Figure 48). This value was a B soil horizon outlier (Figure 49), the HNO_3 digestion result was greater than the total result, and the residual of this outlier represented about 15% of the SAL (36.9 ppm divided by 210 ppm). This outlier was excluded from the combined background data set (Table 16).

Table 16. Summary of chromium values excluded from the combined background data set.

Sample ID	Sample location	Soil Horizon	Residual	Excluded	Rationale
FS2170	TA-67	B	36.9	Yes	Outlier in B horizon, Nitric acid result of 46 > total result of 25, Residual is a large fraction of SAL

Detection of Cobalt Outliers

No outliers were detected in the regression analyses.

Detection of Copper Outliers

No outliers were detected in the regression analyses.

Detection of Lead Outliers

Three high values were identified by the regression analysis of Pb (Figure 50). These values were collected from the A and B soil horizons (Figure 51), and only one value represents a significant fraction of the SAL (22.9 ppm of 400 ppm) and represents an outlier in the A soil horizon group. The C soil horizon outlier was excluded, because it was not viewed that this value could reasonably represent an impact from Laboratory operations or airborne deposition of leaded gas exhaust. These values are summarized in Table 17, which presents the rationale for excluding one of the three outliers from the combined background data set.

Table 17. Summary of lead values excluded from the combined background data set.

Sample ID	Sample location	Soil Horizon	Residual	Excluded	Rationale
FS2054	TA-16	A	22.9	Yes	A horizon outlier, Residual is a large fraction of SAL
FS2079	Tsk.	C	16.9	No	Not a significant C horizon outlier, Residual is a small fraction of SAL
FS2118	TA-63	A	13.7	No	Not a significant A horizon outlier, Residual is a small fraction of SAL

Detection of Magnesium Outliers

No outliers were detected in the regression analyses.

Detection of Manganese Outliers

No outliers were detected in the regression analyses.

Detection of Nickel Outliers

One high value was identified by the regression analysis of Ni (Figure 52). This value was collected from the B soil horizon (Figure 53), and does not represent a significant fraction of the SAL (12.6 ppm of 1500 ppm). This value is summarized in Table 18, and presents the rationale for not excluding this value from the combined background data set.

Table 18 Summary of nickel outlier, and rationale for not excluding from the combined background data set.

Sample ID	Sample location	Soil Horizon	Residual	Excluded	Rationale
FS2090	LA	B	12.6	No	Small fraction of SAL, not an outlier in the B soil horizon

Detection of Sodium Outliers

No outliers were detected in the regression analyses.

Detection of Sulfate Outliers

No outliers were detected in the regression analyses.

Detection of Vanadium Outliers

No outliers were detected in the regression analyses.

Detection of Zinc Outliers

One high value was identified by the regression analysis of Zn (Figure 54). This value was in the A soil horizon (Figure 55), and the HNO_3 digestion result was greater than the total results. This value is summarized in Table 19, and presents the rationale for excluding this value from the combined background data set.

Table 19. Summary of zinc outlier, and rationale for not excluding from the combined background data set.

Sample ID	Sample location	Soil Horizon	Residual	Excluded	Rationale
FS2000	ULAC	A	30.5	Yes	Significant A horizon outlier, Nitric acid result of 58 > the total result of 54.57

Estimating Data Distributions for Updated LANL-wide Background Soil Data

Table 20 summarizes the distributional properties of the inorganic analytes in the combined background data set. Distributions were either normally distributed or were transformed to approach normality with either a log- or square root transformation. The purpose of estimating the statistical distribution that best models the data is to use this estimated statistical distribution to calculate the UTLs.

Calculation of Background Screening Values for Updated LANL-wide Background Soil Data

Upper tolarence limits are calculated for all inorganics elements, except for chloride, where enough values were detected to allow estimation of the statistical distribution. Chloride has an unusual distribution, which does not allow the use of a simple statistical distribution model. We propose to use the maximum detected value for chloride and the rarely detected elements (Sb, Cd, Hg, Se, Ta, and Tl).

For the elements that are normally distributed without any data transformation and the elements that are normally distributed after a square root transformation, parametric tolerance limits were calculated by using the following equation:

$$UTL_{0.95,0.95} = \text{mean} + \text{standard deviation} * k_{0.95,0.95} \qquad (1)$$

The k-factor depends on the number of background samples; complete tables of k-factors are published in the RCRA groundwater statistical analysis document (EPA 1989) and Gilbert (1987). Readers are referred to the LANL ER Project policy paper on background comparisons for example k-factors.

The UTLs for log normally distributed elements were estimated by a simulation process. These simulations were run in the S-plus statistical programming environment. The S-plus code is presented in Appendix A. These simulations were run for 10,000 trials, which were sufficient to estimate these UTLs to two or three significant digits.

After calculating the UTLs, these values were screened to ensure that some UTL values were not artificially inflated due to a small sample size. The raw calculated UTLs are presented in Table 21. The relative value of the median, mean, and calculated UTLs for the soil horizon subgroups and the overall combined background data set were also compared. If the mean and the median for a soil horizon were less than the combined data set mean and median and the UTL for the subset were greater than the combined data set, the overall data UTL was substituted for the soil horizon UTL. These trimmed UTL values for inorganics and naturally occuring radionuclides are presented in Tables 22 and 23, respectively, and it is proposed that these values, which include the sample maximum for the analytes discussed above, be used as the LANL-wide background screening values for LANL ER Project decision-making.

Guidance for ER Project Background Data Users

ER Project background data users are advised to compare their site data to the relevant soil horizon (or geologic strata) that best represent the locations where samples were collected. In some cases, the soil horizon is either not

known or is irrelevant, because the sampled material is fill material of unknown origin. Where the soil horizon is not known, data users are advised to use the combined A, B, and C soil horizon background screening values.

The background screening process for RFI screening assessments consists of the following steps:

1) Use LANL-wide background data, which are presented in this report. These data include:
   a) soil data by horizon,
   b) geological data by stratigraphic layer, and
   c) sediment data from Ancho, Indio, and Water Canyons

2) Data analysts will use the appropriate subset of the LANL-wide data, except where soil horizon is neither known nor relevant (e.g., fill of unknown origin was sampled).

3) The initial comparison for all analytes will be to background screening values for all inorganics and naturally-occurring radionuclides (by background data subsets as described above). Background screening values are based on the following sources:
   a) maximum reported value for fallout-related radionuclides from the LANL environmental surveillance reports,
   b) maximum reported value for inorganics with more than 20% non-detects,
   c) maximum reported value for inorganics where the statistical distribution could not be estimated, and
   d) UTLs calculated for normal, lognormal, or square root-transformed distributions based on a 99th percentile and 95% confidence. NOTE - UTLs for data subsets are checked for consistency with the data group to make sure that inflated UTLs are not used.

4) Additional background analyses are required for the following cases:
   a) background screening values are exceeded AND SALs are exceeded,
   b) ecological risk is determined to be primary decision point, or
   c) aluminum, arsenic, beryllium, or manganese are known (or suspected) to have been released at the PRS.

5) Additional analyses include:
   a) graphical comparisons of background and PRS data,
   b) statistical "distribution shift" tests,
   c) regression analysis of trace elements and major elements (soil and sediment only), or
   d) regression analysis of Th and U (any solid media)

Table 20. Statistical distribution of the combined background data set inorganic analytes. These data are for the nitric acid digestion extraction method (EPA method 3050) unless noted otherwise.

Analyte	Statistical Distribution
Aluminum	Log transformed data are approximately normally distributed.
Antimony	Only 19 of 182 total values are detects; no distribution was estimated.
Arsenic	Data are approximately normally distributed.
Barium	Square root transformed data are approximately normally distributed.
Beryllium	Square root transformed data are approximately normally distributed.
Cadmium	Only 4 of 40 total values are detects; no distribution was estimated.
Calcium	Log transformed data are approximately normally distributed.
Chlorine	Log transformation does not significantly improve fit to a normal distribution; data may be best modeled by a mixture distribution; recommend using the maximum detected value as a background screening value.
Chromium	Log transformed data are normally distributed.
Cobalt	Log transformed data are approximately normally distributed.
Copper	Square root transformed data are approximately normally distributed.
Iron	Square root transformed data are normally distributed.
Lead	Data are approximately normally distributed.
Magnesium	Log transformed data are approximately normally distributed.
Manganese	Square root transformed data are normally distributed.
Mercury	Only 2 of 39 total values are detects; no distribution was estimated.
Nickel	Data transformations do not improve fit to normality; untransformed data were used to estimate parameters of the normal distribution.
Potassium	Square root transformed data are more normally distributed.
Potassium-total	Data are approximately normally distributed.
Selenium	Only 23 of 41 total values are detects, no distribution was estimated.
Sodium	Log transformed data are approximately normally distributed.
Sulfate	Log transformed data are normally distributed.
Tantalum	Zero of 183 total values are detects, no distribution was estimated.
Thallium	Only 111 of 182 total values are detects; no distribution was estimated.
Thorium	Data are approximately normally distributed.
Thorium-total	Data are approximately normally distributed.
Uranium	Data are approximately normally distributed.
Uranium-total	Data are approximately normally distributed.
Vanadium	Square root transformed data are approximately normally distributed.
Zinc	Square root transformed data are approximately normally distributed.

Table 21. Summary of calculated UTLs and maximum concentrations by soil horizons.

Aluminum

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} by sim
A	24	2350	8500	23000	8581	4875	0.107	26642
B	126	1400	11000	61500	12574	9498		43594
C	24	900	11000	33000	10083	7265		46090
All Horizons	174	900	10000	61500	11680	8810		38691

Antimony

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	Max. detect
A	24	0.2	0.7	2.5	1.248	1.000	0.0267	0.5
B	126	0.2	0.55	2.5	0.818	0.752		1
C	23	0.1	0.7	2.5	1.307	0.988		ND
All Horizons	173	0.1	0.6	2.5	0.943	0.844		1

Arsenic

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th}
A	21	0.8	3.9	5.4	3.39	1.52	0.0001	6.99
B	108	1	4	9.3	4.34	1.87		8.12
C	21	0.3	2.4	6.7	2.50	1.72		6.58
All Horizons	150	0.3	4	9.3	3.95	1.92		7.82

Barium

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} (sqrt)
A	24	27	135	190	128.9	42.9	0	263
B	125	46	140	370	155.4	72.8		321
C	24	21	75	410	90.3	81.7		286
All Horizons	173	21	130	410	142.7	74.1		315

Beryllium

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th}
A	24	0.105	0.695	1.2	0.681	0.239	0.0001	1.41
B	126	0.25	0.965	3.95	0.992	0.442		1.91
C	24	0.04	0.745	1.9	0.715	0.505		2.38
All Horizons	174	0.04	0.895	3.95	0.911	0.447		1.95

Cadmium

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	Max. detect
A	9	0.2	0.2	1.4	0.422	0.452	0.3002	1.4
B	20	0.2	0.2	2.6	0.420	0.573		2.7
C	10	0.2	0.2	0.2	0.2	0		ND
All Horizons	39	0.2	0.2	2.6	0.364	0.465		2.7

Table 21 (cont.). Summary of calculated UTLs and maximum concentrations by soil horizons.

