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Characterization of Vadose Zone Sediment: Uncontaminated RCRA Borehole Core Samples and Composite Samples

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Executive Summary

The overall goal of the of the Tank Farm Vadose Zone Project, led by CH2M HILL Hanford Group, Inc., is to define risks from past and future single-shell tank farm activities. To meet this goal, CH2M HILL Hanford Group, Inc. asked scientists from Pacific Northwest National Laboratory to perform detailed analyses on vadose zone sediment from within the S-SX Waste Management Area. This report is one in a series of four reports to present the results of these analyses. Specifically, this report contains all the geologic, geochemical, and selected physical characterization data collected on vadose zone sediment recovered from Resource Conservation and Recovery Act (RCRA) borehole bore samples and composite samples.

Intact cores from two “clean” RCRA boreholes (299-W22-48 and 299-W22-50) near the SX Tank Farm and four, large-quantity grab samples from outcrop sediment on the Hanford Site were sampled to better understand the fate of contaminants in the vadose zone beneath underground storage tanks at the Hanford Site. Borehole and outcrop samples analyzed for this report are located outside the tank farms, and therefore may be considered standard or background samples from which to compare contaminated sediments within the tank farms themselves. This report presents our interpretation of the physical, chemical, and mineralogical properties of the uncontaminated vadose zone sediments, and variations in the vertical distribution of these properties. The information presented in this report is intended to support preparation of the S-SX field investigation report^(a) prepared by CH2M HILL Hanford Group, Inc. as well as future remediation actions at the S-SX Tank Farm.

The geology under the SX Tank Farm forms the framework through which the contaminants move, and provides the basis with which to interpret and extrapolate the physical and geochemical properties that control the migration and distribution of contaminants. Of particular interest are the interrelationships between the coarser- and finer-grained facies, and the degree of contrast in their physical and geochemical properties. For the two boreholes, lithologic sections were constructed using detailed geologic descriptions and geophysical logs. In some cases the results of laboratory analyses (e.g., particle-size distribution, moisture, calcium carbonate content) helped to refine the resulting stratigraphic and lithologic interpretations.

Our conceptual model of the 67-meter (220-foot)-thick vadose zone beneath the SX Tank Farm consists of seven stratigraphic units. These include two members of the Ringold Formation (member of Wooded Island/Unit E [Rwi(e)] and member of Taylor Flat [Rtf]), two Plio-Pleistocene subunits (very fine sand to mud sequence [PPlz] and a carbonate-rich paleosol sequence [PPlc]), and three units of the Hanford formation (H1a, H1, and H2 units). Most of the Hanford formation H1a unit was removed during excavation of the SX Tank Farm and replaced with backfill to a depth of about 17 meters (55 feet). All but the Hanford formation strata dip slightly toward the southwest.

(a) *Draft Field Investigation Report for Waste Management Area S-SX*. RPP-7884, Draft, Volume 2, Appendix D, CH2M HILL Hanford Group, Inc., Richland, Washington.

Sediment samples from the various stratigraphic units were analyzed and characterized in the laboratory for the following parameters:

- mass water content
- particle-size distribution
- particle density
- calcium carbonate and organic carbon contents
- bulk chemical composition
- mineralogy
- cation exchange capacity
- exchangeable base cation distribution
- water leach (1:1 sediment-to-water extraction)
- acid leach (8 M nitric acid extraction)
- unsaturated flow apparatus- (UFA)-extracted porewater composition.

Physical properties, such as particle-size distribution and moisture content, also vary according to lithology. Strata with finer particle sizes (e.g., lower Hanford formation), and the top of PPlc subunit with its high cement/clay content, retain more moisture in the vadose zone. High moisture is also associated with a subvertical clastic dike within the upper Ringold unit (Rtf) in borehole 299-W22-48. Of the two methods used to determine particle-size distribution (dry sieve and wet sieve/hydrometer), the wet sieve method is superior to the dry sieve method, especially in fine-grained sediments, which tend to cling together during dry sieving.

Past studies have shown that sediments in the vadose zone are dominated by quartz, potassium- and plagioclase-feldspar, basalt, and other lithic fragments with minor amounts of mica, amphibole, calcite, and other trace minerals (Tallman et al. 1979). The x-ray diffraction (XRD) work done for this study is in agreement with past work and shows that the sediment is 25 to 95 wt% quartz, 5 to (possibly) 40 wt% potassium feldspar, 10 to 20 wt% plagioclase feldspar, and 0 to 40 wt% calcite with trace to minor amounts of amphibole, mica, and chlorite.

Mineralogical and geochemical variations, some significant, exist between the different stratigraphic units, as a result of differing depositional environments and sources for the sediments. For example, calcite-rich samples are associated with the lower Plio-Pleistocene subunit (PPlc), which unlike other stratigraphic units, underwent significant pedogenic alteration. In addition to high calcium oxide the PPlc subunit is relatively high in magnesium oxide, which co-precipitated with calcium during pedogenesis. Vadose-zone sediments contain very little organic carbon (average 0.05 wt%). The organic carbon is slightly greater for the PPlc subunit (up to 0.2 wt%), compared to all the other units, which are all <0.1 wt% carbon. Calcium carbonate content, calculated from the amount of inorganic carbon present, approaches 40 wt% for the PPlc subunit; all other units are generally less than a few wt% calcium carbonate. The concentration of major elements such as silica, iron, and calcium, varies significantly because of different ratios of quartzo-feldspathic to basaltic detritus in the Hanford versus Ringold formations. Samples high in potassium oxide may reflect the relatively high illite content of the Ringold Formation and finer-grained portions of the Hanford formation.

Clay minerals, measured semiquantitatively using XRD, include smectite, illite, chlorite, and kaolinite. Overall in the clay-sized fraction of the vadose zone sediments, smectite ranged in concentration from 10 to 30 (wt%). Illite concentrations ranged from ~10% to 50% and chlorite concentrations were a little less (~5 to 35 wt%). Minor amounts of kaolinite (~5% to 10%) were also detected. Quartz, feldspar, and amphiboles made up less than ~15 wt% of the clay fraction. The only consistent trend in the mineral content of samples is the substantial increase in calcite, relative to other minerals, for the PPLc subunit. This trend is noted in both the bulk sample as well as the ≤ 2 -micron fraction.

Base cations, displaced via ammonium acetate extraction, are dominated by alkaline earth elements (calcium and magnesium), especially within the PPLc subunit. The relative contribution of the alkali metals (sodium and potassium) to the natural distribution of exchangeable cations is small (<10%). Though some relationships can be made comparing cation exchange capacity to the lithology, mineralogy and grain-size distribution of some samples, enough discrepancies exist to make most comparisons tentative. Cation exchange capacity was measured using two analytical techniques, each of which provided significantly different results. More work is needed to establish the best way to measure cation exchange capacities on sediments from the Hanford Site.

The results from the 1:1 sediment-to-water extracts are similar for samples from both of the clean boreholes. This gives credence to the representativeness of the results. Also, most, but not all, results yield a reasonable charge balance among cations and anions. There is one sample in borehole 299-W22-50 near the base of the coarse-grained Hanford formation H1 unit that shows high pH, electrical conductivity (EC), and water-leachable cations and anions, but it appears to be natural and perhaps was caused by dissolution of natural evaporates (see below).

Porewater in the vadose zone was evaluated via a comparison of a few actual UFA-extracted porewater samples with a larger data set of 1:1 sediment-to-water extracts. Water extracts are in agreement with actual porewaters for only a limited number of constituents and the water extracts generally produced higher chemical concentrations than those found in the actual porewater sampled from the same interval and thus the water extracts should be considered maximum values. The concentrations of many constituents in the water extracts of the four composite sediment samples are similar to those in the two sampled boreholes. A few exceptions are higher calcium, chloride, magnesium, sodium, and sulfate in the sediment composite samples relative to the clean borehole samples, probably as a result of natural near-surface recharge and leaching, which does not occur at depth within borehole samples. As expected, the calcic PPLc subunit yielded significantly different water extract results than the Hanford or Ringold formation samples. Water leachate from the PPLc produced relatively higher EC, alkalinity, cations (silicon, calcium, magnesium), anions (nitrate and sulfate), as well as trace elements (selenium, strontium, copper, manganese, and uranium). Elevated concentrations of these parameters, combined with depleted aluminum, are a reflection of the pedogenic origin for the PPLc subunit. Differences among samples from the Ringold and Hanford formations are generally small (except water-extractable magnesium and potassium, which are higher for the older Ringold Formation) and not consistent among all samples. This is not surprising considering the wide range in mineral and physical properties for these samples.

Most noteworthy in the water extract profile for borehole 299 W22-50 is high water-leachable pH, alkalinity, EC, calcium, chloride, chromium, strontium, and sulfate at the base of the coarser-grained facies (Hanford formation H1 unit) of the Hanford formation.

In general, acid extraction is effective at removing from sediment samples, in decreasing order, 25% to 70% of the total trace metals, 40% to 60% of the iron and manganese, about 25% of the major alkaline earth metals (calcium and magnesium), about 15% of the aluminum and titanium, about 10% to 15% of the minor alkaline earths (barium and strontium), 1% to 10% of the alkali metals (potassium and sodium). In contrast, negligible amounts of silicon (<0.03%) are removed during acid extraction. The amount of any element removed from the coarse-grained Hanford formation H1 unit by acid digestion is less than for the other stratigraphic units, perhaps due to the larger particle sizes, which have overall less surface area and are thus less prone to leaching. Acid extraction within the calcic PPLc releases almost all the calcium and strontium and slightly more of several of the other elements when compared to other non-calcic sediment samples. Most calcium and strontium in the PPLc subunit are combined with carbonate, which readily decomposes in contact with acid. Calcium in the other units is associated with silicates (e.g., pyroxene, plagioclase, etc.), which do not readily react with the acid leach.

The high concentrations of these parameters may be natural from past pedogenic/evaporitic processes or perhaps they represent lateral spreading along the H1/H2 contact of fluids disposed to nearby facilities or fluids from pipe leaks.

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Acronyms and Abbreviations

amsl	above mean sea level
ASA	American Society of Agronomy
ASTM	American Society for Testing and Materials
bgs	below ground surface
BHI	Bechtel Hanford, Inc.
DOE	U.S. Department of Energy
EC	electrical conductivity
EMSP	Environmental Management Science Program
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
FIR	field investigation report
FY	fiscal year
IC	ion chromatography
ICP	inductively coupled plasma
ICP-AES	inductively coupled plasma atomic emission spectrometry
ICP-MS	inductively coupled plasma mass spectrometry
msl	mean sea level
PNNL	Pacific Northwest National Laboratory
PPlc	Plio-Pleistocene carbonate
PPlz	Plio-Pleistocene mud
PPUcp	Plio-Pleistocene calcic paleosol facies
PPUoe	Plio-Pleistocene unit overbank-eolian facies
PPUsa	Plio-Pleistocene side-stream alluvial facies
RCRA	Resource Conservation and Recovery Act
Rtf	Ringold Member of Taylor Flat
Rwi(e)	Ringold Member of Wooded Island (Unit E)
TEM	transmission electron microscopy
UFA	unsaturated flow apparatus

XRD
XRF

x-ray diffraction
x-ray fluorescence

Contents

Executive Summary	iii
Acknowledgments.....	vii
Acronyms and Abbreviations	ix
1.0 Introduction	1.1
2.0 Geology	2.1
2.1 Regional Geologic Setting	2.1
2.2 Geology of the SX Tank Farm	2.1
2.2.1 Columbia River Basalt Group	2.8
2.2.2 Ringold Formation	2.8
2.2.3 Plio-Pleistocene Unit.....	2.9
2.2.4 Hanford Formation.....	2.14
2.2.5 Backfill	2.17
2.3 Historical Water Levels.....	2.19
2.4 Geologic Characterization.....	2.20
2.4.1 Composite Samples	2.20
2.4.2 Geologic Characterization of Clean Boreholes	2.29
3.0 Characterization Analytical Methods	3.1
3.1 Post Sampling Sediment Preparation	3.1
3.1.1 Composites	3.1
3.1.2 Borehole Core Samples	3.1
3.2 Laboratory Analytical Methods	3.2
3.2.1 Mass Water Content	3.2
3.2.2 Particle Size Distribution	3.2
3.2.3 Particle Density	3.3
3.2.4 Calcium Carbonate and Organic Carbon Content.....	3.3
3.2.5 Elemental Analysis.....	3.3
3.2.6 Mineralogy	3.4
3.2.7 Cation Exchange Capacity	3.6
3.2.8 Ammonium Acetate Extract	3.7
3.2.9 1:1 Sediment-to-Water Extract.....	3.8
3.2.10 8 M Nitric Acid Extract.....	3.8
3.2.11 Porewater Composition	3.8

4.0	Analytical Results for Composite Sediment Samples	4.1
4.1	Mass Water Content	4.1
4.2	Particle-Size Distribution	4.1
4.3	Particle Density	4.4
4.4	Calcium Carbonate and Organic Carbon Content	4.5
4.5	Bulk Chemical Composition	4.6
4.6	Mineralogy	4.8
4.7	Cation Exchange Capacity	4.14
4.8	1:1 Sediment-to-Water Extraction.....	4.17
4.9	8 M Nitrate Acid Extraction.....	4.19
4.10	Exchangeable Base Cations	4.20
5.0	Analytical Results for Clean Borehole Samples.....	5.1
5.1	Analytical Results for Borehole 299-W22-48.....	5.1
5.1.1	Mass Water Content	5.2
5.1.2	Particle-Size Distribution	5.4
5.1.3	Particle Density	5.7
5.1.4	Calcium Carbonate and Organic Carbon Content.....	5.7
5.1.5	Bulk Chemical Composition	5.8
5.1.6	Mineralogy	5.10
5.1.7	Cation Exchange Capacity	5.16
5.1.8	Exchangeable Base Cations.....	5.17
5.1.9	1:1 Sediment-to-Water Extraction.....	5.18
5.1.10	Acid Extraction	5.22
5.1.11	Porewater Composition	5.25
5.2	Analytical Results for Borehole 299-W22-50.....	5.33
5.2.1	Mass Water Content	5.33
5.2.2	Particle-Size Distribution	5.35
5.2.3	Particle Density	5.39
5.2.4	Calcium Carbonate and Organic Carbon Content.....	5.40
5.2.5	Bulk Chemical Composition	5.41
5.2.6	Mineralogy	5.41
5.2.7	Cation Exchange Capacity	5.4.1
5.2.8	Exchangeable Base Cations.....	5.43
5.2.9	1:1 Sediment-to-Water Extraction.....	5.44
5.2.10	Acid Extraction	5.45
5.2.11	Porewater Composition	5.53
5.3	Discussion: Comparison Between Boreholes 299-W22-48 and 299-W22-50.....	5.59
6.0	Summary and Conclusions	6.1
7.0	References	7.1

Appendix A – Summary of Field Geologists’ Sample Descriptions for Borehole 299-W22-48 and Borehole 299-W22-50	A.1
Appendix B – Summary of Geologists’ Core Sample Descriptions from Borehole 299-W22-48 ...	B.1
Appendix C – Summary Geophysical Logs for Borehole 299-W22-48 and Borehole 299-W22-50	C.1
Appendix D – Particles-Size Results from Seven Boreholes in Vicinity of the S-SX Tank Farm ...	D.1
Appendix E – Inventory of Core Sleeves from Borehole 299-W22-48	E.1
Appendix F – Inventory of Core Sleeves from Borehole 299-W22-50	F.1
Appendix G – Some Mineralogical Analyses of the Composite Sediment Samples	G.1
Appendix H – Some Mineralogical Analyses from Boreholes 299-W22-48 and –50	H.1

Figures

2.1	Generalized, Composite Stratigraphy for the Late Cenozoic Sediments Overlying the Columbia River Basalt Group on the Hanford Site.....	2.2
2.2	Location Map and Hydrogeologic Cross Sections Through the SX Tank Farm.....	2.3
2.3	Geologic Cross Section A-A'	2.4
2.4	Geologic Cross Section B-B'	2.5
2.5	Geologic Cross Section C-C'	2.6
2.6	Lithofacies Distribution for the Lower Plio-Pleistocene Unit (PPlc).....	2.12
2.7	Digital Elevation Model (DEM) Map of a Portion of the Pasco Basin Showing Routes and Facies Distributions for the Last Pleistocene Cataclysmic Floods	2.15
2.8	Historic Water Levels Beneath the SX Tank Farm	2.20
2.9	Locations for the Four Composite Sediment Samples.....	2.22
2.10	Stratigraphic Column of the Upper Portion of the White Bluffs Showing Sample Collection Depths	2.23
2.11	Location of Sample Collected from Lacustrine Laminated Silt of the Ringold Formation.....	2.23
2.12	Series of Buried Giant Current Ripples at the 218-E-12B Site	2.25
2.13	Example of Pebbly Sand Facies as it Appears In Situ.....	2.25
2.14	Representation of All Three Facies of the Hanford Formation at the 218-E-12B Site.....	2.26
2.15	Lower Silty Sand Layer at 218-E-12B Site	2.26
2.16	Samples Obtained for Detailed Characterization from the 218-E-12B Site	2.27
2.17	Environmental Restoration Disposal Facility Sampling Site	2.28
2.18	Vadose Zone Stratigraphy for Borehole 299-W22-50.....	2.29
2.19	Vadose Zone Stratigraphy for Borehole 299-W22-48.....	2.33
2.20	Split-Spoon Sample from Within Coarse-Grained Hanford Formation H1 Unit in Borehole 299-W22-48	2.34
2.21	Split-Spoon Sample from Within Hanford Formation H2 Unit in Borehole 299-W22-48	2.34
2.22	Split-Spoon Sample from Within Plio-Pleistocene Mud (PPlz) Unit in Borehole 299-W22-48	2.35
2.23	Split-Spoon Samples Representing a) Plio-Pleistocene Mud (PPlz) and Plio-Pleistocene Carbonate (PPlc) Subunits Contact (white dashed line), and b) Plio-Pleistocene Carbonate (PPlc) in Borehole 299-W22-48.....	2.36
2.24	Split-Spoon Samples Representing Ringold Formation Unit E (Rwi[e]) in Borehole 299-W22-48	2.36
2.25	Split-Spoon Sample Representing Upper Ringold Formation (Rtf) in Borehole 299-W22-48	2.37
2.26	Split-Spoon Sample Illustrating Contrasts Within the Hanford Formation H2 Unit.....	2.38
2.27	Upper Portion of Subvertical Clastic Dike Completely Filling Core Liner Within Ringold Formation from 51.4 to 51.7 Meters (168.5 to 169.5 feet) bgs	2.40
2.28	Split-Spoon Sample of Sandy Gravel from the Hanford Formation H1 Unit.....	2.41
2.29	Split-Spoon Sample from Within Hanford Formation H2 Unit in Borehole 299-W22-50	2.42

2.30 Split-Spoon Sample from Within Upper Plio-Pleistocene Unit (PPlz) in Borehole 299-W22-50	2.43
2.31 Split-Spoon Sample Containing the Contact Between the Plio-Pleistocene Mud (PPlz) and Carbonate (PPlc) Subunits in Borehole 299-W22-50.....	2.44
4.1 Ringold Silt Composite Sample After Air Drying and Disaggregation	4.2
4.2 Hanford Coarse Sand Composite Sample After Air Drying and Disaggregation	4.2
4.3 Hanford Fine Sand Composite Sample After Air Drying and Disaggregation	4.2
4.4 Borehole Fine Sand Composite Sample After Air Drying and Disaggregation	4.3
4.5 Particle-Size Distributions for the Four Composite Sediment Samples	4.4
4.6 Typical Illite Particle (~5 microns long) Common to the Hanford Fine Sand Composite Sample.....	4.11
4.7 Typical Illite Particle (~3 microns long) from Clay Fraction of the Borehole Fine Sand Composite Sample	4.11
4.8 Chlorite Particle (~1.5 micron) from the Borehole Fine Sand Composite Sample	4.13
4.9 A Thick, Hexagonal Kaolinite Particle (~1 micron) from the Borehole Fine Sand Composite Sample	4.13
4.10 Smectite Aggregate (~2 microns) from the Hanford Coarse Sand Composite Sample.....	4.14
5.1 Particle-Size Distributions Curves of Hanford Formation Sediment Samples from Borehole 299-W22-48	5.6
5.2 Particle-Size Distribution Curves of Sediment Samples below 41.4 meters bgs in Borehole 299-W22-48.....	5.6
5.3 Typical Illite Particle from Borehole 299-W22-48	5.12
5.4 Chlorite Particle from Borehole 299-W22-48	5.13
5.5 Thin Smectite Flakes from the Rtf Unit in Borehole 299-W22-48	5.14
5.6 Kaolinite Particle from the H2 Unit in Borehole 299-W22-48	5.15
5.7 Moisture Content and Comparison of pH and Dilution-Corrected Electrical Conductivity of 1:1 Sediment-to-Water Extracts and UFA-Extracted Porewater from Sediment Samples in Borehole 299-W22-48	5.30
5.8 Comparison of Dilution-Corrected Anion Concentration of 1:1 Sediment to Water Extracts and UFA-Extracted Porewaters from Sediment Samples in Borehole 299-W22-48.....	5.31
5.9 Comparison of Dilution-Corrected Cation Concentrations of 1:1 Water Extracts and UFA-Extracted Porewaters from Sediment Samples in Borehole 299-W22-48.....	5.32
5.10 Particle-Size Distribution Curves of Sediment Samples from the Hanford Formation at Borehole 299-W22-50	5.38
5.11 Particle-Size Distribution Curves of Sediment Samples from the Plio-Pleistocene Unit and Ringold Formation at Borehole 299-W22-50.....	5.39
5.12 Moisture Content, 1:1 Sediment-to-Water Extract, pH, and Electrical Conductivity Data Versus Depth in Borehole 299-W22-50	5.49
5.13 Calculated and UFA-Extracted Porewater Concentration of Anions Versus Depth in Borehole 299-W22-50	5.59
5.14 Calculated and UFA-Extracted Porewater Concentrations of Cations Versus Depth in Borehole 299-W22-50	5.60

Tables

2.1	Stratigraphy of the Vadose Zone Beneath the SX Tank Farm	2.7
2.2	Granulometric Data from Core Samples of Ringold Unit E Encountered Within the 200 West Area	2.9
2.3	Example of Granulometric and Calcium Carbonate Data from Samples of the Lower Plio-Pleistocene (PPlc) Unit Encountered Beneath the SX Tank Farm	2.10
2.4	Example of Granulometric and Calcium Carbonate Data from Drive-Barrel Samples of the Upper Plio-Pleistocene Unit (PPlz) Encountered Beneath the SX Tank Farm	2.13
2.5	Granulometric and Calcium Carbonate Data from Core Samples of the Hanford Formation Beneath SX Tank Farm and Average Bulk Densities.....	2.18
2.6	Summary of Recent Particle Size Analytical Results from Seven Boreholes in and Around the SX Tank Farm.....	2.19
2.7	Composite Sediment Sample Descriptions.....	2.21
4.1	Moisture Content of Composite Sediment Samples After Air Drying	4.1
4.2	Particle-Size Distributions for Composite Sediment Samples Determined by Dry Sieve Method.....	4.3
4.3	Particle-Size Distributions for Composite Sediment Samples Determined by Wet Sieving/Hydrometer Method	4.3
4.4	Particle Densities for Composite Sediment Samples.....	4.5
4.5	Calcium Carbonate and Organic Carbon Content (% wt.) for Composite Samples	4.6
4.6	Bulk Chemical Composition of Composite Sediment Samples (% as Oxides).....	4.7
4.7	Semiquantitative Mineral Content of Composite Sediment Samples	4.8
4.8	Bulk Chemical Composition of Clay Fraction (% as Oxides) in Composite Sediment Samples	4.10
4.9	Results of Cation Exchange Capacity (meq/100 g) of Composite Sediment Samples Using Two Different Techniques	4.15
4.10	pH, Electrical Conductivity, Alkalinity, and Anions in 1:1 Sediment to Water Extracts for Composite Sediment Samples	4.16
4.11	Major Cations in 1:1 Sediment to Water Extracts (ICP) for Composite Sediment Samples.....	4.16
4.12	Trace Metals in 1:1 Sediment to Water Extracts of Composite Sediment Samples	4.17
4.13	Charge Balance for Water Extracts of Composite Sediment Samples	4.18
4.14	Major Cations in Acid Extracts for Composite Sediment Samples.....	4.20
4.15	Trace Metals in Acid Extracts of Composite Sediment Samples	4.21
4.16	Percentage of the Total Element that Dissolves During Acid Extraction of Composite Sediment Samples.....	4.22
4.17	Chemical Composition of Ammonium Acetate Extraction for Composite Sediment Samples.....	4.23
4.18	Exchangeable Base Cations Compared to Cation Exchange Capacities Estimates for Composite Sediment Samples.....	4.23

5.1	Sediment Core Samples Selected from Borehole 299-W22-48 for Laboratory Analysis	5.1
5.2	Moisture Content (wt%) Measured in Laboratory for Sediment Samples from Borehole 299-W22-48	5.3
5.3	Dry Sieve Results from Borehole 299-W22-48	5.4
5.4	Particle-Size Distribution Determined by Wet Sieving/Hydrometer Method	5.5
5.5	Comparison of Particle-Size Distributions for Dry Versus Wet Sieving	5.5
5.6	Particle Densities for Selected Sediment Samples from Borehole 299-W22-48	5.7
5.7	Calcium Carbonate and Organic Carbon Content (wt%) for Sediment Samples from Borehole 299-W22-48	5.8
5.8	Bulk Chemical Composition of Sediment Samples from Borehole 299-W22-48	5.9
5.9	Semiquantitative Mineral Content (wt%) for Sediment Samples from Borehole 299-W22-48-Bulk Sediment Sample	5.10
5.10	Semiquantitative Mineral Content (wt%) for Sediment Samples from Borehole 299-W22-48-Clay-Size Fraction Only	5.11
5.11	Comparison of Cation Exchange Capacity (meq/100 g) Between Sediment Samples from Borehole 299-W22-48 Using Two-Different Analytical Methods	5.16
5.12	Additional Cation Exchange Capacity Data Obtained from Sediment Samples in Borehole 41-09-39	5.17
5.13	Exchangeable Base Cation Composition of Sediment Samples in Borehole 299-W22-48	5.18
5.14	Comparison of the Base Cation Sum and Cation Exchange Capacity Measurements from Sediment Samples in Borehole 299-W22-48	5.18
5.15	pH, Electrical Conductivity, Alkalinity, and Anions in Water Extracts from Sediment Samples in Borehole 299-W22-48	5.19
5.16	Major Cations in Water Extracts from Sediment Samples in Borehole 299-W22-48	5.20
5.17	Trace Metals in Water Extracts of Sediment Samples from Borehole 299-W22-48	5.21
5.18	Charge Balance in Water Extracts of Sediment Samples from Borehole 299-W22-48	5.22
5.19	Ranges of Parameters and Selected Ions Found in Water Extracts for Stratigraphic Units Sampled within Borehole 299-W22-48	5.23
5.20	Major Cations in Acid Extracts of Sediment Samples from Borehole 299-W22-48	5.24
5.21	Trace Metals ($\mu\text{g/g}$) in Acid Extracts of Sediment Samples from Borehole 299-W22-48	5.25
5.22	Mass Percent of Total Element Leached by Acid Extraction Compared to Bulk Chemical Composition	5.26
5.23	pH, Electrical Conductivity, Alkalinity, Anions, Cations, and Trace Metals Measured in UFA-Extracted Porewater from Two Samples in Borehole 299-W22-48	5.27
5.24	Charge Balance for UFA-Extracted Porewater from Two Sediment Samples in Borehole 299-W22-48	5.28
5.25	Theoretically Calculated Composition of Vadose-Zone Porewater	5.28
5.26	Comparison of UFA-Extracted Porewater to Theoretically Calculated Porewater from the Hanford Formation H2 Unit in Borehole 299-W22-48	5.29
5.27	Sediment Core Samples Selected from Borehole 299-W22-50 for Laboratory Analysis	5.34
5.28	Moisture Content (wt%) Measured in the Laboratory for Sediment Samples from Borehole 299-W22-50	5.36
5.29	Particle-Size Distributions for Sediment Samples from Borehole 299-W22-50	5.37
5.30	Particle-Size Distributions Determined by Wet Sieving/Hydrometer Method for Borehole 299-W22-50	5.37

5.31 Comparison of Particle-Size Distributions Using the Dry Versus Wet Sieving/Hydrometer Methods for Borehole 299-W22-50	5.38
5.32 Particle Densities for Sediment Samples from Borehole 299-W22-50	5.39
5.33 Calcium Carbonate and Organic Carbon Content (wt%) for Sediment Samples from Borehole 299-W22-50	5.40
5.34 Bulk Chemical Composition of Sediment Samples from Borehole 299-W22-50	5.42
5.35 Semiquantitative Mineral Content of Sediment Samples from Borehole 299-W22-50	5.42
5.36 Exchangeable Base Cations for Sediment Samples from Borehole 299-W22-50	5.43
5.37 Comparison of the Base Cation Sum and Cation Exchange Capacity Measurements from Borehole 299-W22-50	5.43
5.38 pH, Electrical Conductivity, Alkalinity, and Anions in Water Extracts of Sediment Samples from Borehole 299-W22-50	5.45
5.39 Major Cations in Water Extracts of Sediment Samples from Borehole 299-W22-50	5.46
5.40 Trace Metals in Water Extracts of Sediment Samples from Borehole 299-W22-50	5.47
5.41 Charge Balance for Water Extracts of Sediment Samples from Borehole 299-W22-50	5.48
5.42 Ranges of Parameters and Selected Ions Found in Water Extracts for Stratigraphic Units Sampled Within Borehole 299-W22-50	5.50
5.43 Major Cations ($\mu\text{g/g}$) in Acid Extracts of Sediment Samples from Borehole 299-W22-50	5.51
5.44 Trace Metals ($\mu\text{g/g}$) in Acid Extracts of Sediment Samples from Borehole 299-W22-50	5.51
5.45 Percent of Total Element (XRF) in Sediment Samples Leached by Acid Extraction of Sediment Samples in Borehole 299-W22-50	5.52
5.46 pH, Electrical Conductivity, Alkalinity, Cations, Anions, and Trace Metals for UFA-Extracted Porewater from Sediment Samples within Borehole 299-W22-50	5.54
5.47 Charge Balance for UFA-Extracted Porewater from Sediment Samples in Borehole 299-W22-50	5.55
5.48 Calculated Composition of Vadose-Zone Porewater	5.56
5.49 Comparison of UFA-Extracted Porewater to Calculated Porewater Based on Water Extract Data from Sediment Samples in Borehole 299-W22-50	5.57
5.50 Comparison of UFA-Extracted Porewater to Calculated Porewater Charge Balance Based on Water Extracts of Sediment Samples from Borehole 299-W22-50	5.57

1.0 Introduction

In fiscal year 1999, several offices within the U.S. Department of Energy (DOE) initiated and funded coordinated activities at the Hanford Reservation to study the vadose zone to better understand the fate of contaminants that have leaked from underground storage tanks. As part of this effort, the Pacific Northwest National Laboratory (PNNL), Bechtel Hanford Inc., and CH2M HILL Hanford Group, Inc., collected intact sediment cores from the subsurface in the vicinity of the S-SX Waste Management Area. These cores were collected from two new monitoring wells surrounding the S-SX Waste Management Area. In addition, large quantities of sediment were collected from outcrops in the Pasco Basin that may be representative of strata beneath the S-SX Waste Management Area. Location maps and more details on sampling locations are presented in Section 2.0.

Outcrop and borehole samples were collected and analyzed for their physical, mineralogical, and chemical properties to serve as Hanford Site standards. The characterized standards are available to researchers for experiments relative to environmental problems at the Hanford Site. To obtain sediment, contact Clark Lindenmeier at PNNL by the following venues: telephone (509) 376-8419, fax (509) 376-5368, or email clark.lindenmeier@pnl.gov.

This report describes samples and documents the results of characterization activities completed to date. This document is considered a living document because any characterization data from other researchers should be added to the data reported here. The addition of analytical results to the current characterization database will significantly increase our confidence in the physical, mineralogical, and geochemical characterization of the standards. The goal is to produce a set of comprehensive, well-characterized uncontaminated Hanford Site sediment to serve as standards for future experimental work.

Primary support of this work was provided by CH2M HILL Hanford Group, Inc., specifically the Tank Farm Vadose Zone Project, and the Science and Technology Program portion of the Groundwater/Vadose Zone/Columbia River Integration Project. The overall goal of the of the Tank Farm Vadose Zone Project is to define risks from past and future single-shell tank farm activities, to identify and evaluate the efficacy of interim measures, and to aid future decisions that must be made by DOE regarding the near-term operations, future waste retrieval, and final closure activities for the single-shell tank Waste Management Areas. For a more complete discussion of the goals of the Tank Farm Vadose Zone Project, see the overall work plan, Phase 1 Resource Conservation and Recovery Act (RCRA) Facility Investigation/Corrective Measures Study Work Plan for the Single-Shell Tank Waste Management Areas (DOE/RL 1999).

The overall goal of the Groundwater/Vadose Zone/Columbia River Integration Project is to assess the cumulative effects of all Hanford activities on the Columbia River and to aid in making remediation decisions that consider all project activities. The Science and Technology Program portion of the integration project emphasizes applied research to evaluate the mechanisms that control the fate of contaminants released into the Hanford ecosystem.

This document is the first in a series of four PNNL reports that characterizes sediments beneath the S-SX Waste Management Area. The objective of these documents is to present recent data from vadose zone sediments, both uncontaminated and contaminated sediment, from the S-SX Waste Management Area. The information will be used in single-shell tank Waste Management Area field investigation reports.

This report summarizes the findings for uncontaminated subsurface sediment immediately adjacent to the S-SX Waste Management Area. Three other reports in the series summarize results from sediment directly affected by waste leaks from the S-SX tank farms. Each of the other reports in this series summarizes results from a separate borehole: (1) the single-shell tank SX-115 borehole (299-W23-19) (Serne et al. 2002c), (2) the 41-09-39 borehole (299-W23-234) drilled between single-shell tanks SX-109 and -112 (Serne et al. 2002a), and (3) a slant borehole that penetrated below single-shell tank SX-108 (Serne et al. 2002b). In addition, large-volume grab or “composite” samples were collected from various outcrops/excavations within the Pasco Basin as well as from a nearly continuous, uncontaminated 10-centimeter (4-inch) core from a borehole nearby the S-SX Waste Management Area.

The grab samples and cores were obtained for the DOE Environmental Management Science Program, Science and Technology Program, and CH2M HILL Hanford Group, Inc., Tank Farm Vadose Zone research. This report documents the characterization performed to date on those samples. A second objective was to determine depth-variant physical and geochemical characteristics of uncontaminated sediments from the Hanford formation, Plio-Pleistocene unit, and Ringold Formation strata in the vadose zone so that changes caused by interaction with tank fluids can be more clearly understood.

Two RCRA boreholes (299-W22-48 and 299-W22-50) summarized in this report provided ~104 meters (340 feet) of vadose zone core for characterization; borehole 299-W22-48 provided 50 meters (164 feet) and borehole 299-W22-50 provided 54 meters (176 feet) of core, respectively. The stratigraphy and lithology in these boreholes is summarized in Section 3.2. Discrete sampling points for geochemical analysis were selected from the cores with emphasis on delineating the range and magnitude of differences observed within the various lithologies whenever possible. Physical, geochemical, and mineralogical analyses included the following:

1. mass water content
2. particle-size distribution
3. particle density
4. calcium carbonate and organic carbon content
5. chemical composition of the bulk sediment by x-ray fluorescence
6. crystalline mineralogy of the bulk sediment, and silt- and clay-size fractions by x-ray diffraction techniques
7. cation exchange capacity
8. exchangeable base cation distribution
9. 1:1 water extract pH, electrical conductivity, major cation and anion and trace metal composition,
10. 8 M nitric acid extract composition
11. geochemical composition of porewater after ultra centrifugation.

A few selected intact core sleeves also were exclusively analyzed by others to measure hydraulic conductivity as a function of moisture content. The results of these analyses will be documented elsewhere. We also provide our interpretation of the data in the context of determining the appropriate geologic conceptual model, the vertical extent of contamination, the migration potential of the contaminants that still reside in the vadose zone, and the correlation of the contaminant distribution in the borehole sediment in relationship to groundwater plumes in the aquifer proximate and downgradient from the SX Tank Farm.

This report is organized into seven sections that describe the geology, analytical methods, analytical results, and summary and conclusions, references cited, in addition to eight appendices.

2.0 Geology

This section presents a general discussion on the regional geology as well as the geology of the vadose zone in the vicinity of the SX Tank Farm. The history of water-level fluctuations is also discussed. Also presented is a discussion of the geologic context of the composite samples and geologic characteristics of the vadose-zone materials penetrated by boreholes 299-W22-48 and -50.

2.1 Regional Geologic Setting

The Hanford Site is located within the Columbia Plateau of southeastern Washington State. This broad plain, situated between the Cascade Mountains to the west and the Rocky Mountains to the east, is underlain by a thick sequence of Miocene age tholeiitic basalt flows (the Columbia River Basalt Group) (Myers and Price 1979, Myers et al. 1981, DOE 1988, Tolan et al. 1989, Reidel et al. 1989). These basalt flows have been folded and faulted creating broad structural and topographic basins, separated by asymmetric anticlinal ridges. Sediments of late Miocene, Pliocene, and Pleistocene age have accumulated up to 518 meters (1700 feet) thick in some of these basins. The Hanford Site lies within one of the larger of these basins, the Pasco Basin. This basin is partially bisected by the Umtanum-Gable Mountain anticline creating two subordinate synclinal basins. The largest of these is the Cold Creek syncline, which is further subdivided into two basins, the Wye Barricade depression and the Cold Creek depression. The Cold Creek depression underlies the principal waste management areas (200 East and 200 West Areas) of the Hanford Site.

The generalized stratigraphy beneath the Hanford Site consists of, in ascending order, the Columbia River Basalt Group, the Ringold Formation, the Plio-Pleistocene unit, and the Hanford formation (Figure 2.1). Thin veneers of Holocene alluvium, colluvium, and/or eolian sediments discontinuously overlie these principal geologic units. More thorough discussions of the regional geology, including the saturated zone, of the area are documented elsewhere (Tallman et al. 1979, DOE 1988, DOE 1993, Lindsey et al. 1994).

2.2 Geology of the SX Tank Farm

The SX Tank Farm is an excavation cut into the upper Hanford formation sediments underlying 200 West Area, along the north limb of the Cold Creek syncline. Stratigraphic units underlying or adjacent to the tank farm (in descending order), include backfill materials, Hanford formation, the Plio-Pleistocene unit, the Miocene- to Pliocene-age Ringold Formation, and the Columbia River Basalt Group.

The geology beneath this tank farm has been the subject of numerous reports. Price and Fecht (1976) and Fecht and Price (1977) presented an initial detailed interpretation of the geology. DOE (1996) presented an interpretation of the geology based primarily on groundwater monitoring wells constructed

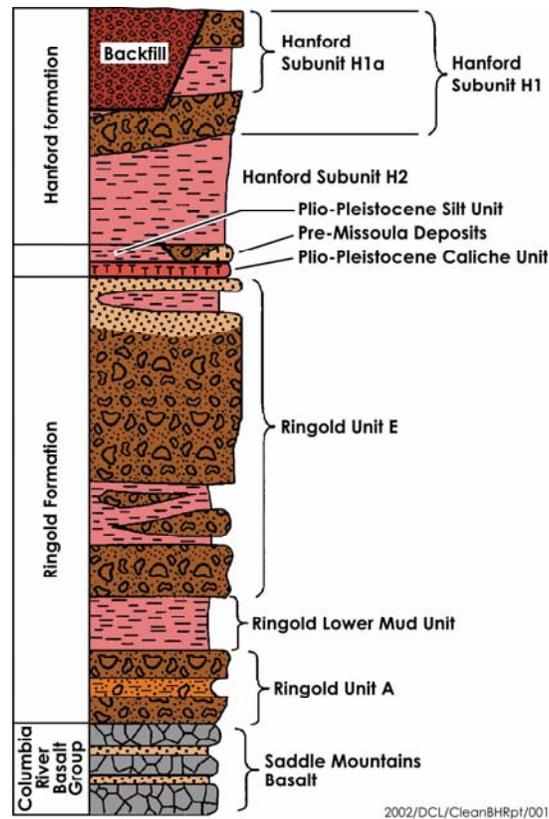


Figure 2.1. Generalized, Composite Stratigraphy for the Late Cenozoic Sediments Overlying the Columbia River Basalt Group on the Hanford Site (After Johnson and Chou 1998, 1999).

around the perimeter of the tank farm in the early 1990s. Johnson and Chou (1998) updated and refined the geologic interpretation. Myers et al. (1998) and Part 3 in this series present detailed discussions on the geologic materials penetrated by the extension of borehole 41-09-39 (299-W23-234). Johnson et al. (1999) further described the geology and other subsurface contaminants. Lindsey et al. (2000) provided additional interpretations on the geology, facilitated by the collection of near continuous split-spoon samples from two boreholes (299-W22-50 and 299-W23-19). Comprehensive and detailed physical, mineralogical, and geochemical analyses on vadose zone samples are presented in the present series. This report, Part 1 in the four-part series, presents results from boreholes 299-W22-48 and -50, drilled just outside the SX Tank Farm (Figure 2.2). Subsequent parts of the series present results of similar analyses for contaminated boreholes drilled within the SX Tank Farm, including the 299-W23-19 (Part 2), SX 41-09-39 (Part 3), and SX-108 Slant Borehole (Part 4).

Horton and Johnson (2000) compiled a data package on three ground-water monitoring wells (299-W22-48, -49, and -50) completed near the SX Tank Farm in 1999/2000. Most recently, Sobczyk (2000) presented a reinterpretation on the geology based on gross gamma-ray logs of 98 boreholes within the SX Tank Farm and published geology reports of the area (e.g., Johnson et al. 1999 and Lindsey et al. 2000).

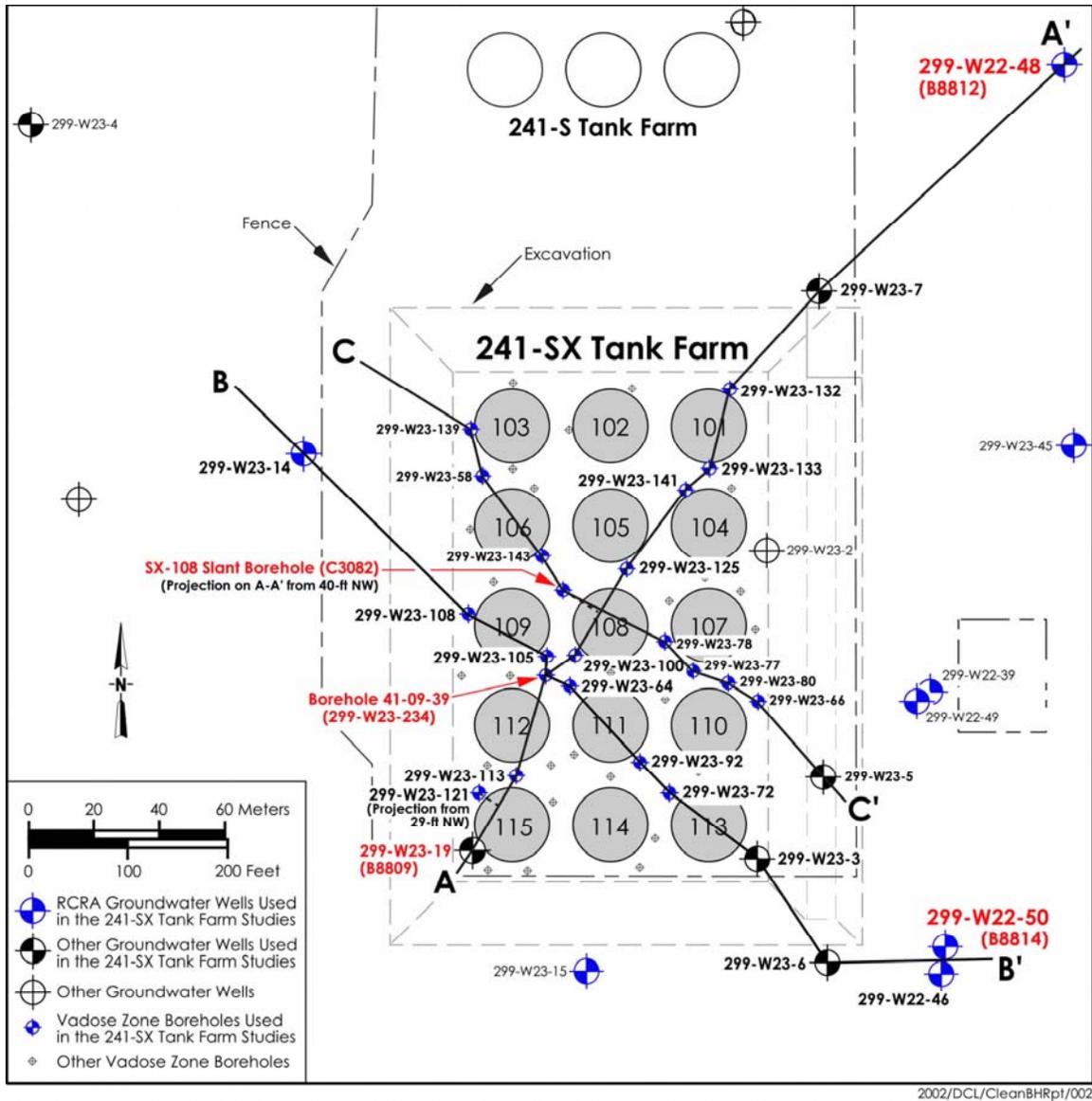


Figure 2.2. Location Map and Hydrogeologic Cross Sections Through the SX Tank Farm. Cross Section A-A' through C-C' are presented in Figures 2.3 through 2.5, respectively.

Several hydrogeologic cross sections, constructed from a series of densely spaced boreholes beneath the SX Tank Farm, are presented in Figures 2.3 through 2.5. Some differences in interpretation occur between the depths of the geologic contacts presented here, and those presented by other authors, due to the various source of uncertainty in the geologic data sets and the individual geologist's interpretation.

The stratigraphic terminology used in this report is summarized in Table 2.1. The general stratigraphic interpretation presented here differs somewhat from that presented by Lindsey et al. (2000).

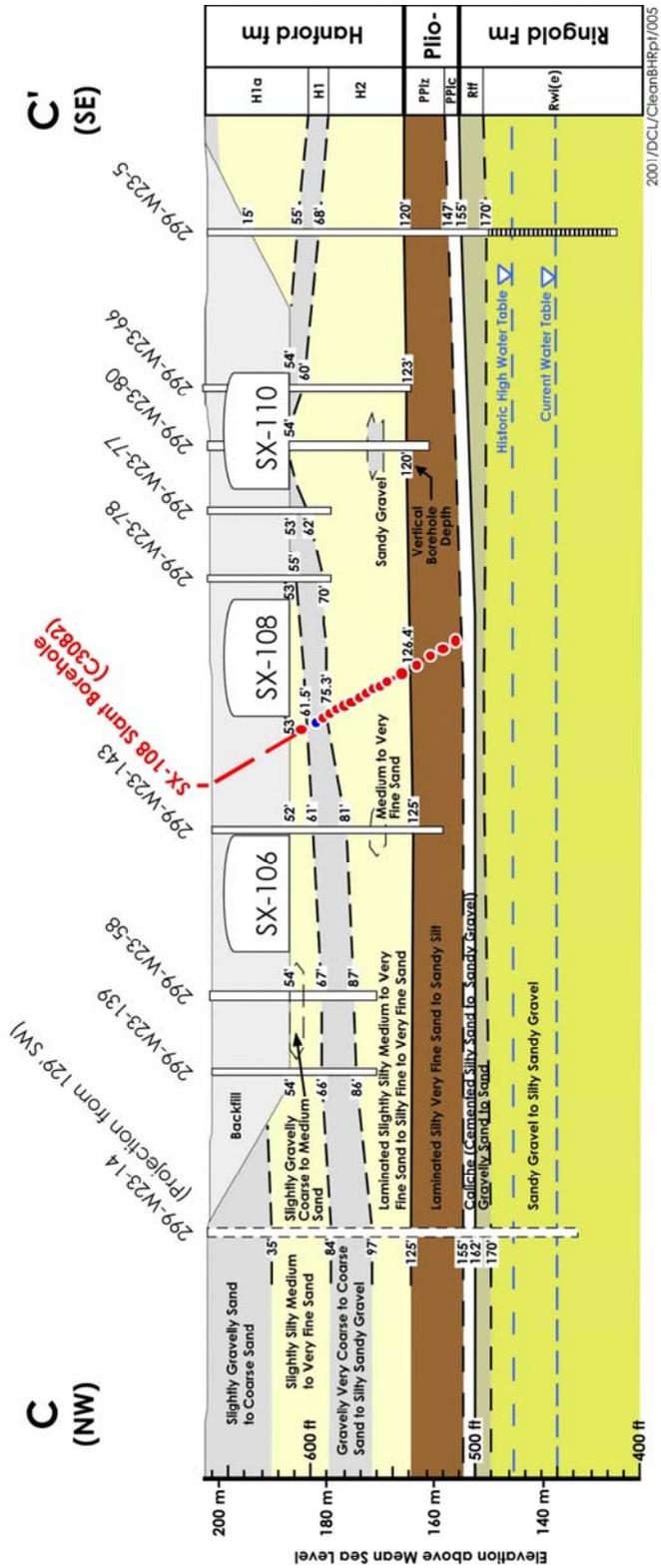


Figure 2.5. Geologic Cross Section C-C'

Table 2.1. Stratigraphy of the Vadose Zone Beneath the SX Tank Farm.

Stratigraphic Symbol ^(a)	Formation	Facies/Subunit	Description	Genesis
Holocene/Fill	NA	Backfill	Poorly sorted gravel to medium sands and silt derived from the Hanford formation (Price and Fecht, 1976a)	Anthropogenic
H1a	Hanford formation	Unit H1a - gravelly sand	Upper coarse-grained sequence equivalent to Johnson et al.'s (1999) "Hanford Gravel Unit B" and Sobczyk's (2000) "Hanford Unit B"	Cataclysmic Flood Deposits
		Unit H1a - slightly silty sand	Upper fine sand and silt sequence. Equivalent to "Hanford silty sand" of Sobczyk (2000)	
H1		Unit H1	Lower coarse-grained sequence equivalent to "Gravel Unit A" described by Johnson et al. (1999) and "Hanford Unit A" described by Sobczyk (2000).	
H2		Unit H2	Lower fine sand and silt sequence. Equivalent to "Lower Hanford" of Sobczyk (2000)	
PPlz and/or H/PP1	Plio-Pleistocene Unit	Upper	Very fine sand to mud sequence. Interstratified silt to silty very fine sand and clay deposits at least partially correlative with the "early Palouse soil" described by Tallman et al. (1979) and DOE (1988) and the "unnamed Hanford formation or Plio-Pleistocene Deposits" described by Lindsey et al. (2000), and the H/PP deposits in Wood et al. (2001)	Fluvial and/or Eolian Deposits (with some weakly developed paleosols)
PPlc		Lower	Carbonate-rich sequence. Weathered and naturally altered sandy silt to sandy gravel, moderately to strongly cemented with secondary pedogenic calcium carbonate	Well-developed calcic paleosol or sequence of calcic soils.
Rwi(e)	Ringold Formation	Member of Wooded Island, subunit E	Moderate to strongly cemented well rounded gravel and sand deposits, and interstratified finer-grained deposits	Fluvial

(a) After Lindsey et al. (2000)

As with Price and Fecht (1976a), Johnson and Chou (1998), Myers et al. (1998), Johnson et al. (1999), Khaleel et al. (2000), and Sobczyk (2000), the coarse (gravelly) materials found near the middle of the Hanford formation (correlative with Hanford formation H1 unit of Lindsey et al. (2000)) are interpreted to correlate across the tank farm, and to represent a laterally continuous coarse unit distinct from the overlying and underlying finer sand units. Lindsey et al. (2000) suggest that these coarser materials are not continuous, but rather represent thin, lenticular, discontinuous gravelly beds within stratified sand sheets of the Hanford formation. Additional discussion to support correlation of this coarse unit is discussed below and in the borehole 41-09-39 report (Part 3 of this series).

2.2.1 Columbia River Basalt Group

The Columbia River Basalt Group, composed of hundreds of individual basalt flows, forms the bedrock beneath the site. The surface of the Columbia River Basalt Group lies at an elevation of approximately 26 meters (85 feet) above mean sea level (msl) beneath the SX Tank Farm (a depth of approximately 175 meters (575 feet)) and dips gently to the southwest towards the axis of the Cold Creek syncline (Price and Fecht 1976a, Myers and Price 1979, Myers et al. 1981, DOE 1988, DOE 1993).

2.2.2 Ringold Formation

The Ringold Formation lies directly on top of the Columbia River Basalt Group and is approximately 125 meters (410 feet) thick beneath the SX Tank Farm. It locally consists of three principal stratigraphic units, which combined form the informal Ringold member of Wooded Island (Lindsey 1996): (1) the fluvial gravels of unit A, (2) a fine-grained, paleosol-lacustrine sequence referred to as the lower mud unit, and (3) fluvial gravels of unit E (Figure 2.1). Ringold unit E grades upwards into fluvial sands of the upper Ringold unit (DOE 1993), interpreted as an equivalent to the informal Ringold member of Taylor Flat. Ringold Unit E forms the main unconfined aquifer beneath the 200 West Area.

The thickness of fluvial Ringold unit A is on the order of 30 meters (100 feet) (DOE 1993). Tallman et al. (1979) described this unit as a silty-sandy gravel, which is composed predominantly of gravel supported by a coarse-to-fine sand matrix with intercalated, lenticular beds of sand and silt. The unit is occasionally cemented and/or compacted into a conglomerate.

The thickness of the lower mud unit is on the order of 12 to 30 meters (40 to 100 feet) (Tallman 1979 DOE 1993). This unit consists of predominantly mud (i.e., silt and clay); the lower portion contains well-developed argillic to calcic paleosol sequence (DOE 1988). The high clay content (up to 43 wt%) and the low hydraulic conductivity (perhaps as low as 10^{-12} feet per day) of this sequence acts to locally confine groundwater within unit A and form a base for the uppermost unconfined aquifer (Last et al. 1989).

The thickness of unit E is estimated to be on the order of 75 to 85 meters (250 to 280 feet) (Tallman et al. 1979, DOE 1993). This unit consists of well-rounded, clast-supported pebbles and small cobbles, in a matrix of mostly sand (Table 2.2). The amount of consolidation is variable, with the lower portion of this unit described as moderate to well indurated conglomerate (Tallman et al. 1979). However, zones of poorly indurated gravel and sand also occur within this zone. The upper part of the unit is generally poorly indurated. Borehole data in the immediate vicinity of the SX Tank Farm indicate that this upper portion is dominated by sandy gravel and muddy sandy gravel, with sand to muddy sand beds becoming more prevalent toward the top of the unit.

Table 2.2. Granulometric Data from Core Samples of Ringold Unit E Encountered Within the 200 West Area (from Lindsey 1996)

Borehole/ Depth	Gravel >2 mm	Sand					Mud <0.06 3 mm	Class
		Very Coarse 1-2 mm	Coarse 0.5-1.0 mm	Medium 0.25-0.5 mm	Fine 0.125- 0.25 mm	Very Fine 0.063- 0.125 mm		
299-W11-26 (DH-6) 178 ft	76	0	0	9	8	5	0	sG
299-W14-7 (DH-12) 243 ft	90	1	1	2	4	1	1	G

A relict erosional and weathered surface occurs at the top of the Ringold Formation beneath the SX Tank Farm (DOE 1988, Slate 1996, 2000). The uppermost portion of this paleosurface is highly weathered and often cemented with secondary pedogenic calcium carbonate, referred to in this report as the carbonate-rich facies (PPlc) of the Plio-Pleistocene unit (Table 2.1). The northwest-southeast trending trough-shaped surface appears to conform to an ancestral Cold Creek channel and drainage system that developed following late Pliocene incision of the Ringold Formation, and prior to early Pleistocene cataclysmic flooding. The SX Tank Farm lies north of the ancestral Cold Creek paleochannel and the eroded Ringold paleosurface dips to the southwest beneath the SX Tank Farm (DOE 1988).

2.2.3 Plio-Pleistocene Unit

The Plio-Pleistocene unit lies unconformably on the tilted and truncated Ringold Formation. The Ringold Formation was tilted both during and following deposition of the Ringold. The Plio-Pleistocene unit includes all material overlying the Ringold Formation, including the weathered horizon at the top of the Ringold Formation, and beneath cataclysmic flood deposits of the Hanford formation (Lindsey et al. 1994). The Plio-Pleistocene unit includes the “Early Palouse Soil” described by Brown (1960), Tallman et al. (1979), and DOE (1988), the “Pre-Missoula Gravels” (or equivalent), the “unnamed Hanford formation or Plio-Pleistocene Deposits” described by Lindsey et al. (2000), and H/PP deposits of Wood et al. (2001).

Two distinct facies of the Plio-Pleistocene unit are recognized beneath the SX Tank Farm; these consist of an upper (PPlz) and lower (PPlc) subunit (Table 2.1). The upper subunit is characterized by an abundance of silt, signified by the letter “z,” and the lower unit is characterized by an abundance of pedogenic calcium-carbonate cement, signified by the letter “c.” The combined total thickness of the Plio-Pleistocene unit is up to 13.1 meters (43 feet) in the vicinity of the SX Tank Farm (Figures 2.3 through 2.5). The PPlz subunit is relatively thick (up to 10.7 meters [35 feet]), compared to the PPlc, which measures only 1 to 4 meters (4 to 13 feet) in thickness.

2.2.3.1 Lower Subunit (PPlc)

The lower Plio-Pleistocene unit (PPlc) subunit represents a highly weathered paleosurface that developed atop the Ringold Formation (Brown 1959, 1960), which represents a long period of surficial weathering in a semi-arid climate, similar to climatic conditions that exist today. Root traces and animal burrows, as well as other relict soil structures, point to a pedogenic origin for the CaCO₃, although Slate (1996, 2000) has also suggested the CaCO₃ could be associated with moisture from paleo-groundwater levels. Calcium carbonate contents as high as 70 wt% have been reported within the PPlc subunit elsewhere within the 200 West Area; however, in the vicinity of the SX Tank Farm, the CaCO₃ content generally does not exceed 25 wt%. The CaCO₃ content from three randomly chosen boreholes within the SX Tank Farm did not exceed 10 wt% (Table 2.3). Other names used for the PPlc subunit, including “caliche” and “calcrete,” are somewhat misleading since they imply a single, homogeneously cemented layer, which is not the case. Considerable internal variation exists within the PPlc subunit, often with multiple carbonate-cemented zones present (Bjornstad 1990, Lindsey et al. 1994, Slate 1996, 2000, Wood et al. 2001).

Table 2.3. Example of Granulometric and Calcium Carbonate Data from Samples of the Lower Plio-Pleistocene (PPlc) Unit Encountered Beneath the SX Tank Farm

Borehole /Depth	CaCO ₃ %	Gravel >2 mm	Sand					Mud <0.063 mm	Class
			Very Coarse 1-2 mm	Coarse 0.5-1.0 mm	Medium 0.25-0.5 mm	Fine 0.125-0.25 mm	Very Fine 0.063-0.125 mm		
299-W23-2 135 ft ^(a)	9.3	0.0	2.1	4.3	5.9	9.1	25.2	53.5	SM
299-W23-5 150 ft ^(a)	9.4	5.3	5.8	17.6	25.1	10.5	8.8	26.9	(g)mS
299-W23-6 140 ft ^(a)	4.4	6.4	1.3	3.9	9.8	10.7	16.9	51.0	(g)sM

(a) Hard-Tool Sample, Use For Indication Only. Multiply by 0.3048 to convert to meters.

The CaCO₃ overprint may occur on a variety of lithologies, including silt, sand, felsic sand and gravel, as well as basaltic sand and gravel (Lindsey et al. 2000). In places, pedogenic alteration occurs directly on top of Ringold gravels (Rwi(e)) or sands (Rtf). In other places, the carbonate horizons occur within younger, pedogenically altered, fine-grained, eolian or sidestream-alluvial deposits overlying the Ringold Formation. The top of the PPlc subunit is well defined by a coincident significant increase in CaCO₃ and decrease in mud content and sorting, accompanied by a sudden and sustained decrease in background gamma counts (i.e., ⁴⁰K) on borehole geophysical logs (DOE 1988, Last et al. 1989, Bjornstad 1990, Wood et al. 2001). While the top of the PPlc unit is relatively easy to recognize, considerable variation may exist internally within the subunit due to natural heterogeneity inherent in soils and soil processes, which vary under different physical, chemical, and biological conditions (e.g., moisture, grain size, aspect, mineralogy, bioturbation, microbial activity, etc.). Added to this is the complicating factor that the land surface during Plio-Pleistocene time was undergoing many changes under the influence of local fluvial and eolian activity resulting in variable rates of aggradation, degradation, and soil development. Normally, only a single paleosol horizon is present within the lower

Plio-Pleistocene unit within the SX Tank Farm, suggesting slow or negligible aggradation and/or subsequent erosion during paleosol development. This is in contrast to other areas to the west and south, which show up to five separate calcic horizons (Figure 2.6), separated by relatively non-calcareous, uncemented sand, silt and even indigenous, basaltic sand and/or gravel (Slate 1996, 2000; Wood et al. 2001). Multiple carbonate horizons within the lower Plio-Pleistocene are indicative of several periods of calcic-soil development interrupted temporarily by periodic aggradational events (i.e., localized overbank flood, eolian accumulation, channel fill, etc.). The evolution of calcic paleosols and their morphogenetic development are discussed further in Slate (1996, 2000) and Wood et al. (2001).

In the T-TX-TY Waste Management Area, 1800 meters (5900 feet) north of the SX Tank Farm, the top of the lower Plio-Pleistocene slopes to the southwest at about 1 degree (Wood et al. 2001). At least some of the slope reflects the paleotopography that existed during subaerial weathering of the eroded Ringold surface. This is inferred based on the relief on top of the lower Plio-Pleistocene, which is almost double that of the underlying Ringold lower mud unit. Therefore, it appears that during development of the lower Plio-Pleistocene unit there was a gentle slope to the land surface to the southwest, toward the Cold Creek valley axis. Since Plio-Pleistocene time this surface has been steepened further by continued long-term downwarping along the north limb of the Cold Creek syncline (DOE 1988).

Another recognized facies of the Plio-Pleistocene unit is a coarse-grained side-stream-alluvial facies (Bjornstad 1984, DOE 1988, Slate 1996, 2000), which is laterally equivalent to the PPlc subunit to the south and west of SX Tank Farm. The side-stream alluvial facies (gravel facies in Figure 2.6) fills and is restricted to the northwest-southeast trending, ancestral Cold Creek channel, located south and west of the 200 West Area. The eastern edge of this gravel facies occurs along the southwest boundary of 200 West Area near the SX Tank Farm (Figure 2.6). North and east of the 200 West Area the Plio-Pleistocene unit is generally not present, and is interpreted to have been scoured away during either post-Ringold erosion and/or Pleistocene cataclysmic flooding.

2.2.3.2 Upper Subunit (PPlz)

Unconformably overlying the lower subunit of the Plio-Pleistocene unit is the upper subunit (PPlz), which consists of interstratified, uncemented fine sand, silt, and/or clay that only displays occasional, very weak soil development in the vicinity of the SX Tank Farm. Based on its fine-grained texture and relatively high natural-gamma activity on geophysical logs, this unit can be correlated across most of the 200 West Area (Wood et al. 2001). The PPlz sediments appear to be predominantly fluvial-overbank-type deposits intercalated with some eolian deposits (Lindsey et al. 2000, Slate 2000, Wood et al. 2001). The PPlz subunit is at least partially correlative with the “early Palouse soil” described by previous reports (Brown 1960, Tallman et al. 1979, Bjornstad 1984, Last et al. 1989, Bjornstad 1990, DOE 1988), the “unnamed Hanford Formation or Plio-Pleistocene Deposits” described by Lindsey et al. (2000), and the H/PP unit in Wood et al (2001).

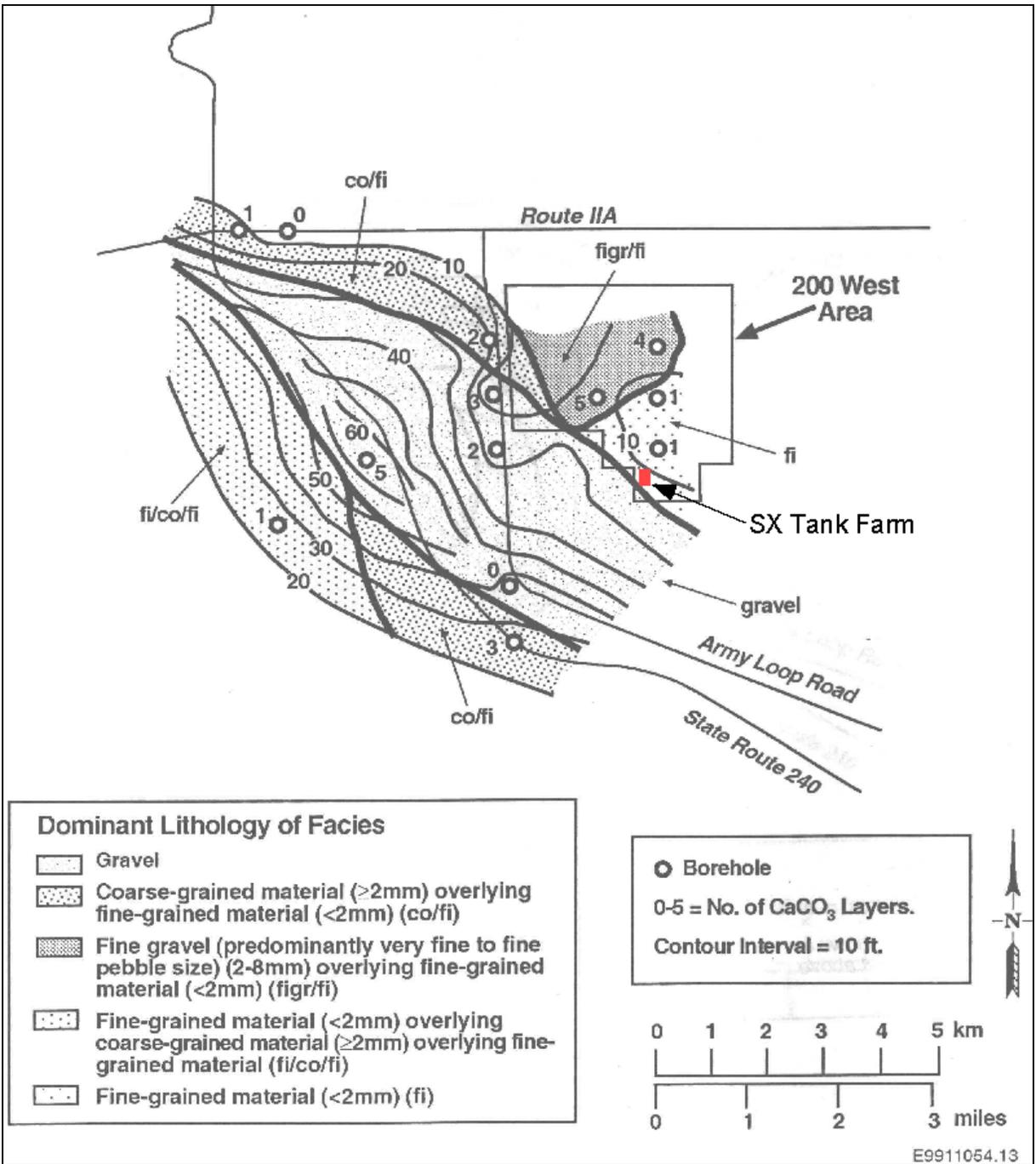


Figure 2.6. Lithofacies Distribution for the Lower Plio-Pleistocene Unit (PPlc). Modified after Slate (2000). Heavy weight lines mark facies boundaries, lighter weight lines are isopach contours.

The upper Plio-Pleistocene unit contains moderate amounts (up to a few wt%) of CaCO₃ (Table 2.4), generally more than the overlying Hanford formation. The source of the CaCO₃ within the two subunits of the Plio-Pleistocene unit appears distinctly different. Within the PPlc subunit, most of the CaCO₃ appears as stringers or in massive horizons, which formed in situ as a result of pedogenesis (Wood et al. 2001). Within the PPlz subunit, on the other hand, the CaCO₃ is evenly disseminated and does not occur in discrete zones, and therefore is interpreted to be detrital in origin (Wood et al. 2001). In fact, the bulk of the detrital, CaCO₃ mineral grains in the PPlz unit are probably derived from the disintegration and mechanical reworking and redeposition of the underlying PPlc subunit.

Table 2.4. Example of Granulometric and Calcium Carbonate Data from Drive-Barrel Samples of the Upper Plio-Pleistocene Unit (PPlz) Encountered Beneath the SX Tank Farm

Borehole/ Depth	CaCO ₃ %	Gravel >2 mm	Sand					Mud <0.063 mm	Class
			Very Coarse 1-2 mm	Coarse 0.5-1.0 mm	Medium 0.25-0.5 mm	Fine 0.125- 0.25 mm	Very Fine 0.063- 0.125 mm		
299-W23-5 120 ft	2.6	0.0	1.8	1.9	4.8	12.3	31.1	48	mS
299-W23-5 125 ft	2.3	0.0	1.6	7.0	9.2	7.3	8.1	66.8	sM
299-W23-6 125 ft	2.4	0.0	0.1	2.0	7.7	10.1	23.5	56.5	sM

(a) Hard-Tool Sample, Use for Indication Only. Multiply by 0.3048 to convert to meters.

The contact between the PPlz and PPlc subunits is distinctive and easily identified. The PPlz subunit consists of relatively loose, stratified, non-pedogenically altered, well-sorted silt to very fine sand in contrast to poorly sorted, weathered, and carbonate-cemented deposits of the PPlc subunit. Also distinctive is a sudden increase in total gamma activity upward across the contact (DOE 1988, Last et al. 1989, Bjornstad 1990, Johnson et al. 1999). The upper contact of the PPlz subunit with the overlying Hanford formation, on the other hand, often appears gradational, both texturally and structurally, and thus is often difficult to identify based on lithologic observations alone, especially in the vicinity of the SX Tank Farm. Because of this uncertainty, the upper Plio-Pleistocene unit in the past has been combined and queried with the lower Hanford formation in some recent reports (Lindsey et al. 2000, Wood et al. 2001). However, we believe the total gamma activity on borehole geophysical logs can effectively be used to identify the upper contact for the Plio-Pleistocene unit. Accordingly, a subtle decrease in total gamma activity appears to be associated with the top of the PPlz subunit, probably as a result of a lower silt/clay content within the Hanford formation. Therefore, we recommend that this change in background gamma counts and grain size be used to define the upper contact for the upper Plio-Pleistocene unit.

2.2.4 Hanford Formation

Pleistocene-age deposits of the Hanford formation overlie the Plio-Pleistocene unit directly beneath the SX tank farm. The Hanford formation is the informal name given to all deposits from Ice-Age cataclysmic floods including any intercalated non-flood deposits.

The Hanford formation can generally be divided into three facies: 1) gravel-dominated, 2) sand-dominated, and 3) silt-dominated, also referred to as coarse-grained deposits, plane-laminated sand facies, and rhythmite facies, respectively (Baker et al. 1991). The coarse-grained facies have also been referred to as the “Pasco gravels,” and the rhythmite facies as Touchet Beds.

The gravel-dominated facies generally consists of poorly sorted coarse-grained basaltic sand and granule-to boulder-size gravel. These deposits often display an open framework texture, massive bedding, plane to low-angle bedding, and large-scale fore-set bedding in outcrop. The gravel clasts (dominated by basalt) are usually subangular to subrounded. The gravel-dominated facies was deposited by high-energy floodwaters in or immediately adjacent to the main cataclysmic flood channel ways (Figure 2.7).

The sand-dominated facies consists of fine- to coarse-grained sand and granule gravel displaying horizontal lamination and bedding and less commonly planar to trough laminations. These sands may contain small pebbles and rip-up clasts in addition to pebble-gravel interbeds and silty interbeds less than 1 meter (3 feet) thick. The silt content of these sands is variable, but where it is low, a well sorted and open framework texture of the gravel is common. These sands typically are basaltic, commonly being referred to as black, gray, or “salt-and-pepper” sands. The laminated sand facies was deposited at higher elevations where the floodwaters were starved of gravel, and/or adjacent to main flood channel ways during the waning stages of flooding (Figure 2.7). This is a transitional facies between the gravel-dominated facies and the silt-dominated facies. The sand-dominated facies is the predominant facies of the Hanford formation beneath the SX Tank Farm.

The silt-dominated facies consists of rhythmically bedded, ripple-cross-laminated sand and silt, and fine- to coarse-grained sand grading upward to plane laminated silt. Individual rhythmites range from a few centimeters to several tens of centimeters thick (Myers and Price 1979, DOE 1988, Baker et al. 1991). These sediments were deposited under slack-water conditions and in back-flooded areas (DOE 1988), mostly around the margins of the basins (Figure 2.7). The silt-dominated facies is the predominant facies of the Hanford formation south and west of the SX Tank Farm.

The Hanford formation beneath the SX Tank Farm is mostly represented by sand-dominated facies consisting of fine-grained sands intercalated with coarse sand and gravel, and thinner lenses of silt. The basal portion of the Hanford formation is predominantly silty fine sand, described by DOE (1996) and Lindsey et al. (2000) as the Hanford formation H2 unit (Table 2.1). A sandy gravel facies dominates the middle portion of the Hanford formation, which is then overlain by a slightly silty medium sand and finally by a slightly gravelly coarse sand. The sandy gravel facies makes up the Hanford formation H1

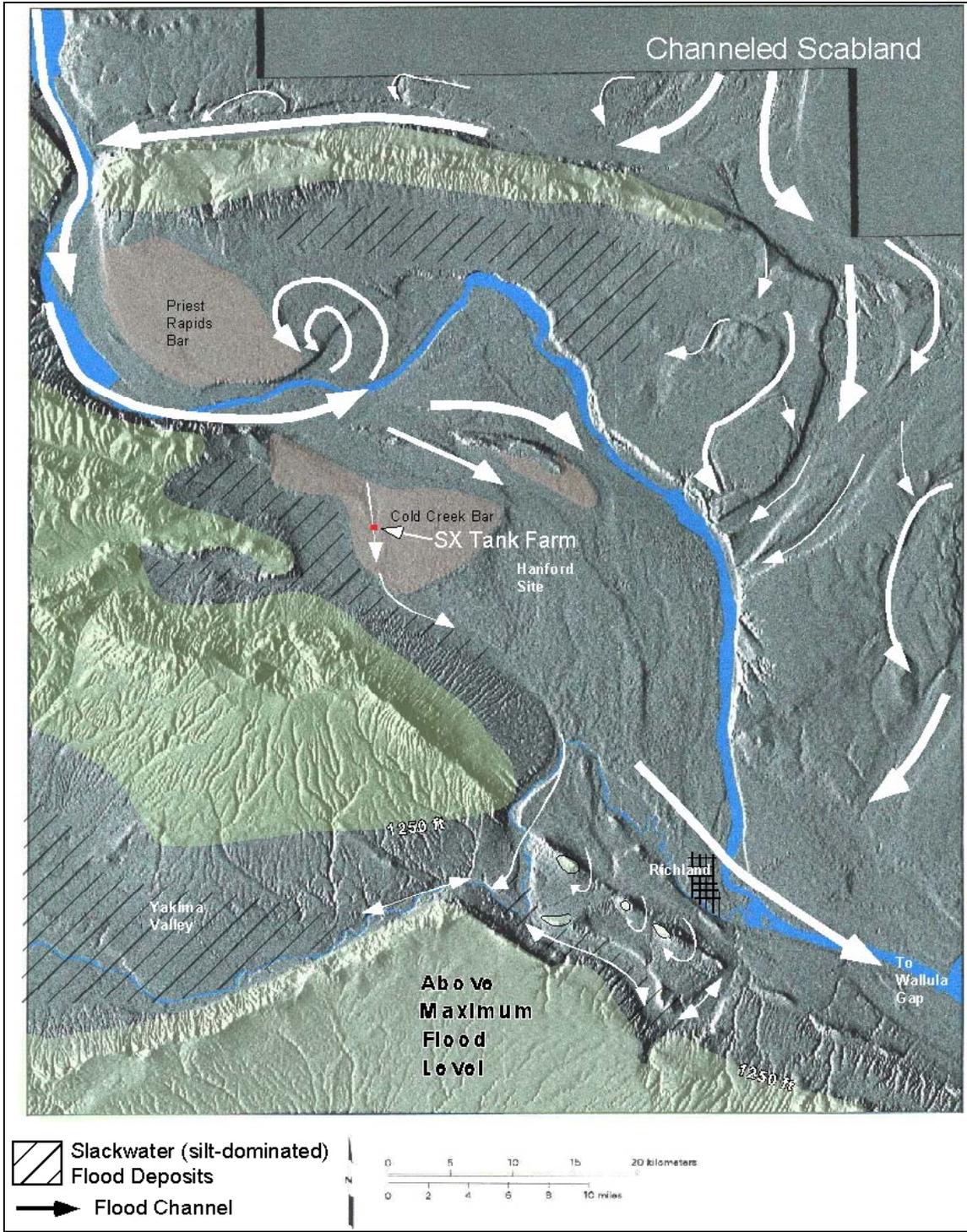


Figure 2.7. Digital Elevation Model (DEM) Map of a Portion of the Pasco Basin Showing Routes and Facies Distributions for the Last Pleistocene Cataclysmic Floods (i.e., Hanford formation).

unit described by DOE (1996), Johnson et al. (1999) and Lindsey et al. (2000). The slightly silty medium sand and overlying slightly gravelly coarse sand is equivalent to the Hanford formation H1a unit (Johnson et al. 1999, Lindsey et al. 2000).

2.2.4.1 Lower Fine Sand and Silt Sequence (Hanford Formation H2 Unit)

The lower portion of the Hanford formation (equivalent to the Hanford formation H2 unit) consists primarily of interstratified silty sands. This sequence generally thins from about 24.3 meters (80 feet) east of the SX Tank Farm to approximately 10.7 meters (35 feet) west of the tank farm (Figures 2.3 through 2.5). Johnson and Chou (1998) suggested that this thinning may signify some scouring on top of the unit, perhaps associated with a secondary flood channel, similar to the north-south trending flood channel that bisects Cold Creek bar in Figure 2.7. The grain size within the Hanford formation H2 unit appears to coarsen upward slightly (see Table 2.5). Sobczyk (2000) and Johnson et al. (1999) found that the top of this unit generally slopes about six degrees to the southwest, with some local relative highs and lows present throughout. Below the Hanford formation H2 unit are slightly finer-grained deposits of interstratified very fine sand, silt and clay, associated with the upper Plio-Pleistocene unit. As mentioned previously, the base of the Hanford formation is indicated by a diagnostic increase in background gamma counts on borehole geophysical logs.

