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Pacific Northwest National Laboratory
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S. P. Reidel
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Prepared for the U.S. Department of Energy
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Summary

The second borehole for the Immobilized Low-Activity Waste Disposal site Performance Assessment was drilled in March 2001. Continuous core samples were obtained for characterization activities in support of the Performance Assessment. The borehole was drilled to a depth of 335 feet below ground surface and completed as a groundwater monitoring well. Only sediments of the Hanford formation were penetrated further defining the paleochannel that trends northwest southeast through the 200 East Area. Open-framework gravel was encountered from 335 feet drilled depth to 270 feet. From 270 feet to the surface, sands dominate the stratigraphy with minor amounts of gravel. The stratigraphic section can be divided into three layers defined by paleosols at the top of each layer. The water table is at 312.45 feet below ground surface. Aquifer testing indicates that a lower bounding value for hydraulic conductivity of the gravels comprising the paleochannel is 2952.76 in./day (75 m/day).

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1.0 Introduction

The U.S. Department of Energy Office of River Protection is responsible for safe underground storage of liquid waste from previous Hanford Site operations, the storage and disposal of immobilized tank waste, and closure of underground tanks. The current plan is to dispose of immobilized low-activity tank waste (ILAW) in the south-central part of the 200 East Area (Figure 1).

Borehole 299-E24-21 was drilled at the northeast corner of the ILAW site in support of the Performance Assessment activities for the disposal options (Mann et al. 2001). Borehole 299-E24-21 is the second borehole drilled for this purpose. This report summarizes the results of geophysical logging of the borehole and geologic logging of cores obtained from the borehole. The drilling and testing activities associated with the borehole were done in accordance with the approved Sampling and Analysis Plan (Reidel 2000).

Because it is customary to report borehole depth data in feet rather than meters, this report uses the English system of units where discussing drill depth. Multiply feet by 0.3048 to convert to meters. All other measurements are in metric units.

1.1 Borehole 299-E24-21

Borehole 299-E24-21 was drilled at the northeast corner of the ILAW site in March 2001 (see Figure 1). The location of the borehole was based on characterization needs for developing the geohydrologic model for the site and satisfying Data Quality Objectives (Reidel et al. 1995, Reidel 2000). The borehole was drilled to characterize subsurface conditions beneath the ILAW site including discerning the extent of the paleochannel that crosses the site in a northwest-southeast direction (Reidel and Horton 1999; Williams et al. 2000). The borehole provides data on the vadose zone and saturated zone in a previously uncharacterized portion of the 200 East Area.

1.2 Technical Objective

The technical objective of borehole 299-E24-21 was to provide geologic samples to characterize the sediments in the vadose zone in support of the ILAW Performance Assessment. This includes physical, hydrologic, and geochemical characterization.

1.3 Report Organization

This report consists of five chapters and two appendices. The first chapter is the introduction and background for the project. Chapter 2 provides a summary on the drilling and sampling methods that were used. Chapter 3 summarizes the technical results. Chapter 4 is a summary and conclusions and Chapter 5 contains cited references. Appendix A provides the results of aquifer testing and Appendix B provides the geophysical logs.