Calcium

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} by sim
A	24	670	1800	4500	1860	774	0.0001	4033
B	126	1100	2300	14000	2937	1919		6479
C	23	500	1700	4100	1854	1066		5930
All Horizons	173	500	2100	14000	2644	1771		6115

Chlorine

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} by sim
A	24	8	12.45	24	13.33	4.22	0.0037	25.0
B	126	8	14	246	27.81	40.74	.	78.2
C	24	9	23	303	44.18	64.36		170.4
All Horizons	174	8	14.45	303	28.07	42.64		75.9

Chromium

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} by sim
A	24	1.9	8.15	16	8.20	3.25	0	20.5
B	125	2.8	9.3	36.5	9.76	4.49		19.0
C	24	1.9	5.6	15	6.10	3.24		17.0
Chromium	173	1.9	8.6	36.5	9.04	4.36		19.3

Cobalt

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} by sim
A	24	2.8	7.3	29	10.41	7.05	0.0147	31.0
B	126	1.6	6	22	6.67	3.61		14.8
C	24	1	4	34	8.32	8.74		41.2
All Horizons	174	1	6	34	7.41	5.28		19.2

Copper

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} by sim
A	24	0.25	5.7	12	5.80	2.88	0	42.3
B	126	2.7	6	16	6.55	2.39		29.2
C	24	0.25	3.9	7.3	3.75	1.99		22.2
All Horizons	174	0.25	5.75	16	6.06	2.59		30.7

Table 21 (cont.). Summary of calculated UTLs and maximum concentrations by soil horizons.

Iron

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} (sqrt)
A	24	3300	11000	16000	10363	2751	0	18116
B	126	6800	13000	36000	13085	4246		21760
C	24	3300	8450	17000	9021	3513		18499
All Horizons	174	3300	12000	36000	12149	4256		21294

Magnesium

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} by sim
A	24	485	1650	2800	1628	534	0	3460
B	126	800	2100	10000	2335	1138		4484
C	24	420	1550	7400	1773	1416		5962
All Horizons	174	420	1975	10000	2160	1150		4613

Manganese

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} (sqrt)
A	24	140	405	1100	446.9	216.0	0	1003
B	125	76	330	1000	348.3	146.6		673
C	24	76	160	440	193.6	99.4		463
All Horizons	173	76	320	1100	340.5	166.4		714

Mercury

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	Max. detect
A	9	0.05	0.05	0.05	0.05	0	0.6219	ND
B	20	0.05	0.05	0.1	0.0525	0.0112		0.1
C	10	0.05	0.05	0.1	0.0550	0.0158		0.1
All Horizons	39	0.05	0.05	0.1	0.0526	0.0112		0.1

Nickel

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th}
A	24	1	6	12	5.93	2.73	0.0017	12.2
B	126	1	7	29	7.73	4.08		16.0
C	24	1	4.45	15	4.79	3.70		13.3
All Horizons	174	1	7	29	7.07	4.01		15.2

Table 21 (cont.). Summary of calculated UTLs and maximum concentrations by soil horizons.

Potassium-TOTAL

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th}
A	23	20000	23090	32050	24016	3960	0	33239
B	125	11000	23000	36000	24065	4604		33374
C	23	16270	30000	42000	30194	4982		41796
All Horizons	171	11000	24000	42000	24882	5011		35015

Selenium

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	Max. detect
A	9	0.1	0.1	0.7	0.172	0.199	0.0005	0.7
B	20	0.1	0.5	1.3	0.625	0.369		1.3
C	10	0.1	0.125	1.7	0.340	0.503		1.7
All Horizons	39	0.1	0.3	1.7	0.447	0.417		1.7

Sodium

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} by sim
A	24	64	105	660	179	166	0.0004	602
B	126	58	235	1800	286	239		798
C	24	90	365	1700	524	484		2682
All Horizons	174	58	225	1800	304	292		915

Sulfate

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th}
A	24	6	17.5	44	21.42	9.22	0.0039	42.7
B	126	9	30	722	58.79	94.06		249.0
C	24	12	44.5	1200	122.83	254.99		711.6
All Horizons	174	6	28.5	1200	62.47	125.69		316.6

Tantalum

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	Max. detect
A	24	0.1	0.1	0.45	0.160	0.117	0.803	ND
B	126	0.1	0.1	0.45	0.182	0.130		ND
C	24	0.06	0.1	0.45	0.199	0.155		ND
All Horizons	174	0.06	0.1	0.45	0.182	0.132		ND

Table 21 (cont.). Summary of calculated UTLs and maximum concentrations by soil horizons.

Thallium

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	Max. detect
A	24	0.1	0.2	0.5	0.242	0.125	0.0002	0.4
B	126	0.1	0.2	1	0.302	0.194		1
C	23	0.0625	0.1	0.6	0.168	0.150		0.6
All Horizons	173	0.0625	0.2	1	0.276	0.186		1

Thorium-TOTAL

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th}
A	23	11.8	14	22.6	14.8	2.49	0.0193	20.5
B	125	10	16.4	27.15	16.4	3.09		22.7
C	23	7.8	16.46	23.23	15.8	4.11		25.3
All Horizons	171	7.8	16	27.15	16.1	3.21		22.6

Uranium

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th}
A	15	0.2	1	3.6	1.316	0.835	0	3.46
B	123	0.5	0.9	2.4	1.003	0.353		1.72
C	24	0.2	0.7	1.5	0.688	0.289		1.36
All Horizons	162	0.2	0.9	3.6	0.985	0.436		1.87

Uranium-TOTAL

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th}
A	15	3	3.851	5.1	3.907	0.465	0.5	5.10
B	122	2.182	3.7	6.3	3.766	0.781		5.34
C	23	1.7	3.8	6.728	3.911	1.148		6.58
All Horizons	160	1.7	3.7	6.728	3.800	0.818		5.45

Vanadium

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} (sqrt)
A	24	4.6	21	35	20.7	7.62	0	42.8
B	126	7.4	22.5	56.5	22.9	8.69		42.0
C	24	4	14	32	13.2	6.89		32.0
All Horizons	174	4	21	56.5	21.3	8.92		41.9

Table 21 (cont.). Summary of calculated UTLs and maximum concentrations by soil horizons.

Zinc

Data Group	Count	minimum	median	maximum	Mean	Std Dev	Prob>ChiSq (1)	UTL_{95th} (sqrt)
A	23	14	28	40	27.1	7.45	0.008	47.1
B	125	14	31	75.5	32.8	8.91		51.5
C	24	14	29	57	29.0	9.27		52.5
All Horizons	172	14	30.75	75.5	31.5	9.00		50.8

UTL95th - 95% upper tolerance limit of the 95th percentile calculated using normal theory.
UTL95th (sqrt) - 95% upper tolerance limit of the 95th percentile calculated using normal theory on square root transformed data.
UTL95th by sim - 95% upper tolerance limit of the 95th percentile calculated using log-transformed data and computer simulation.
Max. detect. - maximum detected value is proposed as a background screening value due to a small number of detects.
ND - Not detected
(1) Probability that the A, B and C horizon data are drawn from the same distribution, or are statistically not different, as measured the Kruskal-Wallis test. The Kruskal-Wallis is a three or more data group extension of the Wilcoxon rank sum test. Probabilities less than 0.05 indicate that there is a statistically significant difference between the horizons, and a probability greater than 0.05 indicates that there is no statistically significant difference between the soil horizons.

Table 22. Summary of proposed background soil screening values.

Analyte	Soil Horizon A	B	C	All Data
Aluminum	26600	43600	38700 *	38700
Antimony	0.5	1	ND	1
Arsenic	6.99	8.12	6.58	7.82
Barium	263	321	286	315
Beryllium	1.41	1.91	1.95 *	1.95
Cadmium	1.4	2.7	ND	2.7
Calcium	4030	6480	5930	6120
Chlorine	25.0	78.2	170	75.9
Chromium	19.3 *	19.0	17.0	19.3
Cobalt	31.0	14.8	41.2	19.2
Copper	30.7 *	29.2	22.2	30.7
Iron	18100	21800	18500	21300
Lead	28.4	22.3	21.9	23.3
Magnesium	3460	4480	4610 *	4610
Manganese	1000	673	463	714
Mercury	ND	0.1	0.1	0.1
Nickel	12.2	16.0	13.3	15.2
Potassium-TOTAL	33200	33400	41800	35000
Potassium	3070	3420	3410 *	3410
Selenium	0.7	1.3	1.7	1.7
Sodium	602	798	2680	915
Sulfate	42.7	249	712	317
Tantalum	ND	ND	ND	ND
Thallium	0.4	1	0.6	1
Thorium	13.3	15.0	12.3	14.6
Thorium-TOTAL	20.5	22.7	25.3	22.6
Uranium	1.87 *	1.72	1.36	1.87
Uranium-TOTAL	5.10	5.34	6.58	5.45
Vanadium	42.8	42.0	32.0	41.9
Zinc	47.1	51.5	50.8 *	50.8

* Values were trimmed to the all data UTL to eliminate inflated UTLs.
ND = Not detected.
Units are mg/kg.

Table 23. Computed background screening values for naturally occurring radionuclides compiled by soil horizon.

Analyte	Soil Horizon A	B	C	All Data
Total Potassium (mg/kg)	33200	33400	41800	35000
Potassium-40 (pCi/g)	27.2	27.3	34.2	28.6
Total Thorium (mg/kg)	20.5	22.7	25.3	22.6
Thorium-232 (pCi/g)	2.24	2.48	2.77	2.47
Total Uranium (mg/kg)	5.10	5.34	6.58	5.45
Uranium-234 (pCi/g)	1.81	1.90	2.33	1.94
Uranium-235 (pCi/g)	0.078	0.082	0.101	0.084
Uranium-238 (pCi/g)	1.70	1.78	2.20	1.82
Total Uranium (pCi/g)	3.59	3.76	4.64	3.84