2.2.4.2 Lower Coarse-Grained Sequence (Hanford Formation H1 Unit)

The lower fine sand and silt sequence (Hanford formation H2 unit) is bounded above by a coarse unit dominated by sandy gravel to gravelly sand (Table 2.5) that appears to correlate beneath the SX Tank Farm (Figures 2.3 through 2.5). This sequence, referred to as “Gravel Unit A” by Johnson et al. (1999) and as “Hanford Unit A” by Sobczyk (2000), is equivalent to the Hanford formation H1 unit described by DOE (1996) and Lindsey et al. (2000) and ranges in thickness from 1 meter to nearly 10 meters (3 to 30 feet) beneath the tank farm. The Hanford formation H1 unit is thickest beneath the SX-102 tank where coarse-grained flood deposits backfilled an apparent channel eroded into the top of the underlying Hanford formation H2 unit (Johnson et al. 1999, Sobczyk 2000).

Recent particle-size results using dry sieving for 100 selected samples from seven boreholes drilled in and around the tank farm suggest the coarse-grained Hanford formation H1 unit is continuous beneath the SX Tank Farm, as indicated by Johnson et al. (1999) and Sobczyk (2000). Accordingly, the Hanford formation H1 unit averages ~30% gravel, 66% sand, and only 4 % mud (Table 2.6). This is compared to the materials directly above and below it, that both average <1% gravel, nearly 90% sand, and 9% mud. Based on the modified Folk/Wentworth classification scheme, traditionally used for geologic studies on the Hanford Site, the classification of the average particle size for this unit falls near the boundary between the sandy gravel and gravelly sand classes. Furthermore, a zone with low background gamma counts appears to correlate beneath the SX Tank Farm, which is interpreted to conform to the gravel-rich Hanford formation H1 unit, is interpreted to be continuous in this area (Sobczyk 2000). Granulometric data from all seven wells used in the compilation of Table 2.6 is presented in Appendix D.

2.2.4.3 Upper Fine Sand and Silt Sequence (Hanford Formation H1a Unit [fine])

Above the middle coarse facies of the Hanford formation H1 unit lies an upper fine sand to silty-sand sequence, equivalent to the Hanford formation H1a unit described by Lindsey et al. (1994, 2000), and the “Hanford silty sand” described by Sobczyk (2000). This sequence consists predominantly of interstratified slightly silty medium to very fine sands (Table 2.5) and ranges in thickness from 0 meter, where it was removed during excavation of the tank farm, to about 9 to 12 meters (30 to 40 feet) to the southwest (Figures 2.3 through 2.5). The top of this unit slopes slightly (~2 degrees) to the southwest (Johnson et al. 1999, Sobczyk 2000). Sobczyk (2000) also suggests that this unit may become coarser textured to the west.

2.2.4.4 Upper Coarse-Grained Sequence (Hanford Formation H1a Unit [Coarse])

A coarse-grained sand to gravelly sand unit (Table 2.5) overlies the fine sand sequence of the Hanford formation H1a subunit, and may be intercalated with some sandy gravel to the west. This unit is equivalent to Gravel Unit B (Johnson et al. 1999) and Hanford Unit B (Sobczyk 2000). It is the uppermost stratigraphic unit in the tank farm area, but is completely missing beneath the tank farm, where it was removed during construction. In surrounding boreholes, however, this unit ranges from a few meters in thickness to east to up 12 meters (40 feet) to the west.

2.2.5 Backfill

Price and Fecht (1976a) described the backfill surrounding the high-level waste tanks of the SX Tank Farm as consisting predominantly of poorly sorted cobbles, pebbles, and coarse to medium sands to silt derived from the Hanford formation. Lindsey et al. (2000) described the backfill as relatively non-cohesive, friable, massive sand with variable amounts of silt and pebbles. They also observed a hardened zone at the base of the backfill, extending to a depth of approximately 18.6 meters (61 feet) that was significantly harder and drier than the overlying materials. However, this hardened zone has not been observed in adjacent boreholes, so it may or may not extend laterally.

Engineering drawings H-237985 Sheet 1 and 2 show that the tank farm was excavated to create three terraces for construction of the cascading tanks. This excavation extended to an elevation of 185.3 meters (608 feet) on the west side and 185.9 meters (610 feet) on the east side.

Table 2.5. Granulometric and Calcium Carbonate Data from Core Samples of the Hanford Formation Beneath SX Tank Farm and Average Bulk Densities

Hanford Formation Subunit	Borehole /Depth	CaCO ₃ %	Gravel >2 mm	Sand (mm)						Mud <0.063 mm	Class	Average Bulk Density from 299-W22-50 ^(a)
				Very Coarse 1-2 mm	Coarse 0.5-1.0 mm	Medium 0.25-0.5 mm	Fine 0.125-0.25 mm	Very Fine 0.063-0.125 mm				
H1a - gravelly sand	299-W23-5 5 ft ^(b,c)	1.2	6.7	4.8	10.5	8.6	20.7	30.9	17.9	(gm)S	NA	
H1a - slightly silty sand	299-W23-72 55 ft ^(c)	1.4	0.4	0.5	1	19.1	43.1	22.1	13.9	(m)S	1.95	
	299-W23-92 80 ft ^(c)	NA	2.1	3	12.1	20.4	31.2	19.8	11.4	(m)S		
H1	299-W23-72 70 ft ^(c)	1.7	10.7	23.7	28.7	16.7	8.3	6.0	6.0	gS	2.27	
	299-W23-92 90 ft ^(c)	NA	16.3	16.9	27.9	18.5	8.1	5.7	6.6	gS		
	299-W23-108 85 ft ^(c)	NA	41.8	24.5	14.5	7.1	3.9	3.3	5.0	sG		
H2	299-W23-72 100 ft ^(c)	1.7	0.0	0.2	2.1	37.6	29.7	15.2	15.3	(m)S	2.05	
	299-W23-92 110 ft ^(c)	NA	0.8	1.0	9.4	40.0	22.2	14.6	12.0	(m)S		
	299-W23-92 120 ft ^(c)	NA	2.8	2.2	1.7	9.6	33.5	34.9	15.4	(m)S		
	299-W23-108 110 ft	NA	1.8	0.1	1.8	13.2	26.6	30.9	15.7	mS		

(a) After Horton and Johnson (2000)

(b) Hard-Tool Sample, Use For Indication Only

(c) Multiply by 0.3048 to convert to meters.

NA = Not Analyzed

Table 2.6. Summary of Recent Particle Size Analytical Results from Seven Boreholes in and Around the SX Tank Farm

	% Gravel	% Sand	% Mud
H1a			
Min	0.00	76.76	2.54
Max	5.38	97.15	23.14
Average	0.94	89.18	9.88
STDEV	1.43	6.13	6.51
H1			
Min	0.13	2.64	0.00
Max	97.27	96.05	22.34
Average	30.88	66.87	4.14
STDEV	28.33	26.34	4.77
H1			
Min	0.00	62.13	1.55
Max	13.99	98.11	37.84
Average	0.94	89.75	9.30
STDEV	2.38	7.19	7.17

2.3 Historical Water Levels

Figure 2.8 illustrates hydrographs for wells 299-W23-3 and -4. Since a complete water level record is unavailable for either well, their water level behavior was extrapolated from each other to complete the record. This is justified by the similar behaviors of their common data sets. Based on this extrapolation between the two data sets, and a linear interpolation over the distance between the two wells, it is estimated that the peak water elevation beneath the SX-115 tank was approximately 146 meters (479 feet). This occurred in 1976 and places the water table approximately 55 to 56 meters (182 feet) below ground surface (bgs) or 40 meters (132 feet) beneath the bottom of the tank. A secondary maximum occurred in 1984, just before the 216-U-10 Pond was decommissioned. At this time the water table was estimated to have been almost as high as it was in 1976. The water table was encountered at a depth of approximately 64.5 meters (212 feet) in borehole 299-W23-19, in August 1999. Thus, the water table has dropped an estimated 8 to 9 meters (28.5 feet) over the last 14 years. An examination of the hydrographs since about 1988 suggests that the water level is dropping at a rate of 0.5 to 0.6 meters (1.5 to 1.9 feet) per year.

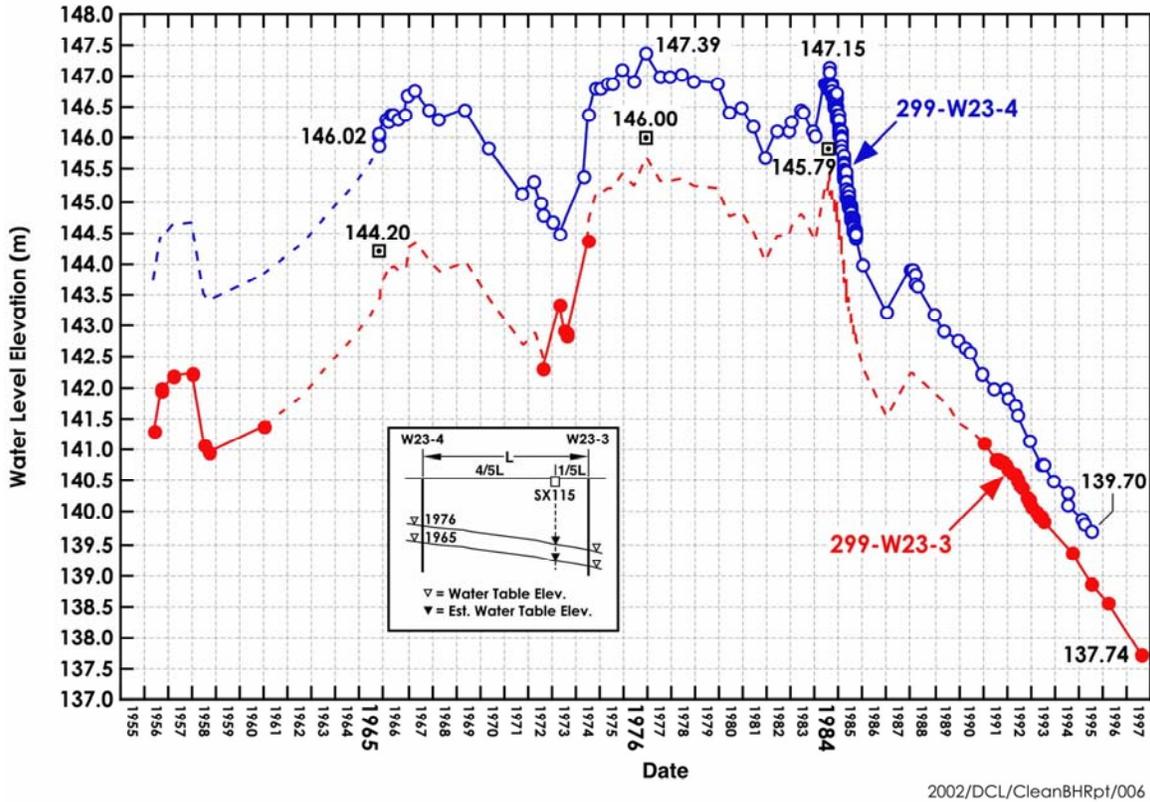


Figure 2.8. Historic Water Levels Beneath the SX Tank Farm

2.4 Geologic Characterization

The following sections describe the geologic characteristics for four composite sediment samples and two Resource Conservation and Recovery Act (RCRA) boreholes (299-W22-48 and -50) analyzed for this report, one of a four-part series of reports for the SX Tank Farm.

2.4.1 Composite Samples

Three surface outcrops or excavation sidewalls and one borehole on the Hanford Site were sampled to obtain large volumes of uncontaminated sediment that could be well homogenized for dispensing to Environmental Management Science Program (EMSP) and Science and Technology Program scientists across the country. A total of five composite samples were obtained from four sampling sites; only four of the five composite samples were analyzed for this report. The samples contained sediment that is somewhat representative of those underlying the S-SX Tank Farm including the following: 1) the White Bluffs, 2) the 218-E-12B burial ground, 3) the Environmental Restoration Disposal Facility (ERDF), and 4) borehole 299-W22-50. Geographic and stratigraphic information associated with the composite samples is summarized in Table 2.7.

All of the composite samples are from the Hanford formation (Pleistocene cataclysmic flood deposits), except for one sample of the lacustrine Ringold Formation from the White Bluffs. Detailed characterization data is reported herein for: (1) Ringold silt from the White Bluffs, (2) Hanford coarse sand, (3) Hanford fine sand from the 218-E-12B burial ground, and (4) borehole fine sand from a 34.5-foot-core interval in borehole 299-W22-50 from within the S-SX Waste Management Area. The fifth composite sample, collected from the ERDF excavation, was sent to Dr. Tetsu Tokunaga at Lawrence Berkeley National Laboratory for use in geohydrologic studies and no characterization is reported here.

2.4.1.1 White Bluffs Site

The White Bluffs occur along the eastern side of the Columbia River (see Figure 2.9). An exposed vertical face, toward the top of the bluffs, has been created by a road that cuts diagonally up the side of the bluffs. The roadcut conveniently exposes the sedimentary layers belonging to the upper Ringold Formation (member of Taylor Flat) and lower Plio-Pleistocene unit (PPlc). Three samples, one from each of the different sedimentary facies (Figure 2.10), were collected on January 11, 2000, into 5-gallon buckets. To date, only one of the samples (Ringold silt) has been characterized in detail. The relative stratigraphic position where this sample was obtained is shown in Figure 2.11.

Table 2.7. Composite Sediment Sample Descriptions

	White Bluffs	218-E-12B	ERDF	299-W22-50
Sample name	Ringold Silt	1) Hanford Coarse Sand 2) Hanford Fine Sand	Not characterized; therefore, no name given here	Borehole Fine Sand
Sample date	1/11/00	1/27/00	2/3/00	
Location	NE1/4 Sec. 11, T.13 N., R.27 E.	SE1/4 Sec 35, T.13 N., R.26 E.	NE1/4 Sec 7,T.12 N., R.26 E.	N134,139 E566,904
Surface elevation (ft amsl)	900	590	720	670
Sampling depth below top of stratigraphic sequence (ft)	~15	~25	~20	62.5 - 97
Stratigraphic unit/facies (depositional environment) sampled	Upper Ringold unit/ laminated silt (lacustrine)	1) Hanford formation/pebbly sand (cataclysmic flood) 2) Hanford formation/silty sand (cataclysmic flood)	Hanford formation/ sand (cataclysmic flood)	Hanford formation/sand (cataclysmic flood)
amsl = Above mean sea level bgs = Below ground surface				

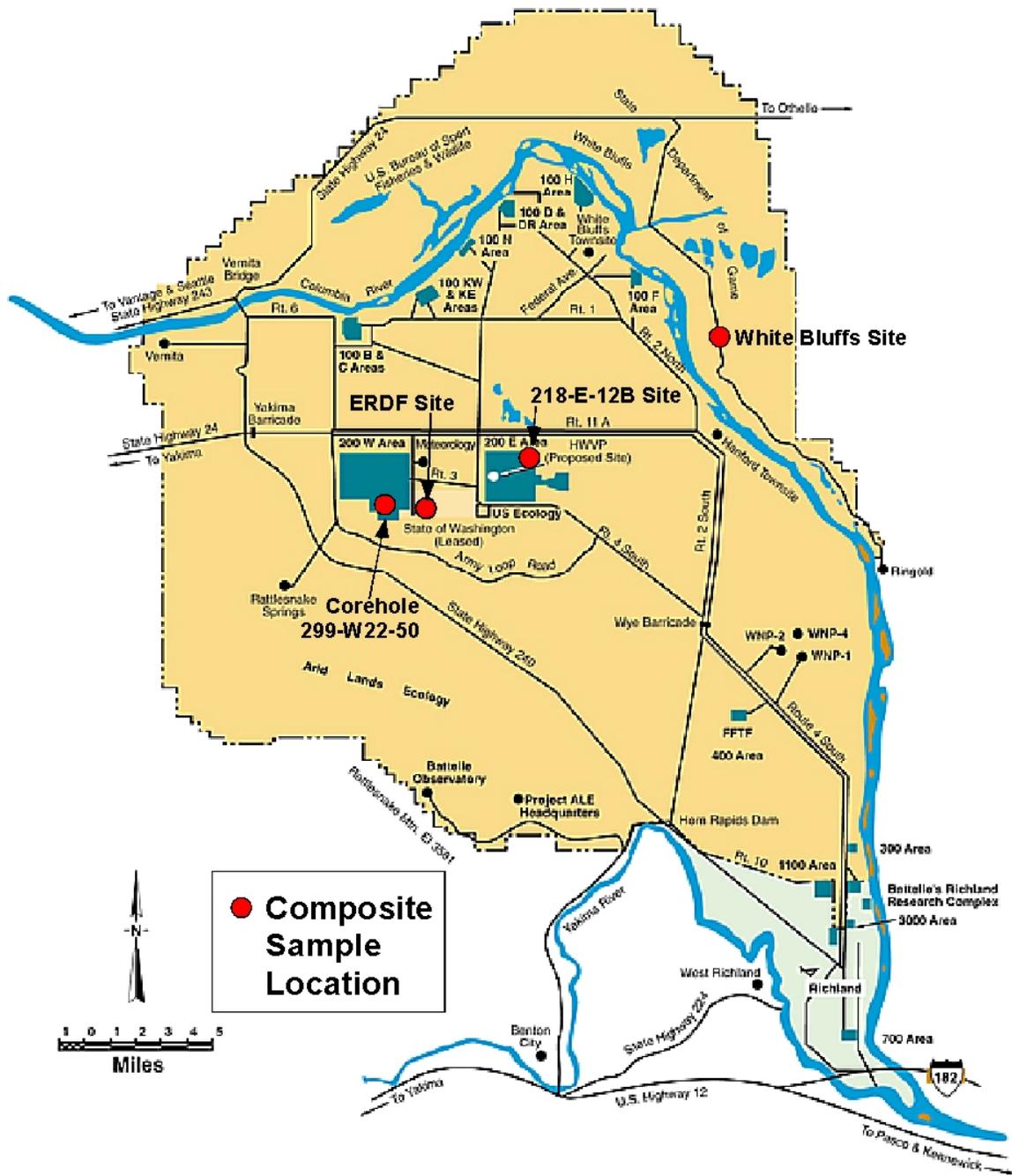


Figure 2.9. Locations for the Four Composite Sediment Samples

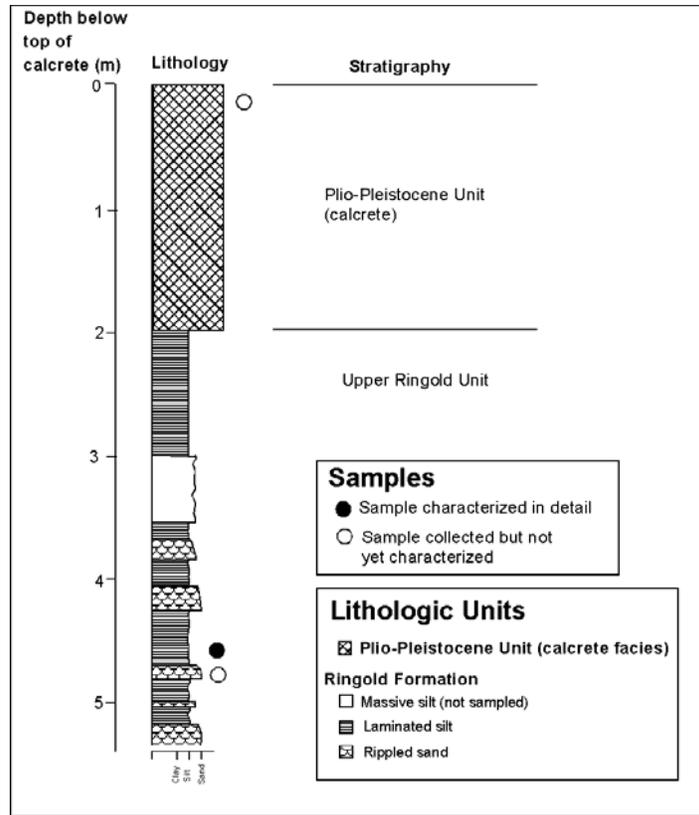


Figure 2.10. Stratigraphic Column of the Upper Portion of the White Bluffs Showing Sample Collection Depths. Samples were collected from a laminated silt and rippled sand within the Ringold Formation, as well as the calcrete cap. Only the Ringold laminated silt has been characterized in detail, thus far. Calcrete cap on the White Bluffs is likely equivalent to Plio-Pleistocene unit carbonate-rich horizon (PPlc) beneath the SX Tank Farm.



Figure 2.11. Location of Sample Collected from Lacustrine Laminated Silt of the Ringold Formation (Ringold Silt). Underlying rippled sand also was collected but not characterized for this study.

The laminated silt sample was characterized in detail and is the composite sample referred to as Ringold silt in the rest of the document. Silt from the Ringold Formation, similar to that at White Bluffs, is present locally within the 200 West Area, including S-SX Tank Farm, associated with the informal Ringold member of Taylor Flat unit (unit Rtf) within the vadose zone. Three 5-gallon buckets were filled with Ringold silt. The white-, gray-, and tan-colored Ringold silt sample is interpreted as lacustrine (i.e., lake environment) in origin, indicated by the continuous and finely laminated nature of these deposits. Layers of light-brown, rippled sand, interbedded with the laminated silt, are probable deltaic deposits that formed during flash-flood events from nearby streams that emptied into the lake that existed in the Pasco Basin during Pliocene time. The adjacent Ringold rippled sand (two 5-gallon buckets) is available for use but has not been characterized. Compared to the Pleistocene-age Hanford formation, where other composite samples were obtained, the Ringold silt is generally finer grained, displays more compaction, cementation, and/or alteration because of its much older age (late Pliocene, 3 to 4 million years ago).

2.4.1.2 218-E-12B Site

Near-surface samples of cataclysmic flood deposits (Hanford formation) were collected from the 218-E-12B burial ground excavation. The Hanford formation can be divided into three facies types: gravel-dominated, sand-dominated, and silt-dominated. Two samples, referred to in this document as Hanford coarse sand and Hanford fine sand (Figures 3.4 through 3.7), were collected and characterized in detail and are representative of the sand-dominated and silt-dominated facies, respectively, which underlie the SX Tank Farm. After the first batch of samples collected in January 2000 was exhausted, an additional forty 5-gallon buckets (20 each of the coarse and fine sand) were collected in May 2001.

Because of its proximity to high-energy flood channels, most of the 15 meters (50 feet) of cataclysmic flood deposits exposed at this site are coarse-grained sand and gravel associated with the gravel-dominated facies of the Hanford formation (Rhoads et al. 1992). About halfway down the exposure lie two beds of finer-grained sand and silt, separated by coarse-grained pebbly sand. Samples collected for characterization were collected from this fine-coarse-fine interval.

The two fine-grained layers vary in thickness and are associated with the slackwater flood deposition that occurred atop a set of giant current ripples during the waning stages of a late-Pleistocene cataclysmic flood (Lewis et al. 1993) (Figure 2.12). These fine-grained deposits were later buried during a subsequent cataclysmic flood.

Deposits are predominantly coarse sand and gravel. The exception is two layers of fine-grained sand and silt, which are draped over a series of buried, giant-current ripples. The upper fine-grained layer is thicker in the troughs (T) and thins along the crests (C) of the ripple train. Vegetation (brown) preferentially grows along the fine-grained layers, which retain more moisture. (Photo taken December 1992.)

Two facies types were sampled at the 218-E-12B site: (1) pebbly sand (referred to as Hanford coarse sand) and (2) silty sand (referred to as Hanford fine sand). These facies are representative of the



Figure 2.12. Series of Buried Giant Current Ripples at the 218-E-12B Site.

Hanford formation in the southern portions of the 200 East and 200 West Areas, where a higher ratio of sand and silt to gravel exists. The pebbly sand facies is predominantly a grayish brown, matrix-supported, medium to coarse sand with occasional pebbles floating in the matrix (Figure 2.13). Most of the pebbles are composed of basalt or caliche clasts. Sedimentary structures include well-developed horizontal laminations to planar-tabular cross bedding (see Figures 2.13 and 2.14).

The silty sand facies (see Figures 2.15 and 2.16), characterized and referred to as Hanford fine sand in this report, consists of two layers of moist, brown, laminated silty fine sand. Several feet of coarse-grained pebbly sand (Hanford coarse sand) separate the two fine-grained layers. The higher moisture content for this unit is the result of its finer particle size, which translates to a higher moisture retention capacity. Zones with higher moisture are directly associated with areas that support recent vegetation growth along the walls of the 218-E-12B trench (see Figure 2.12). Overlying the upper silty sand in sharp contact is a sandy gravel, which represents a high-energy, gravel-dominated flood facies, probably deposited during a subsequent flood. Deposits from the overlying sandy gravel were not characterized as



Figure 2.13. Example of Pebbly Sand Facies (referred to as Hanford Coarse Sand in this report) as it Appears In Situ. Horizontally laminated pebbly sand at the bottom is cut and filled with a layer of cross-bedded pebbly sand, above. Notebook for scale is 18 centimeters (7 inches) long. (Photo taken January 2000.)

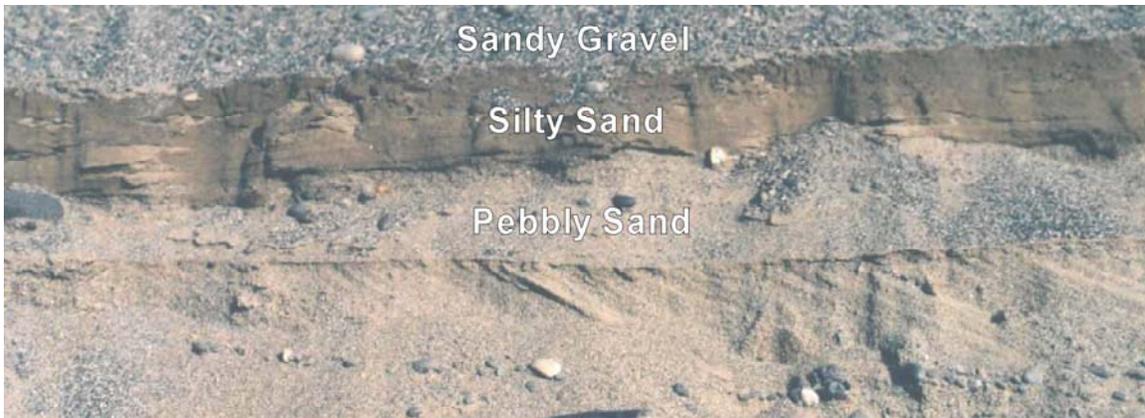


Figure 2.14. Representation of All Three Facies of the Hanford Formation at the 218-E-12B Site. Planar-tabular cross bedding in the pebbly sand facies indicates a paleoflood direction from left (west) to right (east). Stratigraphically, the pebbly sand (i.e., sand-dominated facies) lies directly beneath, and grades upward into, the upper silty sand layer (silt-dominated facies). The silty sand is overlain in sharp contact by sandy gravel (i.e., gravel-dominated facies) along an erosional unconformity. An unknown amount of the silty sand was probably removed prior to deposition of the overlying sandy gravel during a subsequent cataclysmic flood. (Note knife in the bottom center of photo for scale.) The Hanford coarse sand and Hanford fine sand, two samples characterized in detail for this report, came from the pebbly sand and silty sand layers, respectively. Note that the silty sand layer is darker due to its higher moisture content resulting from preferential absorption of meteoric recharge groundwater. (Photo taken January 2000.)



Figure 2.15. Lower Silty Sand Layer at 218-E-12B Site. Lower silty sand layer is sedimentologically identical to upper silty sand layer in Figure 3.6. (Photo taken May 2001.)



Figure 2.16. Samples Obtained for Detailed Characterization from the 218-E-12B Site. Left photo: collected with the aid of a lift and placed into 5-gallon buckets. Brownish layer at the same height as the shovel blade is the upper silty sand (Hanford fine sand); pebbly sand (Hanford coarse sand) was collected from the immediately underlying layer. Right photo: Example of how samples appeared after collection from the pebbly sand and silty sand facies. The pebbly sand (left bucket) is equivalent to the Hanford coarse sand and the silty sand (right bucket) is referred to as Hanford fine sand, both characterized in this report. (Photos taken January 2000.)

part of this study. These three facies occur together over a relatively short interval of several feet within the 218-E-12B excavation (see Figures 2.14 and 2.15). While layers of either flood gravel and sand, or sand and silt, are often observed together, it is rare to find all three facies occurring together in the same outcrop. Despite this rare occurrence, the pebbly sand and silty sand deposits preserved at the 218-E-12B site still appear to be representative of the sand- and silt-dominated facies, respectively, of the Hanford formation, which are more dominant in the southern portions of the 200 Areas beneath many of the tank farms, including the SX Tank Farm.

2.4.1.3 Environmental Restoration Disposal Facility Site

The ERDF site exposes up to 18 meters (60 feet) of predominantly sand-dominated facies (mostly fine- to medium-grained sand) of the Hanford formation. In contrast to the 218-E-12B site, sand-dominated cataclysmic flood deposits at ERDF are finer grained and formed farther from the flood channel ways. The sediment obtained at the ERDF site were sent to EMSP scientists at Lawrence Berkeley National Laboratory without any detailed characterization being performed at PNNL.

A total of twenty 5-gallon buckets of sediment were collected at the ERDF pit on February 3, 2000. Samples came from the base of a single graded bed (≥ 1 meter [3 feet] thick) within the flood sequence consisting of unconsolidated, horizontally laminated, fine- to coarse-grained sand at the base grading upward into a slightly pebbly sandy silt at the top (Figure 2.17). The moderately sorted sand has the characteristic salt-and-pepper appearance due to its mineralogy, which contains an abundance of dark basaltic grains (40% to 70%). Contrasting light-colored minerals include quartz, feldspar, mica, and caliche (i.e., cemented calcium carbonate) fragments (Fecht and Weekes 1996). Due to its relatively



Figure 2.17. Environmental Restoration Disposal Facility Sampling Site. Sampling was restricted to the sand-dominated facies of the Hanford formation. The horizontally laminated structure of the mostly medium-grained sand is apparent in the photo on the right.

young age (~13,000 years B.P.), the material is generally fresh and unweathered. The sampled bed was about 6 meters (20 feet) bgs along a road that cut diagonally down the side of the excavation. Several feet of sloughed surface material were removed with a shovel to expose the fresh, undisturbed sediment underneath for sampling. More detailed descriptions of the ERDF site are presented in Fecht and Weekes (1996) and Weekes et al. (1996).

2.4.1.4 Borehole Fine Sand

A fourth composite sediment sample, referred to as borehole fine sand, is a composite of all the sediment from the 299-W22-50 borehole core sleeves between the depths of 19 and 29.5 meters (62.5 and 97 feet), excepting one 0.3-meter (1-foot)-long sleeve between 25.9 and 26.2 meters (85 and 86 feet). The sleeve from 25.9 and 26.2 meters (85 to 86 feet) was previously reserved by hydrologists to perform hydraulic conductivity measurements on the intact sediment. The contents of twenty-seven, 10-centimeter (4-inch)-diameter sleeves were composited.

Based on a cursory, visual inspection, the 27 cores showed fairly uniform lithologic consistency, although thin stringers and bedding planes were frequently observed. The borehole fine sand consists of laminated, slightly silty medium- to fine-grained, sand represented between the 19 and 29.5-meter (62.5- and 97-foot) depth in Borehole 299-W22-50 (Figure 2.18). This borehole is located just southeast of the SX Tank Farm (Figure 2.2). The borehole fine sand composite sample is part of the Hanford formation H2 unit of the Hanford formation as described in Lindsey et al. 2000. This unit lies below the backfill and a gravelly zone directly underlying the SX Tank Farm. These strata contain much of the contamination currently found in the vadose zone sediment directly beneath leaking single-shell tanks in the S-SX Tank Farm; therefore, this composite sample is very representative of the Hanford formation in this area. A more detailed discussion of borehole 299-W22-50 is presented in Section 2.4.2.2.

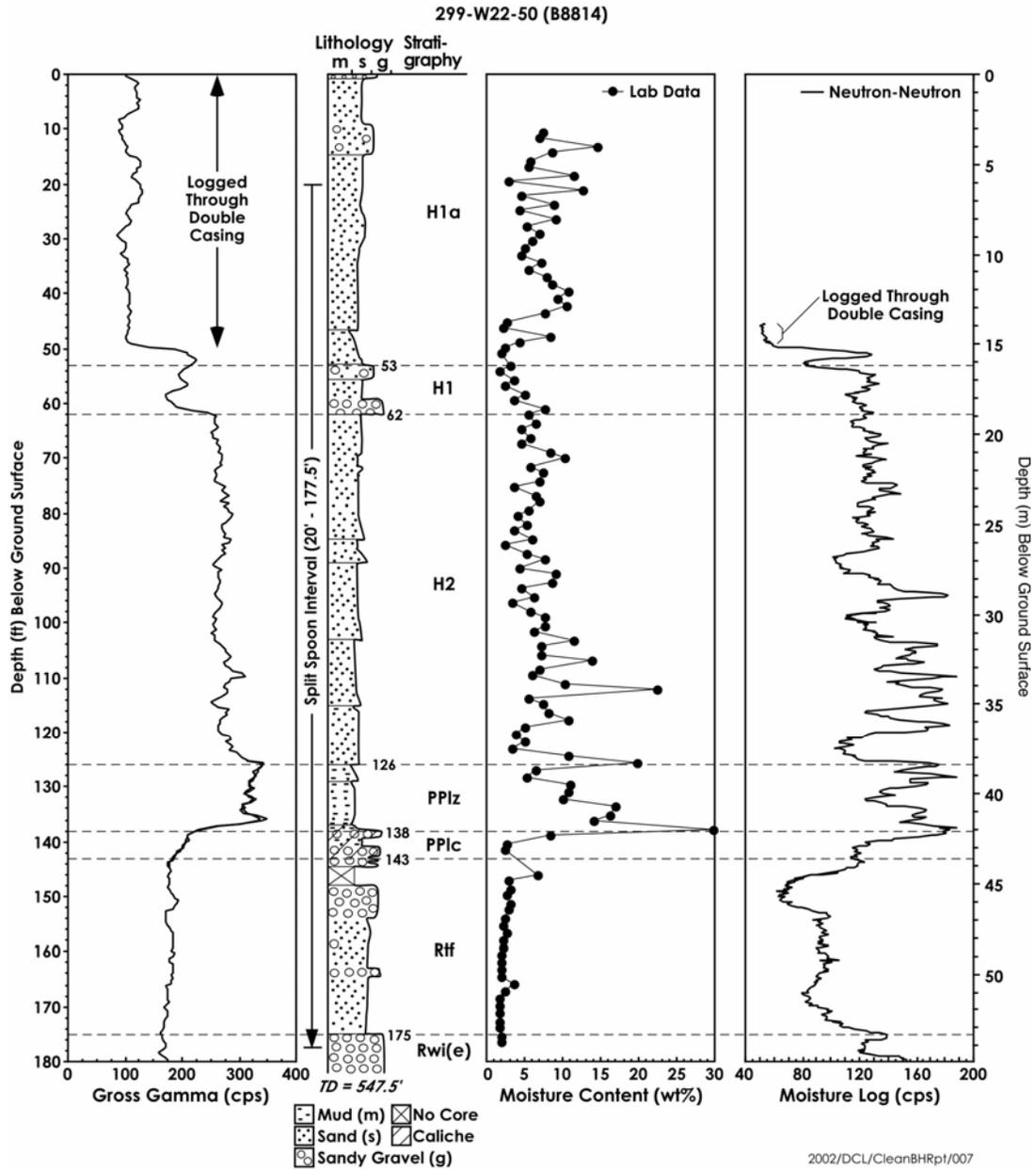


Figure 2.18. Vadose Zone Stratigraphy for Borehole 299-W22-50. See Figure 2.2 for borehole location.

2.4.2 Geologic Characterization of Clean Boreholes

This section describes the borehole locations, drilling, sediment sampling, borehole geophysical logging, and geologic characterization for clean boreholes 299-W22-48 (B8812) and -50 (B8814). These boreholes (locations in Figure 2.2) were drilled as part of an integrated effort to (1) collect intact subsurface core samples for detailed vadose zone characterization and (2) installation of downgradient RCRA groundwater monitoring wells in the uppermost-unconfined aquifer, and (3) create a composite

sample (i.e., borehole fine sand discussed in previous section) for geochemical characterization. Additional well completion, aquifer testing, and water sampling information and results are reported in Horton and Johnson (2000).

The vadose zone portions of these boreholes were drilled using the core- (drive-) barrel cable-tool technique wherever possible. The boreholes were drilled without the aid of drilling fluids such as water or mud, unless noted in the logs, to minimize the introduction of artificial moisture into the sediment samples and core. The lower portion of 299-W22-50 (i.e., below the water table) was drilled using the air rotary technique. After drilling but prior to well construction, the boreholes were geophysically logged with spectral gamma (total gamma and potassium, uranium, thorium [KUT]) and neutron-neutron (moisture) probes.

Borehole sampling consisted of near continuous split-spoon coring and/or sediment grab sampling throughout the borehole. Sediment cores were collected by driving a 10-centimeter (4-inch)-diameter by 76-centimeter (2.5-foot)-long split-spoon sampling device ahead of the drilled borehole. The borehole was then cleaned to the bottom of the cored interval prior to sampling the next interval. Split-spoon core refusal occurred within the Ringold Formation gravel facies (Rwi[e]) in both wells; cable-tool drilling continued to at least the water table using the hard-tool bit. The split-spoon cores are contained in either 15-centimeter (6-inch) or 30-centimeter (1-foot)-long, transparent, Lexan core barrel liners (core sleeves). Core recovery was nearly 100%. All cores were sealed and labeled in the field and transported in ice chests to PNNL's characterization laboratory in the 3720 Building (300 Area) for refrigerated storage and further sampling and analysis.

In addition to Lexan-lined core samples, sediment grab samples were collected in the field from cuttings recovered during drilling and/or from the split-spoon drive shoe. Several types of samples were labeled and contained from each sample interval. Samples for geologic descriptions were collected in 2.5-centimeter (1-inch) plastic chip-sample trays from surface to total depth. With the exception of the drive shoe grab samples, most of the grab samples are composite samples composed of sediment that are churned up and mixed during the drilling and sampling process.

Lexan-lined cores provide the most representative intact samples of the subsurface available and the core depth intervals are believed to be accurate to within 15 centimeters (0.5 foot) of actual depth. Geophysical logs were used to verify contacts. Fine sediment structure and subtle facies variations are usually well preserved in the split-spoon cores. In the laboratory, the Lexan liners were cut lengthwise with a saw and the core split into two slabs or halves. Subsamples for physical and geochemical characterization were collected from the middle (inside) of these core slabs.

Photographs were taken after opening each core. Often some downward sediment deformation (drilling-induced drag) was observed (up to 2.5 to 5 centimeters [1 to 2 inches]) along the outside surface of some of the cores. Grab samples are less representative of subsurface lithology and sample depth accuracy can be limited to ± 1.5 meters (5 feet), depending on the length of the cable-tool core barrel. Lithologic structure and contact boundaries may not be as easily identified with grab samples.

A field geologist prepared a geologic description (lithologic log) during drilling and coring of the boreholes (Appendix A). These lithologic log descriptions are based on visual inspection of material from the split- spoon core shoe, drill cuttings, and the grab samples. These logs provide a general indication of the lithology encountered. In addition to these field descriptions, a more rigorous and detailed analysis of the vadose-zone stratigraphy was performed by geologists in the laboratory, based on cores observed within opened Lexan liners. Appendix B provides the borehole geologic log for 299-W22-48, which was created based on an examination of every third or fourth intact split- spoon core (opened in the laboratory). Table 2.1 provides the generalized stratigraphic nomenclature used in the correlations. All depths and correlations reported in this section are rounded to the nearest tenth of a meter (.33 foot).

Borehole geophysical surveys were conducted after the boreholes reached total depth and before well construction. A spectral gamma probe was run from total depth to the surface at a rate of 30 centimeters (1 foot) per minute (15-centimeter [6-inch] sampling interval) and a neutron-neutron moisture probe was run from the water table to the surface, at a rate of 30 centimeters (1 foot) per minute (7.6-centimeter [3-inch] sampling interval). Geophysical log profiles for each of the two boreholes are attached in Appendix C. Prior to opening the Lexan-lined cores, geophysical profiles were evaluated for lithostratigraphy, moisture content, and manmade radionuclides. Core subsamples for chemical and physical analysis were collected from specific lithologic intervals as identified from the geophysical and lithologic log evaluations (lithostratigraphy) confirmed by the geologic examination during core opening.

Spectral gamma logs provide a continuous record of the naturally occurring gamma radioactivity emitted from formations encountered in the borehole. In addition, the spectral gamma logs can be evaluated to determine the presence of specific manmade gamma-emitting radionuclides. The gamma-log data is plotted as a continuous curve versus depth, which is referenced to ground surface. This reference can be used to correlate lithologic changes and depth to within 0.5 meters (1 or 2 feet). Gamma-log changes are related to the grain size, mineralogical makeup, and moisture content of the lithofacies encountered. Thin lithologic units (<0.5 meters [1.5 feet]) cannot be easily identified by the gamma logs because they are averaged into the data bounding them.

The neutron-neutron log is also referenced to ground surface and represents a function of relative moisture content (Figure 2.18, Appendix C). Depth resolution can be determined to within 0.3 meters (1 foot). In combination with the geologic log and the total gamma type log, the neutron moisture data can reveal moisture relationships relative to lithologic unit boundaries and grain size (assumes fine-grained intervals retain higher moisture content than coarse-grained intervals). For example, the neutron-moisture curves may display peaks of elevated moisture, which correspond to fine-grained silt and/or sand lenses, and/or lithologic contacts with contrasting grain-size boundaries. Anomalously high moisture intervals signal areas that may be influenced by artificial recharge. These areas are good targets for follow-up sampling and analysis if intact cores are preserved.

2.4.2.1 Borehole 299-W22-48

Borehole 299-W22-48 is located ~135 meters (443 feet) east of tank 110 (S Tank Farm) and ~100 meters (328 feet) north of the SX Tank Farm (see Figure 2.2). UTM coordinates are 566,996.641 east and 134,425.096 north [datum is NAD83 (91)]. Land surface elevation is 207.132 meters (679.567 feet) above msl.

Vadose zone sediment samples obtained for borehole 299-W22-48, along with 299-W22-50, are considered the most comprehensive and representative for the S-SX Tank Farm. Stratigraphic interpretations are based on data from a near continuous intact core, laboratory parameter analysis from selected intact core samples, continuous geophysical gamma and neutron logs, and field data.

This borehole was drilled using the core barrel cable-tool technique, wherever possible. Total depth of the borehole is 76 meters (249 feet) bgs. The water table was encountered at ~69 meters (226 feet) bgs. The borehole was completed as a well in December 1999; it is composed of a 10-centimeter (4-inch)-diameter well casing with a 4.6 meter- (15-foot)-long well screen placed at the water table (see also Horton and Johnson 2000).

Continuous split-spoon coring occurred from ground surface to a depth of 59 meters (193.5 feet) and grab samples were collected at ~1.5-meter (5-foot) intervals throughout the drilling and coring of the borehole. Split-spoon core refusal occurred at 59 meters (193.5 feet). For this interval, 197 core sleeves (132 6-inch-long sleeves and 65 12-inch-long sleeves), each with nearly 100% recovery, were produced. The depths and identification number of the individual core sleeve is summarized in Appendix E. In addition to these samples, eight grab samples of cuttings were collected at 1.5-meter (5-foot) intervals from 59 through 70 meters (195 through 230 feet) bgs. The lithologic log in Appendix A also provides a borehole profile that illustrates the depth of each of the recovered split-spoon cores.

Moisture grab samples were collected, and sealed in moisture tins, at least every 1.5 meters (5 feet) from the split-spoon drive shoe between depths of ~3 to 58.5 meters (~10 feet to 192 feet) bgs. Archive samples were collected every 1.5 meters (5 feet) below the cored interval from 58.5 meters (192 feet) to total depth (76 meters [249 feet]) and are contained in labeled, 1-pint glass jars.

Appendix C contains the geophysical logs for borehole 299-W22-48. The only apparent manmade radionuclide identified by gamma logging in this borehole is cesium-137, which is located within a meter (3 feet) of the surface at a concentration of 5 pCi/g. This is interpreted as surface contamination, which is a common occurrence around the tank farms. The lithologic log was used as a guide to evaluate the total gamma log for lithology (Figure 2.19).

Beginning from 3 meters (10 feet) bgs, two distinct coarse-grained intervals (gravelly sand to gravel) were identified within relatively uniform medium-grained sand, one at 12.5 to 15 meters (41 to 50 feet) (Figure 2.20), and the second from 17.5 to 18.5 meters (58 to 61 feet). The gravelly interval(s) also are identified in surrounding vadose boreholes and wells based on geophysical log correlations (see Sobczyk 2000) but have not been easily or clearly identified in the geologic grab samples. The base of the lower gravelly unit correlates with the base of Lindsey's Hanford formation H1 unit.

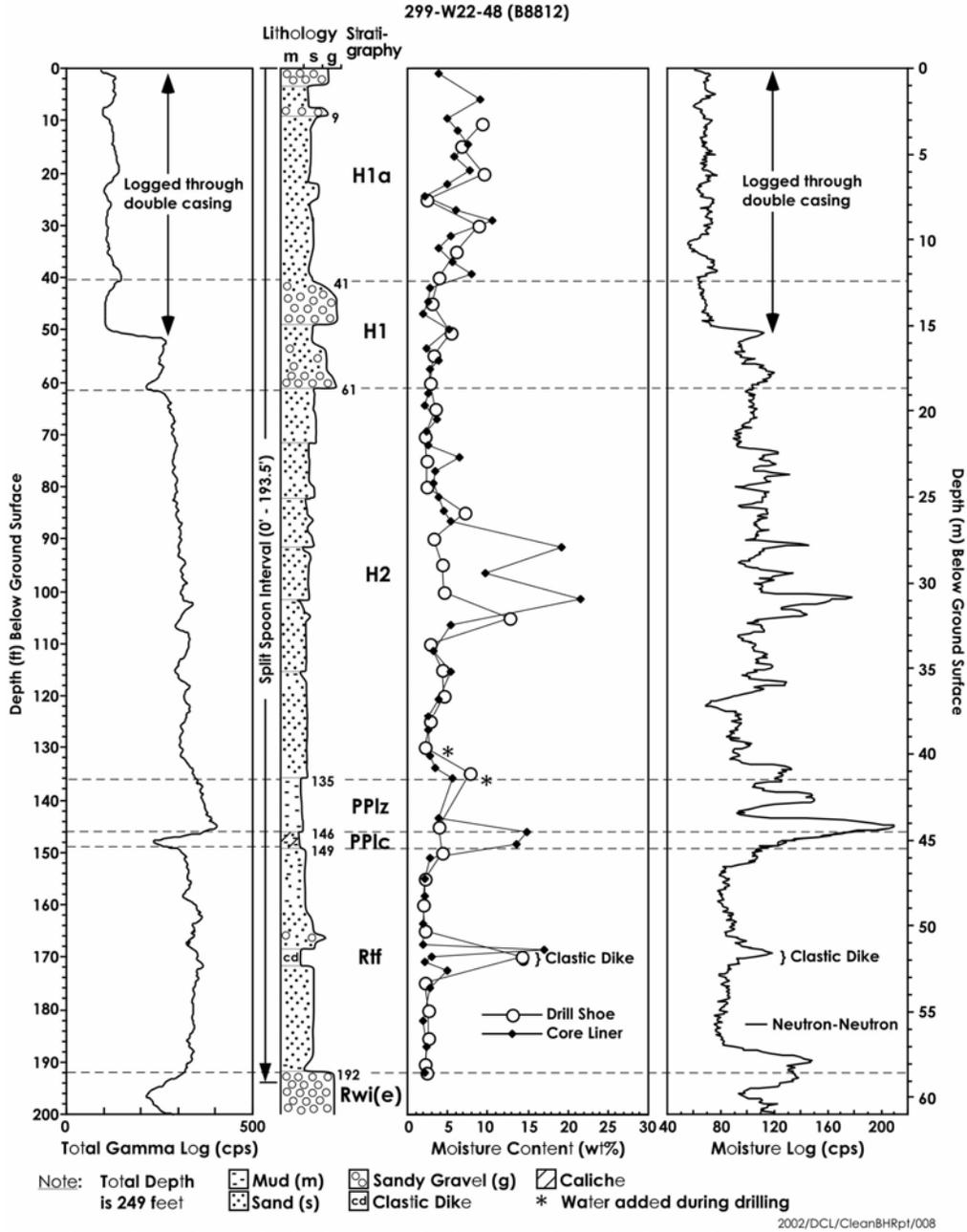


Figure 2.19. Vadose Zone Stratigraphy for Borehole 299-W22-48. See Figure 2.2 for borehole location.

The gravelly units are believed to be a key geologic control for the vertical and lateral dispersion of liquid effluent leaking from beneath the S-SX Tank Farm. The Vadose Characterization Project's geophysical spectral logging campaign provides the data to corroborate this. Many of the vadose-zone boreholes logged within the S-SX Tank Farm have high levels of cesium-137 contamination associated with this coarse-grained unit (Johnson and Chou 1998, Sobczyk 2000). Below the Hanford formation H1 unit is fine- to medium-grained sand (Figure 2.21), which decreases slightly in grain size with depth.

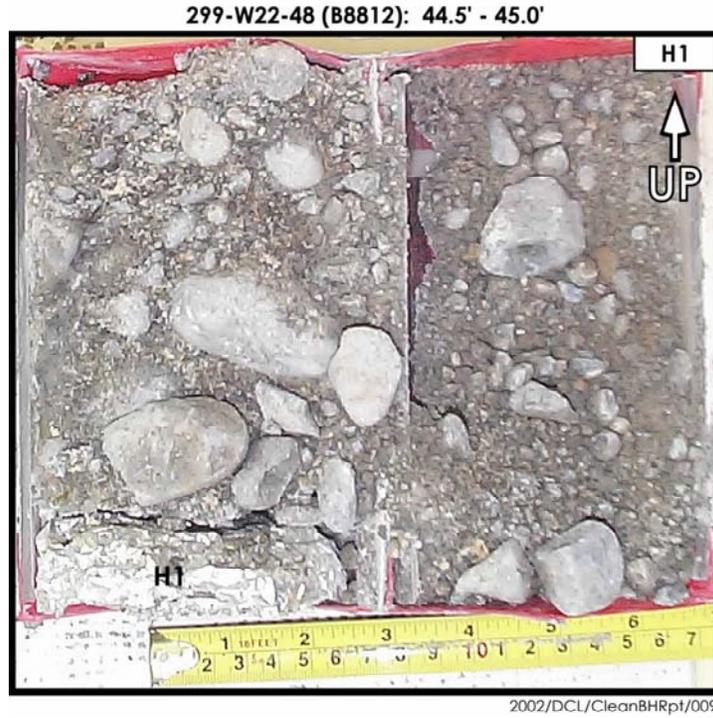


Figure 2.20. Split-Spoon Sample from Within Coarse-Grained Hanford Formation H1 Unit in Borehole 299-W22-48.



Figure 2.21. Split-Spoon Sample from Within Hanford Formation H2 Unit in Borehole 299-W22-48.

This unit is correlated as the Hanford formation H2 unit, which is interpreted to occur between 18.5 to 41 meters (61 to 135 feet) bgs. The next notable change in the gamma logs occurs from 41 to 44.5 meters (135 to 146 feet) bgs. This easily recognizable and characteristic gamma increase reflects a downward decreasing grain size from silty sand to silt (Figure 2.22). This unit represents a gradational coarsening upward contact between the Plio-Pleistocene mud (PPlz) subunit and younger, coarser-grained, cataclysmic flood deposits of the overlying Hanford formation.

The distinctive Plio-Pleistocene carbonate-rich sequence (PPlc), correlates to a thin interval between 44.5 to 45.4 meters (146 to 149 feet) bgs (Figures 2.23). More discussion is provided on the correlation of this unit below. The reduced gamma signal beginning at 58.5 meters (192 feet) bgs identifies the top of the Ringold Formation Unit E (Rwi[e]) as a silty sandy gravel interval (Figure 2.24).

The interval between the PPlc subunit and the top of the Rwi(e), between 45.4 to 58.5 meters (149 to 192 feet) bgs, is described as fairly uniform slightly silty sand (Figure 2.25) and correlates to the upper Ringold unit or Ringold member of Taylor Flat (Rtf).



Figure 2.22. Split-Spoon Sample from Within Plio-Pleistocene Mud (PPlz) Subunit in Borehole 299-W22-48.

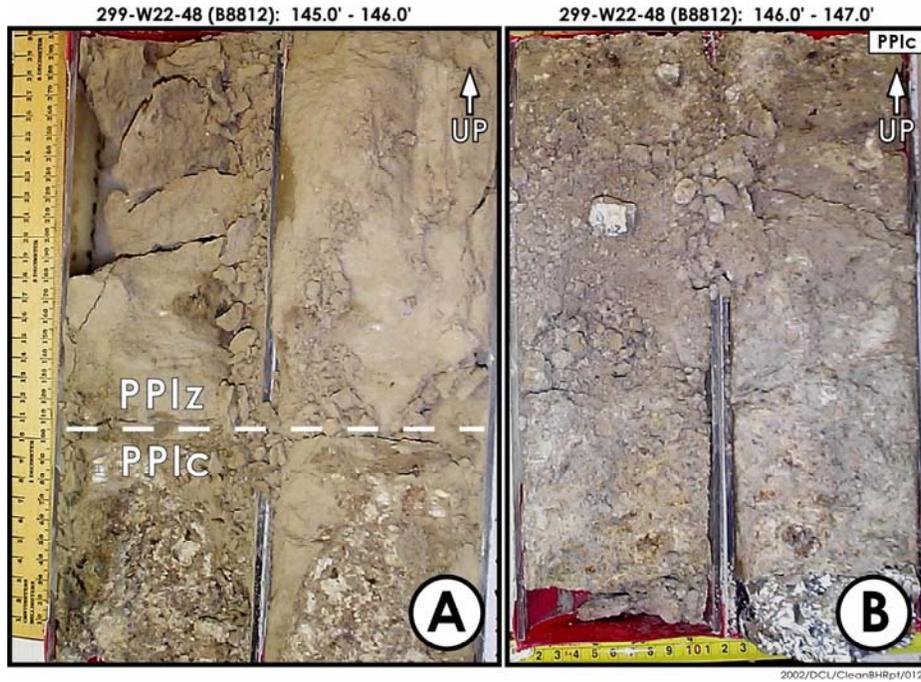


Figure 2.23. Split-Spoon Samples Representing a) Plio-Pleistocene Mud (PPIz) and Plio-Pleistocene Carbonate (PPIc) Subunits Contact (white dashed line), and b) Plio-Pleistocene Carbonate (PPIc) in Borehole 299-W22-48.

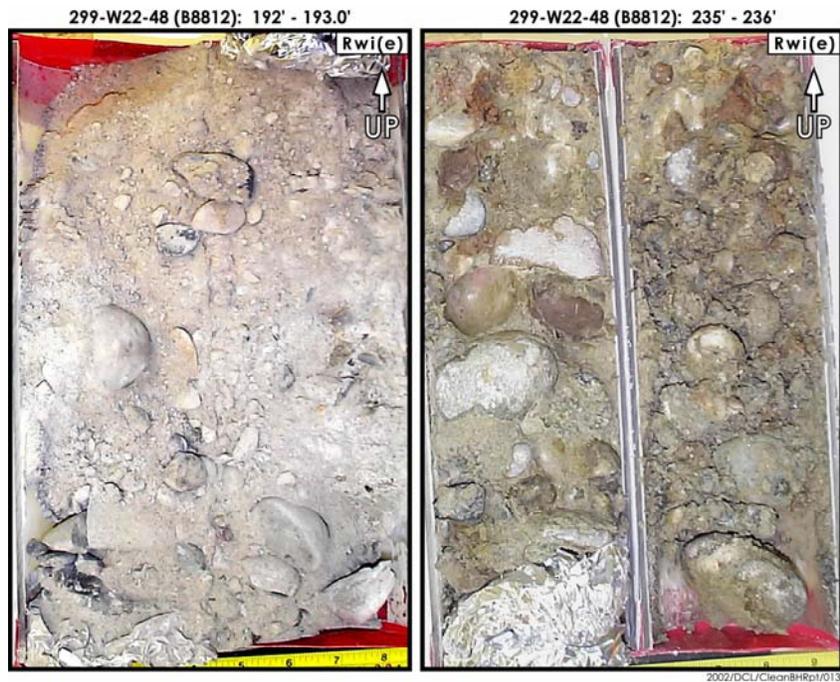


Figure 2.24. Split-Spoon Samples Representing Ringold Formation Unit E (Rwi[e]) in Borehole 299-W22-48.



Figure 2.25. Split-Spoon Sample Representing Upper Ringold Formation (Rtf) in Borehole 299-W22-48.

The addition of the neutron moisture data to the interpretation resulted in some additional observations and features. Due to the dual surface casing in borehole 299-W22-48, only the moisture data between 15.5 meters (51 feet) depth and the water table (69.3 meters [227.5 feet]) are calibrated and are representative of borehole moisture conditions. That is, the neutron moisture probe is not calibrated for conditions where two layers of metal casing are present. Based on the calibrated interval (15.5 to 69.3 meters [51 to 227.5 feet]) the average overall moisture content in borehole 299-W22-48 is less than 5% (by volume). This average moisture probably represents the natural background moisture for the units encountered and indicates that the vadose zone has a relatively low moisture content at this location. A few minor peaks, averaging about 2.5% higher than the background, are in the sand interval between about 21 to 36.5 meters (70 to 120 feet); these probably represent alternating laminae and beds of fine sand and silt, which possess varying moisture-retention properties (e.g., Figure 2.26). One larger peak (10% moisture) located at 31 meters (102 feet) bgs was also recorded in the field geologists' log as a bedding contact, which is also visible on the gamma log (Figure 2.19). Anomalously high moisture intervals between 36.5 and 42.5 meters (120 and 140 feet) bgs may correspond to zones where it was



Figure 2.26. Split-Spoon Sample Illustrating Contrasts Within the Hanford Formation H2 Unit. Laminated, darker, high-moisture retention silt occurs at bottom, in contrast to fine sand at top.

necessary to add water to the borehole during drilling. The PPlc subunit between 45.4 to 58.5 meters (146 to 149 feet) bgs displays a characteristic inverse relationship between the total gamma and neutron-neutron geophysical logs.

The contact with Rwi(e) (silty sandy gravel interval) unit also can be correlated to the increase in moisture at 58.5 meters (192 feet) bgs. Moisture values increase anomalously from 66 meters (216 feet) bgs to the water table at 69 meters (226 feet) bgs (see neutron-neutron log in Appendix C). This increase may be due to previously saturated Ringold sediment (when the water table was higher during high liquid waste disposal periods) that are now draining and, thus, have a higher overall residual moisture content than overlying Ringold sediments that have not been completely saturated.

A discordant clastic dike was intersected near the 52-meter (171.0-foot) depth in borehole 299-W22-48 within a sandy sequence of the upper Rtf unit (Figure 3.11). The dike completely fills one core sleeve (Figure 2.27) and partially fills the underlying core sleeve. The dike, up to 0.75 meter (2.5 feet) thick, is characterized by vertical to subvertical laminations alternating between olive clay and silt to pale yellow silt and sand. Dike laminations are weakly to strongly calcareous. The dike contains a distinctly higher moisture content (~15 wt%), as corroborated on the neutron-neutron geophysical log, yet is only slightly elevated on the total gamma log (see Figure 2.19).

Clastic dikes, which are usually associated with cataclysmic ice-age flood deposits of the Hanford formation, are sometimes reported in underlying stratigraphic units, including the Ringold Formation (Fecht et al. 1999). Of particular significance is the fact that this clastic dike lies 10.7 meters (35 feet) below the base of the flood deposits and 6 meters (20 feet) below the indurated Plio-Pleistocene caliche (PPlc) unit (see Figure 2.19). While it is possible this dike is connected with Pleistocene cataclysmic flooding, the possibility also exists that the dike is of Ringold age and occurred prior to ice-age flooding. If the dike formed during Pleistocene time, the implication is that clastic dikes (i.e., preferential pathways) might be connected from the near surface to the water table beneath the southern portion of the 200 Area's Plateau. Alternatively, if the dike is Ringold in age, it is probably truncated along the overlying Plio-Pleistocene unit and/or Hanford formation boundaries.

To identify the relative age and origin of the dike, as well as any possible manmade contaminants present, detailed sampling and measurements will be performed for grain size, mineralogy, major and trace element composition, and paleomagnetic field orientation of the dike and immediately adjacent material. The hydraulic properties of the cored dike material will also be measured.

2.4.2.2 Borehole 299-W22-50

Well 299-W22-50 is located ~25 meters (82 feet) southeast of the southeast corner of the S-SX Tank Farm fence (see Figure 2.2). UTM coordinates are 566,904.261 east and 134,139.756 north [datum is NAD83 (91)]. Land surface elevation is 204.14 meters (669.75 feet) above msl.

This borehole was drilled from the surface to 73.5 meters (241 feet) bgs using the core-barrel cable tool technique and from 73.5 to 167 meters (241 feet to 547.5 feet) bgs using the air rotary technique. Total depth was 167 meters (547.5 feet) bgs. The water table was encountered at ~67 meters (219 feet) bgs. The borehole was completed as a well in January 2000; it is composed of a 10-centimeter (4-inch)-diameter well casing with a 4.6 meter (15-foot)-long sampling screen placed at the water table (see Horton and Johnson 2000).



Figure 2.27. Upper Portion of Subvertical Clastic Dike Completely Filling Core Liner Within Ringold Formation from 51.4 to 51.7 Meters (168.5 to 169.5 feet) bgs.

Borehole sampling consisted of near continuous split-spoon coring from ~6 meters (20 feet) bgs to a depth of 54 meters (177.5 feet) bgs and sediment grab samples collected at ~5-foot intervals throughout the drilling and coring of the borehole. Split-spoon core refusal occurred at 54 meters (177.5 feet) bgs atop Ringold Formation Unit E (Rwi[e]); cable-tool drilling continued below this depth with a hard-tool bit to ~74 meters (243 feet) bgs. Drilling continued with the air rotary technique to total depth (166.9 meters [547.5 feet] bgs). Within the split-spoon cored interval, 124 Lexan core sleeves (30-centimeter [12-inch] liners) were recovered. The depths and identification number of the individual core sleeves are summarized in Appendix F. The lithologic log in Appendix A also provides a borehole

profile that illustrates the depth of each of the recovered split-spoon cores. Archive grab samples were collected at ~1.5-meter (5-foot) intervals from surface to 6 meters (20 feet) bgs and below the cored interval, from 55 meters (180.5 feet) to total depth (166.9 meters [547.5 feet] bgs).

Lindsey et al. (2000) provides a detailed discussion and geologic log for 299-W22-50. The geophysical logs for this borehole are presented in Appendix C. Stratigraphic, lithologic, and geophysical-log information is summarized in Figure 2.18. The only manmade radionuclide identified by gamma logging in borehole 299-W22-50 is cesium-137, which is located at the surface at a concentration of 19 pCi/g. This radioactivity is likely surface contamination from nearby tank farm operations.

The total gamma log reflects the lithology, which for the Hanford formation is mostly sand. An exception is a relatively coarse-grained unit (gravelly sand) at a depth between 2.4 and 4.3 meters (8 and 14 feet) bgs. This unit, also noted in the lithologic field log, belongs to a coarse facies of the Hanford formation H1a unit (Lindsey et al. 2000). Another coarse-grained facies, defined as sandy gravel in the lithology log, is present between 16 and 19 meters (53 and 62 feet) bgs and represents the Hanford formation H1 unit (Figure 2.28). This gravelly interval is thinner in this borehole but can be correlated to a comparable coarse-grained interval in surrounding vadose boreholes (Sobczyk 2000), including borehole 299-W22-48 (Figure 2.19). The base of the gravelly unit at 19 meters (62 feet) bgs defines the base of the Hanford formation H1 unit.



Figure 2.28. Split-Spoon Sample of Sandy Gravel from the Hanford Formation H1 Unit.

The underlying Hanford formation H2 unit, which occurs between a depth of 19 to 38.5 meters (62 to 126 feet) bgs, is predominantly medium-grained sand (Figure 2.29), which decreases slightly in grain size with depth (see Figure 2.18).



Figure 2.29. Split-Spoon Sample from Within Hanford Formation H2 Unit in Borehole 299-W22-50.

The contact between the Hanford formation and the underlying Plio-Pleistocene unit occurs at or near 38.5 meters (126 feet) bgs based on a decrease in grain size, accompanied by an increase in total gamma activity, and an abrupt increase in moisture content. The upper Plio Pleistocene unit (Figure 2.30), equivalent to the Plio Pleistocene Mud (PPlz) subunit, occurs from 38.5 to 42 meters (126 feet to 138 feet) bgs (Figure 2.18), while the lower Plio-Pleistocene unit (PPlc) lies between 42 and 43.6 meters (138 and 143 feet) bgs.

299-W22-50 (B8814): 133.5' - 134.5'



2002/DCL/CleanBHRpt/019

Figure 2.30. Split-Spoon Sample from Within Upper Plio-Pleistocene Subunit (PPlz) in Borehole 299-W22-50.

The contact between the loose PPlz and carbonate-cemented PPlc subunits is sharp and distinct (Figure 2.31). Unlike the carbonate-rich horizon in 299-W22-48, which is developed exclusively in fine-grained sediment, pedogenic carbonate in 299-W22-50 appears to be overprinted and developed onto a gravelly lag deposit of the Ringold Formation. Below the PPlc subunit, from 43.6 to 53 meters (143 to 175 feet) bgs, are quartzofeldspathic sands and gravels of the upper Ringold (Rtf) unit. The top of the Rwi(e) silty sandy gravel is defined as the top of a relatively thick gravel sequence accompanied by an increase in moisture on the neutron-neutron log starting at 53 meters (175 feet) bgs (see Figure 2.18).

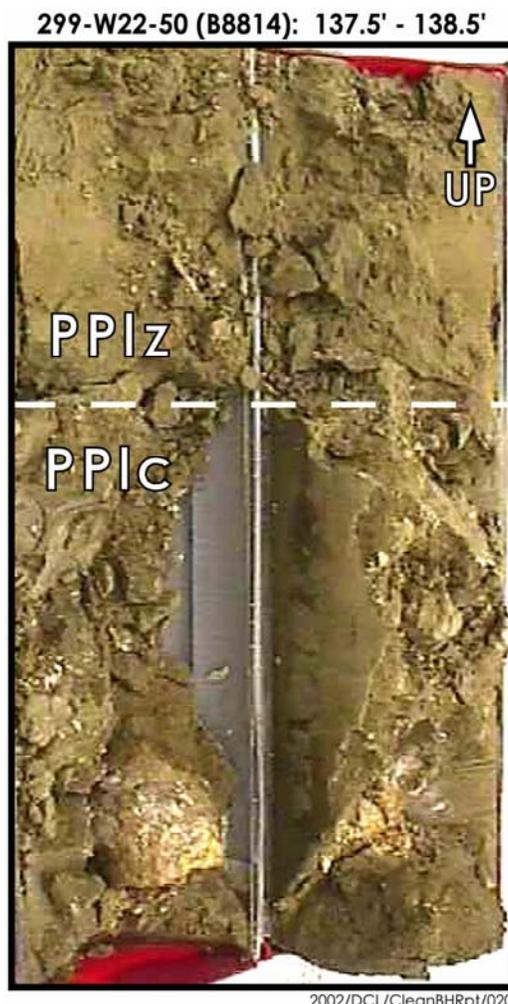


Figure 2.31. Split-Spoon Sample Containing the Contact Between the Plio-Pleistocene Mud (PPlz) and Carbonate (PPlc) Subunits in Borehole 299-W22-50. The PPlz unit is composed of loose, variably calcareous, overbank-eolian fine sand and silt while the PPlc unit consists of calcium carbonate cemented muddy sandy gravel.

The addition of the neutron moisture data to the interpretation resulted in some additional observations and features. Due to the dual surface casing in borehole 299-W22-50, only the borehole below 15 meters (50 feet) to the water table (66.5 meters [218.3 feet]) was logged and calibrated. Within the logged interval, the average overall moisture content in borehole 299-W22-50 is slightly higher than that found in 299-W22-48. Logged moisture between 29 to 38 meters (95 to 124 feet) bgs, is anomalously high, by comparison to the same interval in 299-W22-48. Peaks in moisture are twice as high as the apparent background values at 299-W22-48, suggesting more moisture in the vadose zone in this area. Relatively high moisture occurs in the lower portion of the Hanford formation H2 unit below ~27 meters (90 feet) and the Plio-Pleistocene unit down to a depth of ~43 meters (140 feet) bgs. Similar to borehole 299-W22-48, the top of the carbonate (PPlc) in borehole 299-W22-50 is characterized by a sudden decrease in total gamma activity and an increase in neutron-neutron moisture (see Figure 2.18).

3.0 Characterization Analytical Methods

3.1 Post Sampling Sediment Preparation

Preparation and processing of sediment samples, performed prior to analysis in the laboratory, is discussed in this section.

3.1.1 Composites

The four composite samples were spread out on polyethylene tarps inside a large empty room in the laboratory. After air drying for several days, the sand composites were individually mixed by repeated cone and quartering. A few root hairs and small pieces of organic matter were removed by handpicking from the Hanford coarse sand and Hanford fine sand composites. The Hanford coarse sand composite is comparable to the Hanford formation H1a (coarse facies) unit while the Hanford fine sand is comparable to the Hanford formation H1a (fine facies) and H2 units in the SX Tank Farm geologic model presented in Section 2.2. The Ringold silt composite sample air dried into hard aggregates. These aggregates were crushed with a flat-ended tamper until all the aggregates were disaggregated particles smaller than 2 millimeters. The Ringold silt was then mixed several times using the cone and quartering method. These three composites were not sieved. However, the air-dried borehole fine sand was dry sieved through a 2-millimeter sieve. Out of a total air-dry weight of 68,170 grams, 270 grams of coarse (>2-millimeter) particles were discarded to make this composite conform to traditional soil scientists' sample protocol. The >2-millimeter particles represented only 0.4% of the air-dried material; thus, there should be very little difference in the properties of the Hanford fine sand and the borehole fine sand composites caused by the removal of >2 millimeters of material from the latter composite.

The air-dried composite samples were then stored in 5-gallon plastic buckets until needed. Each time an aliquot was needed the whole contents of one 5-gallon bucket was spread on a polyethylene tarp and the entire sample remixed by cone and quartering with small aliquots taken randomly out of each quarter of the mixed sample.

3.1.2 Borehole Core Samples

The samples that were characterized from the two Resource Conservation and Recovery Act (RCRA) boreholes (299-W22-48 and -50) were obtained during the geologic description process immediately upon opening the sealed liners. The split-spoon samples were obtained in clear, plastic Lexan liners that were either 6 or 12 inches long. Plastic end caps were removed, and the liners were cut down both sides with a circular saw. The core was opened in a fashion similar to opening a clam shell, facilitated by the relatively unconsolidated nature of the sediment. The two halves of the liner were laid on a table and quickly subsampled to avoid excessive loss of moisture. Small aliquots were removed from the halves of sediment in an attempt to construct a representative sample for the entire sleeve. When distinct contacts

were observed in a core sample, the sampling was performed separately on the different lithologies. After sampling and geologic description was completed, the two halves of the liner were reassembled and retaped to prevent further disturbance or escape of moisture. Liners were then returned to refrigerated storage in the dark at 4°C.

Selected split-spoon sleeves from the borehole 299-W22-48 and 299-W22-50 were subsampled using stainless steel spatulas. The depths and corresponding stratigraphic unit designations from the conceptual geologic model described in Section 2.0 are shown in Tables 6.1 and 6.2. In most cases, field moist sediment was used to measure the various parameters discussed below but the results are reported on an oven-dry weight basis. In a few cases, aliquots of the borehole sleeves were oven dried before testing was performed (e.g., particle density and dry sieving).

Core sleeves selected for characterization were chosen so that each of the principal stratigraphic units were analyzed and each of the two boreholes were characterized about equally. The available budget allowed for the detailed characterization of approximately 6 to 8 core samples from each of the boreholes. Emphasis on characterization was placed on the Hanford formation units H1 and H2 because preliminary information suggested that contaminants beneath leaking tanks in the S-SX Tank Farm are concentrated within these two units.

3.2 Laboratory Analytical Methods

Analytical methods used in the laboratory to characterize the composite and core sediment samples are discussed in this section. Physical properties analyzed include mass water content, particle-size distribution, and particle density. A variety of geochemical techniques were performed on sediment as well as porewater including elemental analysis, cation exchange capacity, ammonium acetate extraction, 1:1 sediment to water extraction, and 8M nitric acid extraction. Mineralogical analyses were performed using x-ray fluorescence (XRF) and x-ray diffraction (XRD).

3.2.1 Mass Water Content

All geochemical characterization data in this document are reported on an oven-dry basis; however, the composite samples were stored in an air-dried state. Thus, we determined the amount of moisture in the air-dry composite sediment or field moist core materials using the traditional moisture content method in Methods of Soil Analysis, Part 1, Method 21-2.2 Gravimetry with Oven Drying (pages 503-507) (American Society of Agronomy [ASA] 1986).

3.2.2 Particle Size Distribution

Both dry sieving and wet sieving/hydrometer methods were used to determine the particle-size distribution. For the dry sieving, an aliquot of the oven-dry sediment was sieved through the following sequence of sieves: 4, 2, 1, 0.5, 0.25, 0.212, 0.125, 0.063 millimeter, and pan. Between 120 and 210 grams of oven-dry sediment were used and total mass recovery was measured. An auto shaker, either

Rotap Model RX-29 or Gilson SS-8R, was used. The method is similar to that in (ASTM D 421-85). The second particle-size measurement technique used the wet sieve/hydrometer method (ASA [1996], Part 1; Method 15-5 Hydrometer Method [pages 404-408]) and concentrated on quantifying the silt and clay distribution. The silt and clay separates were saved for mineralogical analyses. Samples from the two RCRA boreholes that were used for the hydrometer method were not air or oven dried to minimize the effects of particle aggregation that can affect the separation of clay grains from the coarser material. A more qualitative estimate of particle-size distribution was also determined in the field and upon opening core sleeves using a visual-manual technique by geologists logging the core (ASTM 1993). Geologists' estimates of particle-size distribution are summarized onto the geologic logs in Appendices A and B.

3.2.3 Particle Density

The particle density of bulk grains was determined using pycnometers (see ASA 1986, Part 1; Method 14-3 Pycnometer Method [pages 378-379]) and oven-dried material.

3.2.4 Calcium Carbonate and Organic Carbon Content

The calcium carbonate equivalent and organic carbon content of the bulk sediment (oven dried) were determined using ASTM Procedure D-513, Method G "Carbon Dioxide (CO₂) Evolution" and ASTM Procedure D-4129-98, "Standard Test Method for Total and Organic Carbon in Water by High-Temperature Oxidation and by Coulometric Detection." Analyses were performed on a Coulometrics Inc. Carbon Analyzer Model 5010. Using reagent-grade calcium carbonate, the evolved carbon dioxide gas is used to generate calibration curves for calcite equivalent content in the sediment.

3.2.5 Elemental Analysis

The elemental composition of the bulk sediment was determined by a combination of energy- and wavelength-dispersive XRF. Samples analyzed by the energy-dispersive XRF method follow the KLM Procedure XRF-01, which utilizes a Kevex 0810A commercial XRF excitation and detection subsystem. Sample preparation involved mixing the sample in a Coors high-density alumina (aluminum oxide) mortar and pestle. Six hundred milligrams of the mixed sample were removed and further ground to ~300 mesh size, placed between two sheets of stretched para-film, and loaded into the 0810A XRF unit. Acquisition times ranged between 600 and 3,000 seconds, depending on the targets (gadolinium, iron, silver, zirconium). Forty-one elements (aluminum, antimony, arsenic, barium, bromine, cadmium, calcium, cerium, cesium, chlorine, chromium, copper, gallium, iodine, indium, iron, lanthanum, lead, manganese, molybdenum, nickel, niobium, palladium, potassium, phosphorous, rhodium, rubidium, ruthenium, selenium, silicon, silver, strontium, sulfur, tellurium, thorium, tin, titanium, uranium, vanadium, yttrium, and zinc) were analyzed on each sample and the spectrum interpretation was by the backscatter fundamental parameter approach (described in KLM-01, pages 2-3). Sample analysis by the wavelength method was accomplished using a Siemens Spectra 3000 instrument, equipped with both a flow counter detector to detect soft radiation of the low Z elements and a scintillation counter detector for the harder radiation of the higher Z elements. Bulk solid samples were prepared by taking 180 to 1,500 milligrams of ~300 mesh ground sample and pressing it into a 3.2-centimeter (1.3-inch)-diameter pellet, using a

27,000-kilogram laboratory press. Standard addition and similar matrix methods were used to generate calibration curves for sodium and magnesium, which were then used to process the data. Additional discussion of XRF techniques for quantitative analysis of sediment are found in Section 7.0, "Elemental Analysis by X-Ray Fluorescence Spectroscopy" of ASA (1996), Part 3, pages 161-223 and in the Siemens Spectra 3000 Reference Manual (1994).

3.2.6 Mineralogy

The mineralogy of the bulk sample, silt and clay-size fractions of the sediment was determined by XRD techniques. Bulk sediment samples were dispersed by transferring 100 grams of sediment into a 1-liter bottle and mixing with 1.0 L of 0.001 M solution of sodium hexametaphosphate. The suspensions were allowed to shake overnight to ensure complete dispersion. The sand fraction was separated from the dispersed sample by wet sieving through a #230 sieve. The silt fractions were separated from the clay fractions by using Stoke's settling law described in Jackson (1969). The lower limit of the fraction was taken at >2 microns. Sand and silt fractions were oven dried at 110°C and prepared for XRD and XRF analysis.