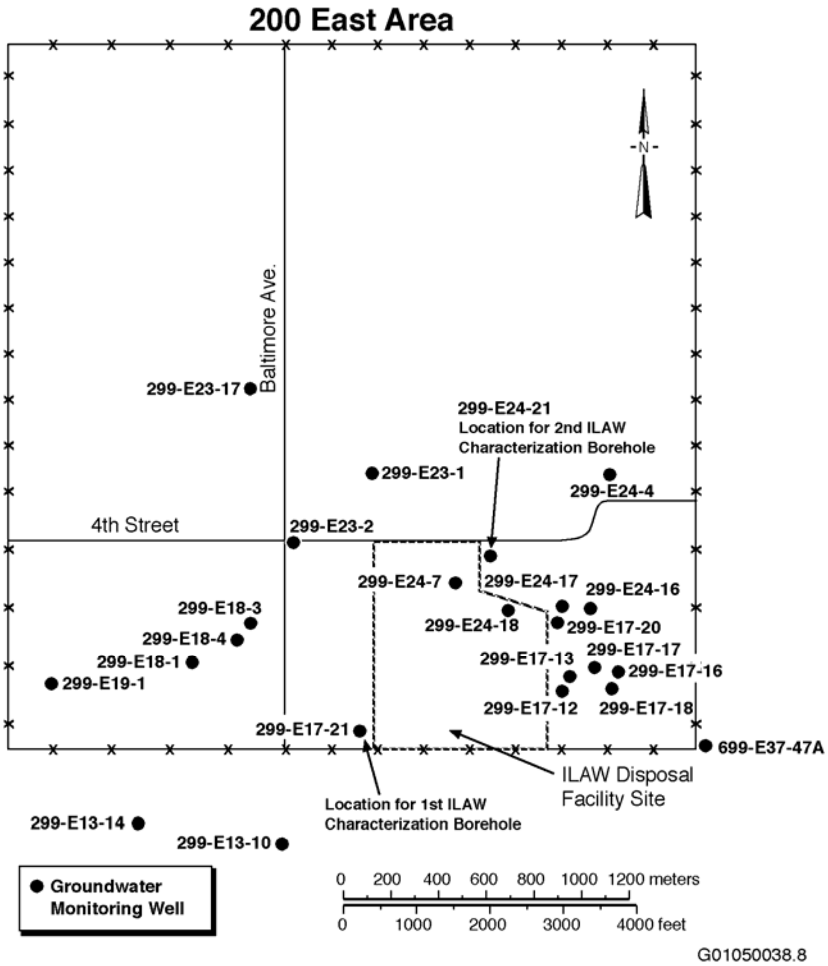

Figure 1. Location Map Showing the ILAW Site and Boreholes

2.0 ILAW Drilling and Sampling Activities

Drilling, sampling, and well construction objectives for the project are presented in Reidel 2000. That report called for drilling and sampling of one borehole to be constructed as a groundwater monitoring well. To achieve the goals of the sampling plan, continuous sample retrieval was needed from 45 ft below ground surface (bgs) to total depth or refusal.

2.1 Drilling and Well Construction

The details of drilling, well construction, and well development are documented in Walker (2001). In summary, the borehole was drilled in March 2001 by the Becker hammer drilling method from the surface to a total depth of 335 ft bgs. Groundwater was encountered at 312 ft bgs.

The borehole was completed as a Resource Conservation and Recovery Act groundwater-monitoring well. The well has a 4-in. diameter stainless steel casing and a 20-ft long stainless steel, continuous wire wrap, 0.020-in. slot screen. A protective casing with locking cap, a cement pad, and protective posts were installed to complete the surface installation.

Well 299-E24-21 was developed in March 2001 with a 3 horsepower, submersible pump. About 650 gallons of formation water were pumped at a rate of 15 gallons per minute; there was no measurable drawdown.

2.2 Sampling

Walker (2001) has described the field sampling activities associated with drilling borehole 299-E24-21. Briefly, split tube samples were collected in 4-in. diameter, 2-ft long lexan liners. Split tube samples were collected from 45 to 272.5 ft bgs with nearly 100% recovery. Split tube sampling was discontinued at 272.5 ft because it was no longer possible to drive the sampler in the Hanford formation gravel sequence. Above 50 ft and below 272 ft bgs, grab samples were collected every 5 ft for archive purposes.

End caps were taped to each 2-ft lexan liner. The liners were double bagged in plastic and placed in ice chests with an additional layer of plastic between the samples and the ice for transportation to the laboratory. Samples were transported under chain-of-custody and stored in refrigerators until they were opened for examination.

The lexan liners containing the cores from borehole 299-E24-21 were split open in the laboratory and logged following the approved test plan (Reidel 2000). Subsamples were collected for paleomagnetic analysis and possible future petrographic analysis during the detailed geologic logging.

Detailed laboratory geologic descriptions included geologic structure, grain-size, grain shape, sorting, color, moisture, cementation, hardness, and reaction to HCl. Each core sample was photographed. Sample liners were resealed with tape and returned to the refrigerator after examination. All core samples will be archived in the Hanford Geotechnical Sample Library.

2.3 Aquifer Testing

The Sampling and Analysis Plan (Reidel 2000) outlined a testing program for the hydrologic properties of the well. This testing was designed to provide information on recovery rates, effective permeability, and other hydrologic properties for the zone in which the aquifer was screened. Testing consisted of slug withdrawal testing and analysis (Appendix A).