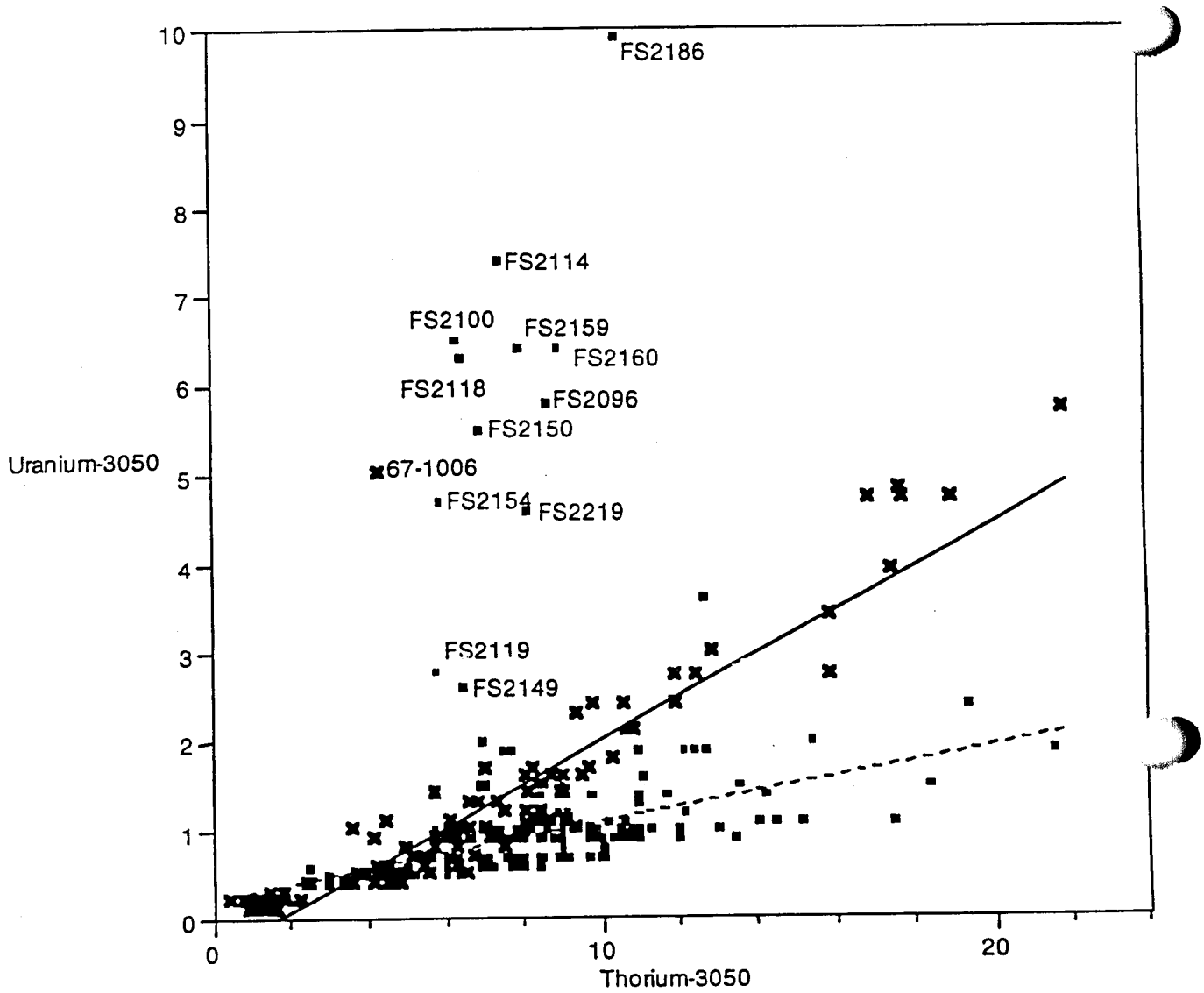

Figure 40. Correlation between Th and U results (both extracted by method 3050). Labeled values are outliers in the Th-U regression analysis. Solid line is the linear regression between Th and U for the Bandelier tuff data (Longmire et al., 1995) ($y=-0.403+ 0.241x$, $r^2=0.907$, where the one outlier was excluded from the analysis). Dashed line is the linear regression between Th and U for the A, B and C soil horizon data ($0.233+0.0867x$, $r^2=0.367$, where the 11 outliers were excluded from the analysis).

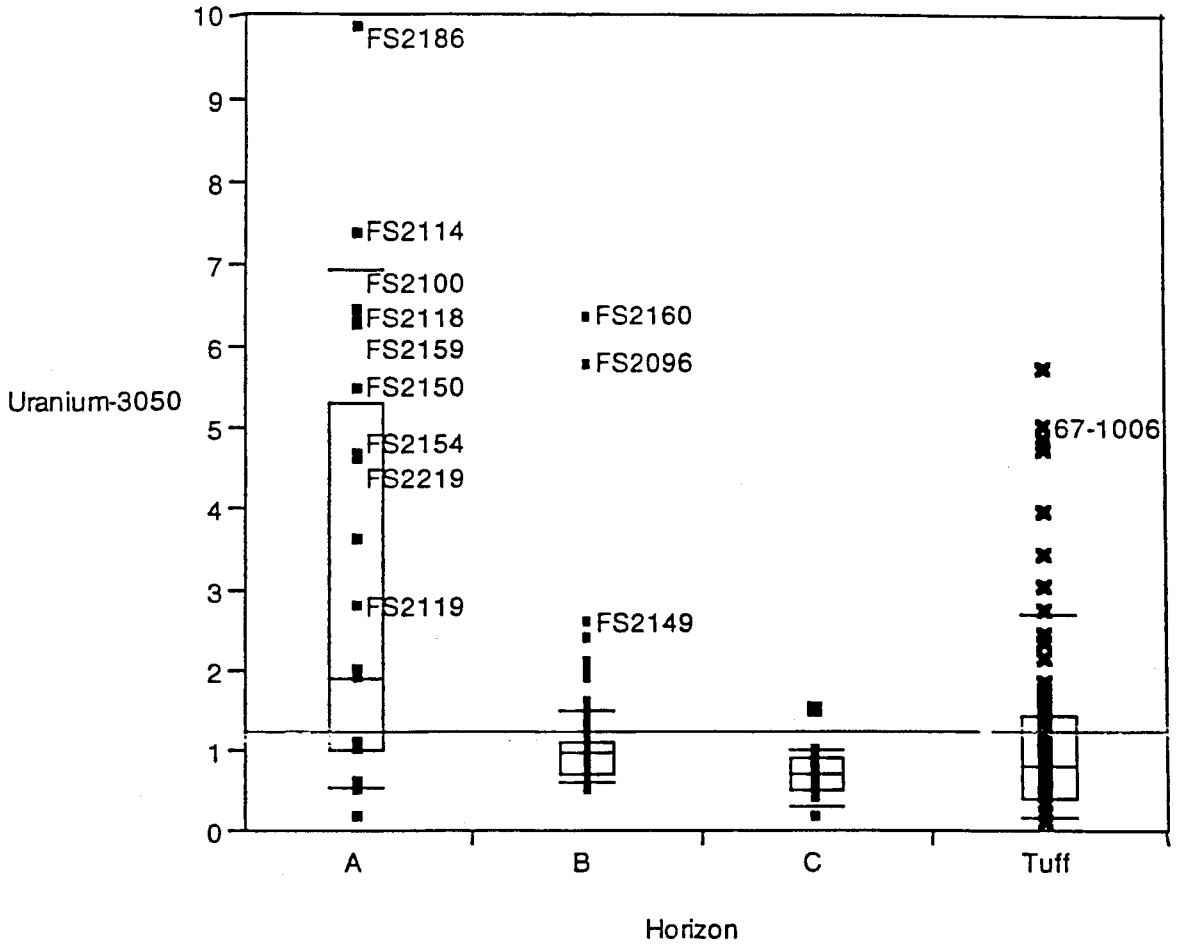

Figure 41. Uranium (3050 extraction method) results by soil horizon. Labeled values are outliers in the U-Th regression analysis.

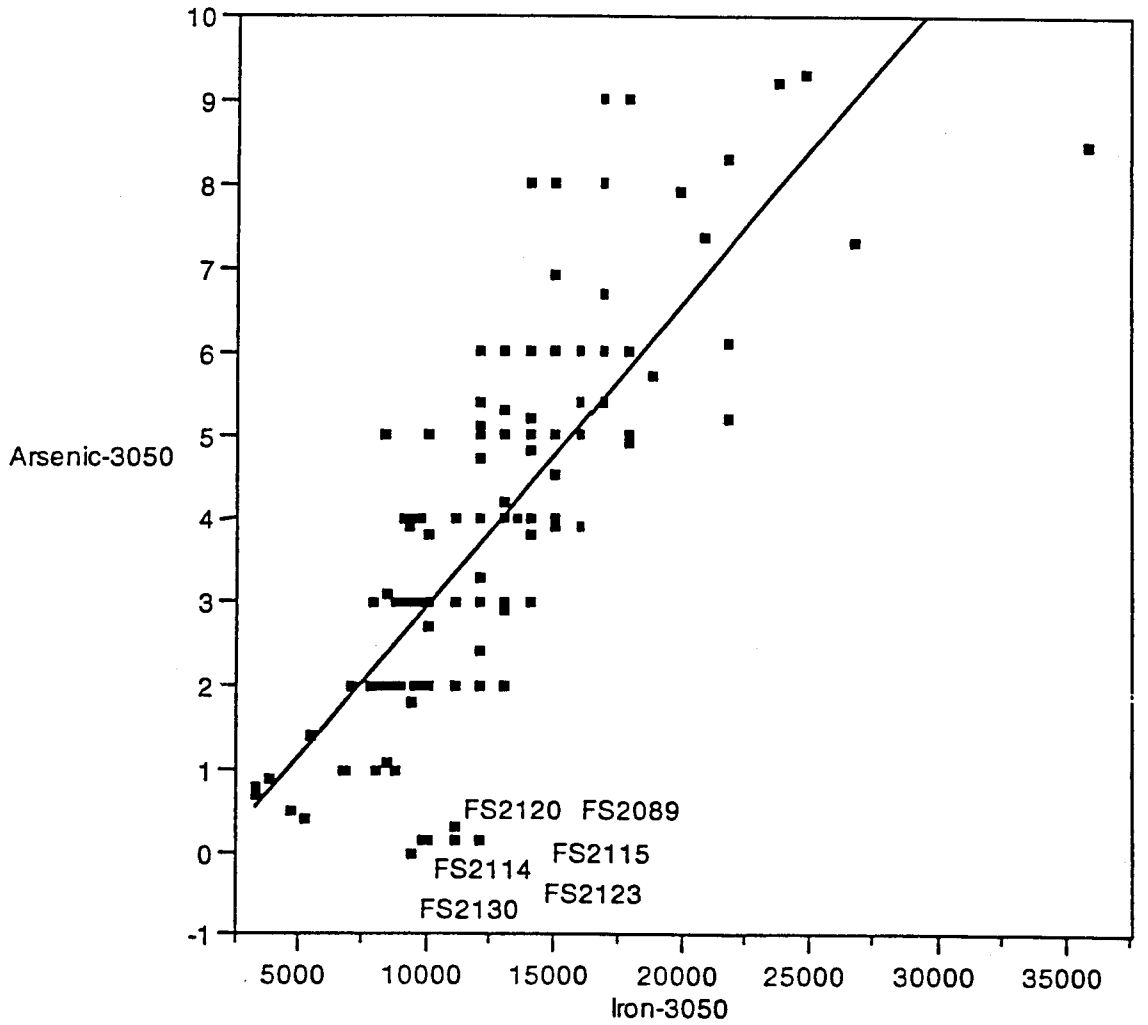

Figure 42. Correlation of As to Fe results (both extracted by method 3050). Labeled values are outliers in the As-Fe regression analysis. The solid line is the linear regression between As and Fe for the A, B and C soil horizons data (-0.654+0.000359x, r^2=0.600), where the six outliers were included in the analysis).