Each clay suspension was concentrated to an approximate volume of 10 milliliters by adding a few drops of 10-N magnesium chloride to the dispersing solution. Concentrations of the clay in the concentrated suspensions were determined by drying known volumes and weighing the dried sediment. The density of the slurry was calculated from the volume pipetted and the final weight of dried sediment. Volumes of slurry equaling 250 milligrams of clay were transferred into centrifuge tubes and treated to remove carbonates following Jackson (1969). The carbonate-free clay was then saturated with either magnesium (II) or potassium cations. Clay samples were prepared using the Drever (1973) method and placed onto an aluminum slide for XRD analysis. Due to the tendency of the clay film to peel and curl, the specimens saturated with magnesium (II) were solvated with a few drops of a 10% solution of ethylene glycol in ethanol and placed into a dessiccator containing excess ethylene glycol for a minimum of 24 hours. After the analysis of the magnesium (II) -saturated, ethylene glycol-solvated specimen, two of the samples (Hanford fine sand composite and borehole B8812 composite) were allowed to air dry overnight before reanalysis. Potassium-saturated slides were air dried and analyzed, then heated to 575°C and reanalyzed.

All samples were analyzed on a Scintag XRD unit equipped with a Pelter thermoelectrically cooled detector and a copper x-ray tube. Slides of preferentially oriented clay were scanned from 2 to 45 degrees 2θ , and randomly oriented powder mounts were scanned from 2 to 75 degrees 2θ . The bulk samples were prepared by crushing approximately 0.5 gram of sample to a fine powder that was then packed into a small circular holder. After air-drying ~0.5 gram of the clay slurry, a random mount was prepared and analyzed from 2 to 75 degrees 2θ .

Semi-quantification of mineral phases by XRD was performed according to Brindley and Brown (1980). The relationship of intensity and mass absorption to the weight fraction of an unknown phase is expressed as:

$$I/I_p = \mu_p/\mu (wf)$$

where

I is the intensity of the unknown phase

I_p is the intensity of the pure phase

μ_p is the mass absorption of the pure phase

μ is the average mass absorption of the unknown mixture

wf is the weight fraction of the unknown.

Pure mineral phases of illite, smectite, kaolinite, and chlorite were obtained from the Clay Mineral Society's source clays repository (operated from the University of Missouri in Columbia, Missouri) and analyzed under the same conditions as the sediment samples. Quartz, feldspars, and calcite standards were purchased from the Excalibur Mineral Company, Peekskill, New York, ground and analyzed on the diffractometer to obtain intensities for pure non-clay phases.

The mass attenuation coefficients of selected samples were measured according to Brindley and Brown (1980). Ground bulk powders and air-dried clays were packed into a 0.94-inch-thick circular holder with no backing. The holder was placed in front of the detector and positioned to allow the x-ray beam, diffracted from pure quartz, to pass through the sample and into the detector. The scan was analyzed from 26.0 to 27.0 degrees 2θ . The mass attenuation coefficients were measured directly using the following equation:

$$\mu = (1/\rho x) \ln (I_0/I_x)$$

where

$1/\rho x$ is the mass per unit area as the sample is prepared

I_0 is the intensity of the incident beam

I_x is the intensity of the transmitted beam through sample thickness x .

In addition to XRD, transmission electron microscopy (TEM) characterization of selected samples was conducted on a JEOL 1200X electron microscope equipped with a Link detector system. Samples were prepared for TEM by transferring a small aliquot of a dilute clay slurry onto a formvar carbon-coated 3-millimeter copper support grid. The clay solution contained 0.15% tert-butylamine to reduce the surface tension of water.

Structural formulas were derived from data collected from the TEM analysis. On average, an energy-dispersive x-ray spectra was collected from a minimum of five particles from the same mineral phase common to the sample. The x-ray spectra were collected and processed using the Cliff-Lorimer Ratio Thin Section method and then converted to a structural formula (based on half-unit cell $(O_{10}(OH)_2)$) by the method described in Reynolds and Reynolds (1989) and Newman (1987).

3.2.7 Cation Exchange Capacity

The cation exchange capacity of the sediment was determined using two different procedures, Polemio and Rhoades (1977) and Amrhein and Suarez (1990), both developed to accommodate calcareous sediment. Five grams of each sediment, oven dried, was used in triplicate determinations using both methods.

Rhoades (1982) describes a method to measure the cation exchange capacity of arid land soil that contains carbonates, gypsum, and zeolites. The first step is to saturate the cation exchange sites with sodium by equilibration of the soil sample with a pH = 8.2, 60% ethanol and 40% salt solution. The alcohol/aqueous mixture has a total concentration of 0.4 N sodium acetate-0.1 N sodium chloride. The second step is to displace the sodium and other cations with a 0.5 N magnesium nitrate solution. Sodium and chloride analyses are performed on the extracted solutions and on the excess saturating solution. The chloride determination in the extracting solution is used to deduce the amount of excess sodium left in the soil pores after saturation. After correction, the remaining sodium (the exchangeable sodium) represents the cation exchange capacity. The cation exchange capacity is determined using equation 1 for the Polemio and Rhoades (1977) method.

$$\text{cation exchange capacity} = \text{Na}_t - (\text{Cl}_t) * (\text{Na/Cl})_{\text{sat soln}} \quad (1)$$

where

Na_t and Cl_t are the total sodium and chloride, respectively, in the extraction solution
 $(\text{Na/Cl})_{\text{sat soln}}$ is the sodium-to-chloride ratio in the saturating solution.

Amrhein and Suarez (1990) describe a method for measuring the cation exchange capacity of arid soil by taking into account the dissolution of carbonates and gypsum in the saturation and extraction steps. Five grams of each sediment were weighed and placed into a centrifuge tube along with 20 milliliters of a 0.2 M calcium chloride/0.0125 M calcium sulfate adjusted to a pH of 8.2. The saturating solution was carefully removed from the centrifuge tubes, to avoid resuspending the sediment, and poured into separate 100-milliliter (3.4-ounce) volumetric flasks. The saturating, shaking, and centrifuging steps were repeated so that the sediment contacted the saturation solution four times. Saturation solutions were saved to measure magnesium, potassium, and sodium.

After transferring the concentrated saturation solution for the final time, 30 milliliters (1.01 ounces) of a dilute saturating solution of 0.025-M calcium chloride was added to each centrifuge tube. The centrifuge tubes were placed on a shaker table for 30 minutes and then centrifuged. The dilute solution was decanted and discarded. The sediment was contacted three times with the dilute solution; however, the final dilute contact solution was saved to determine calcium, sulfate, chloride, and alkalinity.

Next, the tubes were reweighed to determine the amount of entrained solution. After weighing the tubes, the calcium was extracted with a 0.5-M magnesium nitrate solution. Twenty milliliters (.68 ounces) of the extraction solution were added to the centrifuge tubes and shaken for 30 minutes. The extraction solution was then decanted into separate 100-milliliter (3.4-ounce) volumetric flasks. The sediment was contacted with the extraction solution five times. Calcium, sodium, sulfate, chloride, and alkalinity were measured in the extracted solution so that the amount of exchangeable and dissolved calcium and any sodium that might have remained on exchange sites after calcium saturating can be determined.

The cations in the saturating solution (0.2 M calcium chloride -0.0125 M calcium sulfite), dilute rinse solution (0.025 M calcium chloride), and the exchange solution (0.5 M magnesium nitrate) were measured by inductively coupled plasma atomic emission spectrometry (ICP-AES). The anions were measured by ion chromatography (IC). The equation for calculating cation exchange capacity is:

$$CEC = \{T_{Ca} - T_{HCO_3} - T_{SO_4} + V([HCO_3] + [SO_4] - [Ca]) - (T_{Cl} - V[Cl]) - [SO_4](T_{Cl} - V[Cl])/[Cl] - [HCO_3](T_{Cl} - V[Cl])/[Cl]\} / 10$$

where

T_i is the concentration of the specified species in the magnesium-nitrate extraction solution in units of millimoles charge/kg of soil

$[i]$ is the concentration of the specified ion in the final rinse of the diluting solution in millimoles of charge per liter of solution

V is the residual entrained diluting solution in the vial just prior to addition of the magnesium-nitrate extracting solution in liters per kilogram of sediment.

3.2.8 Ammonium Acetate Extract (Exchangeable Base Cations)

The exchangeable base cations adsorbed on the composite sediment were determined by exchanging them with high ionic strength ammonium acetate. The cations in the ammonium acetate extract were then measured by the inductively coupled plasma (ICP) technique and the results converted to meq of each cation displaced. The cations were then summed to get another estimate of the total cation exchange capacity of the composite sediment.

Our method to determine the exchangeable base cations (barium, calcium, potassium, magnesium, sodium, and strontium) is similar to the ammonium acetate procedure in ASA (1996, Part 3, pages 582-584). We used 20 grams of air-dried sediment to 50 milliliters of 0.5 M ammonium acetate adjusted to pH 7. The slurries were shaken for ~1 hour, centrifuged, and then filtered through 0.2-micron membranes. The cation concentrations were then measured by the ICP technique. Unlike the method in ASA (1996), we did not repeat the extraction three times to ensure complete removal of base cations from exchange sites. We felt that additional extractions would be influenced by dissolution of more calcite rather than extracting more recalcitrant-exchangeable cations from the low exchange capacity sediment.

3.2.9 1:1 Sediment-to-Water Extract

The 1:1 sediment-to-water extracts of the samples were prepared using the procedure described in ASA (1996, Part 3 pages 417-422). For the borehole samples, field moist aliquots were used and, based on the known moisture contents, just enough deionized water was added to get the 1:1 ratio based on oven-dry weight. The extracts were then analyzed for pH, electrical conductivity (EC), major cation and anion, and trace metal composition using standard electrodes, titrators, IC, ICP, and inductively coupled plasma mass spectrometry (ICP-MS). Approximately 50 to 100 grams of air-dried sediment was mixed with an equal amount of deionized water (corrected for the small amount of porewater in the air-dry sediment).

3.2.10 8 M Nitric Acid Extract

Approximately 20 grams of oven-dry sediment was contacted with 8 M nitric acid at a ratio of ~5 parts acid to 1 part sediment. The slurries were heated to ~80° C for several hours, and then the fluid was separated by centrifugation and filtration through 0.2 micrometer membranes. The acid extracts were analyzed for major cations and trace metals using ICP and ICP-MS, respectively. In a few instances, both instruments could measure the concentrations leached so that independent method results could be compared. For example, both instruments measured chromium and lead and both results are shown to allow comparison. We are quite pleased with the agreement. The acid digestion procedure is based on EPA SW-846 method 3050B (EPA 2000) that can be accessed online at <http://www.epa.gov/epaoswer/hazwaste/test/sw846.htm>.

3.2.11 Porewater Composition

Selected samples from the two boreholes were packed in drainable cells that were inserted into an ultracentrifuge (Beckman Model LM-8, Beckman Instruments, Fullerton, California). The sample was centrifuged for up to 8 hours and several thousand g's to extract the porewater from the sediment. The pH, EC, cation, trace metals, and anions were measured using the same techniques as used for the 1:1 sediment-to-water extracts.

4.0 Analytical Results for Composite Sediment Samples

4.1 Mass Water Content

Because of the large volume of the composite sediment samples, their moisture content was determined after they were air dried. This is in contrast to the discrete borehole samples (discussed in Section 5.0) whose moisture content was determined after oven drying. Slightly more moisture is probably removed during oven drying (i.e., lower humidity) compared to air drying, therefore the results are not exactly the same. The results, presented in Table 4.1, are typical of the residual water contents found in air-dry coarse materials in the relatively low humidity conditions found in the laboratory. As one would expect, the finest grain-size composite, the Ringold silt, retained the highest amount of moisture upon air drying for the composite samples.

All the measured moisture contents from the composite samples are low compared to measurements made on discrete samples from the field and geophysical logs because the samples were air dried to aid in homogenization. The values in Table 4.1 have no bearing on natural conditions and are reported here only to aid scientists who will work with the samples in laboratory experiments. The reported air-dry water contents would be expected to change if the samples are stored in different relative humidity conditions.

Photographs of the four composite samples in their air-dried state are shown in Figures 4.1 through 4.4.

Table 4.1. Moisture Content of Composite Sediment Samples After Air Drying

Composite Name	Representative Stratigraphic Unit (lithology)	Water (wt%)
Ringold Silt	Upper Ringold Unit (silt)	2.17
Hanford Coarse Sand	Hanford Formation Unit H1 (gravelly sand)	1.12
Hanford Fine Sand	Hanford Formation Unit H2 (silty sand)	1.50
Borehole Fine Sand	Hanford Formation Unit H2 (silty sand)	0.80

4.2 Particle-Size Distribution

Both dry sieving and the hydrometer methods were used to determine the particle-size distributions of the composite samples. The dry sieving results are shown in Table 4.2 and the hydrometer/wet sieve results are shown in Table 4.3 and Figure 4.5.

Ringold Silt - Composite Sample



Figure 4.1. Ringold Silt Composite Sample After Air Drying and Disaggregation.

Hanford Coarse Sand - Composite Sample



Figure 4.2. Hanford Coarse Sand Composite Sample After Air Drying and Disaggregation.

Hanford Fine Sand - Composite Sample

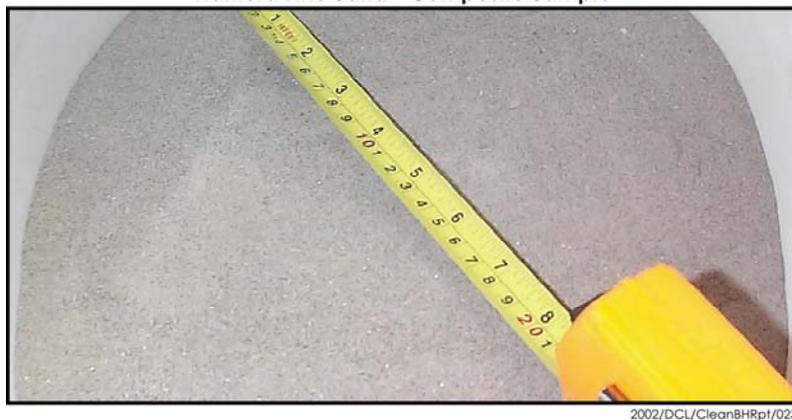


Figure 4.3. Hanford Fine Sand Composite Sample After Air Drying and Disaggregation.



Figure 4.4. Borehole Fine Sand Composite Sample After Air Drying and Disaggregation.

Table 4.2. Particle-Size Distributions for Composite Sediment Samples Determined by Dry Sieve Method

Weight Percent Retained on Each Sieve									
Composite Name	4.00 mm	2.00 mm	1.00 mm	500 um	250 um	212 um	125 um	63 um	<63 um
Ringold Silt	0.01	0.08	18.05	13.01	8.90	1.55	3.54	4.61	50.26
Hanford Coarse Sand	0.87	30.17	41.26	17.72	6.96	0.22	1.20	0.71	0.89
Hanford Fine Sand	0.01	0.17	0.18	0.43	4.32	5.86	29.22	42.57	17.26
Borehole Fine Sand	0.00	0.02	1.99	5.95	18.97	7.14	23.47	29.25	13.21

Composite Name	% Gravel	% Coarse Sand	% Med. + Fine Sand	% Silt+Clay	Classification (Folk 1968)
Ringold Silt*	0.09	31.06	18.60	50.26	Sandy mud
Hanford Coarse Sand	31.04	58.98	9.09	0.89	Gravelly sand
Hanford Fine Sand	0.18	0.61	81.95	17.26	Slightly muddy sand
Borehole Fine Sand	0.02	7.94	78.83	13.21	Slightly muddy sand

* Results in Table 4.3 are more representative of actual particle-size distribution since dry sieving apparently did not completely disaggregate sample.

Table 4.3. Particle-Size Distributions for Composite Sediment Samples Determined by Wet Sieving/Hydrometer Method

Composite Name	% Gravel	% Sand	% Silt	% Clay	Classification (Folk 1968)
Ringold Silt	0.00	1.82	83.91	14.27	Clayey silt
Hanford Coarse Sand	42.82	53.01	1.68	2.49	Gravelly sand
Hanford Fine Sand	0.23	72.61	20.57	6.59	Muddy sand
Borehole Fine Sand	0.00	77.43	18.19	4.38	Muddy sand

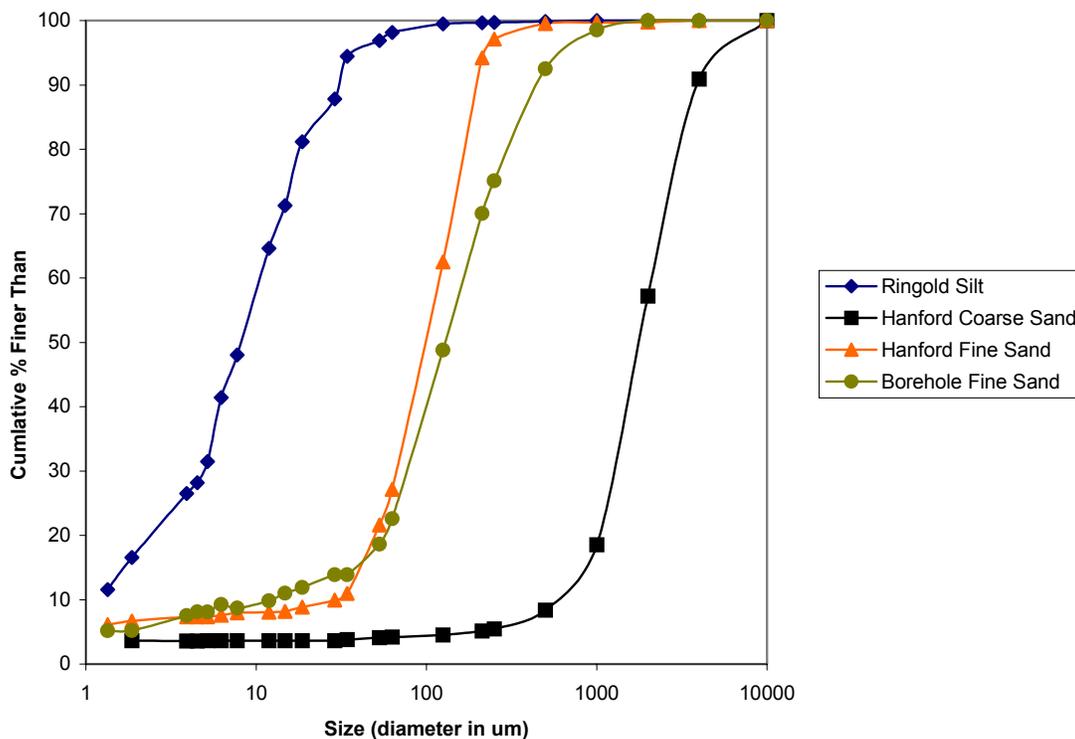


Figure 4.5. Particle-Size Distributions for the Four Composite Sediment Samples

There is a large difference between the dry sieving and the wet sieving in the particle-size distribution for fine-grained samples, which often tend to form sedimentary aggregates. The dispersant used to facilitate particle separation during the wet sieving/hydrometer analysis was more effective at disaggregating the sample than was the dry sieving technique; therefore, the data in Table 4.3 is more representative of the true particle size, especially for the Ringold silt composite. There also appears to be measurable agglomeration in the two fine sands that is also broken down when wet sieving is used. Thus, we suggest that the wet sieving/hydrometer data are more accurate and useful, at least for the analysis of fine-grained sediment.

Particle sorting is indicated by the shape of the curves in Figure 4.5. Samples that are well sorted (e.g., Hanford fine sand) show a particle-size distribution curve with a steep midsection and flat tails on either end of the curve. The borehole fine sand is less well sorted, which probably reflects the fact that this sample was composited over a relatively long (10.5-meter or 34.5-foot) interval whereby many different strata were mixed together. The Ringold silt composite is also less well sorted than the two composites from the Hanford formation (i.e., Hanford coarse sand and Hanford fine sand).

4.3 Particle Density

The particle density results are shown in Table 4.4.

Table 4.4. Particle Densities for Composite Sediment Samples

Sample Name	Particle Density (g/cm ³)	Standard Deviation (3 trials)
Ringold Silt	2.612	0.008
Hanford Coarse Sand	2.742	0.005
Hanford Fine Sand	2.662	0.010
Borehole Fine Sand	2.675	0.011

Clastic sediment of the Hanford and Ringold Formations is composed mostly of quartz, plagioclase, and rock fragments (see Tallman et al. 1979; Bjornstad 1990). However, the coarser-grained fractions of the Hanford formation generally contain relatively higher percentages of mafic (i.e., basaltic) rock fragments. These minerals and rock fragments have particle densities similar to those in Table 4.4.

The values for Hanford formation sediment in Table 4.4 are slightly lower than values reported by Serne et al. (1993) (2.70 to 2.82 g/cm³), but the differences are small and are not considered significant for most experimental applications in which the Hanford formation standards would be used. It is encouraging to note, however, that the particle density measurements for the composite samples in Table 4.4 compare favorably with the particle density measurements made on discrete samples from boreholes 299-W22-48 and 299-W22-50 (see Tables 5.6 and 5.32). We suspect that the small differences between the current work and measurements in 1993 are caused by slight differences in analytical technique.

4.4 Calcium Carbonate and Organic Carbon Content

The carbon results are shown in Table 4.5. In general, the measurements were made on triplicate aliquots; in some cases, more than three measurements were averaged. The calcium carbonate equivalent (in terms of grams of calcite per gram of oven-dry sediment) is low but within the normal range for non-pedogenically altered Hanford formation sediment. The amount of calcium carbonate is a function of (1) how much soil development has taken place or (2) how much carbonate-cemented detrital material has been transported and redeposited. The Hanford formation generally contains more detrital calcium carbonate than the Ringold, because the cataclysmic floods were more effective at eroding cemented calcic paleosols and redistributing the material. In the case of our composite samples, the Ringold has a higher calcium carbonate content, because it is located just below (slightly over 2 meters or 6.6 feet) a well-developed calcic paleosol sequence (equivalent to Plio-Pleistocene PPlc subunit) that caps the Ringold Formation on the White Bluffs (see Figure 2.2). Normally the Ringold Formation contains less than 1% calcium carbonate, regardless of grain size, unless near a paleosol (Last et al. 1989).

Although the calcium carbonate content of Hanford formation sediment varies greatly depending on the degree of calcic-soil development, typical values are on the order of 1 to 5 wt% (Last et al. 1989). Thus, the values for the composite samples in Table 4.5 are reasonable. More normally, however, the Ringold Formation will contain <1 wt% calcium carbonate.

Table 4.5. Calcium Carbonate and Organic Carbon Content (wt%) for Composite Sediment Samples

Sample Name	Total Carbon	Standard Deviation	CaCO ₃ Equivalent	Standard Deviation	Organic C (by difference)	Standard Deviation
Ringold Silt	0.39	0.006	2.75	0.05	0.06	0.01
Hanford Coarse Sand	0.11	0.00	0.75	0.08	0.02	0.01
Hanford Fine Sand	0.25	0.013	1.75	0.11	0.04	0.02
Borehole Fine Sand	0.28	0.007	1.92	0.06	0.05	0.01

The organic carbon content of the bulk composite sediment samples is quite low. The method used to measure the organic carbon relies on subtracting the inorganic carbon from the total carbon in the sample and for such low C values is not accurate. The low values are within the ranges generally reported for Hanford formation sediment but if more accurate values are desired a different method that is more sensitive should be used.

The values for total carbon, calcium carbonate, and organic carbon for the borehole fine sand agree well with measurements of discrete samples analyzed from borehole 299-W22-50 (see Table 5.33) from which the composite sample was constructed.

4.5 Bulk Chemical Composition

The bulk chemical compositions of the composite sediment samples, as determined by x-ray fluorescence (XRF) and converted to oxides (see Section 3.2.5), are presented in Table 4.6. We have assumed that all iron is ferric oxide, though a large proportion of the iron is probably associated with the basaltic component of the sediment; and that iron is mostly ferrous oxide. Depending on the types of experiments for which the Hanford Site composites are used, the assumption that all iron is ferric iron will not be adequate. We have adjusted the total content to reflect the presence of some calcium carbonate by converting the calcium carbonate in Table 4.5 back to percent carbonate and adding it to the XRF totals.

The three Hanford formation sediment composites show slightly more than 100% mass balance using the stated assumptions and the Ringold silt shows about 97% of the total composition accounted for. The major element concentrations in the composite samples of the Hanford formation generally are similar to the concentrations in discrete core samples from boreholes 299-W22-48 and -50 (compare Table 4.6 with Tables 5.8 and 5.34). Comparing the composite borehole fine sand sample with the discrete samples from borehole 299-W22-50 from which the composite was derived, shows that the elemental concentrations in the composite sample fall within the range of the concentrations of the discrete samples except for silicon dioxide, which is slightly high, and calcium oxide, which is slightly low (neither difference is very significant).

Table 4.6. Bulk Chemical Composition of Composite Sediment Samples (% as Oxides)

Oxide	Ringold Silt	Hanford Coarse Sand	Hanford Fine Sand	Borehole Fine Sand
Na ₂ O	0.97	3.09	2.26	2.37
MgO	5.19	3.20	3.70	3.12
CO ₃	1.65	0.45	1.05	1.15
Al ₂ O ₃	16.82	14.06	13.79	13.25
SiO ₂	58.94	66.24	68.67	71.03
P ₂ O ₅	<0.18	<0.22	<0.22	<0.20
SO ₃	0.06	0.07	0.11	0.06
Cl	0.04	0.03	0.04	0.04
K ₂ O	2.88	1.92	1.92	2.39
CaO	2.44	4.39	3.93	3.13
TiO ₂	0.71	0.89	0.78	0.55
V ₂ O ₅	0.02	0.02	0.02	0.01
Cr ₂ O ₃	0.01	0.01	0.01	0.01
MnO	0.08	0.09	0.09	0.06
Fe ₂ O ₃	6.10	6.15	5.00	3.54
SrO	0.02	0.05	0.04	0.04
BaO	0.09	0.08	0.07	0.08
Total	96.92	102.26	102.50	101.58
Note that other trace metals are present but contribute <0.1%.				

The Ringold silt shows slight differences in the concentrations of some elements compared to the Hanford formation composites. The Ringold silt composite is lower in sodium oxide and calcium oxide and higher in aluminum oxide, silicon dioxide, and potassium oxide than the Hanford formation composites. These differences reflect differences in mineral content, which is due to differences in the particle-size makeup of the samples, and in provenance. The relatively low sodium oxide and calcium oxide reflect the lower plagioclase feldspar composition of the Ringold silt sample and the high potassium oxide reflects the relatively high illite content of the Ringold silt compared to the Hanford formation composites (see discussions in the mineralogy section).

Because the number of major element analyses of Hanford and Ringold Formation sediment are limited, a larger database and experience base are needed to better account for slight differences in composition such as are shown in Table 4.6. The bulk chemical composition of other near-surface samples from the Hanford Site are reported in DOE/RL (1994).

4.6 Mineralogy

The mineralogy of the bulk and silt and clay-size fractions of the composite sediment was determined by x-ray diffraction (XRD) techniques. The XRD analyses show the Hanford formation composite samples are dominated by quartz (30% to 80%), and plagioclase feldspar (5% to 20%), with minor amounts (<10%) of potassium feldspar (Table 4.7).

The XRD results are in agreement with petrographic analyses of the coarser fraction of the Hanford formation, which after rock fragments (30% to 50% of the total), is followed by approximately equal amounts of quartz and plagioclase feldspar (15% to 30%), followed by biotite (2% to 6%) and pyroxene (0.5% to 2.5%) (Bjornstad 1990). Additionally, calcite was identified in the Ringold silt sediment at <5%. Clay minerals identified in the bulk sample, but not quantified, were mica and chlorite. Comparison of the XRD tracings shows the mica and chlorite phases are more abundant in the Ringold silt composite than any Hanford formation composites. This reflects the larger contribution of felsic igneous and low-grade metamorphic detritus in the Ringold Formation. Micas also tend to weather and break up into fine sand to silt-size particles and thus are more concentrated in strata with sediments in this range. Examples of XRD tracings and semiquantification of the major minerals (quartz, feldspar, and calcite) are provided in Appendix G. The mineralogy of other near-surface samples from the Hanford Site are reported in DOE/RL (1994).

The clay fraction (<2 microns) of the composites is dominated by four clay minerals: illite (10Å), smectite (15Å), chlorite (14.1Å), and kaolinite (7Å) with minor amounts of quartz (3.34Å), feldspar (3.18Å), and amphibole (8.4Å). The smectites, when saturated with magnesium (II) ion, gave a basal reflection of 15.0 Å, overlapping the chlorite 14.1 Å peak (see Appendix G). When solvated with

Table 4.7. Semiquantitative Mineral Content of Composite Sediment Samples

Semiquantification of Minerals in Bulk Composite Samples (wt%)				
Sample ID	Quartz	K-Feldspar	Na-Feldspar	Calcite
Borehole Fine Sand	50	10	20	ND
Hanford Fine Sand	80	10	20	ND
Hanford Coarse Sand	55	5	15	ND
Ringold Silt	30	5	5	<5

Semiquantification of Minerals in the Clay Fraction from Composite Samples (wt%)						
Sample ID	Quartz	Feldspar	Smectite	Illite	Chlorite	Kaolinite
Borehole Fine Sand	5	<5	30	40	20	5
Hanford Fine Sand	5	<5	30	15	15	10
Hanford Coarse Sand	5	<5	30	15	15	5
Ringold Silt	10	<5	35	35	20	ND

ND = not detected

ethylene glycol, the smectite structure expanded up to 17 Å leaving the chlorite (14.1 Å) and illite (10 Å) reflections unchanged. An additional analysis with potassium ion as the interlayer cation shifted the smectite peak to approximately 12 Å and again the chlorite and illite reflections remain unaffected. Sample cracking on the potassium ion-saturated slide for the Hanford fine sand composite prevented analysis of that sample. Heating the potassium ion-saturated slide collapses the smectite structure from 12 Å to 10 Å and the 7.01 Å and 3.58 Å kaolinite peaks disappear. The chlorite reflection at 14.1 Å remained constant whereas the 7.1 Å and 3.54 Å peaks almost disappear. The identification of kaolinite is based primarily on XRD data (the separation of two peaks at 3.58 Å and 3.55 Å, the latter belonging to chlorite), and by transmission electron microscopy (TEM) analysis. Kaolinite was not identified in the Ringold silt composite. Additionally, trace amounts of apatite, iron oxides, and sepiolite were detected in the clay fraction during the TEM analysis of the Hanford formation composites.

The semiquantitative analysis of minerals in the clay fraction of the composite sediment is given in Appendix G. Overall, smectite was the dominant mineral in the clay fraction for all the composites (30 to 40 wt%). This is in general agreement with the clay-mineral composition reported in Bjornstad (1990). Illite ranged in concentrations from a high of 40 wt% (borehole fine sand) to a low of 15 wt% and chlorite averaged between ~15 to 20 wt%. Minor amounts of kaolinite (<10 wt%) were detected in all three Hanford formation composite samples. Kaolinite was not identified by XRD in the Ringold silt. Quartz and feldspar made up ~5 to 10 wt% of the clay fraction. Amphibole was identified in the clay fraction in minor amounts; however, it was not quantified. Total recovery for the clay fraction ranged from a low of 69 wt% (Hanford fine sand) to a high of 106 wt% (borehole fine sand). Recoveries ranging from 80 to 120 wt% are acceptable for XRD semiquantification.

XRF analysis on the <2-micron fraction was conducted on both Hanford fine sand, Hanford coarse sand, and the borehole fine sand composite samples. The results, converted to oxides, are presented in Table 4.8. Overall, approximately 45 wt% of the clay fraction consists of silicon, followed by lesser amounts of aluminum (~15 wt%) and iron (~12 wt%). The clay fraction contains <1 wt% of the total iron oxide and <1.2 wt% of the total aluminum oxide in the bulk sample. Iron oxides were detected in only trace amounts during the TEM analysis of the clay fraction, which suggests that most of the iron in the <2-micron fraction is incorporated into the clay mineral structures (smectites, chlorites, and illites). Based on XRF data, semiquantitative estimates of illite in the <2-micron fraction (assuming all potassium resides in the illite structure) show ~15 and 10 wt% in the Hanford coarse sand and Hanford fine sand composite samples, respectively. This agrees well with the XRD quantification for illite in the same samples. However, for the borehole fine sand composite sample, illite concentration of 20 wt% is much lower than the value of 40 wt% reported by XRD.

Analysis of illites from the Hanford fine sand by TEM showed a variation of iron content as well as particle morphology. Dominating the illitic material were large (>1-micron)-thick platy mica particles (Figure 4.6).

Table 4.8. Bulk Chemical Composition of Clay Fraction (% as Oxides) in Composite Sediment Samples

Oxide	Hanford Coarse Sand	Hanford Fine Sand	Borehole Fine Sand
Na ₂ O	NM	NM	NM
MgO	NM	NM	NM
CO ₃	NM	NM	NM
Al ₂ O ₃	12.80	14.31	16.79
SiO ₂	45.25	43.86	47.60
P ₂ O ₅	2.66	3.17	1.23
SO ₃	0.07	0.09	0.06
Cl	0.14	0.23	0.14
K ₂ O	1.61	1.21	2.49
CaO	1.83	1.77	1.00
TiO ₂	0.61	0.49	0.58
V ₂ O ₅	0.02	0.01	0.02
Cr ₂ O ₃	0.01	0.01	0.01
MnO	0.13	0.19	0.21
Fe ₂ O ₃	12.37	10.17	11.80
SrO	0.03	0.02	0.02
BaO	0.06	0.04	0.05
Note that other trace metals are present but contribute <0.1%. NM = Analyte not measured.			

These particles were abundant and easily distinguished from other clay minerals. The following structural formula was developed from several illites containing approximately the same amount of ferric iron:



The tetrahedral sheet has a charge of -0.76. The octahedral sheet has a charge of +0.03 and the inter-layer cations have a charge of + 0.76. Ferric iron content in the octahedral site ranged from 0.01 atoms to as high as 0.50 atoms per O₁₀(OH)₂ and Al³⁺ (for both tetrahedral and octahedral positions) varied between 1.96 and 3.13 atoms per O₁₀(OH)₂. Illites in the Hanford coarse sand displayed much the same characteristics as the Hanford fine sand.

Illites examined in the borehole fine sand could be divided into two types based on Fe³⁺ content: <0.3 Fe³⁺ atoms per O₁₀(OH)₂ and >0.3 Fe³⁺ atoms per O₁₀(OH)₂. Figure 4.7 is a common illite particle from the borehole fine sand with a low Fe³⁺ content (0.09 atoms per O₁₀[OH]₂).



Figure 4.6. Typical Illite Particle (~5 microns long) Common to the Hanford Fine Sand Composite Sample



Figure 4.7. Typical Illite Particle (~3 microns long) from Clay Fraction of the Borehole Fine Sand Composite Sample

The structural formula derived from five TEM analysis of the low iron phase is:



The tetrahedral sheet has a charge of -0.87; the octahedral sheet has a charge of +0.14 and an inter-layer cation charge of +0.78. High iron illites (~0.3 atoms per $O_{10}(OH)_2$) had similar particle morphology, with a slight tendency to be thicker and larger in size. These illites also tended to have less Al^{3+} substitution in the tetrahedral sites (~1.52 atoms per $O_{10}(OH)_2$) and slightly more magnesium (II) ion (~0.30 atoms per $O_{10}(OH)_2$).

Chlorites common to the Hanford fine sand, Hanford coarse sand, and the borehole fine sand have chemistry ranging between a chamosite (iron-rich chlorite) to a chlinochlore (magnesium-rich chlorite). Platy chlorite particles averaging in size from 0.5 to >2.0 microns were common throughout the samples. Figure 4.8 is a typical example an iron-rich, platy chlorite from the borehole fine sand.

Assuming all iron as iron (II), an average structural formula was developed from TEM data collected from six chlorite particles from the borehole fine sand:



Most of the layer charge derived from the substitution of Al^{3+} for Si^{+4} in the tetrahedral sheet is balanced by the substitution of Mg^{2+} and Fe^{2+} for Al^{3+} in the octahedral sheets. There was a considerable range of cation substitution in both octahedral sheets for chlorites examined by TEM. Iron concentrations ranged from 0.80 to as high as 2.58 atoms per $O_{10}(OH)_8$ and Mg^{2+} ranged between 1.29 and 3.46 atoms per $O_{10}(OH)_8$. For this structural formula, trace amounts of K^+ and Ca^{2+} were placed into interlayer cations, assuming some mixed layering material to be present in the chlorite. However, it is possible that these cations are a part of the chlorite structure where they would occupy positions in the octahedral sheets. Chlorites in both the Hanford fine sand and Hanford coarse sand composites tended to be richer in Fe^{2+} , but were otherwise similar in chemistry and morphology to chlorites in the borehole fine sand.

Kaolinite was initially identified by XRD in the Hanford formation composites, then subsequently by TEM analysis. Kaolinites typically appear as hexagonally shaped crystals as shown in Figure 4.9.

An average structural formula derived from kaolinites examined from each of the three composite soils appear to have a minor amount of Fe^{3+} substituting for Al^{3+} in the octahedral sheet:



Smectites occurred either as large aggregates of thin films or as discrete particles <0.1 micron in size. Figure 4.10 shows a ~2-micron-size smectite aggregate from the Hanford coarse sand. Smectites are identifiable from other clay minerals by the curled edges of individual smectite flakes.



Figure 4.8. Chlorite Particle (~1.5 micron) from the Borehole Fine Sand Composite Sample.



Figure 4.9. A Thick, Hexagonal Kaolinite Particle (~1 micron) from the Borehole Fine Sand Composite Sample.



Figure 4.10. Smectite Aggregate (~2 microns) from the Hanford Coarse Sand Composite Sample

Chemical composition of the smectites was hard to establish due, in part, to isolating the particle during the TEM analysis. Considering this limitation, and assuming all iron as Fe^{3+} , an average structural formula was developed for the smectites using data from all three Hanford formation composites: Hanford fine sand, Hanford coarse sand, and borehole fine sand:



The tetrahedral sheet has a layer charge of -0.14 and the octahedral sheet has a layer charge of -0.19. Balancing out the sheet charges are interlayer cations: potassium, sodium, and calcium. This type of smectite is classified as a calcium-rich montmorillonite because more than half of the charge originates in the octahedral sheet.

4.7 Cation Exchange Capacity

Five grams of each sediment were used in triplicate determinations using the two methods (Polemia and Rhoades (1977) and Amrhein and Suarez (1990)) discussed in Section 3.2. The results for the four composite sediment samples are summarized in Table 4.9.

The cation exchange capacity results, as determined by the two methods, vary significantly. The Amrhein and Suarez method yields lower results than the Polemio and Rhoades technique. There is a

Table 4.9. Results of Cation Exchange Capacity (meq/100 g) of Composite Sediment Samples Using Two Different Techniques

Composite Name	Polemio and Rhoades (1977)	Amrhein and Suarez (1990)
Ringold Silt	28.5 ± 2.4	11.6 ± 1.1
Hanford Coarse Sand	12.2 ± 2.1	1.7 ± 0.3
Hanford Fine Sand	18.4 ± 2.7	7.8 ± 3.8
Borehole Fine Sand	9.2 ± 8.9	2.9 ± 0.6

large variation in the Polemio and Rhoades results for the borehole fine sand but, in general, the reproducibility for the other five sets of triplicates is good. Not surprisingly, both methods result in significantly larger cation exchange capacity values for the Ringold silt compared to the Hanford formation composites, due to the greater reactive surface area for silt. From other testing where known amounts of reagent-grade calcium carbonate were added to sediment, we found that the Polemio and Rhoades values may not adequately correct for calcium carbonate dissolution and the Amrhein and Suarez method overcorrects. These observations were made for sediment that was spiked with 6 to 20 wt% calcium carbonate. At this time, we have not determined which method is more accurate for the low exchange capacity Hanford formation sediment with low calcite contents.

The cation exchange capacity measured on the Hanford fine sand composite is comparable to those measured on Hanford formation sediment from borehole 299-W22-48 (see Table 5.11, depths 39 to 136 feet below ground surface [bgs]). The borehole fine sand composite, on the other hand, has a much lower cation exchange capacity than either the Hanford fine sand composite or the samples from borehole 299-W22-48. We do not yet understand the discrepancy.

The Hanford fine sand came from a zone that has absorbed (and evaporated) a lot of meteoric water. As a result, it has a higher concentration of water-extractable anions (and cations) as shown in Tables 4.10 and 4.11. Whether this has any influence on cation exchange capacity is not known.

The low cation exchange capacity for the Hanford coarse sand reflects the larger grain size (i.e., less overall reactive surface area). The differences in cation exchange capacity may be the result of differences in grain size and surface area rather than clay content. There are relatively few clay-size particles in the Hanford coarse sand, borehole fine sand, or Hanford fine sand composites, as demonstrated in Table 4.3. The Hanford formation does **not** contain much clay because (1) it is a young deposit, geologically, so there has been insufficient time for diagenetic alteration either via groundwater or soil development, and (2) it was deposited very rapidly during cataclysmic flooding (geologists speculate that each flood lasted no more than a week), so that clay-size particles did not have enough time to settle out of suspension before all the floodwater had drained out of the basin.

Cation exchange capacities for Hanford formation sediment that have been reported in the literature in general are between the range of values reported in Table 4.9 for the two methods. That is, other

Table 4.10. pH, Electrical Conductivity, Alkalinity, and Anions in 1:1 Sediment-to-Water Extracts for Composite Sediment Samples

Constituent	Units	Ringold Silt	Hanford Coarse Sand	Hanford Fine Sand	Borehole Fine Sand
pH		7.87	7.83	7.55	7.84
EC	μS/cm	441	150	1218	219
Alkalinity	mg/L HCO ₃	113	74	113	86
F	mg/L	0.27	0.26	0.26	0.44
Cl	mg/L	12	6.8	180	6.1
Br	mg/L	0.07	0.06	1.2	0.04
NO ₂	mg/L	<0.1	<0.1	<0.1	<0.1
NO ₃	mg/L	42.7	4.5	32.8	8.3
PO ₄	mg/L	0.23	0.15	0.16	0.16
SO ₄	mg/L	73.9	11.7	289	23.8
formate	mg/L	1.38	0.20	0.06	0.86
acetate	mg/L	15.8	<0.1	<0.1	<0.1
oxalate	mg/L	1.01	0.10	0.29	0.27

Table 4.11. Major Cations in 1:1 Sediment-to-Water Extracts (ICP) for Composite Sediment Samples

Constituent	Units	Ringold Silt	Hanford Coarse Sand	Hanford Fine Sand	Borehole Fine Sand
Na	μg/L	31,261	8,140	27,825	16,510
Mg	μg/L	5,193	2,487	32,558	3,233
Al	μg/L	(42) ^(a)	204	<50	115
Si	μg/L	9,633	12,150	18,638	3,233
P	μg/L	378	256	280	332
S	μg/L	26,075	4,754	102,162	8,872
K	μg/L	5,673	(3,294) ^(a)	8,630	(3,844) ^(a)
Ca	μg/L	43,675	11,003	156,136	15,455
Ti	μg/L	<20	<20	<20	<20
Mn	μg/L	<5	<5	<5	<5
Fe	μg/L	90	220	13	77
Sr	μg/L	173	52	663	73
Ba	μg/L	33	15	64	17
(a) Values in parenthesis are just below level of quantification but spectra looked good. Thus, a tentative value was attributed to data.					

literature suggests that the Polemio and Rhoades technique yields cation exchange capacity values biased high and the Amrhein and Suarez method yields values that are biased low. Therefore, the true cation exchange capacity may lie between the values reported for the two methods in Table 4.9.

4.8 1:1 Sediment-to-Water Extraction

The 1:1 sediment-to-water extract results for the composite samples are shown in Tables 4.10 to 4.13. Approximately 50 to 100 grams of air-dried sediment were mixed with an equal amount of deionized water (corrected for the small amount of porewater in the air-dry sediment). In the discussion on the characterization of the core materials, we will compare the chemical composition of the 1:1 water extracts with actual porewater obtained by ultracentrifugation and the calculated equivalent pore chemistry from dilution correction of the 1:1 extracts. For some constituents, the 1:1 water extracts, when corrected for dilution with deionized water, give an accurate measure of the concentration within the native porewater. For other constituents, the amount found in the 1:1 water extract, when dilution-corrected back to the

Table 4.12. Trace Metals in 1:1 Sediment-to-Water Extracts of Composite Sediment Samples. Analyzed using ICP or ICP-MS methods.

Constituent	Units	Ringold Silt	Hanford Coarse Sand	Hanford Fine Sand	Borehole Fine Sand
Be	µg/L	<1	<1	<1	<1
B	µg/L	<20	<20	<20	<20
Cr ^(A)	µg/L	13.3	0.85	3.1	1.4
Co	µg/L	<1	<1	<1	<1
Ni	µg/L	<5	<5	<5	<5
Cu	µg/L	<5	<5	<5	<5
Zn	µg/L	<5	<5	<5	<5
As ^(a)	µg/L	3.1	6.6	6.7	14.2
Se ^(a)	µg/L	(1.2) ^(b)	(0.7) ^(b)	12.3	(0.8) ^(b)
Mo ^(a)	µg/L	5.4	(1.0)	2.0	8.9
Tc ^(a)	µg/L	<0.1	<0.1	<0.1	<0.1
Ru ^(a)	µg/L	<0.01	<0.01	<0.01	<0.01
Ag ^(a)	µg/L	<0.25	<0.25	<0.25	<0.25
Cd ^(a)	µg/L	<0.08	<0.08	<0.08	<0.08
Pb ^(a)	µg/L	0.69	1.44	(0.28) ^(b)	(0.41) ^(b)
Bi	µg/L	<20	<20	<20	<20
U ^(a)	µg/L	0.38	0.29	0.29	0.58

(a) ICP-MS = inductively coupled plasma mass spectrometry method was used.
(b) Values in parenthesis are just below level of quantification but spectra looked good. Thus, a tentative value was attributed to data.

Table 4.13. Charge Balance for Water Extracts of Composite Sediment Samples

Constituent	Units	Ringold Silt	Hanford Coarse Sand	Hanford Fine Sand	Borehole Fine Sand
Alkalinity	meq/L	1.86	1.21	1.86	1.41
Cl	meq/L	0.34	0.19	5.08	0.17
NO ₃	meq/L	0.69	0.07	0.53	0.13
SO ₄	meq/L	1.54	0.24	6.02	0.50
Total Anions	meq/L	4.45	1.74	13.52	2.24
Na	meq/L	1.36	0.35	1.21	0.72
Mg	meq/L	0.43	0.20	2.68	0.27
K	meq/L	0.15	0.08	0.22	0.10
Ca	meq/L	2.18	0.55	7.79	0.77
Total Cations	meq/L	4.12	1.21	11.92	1.86

porewater, over-predicts the porewater concentration because of dissolution of salts/minerals in the sediment. For these composite sediment samples, which were air dried, we will not make comparisons and will only report the observed chemical composition of the 1:1 water extracts. We also have converted them to a per gram of oven-dry sediment and related the values reported on a sediment basis to the amount extracted by strong nitric acid and the total sediment content as determined by XRF measurements.

The data in Tables 4.10 to 4.13 show that the water extracts are dominated by calcium, sodium, magnesium, bicarbonate, and sulfate. There are minor amounts of chloride, nitrate, potassium, and silicon but no highly water-leachable levels of trace metals in the extracts. The water extract from the Hanford fine sand shows high concentrations of calcium, magnesium, sodium, chloride, and sulfate compared to the other Hanford formation sediment. There are no waste sites nearby that could have realistically contaminated this shallow depth where the Hanford fine sand composite came from. The source for the higher anion and cation concentrations in the Hanford fine sand sample is interpreted as evaporitic (absorption and subsequent evaporation of naturally occurring meteoric water). The fact that this unit retains more meteoric water is demonstrated by the presence of vegetation in Figure 2.12 and a darker color due to a higher moisture content shown in Figure 2.14. The only source for this water is natural recharge (i.e., percolating rain and snowmelt from the surface). Over time, the zone containing the Hanford fine sand behaves like a sponge, absorbing a constant supply of constituents dissolved in the groundwater and/or leached from the overlying deposits of the Hanford formation. Simultaneous evaporation of this water over time would lead to a concentration of the dissolved constituents. In contrast, the anions and cations are not elevated in the Hanford coarse sand composite sample, which immediately underlies the Hanford fine sand (see Figure 2.14). This would suggest that either (1) all the recharge water is effectively retained by the Hanford fine sand, or (2) excess recharge water is not absorbed by, and rapidly drains through, the Hanford coarse sand.

The Ringold silt also shows moderate amounts of the same three cations but no elevated chlorine. Instead, there is elevated sulfate and nitrate. As shown in Table 4.13, there is an excess of anions in all the water extracts when comparing the electrical charge balance. The inductively coupled plasma (ICP) sulfur value shown in Table 4.11 compares quite favorably with the sulfate value measured by ion chromatography (IC) shown in Table 4.10. The ICP phosphorous value shown in Table 4.11 is biased high when converted to phosphate and compared to the IC data shown in Table 4.10. Because the ratio of water to sediment used in the water extracts was 1:1, the data in Tables 4.10 to 4.13 with the units of milligrams per liter or meq per liter also represent μg or microequivalents per gram of soil.

The data in Tables 4.10 and 4.11 show that the Ringold silt and the Hanford fine sand are relatively similar compared to the Hanford coarse sand and borehole fine sand especially with respect to EC, alkalinity, calcium, nitrate, potassium, sodium, and sulfate. The Hanford fine sand has particularly high concentrations of calcium, chloride, magnesium, and sulfate. In general, the concentrations of various constituents in the water extracts of the composite samples are similar to those in samples from boreholes 299-W22-48 and 299-W22-50, though several differences exist. For example, chloride and nitrate are lower in the extracts from the discrete boreholes than from the composite samples. This is probably because borehole samples are from depths beyond the influence of near-surface recharge. Other reasons for the differences and similarities among samples may be a function of variables including grain size (surface area), mineralogy, degree of weathering, and man-induced influences. Variations among samples will be better understood as the database of analyses increases.

4.9 8 M Nitric Acid Extraction

The results of the acid extracts are shown in Tables 4.14 and 4.15. Table 4.16 compares the percentage of each element dissolved by the nitric acid extract compared to the total elemental composition in the sediment as determined by XRF. In general, the acid extraction removes only a few percent of the total alkali metals (potassium and sodium), about half of the major alkaline earth metals (calcium and magnesium), and less (about 10% to 15%) of the minor alkaline earths (barium and strontium), very little of the silicon, about 15% of the aluminum and titanium, about 70% of the iron and manganese, and 25% to 70% of the various trace metals. The amount of any element removed from the Hanford coarse sand by acid digestion is less than the other three composite sediment samples. This may be a function of mineralogy, whereby the Hanford coarse sand contains significantly more indigenous basalt, which is depleted in trace metals, compared to the more quartz-feldspar-rich Hanford fine sand and Ringold silt composite samples. Alternatively, the larger particles have less available surface area to react with the acid. The Ringold silt releases a higher percentage of its elements into the acid extract, perhaps as a result of its more highly weathered state.

Table 4.14. Major Cations in Acid Extracts for Composite Sediment Samples.
Analyzed using the ICP method.

Constituent	Units	Ringold Silt	Hanford Coarse Sand	Hanford Fine Sand	Borehole Fine Sand
Na	µg/g	191	211	280	225
Mg	µg/g	12,553	3,029	6,537	5,690
Al	µg/g	23,256	4,067	11,908	8,954
Si	µg/g	11.1	82.3	20.0	38.1
P	µg/g	316 ^(a)	766 ^(a)	647 ^(a)	539 ^(a)
S	µg/g	43.5	62.7	142.5	47.9
K	µg/g	2,455	704	2,079	1915
Ca	µg/g	15,168	4,922	11,101	9674
Ti	µg/g	541	681	1,029	696
Mn	µg/g	648	187	429	316
Fe	µg/g	34,626	12,814	19,741	15,094
Sr	µg/g	41.2	19.9	50.8	37.3
Ba	µg/g	110	43.9	97.3	81.2
(a) Phosphorous data is suspect from spectral/matrix interferences.					

4.10 Exchangeable Base Cations

Exchangeable base cation data are shown in Tables 4.17 and 4.18. The sum of the base exchange cations gives intermediate values between the two cation exchange capacity measurements that were discussed in Section 4.7. The ammonium acetate extracts show that calcium is the dominant cation (~80% to 90% of the total) that can be displaced and magnesium also accounts for about 10% of the displaceable cations. The potassium and sodium make up the remainder of the cations. Barium and strontium make up less than 0.1% of the base exchangeable cations. In general, the ammonium acetate extraction yields an upper limit for the cation exchange capacity for calcareous sediment because it also dissolves some of the calcium carbonate present.

Table 4.15. Trace Metals in Acid Extracts of Composite Sediment Samples.
Analyzed using ICP or ICP-MS methods.

Constituent	Units	Ringold Silt	Hanford Coarse Sand	Hanford Fine Sand	Borehole Fine Sand
Be	µg/g	0.94	0.16	0.41	0.34
B	µg/g	2.09	10.42	7.25	8.55
Cr ^(a)	µg/g	39.7	4.3	17.2	14.9
Cr	µg/g	40.5	4.5	16.7	14.5
Co	µg/g	16.2	6.5	11.5	7.6
Ni	µg/g	35.4	5.7	16.6	12.8
Cu	µg/g	27.4	9.2	12.7	8.9
Zn	µg/g	Conflict ^(b)	Conflict ^(b)	Conflict ^(b)	Conflict ^(b)
As ^(a)	µg/g	15.9	1.0	2.9	3.9
Se ^(a)	µg/g	<0.3	<0.3	<0.3	<0.3
Mo ^(a)	µg/g	0.27	0.14	0.17	0.24
Tc ^(a,c)	pCi/g	<0.03	<0.03	<0.03	<0.03
Ru ^(a)	µg/g	<0.001	<0.001	<0.001	<0.001
Ag ^(a)	µg/g	0.022	0.038	0.055	0.045
Cd ^(a)	µg/g	0.137	0.044	0.077	0.080
Pb ^(a)	µg/g	14.90	2.45	6.38	5.93
Pb	µg/g	14.22	2.84	6.07	5.40
U ^(a)	µg/g	0.95	0.32	0.59	0.62
<p>(a) Inductively coupled plasma mass spectrometry (ICP-MS) instrument was used; when not noted, ICP was used.</p> <p>(b) There were two spectral lines for zinc that were monitored and they gave conflicting data for samples and standards. We did not feel it was useful to pursue resolution of this problem at this time.</p> <p>(c) Values in bold are converted to activity per gram.</p>					

Table 4.16. Percentage of the Total Element that Dissolves During Acid Extraction of Composite Sediment Samples

Constituent	Ringold Silt	Hanford Coarse Sand	Hanford Fine Sand	Borehole Fine Sand
Na	3%	1%	2%	1%
Mg	40%	16%	29%	30%
Al	26%	5%	16%	13%
Si	0%	0%	0%	0%
P	40%	81%	67%	61%
S	19%	22%	31%	20%
K	10%	4%	13%	10%
Ca	87%	16%	40%	43%
Ti	13%	13%	22%	21%
Mn	101%	27%	65%	68%
Fe	81%	30%	56%	61%
Sr	26%	4%	14%	11%
Ba	14%	6%	16%	12%
Cr ^(a)	43%	10%	28%	25%
Cr	44%	11%	27%	24%
Co	>25%	>10%	19%	>15%
Ni	75%	26%	53%	61%
Cu	77%	45%	56%	67%
As ^(a)	69%	28%	65%	111%
Se ^(a)	--	--	--	--
Mo ^(a)	>11%	>6%	>7%	>10%
Ag ^(a)	>0%	>0%	>1%	>1%
Cd ^(a)	>1%	>0%	>1%	>1%
Pb ^(a)	60%	19%	47%	35%
Pb	57%	23%	45%	32%
U ^(a)	>12%	>5%	9%	>9%
(a) Inductively coupled plasma mass spectrometry (ICP-MS) instrument was used; when not noted, ICP was used. -- = selenium concentration in both measurements were < values.				

Table 4.17. Chemical Composition of Ammonium Acetate Extraction for Composite Sediment Samples

Composite Name	meq/L						µg/L		
	Ba	Ca	K	Mg	Sr	Na	Fe	Mn	Si
Ringold Silt	0.10	60.09	1.48	8.30	0.11	1.51	<0.25	0.001	9.03
Hanford Coarse Sand	0.05	28.80	1.36	4.67	0.06	0.53	<0.25	1.336	7.53
Hanford Fine Sand	0.06	43.87	1.32	9.23	0.09	1.03	<0.25	0.026	13.03
Hanford Fine Sand (duplicate)	0.06	44.89	1.35	9.33	0.10	1.06	<0.25	0.026	13.04
Borehole Fine Sand	0.08	30.01	0.84	3.87	0.06	0.84	0.02	0.490	8.12

Table 4.18. Exchangable Base Cations Compared to Cation Exchange Capacities Estimates for Composite Sediment Samples

Composite Name	Ammonium Acetate							Polemio and Rhoades (1977)	Amrhein and Suarez (1990)
	meq/100 g							meq/100 g	
	Ba	Ca	K	Mg	Sr	Na	Sum		
Ringold Silt	0.024	14.057	0.347	1.941	0.026	0.353	16.75	28.5 ± 2.4	11.6 ± 1.1
Hanford Coarse Sand	0.012	6.743	0.317	1.094	0.014	0.124	8.30	12.2 ± 2.1	1.7 ± 0.3
Hanford Fine Sand	0.014	10.431	0.314	2.181	0.022	0.246	13.21	18.4 ± 2.7	7.8 ± 3.8
Borehole Fine Sand	0.019	6.992	0.196	0.902	0.013	0.196	8.32	9.2 ± 8.9	2.9 ± 0.6

5.0 Analytical Results for Clean Borehole Samples

5.1 Analytical Results for Borehole 299-W22-48

Laboratory analytical results of core samples from clean borehole 299-W22-48 are presented in this section. Sample depths, stratigraphic unit, and types of laboratory analyses performed are summarized in Table 5.1. Sampling depths for laboratory moisture analysis are listed in a separate table (Table 5.2).

Table 5.1. Sediment Core Samples Selected from Borehole 299-W22-48 for Laboratory Analysis

Depth (ft bgs) ^(a)	Stratigraphic Unit*	Analysis
1	H1a	WL
6	H1a	WL
9.5	H1a	WL
12.5	H1a	WL
14.5	H1a	WL
17	H1a	WL
19.5	H1a	WL
22	H1a	WL
24.5	H1a	WL
27	H1a	WL
29.5	H1a	CaCO ₃ , WL
32	H1a	CaCO ₃ , WL
37	H1a	DS, WL
39.5	H1a	DS, AL, WL, HY, XRD, XRF, CEC, PD, CaCO ₃ , EBC, WL
42	H1	DS, WL
44.5	H1	DS, WL
47	H1	DS, AL, WL, HY, XRD, XRF, PD, CaCO ₃ , EBC, WL
50	H1	DS, WL
53.5	H1	DS, WL
56	H1	DS, CaCO ₃ , WL
57.5	H1	DS, WL
62	H2	DS
64.5	H2	DS
67	H2	DS
69.5	H2	DS
70	H2	DS
74.5	H2	DS, CaCO ₃ , WL
77	H2	DS, AL
91.5	H2	DS, AL, WL, HY, XRD, XRF, CEC, PD, CaCO ₃ , EBC, WL, PW
101.5	H2	DS, AL, WL, HY, XRD, XRF, CEC, PD, CaCO ₃ , EBC, WL, PW
106.5	H2	CaCO ₃ , WL

Table 5.1. (Contd)

Depth (ft bgs)	Stratigraphic Unit*	Analysis
115.5	H2	CaCO3, WL
136	PPlz	DS, AL, WL, HY, XRD, XRF, CEC, PD, CaCO3, EBC, WL
143.5	PPlz	CaCO3, WL
146	PPlc	AL, WL, HY, XRD, XRF, CEC, PD, CaCO3, EBC, WL
148.5	PPlc	AL, WL, HY, XRD, XRF, CEC, PD, CaCO3, EBC, WL
151	Rtf	CaCO3, WL
163.5	Rtf	DS, AL, WL, HY, XRD, XRF, CEC, PD, CaCO3, EBC, WL
170	Rtf	CaCO3, WL
172.5	Rtf	CaCO3, WL
187	Rtf	CaCO3, WL
192	Rwi(e)	AL, CaCO3, EBC, WL
(a) Multiply by 0.3048 to convert to meters. * See Table 2.1 AL = Acid leach (8M Nitric Acid Extraction) CEC = Cation Exchange Capacity CaCO3 = Calcium Carbonate and Organic Carbon DS = Dry sieve EBC = Exchangeable Base Cations (Ammonium Acetate Extraction) HY = Hydrometer/wet sieve PD = Particle Density PW = Porewater Analysis WL = Water leach (1:1 Sediment-to-Water Extraction) XRD = Mineralogy XRF = Bulk chemical composition		

5.1.1 Mass Water Content

For borehole 299-W22-48, only about ~25% of the cores were opened in the laboratory and sampled for moisture, along with other parameters. However, moisture samples were collected at least every 1.6 meters (5 feet) in the field from the drive shoe of the split-spoon during drilling. Thus, a relatively complete moisture profile is available for borehole 299-W22-48. Moisture data for borehole 299-W22-48 are listed in Table 5.2; a vertical profile of the moisture distribution is illustrated in Figure 2.19. In Figure 2.19, moisture samples collected in the field from the drill shoe are distinguished from those collected later in the laboratory from core liners.

The moisture data in Figure 2.19 show two zones of higher moisture within the Hanford formation H2 unit at about 90 and 105 feet below ground surface (bgs). These are probably associated with thin lenses of fine sand and/or silt that often occur at the tops of graded sand beds within the Hanford formation. The PPlc subunit between 44.4 to 44.9 meters (146 to 149 feet) bgs, displays relatively high moisture content, as does a clastic dike within the upper Ringold unit (Rtf) at 151.8 meters (170 feet) bgs. There is moderate agreement between the laboratory-measured moisture samples and the moisture

Table 5.2. Moisture Content (wt%) Measured in Laboratory for Sediment Samples from Borehole 299-W22-48

Core Liner				Drill Shoe			
Depth (ft bgs) ^(a)	Moisture Content (wt%)	Depth (ft bgs)	Moisture Content (wt%)	Depth (ft bgs)	Moisture Content (wt%)	Depth (ft bgs)	Moisture Content (wt%)
1	3.87	82	3.90	10.5	9.22	105	12.76
6	9.12	84.5	4.46	15	6.67	110	2.79
9.5	4.86	86.5	5.43	20	9.46	115	4.37
12	6.21	91.5	19.14	25	2.41	120	4.56
14.5	7.63	96.5	9.62	30	8.77	125	2.79
17	5.92	101.5	21.62	35	6.06	130	2.14
19.5	7.70	106.5	5.50	40	3.97	135	7.79
22	5.03	111.5	3.14	45	3.08	145	3.80
24.5	2.22	115.5	5.29	50.5	5.31	150	4.25
27	6.04	120.5	3.81	55	3.31	155	2.24
29	10.60	124	2.66	60	2.83	160	1.99
32	5.33	126.5	2.60	65	3.50	165	2.24
34.5	3.85	131.5	2.88	70.5	2.15	170	14.29
37	5.58	134	3.51	75	2.36	175	2.14
39.5	7.90	136	5.70	80	2.40	180	2.52
42	2.80	143.5	3.83	85	7.20	185.5	2.65
44.5	2.53	146	14.86	90	3.15	190.5	2.22
47	1.88	148.5	13.58	95	4.36	192	2.34
50	5.25	151	2.81	100	4.50		
53.5	2.41	155	2.11				
56	3.91	158.5	2.18				
57.5	2.83	163.5	1.88				
62	2.56	167.5	1.87				
64.5	2.23	170	2.99				
67	3.68	172.5	4.97				
69.5	2.43	176	2.84				
72	2.64	182	1.84				
74.5	6.56	187	2.32				
77	3.55	192	2.21				
79.5	3.24	235	10.47				

(a) Multiply by 0.3048 to convert to meters.

content as determined with the neutron probe (see Appendix C and Horton and Johnson 2000), though maxima in one set of data are frequently not observed in the other set (see Figure 2.19).

5.1.2 Particle-Size Distribution

Both dry sieving and the wet sieving/hydrometer methods were used to determine the particle-size distribution for selected depths in borehole 299-W22-48. The results for dry sieving are presented in Table 5.3 and wet sieving in Table 5.4. An estimate of particle-size distribution, using visual-manual techniques, is also standard practice during geologic logging of the borehole (Appendices A and B). The results of geologic logging and dry sieve analysis helps to define the top contact of the coarse-grained Hanford formation H1 unit at 12.4 meters (41 feet) bgs; the bottom contact appears less pronounced at about 18.6 meters or 61 feet (Figure 2.19).

The wet sieving data presented in Table 5.4 are skewed toward finer particle-size distributions, compared to the results of dry sieving (see Table 5.3). This is a similar trend observed for composite sediment samples (see Section 4.2). Table 5.5 shows a comparison between the wet sieving/hydrometer data and the dry sieving data. The most significant difference in results between the two methods occurs for the PPlz subunit sample (41.4 meters or 136 feet bgs) where the sand content decreases from 60% to

Table 5.3. Dry Sieve Results from Borehole 299-W22-48

Depth (ft bgs) ^(a)	Stratigraphic Unit	Gravel (wt%)	Sand (wt%)	Silt/Clay (wt%)
37	H1a	0.60	91.40	7.74
39.5	H1a	1.42	89.80	8.78
42.5	H1	63.17	36.83	
44.5	H1	63.26	36.74	
47	H1	73.38	22.98	3.64
50	H1	19.46	76.70	3.84
53.5	H1	21.22	77.71	1.07
56	H1	9.46	88.02	2.52
57.5	H1	2.96	92.39	4.66
62	H2	0.29	94.52	5.19
64.5	H2	0.06	95.38	4.56
67	H2	0.99	96.06	2.95
70	H2	0.96	99.04	2.89
69.5	H2	1.58	94.26	4.17
74.5	H2	1.74	86.46	11.81
77	H2	0.02	89.77	10.21
91.5	H2	0.39	94.60	5.01
101.5	H2	0.01	98.11	1.88
136	PPlz	1.06	60.33	38.56
163.5	Rtf	0.00	94.18	5.79

(a) Multiply by 0.3048 to convert to meters.

Table 5.4. Particle-Size Distribution Determined by Wet Sieving/Hydrometer Method

Sample (ft bgs) ^(a)	Stratigraphic Unit	Gravel (wt%)	Sand (wt%)	Silt (wt%)	Clay (wt%)
39.5	H1a	0.16	77.59	20.58	1.68
47	H1a	64.64	18.69	15.13	1.55
91.5	H2	0.25	70.65	26.99	2.11
101.5	H2	0	78.71	18.82	2.47
136	PPlz	0.01	18.45	75.89	5.65
146	PPlc*	52.36	27.11	15.23	5.3
148.5	PPlc*	26.31	59.86	10.32	3.5
163.5	Rtf	0.01	89.00	9.67	1.32

(a) Multiply by 0.3048 to convert to meters.
 * Wet sieving samples with high wt% of calcium carbonate dissolves several wt% of the starting mass, which may affect reported values.

Table 5.5. Comparison of Particle-Size Distributions for Dry Versus Wet Sieving

Depth ^(a)	Stratigraphic Unit	Type	Gravel (wt%)	Sand (wt%)	Silt/Clay (wt%)
39.5	H1a	Dry	1.42	89.8	8.78
		Wet	0.16	77.6	22.24
47	H1	Dry	73.4	23.0	3.6
		Wet	64.6	18.7	16.7
91.5	H2	Dry	0.39	94.6	5.01
		Wet	0.25	70.6	29.2
101.5	H2	Dry	0.01	98.11	1.88
		Wet	0	78.7	21.3
136	PPlz	Dry	1.06	60.33	38.56
		Wet	0.01	18.4	81.6
163.5	Rtf	Dry	0	94.18	5.79
		Wet	0.01	89.0	11.0

(a) Multiply by 0.3048 to convert to meters.

18% upon wet sieving. At the same time there is an increase in the silt /clay content with the wet sieved sample. This suggests that the PPlz subunit sample contained many sand-sized aggregates of silt/clay that tend to cling together, perhaps via static electrical forces generated during dry sieving. These electrical forces leading to aggregation disperse upon being wetted with a sodium hexametaphosphate dispersing agent. Thus, the wet sieve method appears superior to the dry sieve method. Most particle-size distributions of Hanford sediment have used the dry sieving technique; the particle-size distributions for the fine-grained fractions of these samples may underestimate the amount of fines in these samples.

Figure 5.1 graphically shows the particle-size distribution (based on wet sieving/hydrometer data) of the four shallower samples (i.e., Hanford formation), and Figure 5.2 shows the distribution for four of the samples collected for particle-size analysis from the Plio Pleistocene unit and Ringold Formation. As

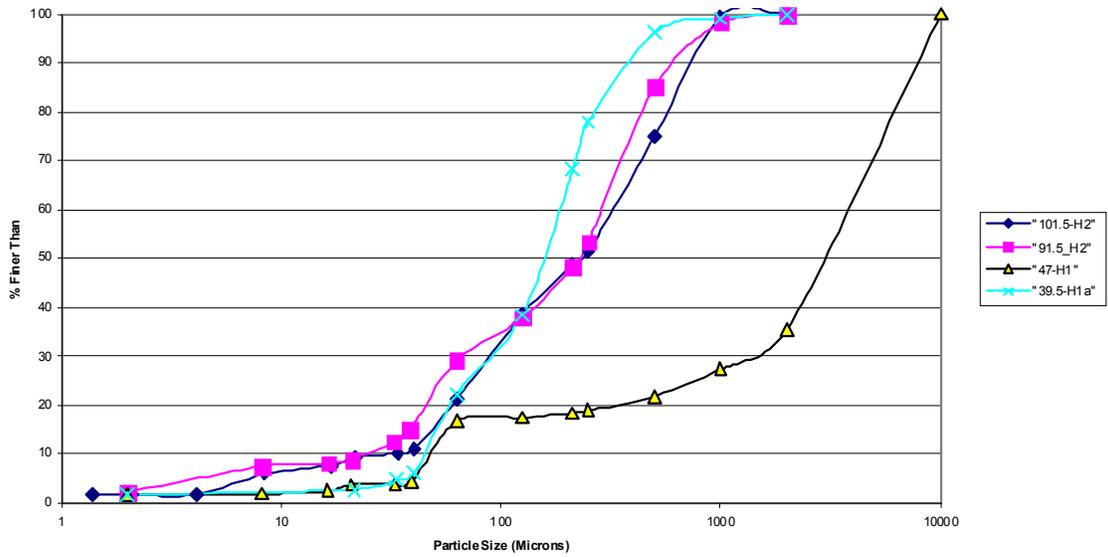


Figure 5.1. Particle-Size Distributions Curves of Hanford Formation Sediment Samples from Borehole 299-W22-48

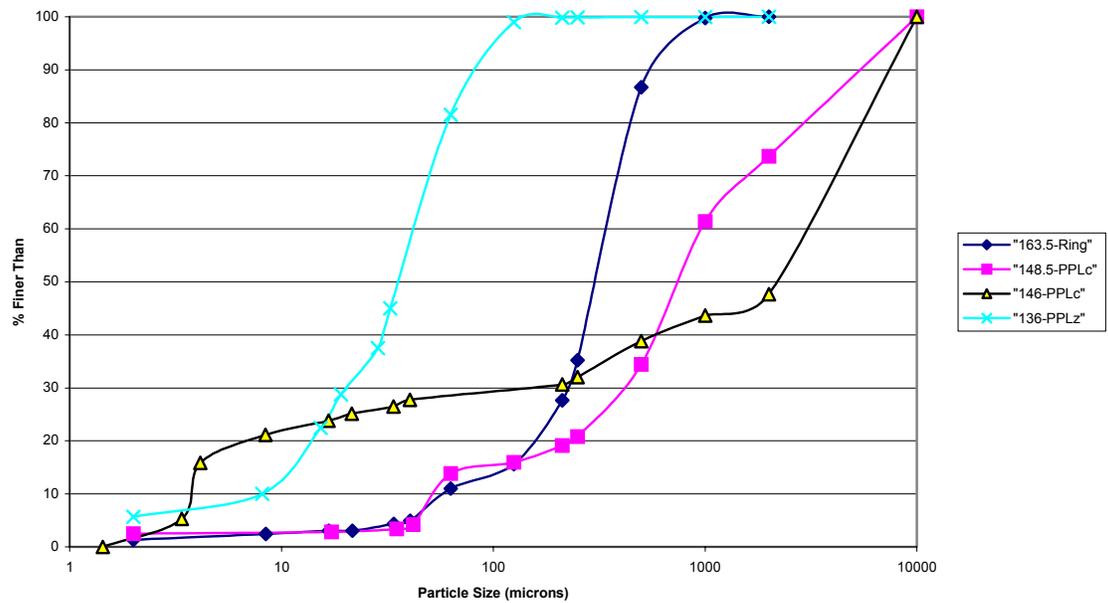


Figure 5.2. Particle-Size Distribution Curves of Sediment Samples below 41.4 meters (136 feet) bgs in Borehole 299-W22-48. Cemented samples from the PPLc subunit could not be completely disaggregated, and, therefore, are not considered representative of the true particle-size distribution of this unit.

represented in Figure 5.1, gravelly sand of the Hanford formation H1 unit is much coarser than strata directly above or below this unit. Figure 5.2 illustrates how the PPlz and Rtf unit samples consist of many fine-grained sedimentary aggregates, compared to the PPlc subunit, which consists of many calcium-carbonate cemented aggregates of widely varying sizes. Because particles within the PPlc subunit are cemented together with pedogenic calcium carbonate an accurate grain-size distribution cannot be obtained for the PPlc via either sieving method. Another more accurate method to determine the particle-size distribution for the PPlc subunit would be to perform a petrographic analysis, or totally dissolve away all the carbonate cement, which makes up the bulk of the sample, and sieve the remaining solid particles.

5.1.3 Particle Density

The particle density of bulk sediment samples was determined for selected aliquots from the borehole 299-W22-48 using pycnometers. The results are shown in Table 5.6.

The particle densities in Table 5.6 reflect the mineral composition of the Hanford formation, Plio-Pleistocene, and upper Ringold units, which are composed of mostly quartz, plagioclase, and potassium feldspar (discussed in Section 5.1.6). Although the values in Table 5.6 are slightly lower than those reported by Serne et al. (1993), the differences are small, likely caused by slight differences in analytical technique, and are not considered significant for most experimental applications in which standards would be used. Greater particle density (2.76) for the 14.3-meter (47-foot) sample is probably a reflection of a greater number of basalt particles in the Hanford formation H1 unit. In contrast, relatively low particle densities for the PPlc subunit are a direct reflection of the lower density for caliche (i.e., calcium carbonate).

5.1.4 Calcium Carbonate and Organic Carbon Content

Carbon results for borehole 299-W22-48 are shown in Table 5.7; the calculated calcium carbonate equivalent (in terms of grams of calcite per gram of oven-dry sediment) is also presented. In general, the

Table 5.6. Particle Densities for Selected Sediment Samples from Borehole 299-W22-48

Depth (ft bgs) ^(a)	Stratigraphic Unit	Particle Density (g/cm ³)	Standard Deviation (3 trials)
39.5	H1a	2.682	0.005
47	H1	2.762	0.003
91.5	H2	2.667	0.034
101.5	H2	2.620	0.016
136	PPlz	2.661	0.003
140	PPlz	2.680	0.007
146	PPlc	2.535	0.011
148	PPlc	2.604	0.012
163.5	Rtf	2.651	0.011
(a) Multiply by 0.3048 to convert to meters.			

Table 5.7. Calcium Carbonate and Organic Carbon Content (wt%) for Sediment Samples from Borehole 299-W22-48

Depth (ft bgs) ^(a)	Stratigraphic Unit	Total Carbon (%)	Inorganic Carbon (%)	Inorganic as CaCO ₃ (%)	Organic Carbon (%)
29.5	H1a	0.18	0.16	1.33	0.02
32	H1a	0.14	0.10	0.83	0.04
39.5	H1a	0.24	0.21	1.75	0.03
47	H1	0.20	0.15	1.25	0.05
56	H1	0.28	0.22	1.83	0.06
74.5	H2	0.29	0.24	2.00	0.05
74.5	H2	0.31	0.26	2.17	0.05
91.5	H2	0.26	0.22	1.83	0.04
101.5	H2	0.43	0.39	3.25	0.04
106.5	H2	0.25	0.22	1.83	0.03
115.5	H2	0.27	0.26	2.17	0.01
136	PPlz	0.40	0.35	2.92	0.05
143.5	PPlc	0.52	0.44	3.67	0.08
146	PPlc	4.78	4.60	38.37	0.17
148.5	PPlc	4.64	4.56	38.00	0.08
151	Rtf	0.16	0.13	1.08	0.03
163.5	Rtf	0.12	0.09	0.75	0.03
170	Rtf	0.15	0.13	1.08	0.02
172.5	Rtf	0.15	0.14	1.17	0.01
187	Rtf	0.02	0.01	0.08	0.01
192	Rwi(e)	0.02	0.01	0.08	0.01

(a) Multiply by 0.3048 to convert to meters.

calcium carbonate values for the Hanford formation, which range between about 1 and 5 wt%, are typical for those reported elsewhere (e.g., Last et al. 1989). Samples from the PPlc subunit between 44.4 and 44.8 meters (146 and 149 feet) bgs have naturally high calcium carbonate (up to 40 wt%) due to pedogenic alteration and secondary cementation with calcium carbonate. The calcium carbonate content decreases sharply again in the underlying upper Ringold unit (Rtf), which lies below the PPlc (Figure 2.19).

The method used to measure the organic carbon relies on subtracting the inorganic carbon from the total carbon in the sample; for such low carbon values this method is not very accurate. The low values for organic carbon are within the ranges generally reported for sediment at the Hanford Site but if more accurate values are desired then a different, more sensitive method should be used.