2.4 Geophysical Logging

The borehole was geophysically logged after construction. High purity germanium logging was conducted to determine the presence of man-made radioactive materials above detection limits; to provide analysis of naturally occurring potassium, thorium, and uranium; and for stratigraphic studies. Appendix B contains copies of the log suite and the logging analysis report.

3.0 Borehole Stratigraphy

Borehole 299-E24-21 penetrated sediments comprising the Hanford formation and an upper eolian deposit. A summary of the main elements of the stratigraphy is shown in Figure 2. Table 1 presents a description of the individual cores as they were opened. The well-site geologist's descriptions (Walker 2001) are in good agreement with the lithology and stratigraphy preserved in the core. Small-scale features that generally are destroyed during drilling are well preserved in the core, thus, allowing a better understanding of the site.

The nomenclature used in this report is consistent with the standardized use for the Hanford Site (i.e., Delaney et al. 1991; Reidel et al. 1992; Lindsey et al. 1994) and with that used in the description of the sediments encountered in the first ILAW borehole (299-E17-21) (Reidel et al. 1998).

3.1 Hanford Formation

The Hanford formation encountered in borehole 299-E24-21 extends from 335 to 8 ft bgs. The entire thickness of the Hanford formation at this location is not known because the borehole did not penetrate into the underlying Ringold Formation. The Hanford formation consists of pebble to cobble conglomerate and fine- to coarse-grained sand with a few interbedded, thin silt and/or clay beds.

3.1.1 Lower Gravel Sequence

A basal conglomerate extends from 270 ft bgs to total depth (335 ft bgs). The upper 20 ft of the conglomerate consists of sandy gravel with very minor silt. The gravel content increases with depth from about 40 to 50% gravel at 270 ft bgs to 80 to 90 % gravel at about 290 ft bgs. Gravel content is in the 80 to 100% range to the bottom of the borehole. The lowermost 10 ft of gravel encountered were open-framework, medium to coarse pebble (with some cobble) gravel. The open-framework texture was recognized by the geologist in the field and was reflected during drilling when air, used to expel the drill cuttings from the borehole, was quickly dissipated into the formation.

The lower grave sequence is equivalent to unit H3 of Lindsey et al. (1994), and may be equivalent to mapping unit Qfg_1, Missoula Outburst flood gravel deposits of Reidel and Fecht (1994a, b).