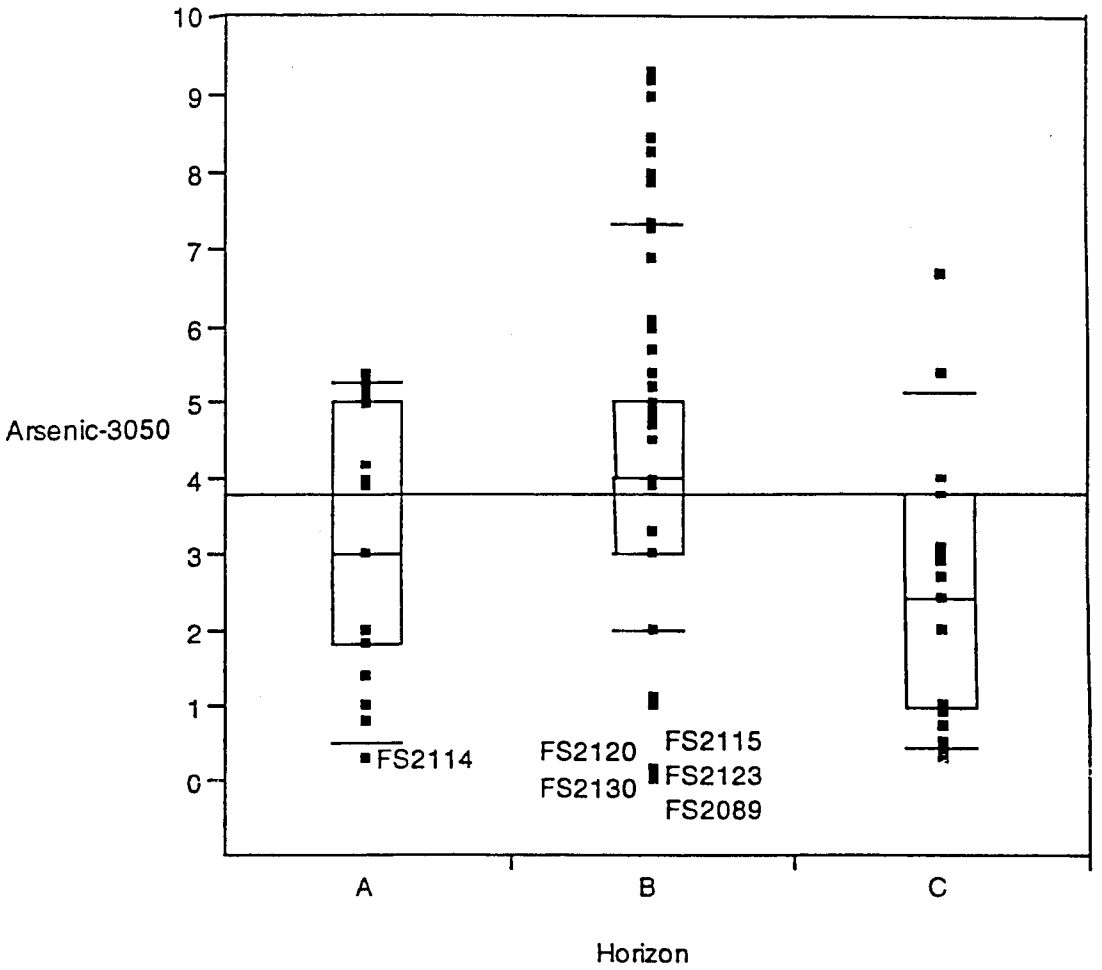

Figure 43. Arsenic (3050 extraction method) results by soil horizon. Labeled values are outliers in the As-Fe regression analysis.

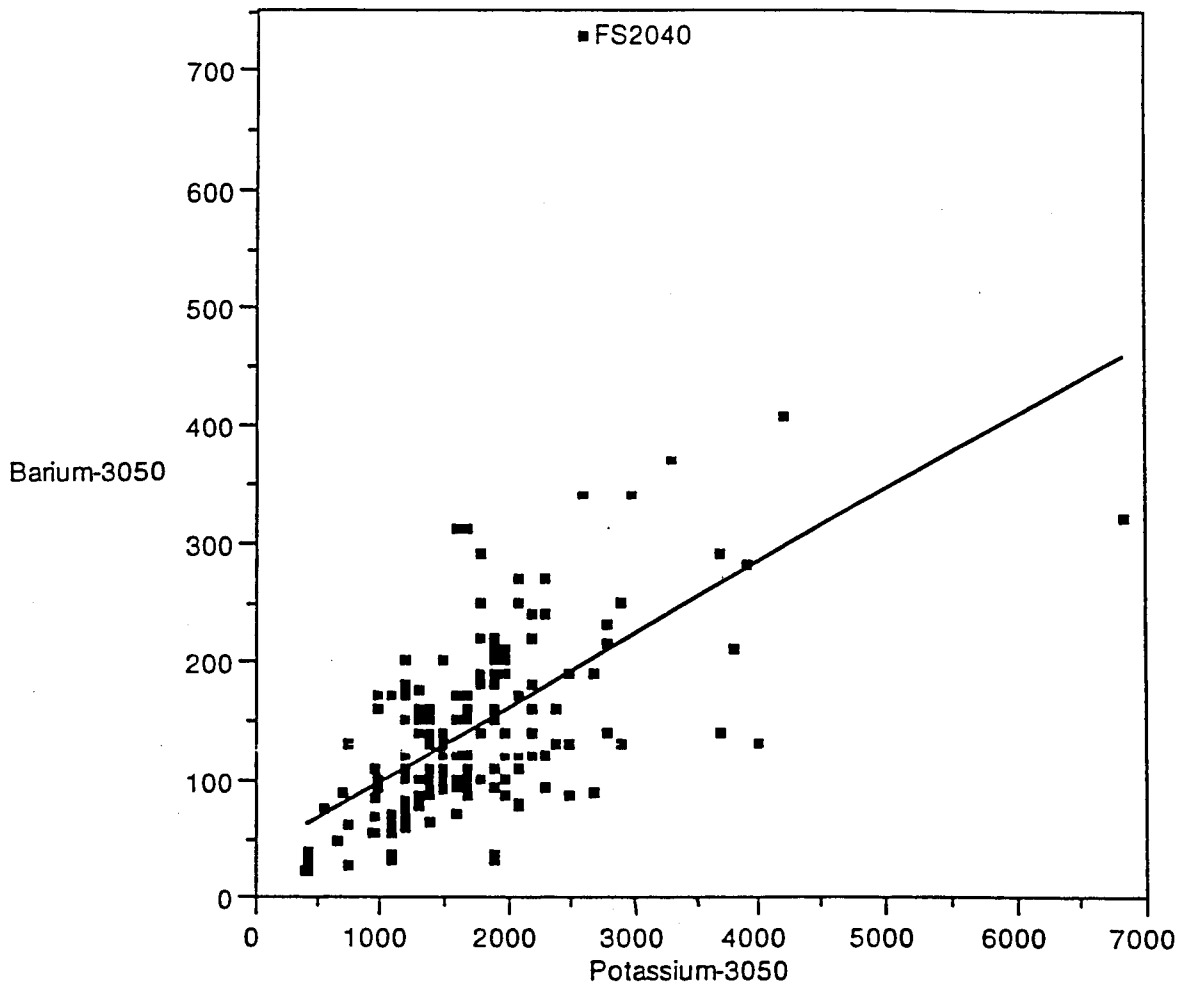

Figure 44. Correlation of Ba to K results (both extracted by method 3050). The labeled value is an outlier in the Ba-K regression analysis. Solid line is the linear regression between Ba and K for the A, B and C soil horizon data (38.9+0.0613x, r^2=0.312, where the one outlier was included in the analysis).

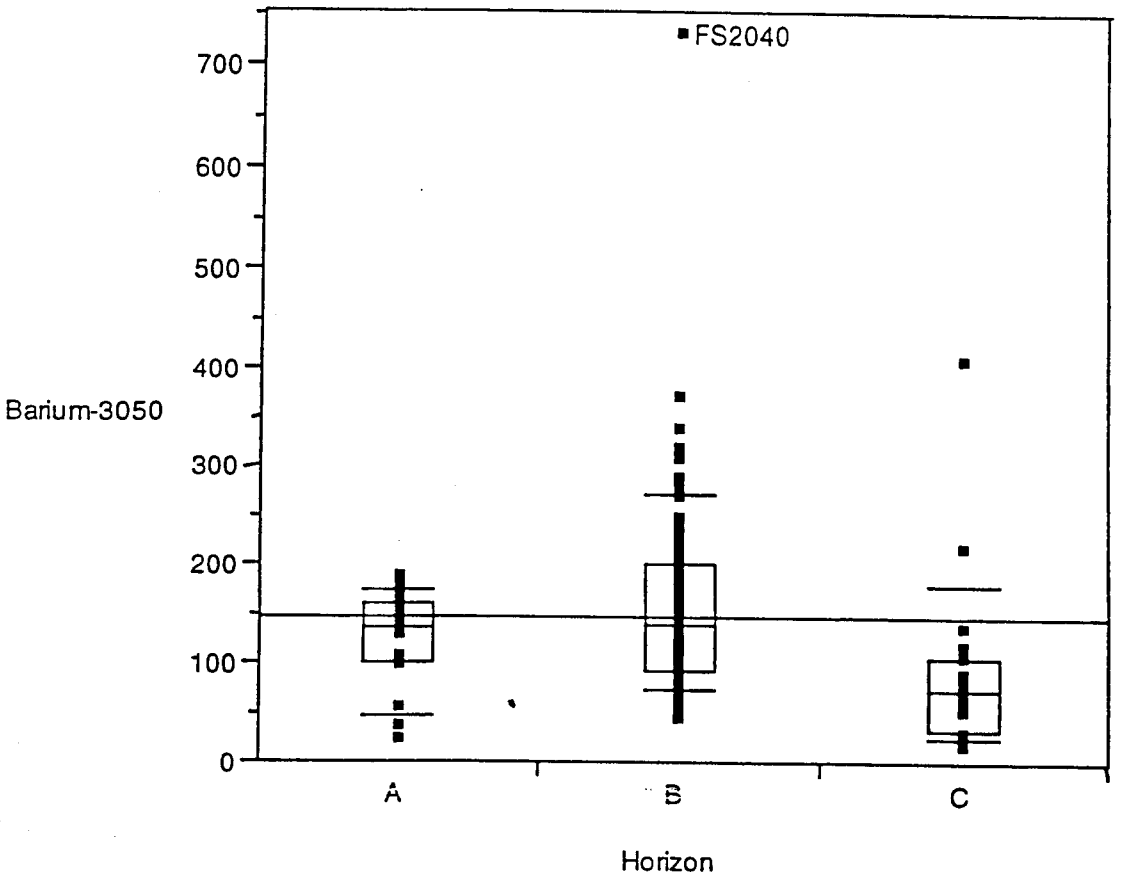

Figure 45. Barium (3050 extraction method) results by soil horizon. The labeled value is an outlier in the Ba-K regression analysis.