5.1.5 Bulk Chemical Composition

The bulk chemical composition of core samples from borehole 299 W22-48, as determined by x-ray fluorescence (XRF) and converted to oxides (see Section 3.2.5), is shown in Table 5.8. We have

Table 5.8. Bulk Chemical Composition of Sediment Samples from Borehole 299-W22-48 (wt% as oxides)

Depth (ft bgs) ^(a)	39.5	47	91.5	101.5	136	146	148.5	163.5
Stratigraphic Unit	H1a	H1	H2	H2	PPlz	PPlc	PPlc	Rtf
Oxides								
Na ₂ O	2.25	2.68	2.26	2.25	1.62	0.63	1.06	2.01
MgO	3.32	4.23	3.00	3.35	4.14	7.24	4.16	2.97
CO ₂	0.84	0.60	0.88	1.56	1.40	18.39	18.24	0.36
Al ₂ O ₃	14.19	14.55	13.13	13.36	13.21	6.24	8.03	13.11
SiO ₂	70.17	62.15	72.20	72.31	67.39	36.43	43.47	73.91
P ₂ O ₅	<0.21	<0.25	<0.20	<0.21	<0.20	<0.32	<0.32	<0.19
SO ₃	0.08	0.12	0.06	0.09	0.06	0.39	0.32	0.06
Cl	0.04	<0.02	0.04	0.04	0.03	<0.02	<0.02	0.04
K ₂ O	2.52	1.49	2.61	2.52	2.31	0.97	1.52	2.90
CaO	3.16	7.72	3.16	3.24	3.37	24.08	20.90	2.08
TiO ₂	0.61	1.53	0.52	0.59	0.64	0.55	0.39	0.54
V ₂ O ₅	0.01	0.05	0.01	0.01	0.01	0.02	0.01	0.01
Cr ₂ O ₃	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00
MnO	0.07	0.14	0.06	0.06	0.06	0.25	0.05	0.05
Fe ₂ O ₃	4.00	9.64	3.46	3.89	4.13	3.41	3.06	3.36
SrO	0.04	0.04	0.04	0.04	0.03	0.04	0.04	0.03
BaO	0.09	0.07	0.09	0.09	0.07	0.04	0.05	0.08
Total	101.61	105.28	101.75	103.63	98.67	99.01	101.65	101.70
(a) Multiply by 0.3048 to convert to meters.								

assumed that the iron present in the sediment is all ferric oxide though there may be some reduced (ferrous oxide) iron as well. We have adjusted the total content to reflect the presence of calcium carbonate by converting the calcium carbonate in Table 5.7 back to percent carbon dioxide and adding it to the XRF totals.

The data in Table 5.8 suggest two trends in bulk chemical composition that are a direct reflection of the geology. The most obvious trend is the substantial increase in calcium oxide and carbon dioxide in the calcic PPlc subunit (44.4 to 44.8 meters or 146 to 149 feet bgs). Less striking is a decrease in potassium oxide and increases in calcium oxide and iron oxide in the gravelly Hanford formation H1 unit (14.3 meters or 47 feet bgs), compared to the strata above and below. This trend is consistent with the higher basalt content for coarser-grained facies of the Hanford formation. Basalt is composed of the minerals plagioclase and pyroxene, which are more concentrated in the elements calcium and iron, respectively. There also appears to be a decrease in sodium oxide and an increase in magnesium oxide in the PPlz subunit at 41.4 meters (136 feet) bgs relative to the overlying H2 unit of the Hanford formation. Similar trends are noted in samples from borehole 299-W22-50 (to be discussed later) and probably represent differences in the mineralogy and/or grain size of the various sediment types.

The calculated mass balances range between 98% and 105% with a mean of 101 ± 2 wt% for the 14 samples.

5.1.6 Mineralogy

The mineralogy of the bulk, as well as the silt- and clay-size fractions from selected depths from boreholes 299-W22-48 and -50 was determined by x-ray diffraction (XRD) techniques (see Section 3.2.6). The results for both boreholes are so similar that the data will only be presented once here and in Appendix H. In fact, aside from differences in the amount of calcite present in the PPlc subunit between the two boreholes, the overall XRD-determined mineralogy for a given geologic unit is almost identical. Table 5.9 presents the semiquantitative mineralogical distribution for the bulk sediment samples and Table 5.10 presents data for the clay-size fraction only from borehole 299-W22-48.

Sediment in both boreholes was largely dominated by quartz (~45% to 95%), plagioclase feldspar (~10% to 20%), and alkali feldspar (~20% to 40%). Minor amounts of mica, chlorite, and amphibole were also detected in the samples. As expected, the Plio-Pleistocene unit caliche (44.4 to 44.8 meters or 146 to 149 feet bgs) in borehole 299-W22-48 is predominantly composed of calcite (~40%). Lesser mineral constituents included quartz (~20% to 25%), plagioclase feldspar (~10% to 20%), and potassium feldspar (<10%).

Additionally, the silt fraction from selected depths was examined by XRD and appeared similar to the bulk sediment in mineral content. XRD patterns of the bulk and silt fractions along with semiquantitative measurements of the non-clay minerals in the bulk sediment are presented in Appendix H for both boreholes.

Table 5.9. Semiquantitative Mineral Content (wt%) for Sediment Samples from Borehole 299-W22-48–Bulk Sediment Sample

Sample Depth (ft bgs) ^(a) (Stratigraphic Unit)	Quartz	K-Feldspar	Na-Feldspar	Calcite	Total
39.5 (H1a)	60	<5	20	ND	~85
47 (H1)	20	<5	15	10	~50
91.5 (H2)	45	40	15	ND	~100
101.5 (H2)	95	<5	20	ND	~115
136 (PPlz)	80	30	10	ND	~120
146 (PPlc)	25	<5	10	40	~80
148.5 (PPlc)	25	10	20	40	~95
163.5 (Rtf)	65	20	10	ND	~95

(a) Multiply by 0.3048 to convert to meters.
ND = Not detected.

Table 5.10. Semiquantitative Mineral Content (wt%) for Sediment Samples from Borehole 299-W22-48–Clay-Size Fraction Only

Sample Depth (ft bgs) ^(a) (Stratigraphic Unit)	Quartz	Feldspar	Calcite	Smectite	Illite	Chlorite	Kaolinite	Total
39.5 (H1a)	<5	<5	Trace	25	20	15	<5	~75
47 (H1)	<5	<5	5	10	10	10	<5	~50
91.5 (H2)	<5	<5	Trace	20	35	20	<5	~90
101.5 (H2)	10	<5	Trace	25	35	35	10	~120
136 (PPlz)	10	<5	Trace	20	30	20	10	~95
146 (PPlc)	<5	<5	40	15	10	10	<5	~90
148.5 (PPlc)	<5	<5	40	<5	10	<5	<5	~85
163.5 (Rtf)	10	<5	ND	30	50	30	<5	~130

(a) Multiply by 0.3048 to convert to meters.
 ND = Not detected.
 Trace = Trace amount detected (<5%).

The clay fraction of sediment samples from both boreholes is dominated by the following four major clay minerals: smectite (17.0 Å), illite (10.0 Å), chlorite (14.1 Å), and kaolinite (7.0 Å). The individual XRD patterns of magnesium (II) -saturated, ethylene-glycol solvated clay fractions are presented in Appendix H. The smectite (001) basal reflection expanded to 17 Å when saturated with ethylene glycol. Illite had a (001) basal reflection of 10.0 Å and a (002) basal reflection of 5.0 Å. Presence of chlorite was confirmed by the (001) basal reflection at 14.1 Å, in addition to the (003) and (004) reflections at 4.74 Å and 3.52 Å, respectively. The identification of kaolinite is based on the (002) reflection. The first two basal reflections for kaolinite, (001) and (002), have d-spacing of 7.1 Å and 3.58 Å, which overlap the chlorite (002) and (004) basal reflections, making identification difficult. Careful examination of the XRD patterns from both boreholes showed a kaolinite (002) reflection on the shoulder of the chlorite (004) reflection. Minor amounts of quartz, feldspar, calcite, and amphibole were detected in the clay fraction of both boreholes, along with substantial amounts of calcite from the PPlc subunit (44.4 to 44.8 meters or 146 to 149 feet bgs) in borehole 299-W22-48. Additionally, transmission electron microscopy (TEM) analysis of the clay fractions confirmed the presence of kaolinite and identified trace amounts of minerals such as iron oxide, anatase, apatite, and sepiolite.

The XRD semiquantitative measurements of minerals in the clay fraction are given in Appendix H. Quantitative measurements of the clay minerals were made after the removal of calcite, and measurements of non-clay minerals (calcite, quartz, amphibole, and feldspar) were made prior to any treatments. Overall, smectite (17.1 Å) ranged in concentration from 10 to 30 (wt%). Illite (10 Å) concentrations ranged from ~10% to 50% and chlorite (14.1 Å) concentrations were a little less (~5 to 35 wt%). Minor amounts of kaolinite (~5% to 10%) were also detected. Quartz, feldspar, and amphiboles made up less than ~15 wt% of the clay fraction. Approximately 40 wt% calcite was detected in the clay fraction from the PPlc subunit (44.4 and 45.1 meters or 146 and 148.5 feet bgs) in borehole 299-W22-48, which is consistent with the amount of calcium carbonate measured via inorganic carbon analysis (see Section 5.1.4). Less calcite (~25 wt%) was observed within the PPlc unit in borehole 299-W22-50.

Total mass balance for the clay fraction ranged from a low of 45 wt% to a high of 130 wt%. Recoveries ranging from 80% to 120% are considered acceptable for XRD semiquantification (Newman 1987). Low recoveries for semiquantitative measurements by XRD can be attributed to several factors. The clay fractions having a significant amount of calcite removed during treatment generally produced low recoveries. The <2-micron fractions in borehole 299-W22-48 (14.3 meters or 47 feet bgs) and borehole 299-W22-50 (50, 60, and 140 feet bgs) had calcite concentrations between 5 to 25 wt%. After treatment to remove calcite from these depths, the amount of clay remaining was not adequate to prepare a sample valid for semiquantitative measurements. Sample degradation (peeling, curling clay substrates) also added to the problem.

The only consistent trend in the mineral content of samples from borehole 299-W22-48 is the substantial increase in calcite, relative to other minerals, for the PPlc subunit. This trend is noted in both the bulk sample as well as the ≤ 2 -micron fraction.

Analysis of illites by TEM from borehole 299-W22-48 (39, 91.5, and 163.5 feet bgs) and 299-W22-50 (15.8 and 35.3 meters or 50 and 116 feet bgs) showed large angular platy particles. Figure 5.3 is an example of a typical illite particle with minor amounts of iron. Using data from TEM analysis and assuming all iron as iron (III), the following structural formula was calculated from data collected from 10 illite particles in sample 49.8 meters (163.5 feet) bgs:

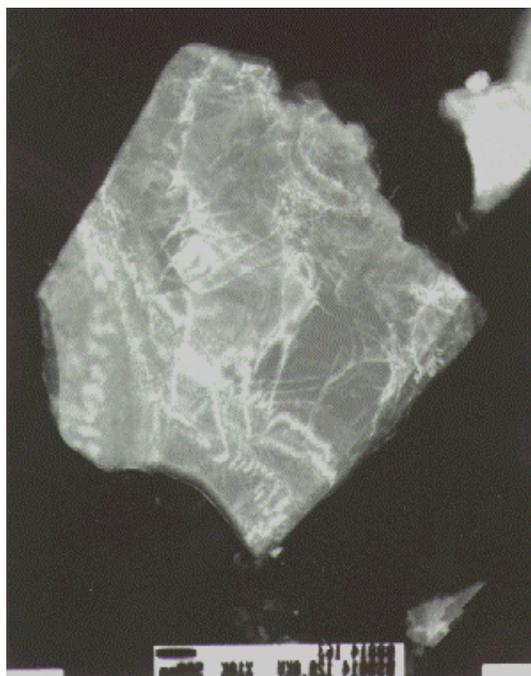
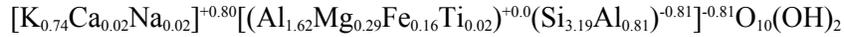


Figure 5.3. Typical Illite Particle from Borehole 299-W22-48 (163.5 feet bgs)



As in muscovite, the layer charge in illite originates from the substitution of Al^{3+} for Si^{4+} in the tetrahedral sheet. No excess layer charge is created with the minor substitutions of Mg^{2+} , Fe^{3+} , and Ti^{4+} for Al^{3+} in the octahedral sheet. The interlayer charge of +0.80 balances the charge on the 2:1 silicate structure. Iron content varied from a low of 0.04 to a high of 0.26 atoms per $\text{O}_{10}(\text{OH})_2$. Examination of illites from four other depths showed similar chemistry and morphology to the illites in the 49.8-meter (163.5-foot) bgs depth sample.

Chlorite particles were typically found at all depths in both boreholes. The particles were characterized as large platy particles with angular edges. Figure 5.4 is an example of a chlorite particle from the Hanford formation H2 unit in borehole 299-W22-48 (27.9 meters or 91.5 feet bgs). The chlorite particle is the large platy particle in the lower half of the figure. Chemistry of the chlorite particles ranged between magnesium-rich and iron-rich varieties. Assuming all the iron is ferrous, a structural formula was developed for similar chlorite particles examined from 27.9 meters (91.5 feet) bgs in borehole 299-W22-48:

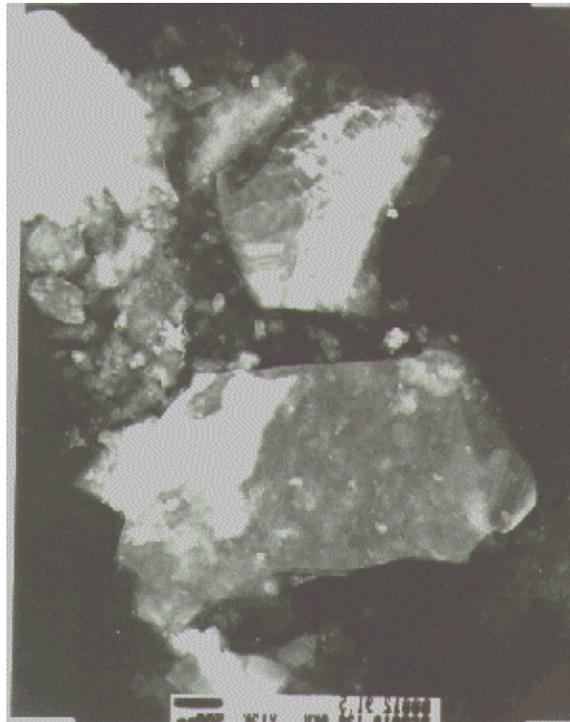
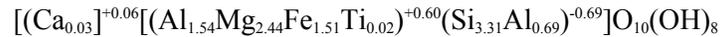


Figure 5.4. Chlorite Particle from Borehole 299-W22-48 (91.5 ft bgs)

The layer charge of -0.69 resulting from the Al³⁺ substituting for Si⁴⁺ in the tetrahedral sheet is compensated by the charge derived from substitution in the octahedral sheet. Fe⁺² content varied from a low of 1.22 to a high of 1.57 atoms per O₁₀(OH)₈ whereas Mg⁺² ranged from a low of 1.72 to a high of 3.38 atoms per O₁₀(OH)₈. Minor amounts of Ti⁺⁴ were routinely detected in chlorite particles along with trace amounts of Ca⁺², Na⁺¹, and K⁺¹.

Smectite clay mineralogy was examined by TEM and was mostly limited to the smaller size particles (<0.5 microns) in the sample. Figure 5.5 is an example of fine delicate smectite flakes with thin curled edges common to the Rtf unit 49.8 meters (163.5 feet) bgs in borehole 299-W22-48.

Chemical composition of the smectites was hard to establish, due in part to the difficulty of isolating the aggregates from other minerals in the sample during TEM analysis. Considering this limitation, a structural formula was developed using data collected from an average smectite particle at the 49.8-meter (163.5-foot) depth in borehole 299-W22-48:



Substitution of Al³⁺ into the tetrahedral site for Si⁴⁺ causes a layer charge of -0.28, which is balanced by the interlayer cations, Mg²⁺ and Ca²⁺. Occupying octahedral sites are trivalent cations (Al³⁺, Fe³⁺) and, in lesser amounts, the divalent cation (Mg²⁺). Trace amounts of Ti⁴⁺ were also detected in the octahedral sites of most smectites. Although only a few smectites were examined from

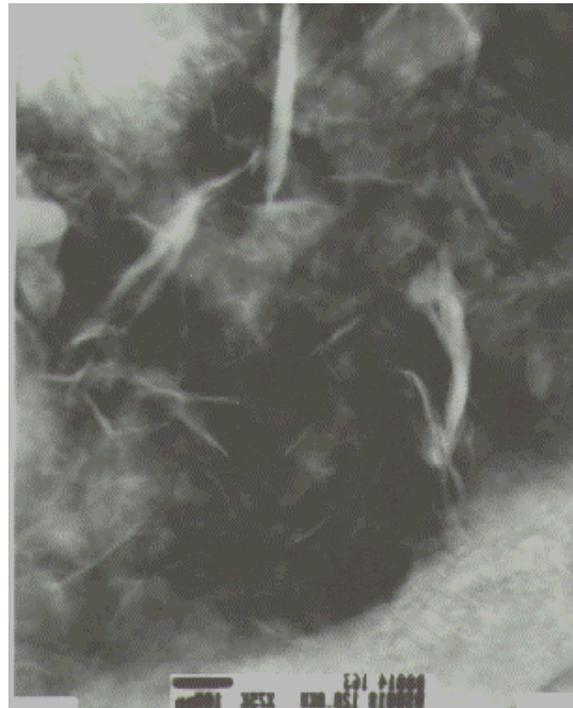
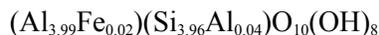


Figure 5.5. Thin Smectite Flakes from the Rtf Unit (163.5 ft bgs) in Borehole 299-W22-48

each depth by TEM, minor variations in chemistry were limited to the proportions of individual cations occupying octahedral sites. Smectite particles had Fe^{3+} ranging between 0.24 and 1.07, atoms per $\text{O}_{10}(\text{OH})_4$, which caused variations in the octahedral Al^{3+} content.

Kaolinite particles were platy in habit and often consisted of aggregates of smaller individual particles. Figure 5.6 is a very well-defined kaolinite particle with the characteristic hexagonal morphology.

Most kaolinite particles in borehole samples did not have a well-defined morphology like that in Figure 5.6 and, thus, were not easily identified by appearance. The structural formula developed from TEM data collected from kaolinite particles in borehole 299-W22-48 (27.9 meters or 91.5 feet bgs) is:



The ideal structure for kaolinite is $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$. The small amount of iron substitution into the octahedral sheet leads to a slight excess positive charge while the small substitution of Al^{3+} for Si in the tetrahedral sheet leads to a comparable excess negative charge. All kaolinites examined by TEM from both boreholes had some degree of Fe^{3+} substitution for Al^{3+} in the octahedral layer.



Figure 5.6. Kaolinite Particle from the H2 Unit in Borehole 299-W22-48 (91.5 ft bgs)

5.1.7 Cation Exchange Capacity

Values for cation exchange capacity collected for sediment samples in borehole 299-W22-48 are presented in Table 5.11. Results are reported using two different techniques, one by Polemio and Rhoades (1977) and the other by Amrhein and Suarez (1990), described in Section 3.2.7.

The greatest cation exchange capacity in Table 5.11 is associated with the PPlc subunit. The reason for this is uncertain in light of the XRD results, which indicate that the PPlc contains overall fewer clay minerals (Table 5.10). Clay minerals are generally thought to have a greater cation exchange capacity than other minerals. The PPlc subunit represents a well-developed calic paleosol that underwent extensive weathering and alteration, including translocation and concentration of clay minerals. The calcium carbonate cement in the PPlc subunit probably includes abundant clay-size particles, along with other grain-size fractions. We believe that clay particles are likely abundant in the PPlc unit but tightly bound together by the cement, which didn't disaggregate during sieving.

As reported for the composite samples (Section 4.7), the results obtained with the two different cation exchange capacity methods vary significantly. The Amrhein and Suarez method yields lower results than the Polemio and Rhoades technique. There is a large variation in the Polemio and Rhoades results for the 27.9-meter (91.5-foot) bgs sample and the Amrhein and Suarez results for the 45.3-meter (148.5-foot) bgs sample but, in general, the reproducibility for the other 12 sets of triplicates is good. It would appear that the Polemio and Rhoades method may not correct for calcium carbonate dissolution or, less likely, the Amrhein and Suarez method overcorrects. Presently, it is unclear which cation exchange capacity method is the most accurate.

The cation exchange capacity results from the Plio-Pleistocene unit presented in Table 5.11 are inconsistent with those from a previous study performed on contaminated sediment from borehole 41-09-39 (Myers et al. 1998) located within the SX Tank Farm. In the 41-09-39 borehole, <2-millimeter-size sediment was analyzed for cation exchange capacity using the Polemio and Rhoades method; results are presented in Table 5.12. Comparing results from the same method in Tables 5.11 and 5.12, it is apparent

Table 5.11. Comparison of Cation Exchange Capacity (meq/100 g) Between Sediment Samples from Borehole 299-W22-48 Using Two Different Analytical Methods

Depth (ft bgs) ^(a)	Stratigraphic Unit	Polemio and Rhoades (1977)	Amrhein and Suarez (1990)
39.5	H1a	16.5 ± 3.9	6.1 ± 0.2
91.5	H2	13.3 ± 7.0	4.8 ± 0.4
101.5	H2	16.3 ± 1.0	6.0 ± 0.4
136	PPlz	25.2 ± 3.0	8.9 ± 2.5
146	PPlc	39.6 ± 5.6	19.4 ± 2.2
148.5	PPlc	26.7 ± 0.8	13.2 ± 5.1
163.5	Rtf	15.7 ± 1.7	5.2 ± 0.2

(a) Multiply by 0.3048 to convert to meters.

Table 5.12. Additional Cation Exchange Capacity Data Obtained from Sediment Samples in Borehole 41-09-39 (from Myers et al. 1998)

Sample Number	Stratigraphic Unit	CEC (meq/100 g)
2C/D	PPlz	13.1
2A/B	PPlz	14.7
3A/B	PPlz	15.6
10A/B	PPlz	15.3
12A/B	PPlc	9.4
17A/B	Rtf	14.7
38A/B	Rwi(e)	1
47A/B	Rwi(e)	2.9
58A/B	Rwi(e)	3

that cation exchange capacity is about 3 times less for the PPlc subunit and about 1.5 times less for the PPlz subunit within the 41-09-39 borehole. We believe that the data in Table 5.11 may be biased high, based on data in Table 12 et al. (1988). Kaplan et al. (1998) published a set of cation exchange capacity values for eight samples from a Hanford formation sand sequence in the 200 East Area (borehole 299-E17-21). Their values ranged from 2.3 to 11 meq/100 g. Those values, though generally low, are more comparable to the values obtained by the Amrhein and Suarez method in this study. Interestingly, Kaplan et al. (1998) used the Polemio and Rhoades technique.

5.1.8 Exchangeable Base Cations

The results of base cation exchange, obtained via ammonium acetate extraction (see Section 3.2.8), are presented in Tables 5.13 and 5.14. Table 5.13 shows the base cations and iron, manganese, and silicon dissolved or displaced from the sediment. Calcium and magnesium (especially within the PPlc subunit) dominate the cations extracted by the ammonium acetate solution. The PPlc also shows higher concentrations of silicon are dissolved during the extraction. Table 5.14 shows the sum of the base cations displaced/dissolved from the sediment compared to the estimates of the cation exchange capacity presented in Section 5.1.7. In general, the sum of the displaced base cations falls between the values for the two cation exchange capacity measurement techniques, except for the two PPlc samples where the sum of the base cations is slightly lower than the Amrhein and Suarez estimates. The base cations that are displaced are dominated by alkaline earth elements (calcium and magnesium). The contribution of the alkali metals (sodium and potassium) to the natural distribution of exchangeable cations is small (<10%).

Table 5.13. Exchangeable Base Cation Composition of Sediment Samples in Borehole 299-W22-48

Sampling Depth (ft bgs) ^(a) [Stratigraphic Unit]	meq/L						µg/L		
	Ba	Ca	K	Mg	Sr	Na	Fe	Mn	Si
39.5 [H1a]	0.07	27.60	0.89	3.13	0.04	1.01	<0.25	0.782	8.58
47 [H1]	0.14	37.08	2.13	6.04	0.07	1.45	<0.25	1.119	9.74
91.5 [H2]	0.08	34.82	1.02	7.12	0.08	1.17	<0.25	0.101	8.34
101.5 [H2]	0.11	40.09	1.16	7.20	0.08	1.25	<0.25	0.050	9.02
136 [PPlz]	0.14	38.05	1.23	7.45	0.08	0.95	<0.25	0.238	10.56
146 [PPlc]	0.11	42.09	1.29	18.30	0.10	1.57	<0.25	<0.125	35.77
148.5 [PPlc]	0.07	37.62	0.92	11.91	0.09	0.93	<0.25	0.013	32.73
163.5 [Rtf]	0.06	26.83	0.80	5.63	0.05	0.57	<0.25	0.623	9.85
192 [Rwi(e)]	0.12	14.43	1.62	6.62	0.05	0.96	<0.25	0.836	10.19

(a) Multiply by 0.3048 to convert to meters.

Table 5.14. Comparison of the Base Cation Sum and Cation Exchange Capacity Measurements from Sediment Samples in Borehole 299-W22-48

Sampling Depth (ft bgs) ^(a) [Stratigraphic Unit]	Exchangeable Base Cations							Cation Exchange Capacity	
	meq/100 g							Polemio and Rhoades (1977)	Amrhein and Suarez (1990)
	Ba	Ca	K	Mg	Sr	Na	Sum	meq/100 g	meq/100 g
39.5 [H1a]	0.017	6.454	0.208	0.731	0.010	0.236	7.66	16.5 ± 3.9	6.1 ± 0.2
47 [H1]	0.033	8.683	0.498	1.414	0.017	0.340	10.99	not done	not done
91.5 [H2]	0.018	8.145	0.239	1.665	0.018	0.274	10.36	13.3 ± 7.0	4.8 ± 0.4
101.5 [H2]	0.026	9.383	0.272	1.686	0.019	0.292	11.68	16.3 ± 1.0	6.0 ± 0.4
136 [PPlz]	0.033	8.911	0.287	1.744	0.018	0.223	11.22	25.2 ± 3.0	8.9 ± 2.5
146 [PPlc]	0.025	9.849	0.302	4.281	0.024	0.368	14.85	39.6 ± 5.6	19.4 ± 2.2
148.5 [PPlc]	0.017	8.801	0.216	2.786	0.020	0.218	12.06	26.7 ± 0.8	13.2 ± 5.1
163.5 [Rtf]	0.014	6.275	0.186	1.317	0.012	0.133	7.94	15.7 ± 1.7	5.2 ± 0.2
192 [Rwi(e)]	0.027	3.376	0.378	1.548	0.012	0.224	5.57	not done	not done

(a) Multiply by 0.3048 to convert to meters.

5.1.9 1:1 Sediment-to-Water Extraction

The 1:1 sediment-to-water extract results for samples from borehole 299-W22-48 sediment are shown in Tables 5.15 to 5.18. Later, in the discussion of the characterization of the core materials, we compare the chemical composition of the dilution-corrected 1:1 water extracts with actual porewater obtained by ultracentrifugation. For some constituents, the water extracts, when corrected for dilution with deionized water, give an accurate measure of the concentration within the native porewater. For other constituents, water extract data, when dilution-corrected back to the porewater, over-predicts the

Table 5.15. pH, Electrical Conductivity, Alkalinity, and Anions in Water Extracts from Sediment Samples in Borehole 299-W22-48

Constituent		pH	EC	Alk	F	Cl	NO ₂	NO ₃	PO ₄	SO ₄
Sample (ft bgs) ^(a)	Stratigraphic Unit		μS/cm	mg/L CaCO ₃	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	H1a				1.56	1.27	<0.1	7.06	0.21	2.42
6	H1a				1.90	0.42	<0.1	7.94	<0.1	5.48
9.5	H1a				1.43	0.39	<0.1	5.89	0.27	8.79
12.5	H1a				3.04	0.32	<0.1	4.37	0.24	5.64
14.5	H1a				2.65	0.30	<0.1	4.46	0.29	14.62
17	H1a				2.66	0.35	<0.1	7.10	0.37	15.20
19.5	H1a				1.74	0.72	<0.1	9.79	<0.1	15.70
22	H1a				1.03	0.49	<0.1	14.50	0.35	16.90
24.5	H1a				0.95	0.37	<0.1	5.27	0.34	18.20
27	H1a				1.39	0.49	<0.1	11.00	0.28	18.30
29.5	H1a	7.38	224	47.94	0.95*	0.32*	<0.1	7.89*	0.27*	20.68*
32	H1a	7.97	171	41.60	0.62	0.26	<0.1	6.97	0.30	9.14
34.3	H1a				0.79	0.39	<0.1	5.20	0.63	9.88
37	H1a				0.72	1.43	<0.1	11.90	0.28	14.80
39.5	H1a	7.39	180	33.14	0.55	0.65	<0.1	13.75	<0.24	14.75
42	H1				0.74	0.43	<0.1	3.99	0.13	11.85
44.5	H1				0.63	0.42	<0.1	3.69	0.18	18.40
47	H1	7.30	126	28.91	<i>0.58**</i>	<i>0.24**</i>	<i><0.1</i>	<i>2.76**</i>	<i>0.13**</i>	<i>9.26**</i>
50	H1				0.65	0.84	<0.1	10.90	0.25	12.10
53.5	H1				0.49	0.53	<0.1	2.46	<0.1	10.10
56	H1	7.20	142	NA	0.45	1.05	<0.1	1.00	0.13	11.47
57.5	H1				0.57	1.72	<0.1	7.07	0.12	13.40
74.5	H2	7.395	216	36.00	0.50	5.06	<0.1	7.28	0.33	24.06
91.5	H2				0.60	4.83	<0.1	8.44	0.39	13.60
101.5	H2				0.63	5.48	<0.1	9.82	0.34	17.15
106.5	H2	7.70	177	33.84	0.33	6.45	<0.1	5.19	<0.1	10.40
115.5	H2	7.39	182	38.07	0.36	2.28	<0.1	7.55	0.38	12.30
136	PPlz	7.20	214	40.19	0.45	1.32	<0.1	22.70	0.50	11.90
143.5	PPlz	7.12	186	34.55	0.27	0.71	<0.1	16.20	0.35	11.10
146	PPlc	7.39	441	47.47	0.91	3.57	<0.1	75.20	0.17	44.40
148.5	PPlc	7.48	291	41.6	1.27	1.84	<0.1	42.80	<0.1	16.90
151	Rtf	7.56	208	49.35	1.21	1.68	<0.1	4.16	<0.1	5.45
163.5	Rtf	7.46	117	29.96	0.49	0.45	<0.1	6.95	0.11	1.69
170	Rtf	7.40	116	31.02	0.46	0.49	<0.1	7.34	0.21	1.84
172.5	Rtf	7.33	190	31.73	0.50	0.40	<0.1	1.96	<0.1	1.50
187	Rtf	7.58	53	15.51	0.48	0.59	<0.1	9.91	<0.1	1.86
192	Rwi(e)	7.78	120	18.33	1.37	1.55	<0.1	9.10	0.29	10.00

(a) Multiply by 0.3048 to convert to meters.

*Data in **bold** is average of duplicate extracts.

**Data in *italic* is the average of triplicate extracts.

NA = Not analyzed.

Table 5.16. Major Cations in Water Extracts from Sediment Samples in Borehole 299-W22-48.
Cation concentration measured by ICP method.

Sample Depth (ft bgs) ^(a) [Stratigraphic Unit]	Na mg/L	Mg mg/L	Al µg/L	Si mg/L	P µg/L	S mg/L	K mg/L	Ca mg/L	Mn µg/L	Fe µg/L	Sr µg/L	Ba µg/L
29.5 [H1a]	28.97	1.42	(35)	17.71	(91)	7.18	4.67	6.78	(1)	49.2	29.7	27.6
32.0 [H1a]	21.10	1.16	(49)	16.46	(113)	2.95	4.12	6.00	(1)	68.8	21.1	12.2
39.5 [H1a]	20.09	1.24	(29)	10.57	<500	4.54	3.83	6.66	(1)	(17)	24.3	15.5
47.0 [H1]	12.70	1.07	(48)	10.46	(2)	3.26	2.93	5.28	(1)	42.5	25.4	21.2
56.0 [H1]	15.36	2.29	50.7	9.06	(135)	4.00	4.70	8.89	(3)	43.1	37.4	(5)
74.5 [H2]	16.45	3.56	76.1	9.55	(83)	8.98	4.36	10.75	(1)	45.0	62.0	17.3
91.5 [H2]	19.14	2.86	286	12.80	(197)	5.30	3.47	9.55	(2)	93.2	49.9	17.0
101.5 [H2]	20.19	2.75	272	13.64	(169)	6.36	3.45	11.95	(3)	90.9	59.3	29.9
106.5 [H2]	14.21	2.15	85.0	8.94	(36)	4.14	3.60	9.65	(1)	63.2	48.5	16.9
115.5 [H2]	14.81	2.27	54.8	11.33	(21)	4.94	3.36	10.47	(1)	58.7	57.1	27.9
136.0 [PPlz]	16.50	3.21	68.5	11.76	(110)	4.78	3.84	12.92	(1)	39.2	65.9	32.3
143.5 [PPlz]	11.32	3.66	(10)	8.83	(88)	4.21	3.27	11.23	(1)	(8)	61.0	29.5
146.0 [PPlc]	22.44	12.21	(5)	26.28	(207)	15.83	5.00	29.60	(0)	(5)	186	29.6
148.5 [PPlc]	15.29	7.52	(8)	28.10	<500	6.40	3.99	18.47	(0)	95.5	121	24.9
151.0 [Rtf]	17.55	4.70	(29)	18.91	(81)	2.39	6.11	10.39	(4)	(19)	60.9	16.5
163.5 [Rtf]	7.24	2.68	(25)	11.73	<500	0.83	2.47	6.65	(0)	(16)	38.2	11.9
170.0 [Rtf]	7.13	2.93	(31)	12.78	<500	0.89	2.82	7.30	(2)	33.2	41.3	44.6
172.5 [Rtf]	8.22	2.80	(29)	13.06	(18)	0.70	3.62	7.01	(1)	(21)	39.3	19.0
187.0 [Rtf]	4.74	0.51	(28)	12.70	(145)	0.77	1.58	1.31	(2)	46.3	(7)	(8)
192.0 [Rwi(e)]	13.95	0.74	65.2	11.65	(125)	3.84	4.22	1.75	(2)	40.7	(10)	16.5

(a) Multiply by 0.3048 to convert to meters.
Values in parenthesis are just below level of quantification but spectra looked good. Thus, a tentative value was attributed to data. Data in **bold** is average of duplicate extracts.

porewater concentration because of dissolution of salts/minerals in the sediment. We also have converted the water extracts to a per gram of oven-dry sediment for comparison to geochemical results obtained by other methods (i.e., acid extraction and bulk chemical composition [XRF]).

The data in Tables 5.15 to 5.18 show that the water extracts are dominated by calcium, magnesium, sodium, bicarbonate (based on the pH and alkalinity data), sulfate, and nitrate. There are minor amounts of chloride, potassium, and dissolved silicon but no elevated levels of trace metals, except in the PPlc subunit. The PPlc water extract data show elevated levels of natural uranium and selenium as well as electrical conductivity (EC), alkalinity, calcium, magnesium, silicon, strontium, sulfate, and nitrate compared to the other geologic strata. In contrast, the Ringold Formation water extracts show lower alkalinity, barium, chromium, sodium, and uranium concentrations compared to the Hanford formation and Plio Pleistocene unit water extracts. In all but two instances the cation-anion balance in Table 5.18 agrees within 10%, suggesting we have an internally consistent data set. Because the ratio of water to sediment used in the water extracts was 1:1, the data in Tables 5.15 through 5.18 with the units of mg/L and µg/L or meq/L also represent milligrams or milliequivalents per kilogram of soil, respectively.

Table 5.17. Trace Metals in Water Extracts of Sediment Samples from Borehole 299-W22-48

Sample Depth (ft bgs) ^(a) [Stratigraphic Unit]	B µg/L	Cr* µg/L	Co µg/L	Ni µg/L	Cu µg/L	Zn µg/L	As* µg/L	Se* µg/L	Mo* µg/L	Tc* µg/L	Pb* µg/L	U* µg/L
29.5 [H1a]	(8)	(0.32)	<10	<100	<25	30.9	37.5	(0.69)	3.97	(0.00)	(0.16)	2.84
32.0 [H1a]	(3)	(0.37)	1.4	<100	<25	15.0	32.1	(0.15)	2.35	(0.00)	(0.03)	1.47
39.5 [H1a]	(0)	(0.39)	<10	<100	<25	22.7	21.6	(1.06)	4.81	(0.00)	(0.29)	1.76
47.0 [H1]	<100	(0.19)	1.1	<100	<25	22.3	9.45	(0.29)	1.20	(0.00)	(0.25)	0.530
56.0 [H1]	(4)	(0.07)	1.0	<100	<25	16.3	9.52	(0.23)	11.35	(0.00)	(0.16)	1.47
74.5 [H2]	(6)	0.470	<10	<100	<25	23.1	21.6	(0.65)	7.08	(0.00)	(0.18)	0.430
91.5 [H2]	2003	0.551	1.3	<100	<25	15.7	22.5	(3.84)	17.64	(0.00)		0.455
101.5 [H2]	1996	0.985	<10	<100	<25	20.0	19.2	5.77	24.2	<0.025		0.430
106.5 [H2]	(6)	0.530	<10	<100	<25	24.5	17.1	(2.25)	12.1	(0.00)	(0.22)	0.375
115.5 [H2]	(10)	0.940	1.8	<100	(0)	26.9	21.2	(3.15)	10.6	(0.00)	(0.31)	0.530
136.0 [PPlz]	(8)	0.665	1.5	<100	<25	44.1	26.4	12.9	9.5	(0.00)	(0.14)	0.510
143.5 [PPlz]	(7)	(0.21)	1.1	<100	<25	25.6	9.20	6.55	17.3	<0.025	(0.14)	0.970
146.0 [PPlc]	(11)	1.86	1.4	<100	<25	29.3	8.44	36.50	57.2	(0.00)	(0.08)	7.90
148.5 [PPlc]	(3)	0.690	<10	<100	<25	23.3	10.8	14.8	9.9	(0.00)	(0.75)	5.68
151.0 [Rtf]	(4)	(0.07)	0.9	<100	(2)	22.1	8.56	(3.22)	7.58	(0.00)	(0.04)	2.48
163.5 [Rtf]	<100	(0.05)	2.0	<100	<25	27.8	15.0	(2.67)	5.17	(0.00)	(0.01)	0.245
170.0 [Rtf]	(0)	(0.24)	0.0	<100	<25	86.8	12.4	(3.39)	5.99	<0.025	(0.22)	0.565
172.5 [Rtf]	(1)	(0.17)	2.2	<100	<25	23.8	10.6	(1.80)	6.94	(0.00)	(0.06)	0.920
187.0 [Rtf]	<100	(0.19)	1.4	<100	<25	26.3	6.31	4.25	3.54	(0.00)	(0.09)	0.000
192.0 [Rwi(e)]	(9)	(0.26)	0.8	<100	<25	96.7	6.80	5.78	7.14	<0.025	(0.13)	0.032

(a) Multiply by 0.3048 to convert to meters.
*ICP-MS instrument was used.
Values in parenthesis are just below level of quantification but spectra looked good. Thus, a tentative value was attributed to data. Data in **bold** are average of duplicate extractions.

Some notable trends are seen in the water extract data. The calcic PPlc subunit is unique, geochemically, apparently because it is the only stratigraphic unit sampled that has gone through a long period of intense pedogenic alteration. Most noticeably, the PPlc has a significantly higher EC and is enriched in at least two anions (nitrate, sulfate) and several cations (silica, magnesium, calcium) (see Tables 5.15 and 5.16). The PPlc is also enriched in several trace elements including chromium, selenium, molybdenum, strontium, and uranium (see Table 5.17). At the same time, the PPlc is depleted in water-leachable aluminum relative to the other stratigraphic units. All these constituents were probably retained during soil-formation processes when this paloesol was developing during late Pliocene and/or early Pleistocene time.

Also noticeable in the water extracts, but less dramatic, are greater chloride contents in the Hanford formation H2 unit, 22.7 to 35.2 meters (74.5 to 115.5 feet) bgs and lower magnesium concentration in the upper portion of the Hanford formation sequence (Hanford formation H1a unit, ≤14 meters or ≤47 feet bgs) relative to the other stratigraphic units. The latter differences are not great and analyses of additional samples are needed to better substantiate and define chemical dissimilarities among different strata within the Hanford formation.

Table 5.18. Charge Balance in Water Extracts of Sediment Samples from Borehole 299-W22-48

Sample Depth (ft bgs) ^(a) [Stratigraphic Unit]	Alk meq/L	F meq/L	Cl meq/L	NO ₃ meq/L	SO ₄ meq/L	ΣAn meq/L	Na meq/L	Mg meq/L	K meq/L	Ca meq/L	ΣCat meq/L
29.5 [H1a]	0.96	0.05	0.01	0.13	0.43	1.58	1.26	0.12	0.12	0.34	1.83
32.0 [H1a]	0.83	0.03	0.01	0.11	0.19	1.17	0.92	0.10	0.11	0.30	1.42
39.5 [H1a]	0.66	0.03	0.02	0.22	0.31	1.24	0.87	0.10	0.10	0.33	1.41
47.0 [H1]	0.58	0.03	0.01	0.04	0.19	0.85	0.55	0.09	0.07	0.26	0.98
56.0 [H1]	ND	0.02	0.03	0.02	0.24		0.67	0.19	0.12	0.44	1.42
74.5 [H2]	0.72	0.03	0.14	0.12	0.50	1.51	0.72	0.29	0.11	0.54	1.66
91.5 [H2]	ND	ND	ND	ND	ND		0.83	0.24	0.09	0.48	1.63
101.5 [H2]	ND	ND	ND	ND	ND		0.88	0.23	0.09	0.60	1.79
106.5 [H2]	0.68	0.02	0.18	0.08	0.22	1.18	0.62	0.18	0.09	0.48	1.37
115.5 [H2]	0.76	0.02	0.06	0.12	0.26	1.22	0.64	0.19	0.09	0.52	1.44
136.0 [PPlz]	0.80	0.02	0.04	0.37	0.25	1.48	0.72	0.26	0.10	0.64	1.72
143.5 [PPlz]	0.69	0.01	0.02	0.26	0.23	1.22	0.49	0.30	0.08	0.56	1.44
146.0 [PPlc]	0.95	0.05	0.10	1.21	0.92	3.24	0.98	1.00	0.13	1.48	3.58
148.5 [PPlc]	0.83	0.07	0.05	0.69	0.35	1.99	0.66	0.62	0.10	0.92	2.31
151.0 [Rtf]	0.99	0.06	0.05	0.07	0.11	1.28	0.76	0.39	0.16	0.52	1.82
163.5 [Rtf]	0.60	0.03	0.01	0.11	0.04	0.78	0.31	0.22	0.06	0.33	0.93
170.0 [Rtf]	0.62	0.02	0.01	0.12	0.04	0.82	0.31	0.24	0.07	0.36	0.99
172.5 [Rtf]	0.63	0.03	0.01	0.03	0.03	0.74	0.36	0.23	0.09	0.35	1.03
187.0 [Rtf]	0.31	0.03	0.02	0.16	0.04	0.55	0.21	0.04	0.04	0.07	0.35
192.0 [Rwi(e)]	0.37	0.07	0.04	0.15	0.21	0.84	0.61	0.06	0.11	0.09	0.86

(a) Multiply by 0.3048 to convert to meters.
 ND = Analysis not done.
 Data in **bold** is average of duplicate extractions.

Table 5.19 summarizes the ranges of major components of water extracts from borehole 299-W22-48 and contrasts the ranges among different stratigraphic units. The data reflects observations made above. Water extracts from the Hanford formation H1a unit are slightly enriched in sodium compared to the Hanford formation H2 unit, which is slightly enriched in chloride, magnesium, and calcium. More discussion is presented in Section 5.1.11 where the dilution-corrected porewaters will be compared to the actual porewaters obtained by ultracentrifugation.

5.1.10 Acid Extraction

8 M nitric acid extraction data are summarized in Tables 5.20 and 5.21. Two instruments were used to measure constituents released by acid extraction (see Section 3.2.10; these are the ICP and the inductively coupled plasma mass spectrometer (ICP-MS). Table 5.20 shows that chromium and lead analyses using the two independent instruments and techniques give excellent agreement.

Table 5.19. Ranges of Parameters and Selected Ions Found in Water Extracts for Stratigraphic Units Sampled within Borehole 299-W22-48

Stratigraphic Unit	Hanford Formation (Unit H1a)	Hanford Formation (Unit H1a)	Hanford Formation (Unit H1)	Hanford Formation (Unit H2)	Upper Plio-Pleistocene Unit (PPlz)	Lower Plio-Pleistocene Unit (PPlc)	Ringold Formation (Rtf)	
General Lithology	Sand and gravel	Sand	Sand and gravel	Sand and silt	Fine sand and silt	Caliche	Sand to gravelly sand	
Depth Interval (ft bgs) ^(a)	0 - 9	9 - 41	41 - 61	61 - 135	135 - 146	146 - 149	149 - 192	
Units								
pH		7.4 - 8.0	7.2 - 7.3	7.4 - 7.7	7.1 - 7.2	7.4 - 7.5	7.3 - 7.8	
EC	µS/cm	170 - 220	120 - 140	180 - 220	190 - 210	300 - 450	50 - 200	
Alk	mg/L CaCO ₃	35 - 45	30 - 35	35	35 - 40	40 - 50	15 - 30	
F	mg/L	1.5 - 2.0	0.5 - 3.0	0.5 - 0.7	0.3 - 0.6	0.3 - 0.4	1 - 1.3	0.5 - 1.4
Cl	mg/L	0.4	0.3 - 1	0.4 - 2	2.0 - 6.0	0.7 - 1.3	2.0 - 4.0	0.4 - 2.0
NO ₃	mg/L	6.0 - 8	4.0 - 15	1.0 - 10	5.0 - 10	16 - 23	43 - 75	2.0 - 10
SO ₄	mg/L	3.0 - 6	5.0 - 20	9.0 - 18	10.0 - 25	10.0 - 12	20 - 45	2.0 - 10
Na	mg/L		20 - 30	12.0 - 15	15 - 20	11.0 - 16	15 - 20	5.0 - 17
Mg	mg/L		1.2 - 1.4	1.1 - 2.3	2.2 - 3.6	3.2 - 3.7	7.0 - 12	0.5 - 5.0
Si	mg/L		11.0 - 18	9.0 - 10	9.0 - 14	8.0 - 12	26 - 28	11.0 - 20
K	mg/L		3.8 - 4.7	3.0 - 5	3.4 - 4.6	3.3 - 3.8	4.0 - 5	1.5 - 6.0
Ca	µg/L		6.0 - 7	5.0 - 9	10.0 - 12	11.0 - 13	20 - 30	1.0 - 10
Sr	µg/L		20 - 30	25 - 35	50 - 60	60 - 65	120 - 200	7.0 - 60
Ba	µg/L		15 - 30	5.0 - 20	17 - 30	30 - 32	25 - 30	10.0 - 20
Cr	µg/L		0.3	0.1 - 0.2	0.4 - 1.0	0.2 - 0.7	0.7 - 2	0.1 - 0.2
U	µg/L		1.5 - 3.0	0.5 - 1.5	0.4 - 0.5	0.5 - 1.0	6.0 - 8	0.0 - 1

(a) Multiply by 0.3048 to convert to meters.

The PPlc subunit shows very high acid-leachable calcium, magnesium, sodium, strontium, and sulfur (likely from sulfate), uranium, copper, and manganese and conversely low leachable iron compared to the other stratigraphic units measured. The high acid-leachable alkaline-earth cations represent the ready dissolution of carbonates. The high release rate of copper, manganese, and uranium also may represent substitution of these trace metals into the carbonate crystal lattice. The coarse-grained facies of the Hanford formation H1 unit shows relatively lower amounts of leachable aluminum, barium, calcium, chromium, iron, magnesium, manganese, potassium, strontium and uranium compared to other stratigraphic units. It is not clear whether this a reflection of the mineralogy (i.e., basaltic), or the fact that larger grains are not leached as efficiently as fine grains during the acid-leach process. The coarse-grained Ringold Formation [Rwi(e)] at 58.5 meters (192 feet) bgs produced a relatively small amount of acid-leachable calcium but a large amount of molybdenum.

Table 5.20. Major Cations in Acid Extracts of Sediment Samples from Borehole 299-W22-48. Cation concentration ($\mu\text{g/g}$) measured by ICP method.

Element $\mu\text{g/g}$	Ft bgs ^(a) 39.5	Ft bgs ^(a) 47	Ft bgs ^(a) 77	Ft bgs ^(a) 91.5	Ft bgs ^(a) 101.5	Ft bgs ^(a) 136	Ft bgs ^(a) 146	Ft bgs ^(a) 148.5	Ft bgs ^(a) 163.5	Ft bgs ^(a) 192
	H1a	H1	H2	H2	H2	PPlz	PPlc	PPlc	Rtf	Rwi(e)
Na	180.5	278.0	204.2	150.2	197.9	185.1	363.6	355.8	168.6	295.0
Mg	4570	2245	5133	4022	5214	6551	20148	9586	4770	3700
Al	6281	3264	7623	5394	7257	9935	6939	5950	6844	6023
Si	35.8	20.1	26.8	85.5	14.7	7.5	11.0	17.8	15.8	16.4
P	389.1	535.4	467.9	362.8	416.2	450.3	432.8	539.0	319.9	446.7
S	45.0	39.6	31.5	31.4	42.0	27.5	353.4	373.2	18.7	36.3
K	1488	446.6	1467	1214	1522	1912	912.9	810.0	857.2	969.4
Ca	7611	5209	8141	6680	8410	11447	148662	203457	4439	2808
Ti	541.3	563.1	527.7	330.0	512.8	446.8	497.3	380.4	537.1	622.6
Mn	275.5	122.2	273.3	234.5	274.3	274.5	1459.1	230.2	257.8	193.8
Fe	12200	9397	12885	10049	12490	14524	9805	8776	13089	11767
Sr	29.1	18.3	35.2	24.6	33.9	36.7	295.2	390.6	21.2	22.0
Ba	80.3	43.8	69.3	60.5	80.4	107.2	128.0	73.2	46.9	113.3

(a) Multiply by 0.3048 to convert to meters.

Table 5.22 presents the percentage of each element dissolved by the nitric acid compared to the bulk chemical composition determined by XRF. This comparison is critical to defining whether the strong acid digestion is in fact dissolving most of a given element. For contaminated sediment, we will compare the acid extract as a measure of the total concentration of contaminants in the samples. In the companion reports on SX tank farm containment sediments we will compare the amounts of a given element that are acid leached from comparable uncontaminated sediment to the values released by the contaminated sediment to attempt to understand the interactions of tank fluids with sediment and to estimate the degree of binding between given contaminants and affected sediment.

In general, for the sediment from borehole 299 W22-48, the acid extraction removes only 1% to 10% of the total mass of alkali metals (potassium and sodium), about 25% of the major alkaline earth metals (calcium and magnesium) and about 10% to 15% of the minor alkaline earths elements (barium and strontium). Among other elements, very little <0.1% silicon, about 15% of the aluminum and titanium, about 40% to 60% of the iron and manganese, and 25% to 70% of the various trace metals are released during acid extraction. The amount of any element removed from the Hanford formation H1 unit (coarse sand and gravel) by acid digestion is less than for the other geologic strata, perhaps signifying that the larger particle sizes are leached less than smaller-grained particles, which have a relatively greater surface area.

In the two samples from the PPlc subunit the acid leached almost all the calcium and strontium and slightly more of several of the other elements when compared to other non-carbonate-rich strata. Most calcium and strontium in the PPlc appears to be combined with calcite (calcium carbonate) cement, which easily decomposes on contact with acid. Calcium in the other stratigraphic units is associated with silicates (e.g., pyroxene, plagioclase, etc.), which do not readily react with the acid leach.

Table 5.21. Trace Metals ($\mu\text{g/g}$) in Acid Extracts of Sediment Samples from Borehole 299-W22-48. Trace metals measured by ICP or ICP-MS methods.

Element $\mu\text{g/g}$	Ft bgs ^(a) 39.5	Ft bgs ^(a) 47	Ft bgs ^(a) 77	Ft bgs ^(a) 91.5	Ft bgs ^(a) 101.5	Ft bgs ^(a) 136	Ft bgs ^(a) 146	Ft bgs ^(a) 148.5	Ft bgs ^(a) 163.5	Ft bgs ^(a) 192
	H1a	H1	H2	H2	H2	PPlz	PPlc	PPlc	Rtf	Rwi(e)
Be	0.23	(0.14)	0.27	0.21	0.24	0.39	0.22	(0.19)	0.24	0.21
B	(8.66)	1.76	9.35	7.02	7.36	1.11	10.32	15.13	8.62	(1.79)
Cr ^(A)	8.47	3.21	13.86	9.49	12.68	14.17	10.84	11.77	8.63	9.81
Cr	8.59	3.12	12.75	8.86	12.06	13.35	9.87	10.18	8.17	9.28
Co	5.82	4.56	6.61	5.09	6.05	8.23	5.51	4.68	5.64	6.00
Ni	7.29	4.25	13.07	9.19	11.19	13.26	9.81	9.25	8.04	8.64
Cu	7.26	7.61	8.93	8.34	7.92	13.50	16.93	9.90	6.59	9.21
Zn	33.34	17.94	36.72	29.10	33.83	45.15	24.58	24.79	32.98	26.44
As ^(b,c)	(2.25)	(0.69)	(4.41)	(3.02)	(2.99)	(4.50)	(5.96)	(19.07)	(2.39)	(1.20)
Se ^(b)	(0.16)	0.22	(0.16)	(0.15)	(0.14)	0.22	0.54	0.71	(0.14)	0.17
Mo ^(b)	0.05	0.05	0.09	0.07	0.08	0.06	0.33	0.08	0.07	0.78
Tc ^(b,d,e)	(0.00)	<27.11	(0.00)	(0.00)	(0.00)	(2.27) ^(e)	(20.10) ^(e)	(17.42) ^(e)	(0.00)	(0.00)
Ru ^(b)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.004)	(0.005)	(0.002)	(0.001)
Ag ^(b)	0.03	0.03	0.04	0.04	0.04	0.06	0.06	0.05	0.02	0.04
Cd ^(b)	0.07	0.04	0.06	0.07	0.06	0.12	0.09	0.16	0.05	0.04
Pb ^(b)	4.42	1.57	5.47	4.58	4.66	9.04	3.19	3.24	4.74	3.99
Pb	4.30	1.73	5.22	4.33	4.17	8.47	2.45	2.44	4.59	3.75
U	0.53	0.25	0.59	0.50	0.48	0.68	3.55	3.22	0.53	0.48

Values in parenthesis are just below level of quantification but spectra looked good. Thus, a tentative value was attributed to data. Values in **bold** are suspect because of poor spike recoveries and for B acid attack on digestion glassware may add additional B.

(a) Multiply by 0.3048 to convert to meters.
(b) ICP-MS instrument was used; when not noted, ICP was used.
(c) Data are suspect because of Ar-Cl molecular species at mass 75.
(d) Check standard was reading high, values are suspect.
(e) Units for Tc are pCi/g.

Water extraction leaches far fewer of the elements shown in Table 5.22 than acid extraction. The only elements that have water leaches that exceed a few tenths of a percent of the amount that is acid-leachable are sodium, sulfur (sulfate), and molybdenum; they water leach between 5% to 10%, 10% to 30%, and 10% to 15% as much as the amount that acid leaches. Thus, the percentages of the total elements in the uncontaminated sediment that leach in water are less than a few percent of the total as determined by XRF. The contaminated sediment differ in that more mass is water-leachable for contaminants that are known to be mobile such as chromium (VI), technetium, molybdenum, sulfate, and nitrate (see Serne et al. 2002 a, b, c).

5.1.11 Porewater Composition

Porewater compositions were determined for two water samples from the Hanford formation H2 unit, extracted from sediment core with an ultracentrifuge (UFA) method (see Section 3.2.11). These data, which compared the calculated porewater compositions of the dilution-corrected water extracts, are presented in Tables 5.23 to 5.26. The chemical composition of UFA-extracted porewater (Table 5.23) suggest that the nitrate value for the sample from 27.9 meters (91.5 feet) bgs is erroneously high.

Table 5.22. Mass Percent of Total Element Leached by Acid Extraction Compared to Bulk Chemical Composition. Bulk chemical composition measured by XRF method.

Element %	Ft bgs ^(a) 39.5	Ft bgs ^(a) 47	Ft bgs ^(a) 91.5	Ft bgs ^(a) 101.5	Ft bgs ^(a) 136	Ft bgs ^(a) 146	Ft bgs ^(a) 148.5	Ft bgs ^(a) 163.5
	H1a	H1	H2	H2	PPlz	PPlc	PPlc	Rtf
Na	1.08	1.40	0.89	1.19	1.54	7.74	4.50	1.13
Mg	22.85	8.80	22.22	25.81	26.20	46.11	38.19	26.65
Al	8.36	4.24	7.76	10.26	14.21	21.03	14.00	9.86
Si	0.01	0.01	0.03	0.00	0.0	0.01	0.01	0.00
P	>43	>49	>41	>46	>51	>31	>39	>38
S	14	8	>13	11	>12	23	29	>8
K	7.1	3.6	5.6	7.3	10.0	11.3	6.4	3.6
Ca	33.7	9.4	29.6	36.3	47.5	86.4	136.2	29.9
Ti	14.9	6.1	10.5	14.4	11.7	15.1	16.	16.5
Mn	51.6	11.6	48.0	54.6	63.9	76.4	60.0	65.1
Fe	43.6	13.9	41.5	45.9	50.3	41.1	41.0	55.8
Sr	8.1	5.9	7.2	9.8	14.6	88.8	116.3	8.0
Ba	10.5	7.5	7.6	9.8	17.0	35.4	17.1	6.7
Cr	28.5	4.9	22.6	20.0	29.7	34.6	30.3	32.9
Co	>11.0	>5.1	>10.4	>11.4	>15.2	>9.5	>8.7	>11.3
Ni	45.0	13.3	49.4	50.4	56.0	50.8	61.6	49.0
Cu	53.0	29.3	59.2	49.8	61.1	71.7	52.7	37.4
Zn	63.4	19.4	64.0	62.0	72.7	63.8	60.5	65.8
As	>68.2	11.2	70.2	76.8	59.2	78.4	104.2	>77.2
Se	>7.0	>7.7	>6.5	>5.6	>9.0	>18.1	>27.2	>6.2
Mo	>2.2	1.4	>2.9	>3.2	>2.1	>10.1	>4.4	>3.6
Ru	>0.0	>0.0	>0.0	>0.0	>0.0	>0.0	>0.1	>0.0
Ag	0.2	>0.4	>0.5	>0.4	>0.6	>0.5	>0.7	>0.3
Cd	>0.8	>0.4	>0.7	>0.6	>1.2	>0.6	>2.0	>0.6
Pb	24.0	28.5	30.4	24.0	61.1	43.7	34.1	34.3
U	>8.0	>3.6	>7.2	>7.0	9.1	>40.8	>53.7	>9.3

(a) Multiply by 0.3048 to convert to meters.

The charge balance for 91.5 ft bgs porewater is poor while that for 101.5 feet is good (see Table 5.24). The nitrate analysis for porewater 91.5 feet appears to be too high. Further investigation found that the aliquot used for anion analysis had been mistakenly preserved with nitric acid. Thus the nitrate value is not correct. The values for all the other constituents are quite similar for the two porewaters. Natural vadose-zone porewaters are similar in chemical composition to the water extracts and groundwater, except they are more concentrated. The fluids from these two Hanford formation H2 unit sediment samples are dominated by calcium, magnesium, and sodium cations and by sulfate, chloride, nitrate, and bicarbonate anions. The sodium and nitrate values seem somewhat high compared to uncontaminated groundwater (Hartman et al. 2000) perhaps reflecting some anthropomorphic input of Hanford's two most ubiquitous chemical contaminants, sodium and nitrate.

Table 5.23. pH, Electrical Conductivity, Alkalinity, Anions, Cations, and Trace Metals Measured in UFA-Extracted Porewater from Two Samples in Borehole 299-W22-48.

		Depth (ft bgs) ^(a)	
Analysis	Units	91.5	101.5
Moisture	Wt %	19.14	21.62
pH		6.93	7.25
EC	μS/cm	1386	1316
Alk	mg/L CaCO ₃	57.11	54.29
F	mg/L	0.48	0.46
Cl	mg/L	98.2	95
Br	mg/L	0.83	0.78
NO ₂	mg/L	<0.1	<0.1
NO ₃	mg/L	941 ^(b)	166
PO ₄	mg/L	<0.1	<0.1
SO ₄	mg/L	176	154
Na	mg/L	88.20	84.51
Mg	mg/L	30.12	22.51
Al	μg/L	(8)	(13)
Si	mg/L	12.91	13.86
P	μg/L	(147)	(80)
S	mg/L	68.35	61.32
K	mg/L	12.07	11.02
Ca	mg/L	104.2	103.1
Mn	μg/L	(5)	(7)
Fe	μg/L	(18)	29.9
Sr	μg/L	521	477
Ba	μg/L	82.6	90.9
B	μg/L	(55)	(46)
Cr ^(c)	μg/L	2.05	1.74
Co	μg/L	2.2	0.8
Ni	μg/L	(0)	<100
Cu	μg/L	(3)	(6)
Zn	μg/L	160	75.6
As ^(c)	μg/L	6.0	6.8
Se ^(c)	μg/L	67.6	81.4
Mo ^(c)	μg/L	25.1	25.0
Tc ^(c)	μg/L	(0.00)	(0.00)
Pb ^(c)	μg/L	(0.65)	(0.48)
U ^(c)	μg/L	2.22	5.00
Ag ^(c)	μg/L	(0.05)	0.140
Cd ^(c)	μg/L	(0.13)	0.340
Ru ^(c)	μg/L		

(a) Multiply by 0.3048 to convert to meters.
(b) Subsequent investigation showed in advertant contamination with nitric acid.
(c) Inductively coupled plasma mass spectrometry (ICP-MS) instrument was used; when not noted, ICP was used.

Table 5.24. Charge Balance for UFA-Extracted Porewater from Two Sediment Samples in Borehole 299-W22-48

Units ft (bgs) ^(a)	Alk (meq/L)	F (meq/L)	Cl (meq/L)	NO ₃ (meq/L)	SO ₄ (meq/L)	ΣAnion (meq/L)	Na (meq/L)	Mg (meq/L)	K (meq/L)	Ca (meq/L)	ΣCation (meq/L)
91.5	1.14	0.03	2.77	15.18	3.67	22.79	3.83	2.48	0.31	5.21	11.85
101.5	1.09	0.02	2.68	2.68	3.21	9.69	3.67	1.85	0.28	5.16	10.98

(a) Multiply by 0.3048 to convert to meters.

Table 5.25. Theoretically Calculated Composition of Vadose-Zone Porewater (1:1 Sediment-to-Water Extracts Multiplied By Dilution Factor)

Constituent Units	EC	Alk	F	Cl	NO ₃	SO ₄	Na	Mg	K	Ca	Sr	Ba
Sample ft bgs ^(a)	μS/cm	mg/L CaCO ₃	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	μg/L	μg/L
Hanford Formation Unit H1a (Sand)												
29.5	2115	452.7	9.0	3.0	74.5	195.3	273.6	13.4	44.1	64.0	280	261
32	3211	781.1	11.6	4.9	130.9	171.6	396.2	21.8	77.4	112.7	396	229
39.5	2279	419.5	7.0	8.2	174.1	186.7	254.3	15.7	48.5	84.3	308	196
Hanford Formation Unit H1 (Sand and Gravel)												
47	6705	1538.4	30.9	12.8	146.9	492.8	675.8	56.9	155.9	281.0	1352	1128
56	3632		11.5	26.9	25.6	293.4	392.9	58.6	120.2	227.4	957	128
Hanford Formation Unit H2 (Fine Sand and Silt)												
74.5	3296	549.3	7.6	77.2	111.1	367.1	251.0	54.3	66.5	164.0	946	264
106.5	3221	615.8	6.0	117.4	94.4	189.3	258.6	39.1	65.5	175.6	883	308
115.5	3442	719.9	6.8	43.1	142.8	232.6	280.1	42.9	63.5	198.0	1080	528
Upper Plio-Pleistocene Unit (PPlz)												
136	3753	704.8	7.9	23.1	398.1	208.7	289.4	56.3	67.3	226.6	1156	566
143.5	4858	902.4	7.1	18.5	423.1	289.9	295.7	95.6	85.4	293.3	1593	771
Lower Plio-Pleistocene Unit (PPlc)												
146	2972	319.9	6.1	24.1	506.8	299.2	151.2	82.3	33.7	199.5	1254	199
148.5	2144	306.4	9.4	13.6	315.3	124.5	112.6	55.4	29.4	136.1	891	183
Ringold Formation (Rtf)												
151	7430	1762.8	43.2	60.0	148.6	194.7	626.9	167.9	218.2	371.1	2175	589
163.5	6225	1594.1	26.1	23.9	369.8	89.9	385.2	142.6	131.4	353.8	2033	633
170	3878	1037.1	15.4	16.4	245.4	61.5	238.4	98.0	94.3	244.1	1381	1491
172.5	3825	638.8	10.1	8.1	39.5	30.2	165.5	56.4	72.9	141.1	791	383
187	2289	669.9	20.7	25.5	428.1	80.3	204.7	22.0	68.2	56.6	302	346
Ringold Formation (Rwi [e])												
192	5427	828.9	62.0	70.1	411.5	452.2	630.9	33.5	190.8	79.1	452	746

(a) Multiply by 0.3048 to convert to meters.

Table 5.26. Comparison of UFA-Extracted Porewater to Theoretically Calculated Porewater from the Hanford Formation H2 Unit in Borehole 299-W22-48

	Alk	F	Cl	NO ₃	SO ₄	ΣAnions	Na	Mg	K	Ca	ΣCations
Units	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L
ft (bgs) ^(a)											
74.5	10.99	0.40	2.18	1.79	7.65	23.01	10.91	4.47	1.70	8.19	25.27
91.5*	1.14	0.03	2.77	15.18	3.67	22.79	3.83	2.48	0.31	5.21	11.85
101.5*	1.09	0.02	2.68	2.68	3.21	9.69	3.67	1.85	0.28	5.16	10.98
106.5	12.32	0.32	3.31	1.52	3.94	21.41	11.24	3.22	1.68	8.76	24.90
115.5	14.40	0.36	1.22	2.30	4.85	23.12	12.18	3.53	1.63	9.88	27.21
Agreement ?	No	No	Yes	Yes	Yes		No	Yes	No	Yes	

(a) Multiply by 0.3048 to convert to meters.
 * Actual UFA-extracted porewater.

Table 5.25 shows the theoretical chemical composition of vadose-zone porewater calculated by assuming that the water extracts represent only solutes present in the native porewater. To convert back to the concentration in the porewater, one only needs to multiply by the dilution factor for the added deionized water. In Table 5.26, we compare the theoretical porewater composition for the neighboring water extracts with the two actual porewater analyses measured. All five data sets in Table 5.26 are from the Hanford formation H2 unit, composed of a sequence of laminated fine sands and silts above the Plio-Pleistocene unit (see Figure 2.19).

Table 5.26 suggests that the water extracts do dissolve excess carbonate, potassium, and sodium during the extraction. The bottom row indicates the qualitative agreement between the calculated porewater and actual porewater for each macro constituent. The additional carbonate alkalinity in water extracts is likely partly due to the dissolution of calcite. The excess potassium and sodium may come from the excess calcium-replacing cation-exchangeable alkali metals, though some potassium dissolution (source may be potassium-feldspar) has been noticed in longer-term water leach tests. Aside from carbonate alkalinity, the water extracts may not dissolve excess anions not already present in the natural porewater. As discussed in the other reports in this series (Serne et al. 2002 a, b, c), which characterize contaminated sediment that have come in contact with highly saline tank liquors, calculated values from water extracts agree more closely with UFA-extracted porewater data for sediments pore waters dominated by leaked tank fluids.

The dilution-corrected water extract data, as well as results from the two actual UFA-extracted porewater samples, versus depth in borehole 299-W22-48, are displayed graphically in Figures 5.7 to 5.9. Figure 5.7 illustrates variations in pH and EC, Figure 5.8 shows anions, and Figure 5.9 shows variations in cations versus depth. Figure 5.7 shows a fairly narrow range in pH values for the water extracts of the selected sediment samples. An exception is the 11.3-meter (37-foot) bgs sample within the lower portion of the Hanford formation H1a unit, which has a significantly higher pH (~8). This may not be significant, however, since most of the uppermost 18.3-meter (60-foot) sediment, including the Hanford formation

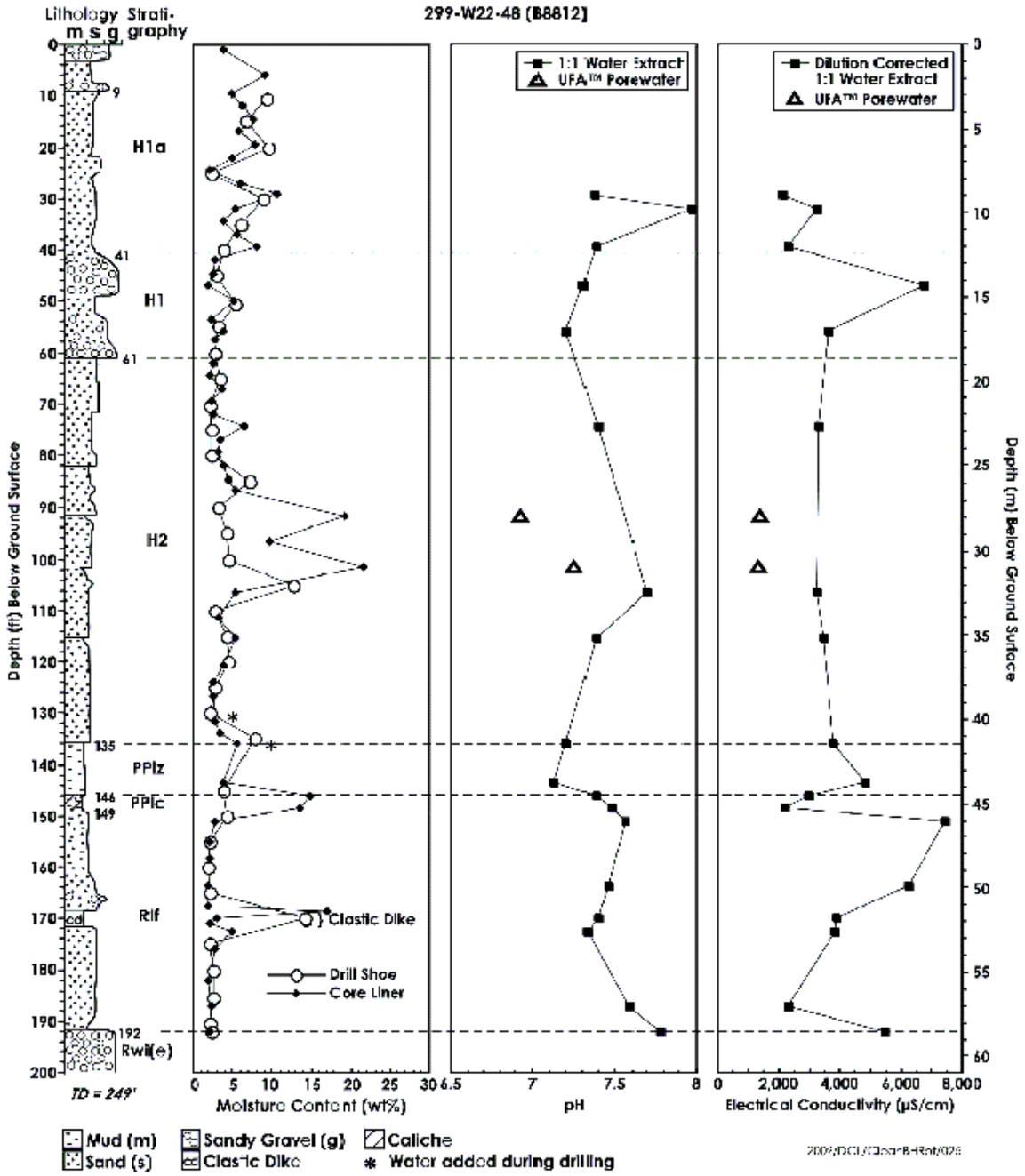


Figure 5.7. Moisture Content and Comparison of pH and Dilution-Corrected Electrical Conductivity of 1:1 Sediment-to-Water Extracts and UFA-Extracted Porewater from Sediment Samples in Borehole 299-W22-48

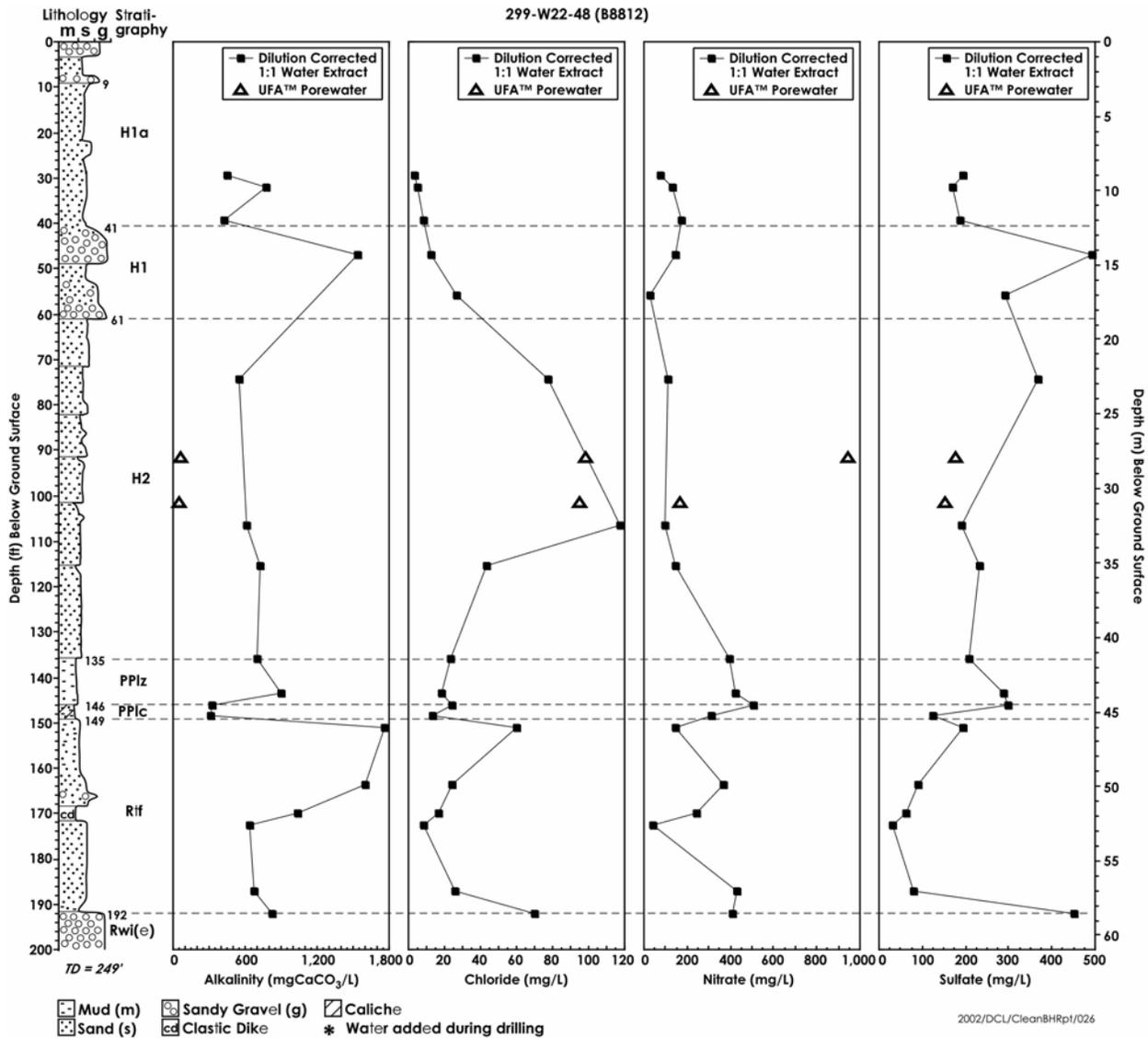


Figure 5.8. Comparison of Dilution-Corrected Anion Concentrations of 1:1 Sediment to Water Extracts and UFA-Extracted Porewaters from Sediment Samples in Borehole 299-W22-48

H1a unit, has been removed and mixed to form backfill within the SX Tank Farm. Below this higher pH spike, the profile is relatively uniform down to the top of the Ringold Formation. Just below the PPlc subunit, the pH is slightly elevated.

The EC profile shows three spikes, one at 14.3 meters (47 feet) bgs toward the top of the coarse-grained Hanford formation H1 unit, one each at the top of the two Ringold units (Rtf and Rwi(e)). The latter two spikes likely represent some evaporite dissolution and the sensitivity to the large dilution correction for very dry sediment. The spike at 14.3 meters (47 feet) bgs might represent the evaporates formed during the natural evapotranspiration cycle back when the Hanford Reservation had a natural

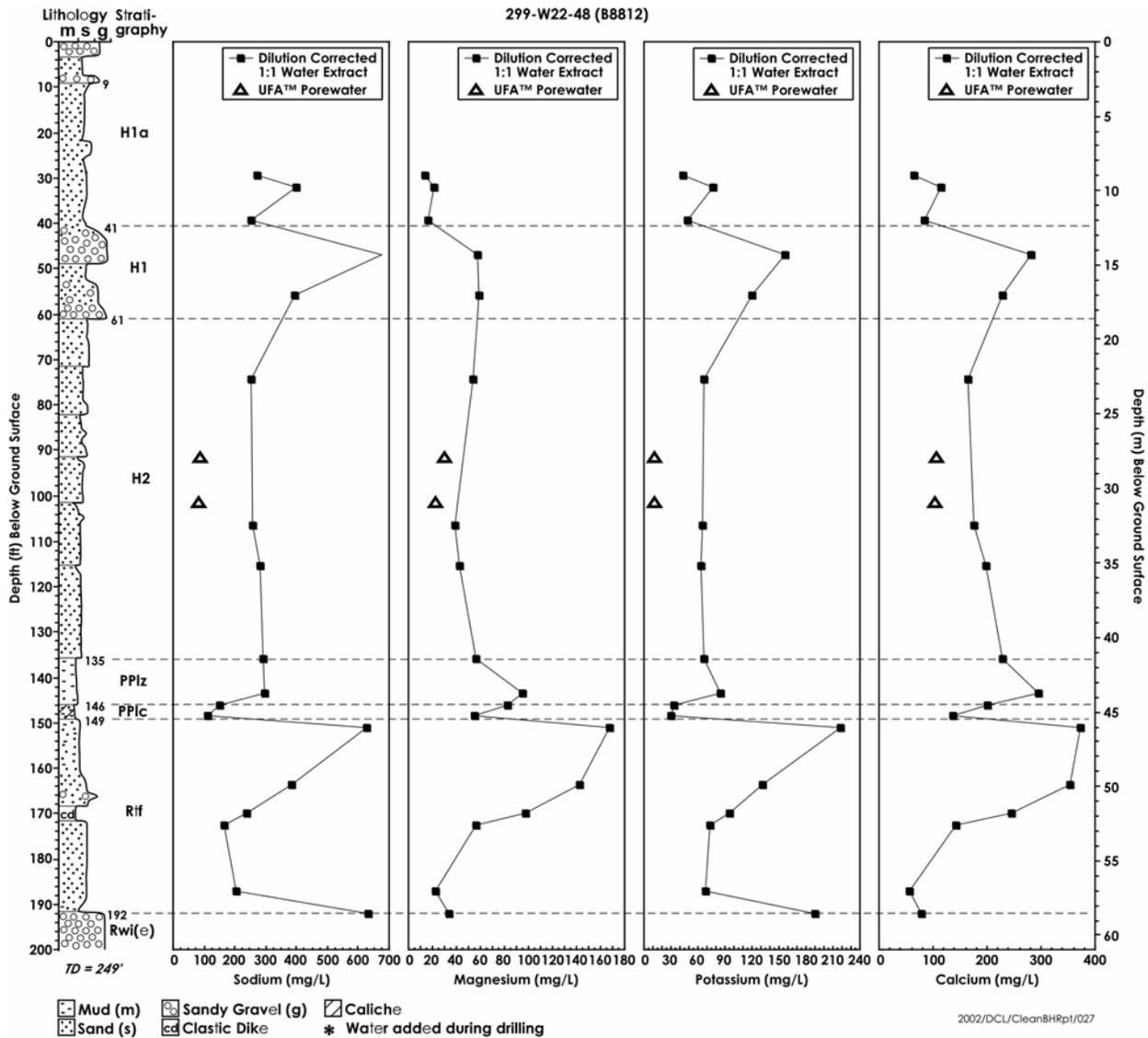


Figure 5.9. Comparison of Dilution-Corrected Cation Concentrations of 1:1 Water Extracts and UFA-Extracted Porewaters from Sediment Samples in Borehole 299-W22-48

vegetation cycle. This may represent a buried soil horizon or a zone of root penetration that transpired natural recharge back into the atmosphere leaving salts behind. For both the pH and EC, the values for the actual UFA-extracted porewaters are lower than the calculated porewaters (dilution-corrected 1:1 sediment-to-water extracts).