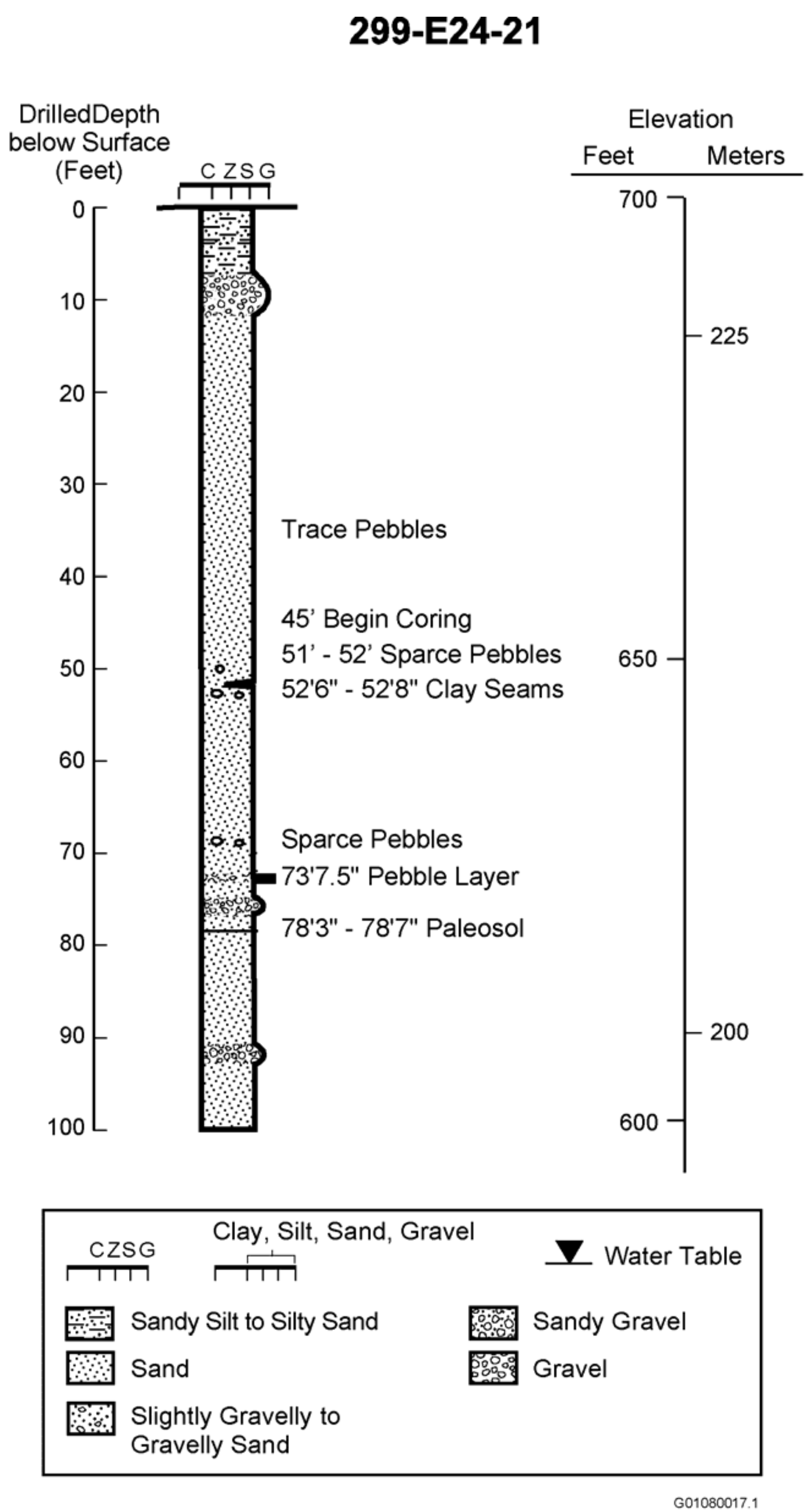

Figure 2. Summary of the Stratigraphy and Lithology Encountered in Borehole 299-E24-21