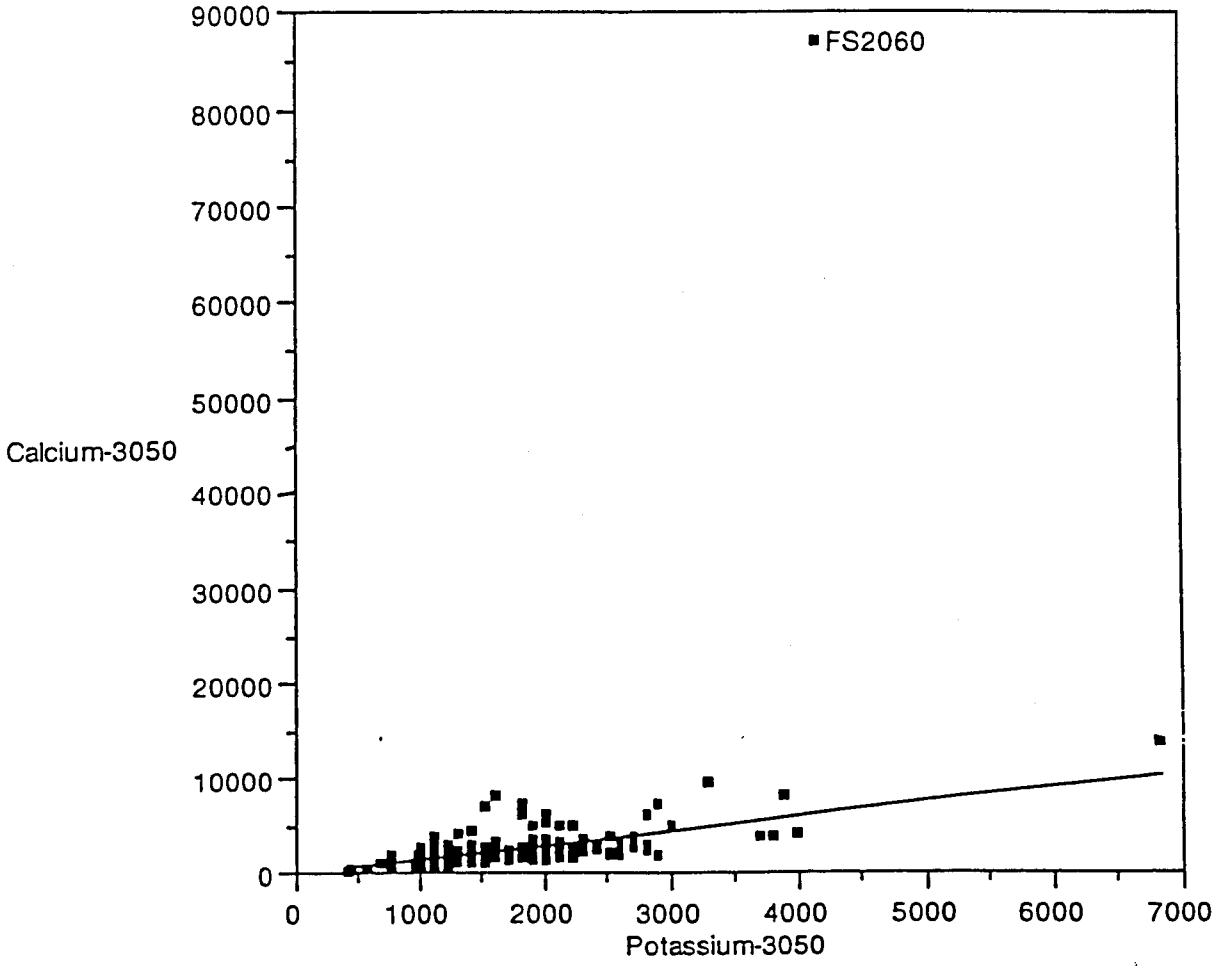

Figure 46. Correlation of Ca to K results (both extracted by method 3050). The labeled value is an outlier in the calcium-potassium regression analysis. Solid line is the linear regression between Ca and K for the A, B and C soil horizon data (-4.61+1.53x, r^2=0.436, where the one statistical outlier was excluded from the analysis).

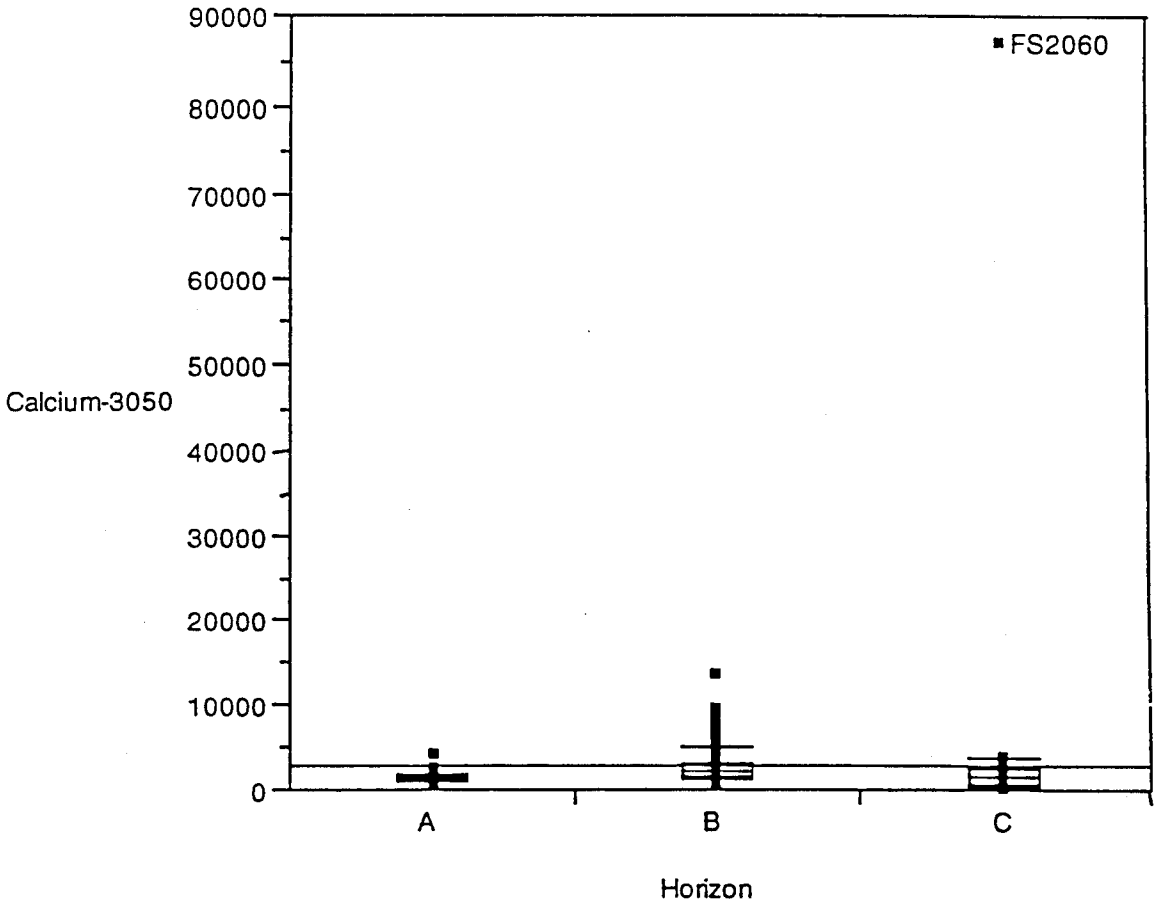

Figure 47. Calcium (3050 extraction method) results by soil horizon. The labeled value is an outlier in the Ca-K regression analysis.

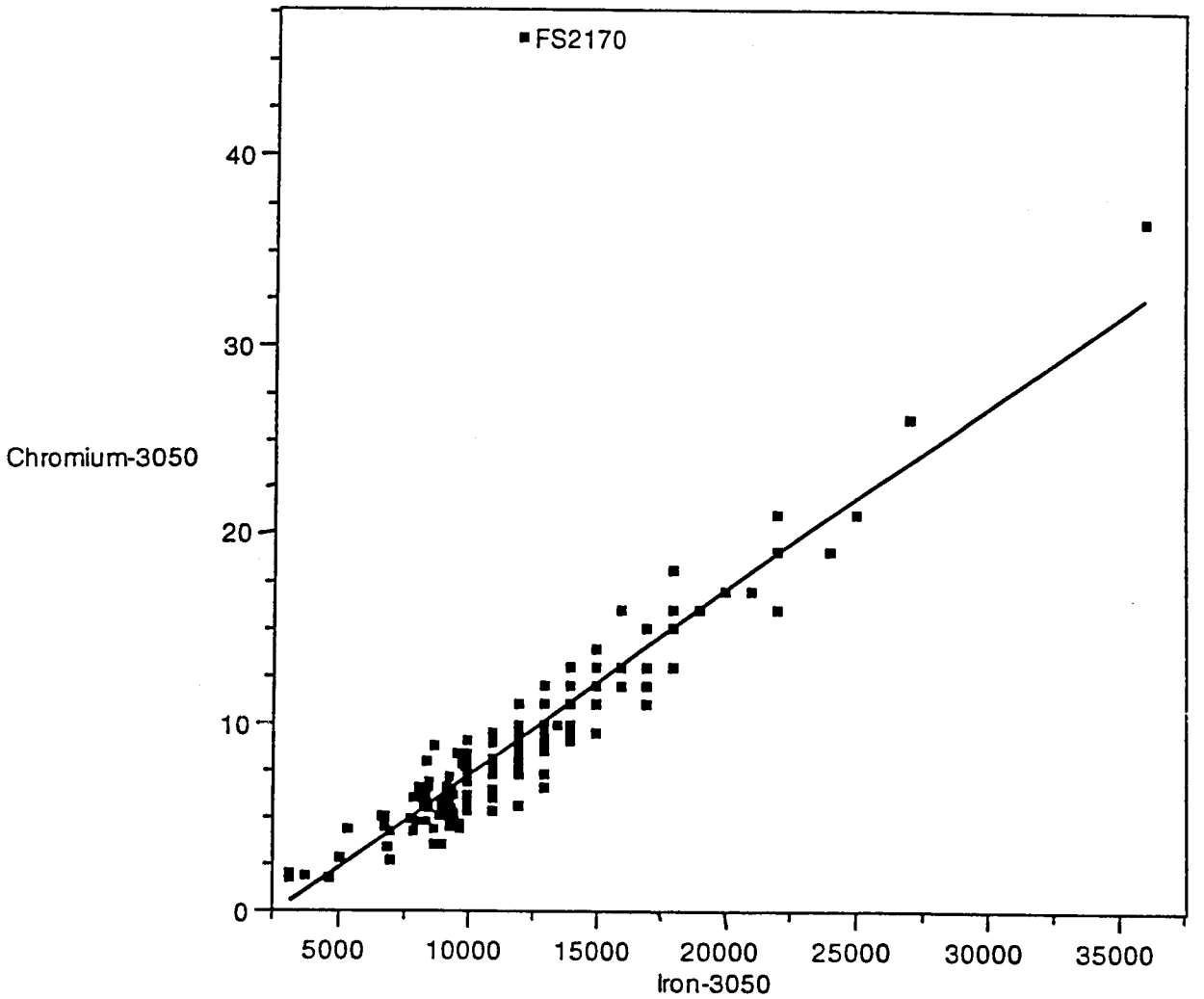

Figure 48. Correlation of Cr to Fe results (both extracted by method 3050). The labeled value is an outlier in the Cr-Fe regression analysis. Solid line is the linear regression between Cr and Fe for the A, B and C soil horizon data (-2.58+0.000974x, r^2=0.641, where the one outlier was included in the analysis).