Figure 5.8 shows the anion profile for the vadose zone in borehole 299 W-22-48. The alkalinity, which is a measure of bicarbonate, shows a peak at 14.3 meters (47 feet) bgs and then a second peak right below the PPlc subunit. The chloride shows a peak near 110 ft bgs near the center of the Hanford formation H2 unit and a smaller peak just below the PPlc subunit. The nitrate profile does not vary significantly, except for a minor peak at the top of the PPlc subunit. The sulfate profile shows a similar

peak as the alkalinity and EC profiles within the Hanford formation H2 unit (47 ft bgs) and second peak at the top of the Rwi(e) unit. The two actual porewater samples measured show lower values for the anions than the calculated porewaters based on the water extracts, excepting the nitrate value at 91.5 ft bgs. As mentioned earlier, this datum is incorrect because of contamination during lab activities. The water extract procedure overestimates the composition of porewaters in the vadose sediment apparently because of some dissolution. However, for contaminated vadose zone sediments, the dilution-corrected water extracts represent a better estimate of actual contaminated porewater because the leaked tank fluids are much higher in salt content, making any minor contribution from dissolving salts from the sediment insignificant.

The cation profiles shown in Figure 5.9 show that the sample at 14.3 meters (47 feet) bgs is slightly elevated in calcium, potassium, and sodium compared to the rest of the Hanford formation sediment. All four plotted cations appear depleted in the PPlc subunit followed by a significant increase within the underlying Ringold Rtf unit. As with the anions, the two actual UFA-extracted porewater samples show lower concentrations of cations than the calculated porewater from the water-extract data. Again, this is interpreted as the result of dissolution of some of the sediment during water extraction. Therefore, estimates of porewater composition based on water extracts, presented in Table 5.25 and plotted in Figures 5.7 to 5.9, are biased high and should be used as upper limit values for the chemical composition of porewaters from the various strata.

5.2 Analytical Results for Borehole 299-W22-50

Laboratory analytical results of core samples from clean borehole 299-W22-50 are presented in this section. Sample depths, stratigraphic unit, and types of analyses performed are summarized in Table 5.27. Sampling depths for laboratory moisture analysis are listed in a separate table (Table 5.28).

5.2.1 Mass Water Content

For borehole 299-W22-50, every core segment between 6.04 and 53.9 meters (between 20 and 177.5 feet) bgs was opened and sampled for moisture content. Unlike borehole 299-W22-48, separate moisture samples were not collected in the field from the drive shoe. The moisture profile, along with the lithology, total gamma log, and neutron-neutron moisture log, is illustrated in Figure 2.18. Moisture, in combination with geophysical logs and particle-size distribution, are useful for helping to define lithologic contacts. For example, the relatively low field moisture content between 15.8 and 19.2 meters (or 52 and 63 feet) bgs can be used to delineate coarser-grained strata within the Hanford formation H1 unit (see Figure 2.18).

The moisture content in this borehole is fairly uniform (5% to 15 wt%) between 6.04 and 36.6 meters (20 and 110 feet) bgs, with the exception of the coarser-grained Hanford formation H1 unit, which ranges between 2% to 8%. Several moisture spikes occur at depths of about 115, 127, and 140 ft bgs. The former appears to be within a finer-grained lens within the Hanford formation H2 unit, the middle spike occurs in the upper PPLz subunit just below the contact with the Hanford formation H2 unit. The

Table 5.27. Sediment Core Samples Selected from Borehole 299-W22-50 for Laboratory Analysis

Depth (ft bgs)^(a)	Stratigraphic Unit*	Analysis
20	H1a	WL, CaCO3
22.5	H1a	WL, CaCO3
25	H1a	WL, CaCO3
27.5	H1a	AL, CaCO3
30	H1a	WL, CaCO3
32.5	H1a	WL, CaCO3
35	H1a	WL, CaCO3
37.5	H1a	WL, CaCO3
40	H1a	WL, CaCO3
42.5	H1a	WL, CaCO3
45	H1a	WL, CaCO3
47.5	H1a	DS, WL, CaCO3
48.5	H1a	DS
51	H1a	DS, AL, WL, HY, XRD, XRF, PD, CaCO3, EBC
52.5	H1a	DS, WL, CaCO3
53.5	H1	DS
54.5	H1	DS, AL, WL, CaCO3
56	H1	DS, WL, CaCO3
57.5	H1	DS
58.5	H1	DS
60	H1	DS, AL, WL, HY, XRD, XRF, PD, CaCO3, EBC
61	H1	DS
62.5	H1	DS
63.5	H2	DS
65	H2	DS
66	H2	DS
67.5	H2	AL, WL, CaCO3
68.5	H2	DS
70	H2	DS
76	H2	WL, CaCO3
96	H2	AL, WL, CaCO3
111	H2	WL, CaCO3
115	H2	WL
116	H2	AL, WL, HY, XRD, XRF, PD, CaCO3, EBC, PW
130	PPlz	WL, CaCO3
135	PPlz	AL, WL, HY, XRD, XRF, PD, CaCO3, EBC
140	PPlc	AL, HY, XRD, XRF, PD, CaCO3, EBC, PW
141	PPlc	AL, WL, CaCO3
150.5	Rtf	AL, WL, CaCO3
160.5	Rtf	AL, WL, HY, XRD, XRF, PD, CaCO3, EBC
174	Rtf	WL, CaCO3

Table 5.27. (Contd)

(a) Multiply by 0.3048 to convert to meters.
* See Table 2.1
AL = Acid leach (8M Nitric Acid Extraction)
CaCO ₃ = Calcium Carbonate and Organic Carbon
DS = Dry sieve
EBC = Exchangeable Base Cations (Ammonium Acetate Extraction)
HY = Hydrometer/wet sieve
PD = Particle Density
PW = Pore Water Analysis
WL = Water leach (1:1 Sediment to Water Extraction)
XRD = Mineralogy
XRF = Bulk chemical composition

lowermost moisture spike (30 wt%) lies within a finer-grained lens of the PPlc subunit. Below the Plio-Pleistocene unit, within the Ringold Rtf unit, the moisture content is consistently very low (few wt%); however, the neutron-moisture log indicates moisture increases again with depth within the gravels of Ringold Rwi(e) unit (see Figure 2.18).

5.2.2 Particle-Size Distribution

Cores from each of the major stratigraphic units in borehole 299-W22-50 were analyzed for particle-size distribution. Two methods, dry sieving and wet sieving/hydrometer, were used (see Section 3.2.2). Most samples were dry sieved (Table 5.29), though many were also wet sieved (Table 5.30). Only two of the samples (15.5 and 18.3 meters or 51 and 60 feet bgs) were analyzed by both methods; a comparison of these is in Table 5.31. Dry sieving was limited to the Hanford formation while wet sieving/hydrometer was performed on the Plio-Pleistocene unit and Ringold Formation, as well as the Hanford formation.

Table 5.31 shows a comparison between the wet sieve/hydrometer and dry sieve data for the two samples that were analyzed using both methods. There is a significant difference in the two particle-size distributions for the coarse-grained Hanford formation H1 unit (18.3 meters or 60 feet) bgs. Based on the wet sieve/hydrometer results, it appears many of the gravel clasts may be aggregates of sand and/or silt/clay. This is consistent with wet sieve results in borehole 299-W22-48, which have been demonstrated to produce more fines under wet sieving (see Table 5.6). However, it is possible that the large difference in particle-size distribution is because the two samples came from two different lithologic units within the same 6-inch-long core liner. In general, the wet sieve/hydrometer technique is more effective at disaggregating the sediment samples and, therefore, is believed to produce more accurate results.

Almost all past particle-size determinations on the Hanford Site have used the dry sieving technique, so historical particle-size distributions may be skewed to coarser distributions than obtained using the wet sieve/hydrometer method.

Table 5.28. Moisture Content (wt%) Measured in the Laboratory for Sediment Samples from Borehole 299-W22-50

Depth (ft bgs) ^(a)	Moisture Content (%)	Depth (ft bgs) ^(a)	Moisture Content (%)	Depth (ft bgs) ^(a)	Moisture Content (%)	Depth (ft bgs) ^(a)	Moisture Content (%)
20	7.33	58	1.96	97.5	8.65	136	17.01
21	7.01	60	3.02	98.5	4.51	137.5	16.14
22.5	14.46	61	1.62	100	6.15	138.5	14.08
23.5	8.55	62.5	3.50	101	3.36	140	29.88
25	5.80	63.5	2.43	102.5	5.79	141	8.29
26	5.51	65	5.10	103.5	7.57	142.5	2.59
27.5	11.47	66	3.69	105	7.55	143.5	2.45
28.5	2.76	67.5	7.51	106	6.16	148	6.74
30	12.56	68.5	5.53	107.5	11.52	149	2.86
31	4.64	70	6.38	108.5	7.14	150.5	3.14
32.5	8.72	71	4.50	110	7.18	151.5	2.60
33.5	4.30	72.5	5.60	111	13.86	153	3.14
35	8.94	73.5	4.48	112.5	6.99	154	2.80
36	5.15	75	8.37	113.5	5.88	155.5	2.28
37.5	6.86	76	10.30	115	10.17	156.5	2.18
38.5	5.92	77.5	5.74	116	22.36	158	2.50
40	5.07	78.5	7.32	117.5	5.42	159	2.03
41	4.41	80	6.94	118.5	7.46	160.5	2.26
42.5	7.14	81	3.61	120	8.09	161.5	1.90
43.5	5.36	82.5	6.48	121	10.77	163	1.84
45	7.87	83.5	6.92	122.5	4.95	164	1.89
46	8.64	85	5.48	123.5	3.81	165.5	1.95
47.5	10.60	86	3.99	125	4.93	166.5	3.48
48.5	9.26	87.5	5.29	126	3.45	168	2.44
50	10.37	88.5	3.65	127.5	10.61	169	1.78
51	7.62	90	6.01	128.5	19.69	170.5	1.67
52.5	2.55	91	2.28	130	6.31	171.5	1.61
53.5	2.08	92.5	5.15	131	5.33	173	1.63
55	8.26	93.5	7.66	132.5	10.85	174	1.74
56	4.25	95	4.30	133.5	10.60	175.5	1.84
57	2.35	96	8.97	135	10.00	176.5	1.92

(a) Multiply by 0.3048 to convert to meters.

Table 5.29. Particle-Size Distributions (determined by dry sieving) for Sediment Samples from Borehole 299-W22-50

Depth (ft bgs) ^(a)	Stratigraphic Unit	Gravel (wt%)	Sand (wt%)	Silt/Clay (wt%)
47.5	H1a	0.99	96.00	3.01
48.5	H1a	0.01	92.45	7.55
50	H1a	0.56	90.11	9.33
51	H1a	0.23	90.81	8.95
52.5	H1a	4.82	90.55	4.63
53.5	H1	6.06	92.09	1.85
54.5	H1	3.95	96.05	0.00
56	H1	10.69	85.34	3.97
57.5	H1	4.55	93.95	1.50
58.5	H1	48.62	49.38	2.01
60	H1	86.63	12.04	1.33
61	H1	50.91	45.67	3.42
62.5	H2	0.99	96.00	3.01
63.5	H2	1.70	96.75	1.56
65	H2	0.26	94.51	5.23
66	H2	1.35	96.69	1.97
68.5	H2	0.00	92.23	7.77
70	H2	2.28	92.22	5.51

(a) Multiply by 0.3048 to convert to meters.

Table 5.30. Particle-Size Distributions Determined by Wet Sieving/Hydrometer Method for Borehole 299-W22-50

Sample (ft bgs) ^(a)	Stratigraphic Unit	Gravel (wt%)	Sand (wt%)	Silt (wt%)	Clay (wt%)
51	H1a	0.03	81.84	15.42	2.71
60	H1	35.93	43.84	17.33	2.9
116	H2	0.00	63.84	33.86	2.29
135	PPlz	0.00	8.76	80.79	10.46
140	PPlc	0.00	11.91	83.7	4.38
160.5	Rtf	5.17	82.88	9.64	2.31

(a) Multiply by 0.3048 to convert to meters.

Table 5.31. Comparison of Particle-Size Distributions Using the Dry Versus Wet Sieving/Hydrometer Methods for Borehole 299-W22-50

Depth (ft bgs) ^(a)	Stratigraphic Unit	Sieve Method	Gravel (wt%)	Sand (wt%)	Silt/Clay (wt%)
51	H1a	Dry	0.23	90.81	8.95
		Wet/Hydrometer	0.03	81.84	18.13
60	H1	Dry	86.63	12.04	1.33
		Wet/Hydrometer	35.93	43.84	20.23

(a) Multiply by 0.3048 to convert to meters.

Figure 5.10 shows the particle-size distribution (determined using wet sieve/hydrometer method) for the three shallower samples from the Hanford formation units while Figure 5.11 shows the distribution of the three other samples from the Plio-Pleistocene unit and Ringold Formation. Particle-size distribution plots confirm that the gravelly sand of the Hanford formation H1 unit is much coarser and more poorly sorted than the other Hanford formation units. Both Plio-Pleistocene subunits (PPlz and PPlc) are relatively fine-grained compared to the underlying Rtf unit. However, because the PPlc subunit is moderately to strongly cemented with pedogenic calcium carbonate, it is not possible to completely disaggregate the sample prior to wet sieving, thus the particle-size distribution is not totally representative of this unit.

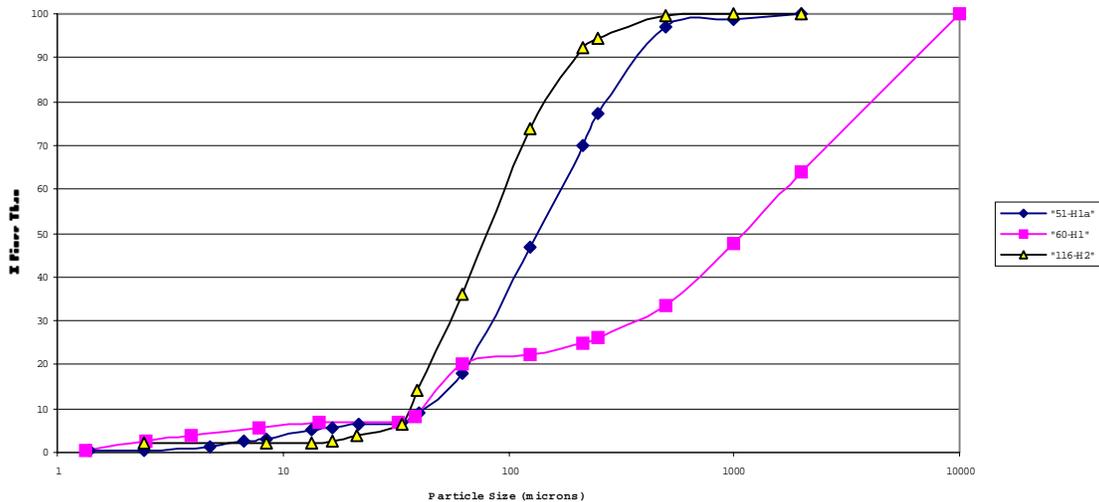


Figure 5.10. Particle-Size Distribution Curves of Sediment Samples from the Hanford Formation at Borehole 299-W22-50

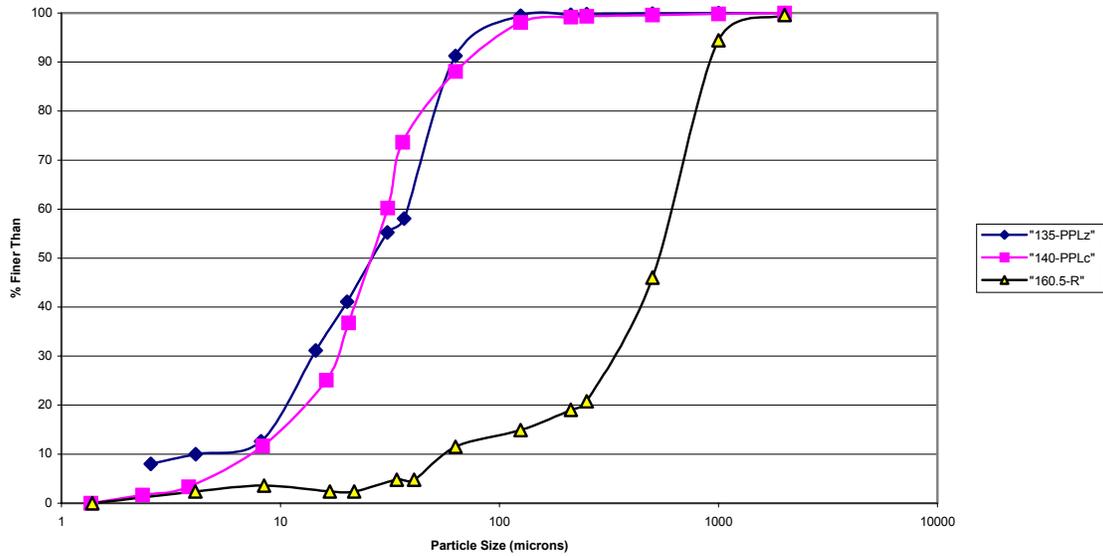


Figure 5.11. Particle-Size Distribution Curves of Sediment Samples from the Plio-Pleistocene Unit and Ringold Formation at Borehole 299-W22-50

5.2.3 Particle Density

The particle density of bulk grains for selected core samples from borehole 299-W22-50 is presented in Table 5.32. Results are similar to those reported for borehole 299-W22-48 in this report (see Table 5.6), but slightly lower than some of those reported previously in Serne et al. (1993), which ranged from 2.70 to 2.82 g/cm³.

Table 5.32. Particle Densities for Sediment Samples from Borehole 299-W22-50

Sample Name	Stratigraphic Unit	Particle Density (g/cm ³)	Standard Deviation (3 trials)
51	H1a	2.626	0.014
60	H1	2.735	0.016
116	H2	2.694	0.017
135	H2	2.652	0.007
140	PPLc	2.680	0.007
160.5	Rtf	2.656	0.011

5.2.4 Calcium Carbonate and Organic Carbon Content

The calcium carbonate equivalent and organic carbon content of the bulk sediment for selected depths from borehole 299-W22-50 are presented in Table 5.33.

Table 5.33. Calcium Carbonate and Organic Carbon Content (wt%) for Sediment Samples from Borehole 299-W22-50

Sampling Depth (ft bgs) ^(a)	Stratigraphic Unit	Total Carbon (%)	Inorganic Carbon (%)	Inorganic as CaCO ₃ (%)	Organic Carbon (%)
20	H1a	0.28	0.23	1.92	0.05
22.5	H1a	0.29	0.25	2.08	0.04
25	H1a	0.21	0.14	1.17	0.07
27.5	H1a	0.21	0.17	1.42	0.04
30	H1a	0.23	0.19	1.58	0.04
32.5	H1a	0.18	0.13	1.08	0.05
35	H1a	0.23	0.18	1.50	0.05
37.5	H1a	0.23	0.19	1.58	0.04
40	H1a	0.22	0.19	1.58	0.03
42.5	H1a	0.26	0.21	1.75	0.05
45	H1a	0.28	0.22	1.83	0.06
47.5	H1a	0.29	0.24	2.00	0.05
51	H1a	0.27	0.23	1.92	0.04
52.5	H1a	0.21	0.18	1.50	0.03
54.5	H1	0.26	0.2	1.67	0.06
56	H1	0.25	0.23	1.92	0.02
60	H1	0.32	0.29	2.42	0.03
67.5	H2	0.27	0.22	1.83	0.05
76	H2	0.23	0.21	1.75	0.02
96	H2	0.26	0.24	2.00	0.02
111	H2	0.36	0.31	2.58	0.05
115	H2	0.31	0.25	2.08	0.06
116	H2	0.26	0.22	1.83	0.04
130	PPlz	0.43	0.35	2.92	0.08
135	PPlz	0.49	0.4	3.33	0.09
140	PPlc	0.28	0.23	1.92	0.05
141	PPlc	1	0.92	7.67	0.08
150.5	Rtf	0.1	0.07	0.58	0.03
160.5	Rtf	0.08	0.04	0.33	0.04
174	Rtf	0.03	0	0.00	0.03

(a) Multiply by 0.3048 to convert to meters.

The calcium carbonate equivalent (in terms of grams of calcite per gram of oven-dry sediment) are low for all samples except the depths at 41.2 through 43 meters (or 135 through 141 feet) bgs for borehole 299-W22-50. Geologist descriptions (Appendices A and B) in combination with the geophysical logs (Figure 2.18) indicate the presence of a carbonate-rich zone (PPlc) at a depth of about 42.1 to 43.5 meters (138 to 143 feet) bgs. However, unlike borehole 299-W22-48, the data presented in Table 5.33 do not show a well-defined calcic zone in borehole 299-W22-50. We believe a carbonate-rich zone is present but representative aliquots with calcic cement dominating were not chosen for analysis.

The method used to measure the organic carbon relies upon subtracting the inorganic carbon from the total carbon in the sample and for such low carbon values is not accurate. The low values for organic carbon are within the ranges generally reported for Hanford sediment but if more accurate values are desired a different method that is more sensitive should be used.

5.2.5 Bulk Chemical Composition

The elemental composition, determined by XRF (see Section 3.2.5) and converted to oxides of the bulk sediment from borehole 299-W22-50, is shown in Table 5.34. We have assumed that the iron present in the sediment is all ferric oxide though there may be some reduced iron (ferrous oxide) also present. The total content has been adjusted to reflect the presence of calcium carbonate by converting the calcium carbonate in Table 5.33 back to percent carbon dioxide and adding it to the XRF totals.

The bulk chemical composition of the sediment samples from borehole 299-W22-50 show that silica is most abundant, followed by alumina. These are followed, in decreasing order, by iron, calcium, magnesium, sodium, potassium, titanium oxides, and carbonate. The calculated mass balances range between 96.95% and 101.76% with a mean of 99.95 ± 1.75 % for the 6 samples. We consider these measurements as outstanding mass balance. The amount of iron and calcium is greater in the coarser-grained units of the Hanford formation (Units H1a and H1), which is consistent with a higher concentration of basaltic particles in these units.

5.2.6 Mineralogy

A total of five bulk sediment samples and the clay fractions (<2 microns) from borehole 299-W22-50 were characterized by XRD methods (see Section 3.2.6). The semiquantitative mass results are presented in Table 5.35. The mineralogy of both the bulk sediment and the clay-size fraction are quite similar to the samples from the same stratigraphic units previously reported for borehole 299-W22-48. Therefore, the reader is referred to the discussion previously presented in Section 5.1.6 for details.

5.2.7 Cation Exchange Capacity

No cation exchange measurements are available for sediment samples from borehole 299-W22-50.

Table 5.34. Bulk Chemical Composition of Sediment Samples from Borehole 299-W22-50 (% as Oxides)

Depth (ft bgs) ^(a)	51 ft	60 ft	116 ft	135 ft	140 ft	160.5 ft
Stratigraphic Unit	H1a	H1	H2	PPlz	PPlc	Rtf
Oxides						
Na ₂ O	2.09	2.56	2.37	1.47	1.85	3.02
MgO	3.55	3.33	3.80	4.31	3.80	2.67
CO ₂	0.92	1.16	0.88	1.60	0.92	0.16
Al ₂ O ₃	12.09	13.08	13.70	14.30	13.26	11.41
SiO ₂	63.86	64.61	69.42	66.00	68.46	68.89
P ₂ O ₅	<0.22	<0.27	<0.21	<0.20	<0.21	<0.20
SO ₃	0.11	0.15	0.08	0.06	0.06	0.06
Cl	<0.016	<0.016	0.046	0.044	0.035	0.020
K ₂ O	1.79	1.77	2.46	2.63	2.33	1.71
CaO	5.30	5.96	3.78	3.76	3.38	3.37
TiO ₂	1.24	1.10	0.65	0.73	0.81	0.70
V ₂ O ₅	0.04	0.03	0.01	0.01	0.01	0.02
Cr ₂ O ₃	0.01	0.01	0.01	0.01	0.01	0.00
MnO	0.12	0.10	0.07	0.08	0.07	0.08
Fe ₂ O ₃	8.00	7.33	4.13	4.78	4.52	4.51
SrO	0.04	0.04	0.05	0.03	0.04	0.05
BaO	0.07	0.08	0.09	0.07	0.08	0.07
Total	99.46	101.59	101.76	100.10	99.83	96.95

(a) Multiply by 0.3048 to convert to meters.

Table 5.35. Semiquantitative Mineral Content of Sediment Samples from Borehole 299-W22-50

Semiquantification of Minerals in Bulk Samples (wt%)								
Sample Depth (ft bgs) ^(a) [Stratigraphic Unit]	Quartz	K-Feldspar	Na-Feldspar	Calcite	Total			
51 [H1a]	60	10	25	ND	~95			
60 [H1]	45	10	25	ND	~80			
116 [H2]	45	15	30	ND	~90			
135 [PPlz]	60	5	15	ND	~80			
140 [PPlc]	60	10	15	ND	~85			
160.5 [Rtf]	50	10	30	ND	~90			
Semiquantification of Minerals in Clay-Size Fraction (wt%)								
Sample Depth (ft bgs) ^(a) [Stratigraphic Unit]	Quartz	Feldspar	Calcite	Smectite	Illite	Chlorite	Kaolinite	Total
51 [H1a]	5	<5	10	30	15	10	10	~85
60 [H1]	5	5	25	5	15	10	10	~75
116 [H2]	10	<5	Trace	30	30	35	10	~120
135 [PPlz]	5	<5	<5	30	30	30	10	~115
140 [PPlc]	10	<5	<5	15	10	10	5	~60
160.5 [Rtf]	5	5	Trace	10	15	15	10	~60

(a) Multiply by 0.3048 to convert to meters.
 ND = Not detected.
 Trace = Trace amount detected ~1% to 4%.

5.2.8 Exchangeable Base Cations

The exchangeable base cations and a few selected trace metals obtained using ammonium acetate extraction (see Section 3.2.8) are shown in Table 5.36. The sum of extractable cations is shown in Table 5.37. All uncontaminated sediment samples from the Hanford Site show that calcium and magnesium dominate (>90% of total displaceable cations) the exchange sites. The sum of the base cations for the sediment from borehole 299-W22-50 cannot be compared with other methods to measure the cation exchange capacity because further testing was not performed. The sum of the base cations does not closely follow the trend of increasing total exchangeable cations with finer-grained particle-size distribution in that the coarse-grained Hanford formation H1 unit shows a relatively high sum compared to the fine-grained PPlz subunit, which shows a lower sum.

Table 5.36. Exchangeable Base Cations for Sediment Samples from Borehole 299-W22-50

Sampling Depth (ft bgs) ^(a) [Stratigraphic Unit]	meq/L						µg/L		
	Ba	Ca	K	Mg	Sr	Na	Fe	Mn	Si
51 [H1a]	0.07	52.20	3.14	10.55	0.13	1.54	<0.25	0.015	13.90
60 [H1]	0.06	45.90	2.06	6.28	0.07	1.40	<0.25	0.415	22.26
116 [H2]	0.13	31.91	0.66	4.04	0.06	0.85	<0.25	0.598	8.42
116 Dup [H2]	0.12	29.76	0.59	3.86	0.06	0.79	<0.25	0.540	8.05
135 [PPlz]	0.17	42.18	1.60	11.10	0.09	1.27	<0.25	0.484	9.70
140 [PPlc]	0.12	33.08	1.14	7.59	0.06	0.92	<0.25	0.413	9.89
160.5 [Rtf]	0.06	24.99	1.16	4.80	0.06	0.65	<0.25	2.139	9.82

(a) Multiply by 0.3048 to convert to meters.

Table 5.37. Comparison of the Base Cation Sum and Cation Exchange Capacity Measurements from Borehole 299-W22-50

Sampling Depth (ft bgs) ^(a) [Stratigraphic Unit]	Exchangeable Base Cations							Cation Exchange Capacity	
								Polemio and Rhoades (1977)	Amrhein and Suarez (1990)
	meq/100 g								
	Ba	Ca	K	Mg	Sr	Na	Sum	ND	ND
51 [H1a]	0.017	12.207	0.733	2.467	0.030	0.359	15.81	ND	ND
60 [H1]	0.015	10.745	0.483	1.469	0.015	0.327	13.05	ND	ND
116 [H2]	0.030	7.469	0.154	0.946	0.015	0.200	8.81	ND	ND
116 Dup [H2]	0.028	6.965	0.139	0.903	0.014	0.186	8.23	ND	ND
135 [PPlz]	0.040	10.005	0.379	2.632	0.022	0.300	13.38	ND	ND
140 [PPlc]	0.028	7.742	0.266	1.777	0.015	0.215	10.04	ND	ND
160.5 [Rtf]	0.013	5.872	0.272	1.127	0.014	0.153	7.45	ND	ND

(a) Multiply by 0.3048 to convert to meters.
ND = Not done.

5.2.9 1:1 Sediment-to-Water Extraction

The 1:1 sediment-to-water extracts results for core samples from borehole 299-W22-50 are presented in Tables 5.38 to 5.41. Later, we compare the chemical composition of dilution-corrected water extracts with actual porewater obtained by ultracentrifugation. For some constituents the water extracts, when corrected for dilution with deionized water, provide an accurate measure of the concentration within the native porewater. For other constituents, the amount found in the water extract, when dilution-corrected back to the porewater, over-predicts the porewater concentration because of dissolution of salts/minerals in the sediment samples. We have also converted them to a per gram of oven-dry sediment and relate the values reported on a sediment basis to the amount extracted by strong nitric acid and the bulk chemical composition as determined by XRF.

The data in Tables 5.38 to 5.41 show that the most water-soluble constituents are calcium, magnesium, sodium, bicarbonate, sulfate, and nitrate. There are minor amounts of chloride, potassium, and dissolved silicon and no evidence of elevated levels of trace metals. Water extracts from the PPlc subunit show slightly elevated levels of selenium compared to other strata. The bottom of the PPlc also shows slightly elevated EC, alkalinity, calcium, magnesium, silicon, strontium, sulfate, and nitrate compared to the other stratigraphic units. Water extracts from the Ringold Formation show lower alkalinity, barium, chromium, sodium, and uranium concentrations than those for either the Hanford formation or the Plio-Pleistocene unit.

Most noteworthy in the water extract profile for borehole 299-W22-50 (Figure 5.12) is highly water-leachable pH and EC within the coarse-grained Hanford formation H1 unit at 18.3 meters (60 feet) bgs (Figure 5.12). Alkalinity and a number of other constituents (i.e., calcium, chromium, strontium, potassium, sodium, sulfate and chloride) are also elevated at this depth. Possible causes for these high values are the presence of gypsum (calcium sulfate) at the 18.3-meter (60-foot) depth, introduction of disposed wastewater via lateral spreading from nearby waste sites, or leaking water lines in the area.

Table 5.42 presents the range in concentration for several constituents for the different stratigraphic units sampled in borehole 299-W22-50. Ringold Formation sediment samples show low values for water-leachable alkalinity, sulfate, sodium, potassium, and alkaline earths (barium, calcium, and strontium). The PPlc water extracts are low in potassium compared to other stratigraphic units. Conversely, water extracts of the Plio-Pleistocene unit have high alkalinity and uranium concentrations. Of particular interest are water extracts from the Hanford formation H2 unit (i.e., 96, 111, and 115 ft bgs), which indicate anomalously high chloride and nitrate concentrations compared to other stratigraphic units (Table 5.38).

In 17 of 28 instances, the cation-anion balance from water extracts listed in Table 5.41 agrees within 15%, suggesting an internally consistent data set. The remaining 11 data sets show a low anion charge, however, perhaps reflecting some bias in the alkalinity measurements. Because the ratio of water to sediment used in the water extracts was 1:1, the data in Tables 5.38 through 5.41 with the units of mg/L and µg/L or meq/L also represent milligrams or milliequivalents per kilogram of soil.

Table 5.38. pH, Electrical Conductivity, Alkalinity, and Anions in Water
Extracts of Sediment Samples from Borehole 299-W22-50

Constituent Sample		pH	EC	Alk	F	Cl	NO ₂	NO ₃	PO ₄	SO ₄
ft (bgs) ^(a)	Stratigraphic Unit		μS/cm	mg/L CaCO ₃	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
20	H1a	7.78	188	52.88	0.72	0.45	<0.1	5.89	0.1	8.56
22.5	H1a	7.72	221	26.79	0.74	1.08	<0.1	4.51	<0.1	13.52
25	H1a	7.68	214	31.73	0.72	0.76	<0.1	3.42	0.2	9.78
27.5	H1a	7.60	214	48.65	0.7	1.88	<0.1	0.63	0.1	19.56
30	H1a	7.65	217	39.48	0.63	4.85	<0.1	2.64	0.15	20.5
32.5	H1a	7.67	186	43.01	0.56	1.62	<0.1	2.51	0.33	11.64
35	H1a	7.49	222	50.06	0.68	0.82	<0.1	0.68	0.29	13.85
37.5	H1a	7.84	203	45.12	0.61	0.67	<0.1	0.57	<0.1	12.51
40	H1a	7.03	184	47.24	0.5	0.57	<0.1	0.36	<0.1	11.49
42.5	H1a	7.11	223	54.29	0.58	0.99	<0.1	1.15	0.16	17.54
45*	H1a	7.46±0.1	224±3	35±19	0.60±0.05	0.82±0.01	<0.1	1.46±0.52	<0.1	17.6±1.1
47.5	H1a	7.40	224	34.55	0.57	0.83	<0.1	0.46	<0.1	16.37
51	H1a	7.90	181	56.40	0.59	0.45	<0.1	3.09	0.1	8.62
52.5	H1a	7.44	181	32.43	0.39	0.85	<0.1	0.72	<0.1	16.15
54.5	H1	7.32	216	54.99	0.47	1.34	<0.1	0.25	<0.1	19.18
56	H1	7.35	129	25.38	0.28	0.54	<0.1	1.25	0.12	8.37
60	H1	10.33	553	60.63	0.41	9.33	<0.1	1.82	<0.1	35.71
67.5	H2	9.00	276		0.38	4.84	<0.1	5.49	0.21	21.9
76	H2	8.55	223	21.86	0.36	4.4	<0.1	8.85	0.18	29.7
96*	H2	7.44±0.02	298±15	35±5	0.39±0.06	23.7±13	<0.1	10.0±1.0	0.20±0.06	28.7±1.0
111	H2	7.45	296	58.52	0.49	11.47	<0.1	25.51	0.15	23.01
115	H2	7.51	309	55.70	0.51	14.41	<0.1	29.8	0.17	16.6
130	PPlz	7.66	231	89.54	0.41	2.01	<0.1	6.32	0.16	9.63
135	PPlz	8.50	226.5	62.04	0.46	2.31	<0.1	20.99	0.2	18.02
141	PPlc	8.12	246	67±36	0.80±0.08	3.3±0.5	<0.1	11±1.3	<0.1	22±2.8
150.5	Rtf	7.77	191	6.35	1.1	1.49	<0.1	<0.1	<0.1	8.62
160.5	Rtf	7.74	135	31.02	0.62	0.76	<0.1	<0.1	<0.1	3.13
174	Rtf	7.75	88	18.33	0.99	4.77	<0.1	10.9	0.13	2.57

(a) Multiply by 0.3048 to convert to meters.
* Average of duplicate extracts.

5.2.10 Acid Extraction

The results of 8 M nitric acid extraction for sediment samples from borehole 299-W22-50 are presented in Tables 5.43 and 5.44. Samples of the PPlc subunit in borehole 299-W22-50 contain less calcium carbonate cement than in borehole 299-W22-48 and, thus, shows only mildly high acid-leachable calcium, lead, and strontium as well as conversely low-leachable iron, compared to the other stratigraphic units. The high acid-leachable alkaline-earth cations represent the rapid dissolution of carbonates. Unlike the PPlc subunit in borehole 299-W22-48, there is no high release of copper, manganese, and

Table 5.39. Major Cations in Water Extracts of Sediment Samples from Borehole 299-W22-50 (ICP)

Depth ft (bgs) ^(a)	Stratigraphic Unit	Na (mg/L)	Mg (mg/L)	Al (µg/L)	Si (mg/L)	P µg/L	S (mg/L)	K (mg/L)	Ca (mg/L)	Mn (µg/L)	Fe (µg/L)	Sr (µg/L)	Ba (µg/L)
20	H1a	19.63	1.65	(29)	16.34	(33)	3.11	5.40	7.14	(0)	33.9	31.6	16.9
22.5	H1a	24.74	2.08	(45)	16.61	<500	4.76	6.48	9.49	(1)	96.2	40.2	20.0
25	H1a	20.05	1.40	(30)	14.22	(91)	3.51	5.41	6.32	(0)	30.6	27.5	18.5
27.5	H1a	22.40	2.35	(38)	15.60	(42)	7.10	6.69	10.72	(2)	76.7	48.1	28.8
30	H1a	20.15	2.42	(20)	17.47	(59)	7.18	5.98	11.24	(0)	45.6	52.1	19.9
32.5	H1a	19.79	1.67	(23)	15.40	(91)	4.48	4.86	7.95	(0)	26.3	34.6	18.2
35	H1a	25.40	2.15	(30)	16.63	(54)	5.56	6.82	10.91	(1)	31.7	49.0	26.3
37.5	H1a	22.52	1.97	(21)	16.02	(80)	5.08	6.37	9.98	(0)	33.2	44.7	19.8
40	H1a	18.18	2.07	(28)	15.41	(37)	4.72	6.18	9.98	(0)	27.5	46.3	23.5
42.5	H1a	22.12	2.62	(25)	17.63	<500	6.85	7.09	12.86	(0)	(22)	55.9	17.5
45	H1a	21.62	2.52	(30)	18.01	(50)	7.06	7.19	12.28	(0)	(22)	55.5	21.3
47.5	H1a	22.33	2.63	(25)	17.90	(41)	6.47	7.31	13.13	(0)	(23)	59.9	21.1
51	H1a	17.25	1.84	(22)	17.61	(126)	3.39	5.20	9.15	(0)	35.2	39.9	13.7
52.5	H1a	15.17	2.17	(34)	13.94	(52)	6.26	5.57	10.12	(0)	(19)	46.3	20.3
54.5	H1	19.45	2.79	(36)	15.40	(56)	7.31	6.56	12.72	(1)	33.7	58.3	27.5
56	H1	11.06	1.77	(47)	9.01	(76)	3.20	4.09	5.74	(1)	(21)	26.8	14.6
60	H1	28.12	0.03	379	28.04	(145)	13.61	10.05	51.55	<10	(7)	176	44.9
67.5	H2	16.36	3.03	103	10.67	(154)	8.21	4.69	12.62	(1)	109	56.8	15.3
76	H2	16.34	2.79	75.1	10.51	(81)	10.64	4.01	14.10	(0)	59.7	58.7	16.4
96	H2	23.18	4.29	(27)	9.95	(139)	11.20	5.93	19.17	(0)	(18)	85.6	26.7
111	H2	22.41	3.93	(14)	11.51	(67)	9.01	5.66	17.85	(0)	(11)	79.7	30.1
115	H2	24.33	4.15	(26)	10.23	(51)	6.75	5.49	18.50	(3)	33.1	85.4	35.5
116	H2	17.48	2.14	308	14.43	(257)	4.05	2.66	10.45	(2)	98.6	46.1	25.8
130	PPlz	18.37	4.03	(29)	9.96	(78)	4.13	3.78	16.15	(2)	(19)	71.8	28.6
135	PPlz	20.96	4.61	(13)	10.58	(179)	7.07	4.72	15.73	(0)	(12)	70.3	28.7
140	PPlc	17.01	3.51	277	14.99	(131)	6.16	3.04	11.41	(3)	117	57.4	34.0
141	PPlc	20.13	5.28	(20)	21.56	(33)	8.93	4.71	17.09	(0)	(13)	82.9	22.7
150.5	Rtf	17.33	3.31	370	13.81	(129)	3.87	4.63	10.44	15.2	352	59.6	15.3
160.5	Rtf	10.02	2.33	(38)	13.98	(88)	1.52	3.60	8.41	(2)	(24)	40.5	16.8
174	Rtf	6.69	0.90	106	13.81	(123)	1.13	2.20	2.98	(2)	44.7	(14)	(5)

(a) Multiply by 0.3048 to convert to meters.
 Values in parenthesis are just below level of quantification but spectra looked good. Thus, a tentative value was attributed to data. Data in **bold** are the average of duplicate extractions.

Table 5.40. Trace Metals in Water Extracts of Sediment Samples from Borehole 299-W22-50

Depth ft (bgs) ^(a)	Strati- graphic Unit	B (µg/L)	Cr* (µg/L)	Co (µg/L)	Ni (µg/L)	Cu (µg/L)	Zn (µg/L)	As* (µg/L)	Se* (µg/L)	Mo* (µg/L)	Tc* (µg/L)	Pb* (µg/L)	U* (µg/L)
20	H1a	(8)	0.910	<10	(6)	(1)	30.3	39.3	<5	1.89	(0.00)	(0.35)	1.11
22.5	H1a	(6)	(0.31)	0.5	(6)	(2)	41.4	34.4	<5	4.81	(0.00)	(0.28)	1.73
25	H1a	(4)	(0.28)	<10	(4)	(1)	48.8	41.3	(0.02)	3.52	(0.00)	(0.84)	1.55
27.5	H1a	(3)	(0.47)	0.1	(2)	(1)	33.6	34.0	(0.14)	6.57	(0.00)	(0.13)	1.44
30	H1a	(5)	(0.32)	<10	(3)	(2)	31.5	13.5	(0.27)	1.62	(0.00)	(0.09)	0.805
32.5	H1a	(3)	(0.41)	0.4	(3)	(1)	30.8	27.0	(0.24)	2.12	(0.00)	(0.01)	1.61
35	H1a	(2)	0.510	0.0	(2)	(1)	31.3	24.3	(0.28)	9.68	(0.00)	(0.03)	2.08
37.5	H1a	(3)	0.625	<10	(2)	(3)	28.6	22.8	(0.21)	12.8	(0.00)	(0.25)	1.72
40	H1a	(4)	0.535	<10	(3)	(1)	42.4	10.1	(0.07)	4.32	(0.00)	(0.02)	1.07
42.5	H1a	(6)	0.590	<10	(4)	(1)	46.7	11.5	(0.17)	6.74	(0.00)	(0.00)	1.15
45	H1a	(5)	(0.49)	<10	(2)	(3)	35.2	13.2	(0.58)	6.05	(0.00)	(0.22)	1.15
47.5	H1a	(5)	(0.49)	<10	(3)	(1)	29.8	11.2	(0.13)	12.54	<0.02	(0.08)	1.21
51	H1a	(0)	(0.39)	<10	(3)	(0)	26.7	12.4	(0.18)	1.03	(0.00)	(0.00)	0.710
52.5	H1a	(2)	(0.32)	<10	(3)	<25	34.8	9.60	(0.50)	3.35	(0.00)	(0.25)	0.565
54.5	H1	(4)	(0.48)	<10	(4)	(2)	26.9	7.09	(0.31)	14.9	(0.00)	(0.02)	0.820
56	H1	<100	(0.15)	<10	(2)	<25	33.3	9.16	(0.42)	2.81	(0.00)	(0.02)	0.565
60	H1	(11)	48.8	<10	(2)	(3)	33.5	2.95	(0.66)	10.21	(0.00)	(0.02)	0.000
67.5	H2	(3)	0.715	<10	(4)	(2)	34.3	16.6	(0.66)	9.96	(0.00)	(0.21)	0.885
76	H2	(4)	0.760	<10	(4)	(0)	31.4	14.7	(1.14)	4.77	(0.00)	(0.14)	0.565
96	H2	(11)	0.775	<10	(2)	<25	30.2	12.7	(1.22)	14.5	(0.00)	(0.10)	0.567
111	H2	(12)	1.85	<10	(8)	(5)	27.7	13.8	(1.64)	20.2	(0.00)	(0.00)	0.615
115	H2	(14)	0.500	0.0	(6)	(4)	28.7	11.7	(3.40)	17.6	(0.00)	(0.05)	0.810
116	H2	2161	0.705	0.1	(3)	(4)	19.9	29.7	(1.43)	11.1	(0.00)		0.348
130	PPlz	(9)	(0.39)	<10	(3)	(4)	25.5	9.81	(3.12)	15.1	(0.00)	(0.02)	0.935
135	PPlz	(12)	1.65	<10	(5)	(3)	33.3	6.76	5.38	28.1	(0.00)	(0.07)	0.870
140	PPlc	2089	0.925	1.2	<100	(1)	21.1	9.51	(2.00)	25.7	(0.00)		0.975
141	PPlc	(8)	0.725	<10	(4)	(3)	34.9	18.1	(3.14)	63.6	(0.00)	(0.17)	10.24
150.5	Rtf	(5)	0.565	<10	(5)	(3)	31.4	3.61	(0.10)	8.23	(0.00)	(0.10)	0.775
160.5	Rtf	(5)	(0.29)	0.0	(6)	(4)	30.8	3.82	(0.95)	5.96	(0.00)	(0.04)	0.438
174	Rtf	(1)	0.610	<10	(5)	(5)	32.0	3.44	(3.41)	1.61	(0.00)	(0.24)	0.005

(a) Multiply by 0.3048 to convert to meters.

*ICP-MS instrument was used.

Values in parenthesis are just below level of quantification but spectra looked good. Thus, a tentative value was attributed to data. Data in **bold** type average of duplicate extractions.

Table 5.41. Charge Balance for Water Extracts of Sediment Samples from Borehole 299-W22-50

Depth ft (bgs) ^(a)	Strati- graphic Unit	Alk (meq/L)	F (meq/L)	Cl (meq/L)	NO ₃ (meq/L)	SO ₄ (meq/L)	ΣAnion (meq/L)	Na (meq/L)	Mg (meq/L)	K (meq/L)	Ca (meq/L)	ΣCation (meq/L)
20	H1a	1.06	0.04	0.01	0.10	0.18	1.38	0.85	0.14	0.14	0.36	1.49
22.5	H1a	0.54	0.04	0.03	0.07	0.28	0.96	1.08	0.17	0.17	0.47	1.89
25	H1a	0.63	0.04	0.02	0.06	0.20	0.95	0.87	0.12	0.14	0.32	1.44
27.5	H1a	0.97	0.04	0.05	0.01	0.41	1.48	0.97	0.19	0.17	0.54	1.88
30	H1a	0.79	0.03	0.14	0.04	0.43	1.43	0.88	0.20	0.15	0.56	1.79
32.5	H1a	0.86	0.03	0.05	0.04	0.24	1.22	0.86	0.14	0.12	0.40	1.52
35	H1a	1.00	0.04	0.02	0.01	0.29	1.36	1.10	0.18	0.17	0.55	2.00
37.5	H1a	0.90	0.03	0.02	0.01	0.26	1.22	0.98	0.16	0.16	0.50	1.80
40	H1a	0.94	0.03	0.02	0.01	0.24	1.23	0.79	0.17	0.16	0.50	1.62
42.5	H1a	1.09	0.03	0.03	0.02	0.37	1.53	0.96	0.22	0.18	0.64	2.00
45	H1a	0.99	0.00	0.00	0.00	0.00	0.99	0.94	0.21	0.18	0.61	1.95
47.5	H1a	0.69	0.03	0.02	0.01	0.34	1.09	0.97	0.22	0.19	0.66	2.03
51	H1a	1.13	0.03	0.01	0.05	0.18	1.40	0.75	0.15	0.13	0.46	1.49
52.5	H1a	0.65	0.02	0.02	0.01	0.34	1.04	0.66	0.18	0.14	0.51	1.49
54.5	H1	1.10	0.02	0.04	0.00	0.40	1.57	0.85	0.23	0.17	0.64	1.88
56	H1	0.51	0.01	0.02	0.02	0.17	0.73	0.48	0.15	0.10	0.29	1.02
60	H1	1.21	0.02	0.26	0.03	0.74	2.27	1.22	0.00	0.26	2.58	4.06
67.5	H2	0.00	0.02	0.14	0.09	0.46	0.70	0.71	0.25	0.12	0.63	1.71
76	H2	0.44	0.02	0.12	0.14	0.62	1.34	0.71	0.23	0.10	0.70	1.75
96	H2	0.61	0.00	0.00	0.00	0.00	0.61	1.01	0.35	0.15	0.96	2.47
111	H2	1.17	0.03	0.32	0.41	0.48	2.41	0.97	0.32	0.14	0.89	2.34
115	H2	1.11	0.03	0.41	0.48	0.35	2.37	1.06	0.34	0.14	0.93	2.47
116	H2	--	--	--	--	--	--	0.76	0.18	0.07	0.52	1.53
130	PPlz	1.79	0.02	0.06	0.10	0.20	2.17	0.80	0.33	0.10	0.81	2.04
135	PPlz	1.24	0.02	0.07	0.34	0.38	2.04	0.91	0.38	0.12	0.79	2.20
140	PPlc	--	--	--	--	--	--	0.74	0.29	0.08	0.57	1.68
141	PPlc	1.85	0.00	0.00	0.00	0.00	1.85	0.88	0.43	0.12	0.85	2.29
150.5	Rtf	0.13	0.06	0.04	0.00	0.18	0.41	0.75	0.27	0.12	0.52	1.67
160.5	Rtf	0.62	0.03	0.02	0.00	0.07	0.74	0.44	0.19	0.09	0.42	1.14
174	Rtf	0.37	0.05	0.13	0.18	0.05	0.78	0.29	0.07	0.06	0.15	0.57

(a) Multiply by 0.3048 to convert to meters.

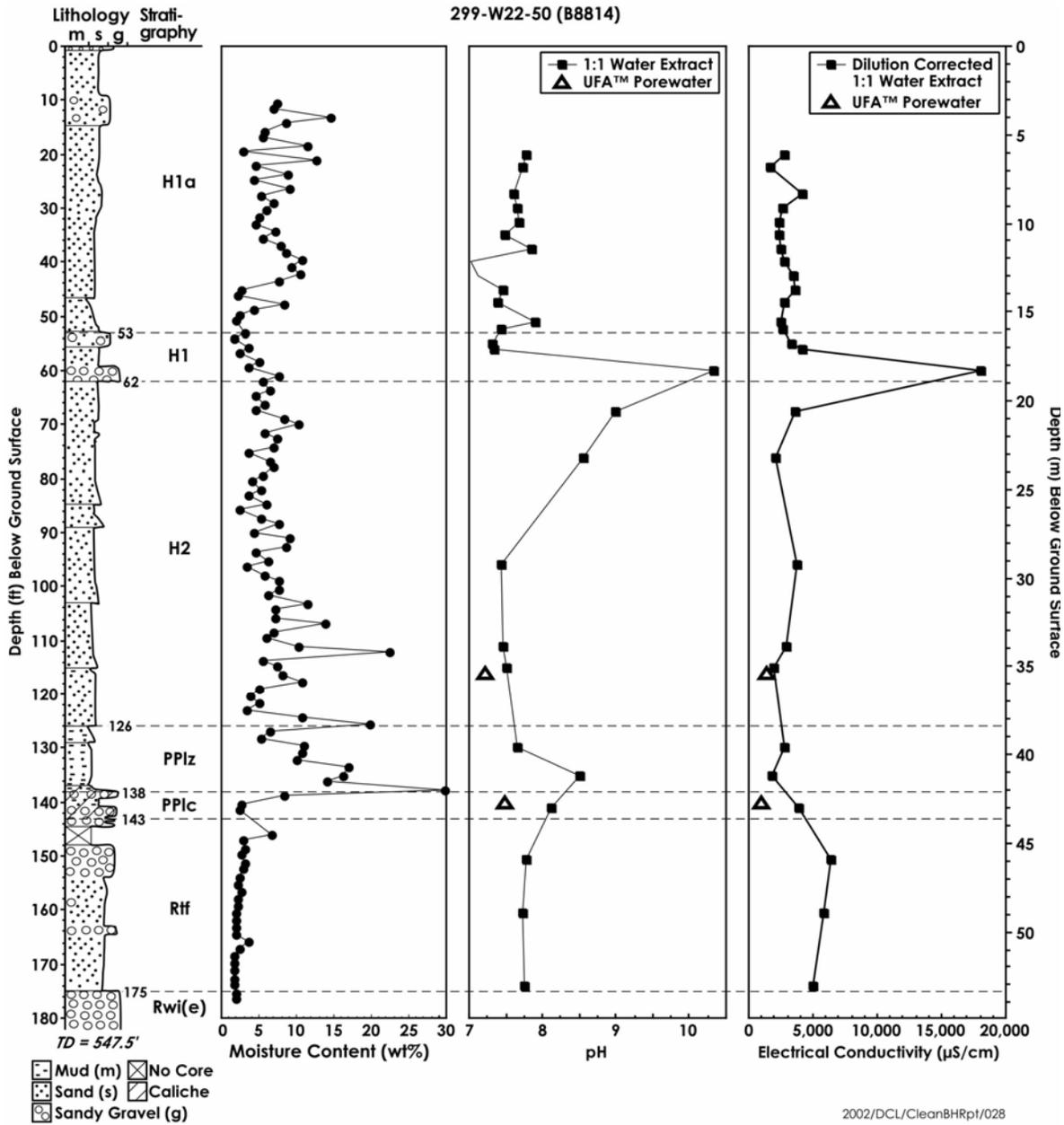


Figure 5.12. Moisture Content, 1:1 Sediment-to-Water Extract, pH, and Electrical Conductivity Data Versus Depth in Borehole 299-W22-50

Table 5.42. Ranges of Parameters and Selected Ions Found in Water Extracts for Stratigraphic Units Sampled Within Borehole 299-W22-50

Stratigraphic Unit		Hanford Formation (Unit H1a)	Hanford Formation (Unit H1a)	Hanford Formation (Unit H1)	Hanford Formation (Unit H2)	Upper Plio-Pleistocene Unit (PPlz)	Lower Plio-Pleistocene Unit (PPlc)	Ringold Formation (Rtf)
Lithology		Sand and Gravel	Sand	Sand and Gravel	Sand and Silt	Fine Sand and Silt	Caliche	Sand to Gravelly Sand
Depth Interval (ft bgs) ^(a)		0 to 14	14 to 53	53 to 62	62 to 126	126 to 138	138 to 143	143 to 175
	Units							
pH		---	7.7 – 7.8	7.3 – 10.3	7.4 – 9.0	7.6 – 8.5	8.1	7.7 – 7.8
EC	µS/cm	---	180 -220	130 - 550	220 -310	220 - 230	250	100 - 200
Alk	mg/L	---	30 - 56	25 - 60	22 - 60	60 - 90	60 - 70	6 – 30
F	mg/L	---	0.5 – 0.7	0.3 – 0.5	0.4 – 0.5	0.4 – 0.5	0.8	0.6 – 1.2
Cl	mg/L	---	0.6 – 4.8	0.5 – 9.3	4 - 23	2 - 3	3	1 – 5
NO3	mg/L	---	0.4 – 5.9	0.2 – 2.0	5 - 30	6 - 21	11	0 – 10
SO4	mg/L	---	8.6 – 20.5	8 - 36	16 - 30	9 -18	20 - 25	2 – 10
Na	mg/L	---	15 - 25	11 - 28	16 - 24	18 - 21	17 -20	6 – 10
Mg	mg/L	---	1.4 – 2.6	0 - 3	2 - 4	4- 4.5	3.5 – 5.5	1 – 2.5
Si	mg/L	---	14 - 18	9 - 28	10 - 14	10 - 11	15 - 22	13 – 14
K	mg/L	---	5.0 – 7.5	4 - 10	4 - 11	3.8 – 4.8	3.0 – 4.7	2 – 4
Ca	mg/L	---	6 - 13	6 - 50	10 - 20	15 - 16	11 - 17	3 – 8
Sr	µg/L	---	27 - 60	25 - 175	45 - 85	70 -72	55 - 85	15 – 40
Ba	µg/L	---	13 - 26	15 - 45	15 - 35	28 - 29	23 - 34	5 – 17
Cr	µg/L	---	0.4 – 0.9	0.2 - 50	0.7 – 1.8	0.4 – 1.6	0.7 – 0.9	0.3 – 0.6
U	µg/L	---	0.6 – 2.0	0 – 0.8	0.4 – 0.9	0.9 – 1.0	1 - 10	0.0 – 0.8

(a) Multiply by 0.3048 to convert to meters.
 ---No samples collected from this unit.

uranium that may represent substitution of these trace metals into the carbonate crystal lattice. The coarse-grained Hanford formation H1 unit produced relatively low amounts of leachable aluminum, calcium, iron, manganese, potassium, and strontium compared to the other units. This is probably a function of the relatively larger particle sizes and less surface area of the Hanford formation H1 unit, which are not leached as efficiently as fine particles during the acid-leach process. The Ringold Formation shows lower amounts of acid-leachable aluminum, barium, calcium, manganese, potassium, and strontium than other units. The finer-grained Hanford formation unit H1a shows high acid-leachable iron and sodium, unlike the same strata at borehole 299-W22-48. Again, the Plio-Pleistocene unit shows high acid-leachable aluminum and magnesium, perhaps coincident with higher clay content.

Table 5.43. Major Cations ($\mu\text{g/g}$) in Acid Extracts of Sediment Samples from Borehole 299-W22-50. Measured using ICP method.

Element ($\mu\text{g/g}$)	ft bgs ^(a) 27.5	ft bgs ^(a) 51	ft bgs ^(a) 54.5	ft bgs ^(a) 60	ft bgs ^(a) 67.5	ft bgs ^(a) 96	ft bgs ^(a) 116	ft bgs ^(a) 135	ft bgs ^(a) 140	ft bgs ^(a) 141	ft bgs ^(a) 150.5	ft bgs ^(a) 160.5
	H1a	H1a	H1	H1	H2	H2	H2	H2	PP1c	PP1c	Rtf	Rtf
Na	332.4	425.2	240.2	309.4	209.4	218.7	227.8	272.0	212.6	252.9	365.3	251.7
Mg	5523	5,318	4,293	2,717	6,360	5,137	6,507	7,766	7,019	5,020	3,333	3,823
Al	8,245	10,251	6,311	3,711	9,097	8,388	10,940	16268	9,828	6,220	5,402	5,939
Si	64.67	18.22	37.68	10.56	23.37	27.19	4.59	13.34	13.46	11.00	22.83	32.66
P	915.7	773.0	630.8	834.4	565.2	502.5	553.0	484.9	864.6	489.8	507.1	510.9
S	73.75	71.86	49.10	229.95	51.92	33.36	25.78	27.00	32.27	102.13	36.99	37.47
K	1,486	1,435	1,132	561	1,998	1696	2,302	2,541	1,926	887	718	701
Ca	10,577	1,1316	8,421	14,424	10,802	8,622	9,991	13,341	11,254	34,412	3,862	3,954
Ti	1,203.2	1,818.8	789.1	464.9	601.1	677.1	748.1	872.1	507.9	470.7	809.0	783.6
Mn	424.4	444.5	293.7	144.9	349.3	280.4	310.1	412.3	300.3	430.0	198.7	226.9
Fe	23,264	26451	14,965	10,619	15,069	12,898	17,210	21,168	16,361	10,439	11,380	12,401
Sr	42.32	47.63	33.07	31.44	43.61	37.12	46.75	45.17	38.45	83.65	25.88	24.99
Ba	121.5	107.1	74.7	63.2	80.3	74.4	101.9	124.5	109.1	78.4	48.8	50.5

(a) Multiply by 0.3048 to convert to meters.

Table 5.44. Trace Metals ($\mu\text{g/g}$) in Acid Extracts of Sediment Samples from Borehole 299-W22-50. Measured using ICP or ICP-MS method.

Element ($\mu\text{g/g}$)	ft bgs ^(a) 27.5	ft bgs ^(a) 51	ft bgs ^(a) 55	ft bgs ^(a) 60	ft bgs ^(a) 67.5	ft bgs ^(a) 96	ft bgs ^(a) 116	ft bgs ^(a) 135	ft bgs ^(a) 140	ft bgs ^(a) 141	ft bgs ^(a) 150.5	ft bgs ^(a) 160.5
	H1a	H1a	H1	H1	H2	H2	H2	H2	PP1c	PP1c	Rtf	Rtf
Be ^(b)	(0.37)	(0.33)	(0.40)	(0.24)	(0.16)	(0.33)	(0.30)	(0.36)	(0.56)	(0.40)	(0.22)	(0.17)
B ^(b)	1.64	0.28	3.86	4.98	9.70	6.38	2.72	5.55	4.75	7.56	3.78	4.98
Cr ^(c)	9.78	8.97	8.78	4.25	14.96	15.69	19.49	19.32	16.65	9.36	7.44	7.88
Cr	10.45	8.79	8.43	8.30	4.25	14.59	15.14	18.62	18.45	16.89	8.41	7.06
Co	12.17	10.91	13.79	7.74	5.62	7.65	6.86	8.70	10.48	8.99	7.15	6.41
Ni	11.17	10.33	8.94	8.49	5.36	13.69	12.61	17.45	15.87	16.94	9.70	8.25
Cu	10.91	10.86	9.45	7.92	10.58	9.98	8.41	13.38	18.79	17.23	10.86	9.17
Zn	47.71	43.65	47.50	32.14	35.96	44.08	35.76	49.19	55.24	45.14	25.27	25.39
As ^(c,d)	(4.76)	(2.04)	(1.65)	(1.00)	(3.78)	(4.02)	(6.16)	(4.56)	(2.65)	(3.64)	(1.06)	(1.30)
Se ^(c)	0.35	0.33	0.24	0.35	0.15	0.16	0.18	0.27	0.29	0.16	0.22	0.17
Mo ^(c)	0.10	0.09	0.09	0.12	0.10	0.09	0.10	0.09	0.08	0.28	0.22	0.14
Tc ^(b,c)	1.20	2.52	0.00	0.00	2.49	0.00	2.29	2.39	0.00	5.93	0.00	<29.80
Ru ^(c)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
Ag ^(c)	0.06	0.06	0.05	0.05	0.05	0.04	0.05	0.06	0.07	0.03	0.03	0.05
Cd ^(c)	0.09	0.08	0.06	0.06	0.07	0.06	0.12	0.14	0.11	0.07	0.04	0.05
Pb ^(c)	5.06	4.28	3.69	2.65	6.28	5.16	6.31	10.45	8.34	2.93	2.52	3.96
Pb	5.57	4.94	4.09	3.96	2.89	5.70	4.78	5.64	9.33	8.79	2.44	2.28
U	0.82	0.68	0.51	0.45	0.74	0.82	0.78	0.97	1.20	1.29	0.40	0.39

(a) Multiply by 0.3048 to convert to meters.
(b) B check standard was reading high values are suspect. (B values are suspect because of acid attack on digestion glassware may add additional B.)
(c) ICP-MS instrument was used; when not noted, ICP was used.
Values in parenthesis are just below level of quantification but spectra looked good. Thus, a tentative value was attributed to data.
(d) Arsenic data are suspect because of Ar-Cl molecular species at mass 75.

Table 5.45 expresses the percentage of each element released during nitric acid extraction in relation to the bulk chemical composition of the sediment as determined by XRF. In general, the acid extraction removes only 1% to 10% of the total alkali metals (potassium and sodium), about 25% of the major alkaline earth metals (calcium and magnesium), and less (about 10% to 20%) of the minor alkaline earths (barium or strontium, very little of the silicon, about 15% of the aluminum and titanium, about 40% to 60% of the iron and manganese, and 25% to 70% of the various trace metals. The amount of any element removed from the Hanford formation H1 unit and to some degree the Ringold Formation coarse sands by

Table 5.45. Percent of Total Element (XRF) in Sediment Samples Leached by Acid Extraction of Sediment Samples in Borehole 299-W22-50

Depth (ft bgs)^(a)	51	60	116	135	140	160.5
Stratigraphic Unit	H1a	H1	H2	PPlz	PPlc	Rtf
Na	2.7	1.6	1.3	2.5	1.6	1.1
Mg	24.9	13.5	28.4	29.9	30.6	23.7
Al	16.0	5.4	15.1	21.5	14.0	9.8
Si	0.0	0.0	0.0	0.0	0.0	0.0
P	>79.7	71.9	>60.1	>55.7	>95.0	>57.4
S	16.7	38.3	7.6	>10.8	>12.4	>14.4
K	9.7	3.8	11.3	11.6	10.0	4.9
Ca	29.9	33.9	36.9	49.7	46.6	16.4
Ti	24.4	7.1	19.1	19.9	10.5	18.7
Mn	46.6	17.9	56.3	67.0	57.4	39.1
Fe	47.3	20.7	59.6	63.3	51.8	39.3
Sr	14.6	9.4	11.9	17.7	12.3	5.9
Ba	17.4	9.3	13.3	18.7	15.6	7.7
Cr ^(b)	>21.7	8.3	33.3	33.5	34.5	>26.8
Co	>13.5	>9.9	>12.0	>14.3	>17.8	>10.9
Ni	46.6	26.4	37.	60.2	59.0	42.3
Cu	44.3	34.3	42.2	46.6	88.2	51.5
Zn	48.9	34.4	55.2	64.0	86.9	46.8
As ^(b,c)	35.8	23.8	68.4	46.5	32.3	40.8
Se ^(b)	>12.8	>13.4	>7.5	>11.3	>12.2	>7.4
Mo ^(b)	>4.5	3.0	>4.9	>4.1	>3.4	>8.0
Ru ^(b)	>0.0	>0.0	>0.0	>0.0	>0.0	>0.0
Ag ^(b)	0.8	0.5	>0.7	>0.8	>1.0	>0.6
Cd ^(b)	>0.9	>0.7	>1.4	>1.6	>1.3	>0.6
Pb ^(b)	62.1	26.5	48.6	59.7	57.2	34.1
U	>12.4	>8.0	>14.3	>16.4	21.4	>7.7
(a) Multiply by 0.3048 to convert to meters.						
(c) ICP-MS instrument was used; when not noted, ICP was used.						
(d) Arsenic data are suspect because of Ar-Cl molecular species at mass 75.						

acid digestion, is less than for the other geologic units signifying that the coarse sand consists of mostly unweathered primary minerals. The acid leach process releases most of the calcium and magnesium, and slightly more of several of the trace metal elements from the calcic PPlc subunit (42.6-meter or 140-foot depth) compared to noncalcareous strata. These relationships hold true for sediment samples from borehole 299-W22-48 as well.

Nitric acid is much more effective at leaching than 1:1 sediment-to-water solutions, which were discussed in Section 5.2.9. The only elements where water extraction exceeds a few tenths of a percent of the amount that the acid leached are sodium, sulfur (sulfate), and molybdenum; they water-leach between 5% to 10%, 10% to 30%, and 10% to 15% as much as the amount that acid leaches, respectively. Thus, the percentages of the total elements in the uncontaminated sediment that leach in water is less than a few percent of the total as determined by XRF. The contaminated sediment differs in that more mass is water-leachable for contaminants that are known to be mobile, such as chromium (IV), molybdenum, nitrate, sulfate, and technetium (see Serne et al. 2002 a, b, c for further discussion).

5.2.11 Porewater Composition

Actual porewater was extracted and measured from two sediment samples in borehole 299-W22-50 via ultracentrifugation (Table 5.46). The two samples selected for analysis came from the Hanford formation H2 unit (35.3 meters or 116 feet bgs) and the PPlc subunit (42.6 meters or 140 feet bgs).

The pH, EC, and alkalinity, as well as concentration of cations, anions, and trace metals, were measured using the same techniques as used for the water extracts (see Section 5.2.9); these are listed in Table 5.46. The charge balance for UFA-extracted porewater from the two sediment samples is presented in Table 5.47.

The chemical composition of the UFA-extracted porewater suggests that the nitrate values for both the 35.3 and 42.6 meters (116 and 140 feet) bgs are higher than normal for uncontaminated vadose zone sediment (see Table 5.45). The values for all the constituents are quite similar for the two porewaters despite the fact that the shallower sample is from the Hanford formation H2 unit and the deeper sample is from the PPlc subunit. Natural vadose-zone porewaters are quite similar in chemical composition to sediment water extracts and groundwater, except they are more concentrated. These two fluids are dominated by calcium, magnesium, and sodium cations and by bicarbonate, chloride, nitrate, and sulfate anions (see Tables 6.46 and 6.47). The nitrate and sodium values seem somewhat high compared to uncontaminated groundwater, perhaps reflecting some manmade input of Hanford's two most ubiquitous chemicals – nitrate and sodium.

The UFA extractions represent actual porewater that may have been in contact (and in equilibrium) with the sediment for hundreds to thousands of years. However, it may be difficult to nearly impossible, and thus costly, to extract porewater from some of the drier vadose-zone sediments on the Hanford Site. Therefore, we attempted to compare UFA-extracted porewater with the dilution-corrected 1:1 sediment

Table 5.46. pH, Electrical Conductivity, Alkalinity, Cations, Anions, and Trace Metals for UFA-Extracted Porewater from Sediment Samples within Borehole 299-W22-50

Constituent	Units	ft bgs ^(a)	
		116	140
Moisture	wt%	22.61	29.67
pH		7.21	7.49
EC	μS/cm	1415	956
Alk	mg/L CaCO ₃	46.53	88.84
F	mg/L	0.58	0.38
Cl	mg/L	119.4	25.47
Br	mg/L	0.69	0.34
NO ₂	mg/L	<0.1	<0.1
NO ₃	mg/L	243.8	96.5
PO ₄	mg/L	<0.1	0.96
SO ₄	mg/L	122.3	178
Na	mg/L	90.31	69.21
Mg	mg/L	23.23	22.02
Al	μg/L	<100	(13)
Si	mg/L	15.07	17.07
P	μg/L	(175)	(178)
S	mg/L	49.98	67.73
K	mg/L	12.16	9.53
Ca	mg/L	109.2	75.2
Mn	μg/L	(7)	13.1
Fe	μg/L	(13)	43.1
Sr	μg/L	498	328
Ba	μg/L	144	90.1
B	μg/L	(46)	(54)
Cr*	μg/L	0.675	1.10
Co	μg/L	<10	<10
Ni	μg/L	(8)	(6)
Cu	μg/L	(8)	(11)
Zn	μg/L	51.0	45.4
As*	μg/L	8.7	4.16
Se*	μg/L	20.4	35.7
Mo*	μg/L	37.3	59.8
Tc*	μg/L	(0.04)	(0.00)
Pb*	μg/L	(0.35)	(0.27)
U*	μg/L	1.26	4.86
Ag*	μg/L	(0.10)	(0.05)
Cd*	μg/L	(0.26)	(0.16)
Ru*	μg/L	(0.02)	(0.02)

(a) Multiply by 0.3048 to convert to meters.
*ICP-MS instrument was used.

Table 5.47. Charge Balance for UFA-Extracted Porewater from Sediment Samples in Borehole 299-W22-50

ft (bgs) ^(a)	Alk (meq/L)	F (meq/L)	Cl (meq/L)	NO ₃ (meq/L)	SO ₄ (meq/L)	ΣAnion (meq/L)	Na (meq/L)	Mg (meq/L)	K (meq/L)	Ca (meq/L)	ΣCation (meq/L)
116	0.93	0.03	3.37	3.93	2.55	10.82	3.93	1.91	0.31	5.46	11.62
140	1.78	0.02	0.72	1.56	3.71	7.78	3.01	1.81	0.24	3.76	8.83

(a) Multiply by 0.3048 to convert to meters.

to water extracts. This comparison is shown in Tables 5.48 to 5.50 where the dilution-corrected water extracts (i.e., calculated porewater compositions) are listed along with the values obtained from actual porewater extracted with the UFA.

Table 5.48 shows the theoretical chemical composition of vadose zone porewater calculated by assuming that the water extracts represent the actual solutes present in the native porewater. To convert back to the concentration of the porewater, multiply by the dilution factor for the added deionized water.

We did not perform water extracts on aliquots of sediment from the same core sleeves that we ultracentrifuged so we cannot make direct comparisons. However, if we assume that the sediment in proximity should have similar pore chemistry, then comparisons can be made. In Tables 5.49 and 5.50, we compare calculated porewater compositions for neighboring water extracts with the two actual UFA-extracted porewater samples. The comparisons require that we look at data from three different stratigraphic units: the Hanford formation H2 unit, and the upper and lower Plio-Pleistocene subunits (PPlz and PPlc, respectively). Tables 5.49 and 5.50 indicate that water leaching does dissolve excess carbonate, fluoride, potassium, and sodium from sediment within the Hanford formation H2 unit, compared to the native porewater. For the calcic (PPlc) sample, all the major chemical species are higher in the theoretically calculated pore fluid suggesting that water leaches material and, thus, we cannot accurately predict the actual porewater composition for this sediment type. The theoretically calculated composition is much higher than the actual porewater because the water leaching dissolves a significant portion of the carbonates and other salts. The additional carbonate alkalinity is likely due to partial dissolution of calcite. The excess potassium and sodium may come from the excess calcium replacing cation-exchangeable alkali metals during the water extraction process, though some potassium dissolution (perhaps potassium-feldspar is the source) has been noticed in longer-term water leach tests.

Aside from carbonate alkalinity, the water extracts may not dissolve excess anions not already present in the native porewater of non-calcareous sediment. As will be discussed in the other reports in this series (Serne et al. 2002 a, b, c), which report on contaminated sediment that contain highly saline tank fluids, water extracts multiplied by the dilution factor agree more closely with UFA-extracted porewater from vadose zone contaminated sediment because the tank fluid in porewaters contains such high concentrations that it dwarfs the contribution from dissolution/ion exchange displacement from the sediment during the water extraction process.

Table 5.48. Calculated Composition of Vadose-Zone Porewater (1:1 Sediment-to-Water Extracts Multiplied By Dilution Factor)

Constituent Units	EC	Alk	F	Cl	NO3	SO4	Na	Mg	K	Ca	Sr	Ba
Sample ft bgs ^(a)	µS/cm	mg/L CaCO ₃	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L
Hanford Formation H1a Unit (Sand)												
20	2,799	787	10.7	6.7	87.7	127.4	292.2	24.6	80.4	106.3	470.4	251.6
22.5	1,679	203	5.6	8.2	34.3	102.7	187.9	15.8	49.2	72.1	305.3	151.9
27.5	4,165	617	14.0	14.8	66.6	190.3	390.2	27.2	105.3	123.0	535.2	360.0
30	2,626	597	8.6	23.1	7.7	240.1	274.9	28.8	82.1	131.6	590.3	353.5
32.5	2,301	419	6.7	51.4	28.0	217.4	213.7	25.7	63.4	119.2	552.5	211.0
35	2,298	531	6.9	20.0	31.0	143.8	244.5	20.6	60.0	98.2	427.5	224.8
37.5	2,527	570	7.7	9.3	7.7	157.7	289.1	24.5	77.6	124.2	557.8	299.4
40	2,839	631	8.5	9.4	8.0	175.0	315.0	27.6	89.1	139.6	625.2	276.9
42.5	3,470	891	9.4	10.7	6.8	216.7	342.8	39.0	116.5	188.2	873.1	443.1
45	3,570	869	9.3	15.8	18.4	280.8	354.1	41.9	113.5	205.9	894.8	280.1
47.5	2,804	438	7.5	10.3	18.3	220.3	270.6	31.5	90.0	153.7	694.7	266.6
51	2,510	387	6.4	9.3	5.2	183.4	250.2	29.5	81.9	147.1	671.2	236.4
52.5	2,675	833	8.7	6.6	45.7	127.4	254.9	27.2	76.8	135.2	589.6	202.4
Hanford Formation H1 Unit (Gravel and Sand)												
55	3,289	837	7.2	20.4	3.8	292.0	296.2	42.5	99.9	193.7	887.7	418.7
56	4,219	830	9.2	17.7	40.9	273.7	361.7	57.9	133.8	187.7	876.5	477.5
60	18,009	1,974	13.4	303.8	59.3	1,162.9	915.7	1.0	327.3	1,678.7	5,731.5	1,462.2
Hanford Formation H2 Unit (Sand and Silt)												
67.5	3,591	---	4.9	63.0	71.4	284.9	212.9	39.4	61.0	164.2	739.0	199.1
76	2,113	207	3.4	41.7	83.9	281.4	154.8	26.4	38.0	133.6	556.2	155.4
96	3,743	440	4.9	297.7	125.6	360.5	291.1	53.9	74.5	240.8	1,075.1	335.3
111	2,914	576	4.8	112.9	251.2	226.6	220.6	38.7	55.7	175.7	784.7	296.4
115	1,933	348	3.2	90.1	186.4	103.8	152.2	26.0	34.3	115.7	534.2	222.1
116	--	--	--	--	--	--	730.9	89.5	111.2	436.9	1,927.5	1,078.7
Upper Plio-Pleistocene Unit (PPlz)												
130	2,801	1,086	5.0	24.4	76.6	116.8	222.7	48.9	45.8	195.8	870.6	346.8
135	1,829	501	3.7	18.6	169.5	145.5	169.2	37.2	38.1	127.0	567.5	231.7
Lower Plio-Pleistocene Unit (PPlc)												
140	--	--	--	--	--	--	288.0	59.4	51.5	193.2	971.8	575.6
141	3,955	1,077	12.9	53.1	176.8	353.7	323.6	84.9	75.7	274.7	1,332.7	364.9
Upper Ringold Unit (Rtf Member) (Sand)												
150.5	6,403	213	36.9	49.9	<3.4	289.0	581.0	111.0	155.2	350.0	1,998.0	512.9
160.5	5,867	1,348	26.9	33.0	<4.3	136.0	435.5	101.3	156.5	365.5	1,760.1	730.1
174	5,003	1,042	56.3	271.2	619.6	146.1	380.3	51.2	125.1	169.4	(796)	(284)

(a) Multiply by 0.3048 to convert to meters.