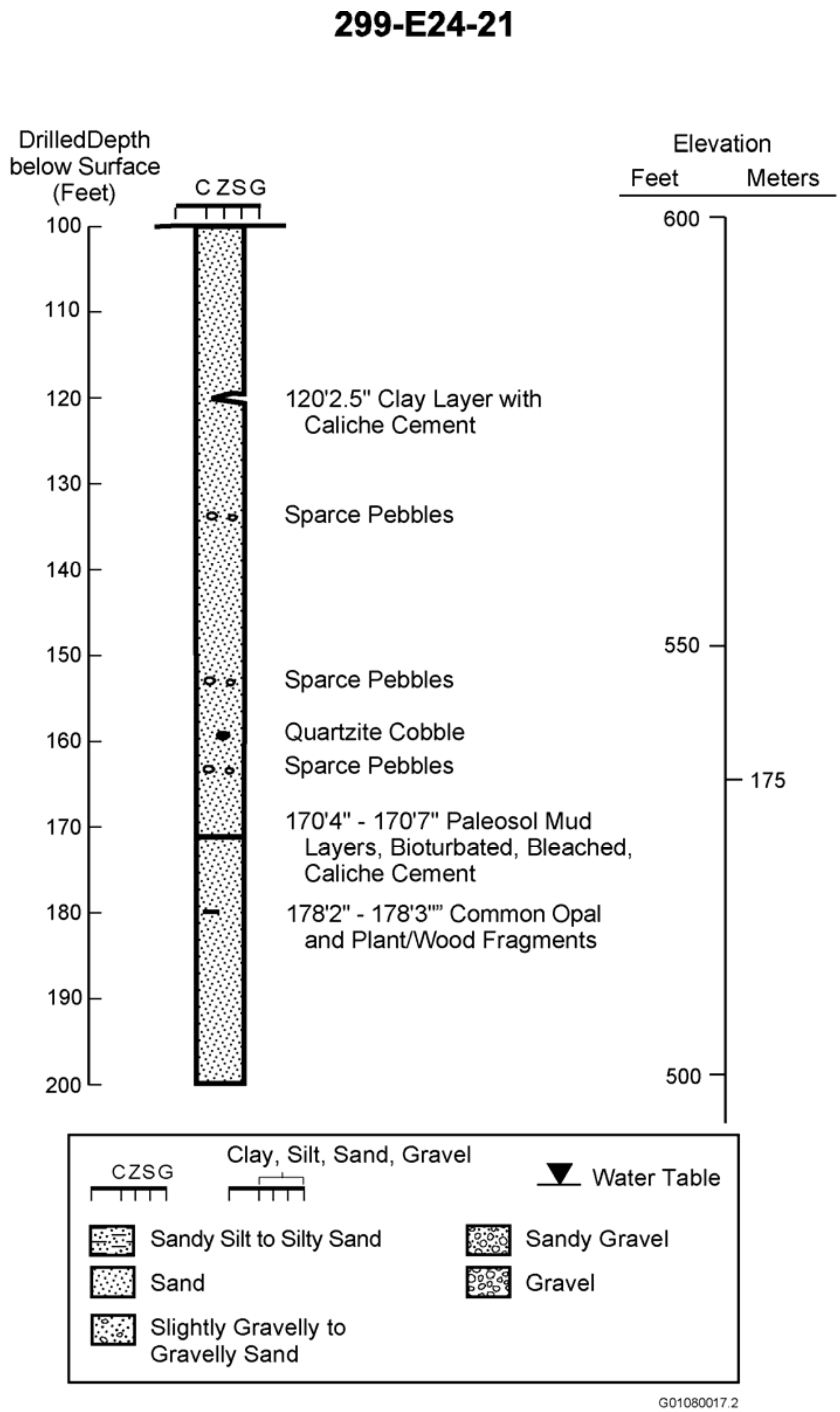

Figure 2. (contd)