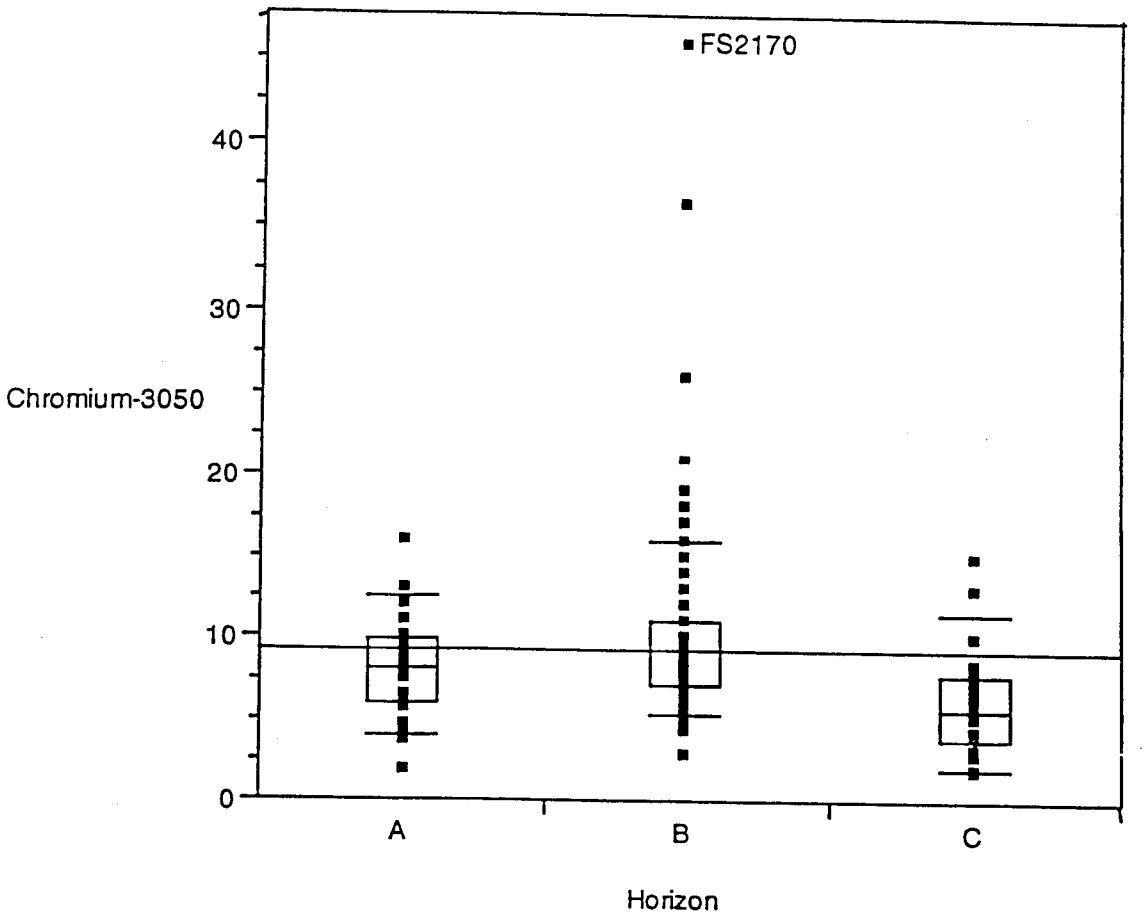

Figure 49. Chromium (3050 extraction method) results by soil horizon. The labeled value is an outlier in the Cr-Fe regression analysis.

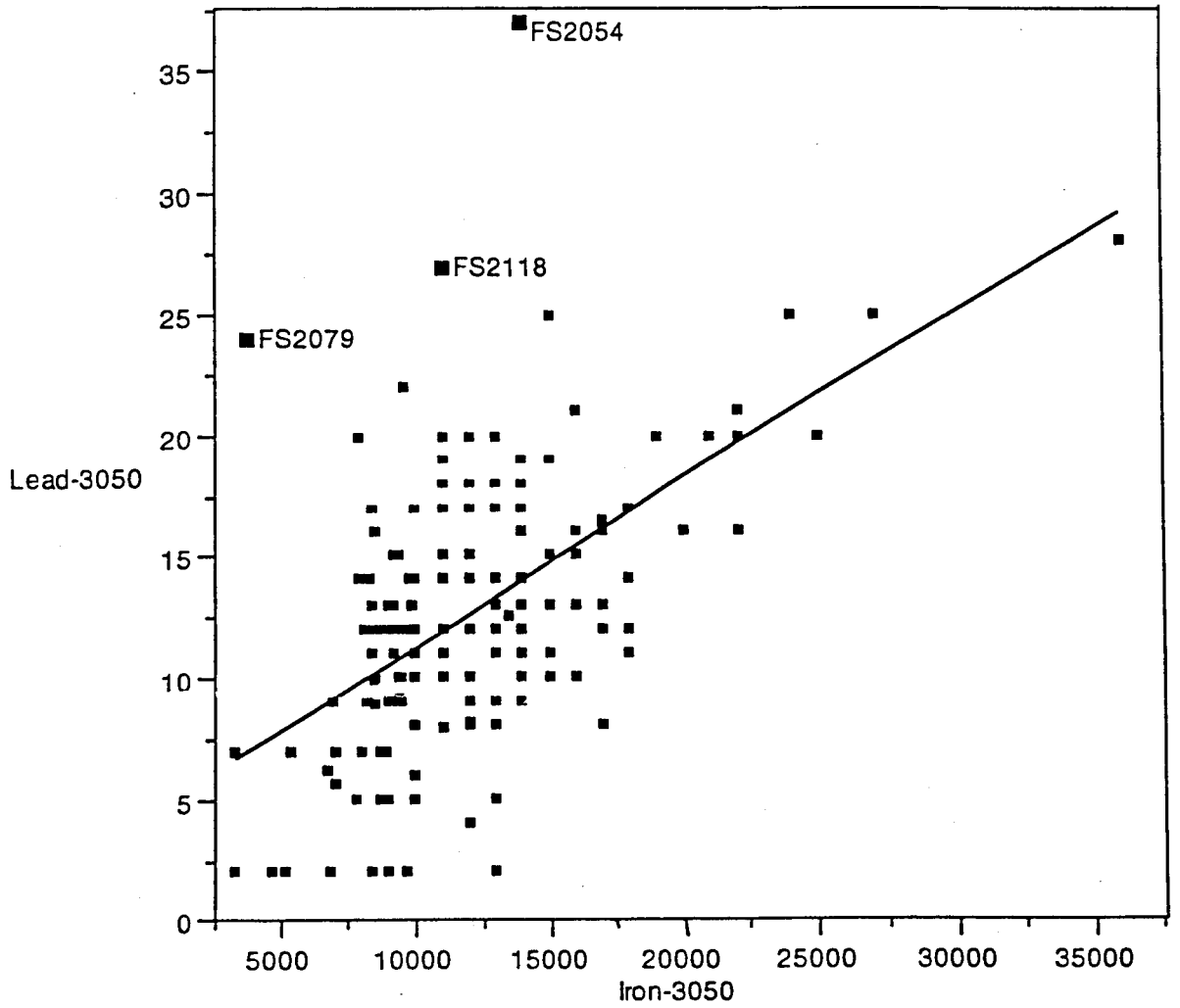

Figure 50. Correlation of Pb to Fe results (both extracted by method 3050). The labeled values are outliers in the Pb-Fe regression analysis. Solid line is the linear regression between Pb and Fe for the A, B and C soil horizon data (4.47+0.000685x, r^2=0.276, where the outliers were included in the analysis).

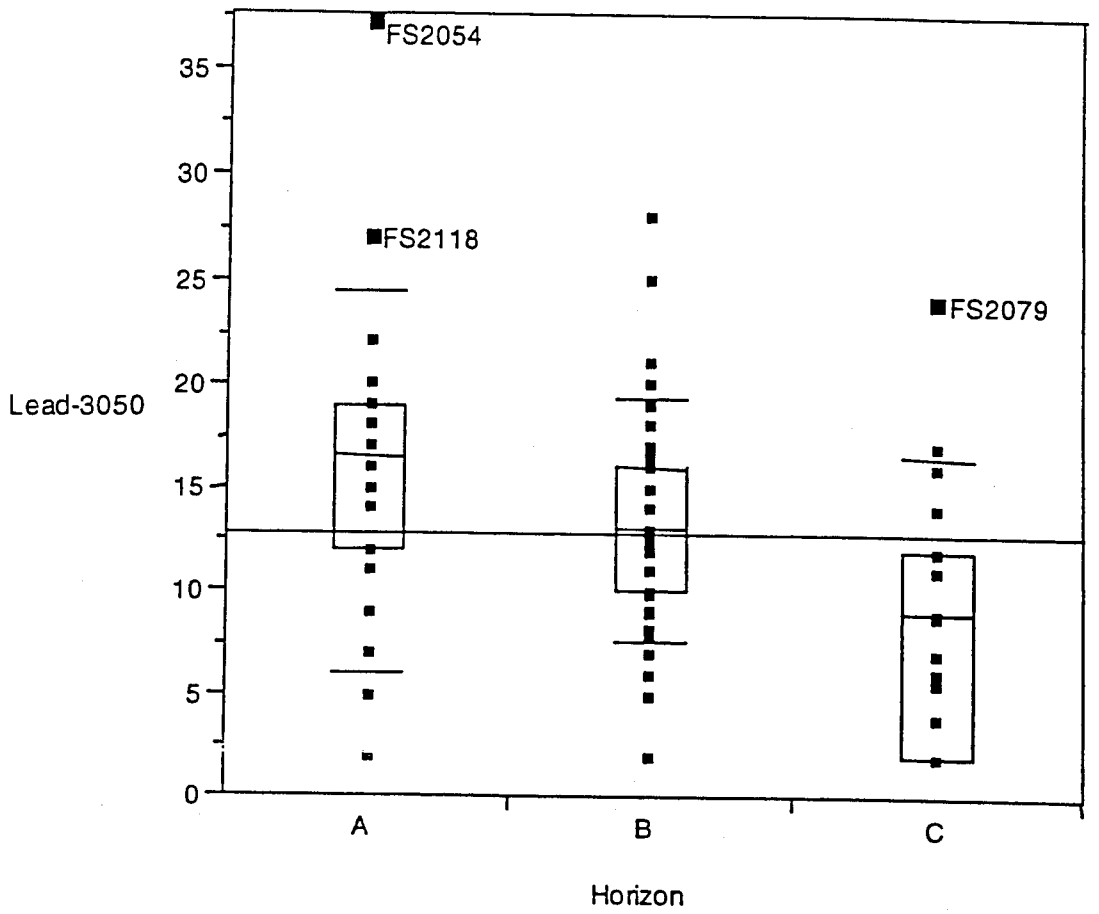

Figure 51. Lead (3050 extraction method) results by soil horizon. The labeled values are outliers in the Pb-Fe regression analysis.