Table 5.49. Comparison of UFA-Extracted Porewater to Calculated Porewater Based on Water Extract Data from Sediment Samples in Borehole 299-W22-50

Constituent Units	EC	Alk	F	Cl	NO ₃	SO ₄	Na	Mg	K	Ca	Sr	Ba
Sample ft bgs ^(a)	μS/cm	mg/L CaCO ₃	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	μg/L	μg/L
Hanford Formation H2 Unit (Sand and Silt)												
111	2,914	576	4.8	1,12.9	251.2	226.6	220.6	38.7	55.7	175.7	784.7	296.4
115	1,933	348	3.2	90.1	186.4	103.8	152.2	26	34.3	115.7	534.2	222.1
116	1,415	46.53	0.58	119.4	243.8	122.3	90.3	23.2	12.2	109.2	498	144
Upper Plio-Pleistocene Unit (PPlz Facies) (Fine Sand and Silt)												
130	2,801	1,086	5	24.4	76.6	116.8	222.7	48.9	45.8	195.8	870.6	346.8
135	1,829	501	3.7	18.6	169.5	145.5	169.2	37.2	38.1	127	567.5	231.7
Lower Plio-Pleistocene Unit (PPlc) (Caliche)												
140	956	88.84	0.38	25.47	96.5	178	69.2	22	9.5	75.2	328	90.1
141	3,955	1,077	13	53	177	354	324	85	76	275	1,333	365

(a) Multiply by 0.3048 to convert to meters.
(b) The two values in **bold** are the actual UFA-extracted porewater while the other values are calculated from the 1:1 sediment-to-water extracts by dilution correction.

Table 5.50. Comparison of UFA-Extracted Porewater to Calculated Porewater Charge Balance Based on Water Extracts of Sediment Samples from Borehole 299-W22-50

Constituent Units	Alk	F	Cl	NO ₃	SO ₄	Na	Mg	K	Ca	Anions Σ	Cations Σ
Sample ft bgs ^(a)	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L
Hanford Formation Unit H2 (Sand and Silt)											
111	11.52	0.25	3.18	4.05	4.72	9.59	3.19	1.42	8.77	23.73	22.97
115	6.96	0.17	2.54	3.01	2.16	6.62	2.14	0.88	5.77	14.84	15.41
116	0.93	0.03	3.37	3.93	2.55	3.93	1.91	0.31	5.45	10.81	11.60
Upper Plio-Pleistocene Unit (PPlz) (Fine Sand and Silt)											
130	21.72	0.26	0.69	1.24	2.43	9.68	4.02	0.92	9.77	26.34	24.39
135	10.02	0.19	0.52	2.73	3.03	7.36	3.06	0.97	6.34	16.50	17.73
Lower Plio-Pleistocene Unit (PPlc) (Caliche)											
140	1.78	0.02	0.72	1.56	3.71	3.01	1.81	0.24	3.75	7.78	8.81
141	21.54	0.68	1.50	2.85	7.37	14.07	6.99	1.94	13.71	33.94	36.70

(a) Multiply by 0.3048 to convert to meters.
The two values in **bold** are the actual UFA-extracted porewater while the other values are calculated from the 1:1 sediment-to-water extracts by dilution correction.

In Tables 5.49 and 5.50, we present calculated porewater compositions for two samples from the PPlz subunit, even though we have no actual UFA-extracted porewater data for this unit in borehole 299-W22-50. The data are shown to allow some comparison between the porewater from the two mineralogically and granulometrically diverse sediment types. It can be seen from the two tables that chemical composition of the porewaters for the different sediment types is quite variable and more samples would need to be run to narrow the variability to the point that subtle differences could be used to aid in fate and transport predictions for the contaminants of concern.

Figure 5.12 shows the pH and the dilution-corrected EC in the water extracts versus depth in borehole 299-W22-50. The data in Figure 5.12 suggests that there is either a high pH, readily water-leachable natural mineral near the bottom of the coarse-grained Hanford formation H1 unit or that manmade fluids have migrated laterally along the contact with the underlying finer-grained Hanford formation H2 unit. The pH of the two UFA-extracted porewater samples are lower (more neutral) than the pH values for the water extracts but the actual porewater EC is not very different from the dilution-corrected water extracts. As mentioned, the PPlc subunit does promote some extra dissolution during water extraction. Figure 5.13 shows the dilution-corrected anion concentrations in the water extracts versus stratigraphy. All the anions excepting nitrate, show a sharp peak at the bottom of the Hanford formation H1 unit, which suggests that this sample has some readily soluble carbonate and sulfate (i.e., calcite and/or gypsum) or some other evaporites. The anion data for the actual UFA-extracted porewater sample from the Hanford formation H2 unit agrees very well with the calculated porewater composition from water extracts but the other UFA-extracted sample from the PPlc unit shows lower anion concentrations than the calculated porewater based on water extraction because the calcic sediments are especially prone to dissolution. Figure 5.14 shows the dilution-corrected cations in the water extracts vs. depth in borehole 299-W22-50. Again, there is a significant spike in calcium, potassium and sodium in the calculated porewater at the base of the Hanford formation H1 unit. In contrast, the magnesium concentration is depleted for this sample. If the material that is readily dissolving in this sample is the typical calcite and gypsum, we would expect elevated magnesium and perhaps only small enrichments in potassium and sodium. We speculate that this zone is enriched in readily soluble calcium, potassium, and sodium carbonates, chlorides, and sulfates from natural evapotranspiration. The sediment calcium carbonate data for the base of the Hanford H1 unit in Table 5.33 shows a slight enrichment in carbonate (0.5% to 1%) compared to adjacent samples but the XRD mineralogical analyses did not show any distinct differences.

As with the anions, the actual cation composition of the UFA-extracted porewaters show good agreement for the sample from the Hanford formation H2 unit but lower cation values than calculated porewater samples from the calcic PPlc subunit.

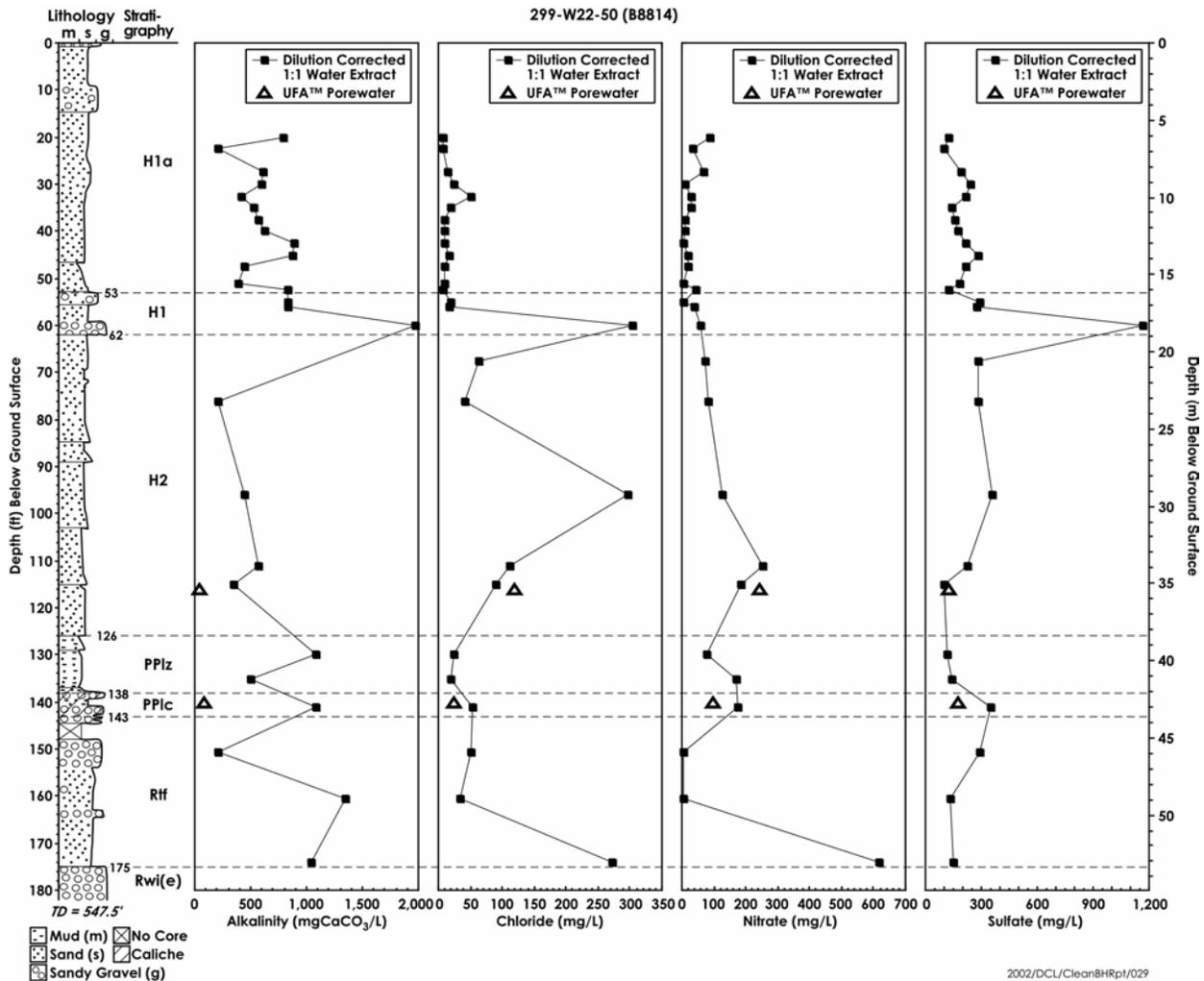


Figure 5.13. Calculated and UFA-Extracted Porewater Concentration of Anions Versus Depth in Borehole 299-W22-50

5.3 Discussion: Comparison Between Boreholes 299-W22-48 and 299-W22-50

The moisture profiles in the two RCRA boreholes show similar trends in the same sediment types, though the moisture spikes in borehole 299-W22-48 within the Hanford formation H2 unit indicate a greater absolute moisture content. Both boreholes show several moist zones in the Hanford formation H2 unit, associated with thin finer-grained lenses that are common in this facies of the Hanford formation. Both boreholes also show higher moisture within the PPlc subunit. Another higher-moisture zone occurs at the contact between the Hanford formation H2 unit and underlying fine-grained Plio-Pleistocene mud (PPlz) subunit. As discussed in companion documents on contaminated sediment, the moisture content itself is not indicative as to whether a certain strata is draining or accumulating water.

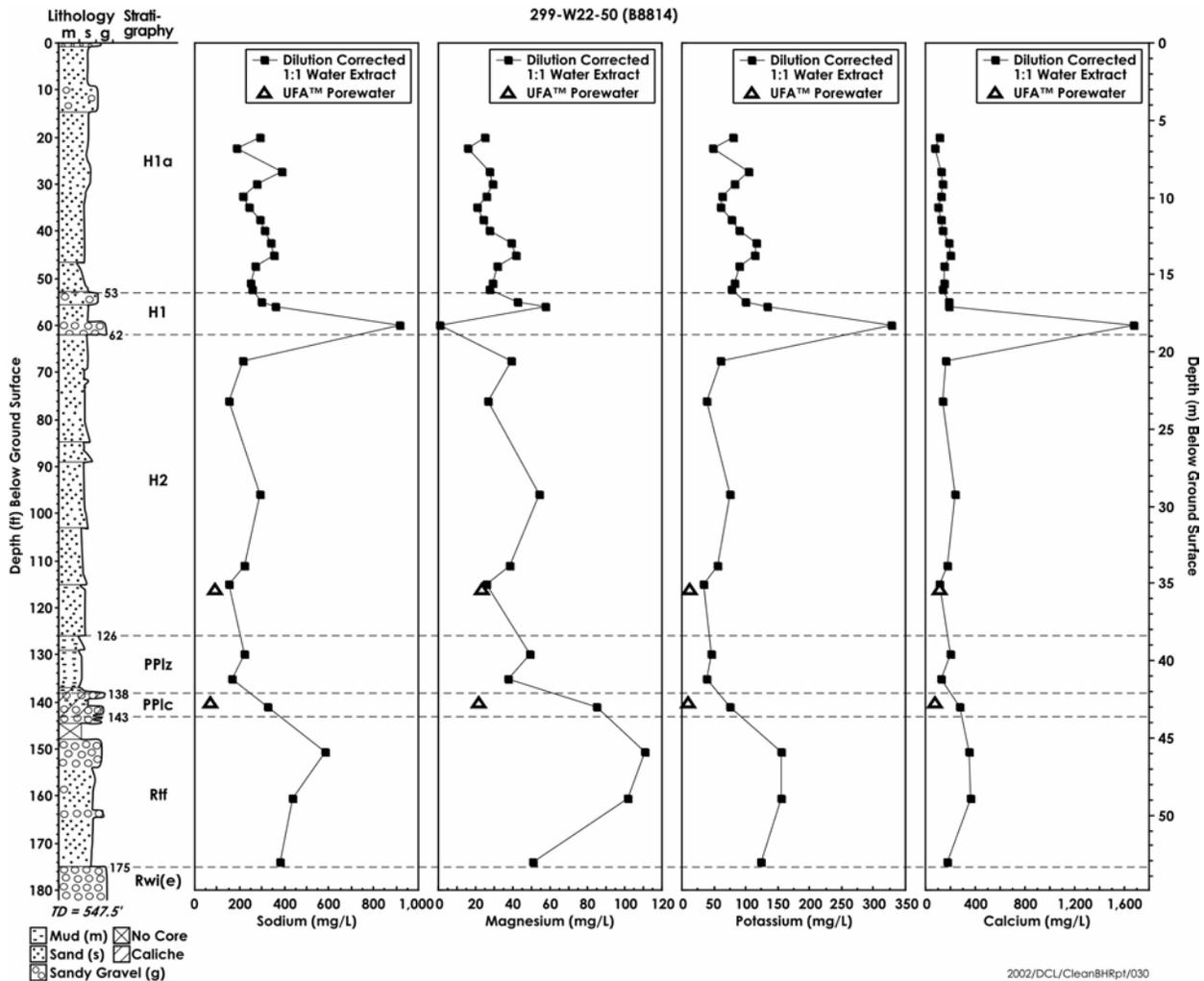


Figure 5.14. Calculated and UFA-Extracted Porewater Concentrations of Cations Versus Depth in Borehole 299-W22-50

No significant differences were detected in particle-size distribution, total chemical composition (oxide content), or mineralogy between samples from the same stratigraphic units in the two boreholes. The PPlc subunit in borehole 299-W22-48, however, is much better defined and more enriched in calcite compared to borehole 299-W22-50.

The water extract data for the sample at the base of the Hanford formation H1 unit in borehole 299-W22-50 shows a high pH and high EC/anion/cation spike that is not present in borehole 299-W22-48, though there is a muted increase in EC at about the same relative position. Currently, we do not have an explanation for the high water extract values at the base of the Hanford formation H1 unit. We did not observe pedogenic alteration upon visual inspection that might indicate past evaporation might be the cause. The other cause may be the lateral spreading of Hanford waste waters or water line leakage along the geologic contact. Both borehole water extract profiles suggest that there are higher water-leachable nitrate concentrations in the lower portion of the Ringold Formation (Rwi[e]) than within shallower strata.

We speculate that the elevated nitrate is manmade nitrate that was present in the groundwater when the water table was much shallower (closer to the ground surface). Aside from the one spike (elevated concentrations) in the Hanford formation H1 unit at borehole 299-W22-50, the calculated porewater cation concentrations are quite similar in the same sediment types for the two boreholes. There are higher concentrations of magnesium and potassium leachable in the Ringold Formation at both boreholes than in the overlying Hanford formation sediment. This undoubtedly is related to geologic age and degree of weathering.

6.0 Summary and Conclusions

Cores from two boreholes near the SX Tank Farm and four large-quantity grab samples from outcrop sediment on the Hanford Site have been characterized to better understand the fate of contaminants that have leaked from underground storage tanks at the Hanford Site. Completion of a suite of physical, mineralogical, and geochemical analyses on two “clean” boreholes has resulted in well-characterized samples that can be considered as standards for geologic strata that underlie waste facilities at Hanford. Many of these standards are now available to researchers throughout the country for experiments relative to environmental problems at the Hanford Site. In general, these standards represent baseline or background sediment mostly free of contact with any fluids associated with Hanford’s waste facilities.

The geology under the SX Tank Farm forms the framework through which the contaminants move, and provides the basis with which to interpret and extrapolate the physical and geochemical properties that control the migration and distribution of contaminants. Of particular interest are the interrelationships between the coarser- and finer-grained facies, and the degree of contrast in their physical and geochemical properties. For the two boreholes, lithologic sections were constructed using detailed geologic descriptions and geophysical logs. In some cases the results of laboratory analyses (e.g., particle-size distribution, moisture, calcium carbonate content) helped to refine the resulting stratigraphic and lithologic interpretations.

Our conceptual model of the 67-meter (220-foot)-thick vadose zone beneath the SX Tank Farm consists of seven stratigraphic units. These include two members of the Ringold Formation (member of Wooded Island/Unit E [Rwi(e)] and member of Taylor Flat [Rtf]), two Plio-Pleistocene subunits (very fine sand to mud sequence [PPlz] and a carbonate-rich paleosol sequence [PPlc]), and three units of the Hanford formation (H1a, H1, and H2). Most of the Hanford formation H1a unit was removed during excavation of the SX Tank Farm and replaced with backfill to a depth of about 17 meters (55 feet). All but the Hanford formation strata dip slightly toward the southwest.

Sediment samples from the various stratigraphic units were analyzed and characterized in the laboratory for the following parameters:

- mass water content
- particle-size distribution
- particle density
- calcium carbonate and organic carbon contents
- bulk chemical composition
- mineralogy
- cation exchange capacity
- exchangeable base cation distribution
- water leach (1:1 sediment-to-water extraction)

- acid leach (8M nitric acid extraction)
- UFA-extracted porewater composition.

Physical properties, such as particle-size distribution and moisture content, also vary according to lithology. Strata with finer particle sizes (e.g., lower Hanford formation), and the top of PPlc subunit with its high cement/clay content, retain more moisture in the vadose zone. High moisture is also associated with a sub-vertical clastic dike within the upper Ringold unit (Rtf) in borehole 299-W22-48. Of the two methods used to determine particle size distribution (dry sieve and wet sieve/hydrometer), the wet sieve method is superior to the dry sieve method, especially in fine-grained sediments, which tend to cling together during dry sieving. Unfortunately, almost all earlier particle size characterization at Hanford was done using the dry sieve method.

Past studies have shown that sediments in the vadose zone are dominated by quartz, potassium- and plagioclase-feldspar, basalt, and other lithic fragments with minor amounts of mica, amphibole, calcite, and other trace minerals (Tallman et al. 1979). The x-ray diffraction (XRD) work done for this study is in agreement with past work and shows that the sediment is 25 to 95 wt% quartz, 5 to (possibly) 40 wt% potassium feldspar, 10 to 20 wt% plagioclase feldspar, and 0 to 40 wt% calcite with trace to minor amounts of amphibole, mica, and chlorite.

Mineralogical and geochemical variations, some significant, exist between the different stratigraphic units, as a result of differing depositional environments and sources for the sediments. For example, calcite-rich samples are associated with the lower Plio-Pleistocene subunit (PPlc), which unlike other stratigraphic units, underwent significant pedogenic alteration. In addition to high calcium oxide the PPlc subunit is relatively high in magnesium oxide, which co-precipitated with calcium during pedogenesis. Vadose-zone sediments contain very little organic carbon. The organic carbon is slightly greater for the PPlc subunit (up to 0.2 wt%), compared to all the other units, which are all <0.1 wt% carbon. Calcium carbonate content, calculated from the amount of inorganic carbon present, approaches 40 wt% for the PPlc subunit; all other units are generally less than a few wt% calcium carbonate. The concentration of major elements such as silica, iron, and calcium, varies significantly because of different ratios of quartzo-feldspathic to basaltic detritus in the Hanford versus Ringold formations. Samples high in potassium oxide may reflect the relatively high illite content of the Ringold Formation and finer-grained portions of the Hanford formation.

Clay minerals, measured semiquantitatively using XRD, include smectite, illite, chlorite, and kaolinite. Overall, within the clay sized fraction of the sediments smectite ranged in concentration from 10 to 30 (wt%). Illite concentrations ranged from ~10% to 50% and chlorite concentrations were a little less (~5 to 35 wt%). Minor amounts of kaolinite (~5% to 10%) were also detected. Quartz, feldspar, and amphiboles made up less than ~15 wt% of the clay fraction. The only consistent trend in the mineral content of samples is the substantial increase in calcite, relative to other minerals, for the PPlc subunit. This trend is noted in both the bulk sample as well as the ≤ 2 -micron fraction.

Base cations, displaced via ammonium acetate extraction, are dominated by alkaline earth elements (calcium and magnesium), especially within the PPlc subunit. The relative contribution of the alkali metals (sodium and potassium) to the natural distribution of exchangeable cations is small (<10%).

Though some relationships can be made comparing cation exchange capacity to the lithology, mineralogy and grain-size distribution of some samples, enough discrepancies exist to make most comparisons tentative. Cation exchange capacity was measured using two analytical techniques, each of which provided significantly different results. More work is needed to establish the best way to measure cation exchange capacities on sediments from the Hanford Site.

The results from the 1:1 sediment-to-water extracts are similar for samples from both of the clean boreholes. This gives credence to the representativeness of the results. Also, most, but not all, results yield a reasonable charge balance among cations and anions. There is one sample in borehole 299-W22-50 near the base of the coarse-grained Hanford formation H1 unit that shows high pH, electrical conductivity (EC), and water-leachable cations and anions, but it appears to be natural and perhaps was caused by dissolution of natural evaporites (see below).

Porewater in the vadose zone was evaluated via a comparison of a few actual UFA-extracted porewater samples with a larger data set of 1:1 sediment-to-water extracts. Water extracts are in agreement with actual porewaters for only a limited number of constituents and the water extracts generally produced higher chemical concentrations than those found in the actual porewater sampled from the same interval and thus the water extracts should be considered maximum values. The concentrations of many constituents in the water extracts of the four composite sediment samples are similar to those in the two sampled boreholes. A few exceptions are higher calcium, chloride, magnesium, sodium, and sulfate in the sediment composite samples relative to the clean borehole samples, probably as a result of natural near-surface recharge and leaching, which does not occur at depth within borehole samples. As expected, the calcic PPlc subunit yielded significantly different water extract results than the Hanford or Ringold formation samples. Water leachate from the PPlc produced relatively higher EC, alkalinity, cations (silicon, calcium, magnesium), anions (nitrate and sulfate), as well as trace elements (selenium, strontium, copper, manganese, and uranium). Elevated concentrations of these parameters, combined with depleted aluminum, are a reflection of the pedogenic origin for the PPlc subunit. Differences among samples from the Ringold and Hanford formations are generally small (except water-extractable magnesium and potassium, which are higher for the older Ringold Formation) and not consistent among all samples. This is not surprising considering the wide range in mineral and physical properties for these samples.

Most noteworthy in the water extract profile for borehole 299 W22-50 is high water-leachable pH, alkalinity, EC, calcium, chloride, chromium, strontium, and sulfate at the base of the coarser-grained facies (H1 unit) of the Hanford formation. We speculate that one possible cause is natural evaporites or gypsum in the sediment from past pedogenic processes. However, no paleosols or anything else unusual was observed in geologic/geophysical logs at this depth. However, gypsum and other evaporites were not observed in these Hanford sediments, except for calcite in PPlc subunit. The other explanation is

horizontal spreading of waste water from Hanford activities or from water line leaks. Thus, the elevated porewater concentrations at the base of the H1 unit at borehole 299 W22-50 warrants further study.

In general, acid extraction is effective at removing from sediment samples, in decreasing order, 25% to 70% of the total trace metals, 40% to 60% of the iron and manganese, about 25% of the major alkaline earth metals (calcium and magnesium), about 15% of the aluminum and titanium, about 10% to 15% of the minor alkaline earths (barium and strontium), 1% to 10% of the alkali metals (potassium and sodium). In contrast, negligible amounts of silicon (<0.03%) are removed during acid extraction. The amount of any element removed from the coarse-grained Hanford formation H1 unit by acid digestion is less than for the other stratigraphic units, perhaps due to the larger particle sizes, which have overall less surface area and are thus less prone to leaching. Acid extraction within the calcic PPlc releases almost all the calcium and strontium and slightly more of several of the other elements when compared to other non-calcic sediment samples. Most calcium and strontium in the PPlc subunit are combined with carbonate, which readily decomposes in contact with acid. Calcium in the other units is associated with silicates (e.g., pyroxene, plagioclase, etc.), which do not readily react with the acid leach.

For researchers interested in performing additional analyses on the four composite sediment samples, ~30 kilograms of Ringold Silt, 200 kilograms of Hanford Coarse Sand (roughly equivalent to the Hanford formation H1 unit), 200 kilograms of Hanford Fine Sand (equivalent to the Hanford formation H2 unit), and 60 kilograms of the Borehole Fine Sand (also representative to the Hanford formation H2 unit) are available for scientific study. Also available are 30 kilograms each of caliche (equivalent to the PPlc subunit) and Ringold Formation sands (equivalent to the Rtf unit) from the White Bluffs that have yet to be characterized. Interested researchers may also obtain core samples from the remaining sleeves in the two clean boreholes (299-W22-48 and -50) reported herein.

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Appendix A

**Summary of Field Geologists' Sample Descriptions for
Borehole 299-W22-48 (contains 8 pages) and
Borehole 299-W22-50 (contains 8 pages)**

BOREHOLE LOG

Page 1 of 9

Date: 10-11-99

Well ID: B8812 Well Name: 299-W22-48 Location: ~ 50 m East of 241-S Tank Farm

Project: RCRA drilling FY 2000 Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample		Graphic Log	Sample Description	Comments:	
	Type No.	Blows Recovery				
0				0' → 3.0': Silty Sandy GRAVEL (msG)	Cable tool C.S. casing	
	SS #1	60% rec.		40% gravel, 45% sand, 15% silt. Gravel is tr cobble, 30% v. cse peb, 30% cse, 40% med- v. Fn; sand 10% v. cse- cse, 40% med, 50% Fn- v. Fn. DK gray brn (10YR 4/2), moist, poorly sorted; gravel rnd, sand sub-ang, 60% basalt; 40% qtz, granite, ether; max gravel ~ 6 cm, common caliche coating on gravel.	Shoe OD = 12", ID = 10 1/4" w/ 5" dia split spoon → continuous	
	DB	NA				rad contam < detect
5	SS #2	100% rec.				4" dia. lexan liners
	SS #3	100% rec.				split spoon 2.0' length w/ 4 x 6" lexan liners.
	SS #4	160 blows				End 10/11/99
10	SS #5	100% rec.			3.0' → 7.0': SAND (S), 95% sand, 5% silt. Tr v. cse sand, 10% cse, 40% med, 40% Fn, 10% v. Fn. Brown (10YR 4/3) moist, well sorted, sub-angular; 40% 30% basalt, 70% qtz/other; max size ~ 2 mm.	Begin 10/12/99
	SS #6	140 blows				10.5' → moisture sample
	SS #7	140 blows			7.0' → 10.0': Sandy GRAVEL (sG) similar to above, lower silt content, predom. cse to med. sand.	No rad contam detected
	SS #8	160 blows			10.0' → 10.5': Silty SAND (mS), 60% sand, 40% silt, brn (10YR 5/3) moist, well sorted sand predom Fn- v. Fn, strong rxn HCl.	OVM < detect
20	SS #9	150 blows			10.5' → 23.0' SAND (S) 90% sand, 5% gravel 5% silt. Sand predom med- Fn, with thin layers of cse- v. cse (less than 0.1' thickness)	15' → moisture samp. * Drive split spoon samplers, then
	SS #10	140 blows				drive 11 3/4" OD casing then clean borehole w/ 10" OD core barrel.
	SS #11	150 blows			Grayish brn (10YR 5/2), moist, well sorted, sub angular; 25% basalt, 75% qtz/other, tr mica, max gravel ~ 1 cm, weak HCl rxn.	repeat.
25	SS #12	100% rec.		23': v. cse sand; 40% basalt, 60% qtz/other	20.0' → moisture samp.	
					25.0' → moisture samp.	

Reported By: <u>L.D. Walker</u>	Reviewed By: <u>DC Weeks DC Weeks</u>
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Signature: <u>[Signature]</u>	Date: <u>11/16/99</u>

BOH HOLE LOG

Date: 10-12-99

Well ID: B8812 Well Name: 299-W22-48 Location: ~ 50m East of 241-S Tank Farm
 Project: RCRA drilling FY 2000 Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample		Graphic Log	Sample Description	Comments:
	Type No.	Blows Recovery			
30	SS #12 → 30.5	100% rec.		23.0' → 37.0' : SAND (S), 95% sand,	Cable tool, 11 3/4" OD CS
	SS #13 30.5' → 33.0'	190 blows 100% rec.		5% silt. Sand 10% v.cse, 30% cse, 50% med, 10% Fn-v.Fn, dk grayish brn (10YR 4/2), sl moist, med-well sorted, sub-angular to angular; 40-45% basalt,	Casing; cont. 5" OD split spoon w/ 4" OD lexan liners
35	SS #14 33.0' → 35.5'	100% rec.		55-60% qtz, felds, other; max size ~ 2 mm; weak rxn HCl - local strong rxn	30.0' → moisture sample
	SS #15 35.5' → 38.0'	100% rec.		34.5' : tr orange - pass. iron oxide stain	35.0' → moisture sample
	SS #16 38.0' → 40.5'	100% rec.		37.0' → 39.0' : SAND (S), 100% sand, tr silt. 10% v.cse - med, 50% Fn, 40% v.Fn.	OVM < detect a, b, c < detect
40	SS #17 40.5' → 43.0'	220 blows 100% rec.		Pale brown (10YR 6/3), moist, well sorted, sub-angular; 10-15% basalt, 85-90% qtz + feldspar, rxn to HCl weak to none.	40.0' → moisture sample
	SS #18 43.0' → 45.5'	100% rec.		39.0' → 41.5' : SAND (S) 100% sand, similar to med/cse sand above	End 10/12/99
45	SS #19 45.5' → 48.5'	95% rec.		40-45% basalt, weak rxn HCl	45' moisture sample
	SS #20 48.5' → 51'	100% rec.		41.5' → 49' : Sandy GRAVEL (SG), 60% g, 30% s, 10% silt; Gravel is 90% bas, 10% other, SR-SA white coating common (CaCO ₃ ?)	
50	SS #21 51' → 53.5'	100% rec.		Some rxn to HCl (slight to med), sand is basalt-rich, SR-SA, 10YR 6/2 (dry) lt brnish gray, moist, poorly sorted, max part = 30 mm	50' moisture sample
	SS #22 53.5' → 56'	100% rec.		Avg clast size increases down hole 49' → 52.3' : SAND (S), 100% sand, tr gravel, 10YR 7/2 (dry) light gray, moist; 10% vc, 10% c, 60% m-f, 10% vf, 10% silt; 30% bas, 70% other,	55' moisture sample
55	SS #23 56' → 58.5'	100% rec.		max size 5mm, SA-SR, strong rxn to HCl, moderately sorted 52.3' → 58.5' : SAND (S), 20% gravel, 25% vc, 20% c, 30% m-vf, 5% silt; moist, as above color, moderately sorted, gravel is 20% bas, SA-SR; sand is 60% bas SA-SR, slight rxn to HCl (strong)	

Reported By: L.D. Walker / DC Weekes Reviewed By: Pat Moore
 Title: Geologist Title: Geologist
 Signature: [Signature] Date: 10/13/99 Signature: Pat Moore Date: 11/17/99

BHI-EE-183 (12/97)

BOR_HOLE LOG

Page 2 of 7

Date: 10/13/99

Well ID: B8812 Well Name: 299-W22-48 Location: ~50m East of 241-S Tank Farm

Project: RCRA Drilling FY2000 Reference Measuring Point: Ground Surface

Depth (FL)	Sample		Graphic Log	Sample Description	Comments:
	Type No.	Blows Recovery			
60	SS #24 DB	100% rec.	0.00	58.5' → 61': Sandy GRAVEL (SG) 50% gravel,	SS #24 stopped at 59.5' due to rock
61	SS #25	100% rec.	0.00	50% sand, moist, color as above, V poorly sorted,	moisture sample at 60' from drive barrel
63	60.5' → 63'	100% rec.		gravels are basalt-rich, SA-R; sand is basalt-rich, A-SR;	
65	SS #26	100% rec.		med to strong rxn to HCl, large rocks @ 59.5', at least 10cm	
65	63' → 65.5'	100% rec.		61' → 76': SAND (S) tr grav, 20% v.c., 30%	65' moisture sample
68	SS #27	100% rec.		m, 40% f-vf, 10% silt, G is basalt-rich, SA-SR; Sand	
68	65.5' → 68'	100% rec.		is 30% bas, 70% qtz & other, A-SA, strong rxn to HCl,	
70	SS #28	100% rec.		max part ~ 4mm, strong rxn to HCl	End of shift 10/13/99
70	68' → 70.5'	100% rec.		@ 65' sand is mostly c-m	Begin 10/14/99
73	SS #29	100% rec.		68' - weak rxn HCl	70.0' moisture sample
73	70.5' → 73'	100% rec.			
75	SS #30	100% rec.		73.5' → 74.5': sand predom. med-fine	
75	73' → 75.5'	100% rec.		15% basalt, 85% qtz/other, weak HCl rxn.	75.0' moisture sample
	SS #31	100% rec.		74.5' Sand cse-med as above.	
	75.5' → 78'	100% rec.			
	SS #32	100% rec.		76' → 79': SAND (S); 100% sand, tr silt.	
80	78' → 80.5'	100% rec.		20% med, 60% fn, 20% v.fn; pale brown (10YR 6/3)	80.0' moisture sample
	SS #33	100% rec.		sl. moist, well sorted; SA-SR; 10-15% basalt,	
	80.5' → 83'	100% rec.		85-90% qtz/other; max size ~ 1mm, weak rxn HCl.	
	SS #34	100% rec.		79 → 81.5': SAND (S) med-cse sand as	
85	83' → 85.5'	100% rec.		above.	
	SS #35	100% rec.		81.5' → 89.0': SAND (S); predom. fine sand	85.0' moisture sample
	85.5' → 88.0'	100% rec.		as 76-79.	
	SS #36	100% rec.			

Reported By: <u>DC Weekes / L.D. Walker</u>	Reviewed By: <u>Pat Moore</u>
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Signature: <u>DC Weekes / L.D. Walker</u>	Signature: <u>Pat Moore</u>
Date: <u>11/16/99</u>	Date: <u>11/17/99</u>

BO HOLE LOG

Page 4 of 7

Date: 10/14/99

Well ID: B8812	Well Name: 299-W22-48	Location: ~50m E of 241-5 Tank Farm
Project: RCRA Drilling FY 2000		Reference Measuring Point: Ground surface

Depth (Ft.)	Sample		Graphic Log	Sample Description	Comments:
	Type No.	Blows Recovery			
90	SS #36 88' - 90.5'	100% rec.		89.0' → 91.5': SAND (S) med-cse as described above	8 3/4" OD Cs casing
	SS #37 90.5' → 93'	100% rec.		91.5' → 92.5': Slightly Silty SAND (mS)	90.0' moisture sample
95	SS #38 93' → 95.5'	100% rec.		85% sand, 15% silt, similar to Fh sand described above. No rxn HCl	
	SS #39 95.5' → 98'	100% rec.		92.5' → 93.0': SAND (S) predom. cse-med, strong rxn HCl	95.0' moisture sample
100	SS #40 98' → 100.5'	100% rec.		93.0' → 101.8': SAND (S) tr vcs-cse, 20% med, 50% Fh, 30% v. Fh, tr silt.	SS #38 very loose sand
	SS #41 100.5' → 103'	100% rec.		Brown (10YR 5/3); sl moist, well sorted-med sort; SA-SR; 15% basalt, 85% qtz/other, tr mica, max size ~1mm, sl rxn HCl.	100' moisture sample
105	SS #42 103' → 105.5'	100% rec.		101.8' → 134.5': SAND (S) 100% vf-f sand, tr silt, 10YR 5/3 (moist) brown, moist, v well sorted, strong rxn to HCl, thin zones of medium-vf sand	Sharp contact @ 101.8'
	SS #43 105.5' → 108'	100% rec.			105' moisture sample
110	SS #44 108' → 110.5'	100% rec.			110' moisture sample
	SS #45 110.5' → 113'	100% rec.			
115	SS #46 113' → 115.5'	100% rec.			115' moisture sample
	SS #47 115.5' → 118'	100% rec.			Possible clastic dikelet @ 116.5' 1" verticle clayey silt (brown)
	SS #48 118' → 120.5'	100% rec.			

Reported By: L.D. Walker / DC Weekes	Reviewed By: Pat Moore
Title: Geologist	Title: Geologist
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Date: 10/14/99	Date: 11/17/99

BOREHOLE LOG

Page 2 of 7

Date: 10/15/99

Well ID: B8812 Well Name: 299-W22-48 Location: ~50m E of 241-S Tank Farm
 Project: RCRA Drilling FY2000 Reference Measuring Point: Ground surface

Depth (Fl.)	Sample		Graphic Log	Sample Description	Comments:	
	Type No.	Blows Recovery				
120	SS #48 118' → 120.5'	100% rec.		101.8' → 134.5': SAND(S): see p.4 description	Adjusted graphic log from previous page. 120' moisture sample.	
	SS #49 120.5' → 123'	100% rec.				
125	SS #50 123' → 125.5'	100% rec.				125' moisture sample.
	SS #51 125.5' → 128'	100% rec.				
130	SS #52 128' → 130.5'	100% rec.				Starting at ~128' the sand is much drier. 130' moisture sample.
	SS #53 130.5' → 133'	100% rec.			134.5' → 146': Silty SAND (mS), 60% sand, 40% silt. Sand is 80% v. F ₈₀ , 20% F ₂₀ . Pale brown (10YR 6/3), sl moist, well sorted; sub-angular; predom qtz, folds, (basalt < 5%), strong rxn HCl. → difficult to keep in core barrel	131': dry sand - difficult to bring out with core barrel. Add 2 gallons water
135	SS #54 133' → 135.5'	100% rec.				135' moisture sample
	SS #55 135.5' → 137.5'	100% rec.				
140	SS #56 137.5' → 140'	80% rec. (none in drive shoe)			138': material is dry	140' no moisture sample
	SS #57 140' → 142.5'	100% rec.			142': trace laminations ~ 1mm in thickness	- no material in drive shoe.
	SS #58 142.5' → 145'	100% rec.				
145	SS #59 145' → 147.5'	100% rec.			146' → 149': Caliche, in a silty sand. lt. brn (7.5YR/6.3) + pink, sl. moist → dry, violent rxn HCl. Gravel starting ~ 148', max size ≈ 2.50 cm. Sub-round, caliche cement.	145' moisture sample very hard drilling SS shoe flattened.
	SS #60 147.5' → 150'	100% rec.		Qtzite, granite predom.	150' moisture sample.	

Reported By: <u>L.D. Walker</u>	Reviewed By: <u>DC Weekes</u>
Title: <u>Geologist</u>	Title: <u>Geologist</u>
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Signature: <u>[Signature]</u>	Date: <u>11/16/99</u>

BHI-EE-183 (12/97)

BC HOLE LOG					Page 6 of 9
Well ID: B8812		Well Name: 299-W22-48		Location: ~50m. East of 241-S Tank Farm	
Project: RCRA Drilling FY 2000		Reference Measuring Point: Ground Surface			
Depth (Ft.)	Sample		Graphic Log	Sample Description	Comments:
	Type No.	Blows Recovery			
150	SS #60		[Graphic Log]	149' → 161': Slightly Silty SAND (m) S	8 3/4" OD CS casing;
	SS #61	100% rec.		85% sand, 15% silt, tr gravel. Sand 10% cse, 20% med, 40% fn, 30% v.fn; gravel v.fn - fn peb. Lt brnish gray (10YR 6/2), dry	Cont. 5" OD split span sampling; cable tool
155	SS #62	100% rec.	[Graphic Log]	mod sorted; gravel SR, sand SA-SR, predom qtz, 10% basalt; strong to violent rxn to HCl - calcareous	155' moisture sample
	SS #63	100% rec.		157 ft: sand as above, but weak to no rxn with HCl.	
160	SS #64	100% rec.	[Graphic Log]	159 ft: sand becomes loose and dry. silt content gradually decreasing	160' moisture sample
	SS #65	100% rec.		161' → 168.5': SAND (S); 90-95% sand, 5-10% silt. 10% cse, 40% med, 40% fn, 10% v.fn sand. Lt. brn. gray (10YR 6/2), dry, mod-well sorted; sub-angular; 10-15% mafics, 85-90% qtz, feldspar, other, tr mica. No rxn to HCl.	End 10/19/99
165	SS #66	100% rec.	[Graphic Log]	166' - 167': trace mod-fn pebbles w/caliche coatings - strong rxn HCl. Gravel is rounded qtzite.	165' moisture sample
	SS #67	100% rec.		168.5' → 170': Silt (M) mixed with traces of sand. Probable clastic dike. Very pale brown (10YR 7/4), moist to wet, strong rxn to HCl.	tr free water at ~170 ft. (drops - not measured)
170	SS #68	100% rec.	[Graphic Log]	170' → 189': SAND (S) as described in 161 → 168.5'. trace of silt/clastic dike 171-172', then only sand. Dry. no rxn to HCl	170' moisture sample
	SS #69	100% rec.			
175	SS #70	100% rec.	[Graphic Log]		
	SS #71	100% rec.			
	SS #72	100% rec.			* No rad contam. detected at clastic dike

Reported By: L.D. Walker	Reviewed By: DC Weekes
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Signature: [Signature]	Signature: [Signature]
Date: 10-20-99	Date: 11/16/99

BOR_HOLE LOG

Page 7 of 9

Date: 10-20-99

Well ID: B8812 Well Name: 299-W22-48 Location: ~50m East of 241-S Tank Farm

Project: RCRA Drilling: FY2000 Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample		Graphic Log	Sample Description	Comments:	
	Type No.	Blows Recovery				
180	SS #72				8 3/4" OD CS casing	
	NA	NA			170' → 189': SAND (S) see page 6 description	Cont. 5" OD split spoon sampling; cable tool
	SS #73	100% rec.				180' moisture sample
	181' → 183.5'					
185	SS #74	100% rec.				185.5' moisture sample
	183.5' → 186'					
	SS #75	100% rec.			189' → 191.5': Slightly Silty SAND (msS)	End 10/20/99
	186' → 188.5'				Sand as above, with silt content	Begin 10/21/99
190	SS #76	100% rec.			increase to 15-20%. Dry; no rxn HCl	190.5' moisture sample
	188.5' → 191'				191': tr med. pebbles	
	SS #77	50% rec.		191.5' → 249': Silty Sandy GRAVEL (msG)	192' moisture sample	
	191' → 193.5'			50-60% Gravel, 30-40% sand, 20% silt.	193.5' switch to	
195	HT	NA		Drilling indicates some cobbles, some round pebbles F _n -v.F _n are unbroken in hard tool slurry. Sand is 10% v.cse, 30% csc, 40% med, 20% F _n -v.F _n ; poorly sorted, gravel round-sub rnd, sand SA-SR,	Hard Tool drilling	
	Archive Grab				195-196': collect	
	HT				HT slurry sample	
					For archive	
200	Archive Grab			20-30% basalt, 70-80% qtz, felds, other tr mica; dried slurry no rxn to HCl.	200' → 201': archive grab. sample	
	HT				Begin 10/22/99	
					Drilling indicates more gravel than sand	
205	Archive and waste charact				205': Waste characterization sample # BOWPB1	
	HT			209.5' → 210' drilling indicates sand, then back to gravel.	and archive sample	

Reported By: <u>L.D. Walker</u>	Reviewed By: <u>DC Weekes</u>
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Signature: <u>DC Weekes</u>	Date: <u>11/16/99</u>

BORLHOLE LOG

Page 8 of 9
Date: 10/22/99

Well ID: B8812 Well Name: 299-W22-48 Location: ~50m East of 241-S Tank Farm
Project: RCRA Drilling FY 2000 Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample		Graphic Log	Sample Description Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
	Type No.	Blows Recovery			
210	Archive	NA			8 3/4" OD CS casing
	Grab			191.5' → 249': Silty Sandy GRAVEL (msG) as described on page 7	cable tool-hard tool
	HT				210' Archive sample
	↓				
215	Archive Grab				215' Archive sample
	HT				
	↓				
220	Archive grab				220' Archive sample
	HT				End 10/22/99
	↓				
225	Archive Grab			225' silt and sand content increasing in the hard tool slurry, otherwise as above	225' → 226' Archive and Near Water Table Sample
	HT				
	↓				
230	Archive Grab				230' Archive sample
	HT				231' Drilling indicated sand/silt
	↓				
235	SS Sieve #1	100% rec.		Silty Sandy GRAVEL (msG) as above. No rxn HCl	233'-water sample ^{w.l.=} 228.0'
	234' → 236.5'				234' → 236.5' First split spem - sieve analysis
	HT	NA		236' slurry grab sample for waste characterization: BOPB ^{1W} BOWPB2, BOWPB4	Also archive 235' Also PNNL hydral. conductivity.

Reported By: <u>L.D. Walker</u>	Reviewed By: <u>D. Weckes</u>
Title: <u>Geologist</u>	Title: <u>Geologist</u>
Signature: <u>L.D. Walker</u>	Date: <u>10/26/99</u>
Signature: <u>D. Weckes</u>	Date: <u>11/16/99</u>

BC HOLE LOG					Page 1 of 1
Well ID: B8814		Well Name: 299-W22-50		Location: outside SE corner 241-SK Tank Farm	
Project: RCRA Drilling FY 2000		Reference Measuring Point: Ground Surface			
Depth (Ft.)	Sample		Graphic Log	Sample Description	Comments:
	Type No.	Blows Recovery			
0	DB	NA		0' → 1.5': Sandy GRAVEL (SG); 40% gravel, 60% sand, tr silt. Construction material / pad fill. Poorly sorted, grayish brn (10YR 5/2), dry	Cable tool, 11 3/4" OD CS casing, 10" drive barrel
5	grab archive			1.5' → 9.0': SAND (S); 100% sand, tr silt; tr v. cse sand, 20% cse, 40% med, 40% fn-v.fn; dark grayish brown (10YR 4/2), moist, mod sorted; aug-sub angular; 40% basalt, 60% qtz, feld, other; max size ~ 2 mm; rxn to HCl weak to strong.	Archive sample collected from drive barrel at 5' (two 1-pint jars)
10	grab archive			9.0' → 14': Gravelly SAND (GS); 15% gravel, 85% sand. Gravel 40% cse-med pb, 60% fn-v.fn pb, sand 75% v.cse, 20% cse, 5% med-v.fn; very dk gray (10YR 3/1), moist, mod sorted; SA-SR sand; 60% basalt, 40% qtz/other, max size ~ 3 cm, weak rxn HCl.	10' collect archive sample
15	grab archive			14.0' → 14.5': Silty SAND (mS)	15' collect archive sample.
20	SS #1 20' → 22.5'	100% rec.		14.5' → 15.5': SAND (S) predom cse similar to sand in 9.0' → 14'	20' collect archive sample
25	SS #2 22.5' → 25'	100% rec.		15.5' → 30': SAND (S) predom med-fn similar to 1.5-9' sand.	20': Begin continuous
	SS #3 25' → 27.5'	100% rec.		Thin layers occasional of cse sand	5" OD x 2.5' split tube sampler for
	SS #4 27.5' → 30.0'	100% rec.		27': thin (0.1') layer silty sand	PVNL chem. analysis

Reported By: L.D. Walker	Reviewed By: J.C. Weckes
Title: Geologist	Title: Geologist
Signature: <i>L.D. Walker</i>	Signature: <i>J.C. Weckes</i>
Date: 11-10-99	Date: 2/9/00

BC HOLE LOG					Page 2 of 19	
Well ID: B8814		Well Name: 299-W22-50		Location: Outside SE corner 241-SX Tank Farm		
Project: RCRA Drilling FY2000				Reference Measuring Point: Ground Surface		
Depth (Ft.)	Sample		Graphic Log	Sample Description	Comments:	
	Type No.	Blows Recovery				
30	SS #5 30' → 32.5'	100% rec.		30' → 53': SAND (S); 100% sand, tr silt. 10% v.cse, 20% cse, 30% med.	Cable tool; 1 3/4" OD CS casing, 10" drive barrel for clean-out	
	SS #6 32.5' → 35'	100% rec.		40% fn-v.fn; Occasional layers less than 0.5' thick predom. cse sand.	Continuous 5" OD split tube samples.	
35	SS #7 35' → 37.5'	100% rec.		Med-fn sand brown (10YR 4/3), cse sand		
	SS #8 37.5' → 40'	100% rec.		gr. brn, moist, mod-well sorted, SA-SR; 30-40% basalt, 60-70% qtz, feld/other. Max size ≈ 2 mm, weak rxn HCl		
40	SS #9 40' → 42.5'	100% rec.			No rad. contam detected w/ field instruments	
	SS #10 42.5' → 45'	100% rec.			ovm < detect	
45	SS #11 45' → 47.5'	100% rec.				
	SS #12 47.5' → 50'	100% rec.				
50	SS #13 50' → 52.5'	100% rec.			1 3/4" casing set at 50.0' bgs	
	SS #14 52.5' → 55'	100% rec.			Continue with 8 3/4" OD CS casing.	
55	SS #15 55' → 57.5'	100% rec.			30% v.cse, 30% cse, 40% med-v.fn; grayish brn (10YR 5/2) - salt/pepper appear, dry, mod sorted, SA-SR; 40% basalt, 30% qtz, 30% felds/other, tr iron oxide staining; max peb 7-8 mm, weak rxn HCl	
	SS #16 57.5' → 59.5'	100% rec.			SS refusal at 59.5' → gravel at 59'	

Reported By: L.D. Walker

Reviewed By: DCWeker

Title: Geologist

Title: Geologist

Signature: *L.D. Walker*

Date: 11-11-99

Signature: *DCWeker*

Date: 2/9/00

BC WELPHOLE LOG

Page 3 of 19

Date: 11-11-99

Well ID: B8814 Well Name: 299-W22-50 Location: outside SE corner 241-SX Tank Farm
 Project: RCRA Drilling FY 2000 Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample		Graphic Log	Sample Description Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
	Type No.	Blows Recovery			
60	SS #17 60 → 62.5'	100% rec.		59' → 62.5': Sandy GRAVEL (SG) 60% gravel, 40% sand, tr silt; gravel 20% v.cse-cse peb, 50% med, 30% fn-	Cable tool; 8 3/4" OD CS casing; Cont. 5" OD split tube
	SS #18 62.5' → 65'	100% rec.		v. fn, sand 20% v.cse, 40% cse, 40% med.	sampler for PNNL chem. anal.
65	SS #19 65' → 67.5'	100% rec.		v. fn, dry, poorly sorted; sand SA, gravel SR-round, 40-50% basalt, 50- 60% qtzite, granite, other; max sizes	Begin 11-12-99 driller notes firmer drilling condition
	SS #20 67.5' → 70'	100% rec.		62.5' → 129': SAND (S) 100% sand. Predom med-cse, then fn by 70'. At 70'	
70	SS #21 70' → 72.5'	100% rec.		10% cse-med, 80% fn, 10% v. fn. Brown, (10YR 5/3), sl moist, well sorted, SA-	
	SS #22 72.5' → 75'	100% rec.		SR, 80% qtz, felds, 20% basalt, max size ~ 1mm, tr mica, tr Fe staining	
75	SS #23 75' → 77.5'	100% rec.		weak rxn HCl	
	SS #24 77.5' → 80'	100% rec.			OVM < detect No rad. contam.
80	SS #25 80' → 82.5'	100% rec.		81-82': med sand, then back to fn sand as above	detected w/ field instruments.
	SS #26 82.5' → 85'	100% rec.			
85	SS #27 85' → 87.5'	100% rec.			
	SS #28 87.5' → 90'	100% rec.			

Reported By: L.D. Walker Reviewed By: DC Weekes
 Title: Geologist Title: Geologist
 Signature: [Signature] Date: 11-12-99 Signature: [Signature] Date: 2/9/00

BHI-EE-183 (12/97)

BC E HOLE LOG

Page 4 of 19

Date: 11-12-99

Well ID: B8814 Well Name: 299-W22-50 Location: Outside SE corner 241-SX Tank Farm
 Project: RCRA Drilling FY 2000 Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample		Graphic Log	Sample Description	Comments:
	Type No.	Blows Recovery			
90	SS #29	100% rec.		62.5' → 129' : SAND(S) as described on page 3. Predom. Fm sand, with intervals < 1 Ft. med-cse sand.	Cable tool; 8 3/4" OD CS casing; Continuous 5" OD split tube samples for PNNL chem. analysis.
90 → 92.5'					
	SS #30	100% rec.			
92.5 → 95'					
95	SS #31	100% rec.			
95 → 97.5'					
	SS #32	100% rec.			
97.5 → 100'					
100	SS #33	100% rec.			
100 → 102.5'					
	SS #34	100% rec.		105': silt stringer noted in split tube shoe. less than 0.1' thick, thin laminations	
102.5 → 105'					
105	SS #35	100% rec.		106': very thin silt layer	107.5': sand in SS shoe very moist
105 → 107.5'					Begin 11-15-99
	SS #36	95% rec.			
107.5 → 110'				111': thin silt layer; very moist, off horizontal angle.	
110	SS #37	100% rec.			Silt fragments in core barrel clean-out runs between split tube samples
110 → 112.5'					
	SS #38	100% rec.			
112.5 → 115'					
115	SS #39	100% rec.		116': very fine sand, tr silt, strong rxn HCl	
115 → 117.5'					
	SS #40	95% rec.			
117.5 → 120'					

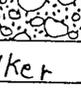
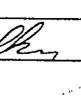
Reported By: L.D. Walker Reviewed By: DC Weekes
 Title: Geologist Title: Geologist
 Signature: [Signature] Date: _____ Signature: [Signature] Date: 2/9/00

BOREHOLE LOG

Page 2 of 17

Date: 11-15-99

Well ID: B8814 Well Name: 299-W22-50 Location: 200W Outside SE corner 241-SX Tank Farm
 Project: RCRA Drilling FY 2000 Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample		Graphic Log	Sample Description	Comments:
	Type No.	Blows Recovery			
120	SS #41	90% rec.		62.5' → 129': SAND (S)	Cable tool 8 3/4" OD CS casing; continuous 5" OD split tube
	120 → 122.5'			similar to description on page 3.	
125	SS #42	100% rec.		121': very fine sand, strong rxn HCl	samples for PNNL chem. analysis
	122.5 → 125'			123.5': Fh-med sand, sl moist to dry	
130	SS #43	100% rec.		127': predom. Fh sand	
	125 → 127.5'				
135	SS #44	100% rec.		129' → 130.5': SILT (M); 100% silt, tr v. Fh sand. lt. olive brown (2.5 Y 5/3), moist, well sorted, max size ~ 0.1 mm, tr fine horizontal laminations, strong rxn HCl.	
	127.5 → 130'				
140	SS #45	100% rec.		130.5' → 136': Silty SAND (mS); 70% sand, 30% silt. Sand tr med, 25% Fh, 75% v. Fh; lt. yel. brown (2.5 Y 6/3), sl moist, well sorted, SA-SP, predom. qtz/felds, tr basalt, strong rxn HCl	Begin 11-16-99
	130 → 132.5'				
145	SS #46	100% rec.		135' → 137.5': Sandy SILT (sM)	Sample is saturated but not enough water for e-tape reading - dry by 142.5'
	132.5 → 135'			As above, except 40% sand, 60% silt.	
150	SS #47	95% rec.		136' → 138': Calcareous Silty Sandy GRAVEL (mSG) 40% gravel, 40% sand, 20% silt.	145': material dry, loose, casing driven very hard - cobbles
	135 → 137.5'			gravel v. cse peb - v. Fh, round; sand predom Fh - v. Fh; grayish brn (2.5 Y 5/2), wet, poorly sorted; sand 80-90% qtz, 10-20% basalt, violent rxn HCl; max gravel ~ 5 cm.	
155	SS #48	100% rec.		- silt content decrease, moisture decrease	
	137.5 → 140'				
160	SS #49	100% rec.		142' → 152': Sandy GRAVEL (sG)	
	140 → 142.5'				
165	SS #50	90% rec.			
	142.5 → 145'				
170	SS #51	100% rec.			
	145 → 146'				
175	SS #52	100% rec.			
	146 → 147'				
180	SS #53	100% rec.			
	147 → 148'				
185	SS #54	100% rec.			
	148 → 150.5'				

Reported By: L.D. Walker Reviewed By: DC Weekes
 Title: Geologist Title: Geologist
 Signature: [Signature] Date: _____ Signature: [Signature] Date: 2/9/00

BO HOLE LOG

Page 6 of 19

Date: 11-16-99

Well ID: B8814 Well Name: 299-W22-50 Location: 200W outside SE corner 241-SX Tank Farm

Project: RCRA Drilling FY 2000 Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample		Graphic Log	Sample Description Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
	Type No.	Blows Recovery			
150	SS #52			142'→152': Sandy GRAVEL (sG) 50% gravel	Cable tool 8 3/4" OD CS
	SS #53			45% sand, 5% silt; gravel tr lg. cob,	casing; continuous
	150.5→ 153'	100% rec.		predom med-v. cse. peb, round; sand predom	5"OD split tube sampler
	SS #54			med-cse, SA-SR, dry, lt brnish gray	For PNNL analysis
	153→ 155.5'	100% rec.		(10YR 6/2), 80% qtz/felds, 20% basalt/other	
155	SS #55			max gravel > 20 cm, weak rxn HCl	
	155.5→ 158'	100% rec.		152'→153': SAND - similar to sand	
				Fraction above.	
	SS #56			153'→156': Sandy GRAVEL (sG)	Begin 11-17-99
	158→ 160.5'	75% rec.		similar to 142→152', without cobbles	
160	SS #57			156'→175.5': SAND (S), 59% gravel,	
	160.5→ 163'	100% rec.		95% sand, 10% v. cse sand, 20% cse,	
				40% med, 30% fn-v. fn., gray (10YR 6/1),	
	SS #58			dry, mod sorted, SA; 80% qtz/feld, 20%	
	163→ 165.5'	100% rec.		basalt, tr Fe-stain; HCl rxn weak/none	
165	SS #59		164-165: short interval gravelly sand.		
	165.5→ 168'	100% rec.	Sand as above, gravel med-cse peb and		
			rounded, predom. qtzite/granite	Sand is dry and	
	SS #60			loose	
	168→ 170.5'	100% rec.			
170	SS #61				
	170.5→ 173'	100% rec.			
	SS #62				
	173→ 175.5'	100% rec.	175': Gravelly Sand		
175	SS #63			177.5':	
	175.5→ 177.5'	60% rec.	175.5'→226': Silty Sandy GRAVEL	Switch over to	
	HT	NA	(msG)	hard tool drilling	

Reported By: <u>L.D. Walker</u>	Reviewed By: <u>DC Weekes</u>
Title: <u>Geologist</u>	Title: <u>Geologist</u>
Signature: <u>[Signature]</u>	Date: <u>11-18-99</u>
Signature: <u>[Signature]</u>	Date: <u>2/9/00</u>

BO. HOLE LOG

Page 7 of 14

Date: 11-18-99

Well ID: B 8814 Well Name: 299-W22-50 Location: 200W outside SE corner 241-SX Tank Farm
 Project: RCRA Drilling FY 2000 Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample		Graphic Log	Sample Description	Comments:	
	Type No.	Blows Recovery				
180	HT	NA		175.5' → 226': Silty Sandy GRAVEL (msc)	Cable tool 8 3/4" up cs	
	Archive grab			60% gravel, 35% sand, 5% silt.		casing; hard tool
				From last split spoon: gravel 10% cobble,		
				40% v.csc-csc peb, 30% med, 20% fn-v.fn.		180.5': Grab sample
				Sand 20% v.csc-csc, 20% med, 40% fn,		For archive
185	Archive grab			20% v.fn. Lt brnsh gray (10YR 6/2),		
	HT			dry; poorly sorted; grave R-SR, sand		185': Archive grab
				SR-SA; 70% qtz/granitic, 30% basalt,		sample
				Max gravel size > 10cm (inferred by drilling)		
				HCl rxn weak to none.		190': Archive grab
190	Grab					sample and chem.
	HT			Drilling indicates smaller gravels -		analysis for PNNL
				no cobbles, but perhaps cemented.		
						195': Grab sample -
195	Grab					Archive and chem.
	HT					
					200': Grab sample -	
200	Grab				archive and	
					chemical analysis	
					205': Grab sample -	
205	Grab				archive and	
					chemical analysis	
				208' → 209': Drill rate increase - then slows	Begin 11-22-99	
				at 209' possible sand content		
				increase 208' → 209'		

Reported By: L.D. Walker Reviewed By: DC Weekes
 Title: Geologist Title: Geologist
 Signature: [Signature] Date: 11-22-99 Signature: [Signature] Date: 2/9/00

BHI-EE-183 (12/97)

BOREHOLE LOG

Page 8 of 14

Date: 11-22-99

Well ID: B8814 Well Name: 299-W22-50 Location: ^{200W} outside SE corner 241-SX Tank Farm
 Project: RCRA Drilling FY 2000 Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample		Graphic Log	Sample Description	Comments:
	Type No.	Blows Recovery			
210	Grab	NA		175.5' → 226': Silty Sandy GRAVEL (msG) (from ss: 220.5' → 223') 60% gravel, 35% sand, 5% silt, Gravel fr sm. cob, 40% v.cse-cse peb, 30% med, 30% fn-v.fn; sand 10% v.cse-cse 30% med, 40% fn, 20% v.fn; brown (10YR 5/3), wet, poorly sorted; gravel rnd-SR, sand SA-A, gravel 30% basalt, 30% granitic, 40% quartz/other; Sand 70% qtz, 30% basalt/other, tr mica, MPS < 28 cm HCl rxn weak/none; well indurated.	210': Grab sample - archive and chem analysis.
	215			Grab	215': Grab sample - archive and chem analysis.
220	Grab	100% rec.		220' Possible sand content increase, faster drilling in saturated zone	220' Grab sample - archive and chem analysis.
	225			Grab	226' → 229': Sandy GRAVEL (SG); 50% gravel, 50% sand, tr silt. Gravel as above, sand 10% v.cse-cse, 60% med, 30% fn-v.fn, wet, loose, mod sorted sand (poor overall), gravel rnd-SR, sand SA-SR; sand 80% qtz, 20% basalt/other, MPS x 8-10 cm
230	Grab	90% rec.		229' → 231': SAND (S); 100% sand. Similar to sand above - predom med, SA-SR, mod-well sorted	11-23-99: Water sample collected w/ bailer - casing shoe at 220', w.l. = 217.5'
	235			Grab	[231': drilling indicates return of gravel]
235	Grab			231' → ^{234'} 302' : Silty Sandy GRAVEL (SG); 50% gravel, 47% sand, 2-3% silt; similar to SG at 226' → 229'	232' → 234': split tube - sieve anal. / chem anal.
					234' → 235': drilling indicates sand lens (sand heaving) 235'-245' SG as 231'-234'

Reported By: L.D. Walker Reviewed By: DC Weekes
 Title: Geologist Title: Geologist
 Signature: [Signature] Date: 11-24-99 Signature: [Signature] Date: 2/9/00

Appendix B

Summary of Geologists' Core Sample Descriptions from Borehole 299-W22-48

Pacific Northwest National Laboratory

DAILY BOREHOLE LOG

Boring/Well No 299-W22-48 (B3812) Depth _____ Date 5/25/00 Sheet 1 of _____

Location 241-S, 200 W Project _____

Logged by G.V. LOST Drilling Contractor NA

Reviewed by _____ Driller _____

Lithologic Class. Scheme Folk/Wentworth Procedure D7181-97-01 Rev D Rig/Method _____

Steel Tape/E-Tape NA / NA Field Indicator Equip. 1) NA 2) NA Depth Control Point _____

DEPTH (FT)	TIME	SAMPLES		CONTAMINATION		MOISTURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G				
61.5-62'	13:40		CORE #1 (in aluminum pan)			DRY								Bob Lenhard's Core #2. Disaggregated and dried by Bob. - Picture taken (digital) - #1?
71-71.5'	13:50		CORE #2 (in tupper ware tray)			DRY								Bob Lenhard's Core #2. Disaggregated and dried by Bob. Digital picture #2
90.5-91.5'	14:15					WET								Cut core open, near fall. Missing top 1". Digital Picture #3
														Sharp contact with underlying weakly laminated, poorly sorted coarse to fine SAND, some silt. Weak to moderate reaction to HCl. Moist color is 2.5Y 5/2.

W = Wet, M = Moist, D = Dry

B.1

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG				Boring/Well No <u>299-W22-48 (BB012)</u> Depth _____ Date <u>6/7/00</u>		Sheet <u>1</u> of <u>1</u>	
Logged by <u>G.Y. LAST</u> <i>[Signature]</i>						Location _____		Project _____	
Reviewed by _____ Date _____						Drilling Contractor _____		Driller _____	
Lithologic Class. Scheme _____ Procedure _____ Rev _____						Rig/Method _____		Depth Control Point _____	
Steel Tape/E-Tape _____ / _____						Field Indicator Equip. 1) _____ 2) _____			

DEPTH (FT)	TIME	SAMPLES		CONTAMINATION		MOISTURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G				
84.4-84.5	8:25		#2			Wet	[Graphic Log: Dotted pattern]				SLIGHTLY GRAVELLY SAND. 70% coarse sand, 15% VCS-Granules, 10% MED. sand. 5% Pebble upto 22 mm. No structure present-sample is disaggregated. Highly Brecciated. Wet color is 2.5Y 2.5/1 (BLACK). No reaction to HCl.			Sample disaggregated by Bob Lachard. Wet from experiment.
57-57.5	8:43					Dry	[Graphic Log: Dotted pattern]				Top 2" Laminated, poorly sorted coarse to fine sand, whitish streaks near contact - weak reaction to HCl. Some granules & pebbles to 8 mm. Dry color is 2.5Y 6/2. Some silt/clay. Massive? coarse to medium sand. Clean, few fines. 25% Brecciated lithics. Dry color is 2.5Y 5/2. No reaction to HCl.			Dried (in air) after Lachard's experiment.

B.3

W = Wet, M = Moist, D = Dry

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG			Boring/Well No <u>299-W22-48 (38212)</u> Depth <u>1' - 12.5'</u> Date <u>1/7/00</u>			Sheet <u>1</u> of <u>6</u>	
Location <u>241-S, 200 W</u>					Project _____				
Logged by <u>GV Last</u> <u>[Signature]</u>					Drilling Contractor <u>NA</u>				
Reviewed by _____ Date _____					Driller _____				
Lithologic Class. Scheme <u>Folk/Wentworth</u> Procedure <u>DTAI-99-GVL-01</u> Rev <u>0</u>					Rig/Method _____				
Steel Tape/E-Tape <u>NA</u> / <u>NA</u> Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>					Depth Control Point _____				

DEPTH (FT)	TIME	SAMPLES		CONTAMINATION		MOISTURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G				
1.0-1.5	0815					M							liner is 90% full.	
6-6.5	0927					M							liner is full. maybe upside down. some kind of drilling created laminations	
9.5-10	0940					M							liner is 90% full. missing bottom 1"	
12-12.5	0950					M							liner is 70% full. missing bottom 1"	

B.4

W = Wet, M = Moist, D = Dry

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG			Boring/Well No <u>299-W22-48</u>		Depth <u>14.5-22.5'</u>		Date <u>1/7/00</u>		Sheet <u>2 of 6</u>	
		Location <u>241-S, 200-W</u>			Project _____							
Logged by <u>EV West</u> <u>EV West</u>					Drilling Contractor <u>NA</u>							
Reviewed by _____ Date _____					Driller _____							
Lithologic Class. Scheme <u>Fdk/Wentworth</u>					Procedure <u>D9781-99-EVL-01</u> Rev <u>0</u>							
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>					Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>					Rig/Method _____		
					Depth Control Point <u>↓</u>							

DEPTH (FT)	TIME	SAMPLES		CONTAMINATION		MOISTURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)		
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G						
14.5-15'	1D10					m	[F]								Fine Sand. No outstanding laminae most color is 2.5Y 4/2. Weak reaction to HCl	Liner is 98% full. Missing bottom 1".
17-17.5'	1D10					m	[F]								Fine Sand on top overlying very fine sand which grades downward to fine sand. Then thin layer of f.m.s. Weak reaction to HCl. Color is 2.5Y 4/2.	Liner is 20% full. Missing bottom 1".
19.5-20'	1D15					m	[F]								Very fine sand. Finely laminated. Color is 2.5Y 4/2. Weak reaction to HCl	Liner is 90% full. Missing bottom 1".
22-22.5'	1D25					m	[F]								Very fine sand grades to fine sand then contacts coarse sand. Then near vertical streak, perhaps old rock cast fill with coarse sand. Most color of F sand is 2.5Y 4/2.	Liner is 70% full. Missing bottom 1".

B.S.

W = Wet, M = Moist, D = Dry

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG			Boring/Well No <u>299-W22-48</u>		Depth <u>24.5-32.5'</u>		Date <u>1/7/00</u>		Sheet <u>3</u> of <u>6</u>	
					Location <u>241-S, 200-W</u>		Project _____					
Logged by <u>GV Last</u> <i>GV Last</i>							Drilling Contractor <u>NA</u>					
Reviewed by _____							Driller _____					
Lithologic Class. Scheme <u>Folk/Wentworth</u>							Procedure <u>D9781-97-GVL-D1</u> Rev <u>D</u>					
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>							Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>					
Date _____							Depth Control Point _____					

DEPTH (FT)	TIME	SAMPLES		CONTAMINATION		MOIS- TURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G				
24.5- 25.0	10:34					M-D	[Hand-drawn lithologic log symbols]				Coarse Sand. Laminated. One small pebble (1/6 mm). Moist color is 2.5Y 4/1. No reaction to HCl.			Liner is 90% full. Missing bottom 1"
27- 27.5	10:45					M	[Hand-drawn lithologic log symbols]				Fine to Very Fine sand well laminated with medium sand. Grades to medium sand, poorly laminated. Color is 2.5Y 4/2. Weak reaction to HCl.			Liner is 90% full. Missing bottom 1"
29.5- 30	10:54					M	[Hand-drawn lithologic log symbols]				Medium Sand. Finely laminated. One 2-3 mm thick silt/mud layer. Color is 2.5Y 3/1. Weak reaction to HCl.			Liner is 95% full. Missing bottom 1/2"
32-32.5	11:00					M	[Hand-drawn lithologic log symbols]				Well laminated medium and fine sand. Mostly medium - laminations of fine sand. Moist color is 2.5Y 3/2. No reaction to HCl.			Liner is 90% full. Missing bottom 1"

B.6

W = Wet, M = Moist, D = Dry

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG			Boring/Well No <u>299-W22-4B</u>		Depth <u>34.5-45'</u>		Date <u>1/9/00</u>		Sheet <u>4 of 6</u>			
					Location <u>241-S, 200-W</u>		Project _____							
Logged by <u>GV Last</u> <u>GV Last</u>					Drilling Contractor <u>NA</u>									
Reviewed by _____					Driller _____									
Lithologic Class. Scheme <u>Folk/Wentworth</u>					Procedure <u>PTBL-99-GU-01</u>		Rev <u>D</u>							
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>					Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>		Depth Control Point <u>↓</u>							
DEPTH (FT)	TIME	SAMPLES		CONTAMINATION		MOISTURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G				
34.5-35'	11:14					D	[Graphic Log: Dashed lines]				Medium to coarse sand. Partly laminated. Thin layer of coarse sand near bottom. Moist color is 2.5Y 4/1. No reaction to HCl.			Liner is 90% complete.
37-37.5'	11:15					M	[Graphic Log: Dashed lines]				Fine sand. looks fairly massive. Wind loss silt zone in center, almost resembles clastic clay - but no clay skins. Siltier on edges of case. Some clay nodules. Moist color is 2.5Y 4/2. Weak reaction.			Liner is 90% complete, (OLD PAUCESOL?)
39.5-40'	11:21					M	[Graphic Log: Dashed lines]				Medium sand. laminated. Two fining upward sequences ~ 1/2" packages. Color is 2.5Y 4/2. Weak reaction to HCl.			Liner is 90% complete.
42-42.5'	11:28					M	[Graphic Log: Dashed lines]				Matrix supported gravel. Clasts up to 18 mm (coarse pebble). Sand is fine to very coarse. 2.5Y 5/1 (moist color). Catche clasts - strong reaction.			Liner is 90% full.
44.5-45'	11:36					M	[Graphic Log: Dashed lines]				Sandy gravel. clasts up to 30 mm (C.V.C) pebble. Sand is F-V.C. Color is 2.5Y 4/1. Weak to strong reaction. Catche clasts			Liner is 90% full.

W = Wet, M = Moist, D = Dry

B.7

DAILY BOREHOLE LOG

Boring/Well No 299-W22-42

Depth 47-56.5'

Date 1/7/00

Sheet

Location 241-SX, 200-W

Project

5 of 6

Logged by GV LAST *[Signature]*

Drilling Contractor NA

Reviewed by _____ Date _____

Driller _____

Lithologic Class. Scheme Folk/Wentworth Procedure Y97A1-99-GVL-D1 Rev 0

Rig/Method _____

Steel Tape/E-Tape NA / NA Field Indicator Equip. 1) NA 2) NA

Depth Control Point _____

DEPTH (FT)	TIME	SAMPLES		CONTAMINATION		MOISTURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G				
47-7/5	11:42					M								Liner is 90% full.
50-50.5	11:47					M								Liner is 90% full.
53.5-54'	11:55					M								Liner is 90% full, but soil packing is on top, and like other suspect core maybe upside down.
56-56.5	12:10					M								Liner is full.

W = Wet, M = Moist, D = Dry

B.8

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG				Boring/Well No <u>299-W22-48</u>		Depth <u>62-70'</u>		Date <u>1/10/00</u>		Sheet <u>1</u> of <u>7</u>	
Logged by <u>G.V. LAST</u> <i>G.V. Last</i>						Drilling Contractor <u>NA</u>							
Reviewed by _____						Driller _____							
Lithologic Class. Scheme <u>Folk/Wentworth</u>						Procedure <u>DTB1-99-6VL-D1</u> Rev <u>0</u>							
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>						Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>							
Rig/Method _____						Depth Control Point _____							

DEPTH (FT)	TIME	SAMPLES		CONTAMINATION		MOISTURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)	
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G					
62-62.5	09:40					M-D									Liner is 90% full. Missing bottom 1".
64.5-65	09:45					M-D									Liner is 20% full. Missing top 2". May be upside down?
67-67.5	09:40					M									Liner is 90% full. Missing bottom 1". Took note here sample of fine grained stuff
69.5-70	09:20					M-D									Liner is 0% full. Missing bottom 1.5".

B.10

W = Wet, M = Moist, D = Dry

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG			Boring/Well No <u>299-W22-4B</u>		Depth <u>74.5 - 82.5'</u>		Date <u>1/10/00</u>		Sheet <u>2 of 7</u>	
		Location <u>241-SX, 200-W</u>			Project _____							
Logged by <u>GV Lest/B. Bjornstad</u>							Drilling Contractor <u>NA</u>					
Reviewed by _____							Driller _____					
Lithologic Class. Scheme <u>Folk/Wentworth</u>							Procedure <u>DPTB-99-GVL-01</u>		Rev <u>0</u>		Rig/Method _____	
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>							Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>		Depth Control Point _____			

DEPTH (FT.)	TIME	SAMPLES		CONTAMINATION		MOISTURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G				
74.5-75	0930					M-D	[Graphic Log: 1.5" interval with fine sand texture]				Top 1.5" is F-VF sand, well laminated. Grades to fine sand. (Fines upward) Color is 2.5Y 5/2 - 5/3. Weak reaction to HCl.		Liner is 90% full. Missing bottom 1". Took moisture from top - finer grained unit. Contact with overlying m-c sand is ~ 73.5'.	
77-77.5	0940					M-D	[Graphic Log: 0.5" interval with fine sand texture]				Fine-Very Fine SAND. Finely laminated. Color is 2.5Y 6/2. Very weak reaction to HCl.		Liner is 90% Full. Missing bottom 1".	
79.5-80	0945					M-D	[Graphic Log: 0.5" interval with fine sand texture]				Fine SAND. Well laminated. Fine laminations - 2 strong clay laminations < 1mm thick. Weak reaction to HCl. Medium SAND. Poorly laminated. Graded contact. No reaction to HCl. Color is 2.5Y 6/2.		Liner is 90% Full. Missing bottom 1".	
82-82.5	0952					M-D	[Graphic Log: 0.5" interval with fine sand texture]				Fine SAND. Finely laminated. 1 prominent clay/silt lamination. Color is 2.5Y 6/2. Weak reaction to HCl.		Liner is 90% Full. Missing bottom 1".	