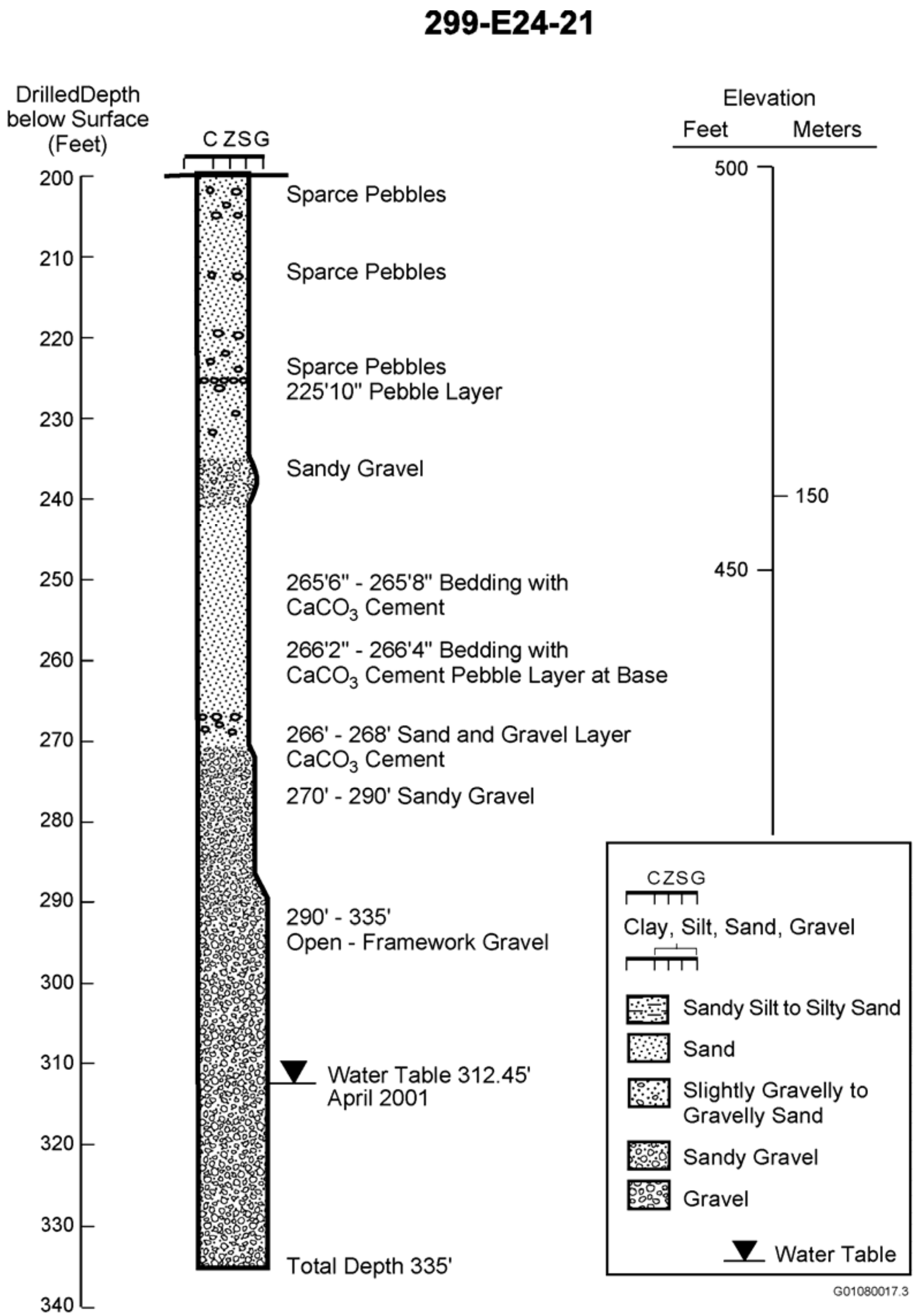

Figure 2. (contd)

Table 1. Descriptions of Core from the Second ILAW Borehole

Depth Below Surface (feet and inches)	Description of Core
0 to 45′	No core collected.
45 to 45′11 1/2″ 46′7″ to 47′	Core is in 2 parts. Some of the core is gone and was sampled for hydrologic properties. 45 to 45′3″ lost when end caps were pulled off for subsampling for hydrologic properties. Core is disturbed, coarse sand (0.5 to 1 mm [0.02 to 0.04 in]); sparse pebbles up to about 4 cm (1.57 in.); sand is subangular; pebbles are round; color is 10 YR5/2; no cementation, no compaction; silt on edge of tube effervesces (strongly) 95% sand, slightly silty, about 2% gravel.
47 to 49′	100% full. Silt shaken to surface; some compaction. Sediment shows layering with a contact at 48′6″. 48′6″ to 49′ is fine to coarse sand, ~0.1 to 1.5 mm (0.004 to 0.06 in.) in size with some subtle bedding and some upward fining. 47 to 48′6″ is very coarse (1.5 to 1.0 mm [0.06 to 0.04]) sand with few sparse pebbles up to 7 mm (0.28 in.) (metamorphic). Sand is subangular, salt and pepper, fining upward with subtle bedding. 40% basalt, 60% felsic (quartz, mica), well sorted. Sediment is ~5% silt and 95% sand. Silt effervesces; sand does not. 49′ angular to subangular; 75% felsic, 25% basalt; some calcite grains. The sample was coherent when opened. Core is slightly moist.
50 to 51′6″	Core was disturbed when sampled for hydrologic properties. Very coarse sand (1.5 to 1 mm [0.06 to 0.04]), subangular to subrounded, moist but not wet, no cementation or compaction. Some grains up to 2 to 3 mm (0.08 to 0.12 in.) (sparse). Core is 30% basalt, 70% felsic. Silt along edge of lexan liner effervesces.
52 to 54′2″	A 1/8″ thick clay seam at 52′6″. Very coarse sand (0.5 to 1 mm [0.02 to 0.04 in.]) above the seam; sand is approximately 50% basalt, 50% felsic, subangular, and moist; slight compaction but no cementation. Rare pebbles to ~5mm (0.20 in.). Silt on edges of lexan liner effervesces strongly. Core is 99% sand. Below the seam is fine sand (0.1 to 0.25 mm [0.004 to 0.01 in.]) with crude bedding at 52′8″. Sparse basalt pebbles (up to 8 mm [0.31 in.]). Silt on edges of lexan liner shows strong effervescence. Banding is 1/8 to 1/4″ thick. 53′ 0.5 mm (0.02 in.); subangular; 60% felsic, 40% basalt. 54′2″ fine grained (0.1 mm [0.004 in.]) with larger (0.5 to 1 mm [0.02 to 0.04 in.]) grains; 60% felsic, 40% mafic.
55 to 59′6″	No recovery.