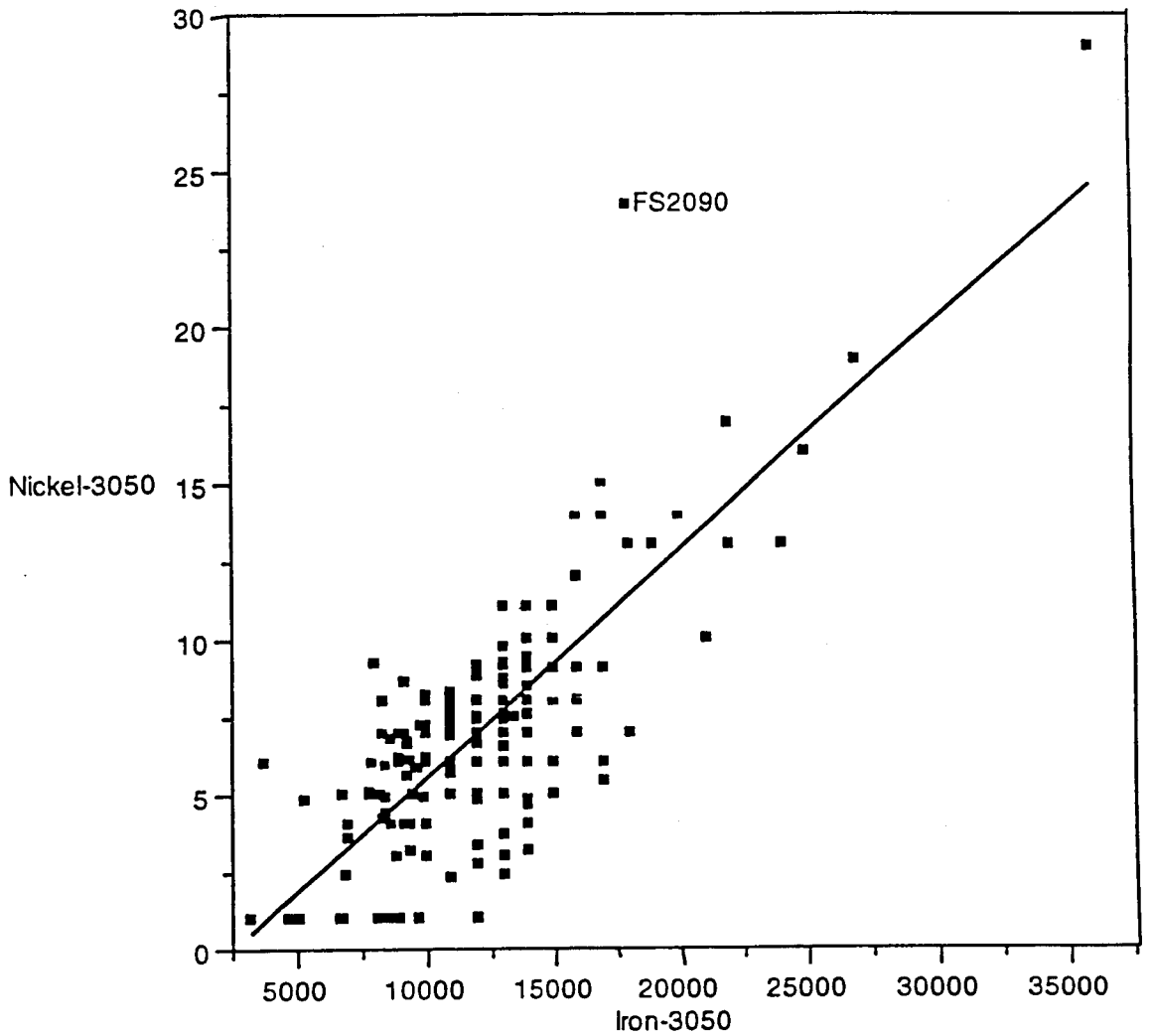

Figure 52. Correlation of Ni to Fe results (both extracted by method 3050). The labeled value is an outlier in the Ni-Fe regression analysis. Solid line is the linear regression between Ni and Fe for the A, B and C soil horizon data (-1.81+0.000731x, r^2=0.604, where the one outlier was included in the analysis).

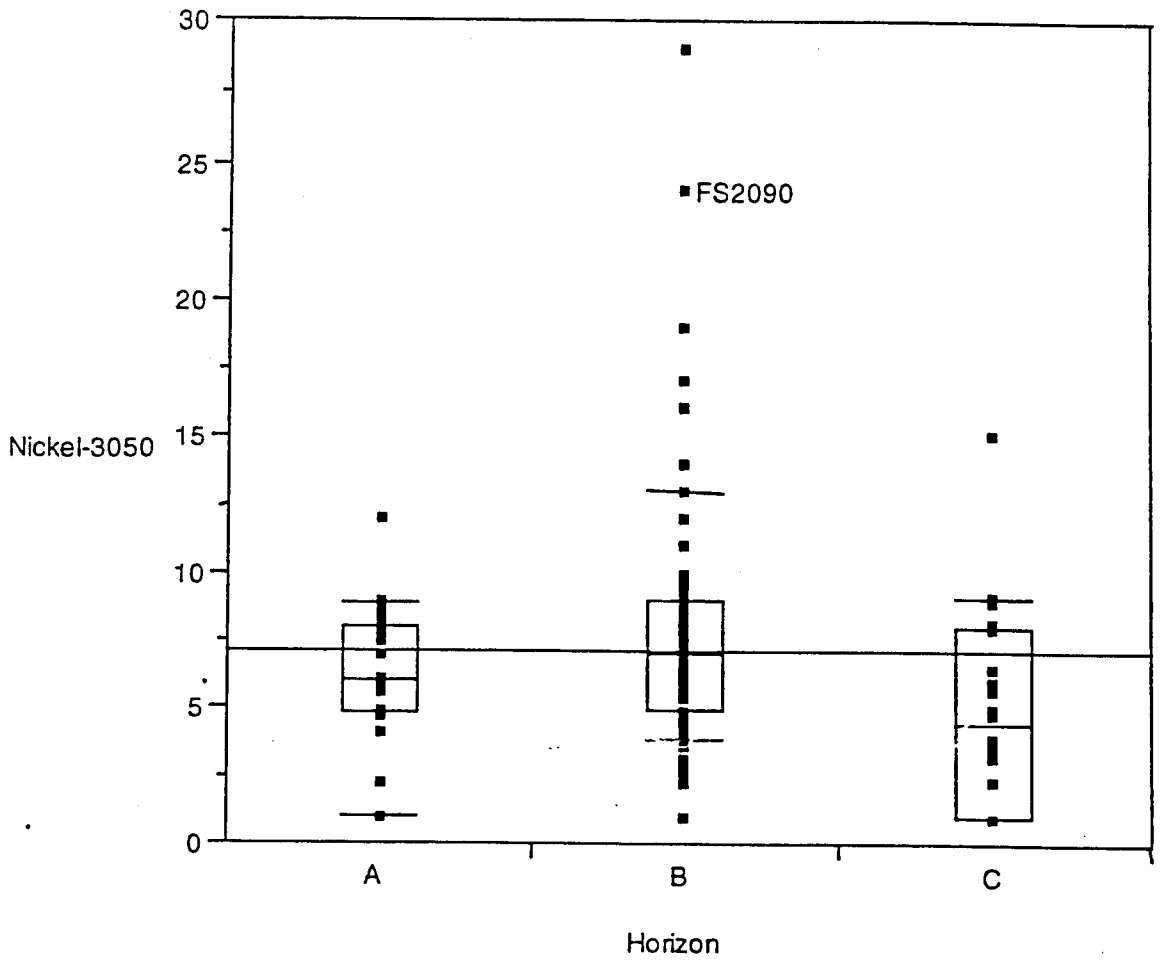

Figure 53. Nickel (3050 extraction method) results by soil horizon. The labeled value is an outlier in the Ni-Fe regression analysis.

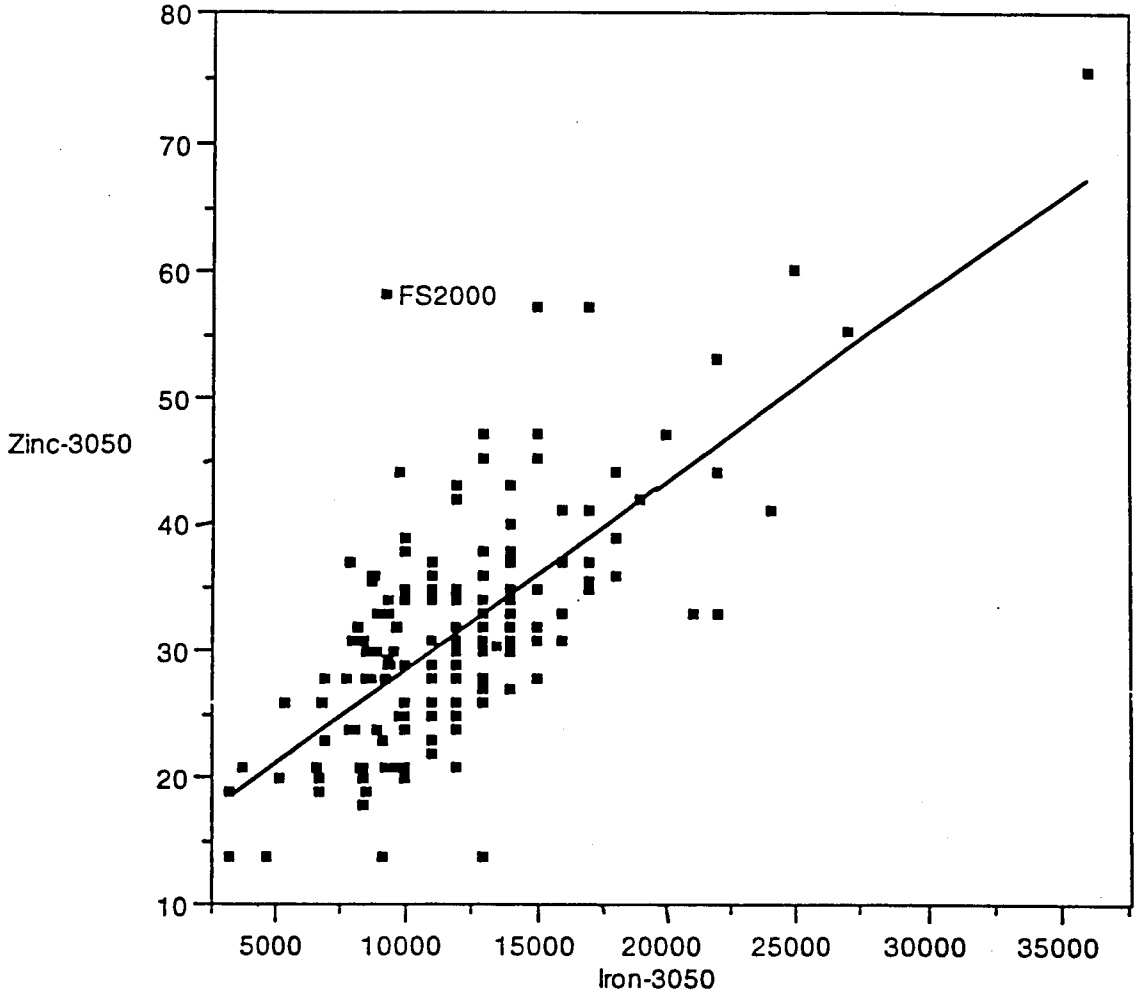

Figure 54. Correlation of Zn to Fe results (both extracted by method 3050). The labeled value is an outlier in the Zn-iFe regression analysis. Solid line is the linear regression between Zn and Fe for the A, B and C soil horizon data (13.631802+0.0014864x, r^2=0.475104, where the one outlier was included in the analysis).