B.11

W = Wet, M = Moist, D = Dry

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG			Boring/Well No <u>299-W22-4B</u>			Depth <u>91.5-97.5'</u>		Date <u>1/10/00</u>		Sheet <u>4</u> of <u>7</u>		
Logged by <u>GULast/B.N. Bjornstul</u> <i>[Signature]</i>					Location <u>241-SX, 200-W</u>					Project _____				
Reviewed by _____					Date _____					Drilling Contractor <u>NA</u>				
Lithologic Class. Scheme <u>Folk/Wentworth</u>					Procedure <u>DTE1-99-EVL-D1</u> Rev <u>0</u>					Driller _____				
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>					Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>					Rig/Method _____				
										Depth Control Point _____				

DEPTH (FT)	TIME	SAMPLES		CONTAMINATION		MOIS- TURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H.O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G				
91.5- 92.5	12:45					M	[Hand-drawn lithologic log column]				Medium SAND, grades downward to coarse sand. Partly laminated. 2.5Y 5/2. Weak reaction.			Liner is 95% full. Missing Bottom 1"
											Very fine Sand, well laminated - some cross stratification. 2.5Y 5/3. Weak			
											SILT, Partly laminated. 2.5Y 5/3. Weak			
											Fine to Very fine Sand, well laminated. Same color. Weak.			
96.5- 97.5	12:47					M	[Hand-drawn lithologic log column]				Fine to Very Fine Sand. Well stratified at bottom. May coarsen upward. 2.5Y 5/3. Weak reaction to HCl.			Liner is 95% full. Missing bottom 1"
											SILT YF sand.			
											SILT. 2.5Y 5/3. Very fine laminated. perhaps cross stratified as well. Weak reaction to HCl.			

B.13

W = Wet, M = Moist, D = Dry

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG			Boring/Well No <u>299-W22-48</u>			Depth <u>101.5-107.5</u>		Date <u>1/10/00</u>		Sheet <u>5</u> of <u>7</u>	
Location <u>241-SX, 200-W</u>					Project _____					Drilling Contractor <u>NA</u>			
Logged by <u>GVLost/BN Bjornstad</u> <i>[Signature]</i>					Reviewed by _____					Date _____			
Lithologic Class. Scheme <u>Folk/Wentworth</u>					Procedure <u>DPT81-99-GVL-01</u> Rev <u>0</u>					Rig/Method _____			
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>					Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>					Depth Control Point _____			

DEPTH (Ft.)	TIME	SAMPLES		CONTAMINATION		MOIS- TURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G				
101.5	11:00					M	[Graphic Log: Vertical line with horizontal dashes]				FINE SAND, Poorly laminated. 2.5Y 6/2. Weak to strong reactions to HCl.			LINER IS 25% Full, missing bottom 1'. Take moisture SAMPLE FROM FINEST LAY.
102.5						M	[Graphic Log: Vertical line with horizontal dashes]				SILT, massive. 2.5Y 4/3-5/3 Weak reaction to HCl.			
						M	[Graphic Log: Vertical line with horizontal dashes]				SILT to Very Fine Sand. Very finely laminated. 2.5Y 4/3-5/3.			
						M	[Graphic Log: Vertical line with horizontal dashes]				M-F SAND Poorly laminated. 2.5Y 6/2 Weak Reaction to HCl.			LINER IS 95% Full, MISSING BOTTOM 1".
106.5	11:15					M	[Graphic Log: Vertical line with horizontal dashes]				SILT OF SAND. Very finely laminated. 2.5Y 6/2. Weak SAND BEHINDS UPWARD FROM MEDIUM TO WF SAND.			
107.5							[Graphic Log: Vertical line with horizontal dashes]				MEDIUM SAND			
							[Graphic Log: Vertical line with horizontal dashes]				FINE-VERY FINE SAND			

W = Wet, M = Moist, D = Dry

B.14

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG			Boring/Well No <u>299-W22-48</u>			Depth <u>111.5 - 116.5'</u>		Date <u>1/10/00</u>		Sheet <u>6</u> of <u>7</u>																																																																																																																																															
Location <u>241-SX, 200-W</u>					Project _____																																																																																																																																																						
Logged by <u>G.V. Last / B.M. Bjornstad</u> <i>G.V. Last</i>								Drilling Contractor <u>NA</u>																																																																																																																																																			
Reviewed by _____								Date _____																																																																																																																																																			
Lithologic Class. Scheme <u>Folk/Wentworth</u>								Procedure <u>DYI 81-97-G/L-D1</u> Rev <u>D</u>																																																																																																																																																			
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>								Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>																																																																																																																																																			
<table border="1" style="width:100%; border-collapse: collapse;"> <thead> <tr> <th rowspan="2">DEPTH (F)</th> <th rowspan="2">TIME</th> <th colspan="2">SAMPLES</th> <th colspan="2">CONTAMINATION</th> <th rowspan="2">MOIS- TURE</th> <th colspan="4">GRAPHIC LOG</th> <th rowspan="2">LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)</th> <th rowspan="2">H₂O ADDED</th> <th rowspan="2">CASING</th> <th rowspan="2">DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)</th> </tr> <tr> <th>TYPE</th> <th>ID NUMBER</th> <th>INSTR.</th> <th>READING</th> <th>C</th> <th>Z</th> <th>S</th> <th>G</th> </tr> </thead> <tbody> <tr> <td>111.5</td> <td>11:25</td> <td></td> <td></td> <td></td> <td></td> <td>M</td> <td colspan="4" style="text-align: center;">←</td> <td>Fine sand, Grades to medium sand. 2.5φ 6/2. Weak to strong reaction</td> <td></td> <td></td> <td>Liner is 95% full, missing bottom 1"</td> </tr> <tr> <td>112.5</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td colspan="4" style="text-align: center;">←</td> <td>medium to fine sand.</td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td colspan="4" style="text-align: center;">←</td> <td>Fine sand. Poorly laminated. Grades to medium sand at bottom of unit. 2.5φ 6/2. Weak reaction.</td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td colspan="4" style="text-align: center;">←</td> <td>medium sand</td> <td></td> <td></td> <td></td> </tr> <tr> <td>115.5</td> <td>11:42</td> <td></td> <td></td> <td></td> <td></td> <td>M</td> <td colspan="4" style="text-align: center;">←</td> <td>FINE-MEDIUM SAND FINE TO MEDIUM? TO FINE-UP SAND. POORLY LAMINATED. 2.5φ 6/2 - 6/3.</td> <td></td> <td></td> <td>Liner is full.</td> </tr> <tr> <td>116.5</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td colspan="4" style="text-align: center;">←</td> <td>FINE SAND, poorly laminated 2.5φ 6/2 - 6/3. Weak reaction.</td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td colspan="4" style="text-align: center;">←</td> <td>FINE-UP SAND</td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td colspan="4" style="text-align: center;">←</td> <td>SILT (2.5φ 4/2 - 3/2) with med sand inclusions. (mottled). Weak reaction.</td> <td></td> <td></td> <td></td> </tr> </tbody> </table>													DEPTH (F)	TIME	SAMPLES		CONTAMINATION		MOIS- TURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)	TYPE	ID NUMBER	INSTR.	READING	C	Z	S	G	111.5	11:25					M	←				Fine sand, Grades to medium sand. 2.5φ 6/2. Weak to strong reaction			Liner is 95% full, missing bottom 1"	112.5							←				medium to fine sand.											←				Fine sand. Poorly laminated. Grades to medium sand at bottom of unit. 2.5φ 6/2. Weak reaction.											←				medium sand				115.5	11:42					M	←				FINE-MEDIUM SAND FINE TO MEDIUM? TO FINE-UP SAND. POORLY LAMINATED. 2.5φ 6/2 - 6/3.			Liner is full.	116.5							←				FINE SAND, poorly laminated 2.5φ 6/2 - 6/3. Weak reaction.											←				FINE-UP SAND											←				SILT (2.5φ 4/2 - 3/2) with med sand inclusions. (mottled). Weak reaction.			
DEPTH (F)	TIME	SAMPLES		CONTAMINATION		MOIS- TURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED			CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)																																																																																																																																											
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W = Wet, M = Moist, D = Dry

1988/DCU/PROC/DBL/001

B.15

Pacific Northwest National Laboratory	DAILY BOREHOLE LOG	Boring/Well No <u>299-W22-48</u>	Depth <u>120.5 - 125</u>	Date <u>1/10/00</u>	Sheet <u>7</u> of <u>7</u>
		Location <u>241-SX, 200-W</u>	Project _____		

Logged by <u>GV [Signature]</u>	Drilling Contractor <u>NA</u>
Reviewed by _____	Driller _____
Lithologic Class. Scheme <u>Folk/Wentworth</u>	Rig/Method _____
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>	Depth Control Point _____
Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>	

DEPTH ()	TIME	SAMPLES		CONTAMINATION		MOIS- TURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G				
120.5	11:55					M	[Hand-drawn lithologic log with vertical scale and horizontal lines]				F. SAND. Poorly laminated. 2.5Y 6/2. Weak to strong reaction to HCl			Liner is full. No silt - dries out fast. Same as others sands above.
121.5							[Hand-drawn lithologic log with vertical scale and horizontal lines]				Fine Sand. Some forest bedding.			
124-120						M-D	[Hand-drawn lithologic log with vertical scale and horizontal lines]				VF-F SAND. Some mica's. Poorly laminated. Weak reaction to HCl. 2.5Y 6/3.			Liner is 95% full missing bottom 1".
125							[Hand-drawn lithologic log with vertical scale and horizontal lines]							

W = Wet, M = Moist, D = Dry

B.16

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG				Boring/Well No <u>299-W22-42</u>		Depth <u>134-137</u>		Date <u>1/12/05</u>		Sheet <u>2</u> of <u>10</u>							
Logged by <u>GL Last</u> <i>[Signature]</i>						Drilling Contractor <u>NA</u>													
Reviewed by _____						Driller _____													
Lithologic Class. Scheme <u>Folk/Wentworth</u>						Procedure <u>D9(B)-99-GVL-01 Rev 0</u>													
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>						Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>													
DEPTH (FT)		TIME		SAMPLES		CONTAMINATION		MOIS-TURE		GRAPHIC LOG		LITHOLOGIC DESCRIPTION		H ₂ O ADDED		CASING		DRILLING COMMENTS	
				TYPE ID NUMBER INSTR. READING		INSTR. READING				C Z S G		(particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)						(drilling rate, down time, blow counts, water level, drill fluid, etc.)	
134-135		0938						D				SILTY FINE to VERY FINE SAND. May be bottom of fining upward sequence. Sharp contact at bottom. SLIGHTLY SILTY FINE TO U.FINE SAND GRADUALLY DOWNWARD TO FINE-MED SAND. COVER IS 2.5' 6/3. Strong reaction to HCl. MEDIUM SAND some ripup clots of silt SILT, MASSIVE. COVER IS 2.3' 5/3. Strong reaction to HCl.						LINER IS 95% FULL. MISSING bottom 1"	
136-137		0945						D				U.F. SANDY SILT. Well laminated. Platy, in 5 mm beds. Thicker bed at bottom. 2.5' 6/3. Strong reaction to HCl.						LINER IS 95% FULL. MISSING bottom 1"	

B.18

W = Wet, M = Moist, D = Dry

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG			Boring/Well No <u>299-W22-42</u>			Depth <u>148.5-152</u>		Date <u>1/12/00</u>		Sheet <u>4</u> of <u>10</u>	
Logged by <u>G.V. LAST / B.N. BJORNSTAD</u> <i>GLV</i>					Location <u>241-SX, 200-W</u>					Project _____			
Reviewed by _____					Date _____					Drilling Contractor <u>NA</u>			
Lithologic Class. Scheme <u>Fulk/Wendworth</u>					Procedure <u>D7121-99-G/L-D1</u> Rev <u>0</u>					Driller _____			
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>					Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>					Rig/Method _____			
										Depth Control Point _____			

DEPTH (FT.)	TIME	SAMPLES		CONTAMINATION		MOIS- TURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H.O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G				
148.5	10:30					D	↑				SILT/CLAY SAND/CALCITE. Very poorly sorted. Color is 2.5Y 8/3. Reaction is very strong. Well consolidated / lithified.			Liner is 95% full. Missing bottom 1"
149.5							←				SILTY SAND - less clay/silt.			
151	10:40					D	X				SILTY COARSE SAND. WITH SCATTERED PEBBLES. No obvious structures Color is 2.5Y 6/2. Reaction is very strong to HCl.			Liner is 95% full. Missing bottom 1"
152							←				pebble > 15mm			
							X							

W = Wet, M = Moist, D = Dry

B.20

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG			Boring/Well No <u>299-W22-4B</u>			Depth <u>170-173.5</u>		Date <u>1/12/00</u>		Sheet <u>7</u> of <u>10</u>	
Logged by <u>GVLast/BN Bjornstad</u> <u>GVLast</u>					Location <u>241-SX, 200-W</u>					Project _____			
Reviewed by _____					Date _____					Drilling Contractor <u>NA</u>			
Lithologic Class. Scheme <u>Folk/Wendworth</u>					Procedure <u>D9781-99-GVL-01</u> Rev <u>D</u>					Driller _____			
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>					Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>					Rig/Method _____			
										Depth Control Point _____			

DEPTH (FT)	TIME	SAMPLES		CONTAMINATION		MOIS- TURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G				
170- 171	11:39					m	(Hand-drawn lithologic log with vertical lines and some shading)				Change in mixture - definitely wetter. Medium SAND. Poorly laminated. Some clasts of SILT/CLAY near top. Color is 2.5Y 5/2 No reaction to HCl.			Liner is full.
172.5- 173.5	11:45					m	(Hand-drawn lithologic log with vertical lines and some shading)				Possible Clastic Dike, SILTY/CLAY WITH bits of med. SAND. soft sed. deformation. Color is 2.5Y 5/3 Weak to strong reaction to HCl.			Liner is full.
											Medium SAND. Siltier at top and in middle. No sharp contacts. Poor laminated at base. Color is 2.5Y 4/2 Weak reaction to HCl.			

W = Wet, M = Moist, D = Dry

B.23

Pacific Northwest National Laboratory		DAILY BOREHOLE LOG			Boring/Well No <u>299-W22-48</u>			Depth <u>187-193</u>		Date <u>1/12/00</u>		Sheet <u>9</u> of <u>10</u>	
					Location <u>241-SX, 200-W</u>			Project _____					
Logged by <u>CV Last</u>							Drilling Contractor <u>NA</u>						
Reviewed by _____							Driller _____						
Lithologic Class. Scheme <u>Folk/Wentworth</u>							Procedure <u>DTP-92-6/L-01</u>			Rev <u>0</u>			
Steel Tape/E-Tape <u>NA</u> / <u>NA</u>							Field Indicator Equip. 1) <u>NA</u> 2) <u>NA</u>			Depth Control Point _____			

DEPTH (FT)	TIME	SAMPLES		CONTAMINATION		MOIS- TURE	GRAPHIC LOG				LITHOLOGIC DESCRIPTION (particle size distribution, sorting, mineralogy, roundness, color, reaction to HCl, etc.)	H ₂ O ADDED	CASING	DRILLING COMMENTS (drilling rate, down time, blow counts, water level, drill fluid, etc.)	
		TYPE	ID NUMBER	INSTR.	READING		C	Z	S	G					
187- 188	1350					D									Liner is 95% full. Missing bottom 1".
															Slightly silty medium SAND. Good contact with finer unit below. Color is 2.5Y 6/2. No Reaction.
															Silty F-m SAND. Coarsens downward to less silty. Partly laminated. Color is 2.5Y 6/2. No reaction
192- 193	1358					D									Liner is 90% full. Missing bottom 1.5".
															SILTY GRAVEL. minor sand (coarse). GRAVEL up to >45 mm. Well rounded Color of matrix is 2.5Y 3/2. No reaction to HCl.
															Roten Granite (highly weathered).

W = Wet, M = Moist, D = Dry

B.25

Appendix C

**Summary Geophysical Logs for Borehole 299-W22-48 (9 pages)
and Borehole 299-W22-50 (9 pages)**

RLS Spectral Gamma Survey
Waste Management Technical Services

LOG HEADER

Project: RCRA drilling 1999

Well: 299-W22-48

Borehole Information

Well # <u>299-W22-48</u>	Water Depth <u>226</u> ft	Total Depth <u>245</u> ft
Elevation Reference <u>n/a</u>	Elevation <u>n/a</u> ft	
Depth Reference <u>Ground Surface</u>	Casing Stickup <u>11.75 in. - 0.38', 8.625 in. - 1.0'</u>	
Casing Diameter <u>11.75</u> in.	Depth Interval <u>0 to 50</u> ft	Thickness <u>0.5</u> in
Casing Diameter <u>8.625</u> in.	Depth Interval <u>0 to 245</u> ft	Thickness <u>0.5</u> in

Logging Information

Log Type:	HPGe Spectral Gamma	
Company	Waste Management Technical Services	
Logging Engineers	<u>J.E. Meisner</u>	
Instrument Series	RLSG07000S00.0	
Logging Unit	RLS-1	
Depth Interval	0' to 166.0'	Prefix A678
	161.0' to 245.5'	A679
Instrument Calibration Date	October 8, 1999	
Calibration Report	WHC-SD-EN-TI-292, Rev. 0	

Analysis Information

Company	Waste Management Technical Services
Analyst	Steven Kos
Date	March 13, 2000
Depth Reference	Ground Surface

Notes Spectral gamma measurements were acquired at 0.5-ft depth intervals at a logging speed of 1.0 ft. min.

RLS Spectral Gamma Survey

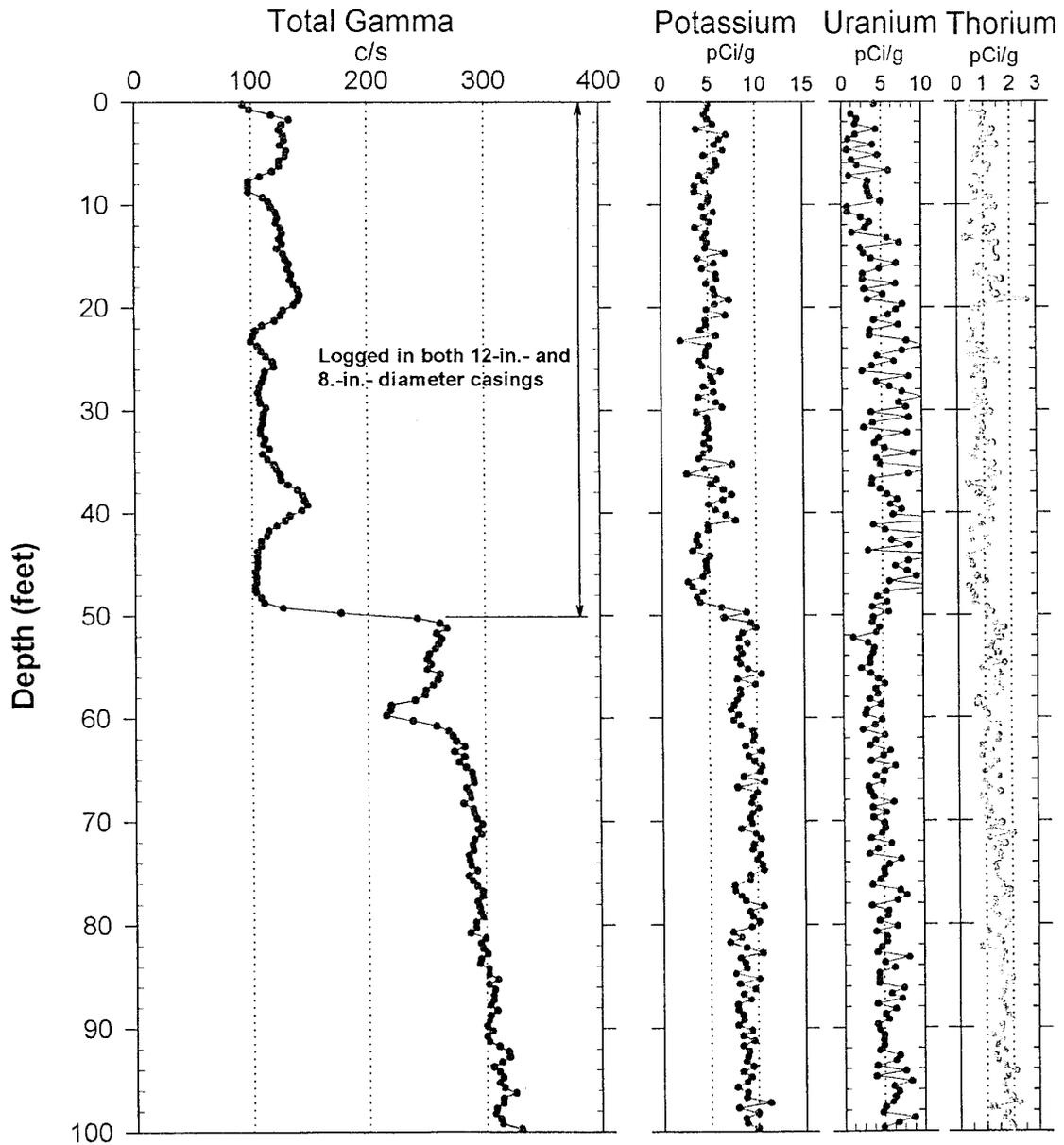
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date: Oct. 27, 1999

Well: 299-W22-48

Depth Datum: Ground Level



RLS Spectral Gamma Survey

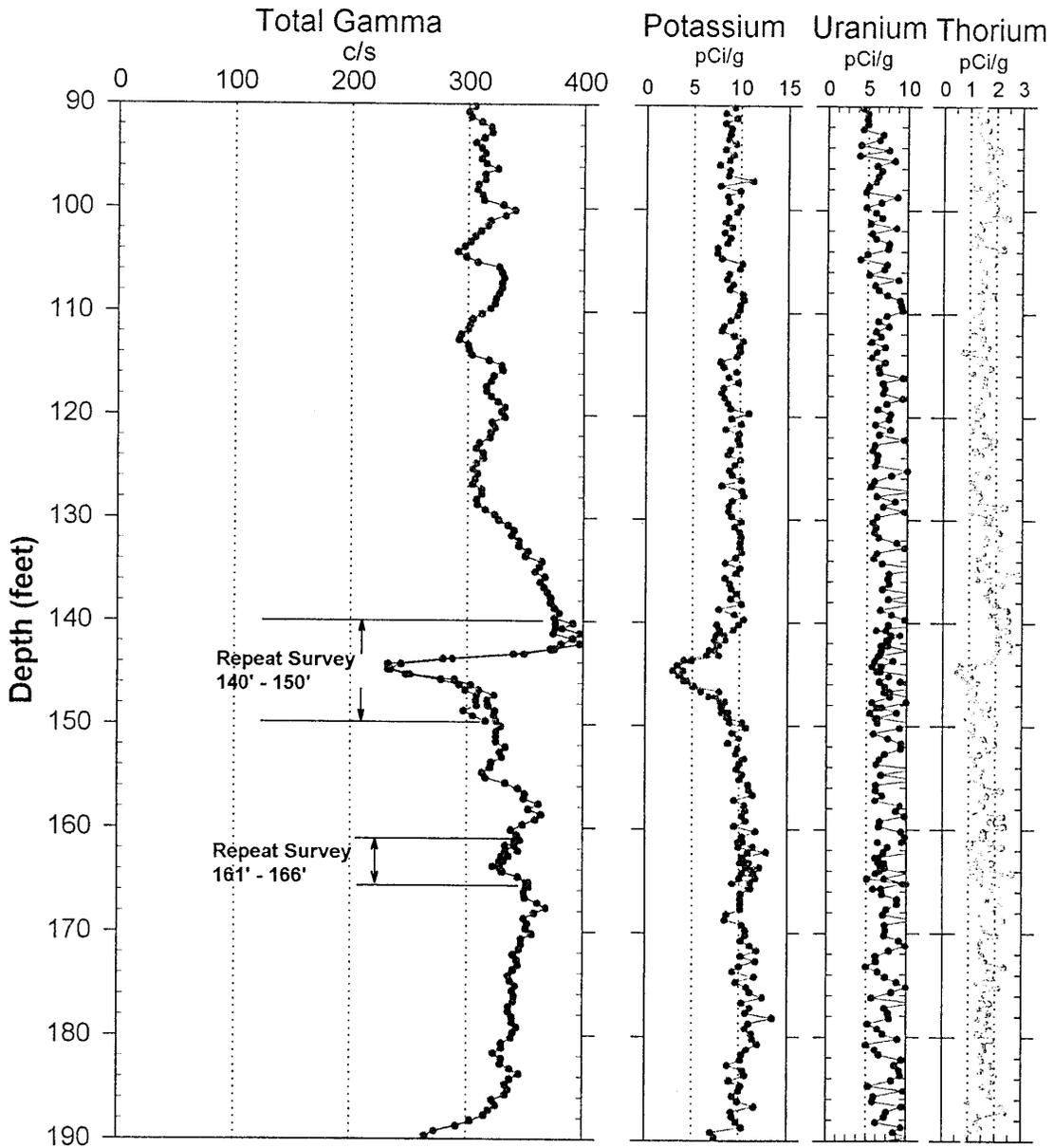
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date: Oct. 27, 1999

Well: 299-W22-48

Depth Datum: Ground Level



RLS Spectral Gamma Survey

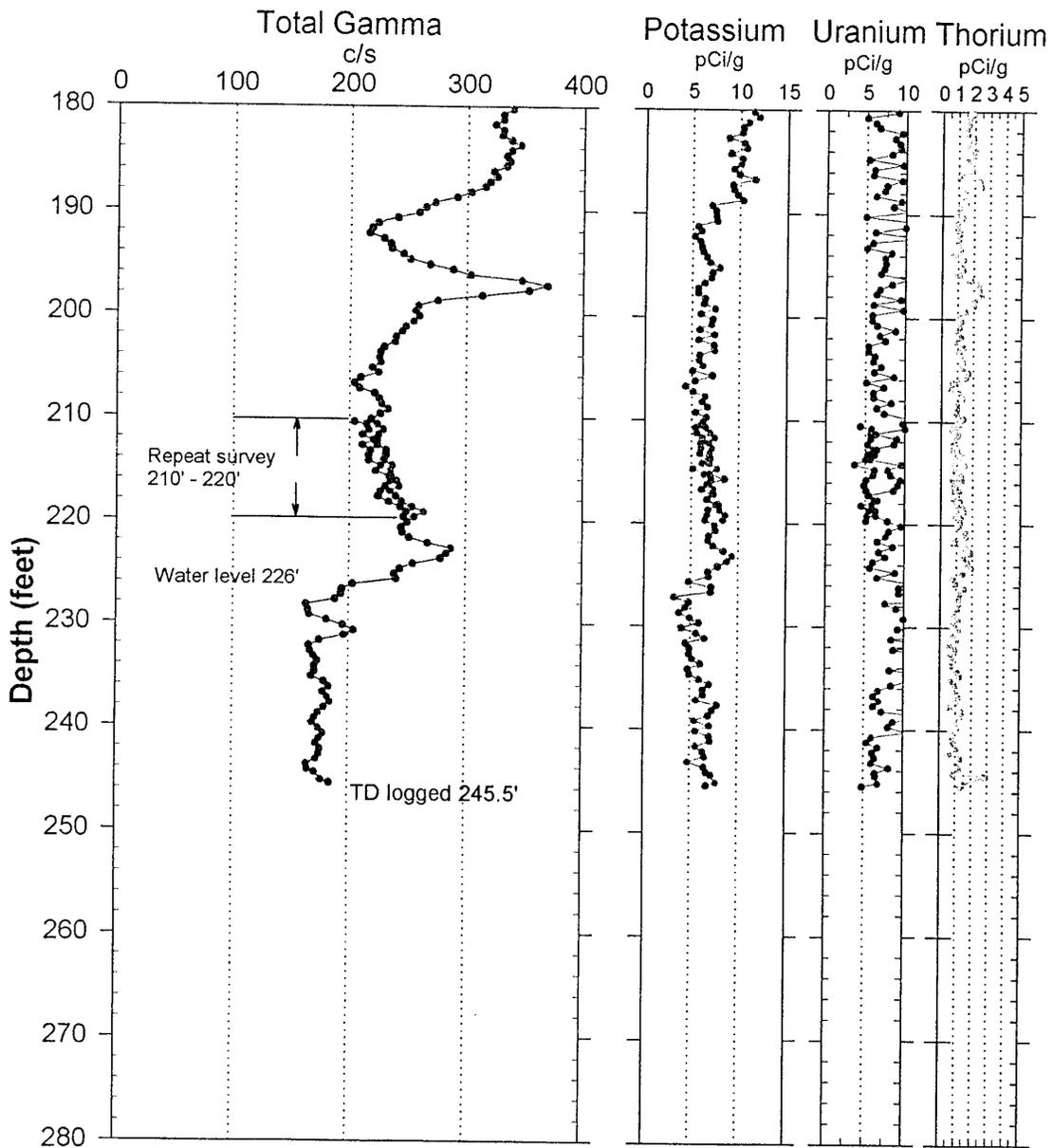
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date: Oct. 27, 1999

Well: 299-W22-48

Depth Datum: Ground Level



RLS Neutron-Neutron Moisture Survey
Waste Management Technical Services

LOG HEADER

Project: RCRA drilling 1999

Well: 299-W22-48

Borehole Information

Well # <u>299-W22-48</u>	Water Depth <u>226</u> ft	Total Depth <u>245</u> ft
Elevation Reference <u>n/a</u>	Elevation <u>n/a</u> ft	
Depth Reference <u>Ground Surface</u>	Casing Stickup <u>11.75 in. - 0.38', 8.625 in. - 1.0'</u>	
Casing Diameter <u>11.75</u> in.	Depth Interval <u>0 to 50</u> ft	Thickness <u>0.5</u> in.
Casing Diameter <u>8.625</u> in.	Depth Interval <u>0 to 245</u> ft	Thickness <u>0.5</u> in.

Logging Information

Log Type:	Neutron-Neutron Moisture	
Company	Waste Management Technical Services	
Logging Engineers	<u>J.E. Meisner</u>	
Instrument Series	RLSM00.0	
Logging Date	October 27, 1999	
Logging Unit	RLS-1	
Depth Interval	0' to 100'	Prefix MS45
	50' to 150'	MA46
	145' to 225.75'	MA47
Instrument Calibration Date	May 13, 1999	
Calibration Report	WHC-SD-EN-TI-306, Rev. 0	

Analysis Information

Company	Waste Management Technical Services
Analyst	Steven Kos
Date	March 15, 2000
Depth Reference	Ground Surface
Notes	The moisture measurements were acquired at 0.250-ft depth intervals at a logging speed of 1.0 ft per minute.

Neutron-Neutron Moisture Survey

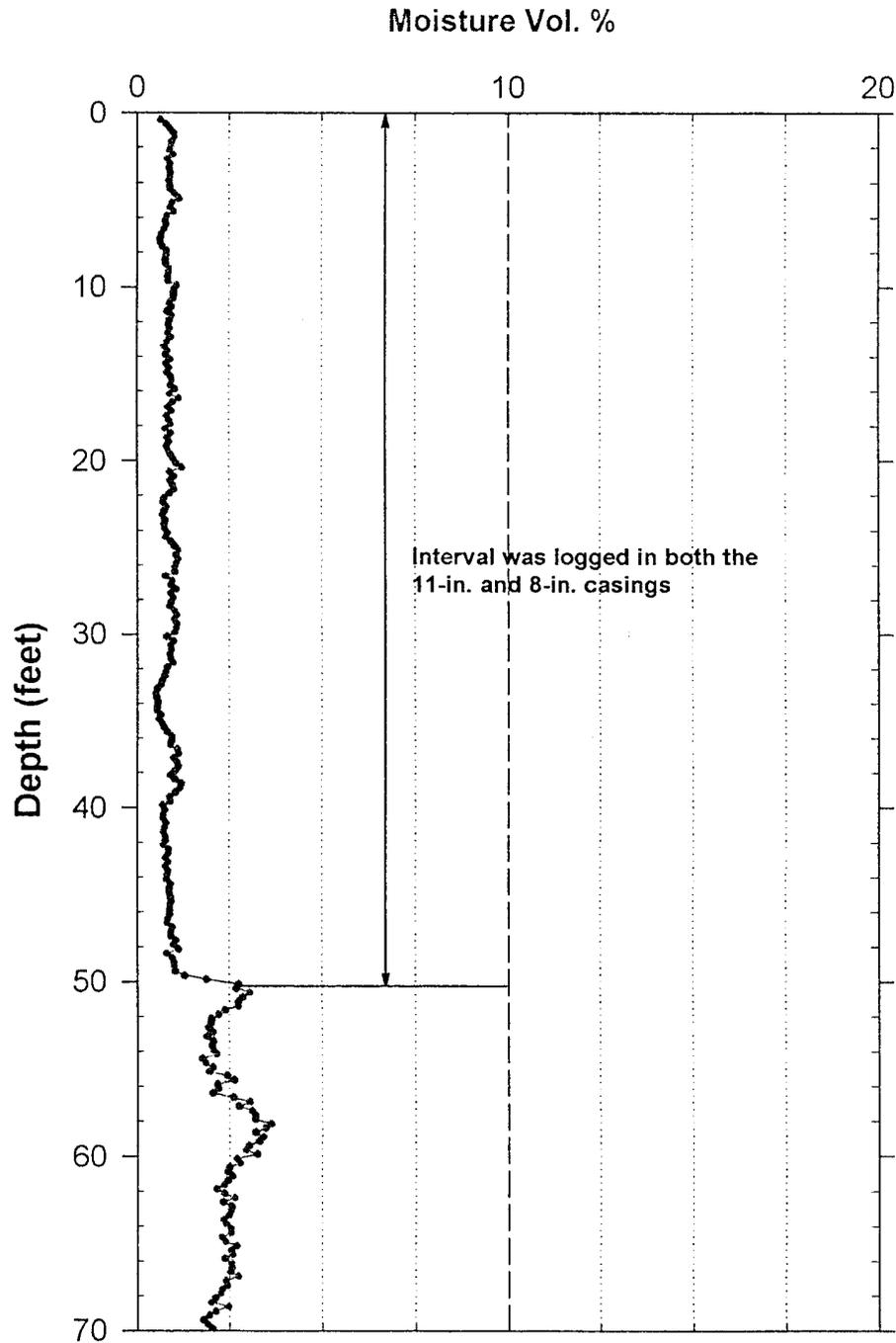
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date : October 27, 1999

Borehole: 299-W22-48

Depth Datum: Ground Level



Neutron-Neutron Moisture Survey

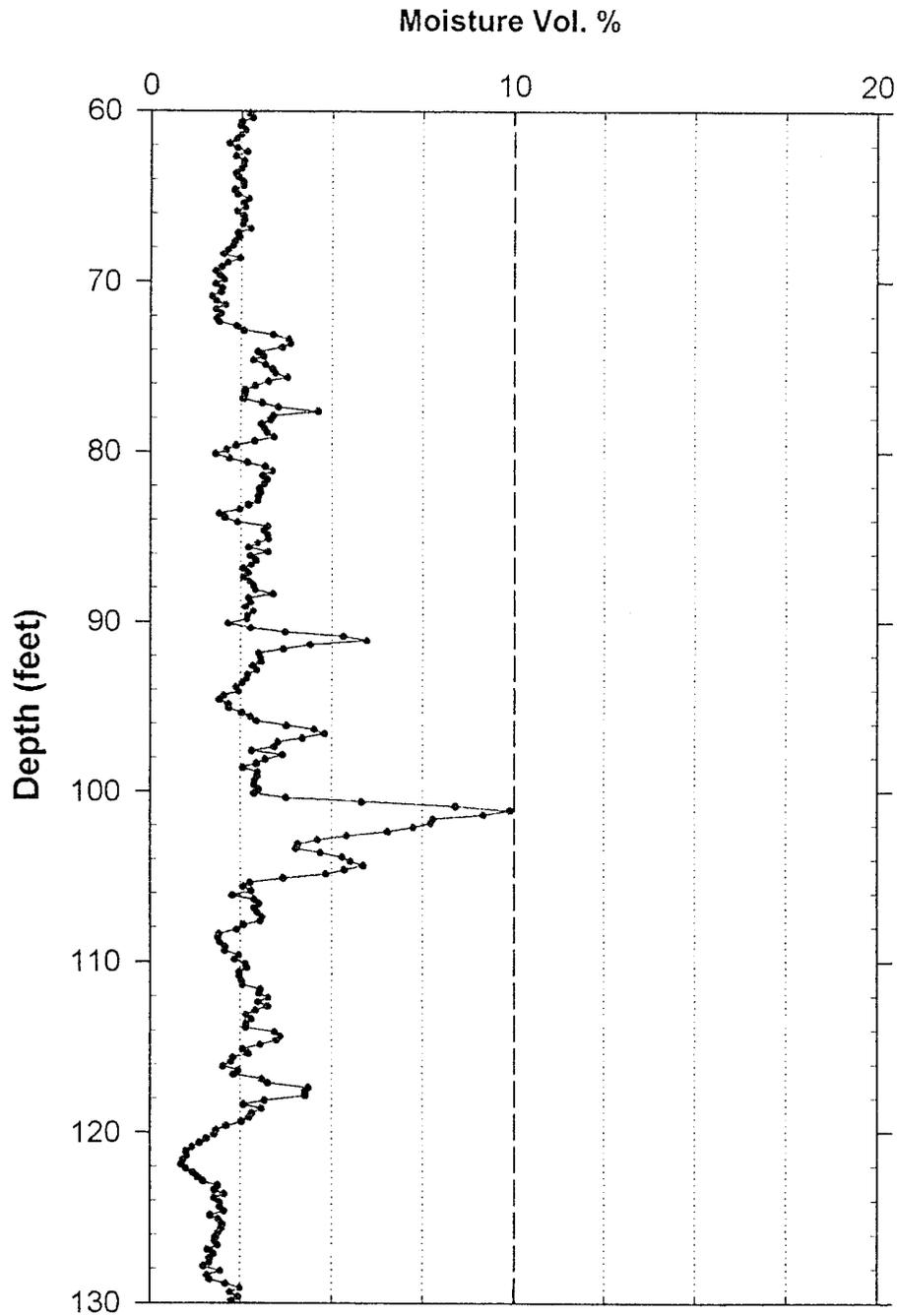
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date : October 27, 1999

Borehole: 299-W22-48

Depth Datum: Ground Level



Neutron-Neutron Moisture Survey

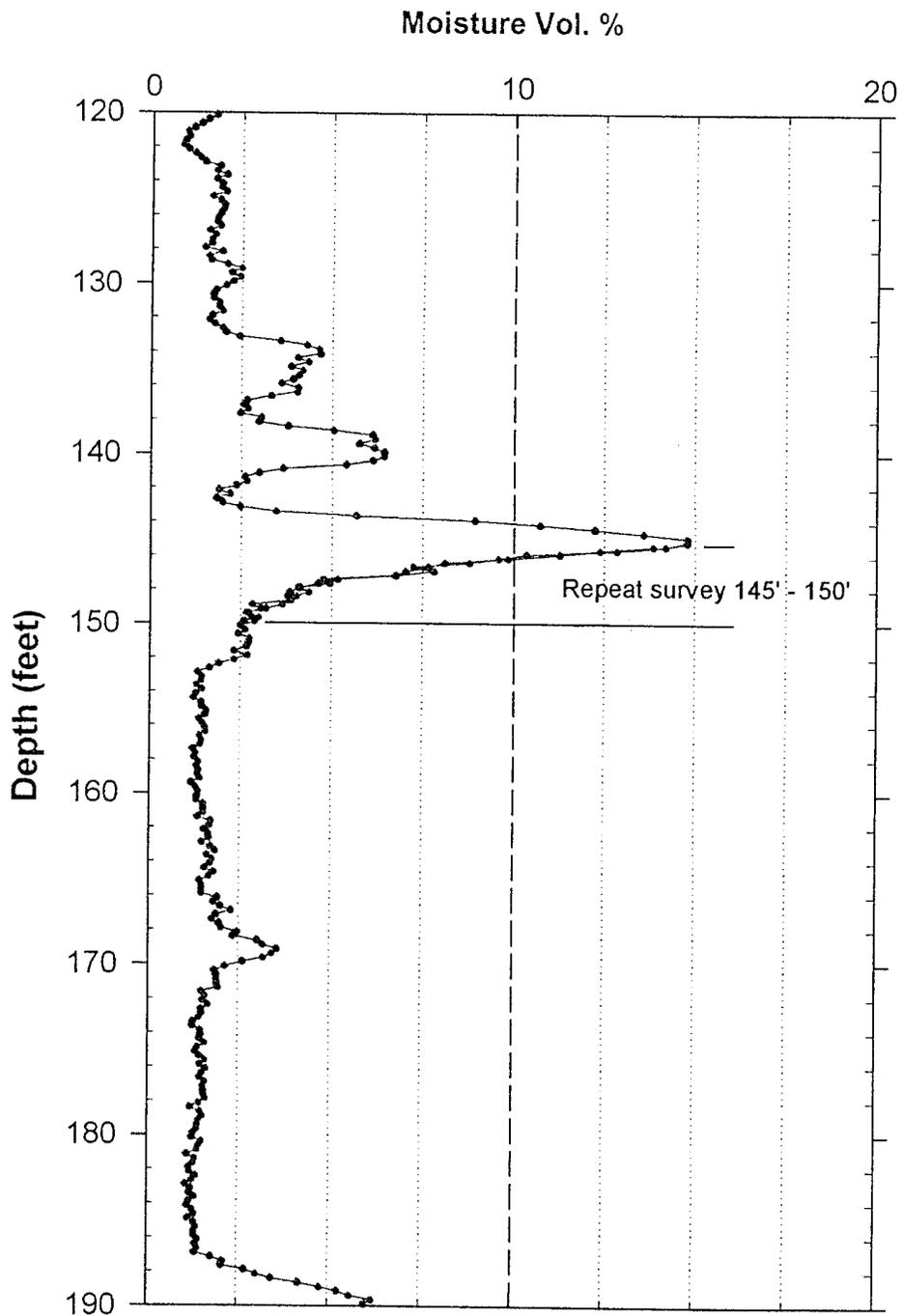
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date : October 27, 1999

Borehole: 299-W22-48

Depth Datum: Ground Level



Neutron-Neutron Moisture Survey

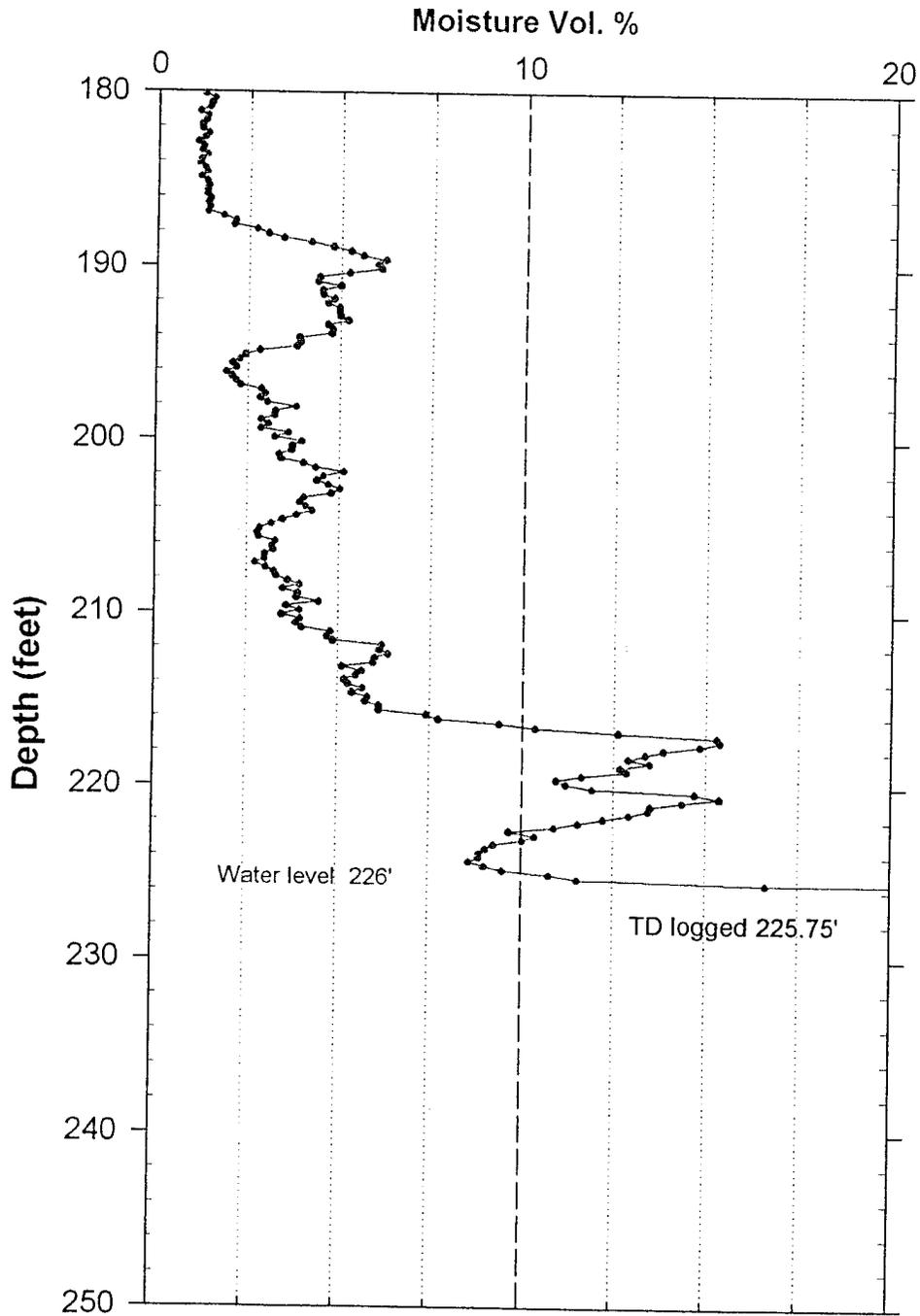
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date : October 27, 1999

Borehole: 299-W22-48

Depth Datum: Ground Level



RLS Spectral Gamma/Sodium Iodide Survey
Waste Management Technical Services

LOG HEADER

Project: RCRA drilling 1999

Well: 299-W22-50

Borehole Information

Well # <u>299-W22-50</u>	Water Depth <u>218</u> ft	Total Depth <u>547.35</u> ft
Elevation Reference <u>n/a</u>	Elevation <u>n/a</u> ft	
Depth Reference <u>Ground Surface</u>	Casing Stickup <u>11.75" - 0', 8.625" - 0', 6.625" - 0.67', 3.75 - 4.2'</u>	
Casing Diameter <u>11.75</u> in.	Depth Interval <u>0 to 50</u> ft	Thickness <u>0.5</u> in
Casing Diameter <u>8.625</u> in.	Depth Interval <u>0 to 241</u> ft	Thickness <u>0.5</u> in
Casing Diameter <u>6.625</u> in.	Depth Interval <u>0 to 474</u> ft	Thickness <u>0.5</u> in
Casing Diameter <u>3.75</u> in.	Depth Interval <u>0 to 547.35</u> ft	Thickness <u>0.375</u> in

Logging Information

Log Type:	HPGe Spectral Gamma	
Company	Waste Management Technical Services	
Logging Engineers	J.E. Meisner	
Logging Dates	November 30, 1999, January 14, 2000	
Instrument Series	RLSG07000S00.0/RLSN2.0*	
Logging Unit	RLS-1	
Depth Interval	0' to 145.0'	Prefix A682
	125.0' to 240.5'	A683
	230.0' to 353.5	A695
	350.0' to 475.5'	A696
	440.0' to 545.5'*	A694
Instrument Calibration Date	October 8, 1999/January 18, 1999*	
Calibration Report	WHC-SD-EN-TI-292, Rev. 0	
	WHC-SD-EN-TI-293, Rev. 0*	

*Bottom of the borehole was logged with a sodium iodide detector designated RLSN2.0

Analysis Information

Company	Waste Management Technical Services
Analyst	Steven Kos
Date	March 13, 2000
Depth Reference	Ground Surface

Notes HGPe spectral gamma and sodium iodide logging tools were utilized to log this borehole. Measurements were acquired with both of these tools at 0.5-ft depth increments at a logging speed of 1.0 ft per minute.

RLS Spectral Gamma Survey

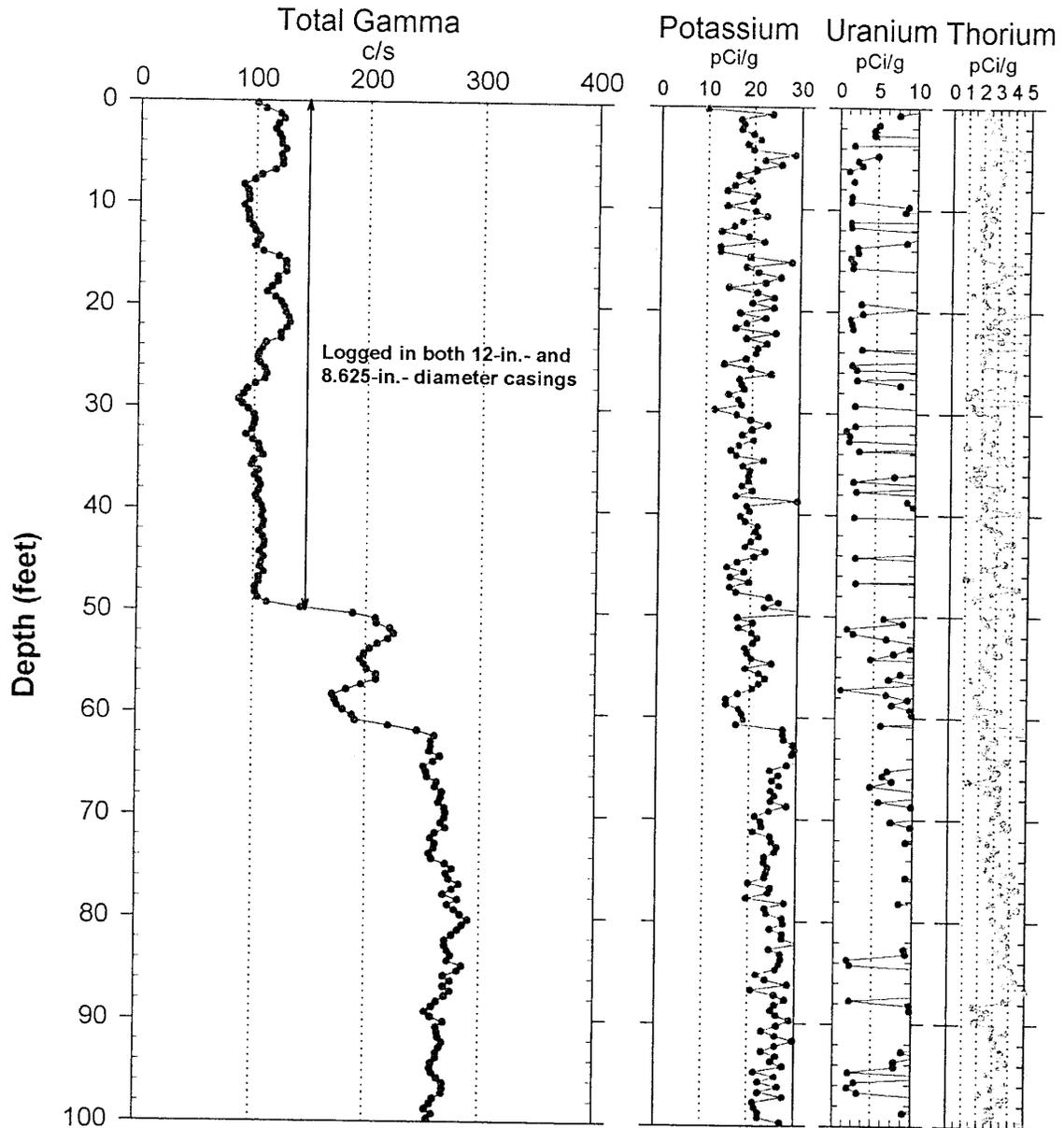
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date: Nov. 30, 1999,
Jan. 14&15, 2000

Well: 299-W22-50

Depth Datum: Ground Level



RLS Spectral Gamma Survey

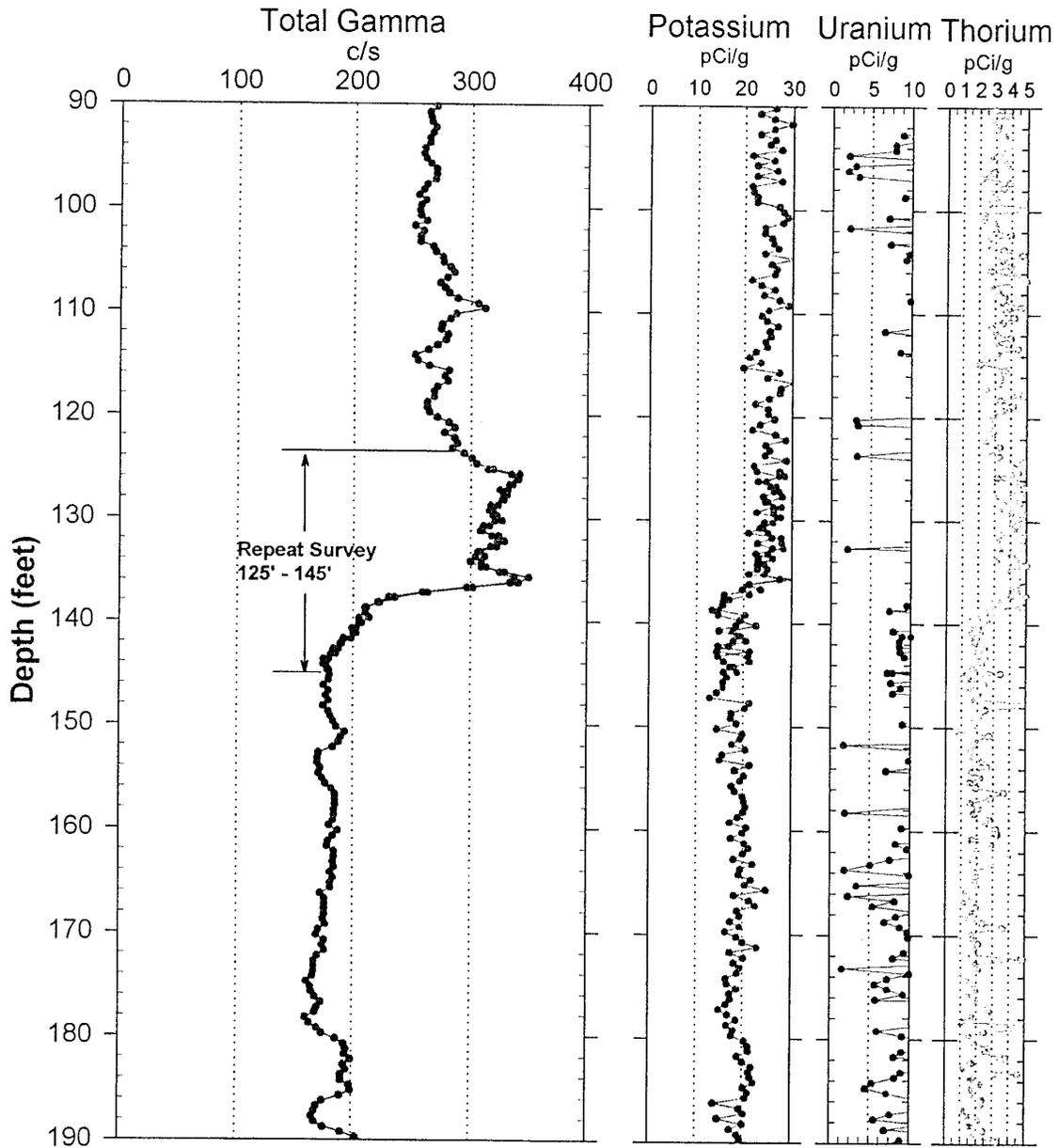
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date: Nov. 30, 1999,
Jan. 14&15, 2000

Well: 299-W22-50

Depth Datum: Ground Level



KLS Spectral Gamma Survey

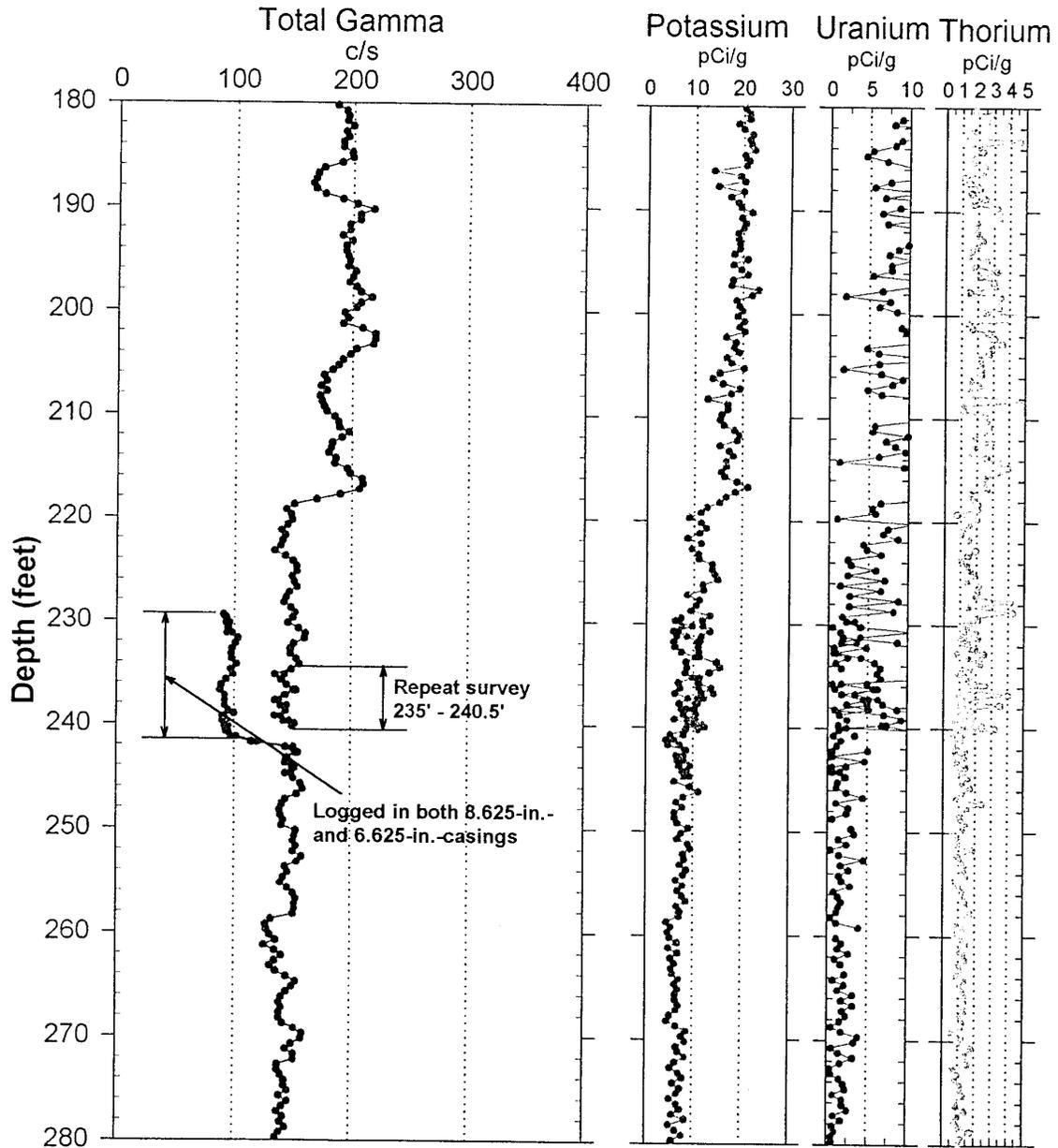
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date: Nov. 30, 1999
Jan. 14 & 15, 2000

Well: 299-W22-50

Depth Datum: Ground Level



RLS Neutron-Neutron Moisture Survey
Waste Management Technical Services

LOG HEADER

Project: RCRA drilling 1999

Well: 299-W22-50

Borehole Information

Well # <u>299-W22-50</u>	Water Depth <u>218</u> ft	Total Depth <u>547.35</u> ft
Elevation Reference <u>n/a</u>	Elevation <u>n/a</u> ft	
Depth Reference <u>Ground Surface</u>	Casing Stickup <u>11.75" - 0', 8.625" - 0', 6.625" - 0.67', 3.75" - 4.2'</u>	
Casing Diameter <u>11.75</u> in.	Depth Interval <u>0 to 50</u> ft	Thickness <u>0.5</u> in.
Casing Diameter <u>8.625</u> in.	Depth Interval <u>0 to 241</u> ft	Thickness <u>0.5</u> in.
Casing Diameter <u>6.625</u> in.	Depth Interval <u>0 to 474</u> ft	Thickness <u>0.5</u> in.
Casing Diameter <u>3.75</u> in.	Depth Interval <u>0 to 547.35</u> ft	Thickness <u>0.375</u> in.

Logging Information

Log Type:	Neutron-Neutron Moisture	
Company	Waste Management Technical Services	
Logging Engineers	<u>J.E. Meisner</u>	
Instrument Series	RLSM00.0	
Logging Date	November 30, 1999	
Logging Unit	RLS-1	
Depth Interval	0' to 150'	Prefix MA50
	145' to 218.3'	MA51
Instrument Calibration Date	May 13, 1999	
Calibration Report	WHC-SD-EN-TI-306, Rev. 0	

Analysis Information

Company	Waste Management Technical Services
Analyst	Steven Kos
Date	December 16, 1999
Depth Reference	Ground Surface

Notes The moisture measurements were acquired at 0.250-ft depth intervals at a logging speed of 1.0 ft per minute.

Neutron-Neutron Moisture Survey

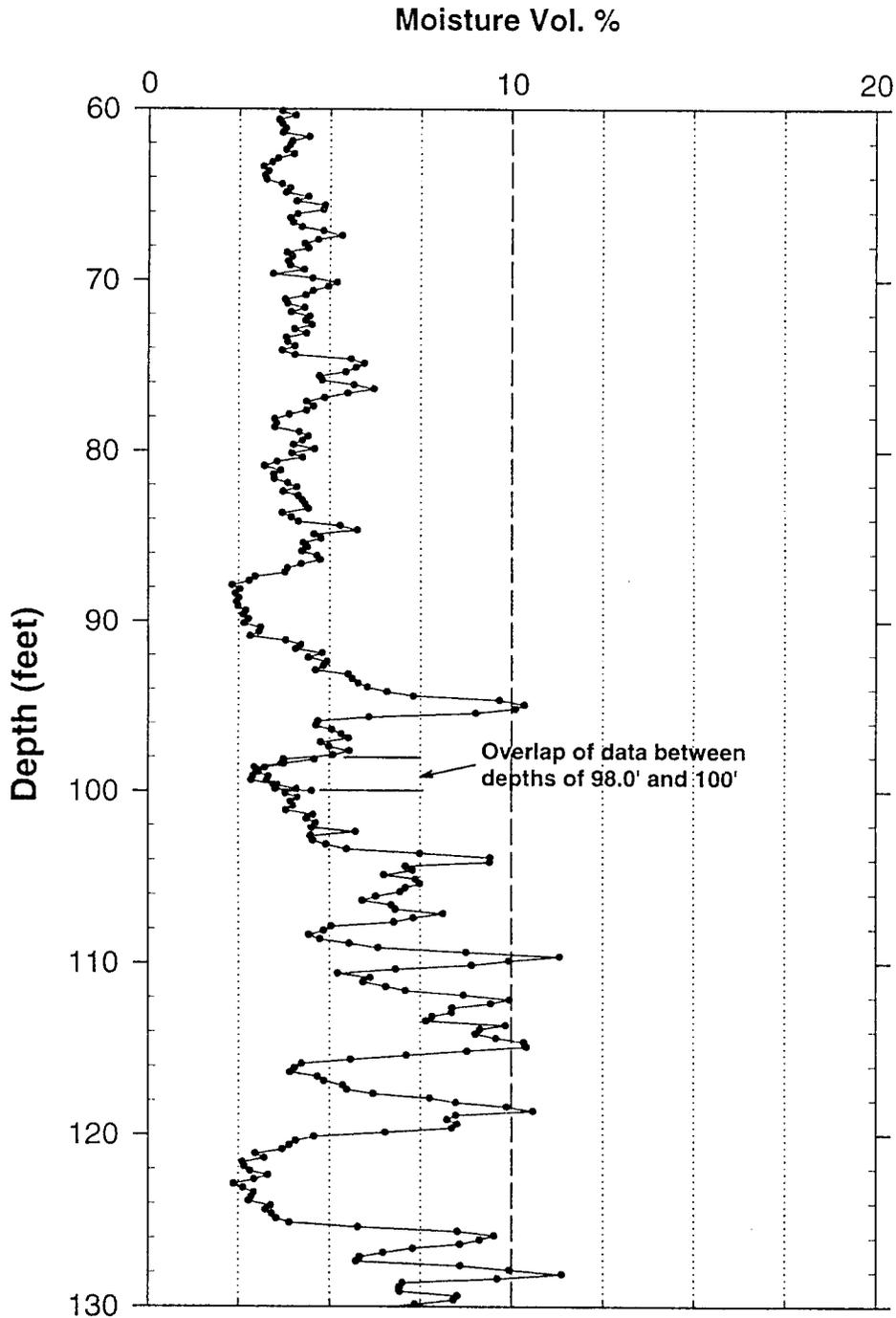
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date: November 30, 1999

Borehole: 299-W22-50

Depth Datum: Ground Level



RLS Neutron-Neutron Moisture

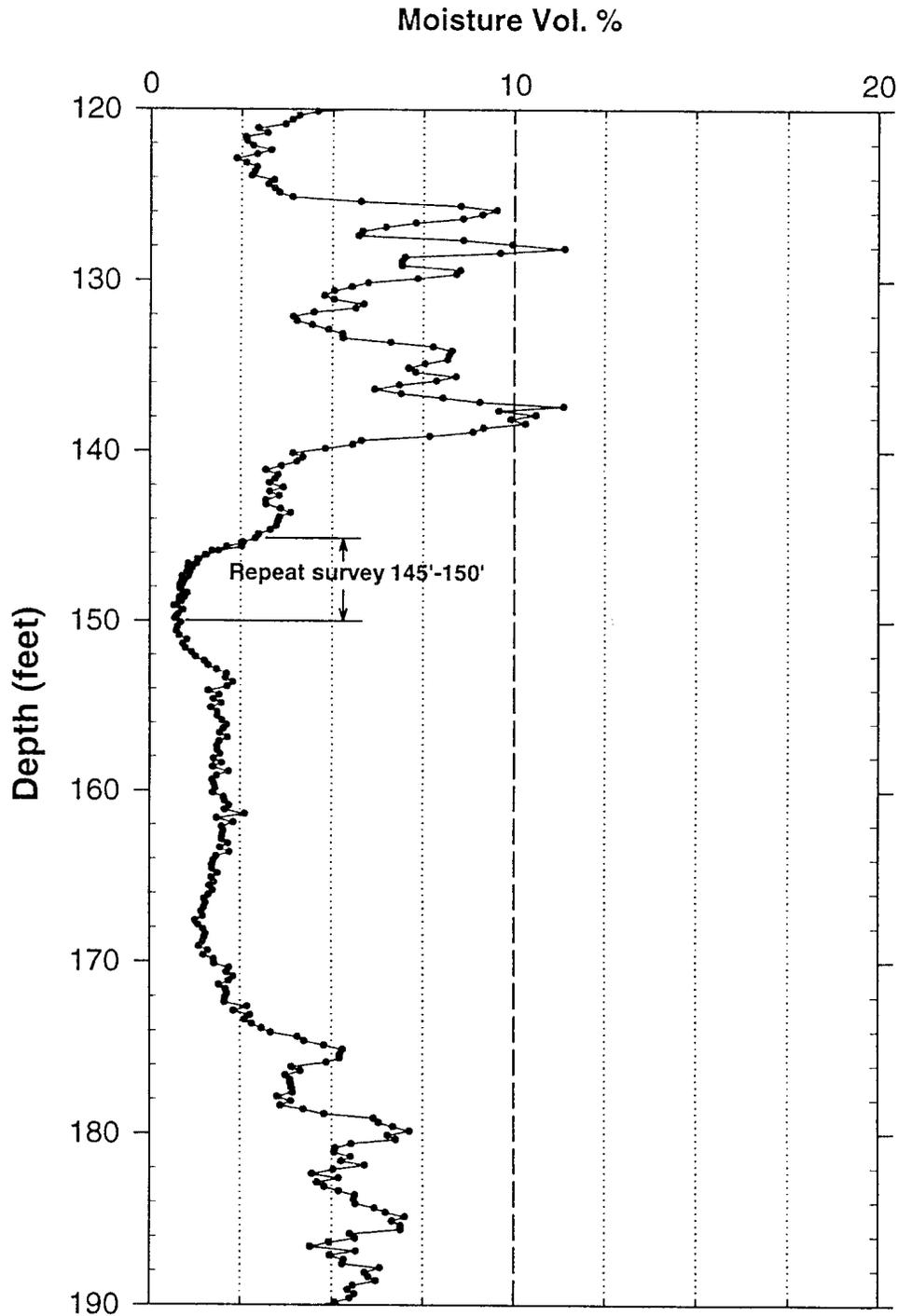
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date : November 30, 1999

Borehole: 299-W22-50

Depth Datum: Ground Level



Neutron-Neutron Moisture Survey

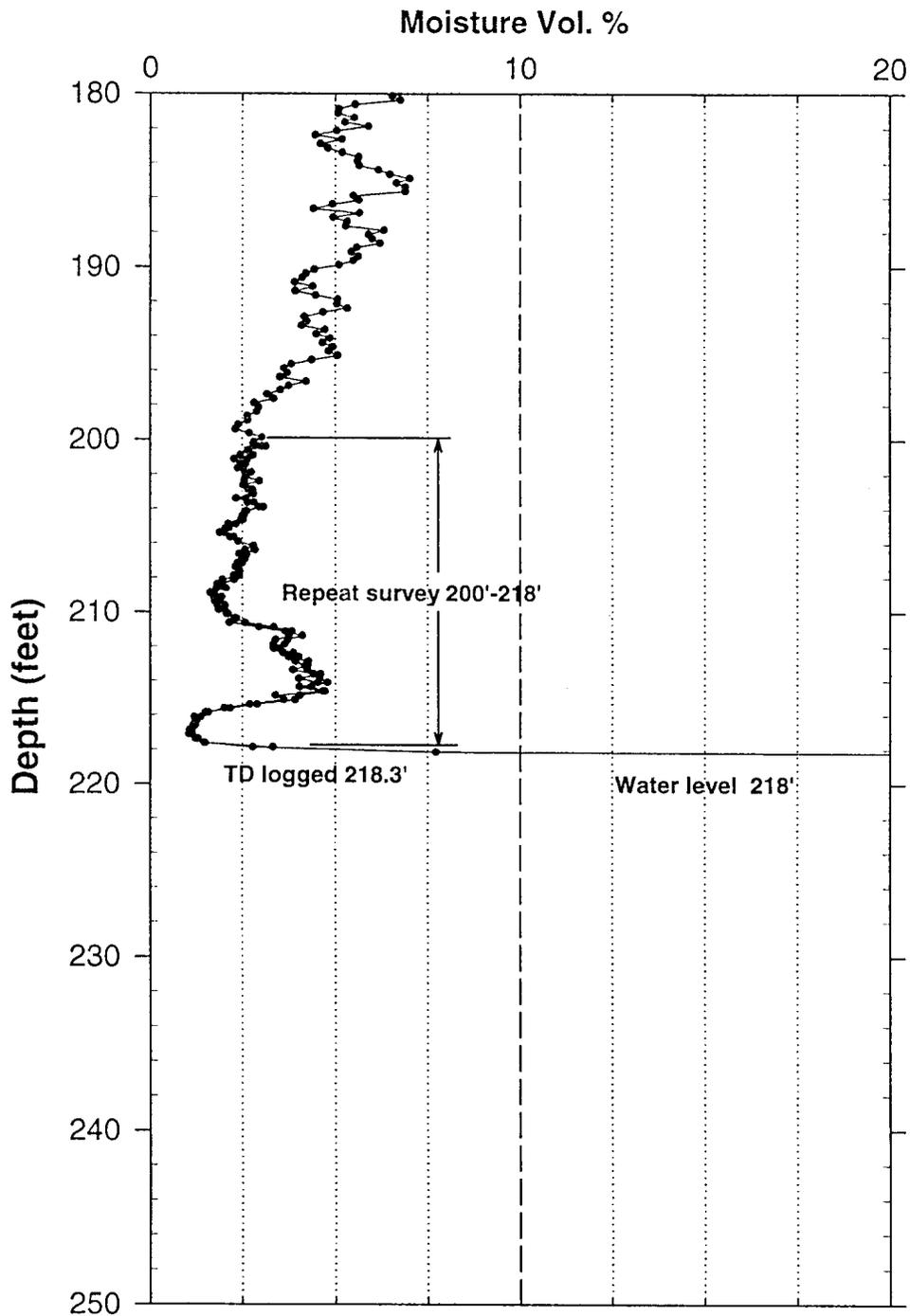
Waste Management Technical Services

Project: RCRA Drilling 1999

Log Date : November 8, 1999

Borehole: 299-W22-50

Depth Datum: Ground Level



Appendix D

Particle-Size Results from Seven Boreholes in Vicinity of the S-SX Tank Farm

Borehole	Sample Type	Depth (ft)	CaCO ₃ wt. %	Gravel		Sand					Mud	% Gravel	% Sand	% Mud	Sand:Mud		Hydrogeologic Unit
				Very Fine Pebble	Fine Pebble	Very Coarse	Coarse	Medium	Fine	Very Fine	Silt & Clay				Ratio	CLASS ^(a)	
				5	10	18	35	60	120	230	Pan						
				>4 mm	2-4 mm	1-2 mm	0.5-1.0 mm	0.25-0.5 mm	0.125-0.25 mm	0.0625-0.125 mm	<0.0625 mm						
299-W22-39		45		0.00%	0.00%	0.20%	6.53%	26.89%	48.39%	13.93%	4.06%	0.00%	95.94%	4.06%	23.7	S	H1a
		50		0.00%	0.35%	2.82%	8.65%	24.51%	32.93%	22.73%	8.03%	0.35%	91.62%	8.03%	11.4	S	H1a
		55		62.85%	5.15%	5.25%	5.51%	4.66%	10.40%	3.39%	2.80%	68.00%	29.21%	2.80%	10.4	sG	H1
		60		0.15%	0.24%	0.98%	9.27%	47.30%	22.80%	10.04%	9.21%	0.39%	90.39%	9.21%	9.8	S	H2
		65		0.44%	1.24%	7.03%	22.98%	32.55%	16.98%	12.83%	5.95%	1.68%	92.36%	5.95%	15.5	S	H2
299-W22-46		50		0.30%	0.34%	0.59%	0.92%	23.26%	40.84%	27.53%	6.21%	0.63%	93.15%	6.21%	15.0	S	H1a
		55		8.03%	13.56%	26.40%	25.01%	11.57%	9.70%	4.75%	0.97%	21.60%	77.43%	0.97%	79.8	gS	H1
		60		95.36%	1.91%	1.27%	0.43%	0.10%	0.80%	0.05%	0.08%	97.27%	2.64%	0.08%	32.0	G	H1
		65		94.51%	2.30%	1.81%	0.85%	0.22%	0.11%	0.08%	0.14%	96.80%	3.06%	0.14%	22.4	G	H1
		70		0.43%	0.04%	0.45%	0.23%	6.49%	56.83%	27.30%	8.22%	0.48%	91.30%	8.22%	11.1	S	H2
		75		0.00%	0.01%	0.17%	1.50%	25.23%	36.83%	28.56%	7.69%	0.01%	92.30%	7.69%	12.0	S	H2
299-W22-48	SS	37		0.20%	0.40%	0.60%	3.89%	13.83%	43.84%	29.54%	7.71%	0.60%	91.69%	7.71%	11.9	S	H1a
B8812	SS	39.5		0.02%	1.40%	0.74%	2.00%	25.21%	40.12%	21.73%	8.78%	1.42%	89.80%	8.78%	10.2	S	H1a
	SS	42-42.5			63.17%						36.83%	63.17%				sG	H1
	SS	44.5			63.26%						36.74%	63.26%				sG	H1
	SS	47		63.69%	9.69%	7.25%	6.53%	3.73%	2.91%	2.55%	3.64%	73.38%	22.98%	3.64%	6.3	msG	H1
	SS	50		18.51%	0.96%	2.45%	8.42%	40.00%	20.94%	4.89%	3.84%	19.46%	76.70%	3.84%	20.0	gS	H1
	SS	53.5		7.32%	13.90%	19.31%	34.85%	17.87%	4.15%	1.53%	1.07%	21.22%	77.71%	1.07%	72.7	gS	H1
	SS	56		4.35%	5.10%	16.32%	36.19%	24.03%	7.90%	3.58%	2.52%	9.46%	88.02%	2.52%	34.9	(g)S	H1
	SS	57.5		2.42%	0.54%	8.25%	37.56%	32.37%	9.20%	5.01%	4.66%	2.96%	92.39%	4.66%	19.8	S	H1
	SS	62		0.00%	0.29%	13.29%	43.59%	25.95%	7.55%	4.15%	5.19%	0.29%	94.52%	5.19%	18.2	S	H2
	SS	64.5		0.06%	0.00%	1.31%	31.13%	45.90%	11.85%	5.18%	4.56%	0.06%	95.38%	4.56%	20.9	S	H2
	SS	67		0.39%	0.59%	8.19%	25.40%	42.95%	12.43%	7.08%	2.95%	0.98%	96.06%	2.95%	32.5	S	H2
	SS	69.5		0.36%	1.21%	7.32%	39.39%	34.53%	8.84%	4.18%	4.17%	1.58%	94.26%	4.17%	22.6	S	H2
	SS	70		0.36%	0.61%	8.31%	43.13%	32.80%	8.73%	3.17%	2.89%	0.96%	96.15%	2.89%	33.3	S	H2
	SS	74.5		0.18%	1.56%	13.92%	6.86%	25.05%	25.78%	14.84%	11.81%	1.74%	86.46%	11.81%	7.3	(m)S	H2
	SS	77		0.00%	0.02%	0.15%	0.10%	1.56%	48.28%	39.67%	10.21%	0.02%	89.77%	10.21%	8.8	(m)S	H2
	SS	91.5		0.09%	0.30%	4.40%	24.23%	42.87%	15.11%	7.99%	5.00%	0.39%	94.60%	5.00%	18.9	S	H2

Borehole	Sample Type	Depth (ft)	CaCO ₃ wt. %	Gravel		Sand					Mud	% Gravel	% Sand	% Mud	Sand:Mud Ratio	CLASS ^(a)	Hydrogeologic Unit
				Very Fine Pebble	Very Fine Pebble	Very Coarse	Coarse	Medium	Fine	Very Fine	Silt & Clay						
				>4 mm	2-4 mm	1-2 mm	0.5-1.0 mm	0.25-0.5 mm	0.125-0.25 mm	0.0625-0.125 mm	<0.0625 mm						
	SS	101.5		0.00%	0.01%	0.35%	24.14%	47.54%	13.83%	12.25%	1.88%	0.01%	98.11%	1.88%	52.1	S	H2
	SS	136		0.01%	1.05%	0.27%	6.12%	4.00%	9.11%	40.88%	38.56%	1.06%	60.38%	38.56%	1.6	mS	PP
	SS	163.5		0.00%	0.03%	0.27%	13.84%	53.61%	20.11%	6.35%	5.79%	0.03%	94.18%	5.79%	16.3	S	Rwi(e)
299-W22-50 B8814	SS	47.5		0.00%	0.00%	0.28%	1.81%	11.66%	26.35%	37.76%	22.14%	0.00%	77.86%	22.14%	3.5	S	H1a
	SS	47.5		1.22%	4.16%	5.01%	4.66%	10.48%	39.04%	27.34%	8.09%	5.38%	86.53%	8.09%	10.7	(g)S	H1a
	SS	48.5		0.01%	0.00%	0.03%	0.76%	10.58%	35.82%	45.25%	7.55%	0.01%	92.45%	7.55%	12.3	S	H1a
	SS	50-51		0.20%	0.36%	0.84%	5.76%	31.29%	29.26%	22.97%	9.33%	0.56%	90.11%	9.33%	9.7	S	H1a
	SS	51		0.01%	0.23%	0.64%	3.03%	23.34%	29.43%	34.38%	8.95%	0.23%	90.81%	8.95%	10.1	S	H1a
	SS	52.5		1.34%	3.48%	14.12%	25.98%	23.20%	17.35%	9.90%	4.63%	4.82%	90.55%	4.63%	19.6	S	H1a
	SS	53.5-53.5-		0.43%	5.63%	28.21%	45.22%	13.56%	3.28%	1.82%	1.85%	6.06%	92.09%	1.85%	49.7	(g)S	H1
	SS	54.5		0.48%	3.46%	28.40%	50.45%	12.90%	2.81%	1.49%	0.00%	3.95%	96.05%	0.00%	96052.4	S	H1
	SS	56		4.02%	6.67%	0.52%	62.35%	12.37%	5.98%	4.12%	3.97%	10.69%	85.34%	3.97%	21.5	gS	H1
	SS	57		1.38%	3.17%	24.29%	41.55%	16.67%	7.49%	3.95%	1.50%	4.55%	93.95%	1.50%	62.5	S	H1
	SS	58		37.16%	11.46%	16.45%	19.19%	8.36%	3.18%	2.21%	2.00%	48.62%	49.38%	2.00%	24.6	sG	H1
	SS	60		81.68%	4.95%	4.36%	3.37%	2.14%	1.14%	1.04%	1.33%	86.63%	12.04%	1.33%	9.0	G	H1
	SS	61		33.76%	17.15%	14.50%	13.81%	9.58%	4.50%	3.29%	3.42%	50.91%	45.67%	3.42%	13.4	sG	H1
	SS	62.5		0.07%	0.92%	4.81%	26.29%	46.08%	13.88%	4.93%	3.01%	0.99%	96.00%	3.01%	31.9	S	H2
	SS	63.5		0.94%	0.76%	6.54%	38.28%	41.57%	8.17%	2.19%	1.55%	1.70%	96.74%	1.55%	62.2	S	H2
	SS	65		0.00%	0.26%	2.44%	21.41%	45.41%	18.51%	6.74%	5.23%	0.26%	94.51%	5.23%	18.1	S	H2
	SS	66		0.30%	1.05%	3.15%	14.22%	40.04%	29.71%	9.56%	1.97%	1.34%	96.69%	1.97%	49.1	S	H2
SS	68.5		0.00%	0.00%	0.01%	0.02%	2.58%	52.17%	37.44%	7.77%	0.00%	92.23%	7.77%	11.9	S	H2	
SS	70-71		1.00%	1.28%	1.04%	1.79%	17.03%	51.16%	21.19%	5.50%	2.28%	92.22%	5.50%	16.8	S	H2	
299-W23-14		65	0.8%	0.01%	0.01%	0.03%	0.38%	3.46%	36.02%	44.16%	15.93%	0.02%	84.05%	15.93%	5.3	(m)S	H1a
		70	0.9%	0.00%	0.06%	0.24%	0.51%	10.86%	39.81%	38.68%	9.84%	0.06%	90.10%	9.84%	9.2	S	H1a
		75	0.5%	0.01%	0.13%	1.64%	8.88%	40.81%	37.75%	8.07%	2.71%	0.13%	97.15%	2.71%	35.8	S	H1a
		81	1.0%	0.07%	0.26%	1.77%	8.97%	12.97%	31.29%	21.95%	22.74%	0.32%	76.94%	22.74%	3.4	mS	H1a
		85	0.5%	2.39%	8.99%	23.99%	16.58%	8.61%	16.46%	15.76%	7.21%	11.38%	81.41%	7.21%	11.3	gS	H1

Borehole	Sample Type	Depth (ft)	CaCO ₃ wt. %	Gravel		Sand					Mud	% Gravel	% Sand	% Mud	Sand:Mud		Hydrogeologic Unit								
				Very Fine Pebble	Fine Pebble	Very Coarse	Coarse	Medium	Fine	Very Fine	Silt & Clay				Ratio	CLASS ^(a)									
																		5	10	18	35	60	120	230	Pan
																		>4 mm	2-4 mm	1-2 mm	0.5-1.0 mm	0.25-0.5 mm	0.125-0.25 mm	0.0625-0.125 mm	
		90	0.3%	18.39%	22.33%	33.34%	16.41%	5.39%	1.89%	1.11%	1.13%	40.73%	58.15%	1.13%	51.7	sG	H1								
		95	0.5%	12.09%	16.22%	34.27%	21.89%	7.35%	4.15%	2.52%	1.53%	28.30%	70.17%	1.53%	46.0	gS	H1								
		101	0.9%	0.06%	0.00%	0.05%	1.37%	9.82%	38.48%	36.84%	13.39%	0.06%	86.55%	13.39%	6.5	(m)S	H2								
		105	1.7%	0.02%	0.02%	0.05%	0.37%	9.03%	34.81%	17.87%	37.84%	0.03%	62.13%	37.84%	1.6	mS	H2								
		111	2.0%	0.00%	0.01%	0.26%	1.00%	4.01%	20.35%	55.21%	19.15%	0.01%	80.84%	19.15%	4.2	(m)S	H2								
299-W23-15		50	0.6%	0.77%	0.61%	1.72%	8.48%	49.50%	22.83%	9.16%	6.94%	1.38%	91.68%	6.94%	13.2	S	H1a								
		55	0.4%	0.01%	0.09%	0.62%	2.80%	17.43%	37.94%	29.21%	11.91%	0.10%	88.00%	11.91%	7.4	(m)S	H1a								
		60		0.07%	0.44%	6.89%	36.38%	30.10%	17.81%	4.57%	3.74%	0.51%	95.75%	3.74%	25.6	S	H1								
		65		31.27%	6.27%	16.52%	21.33%	10.81%	5.09%	3.55%	5.16%	37.54%	57.30%	5.16%	11.1	sG	H1								
		70		16.44%	7.15%	19.46%	19.16%	13.52%	9.66%	9.14%	5.48%	23.59%	70.93%	5.48%	12.9	gS	H1								
		75	0.4%	5.17%	9.46%	26.48%	23.42%	11.91%	8.52%	11.84%	3.20%	14.63%	82.17%	3.20%	25.7	gS	H1								
		80	0.4%	0.00%	0.03%	0.00%	10.33%	31.59%	26.53%	21.31%	10.20%	0.03%	89.77%	10.20%	8.8	(m)S	H2								
		85	0.6%	0.00%	0.42%	1.58%	9.22%	28.93%	22.20%	24.22%	13.43%	0.42%	86.15%	13.43%	6.4	(m)S	H2								
299-W23-19	SS	72-72.5		0.00%	0.14%	1.94%	19.79%	46.48%	18.92%	9.13%	3.60%	0.14%	96.27%	3.60%	26.8	S	H1a								
B8809	SS	72.5-73		1.50%	0.65%	5.39%	32.79%	40.70%	12.14%	4.28%	2.54%	2.15%	95.31%	2.54%	37.5	S	H1a								
	SS	73-73.5		1.38%	0.61%	5.45%	34.81%	32.68%	11.49%	8.08%	5.49%	1.99%	92.52%	5.49%	16.8	S	H1a								
	SS	73.5-74		0.00%	0.30%	1.01%	3.88%	10.14%	34.37%	32.32%	17.98%	0.30%	81.72%	17.98%	4.5	(m)S	H1a								
	SS	74-74.5		0.00%	0.10%	0.95%	3.12%	8.83%	27.18%	36.67%	23.14%	0.10%	76.76%	23.14%	3.3	mS	H1a								
	SS	74.5-75		0.00%	0.01%	0.55%	2.66%	13.15%	27.90%	34.82%	20.90%	0.01%	79.09%	20.90%	3.8	mS	H1a								
	SS	75-75.5		0.00%	0.25%	1.43%	7.87%	28.16%	31.73%	20.33%	10.22%	0.25%	89.52%	10.22%	8.8	(m)S	H1a								
	SS	75.5-76		0.43%	2.17%	9.80%	34.37%	36.75%	8.78%	4.16%	3.55%	2.60%	93.85%	3.55%	26.5	S	H1a								
	SS	76-76.5		0.00%	0.92%	6.60%	41.05%	35.33%	7.71%	4.38%	4.00%	0.92%	95.07%	4.00%	23.8	S	H1a								
	SS	78.5-79		0.51%	1.26%	7.57%	15.32%	28.85%	27.37%	12.19%	6.93%	1.77%	91.31%	6.93%	13.2	S	H1								
	SS	78-78.5		15.63%	14.24%	20.03%	19.98%	12.51%	8.10%	5.65%	3.85%	29.88%	66.28%	3.85%	17.2	gS	H1								
	SS	79-79.5		0.00%	0.70%	3.63%	6.62%	11.07%	28.16%	32.42%	17.40%	0.70%	81.90%	17.40%	4.7	(m)S	H1								
	SS	79.5-80		0.00%	2.37%	4.13%	5.06%	5.74%	32.30%	37.05%	13.36%	2.37%	84.27%	13.36%	6.3	(m)S	H1								
	SS	80-80.5		0.00%	0.13%	0.58%	1.01%	4.76%	19.18%	51.99%	22.34%	0.13%	77.53%	22.34%	3.5	mS	H1								
	SS	81.5-		18.20%	6.41%	20.39%	31.35%	15.42%	4.09%	2.01%	2.14%	24.61%	73.25%	2.14%	34.2	gS	H1								

Borehole	Sample Type	Depth (ft)	CaCO ₃ wt. %	Gravel		Sand					Mud	% Gravel	% Sand	% Mud	Sand:Mud Ratio	CLASS ^(a)	Hydrogeologic Unit
				Fine Pebble	Very Fine Pebble	Very Coarse	Coarse	Medium	Fine	Very Fine	Silt & Clay						
				5 >4 mm	10 2-4 mm	18 1-2 mm	35 0.5-1.0 mm	60 0.25-0.5 mm	120 0.125-0.25 mm	230 0.0625-0.125 mm	Pan <0.0625 mm						
		82.5-															
	SS	82.5-83.5		43.22%	11.18%	15.03%	14.85%	9.67%	3.29%	1.51%	1.24%	54.40%	44.36%	1.24%	35.8	sG	H1
	SS	83.5-84.5		4.76%	9.89%	25.35%	32.66%	17.65%	4.55%	2.42%	2.71%	14.65%	82.64%	2.71%	30.5	gS	H1
	SS	84.5-85.5		7.07%	13.74%	33.04%	29.62%	9.03%	3.00%	1.94%	2.55%	20.82%	76.63%	2.55%	30.0	gS	H1
	SS	85.5-86.6		18.29%	11.03%	25.59%	29.77%	8.69%	2.80%	1.69%	2.15%	29.32%	68.53%	2.15%	31.9	gS	H1
	SS	86.6-87.6		23.23%	5.23%	11.54%	16.58%	11.17%	15.54%	11.53%	5.02%	28.47%	66.35%	5.02%	13.2	gS	H1
	SS	87.6-88.6		0.00%	0.11%	0.10%	0.56%	2.91%	20.35%	56.16%	19.80%	0.11%	80.08%	19.80%	4.0	(m)S	H2
	SS	88.6-89.6		0.00%	0.02%	0.09%	4.73%	48.59%	25.40%	14.05%	7.13%	0.02%	92.86%	7.13%	13.0	S	H2
	SS	89.6-90.6		0.00%	0.03%	0.06%	0.90%	21.81%	43.78%	23.65%	9.76%	0.03%	90.21%	9.76%	9.2	S	H2
	SS	90.6-91.6		0.00%	0.00%	0.05%	0.33%	32.22%	45.68%	13.94%	7.78%	0.00%	92.22%	7.78%	11.9	S	H2
	SS	91.6-92.5		2.62%	0.73%	3.29%	5.76%	14.05%	30.81%	33.81%	8.93%	3.35%	87.72%	8.93%	9.8	S	H2
	SS	92.5-93.5		0.00%	0.45%	1.40%	4.94%	16.67%	33.04%	32.33%	11.17%	0.45%	88.38%	11.17%	7.9	(m)S	H2
	SS	93.5-94.5		0.00%	0.00%	0.01%	0.29%	1.02%	13.13%	63.23%	22.32%	0.00%	77.68%	22.32%	3.5	mS	H2
	SS	94.5-95.6		13.78%	0.22%	0.21%	2.74%	25.02%	29.20%	21.85%	6.79%	13.99%	79.03%	6.79%	11.6	gS	H2
	SS	95.6-96.6		0.00%	0.00%	0.11%	1.74%	21.65%	38.58%	30.87%	7.04%	0.00%	92.96%	7.04%	13.2	S	H2
	SS	96.6-97.6		0.00%	0.01%	0.10%	1.53%	22.71%	33.59%	34.64%	7.43%	0.01%	92.56%	7.43%	12.5	S	H2
	SS	97.6-98.6		0.00%	0.02%	0.24%	1.20%	21.75%	36.34%	32.58%	7.88%	0.02%	92.10%	7.88%	11.7	S	H2
	SS	98.6-99.6		0.00%	0.04%	1.18%	2.60%	14.90%	28.12%	33.08%	20.09%	0.04%	79.87%	20.09%	4.0	(m)S	H2

(a) Folk-Wentworth classification.

CB = Core Barrel

HT = Hard tool

SS = Splitspoon

Appendix E

Inventory of Core Sleeves from Borehole 299-W22-48

BOREHOLE B8812 SAMPLE INVENTORY

STORAGE LOCATION IN BLDG 3720/rm 608

SAMPLE #	Depth (ft)	Container
B8812-0.5	0.5-1	6" Liner
B8812-1	1-1.5	6" Liner
B8812-1.5	1.5-2	6" Liner
B8812-3	3-3.5	6" Liner
B8812-3.5	3.5-4	6" Liner
B8812-4	4-4.5	6" Liner
B8812-4.5	4.5-5	6" Liner
B8812-5.5	5.5-6	6" Liner
B8812-6	6-6.5	6" Liner
B8812-6.5	6.5-7	6" Liner
B8812-7	7-7.5	6" Liner
B8812-8	8-8.5	6" Liner
B8812-8.5	8.5-9	6" Liner
B8812-9	9-9.5	6" Liner
B8812-9.5	9.5-10	6" Liner
B8812-10.5	10.5-11	6" Liner
B8812-11	11-11.5	6" Liner
B8812-11.5	11.5-12	6" Liner
B8812-12	12-12.5	6" Liner
B8812-13	13-13.5	6" Liner
B8812-13.5	13.5-14	6" Liner
B8812-14	14-14.5	6" Liner
B8812-14.5	14.5-15	6" Liner
B8812-15.5	15.5-16	6" Liner
B8812-16	16-16.5	6" Liner
B8812-16.5	16.5-17	6" Liner
B8812-17	17-17.5	6" Liner
B8812-18	18-18.5	6" Liner
B8812-18.5	18.5-19	6" Liner
B8812-19	19-19.5	6" Liner
B8812-19.5	19.5-20	6" Liner
B8812-20.5	20.5-21	6" Liner

SAMPLE #	Depth (ft)	Container
B8812-49	49-49.5	6" Liner
B8812-49.5	49.5-50	6" Liner
B8812-50	50-50.5	6" Liner
B8812-51	51-51.5	6" Liner
B8812-51.5	51.5-52	6" Liner
B8812-52	52-52.5	6" Liner
B8812-52.5	52.5-53	6" Liner
B8812-53.5	53.5-54	6" Liner
B8812-54	54-54.5	6" Liner
B8812-54.5	54.5-55	6" Liner
B8812-55	55-55.5	6" Liner
B8812-56	56-56.5	6" Liner
B8812-56.5	56.5-57	6" Liner
B8812-57	57-57.5	6" Liner
B8812-57.5	57.5-58	6" Liner
B8812-58.5	58.8-59	6" Liner
B8812-60.5	60.5-61	6" Liner
B8812-61	61-61.5	6" Liner
B8812-61.5	61.5-62	6" Liner
B8812-62	62-62.5	6" Liner
B8812-63	63-63.5	6" Liner
B8812-63.5	63.5-64	6" Liner
B8812-64	64-64.5	6" Liner
B8812-64.5	64.5-65	6" Liner
B8812-65.5	65.5-66	6" Liner
B8812-66	66-66.5	6" Liner
B8812-66.5	66.5-67	6" Liner
B8812-67	67-67.5	6" Liner
B8812-68	68-68.5	6" Liner
B8812-68.5	68.5-69	6" Liner
B8812-69	69-69.5	6" Liner
B8812-69.5	69.5-70	6" Liner

SAMPLE #	Depth (ft)	Container
B8812-110.5	110.5-111.5	12" Liner
B8812-111.5	111.5-112.5	12" Liner
B8812-113	113-114	12" Liner
B8812-114	114-115	12" Liner
B8812-115.5	115.5-116.5	12" Liner
B8812-116.5	116.5-117.5	12" Liner
B8812-118	118-119	12" Liner
B8812-119	119-120	12" Liner
B8812-120.5	120.5-121.5	12" Liner
B8812-121.5	121.5-122.5	12" Liner
B8812-123	123-124	12" Liner
B8812-124	124-125	12" Liner
B8812-125.5	125.5-126.5	12" Liner
B8812-126.5	126.5-127.5	12" Liner
B8812-128	128-129	12" Liner
B8812-129	129-130	12" Liner
B8812-130.5	130.5-131.5	12" Liner
B8812-131.5	131.5-132.5	12" Liner
B8812-133	133-134	12" Liner
B8812-134	134-135	12" Liner
B8812-135	135-136	12" Liner
B8812-136	136-137	12" Liner
B8812-137.5	137.5-138.5	12" Liner
B8812-138.5	138.5-139.5	12" Liner
B8812-140	140-141	12" Liner
B8812-141	141-142	12" Liner
B8812-142.5	142.5-143.5	12" Liner
B8812-143.5	143.5-144.5	12" Liner
B8812-145	145-146	12" Liner
B8812-146	146-147	12" Liner
B8812-147.5	147.5-148.5	12" Liner
B8812-148.5	148.5-149.5	12" Liner

E.1

BOREHOLE B8812 SAMPLE INVENTORY

STORAGE LOCATION IN BLDG 3720/rm 608

B8812-21	21-21.5	6" Liner
B8812-21.5	21.5-22	6" Liner
B8812-22	22-22.5	6" Liner
B8812-23	23-23.5	6" Liner
B8812-23.5	23.5-24	6" Liner
B8812-24	24-24.5	6" Liner
B8812-24.5	24.5-25	6" Liner
B8812-25.5	25.5-26	6" Liner
B8812-26	26-26.5	6" Liner
B8812-26.5	26.5-27	6" Liner
B8812-27	27-27.5	6" Liner
B8812-28	28-28.5	6" Liner
B8812-28.5	28.5-29	6" Liner
B8812-29	29-29.5	6" Liner
B8812-29.5	29.5-30	6" Liner
B8812-30.5	30.5-31	6" Liner
B8812-31	31-31.5	6" Liner
B8812-31.5	31.5-32	6" Liner
B8812-32	32-32.5	6" Liner
B8812-33	33-33.5	6" Liner
B8812-33.5	33.5-34	6" Liner
B8812-34	34-34.5	6" Liner
B8812-34.5	34.5-35	6" Liner
B8812-35.5	35.5-36	6" Liner
B8812-36	36-36.5	6" Liner
B8812-36.5	36.5-37	6" Liner
B8812-37	37-37.5	6" Liner
B8812-38	38-38.5	6" Liner
B8812-38.5	38.5-39	6" Liner
B8812-39	39-39.5	6" Liner
B8812-39.5	39.5-40	6" Liner
B8812-40.5	40.5-41	6" Liner
B8812-41	41-41.5	6" Liner

B8812-70.5	70.5-71	6" Liner
B8812-71	71-71.5	6" Liner
B8812-71.5	71.5-72	6" Liner
B8812-72	72-72.5	6" Liner
B8812-73	73-73.5	6" Liner
B8812-73.5	73.5-74	6" Liner
B8812-74	74-74.5	6" Liner
B8812-74.5	74.5-76	6" Liner
B8812-75.5	75.5-76	6" Liner
B8812-76	76-76.5	6" Liner
B8812-76.5	76.5-77	6" Liner
B8812-77	77-77.5	6" Liner
B8812-78	78-78.5	6" Liner
B8812-78.5	78.5-79	6" Liner
B8812-79	79-79.5	6" Liner
B8812-79.5	79.5-80	6" Liner
B8812-80.5	80.5-81	6" Liner
B8812-81	81-81.5	6" Liner
B8812-81.5	81.5-82	6" Liner
B8812-82	82-82.5	6" Liner
B8812-83	83-83.5	6" Liner
B8812-83.5	83.5-84	6" Liner
B8812-84	84-84.5	6" Liner
B8812-84.5	84.5-85	6" Liner
B8812-85.5	85.5-86.5	12" Liner
B8812-86.5	86.5-87.5	12" Liner
B8812-88	88-89	12" Liner
B8812-89	89-90	12" Liner
B8812-90.5	90.5-91.5	12" Liner
B8812-91.5	91.5-92.5	12" Liner
B8812-93	93-94	12" Liner
B8812-94	94-95	12" Liner
B8812-95.5	95.5-96.5	12" Liner

B8812-150	150-151	12" Liner
B8812-151	151-152	12" Liner
B8812-152.5	152.5-153.5	12" Liner
B8812-153.5	153.5-154.5	12" Liner
B8812-155	155-156	12" Liner
B8812-154	156-157	12" Liner
B8812-157.5	157.5-158.5	12" Liner
B8812-158.5	158.5-159	12" Liner
B8812-160	160-161	12" Liner
B8812-161	161-162	12" Liner
B8812-162.5	162.5-163.5	12" Liner
B8812-163.5	163.5-164.5	12" Liner
B8812-165	165-166	12" Liner
B8812-166	166-167	12" Liner
B8812-167.5	167.5-168.5	12" Liner
B8812-168.5	168.5-169.5	12" Liner
B8812-170	170-171	12" Liner
B8812-171	171-172	12" Liner
B8812-172.5	172.5-173.5	12" Liner
B8812-173.5	173.5-174	12" Liner
B8812-175	175-176	12" Liner
B8812-176	176-177	12" Liner
B8812-177.5	177.5-178.5	12" Liner
B8812-178.5	178.5-179.5	12" Liner
B8812-181	181-182	12" Liner
B8812-182	182-183	12" Liner
B8812-183.5	183.5-184.5	12" Liner
B8812-184.5	184.5-185.5	12" Liner
B8812-186	186-187	12" Liner
B8812-187	187-188	12" Liner
B8812-188.5	188.5-189.5	12" Liner
B8812-189.5	189.5-190.5	12" Liner
B8812-192	192-193	12" Liner

BOREHOLE B8812 SAMPLE INVENTORY

STORAGE LOCATION IN BLDG 3720/rm 608

B8812-41.5	41.5-42	6" Liner
B8812-42	42-42.5	6" Liner
B8812-43	43-43.5	6" Liner
B8812-43.5	43.5-44	6" Liner
B8812-44	44-44.5	6" Liner
B8812-44.5	44.5-45	6" Liner
B8812-46	46-46.5	6" Liner
B8812-46.5	46.5-47	6" Liner
B8812-47	47-47.5	6" Liner
B8812-47.5	47.5-48	6" Liner
B8812-48.5	48.5-49	6" Liner

B8812-96.5	96.5-97.5	12" Liner
B8812-98	98-99	12" Liner
B8812-99	99-100	12" Liner
B8812-100.5	100.5-101.5	12" Liner
B8812-101.5	101.5-102.5	12" Liner
B8812-103	103-104	12" Liner
B8812-104	104-105	12" Liner
B8812-105.5	105.5-106.5	12" Liner
B8812-106.5	106.5-107.5	12" Liner
B8812-108	108-109	12" Liner
B8812-109	109-110	12" Liner

B8812-195	195-196	2-1 gal. plastic
B8812-200	200-201	2-1 gal. plastic
B8812-205	205	2-1 gal. plastic
B8812-210	210	2-1 gal. plastic
B8812-215	215	2-1 gal. plastic
B8812-220	220	2-1 gal. plastic
B8812-225	225-226	3-1 gal. plastic
B8812-230	230	2-1 gal. plastic
B8812-235	235-236	12" Liner
B8812-241	241-242	12" Liner

Appendix F

Inventory of Core Sleeves from Borehole 299-W22-50

BOREHOLE B8814 SAMPLE INVENTORY

STORAGE LOCATION IN BLDG 3720
299 W-22-50

SAMPLE #	Depth (ft)	Container
B8814-20	20.0 - 21.0	12" liner
B8814-21	21.0 - 22.0	12" liner
B8814-22.5	22.5 - 23.5	12" liner
B8814-23.5	23.5 - 24.5	12" liner
B8814-25	25.0 - 26.0	12" liner
B8814-26	26.0 - 27.0	12" liner
B8814-27.5	27.5 - 28.5	12" liner
B8814-28.5	28.5 - 29.5	12" liner
B8814-30.0	30.0 - 31.0	12" liner
B8814-31	31.0 - 32.0	12" liner
B8814-32.5	32.5 - 33.5	12" liner
B8814-33.5	33.5 - 34.5	12" liner
B8814-35.0	35.0 - 36.0	12" liner
B8814-36	36.0 - 37.0	12" liner
B8814-37.5	37.5 - 38.5	12" liner
B8814-38.5	38.5 - 39.5	12" liner
B8814-40.0	40.0 - 41.0	12" liner
B8814-41	41.0 - 42.0	12" liner
B8814-42.5	42.5 - 43.5	12" liner
B8814-43.5	43.5 - 44.5	12" liner
B8814-45.0	45.0 - 46.0	12" liner
B8814-46.0	46.0 - 47.0	12" liner
B8814-47.5	47.5 - 48.5	12" liner
B8814-48.5	48.5 - 49.5	12" liner
B8814-50.0	50.0 - 51.0	12" liner
B8814-51.0	51.0 - 52.0	12" liner
B8814-52.5	52.5 - 53.5	12" liner
B8814-53.5	53.5 - 54.5	12" liner
B8814-55.0	55.0 - 56.0	12" liner
B8814-56.0	56.0 - 57.0	12" liner
B8814-57.0	57.0 - 58.0	12" liner
B8814-58.0	58.0 - 59.0	12" liner

SAMPLE #	Depth (ft)	Container
B8814-102.5	102.5 - 103.5	12" liner
B8814-103.5	103.5 - 104.5	12" liner
B8814-105.0	105.0 - 106.0	12" liner
B8814-106.0	106.0 - 107.0	12" liner
B8814-107.5	107.5 - 108.5	12" liner
B8814-108.5	108.5 - 109.5	12" liner
B8814-110.0	110.0 - 111.0	12" liner
B8814-111.0	111.0 - 112.0	12" liner
B8814-112.5	112.5 - 113.5	12" liner
B8814-113.5	113.5 - 114.5	12" liner
B8814-115.0	115.0 - 116.0	12" liner
B8814-116.0	116.0 - 117.0	12" liner
B8814-117.5	117.5 - 118.5	12" liner
B8814-118.5	118.5 - 119.5	12" liner
B8814-120.0	120.0 - 121.0	12" liner
B8814-121.0	121.0 - 122.0	12" liner
B8814-122.5	122.5 - 123.5	12" liner
B8814-123.5	123.5 - 124.5	12" liner
B8814-125.0	125.0 - 126.0	12" liner
B8814-126.0	126.0 - 127.0	12" liner
B8814-127.5	127.5 - 128.5	12" liner
B8814-128.5	128.5 - 129.5	12" liner
B8814-130.0	130.0 - 131.0	12" liner
B8814-131.0	131.0 - 132.0	12" liner
B8814-132.5	132.5 - 133.5	12" liner
B8814-133.5	133.5 - 134.5	12" liner
B8814-135.0	135.0 - 136.0	12" liner
B8814-136.0	136.0 - 137.0	12" liner
B8814-137.5	137.5 - 138.5	12" liner
B8814-138.5	138.5 - 139.5	12" liner
B8814-140.0	140.0 - 141.0	12" liner
B8814-141.0	141.0 - 142.0	12" liner

SAMPLE #	Depth (ft)	Container
B8814-230	230	2-1 pt. glass
B8814-232.5	232.5-233.5	12" liner
B8814-235	235	2-1 pt. glass
B8814-240	240	2-1 pt. glass
B8814-245	245	2-1qt. glass
B8814-250	250	2-1qt. glass
B8814-255	255	2-1qt. glass
B8814-260	260	2-1qt. glass
B8814-265	265	2-1qt. glass
B8814-270	270	2-1qt. glass
B8814-275	275	2-1 pt. glass
B8814-280	280	2-1 pt. glass
B8814-285	285	2-1 pt. glass
B8814-290	290	2-1 pt. glass
B8814-295	295	2-1 pt. glass
B8814-300	300	2-1 pt. glass
B8814-305	305	2-1 pt. glass
B8814-310	310	2-1 pt. glass
B8814-315	315	2-1 pt. glass
B8814-320	320	2-1 pt. glass
B8814-325	325	2-1qt. glass
B8814-330	330	2-1qt. glass
B8814-335	335	4-1qt. glass
B8814-340	340	2-1qt. glass
B8814-345	345	2-1qt. glass
B8814-350	350	1 pt & 1qt glass
B8814-355	355	2-1qt. glass
B8814-360	360	2-1qt. glass
B8814-365	365	2-1qt. glass
B8814-370	370	2-1qt. glass
B8814-375	375	2-1qt. glass
B8814-380	380	2-1qt. glass

BOREHOLE B8814 SAMPLE INVENTORY

STORAGE LOCATION IN BLDG 3720
299 W-22-50

F.2

SAMPLE #	Depth (ft)	Container
B8814-60.0	60.0 - 61.0	12" liner
B8814-61.0	61.0 - 62.0	12" liner
B8814-62.5	62.5 - 63.5	12" liner
B8814-63.5	63.5 - 64.5	12" liner
B8814-65.0	65.0 - 66.0	12" liner
B8814-66.0	66.0 - 67.0	12" liner
B8814-67.5	67.5 - 68.5	12" liner
B8814-68.5	68.5 - 69.5	12" liner
B8814-70	70.0 - 71.0	12" liner
B8814-71	71.0 - 72.0	12" liner
B8814-72.5	72.5 - 73.5	12" liner
B8814-73.5	73.5 - 74.5	12" liner
B8814-75.0	75.0 - 76.0	12" liner
B8814-76.0	76.0 - 77.0	12" liner
B8814-77.5	77.5 - 78.5	12" liner
B8814-78.5	78.5 - 79.5	12" liner
B8814-80.0	80.0 - 81.0	12" liner
B8814-81.0	81.0 - 82.0	12" liner
B8814-82.5	82.5 - 83.5	12" liner
B8814-83.5	83.5 - 84.5	12" liner
B8814-85.0	85.0 - 86.0	12" liner
B8814-86.0	86.0 - 87.0	12" liner
B8814-87.5	87.5 - 88.5	12" liner
B8814-88.5	88.5 - 89.5	12" liner
B8814-90.0	90.0 - 91.0	12" liner
B8814-91.0	91.0 - 92.0	12" liner
B8814-92.5	92.5 - 93.5	12" liner
B8814-93.5	93.5 - 94.5	12" liner
B8814-95.0	95.0 - 96.0	12" liner
B8814-96.0	96.0 - 97.0	12" liner
B8814-97.5	97.5 - 98.5	12" liner
B8814-98.5	98.5 - 99.5	12" liner

SAMPLE #	Depth (ft)	Container
B8814-142.5	142.5 - 143.5	12" liner
B8814-143.5	143.5 - 144.5	12" liner
B8814-148.0	148.0 - 149.0	12" liner
B8814-149.0	149.0 - 150.0	12" liner
B8814-150.5	150.5 - 151.5	12" liner
B8814-151.5	151.5 - 152.5	12" liner
B8814-153.0	153.0 - 154.0	12" liner
B8814-154.0	154.0 - 155.0	12" liner
B8814-155.5	155.5 - 156.5	12" liner
B8814-156.5	156.5 - 157.5	12" liner
B8814-158.0	158.0 - 159.0	12" liner
B8814-159.0	159.0 - 160.0	12" liner
B8814-160.5	160.5 - 161.5	12" liner
B8814-161.5	161.5 - 162.5	12" liner
B8814-163.0	163.0 - 164.0	12" liner
B8814-164.0	164.0 - 165.0	12" liner
B8814-165.5	165.5 - 166.5	12" liner
B8814-166.5	166.5 - 167.5	12" liner
B8814-168.0	168.0 - 169.0	12" liner
B8814-169.0	169.0 - 170.0	12" liner
B8814-170.5	170.5 - 171.5	12" liner
B8814-171.5	171.5 - 172.5	12" liner
B8814-173.0	173.0 - 174.0	12" liner
B8814-174.0	174.0 - 175.0	12" liner
B8814-175.5	175.5 - 176.5	12" liner
B8814-176.5	176.5 - 177.0	12" liner
B8814-210	210	2-1 pt. glass
B8814-215	215	2-1 pt. glass
B8814-215	215	2-1 gal.plastic
B8814-220	220	2-1 gal.plastic
B8814-220	220	2-1 pt. glass
B8814-221.5	221.5-222.5	12" liner

SAMPLE #	Depth (ft)	Container
B8814-385	385	2-1qt. glass
B8814-390	390	2-1qt. glass
B8814-395	395	2-1qt. glass
B8814-400	400	2-1qt. glass
B8814-405	405	2-1qt. glass
B8814-410	410	2-1qt. glass
B8814-415	415	2-1qt. glass
B8814-420	420	2-1qt. glass
B8814-425	425	2-1qt. glass
B8814-430	430	2-1qt. glass
B8814-435	435	2-1qt. glass
B8814-440	440	2-1qt. glass
B8814-445	445	2-1qt. glass
B8814-450	450	2-1qt. glass
B8814-455	455	2-1qt. glass
B8814-459	459-460	12" liner
B8814-460	460	2-1qt. glass
B8814-465	465	2-1qt. glass
B8814-475	475	2-1qt. glass
B8814-490	490	1 pt. glass
B8814-500	500	3-1 pt. glass
B8814-505	505	3-1 pt. glass
B8814-510	510	3-1 pt. glass
B8814-515	515	3-1 pt. glass
B8814-520	520	3-1 pt. glass
B8814-525	525	3-1 pt. glass
B8814-530	530	3-1 pt. glass
B8814-535	535	3-1 pt. glass
B8814-540	540	3-1 pt. glass
B8814-545	545	3-1 pt. glass

BOREHOLE B8814 SAMPLE INVENTORY

STORAGE LOCATION IN BLDG 3720
299 W-22-50

SAMPLE #	Depth (ft)	Container
B8814-100.0	100.0 - 101.0	12" liner
B8814-101.0	101.0 - 102.0	12" liner

SAMPLE #	Depth (ft)	Container
B8814-225	225	2-1 pt. glass
B8814-228	228-229	12" liner

SAMPLE #	Depth (ft)	Container
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Appendix G

Some Mineralogical Analyses of the Composite Sediment Samples

Appendix G

Some Mineralogical Analyses of the Composite Sediment Samples

Table G.1. Semiquantification of Non-Clay Minerals in Composite Samples (wt%)

Sample ID	Quartz	K-Feldspar	Na-Feldspar	Calcite
Borehole Fine Sand	50	10	20	nd
Hanford Fine Sand	80	10	20	nd
Hanford Coarse Sand	55	5	15	nd
Ringold Sand	30	5	5	<5

Table G.2. Semiquantification of Minerals in the Clay Fraction from Composite Samples (wt%)

Sample ID	Quartz	Feldspar	Smectite	Illite	Chlorite	Kaolinite
Borehole Fine Sand	5	<5	30	40	20	5
Hanford Fine Sand	5	<5	30	15	15	10
Hanford Coarse Sand	5	<5	30	15	15	5
Ringold Sand	10	<5	35	35	20	nd

XRD Tracings of Hanford Composite Sediments

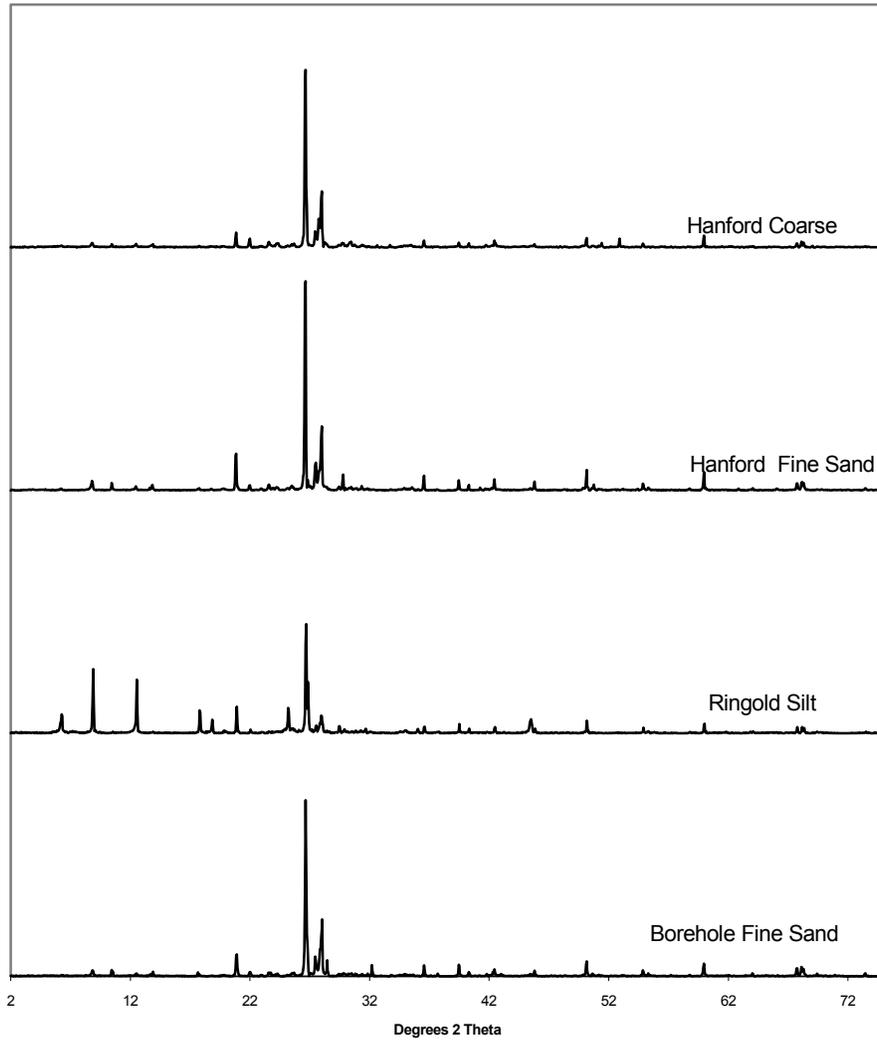


Figure G.1. Bulk Sediment XRD Patterns

XRD Tracings of Hanford Fine Sand Clay Fraction

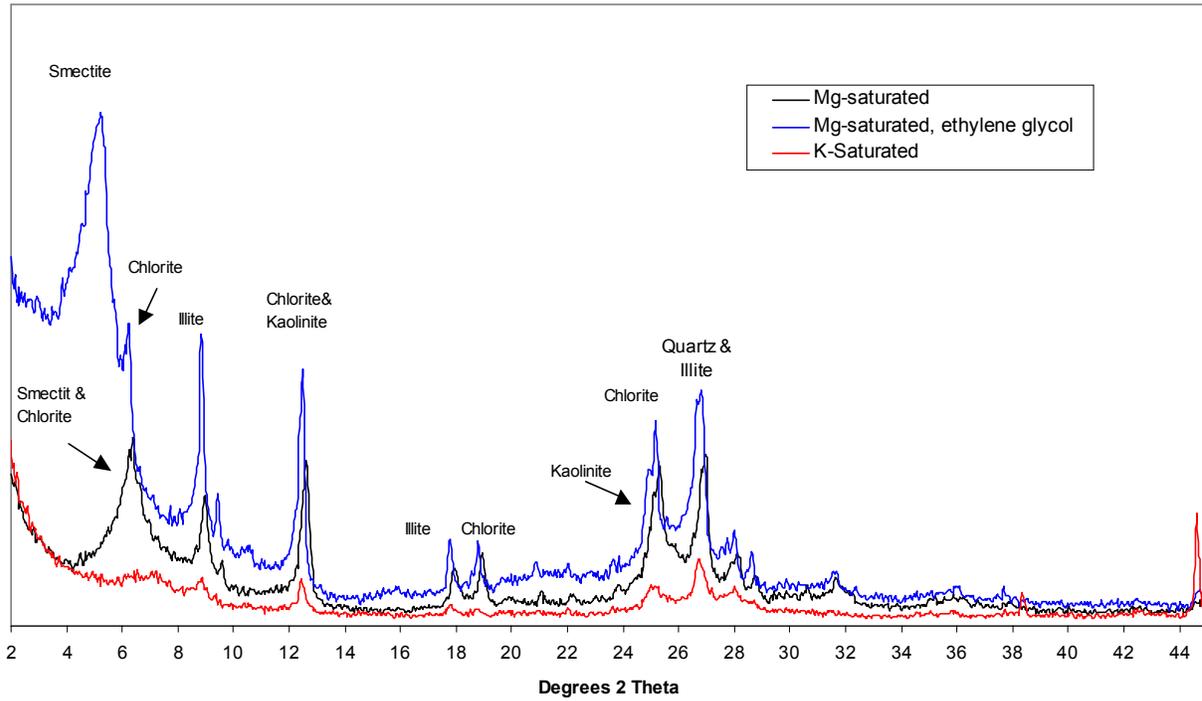


Figure G.2. Diffractogram for Clay-Size Particles in Hanford Fine Sand

XRD Tracings of Hanford Coarse Sand Clay Fraction

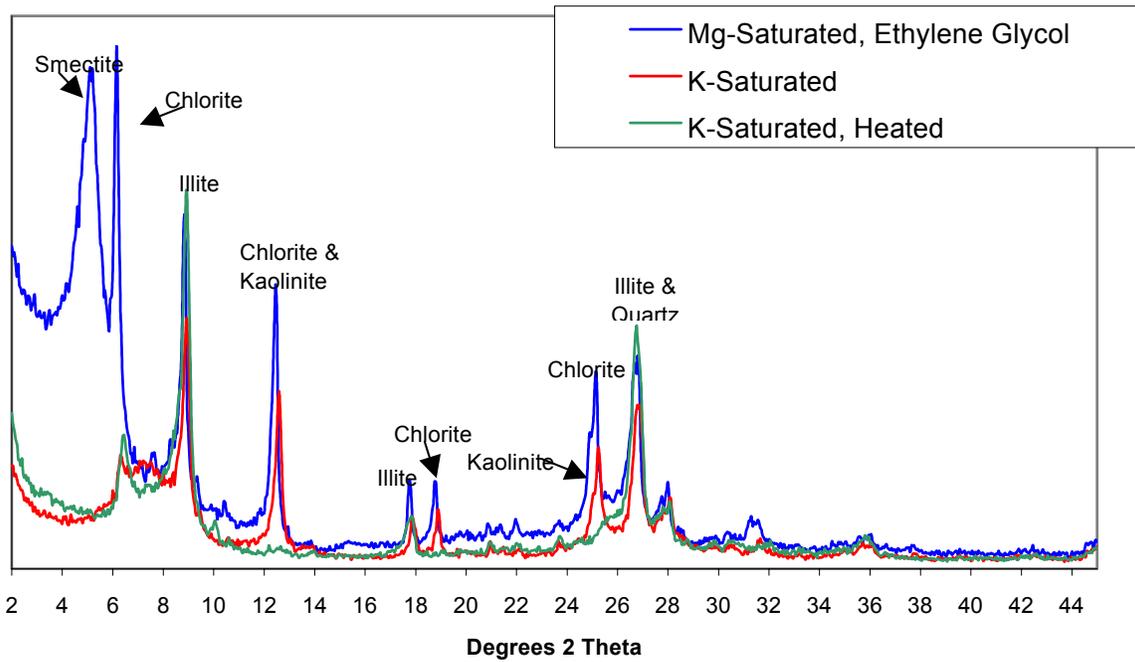


Figure G.3. Diffractogram for Clay-Size Particles in Hanford Coarse Sand

XRD Tracing of Borehole Fine Sand Clay Fraction

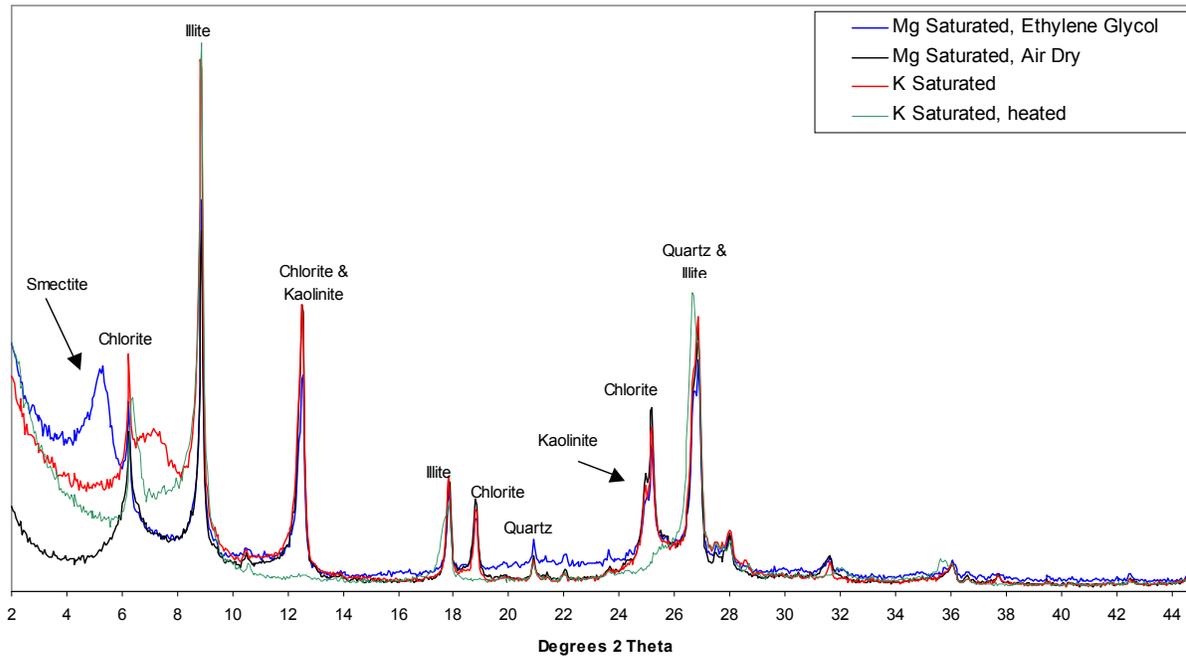


Figure G.4. Diffractogram for Clay-Size Particles in Borehole Fine Sand

XRD Tracing of Ringold Silt Clay Fraction

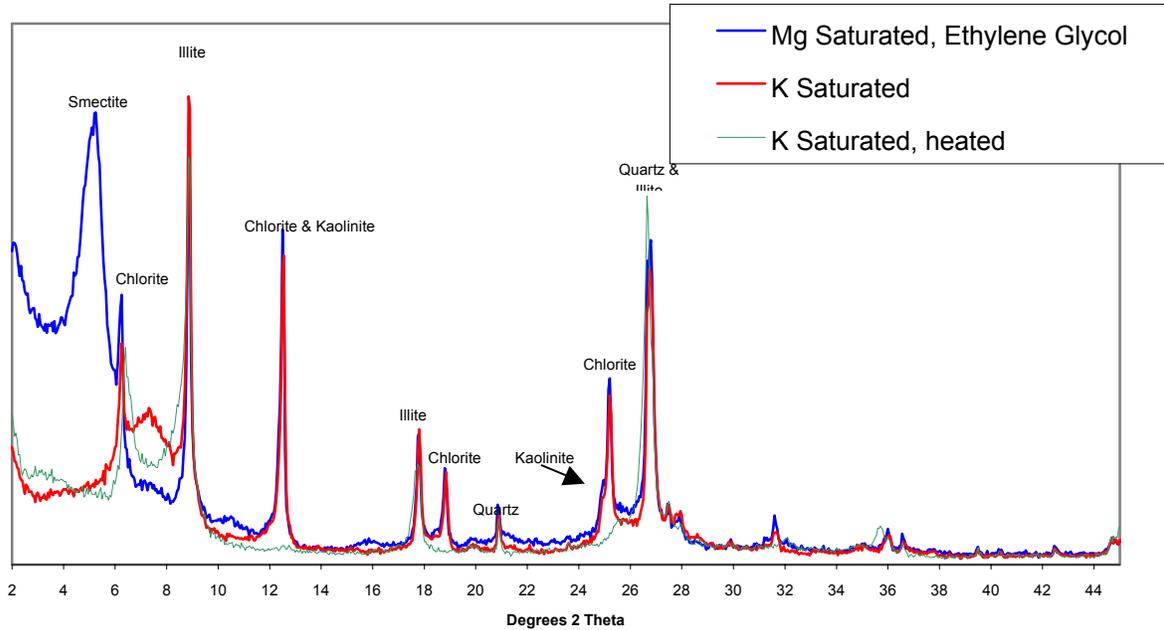


Figure G.5. Diffractogram for Clay-Size Particles in Ringold Silt

Appendix H

Some Mineralogical Analyses from Boreholes 299-W22-48 and -50

Appendix H

Details on XRD for Boreholes 299-W22-48 and -50

Table H.1. Semiquantitative Mineral Content for Boreholes 299-W22-48 and -50 Bulk Sediment (wt%)

Borehole 299-W22-48	Quartz	K-Feldspar	Plagioclase	Calcite	Total
39.5' (H1a)	60	<5	20	ND*	~85
47' (H1)	20	<5	15	10	~50
91.5' (H2)	45	40	15	ND	~100
101.5' (H2)	95	<5	20	ND	~115
136' (PPLz)	80	30	10	ND	~120
146' (PPlc)	25	<5	10	40	~80
148.5' (PPlc)	25	10	20	40	~95
163.5' (Rtf)	65	20	10	ND	~95
Borehole 299-W22-50					
50' (H1a)	60	10	25	ND	~95
60' (H1)	45	10	25	ND	~80
116' (H2)	45	15	30	ND	~90
135' (PPlz)	60	5	15	ND	~80
140' (PPlc)	60	10	15	ND	~85
160.5' (Rtf)	50	10	30	ND	~90

*ND = none detected

Table H.2. Semiquantitative Measurements of Minerals in the Clay Fraction from Boreholes 299-W22-48 and -50 (wt%)

Depth (ft)	Quartz	Feldspar	Calcite	Smectite	Illite	Chlorite	Kaolinite	Total
Borehole 299-W22-48								
39.5' (H1a)	<5	<5	Tr	25	20	15	<5	~75
47'* (H1)	<5	<5	5	10	10	10	<5	~50
91.5' (H2)	<5	<5	Tr	20	35	20	<5	~90
101.5' (H2)	10	<5	Tr	25	35	35	10	~120
136' (PPlz)	10	<5	Tr	20	30	20	10	~95
146'* (PPlc)	<5	<5	40	15	10	10	<5	~90
148.5'* (PPlc)	<5	<5	40	<5	10	<5	<5	~85
163.5' (Rtf)	10	<5	Nd	30	50	30	<5	~130
Borehole 299-W22-50								
50' (H1a)	5	<5	10	30	15	10	10	~85
60' (H1)	5	5	25	5	15	10	10	~75
116' (H2)	10	<5	Tr	30	30	35	10	~120
135' (PPlz)	5	<5	<5	30	30	30	10	~115
140' (PPlc)	10	<5	<5	15	10	10	5	~60
160.5' (Rtf)	5	5	Tr	10	15	15	10	~60

Table H.3. XRF Analysis of Clay Fraction from Borehole 299-W22-48 (wt%)

Sample Depth (ft bgs)	H1a	H1	H2	H2	PPlz	PPlc	Rtf
Strat. Unit	39.5	47	91.5	101.5	136	146	163.5
Oxide							
Na ₂ O	NM						
MgO	NM						
CO ₂	NM						
Al ₂ O ₃	13.74	13.57	16.66	15.23	17.43	5.61	13.90
SiO ₂	42.50	50.38	48.78	46.00	51.24	25.62	45.89
P ₂ O ₅	0.47	0.75	0.67	0.71	0.58	0.82	0.49
SO ₃	0.16	0.19	0.22	0.21	0.21	0.35	0.18
Cl	1.31	0.35	1.00	2.50	0.13	0.44	1.54
K ₂ O	2.09	1.60	2.76	2.42	2.61	0.57	2.44
CaO	2.98	4.46	1.94	1.15	1.95	29.05	1.19
TiO ₂	0.76	1.07	0.80	0.81	0.76	0.17	0.72
V ₂ O ₅	0.03	0.02	0.02	0.02	0.02	0.01	0.02
Cr ₂ O ₃	0.01	0.01	0.01	0.01	0.01	0.00	0.01
MnO	0.18	0.15	0.17	0.18	0.11	0.30	0.31
Fe ₂ O ₃	10.78	12.01	10.24	10.19	10.10	2.98	10.20
SrO	0.02	0.03	0.02	0.01	0.01	0.03	0.02
BaO	0.03	0.05	0.04	0.04	0.04	0.01	0.05
NM-Not measured							

Table H.4. XRF Analysis of Clay Fraction from Borehole B8814 (wt%)

Sample Depth (ft bgs)	H1a	H1	PPlz	PPlc
Strat. Unit	50	60	135	140
Oxide				
NaO	NM	NM	NM	NM
MgO	NM	NM	NM	NM
CO ₂	NM	NM	NM	NM
Al ₂ O ₃	12.90	11.55	17.69	14.98
SiO ₂	46.96	43.54	48.46	45.14
P ₂ O ₅	0.58	0.71	0.60	0.55
SO ₃	0.22	0.27	0.21	0.19
Cl	0.20	0.14	1.14	0.44
K ₂ O	1.36	1.62	2.30	2.02
CaO	5.51	12.76	2.10	3.02
TiO ₂	0.82	0.85	0.67	0.68
V ₂ O ₅	0.02	0.02	0.02	0.02
Cr ₂ O ₃	0.01	0.01	0.01	0.01
MnO	0.15	0.14	0.12	0.10
Fe ₂ O ₃	11.79	9.78	9.39	10.67
SrO	0.02	0.04	0.01	0.02
BaO	0.03	0.06	0.03	0.04
NM-not measured				

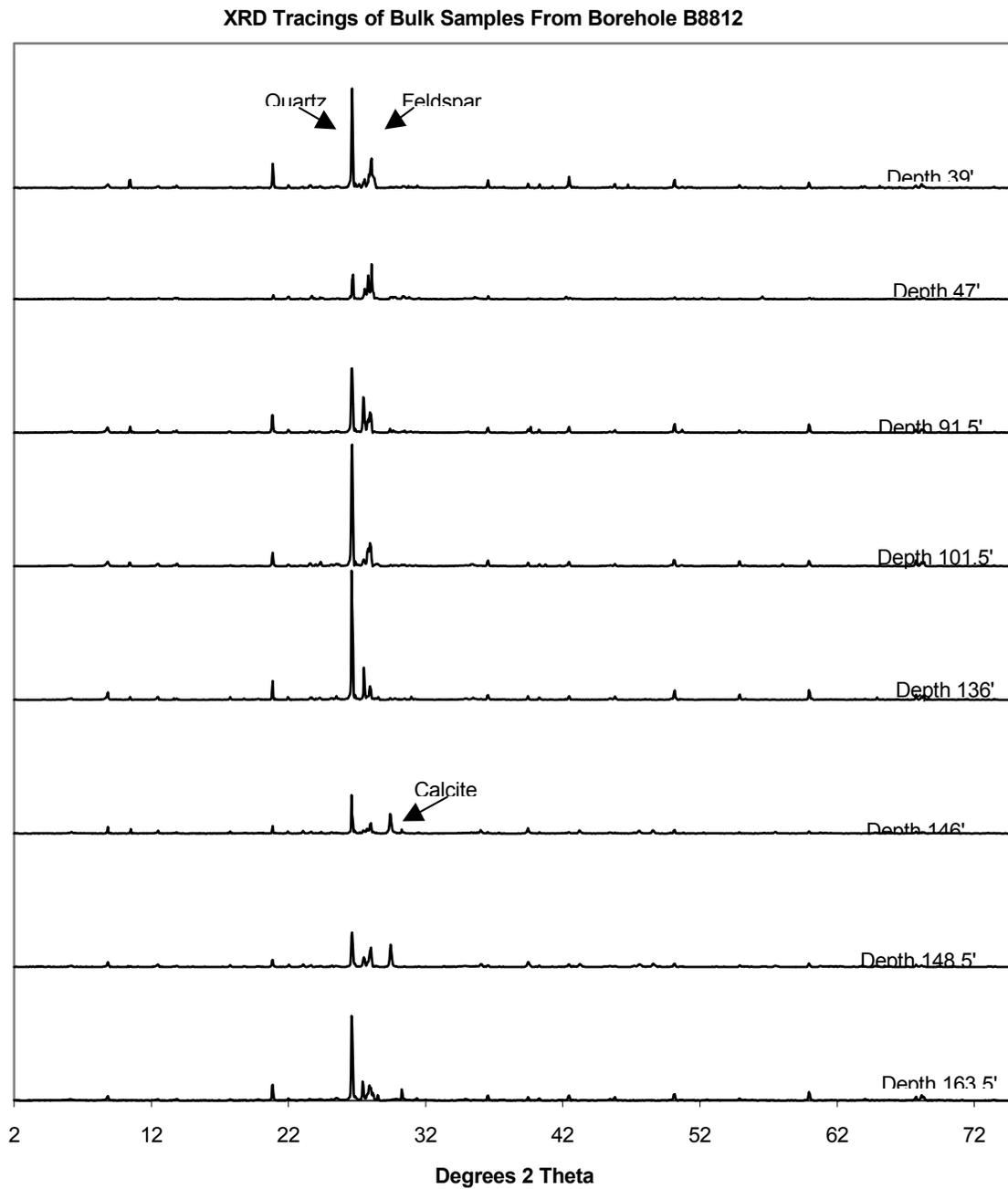


Figure H.1. XRD Pattern for Bulk Samples from 299-W22-48 (B8812)

XRD Tracings of the Silt Fraction From Selected Depths in Borehole B8812

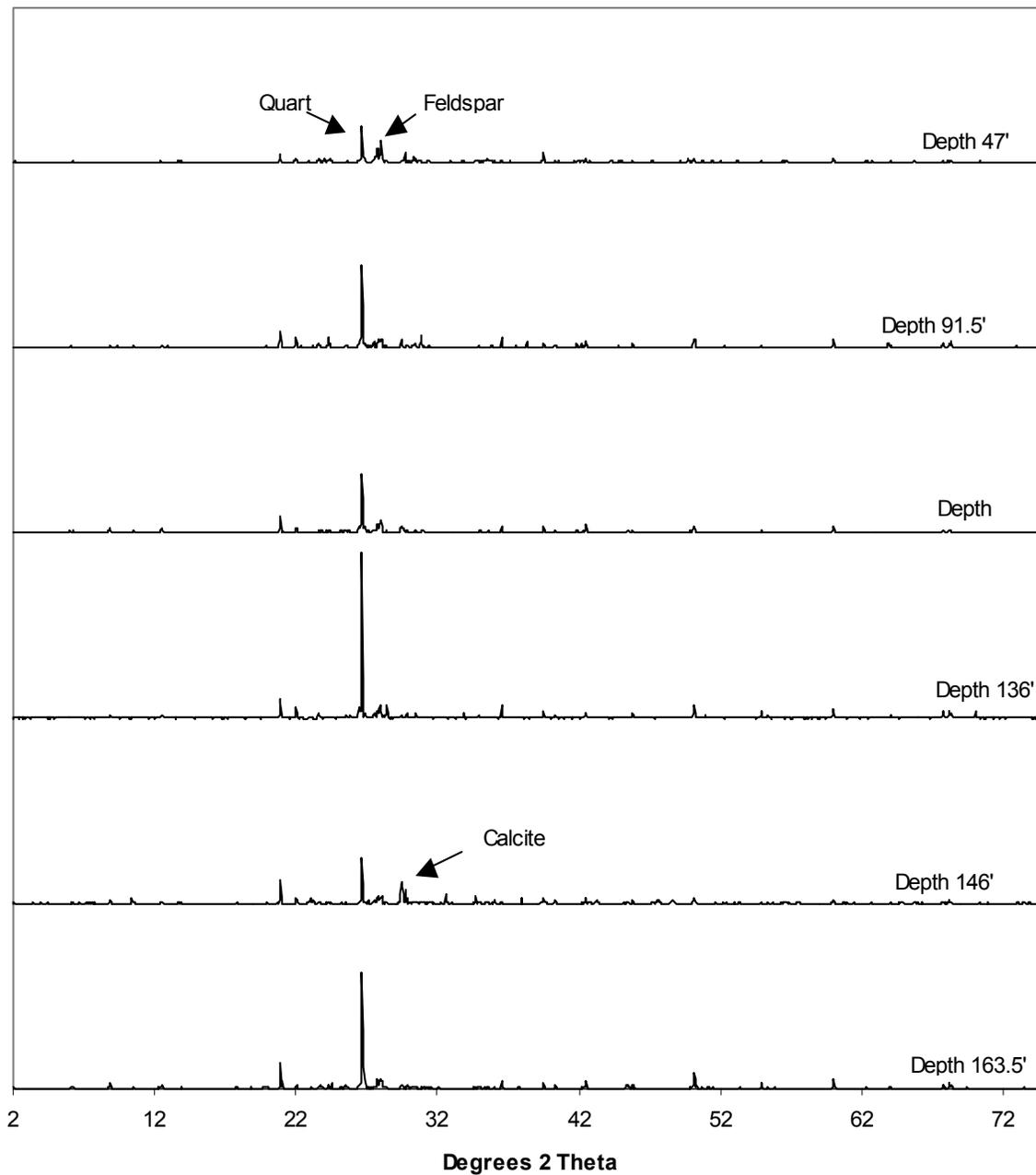


Figure H.2. XRD Patterns for the Silt Fraction from 299-W22-48

**B8812 XRD Tracings of Clay Fraction
(Mg Saturated, Ethylene Glycol)**

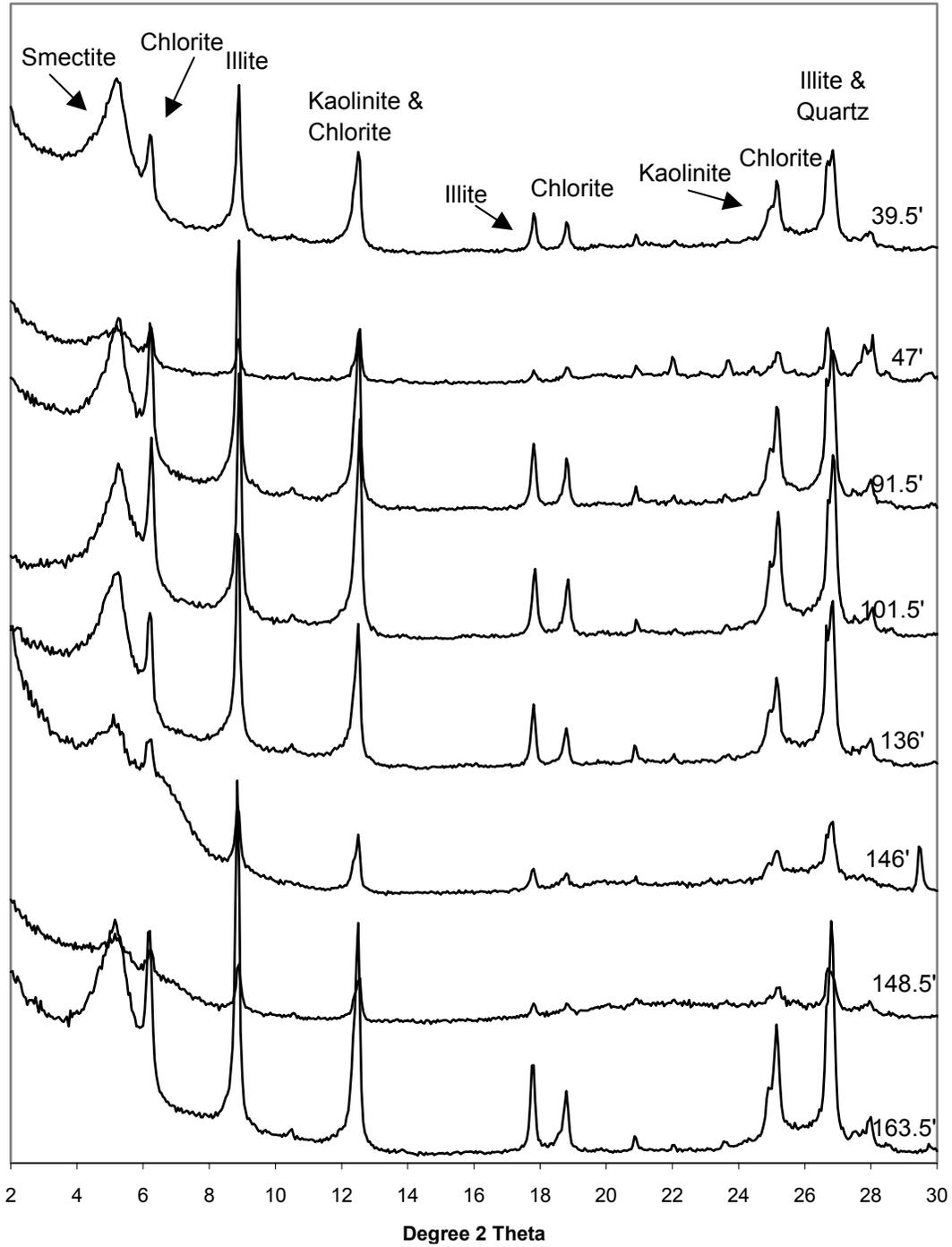


Figure H.3. XRD Patterns for Clay Fraction from 299-W22-48

XRD Patterns of Sediments from Borehole B8814

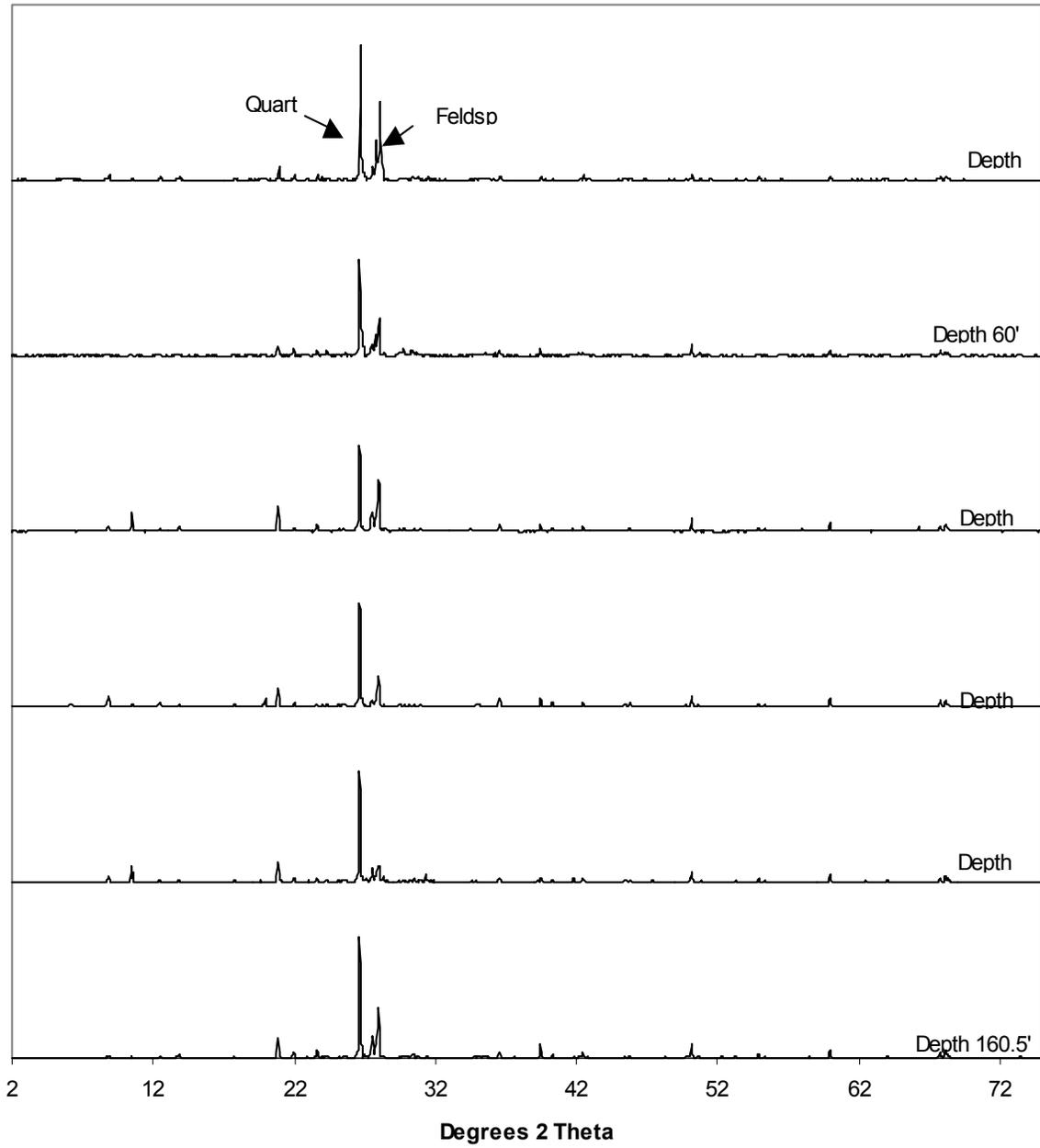


Figure H.4. XRD Patterns for Bulk Sediment from 299-W22-50 (B8814)

XRD Patterns of the Silt Fraction From Sediments in Borehole B8814

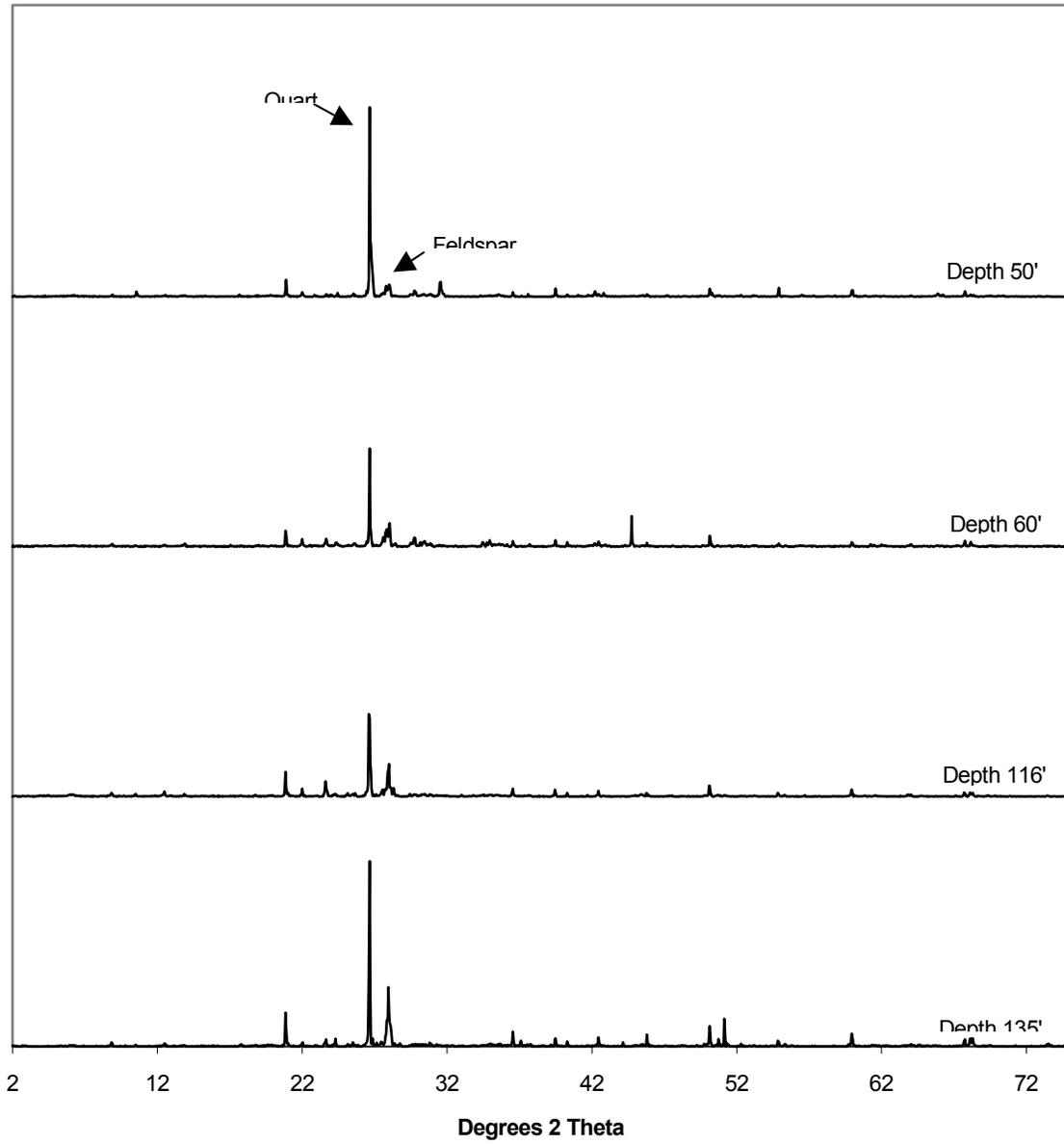


Figure H.5. XRD Patterns for Silt Fraction from 299-W22-50

XRD Patterns of the Clay From B8814
(Mg Saturated & Ethylene Glycol)

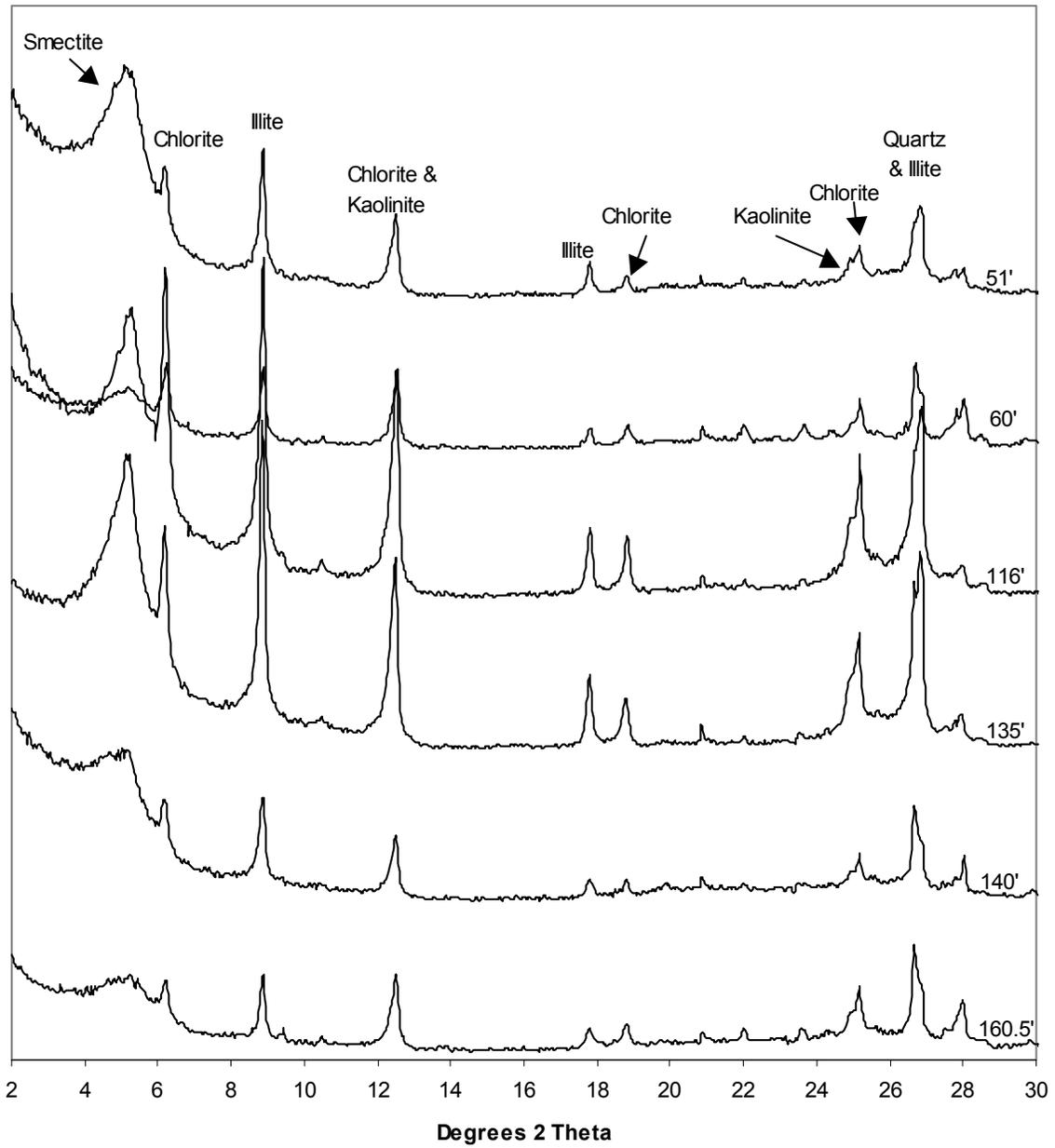


Figure H.6. XRD Patterns for Clay Fractions from 299-W22-50 (B8814)

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