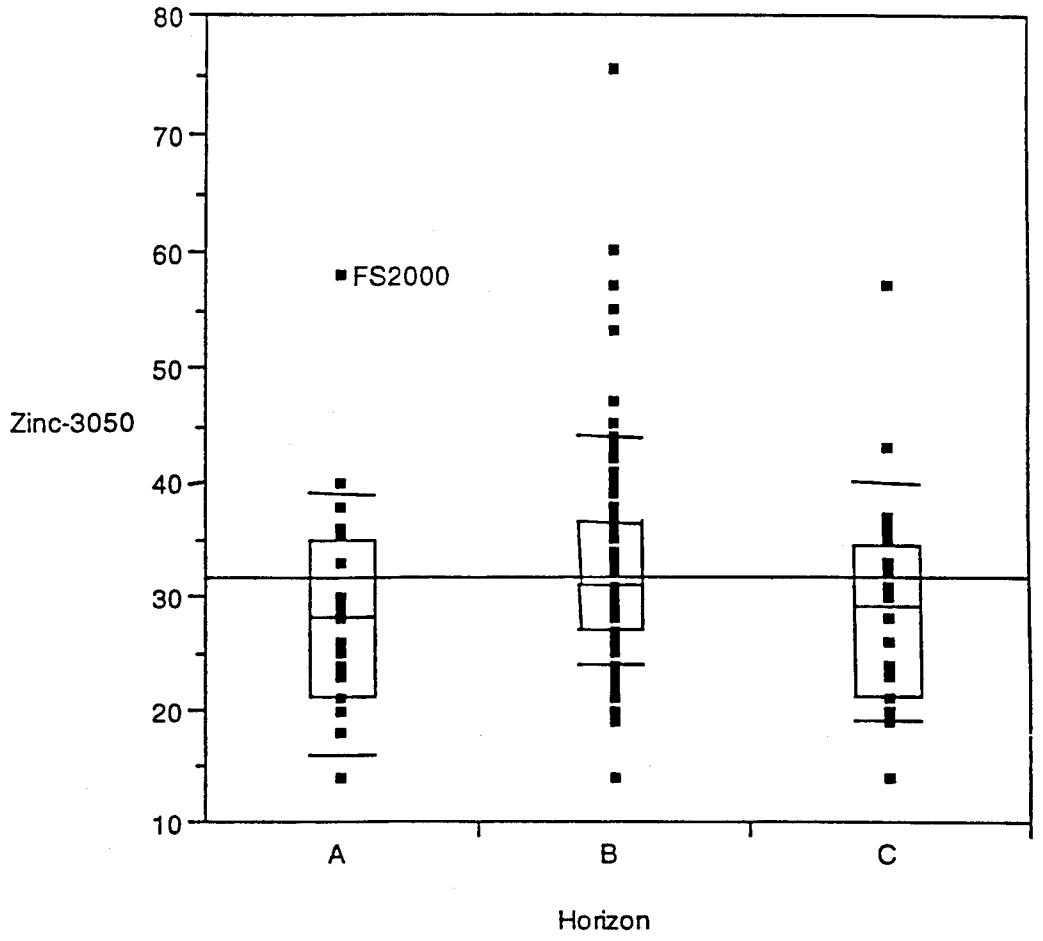

Figure 55. Zinc (3050 extraction method) results by soil horizon. The labeled value is an outlier in the Zn-Fe regression analysis.

SUMMARY AND RECOMMENDATIONS

Background elemental concentrations were detemined for RCRA metals and other elements within fourteen soil profiles at six different geographic locations around the Laboratory. These background characterization studies supplement the previous eight soil profiles reported by Longmire et al. (1995). Background concentrations of analytes do not exceed their respect SALs except for As, Be, and Mn. Because of the dependence of As, Be, Th, U, and other elements on soil development, the selection of appropriate background samples for a specific site should include a consideration of appropriate LANL soil characteristics.

Two types of sample digestion techniques, consisting of HNO_3 and HF, were used prior to chemical analyses. Leachable (HNO_3 digestion) background elemental concentrations in soils provide information relevant to the bioavailability of elements for risk calculations. The leachable elemental concentrations are statistically treated and are the primary focus of this report, whereas the total element concentrations (HF digestion) provide geochemical and pedological information. EPA SW846 methods recommend that nitric acid and other reagents are suitable for digesting solid samples.

Field, analytical, and statistical methods used in this investigation are sufficient for defining background elemental concentrations in soils for inorganic contaminants of concern, excluding radionuclides. This database for background soils enlarges the Laboratory-wide database provided by Longmire et al. (1995). This database primarily consists of mesa top soils, with only three sites within Los Alamos and Ancho Canyons. The UTLs for elements are calculated for the A, B, and C soil horizons in which the greatest number of samples have been collected from the B horizons. Additional sampling and characterization of the A and C horizons is required because few samples (< 30) have been collected from each of these horizons, including samples collected by Longmire et al. (1995). The A horizons are important because they are the surface horizon of many soils found on the Pajarito Plateau underlying potential release sites. Additional soil samples need to be collected on side slopes and within the canyons, because these soils are chemically very different from mesa top soils. There are very few chemical and pedological data and information on canyon soils at the Laboratory.

Longmire et al. (1995) concluded that soils present on the Pajarito Plateau are extremely variable in physical and chemical properties, including particle size, percent calcium carbonate, clay mineralogy, iron oxides, and trace-element chemistry. Results of this investigation support their conclusions and this investigation provides additional information on the local variations of chemical data and different soil parameters at several adjacent soil profiles on mesa tops.

Well-developed soils on mesa tops have higher concentrations of trace elements relative to weakly developed soils found in canyons. The B horizons generally are higher in trace elements relative to A and C horizons, excluding anthropogenic U found at TA-63 and TA-67. High abundances of clay minerals and iron oxides, characterized by relatively high surface areas, within B horizons control trace-element concentrations in soils. Well developed B (Bt) horizons typically found on mesa tops contain higher concentrations of trace elements than do weakly developed B (Bw) horizons found on mesa tops and in canyon bottoms. In addition, variations in soil-elemental concentrations are related to chemical characteristics of a particular soil horizon and to the parent material. Iron is a useful element to include as part of the analyte list for site characterization investigations because As, Be, and other trace elements correlate well with it.

Several soil samples collected from A and B horizons at TA-63 and TA-67 contain elevated concentrations of U, which may represent aerosol dispersion of U from Laboratory firing sites within TA-67 and TA-15. These apparently baised data have been excluded from the background-elemental database for the Laboratory for purposes of calculating UTLs; however, they may be useful for determining local contamination within TA-63, TA-67, and other sites down-wind from firing sites.

1. We recommend that Characterization of Laboratory-wide and site-specific background element distributions in soils requires use of a multidisciplinary approach involving the Decision Support Council, Earth Sciences Council, and Field Units.

2. We recommend standardizing field sampling procedures and requiring better field descriptions of sampling sites.

3. We recommend using consistent sample digestion (HNO_3) procedures (EPA 3050) prior to chemical analyses to compare background soil samples to SWMU samples.

4. We recommend expanding the background-elemental database for canyon soils to refine calculations of the mean, standard deviation, and UTLs for different RCRA metals and other relevant elements.

5. We recommend that additional sampling and characterization of the A and C horizons because few samples (< 30) have been collected from each of these horizons, including samples collected by Longmire et al. (1995).

6. We recommend utilizing results of Laboratory-wide background characterization investigations to the fullest extent to enhance maximal success and benefits of remediation strategies at contaminated sites.

7. We recommend a background screening process for RFI screening assessments consists of the following steps:

1) Use LANL-wide background data, which are presented in this report. These data include:
   a) soil data by horizon,
   b) geological data by stratigraphic layer, and
   c) sediment data from Ancho, Indio, and Water Canyons

2) Data analysts will use the appropriate subset of the LANL-wide data, except where soil horizon is neither known nor relevant (e.g., fill of unknown origin was sampled).

3) The initial comparison for all analytes will be to background screening values for all inorganics and naturally-occurring radionuclides (by background data subsets as described above). Background screening values are based on the following sources:
   a) maximum reported value for fallout-related radionuclides from the LANL environmental surveillance reports,
   b) maximum reported value for inorganics with more than 20% non-detects,
   c) maximum reported value for inorganics where the statistical distribution could not be estimated, and
   d) UTLs calculated for normal, lognormal, or square root-transformed distributions based on a 99th percentile and 95% confidence. NOTE - UTLs for data subsets are checked for consistency with the data group to make sure that inflated UTLs are not used.

4) Additional background analyses are required for the following cases:
   a) background screening values are exceeded AND SALs are exceeded,
   b) ecological risk is determined to be primary decision point, or
   c) aluminum, arsenic, beryllium, or manganese are known (or suspected) to have been released at the PRS.

5) Additional analyses include:
   a) graphical comparisons of background and PRS data,
   b) statistical "distribution shift" tests,
   c) regression analysis of trace elements and major elements (soil and sediment only), or
   d) regression analysis of Th and U (any solid media)

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Appendix A

S-Plus Code Used to Calculate Lognormal UTLs

File: lnorm_utl1.s

```
function(q,p,n,ave,sd,nt)
{
# lnorm_utl1.s is used as function LUTL1 in Splus
# This function is used to estimate the upper 95% CI of the 99th
# percentile for a lognormal distribution.  Uses Gilbert's MBE of LN.
#    q = the quantile to estimate
#    p = the confidence limit of q
#    n = number of values sampled
#  ave = mean of logtranformed data
#   sd = st. dev. of logtranformed data
#   nt = number of simulation trials
#.............................................................

# Calculate the qth quantile of the normal distribution
q1_qnorm(q)

# Initialize arrays
t1_rep(-1,n)
t2_rep(-1,nt)

i_0

repeat

 { i_i+1

# Get the "n" lognormal samples
   t1_rlnorm(n,ave,sd)

# Calculate the mean and sd the hard "Swanson" way
   dummy_lnormUMV.s(t1)
   ave1_dummy$mu
   sd1_sqrt(dummy$s2)

# Calculate an estimate of the 99th percentile
   t2[i]_exp(ave1+q1*sd1)
   if(i>=nt) break
 }

# Find the upper p*100% of the qth percentile
quantile(t2,p)
}
```

File: lnormUMV.s

```
function(x)
{
# lnormUMV.s (Splus function)
# Calls: psi.s
# Min Variance Unbiased ests of parameters of lognormal(mu,var=s2) distn
# for X~lognorm(mu,s2), Y=log(X)~normal(mu,s2)
# returns:E=mean(X), V=var(X)
#       mu=mean(Y),s2=var(Y)
# ref:Gilbert('87),Stat Methods for Env Pollution Mon, pp165-166
        n <- length(x)
        y <- log(x)
        ymu <- mean(y)
        vy <- var(y)
        psi1 <- psi.s(vy/2, n)
        psi2 <- psi.s(2 * vy, n)
        psi3 <- psi.s((vy * (n - 2))/(n - 1), n)
        E <- exp(ymu) * psi1
        V <- exp(2 * ymu) * (psi2 - psi3)
        mu <- log(E^2/(V + E^2)^0.5)
        s2 <- log(V/E^2 + 1)
        return(E, V, mu, s2)
}
```

File: psi.s

```
function(t, n)
{
# psi.s (Splus function)
# called by lnormUMV.s
# psi function in Gilbert('87) Stat. Meth. Env. Pollution. Mon, pp 165
# for Min Variance Unbiased ests of parameters of lognormal(mu,var=s2) distn
        psi <- 0
        psi[1] <- ((n - 1) * t)/n
        for(i in 1:25) {
                psi[i + 1] <- (psi[i] * (n - 1)^2 * t)/((i + 1) * n * (n + (2 *
                        i - 1)))
                if(abs((psi[i + 1] - psi[i])/psi[i]) < 1e-09)
                        break
        }
        psi <- 1 + sum(psi)
        psi
}
```