Table 1. (contd)

Depth Below Surface (feet and inches)	Description of Core
60 to 62′	Upper 3″ of this core was lost in the field during sampling. From 60 to 60′8″ is coarse sand up to 1 mm (0.04 in.). Sand shows fining down structure, slightly moist, no cement. Rare pebbles up to 10 mm (0.40 in.) consisting of quartzite. Silt on edges of lexan liner effervesces strongly. From 60′8″ to 62′ is finer sand. 50% basaltic. Sand is subround to subangular; no cement and little compaction. 61′ 0.5 to 1.5 mm (0.02 to 0.06 in.) sand with some grains as large as 2 mm (0.08 in.); smaller grains are subangular; larger grains subrounded; 70% felsic, 30% mafic.
62 to 64′	Liner is full, sample not disturbed. Core is 95% sand and 5% silt. Sand is coarse (0.5 to 1 mm [0.02 to 0.04 in.]), angular, salt and pepper sand with no apparent bedding, no cementation, and no compaction. About 50% basaltic and 50% felsic; the felsic fraction is quartz and feldspar with mica up to 3 mm (0.12 in.). Sand is poorly sorted. 63′ 0.5 to 1 mm (0.02 to 0.04 in.) sand; subangular to subrounded; 60% felsic, 40% mafic; some calcite grains. Silt portion effervesces strongly. Silt shakes to surface of core. 2′ section is uniform throughout.
65 to 67′	Lost material at 67′ when dropped in field. Sand is ~0.25 to 0.5 mm (0.01 to 0.02 in.) in size; 40% basalt; 60% felsic; angular to subangular. Some granules up to ~2 mm (0.08 in.). Core shows no sorting, no cementation and no compaction. Core is dry. Silt on edge effervesces strongly.
67 to 69′	Core is composed of sand that is 0.25 to 0.5 mm (0.01 to 0.02 in.) in size; 40% basalt 60% felsic; larger grains are subangular. A few basalt pebbles up to 10 mm (0.40 in.). Core shows no sorting, is slightly moist, and has some faint bedding noted by color changes. No compaction, no cementation. Core is 99% sand and 1% silt (effervesces). Top 8″ of core is slightly cemented with $CaCO_3$.
70 to 72′	70 to 70′6″ lost in the field. Core is coarse sand (~0.5 to 1.5 mm [0.02 to 0.06 in.]) that is 40% basalt and 60% felsic. No pebbles. Sand is well sorted, slightly moist, and shows no structure or cementation. Core is 99.9% sand with minor silt on edges of lexan liner that effervesces strongly.
72 to 74′	Core shows fining upward sequences ~ 2″ thick. Sediment is 99.9% sand from about 0.25 to 0.6 mm (0.01 to 0.02 in.) in size, subangular, and 50% felsic 50% basaltic. Small pebble layer at 73′7 1/2″ that is 1/4″ thick with pebbles ~5 mm (0.20 in.) in size. Color ranges from 5YR5/1 (lighter material) to 10YR5/1 (darker material). Core is slightly damp with no cementation and good compaction. Silt on edges of lexan liner strongly effervesces.

Table 1. (contd)

Depth Below Surface (feet and inches)	Description of Core
75 to 77′	Core shows no geologic structure. Core consists of coarse, subangular sand and gravel (1 to 7 mm [0.04 to 0.28 in.] in size) and contains about 10% subrounded pebbles. Sand is 40% basalt and 60% felsic; pebbles are basalt. Core is compact but no cement. About 2% silt on edges of liner that effervesces.
77 to 79′	77′1 1/2″ is well-compacted, coarse sand (up to 1 mm [0.04 in.] in size) with up to 5% pebbles up to 7 mm (0.28 in.) in size; unit is fining upward. 77′6″ to 77′8″ is finer grained (<1 mm [<0.04 in.]) with fewer pebbles. 77′8″ is a fine pebble band ~1/4″ thick (basalt pebbles); pebbles are rounded and sand is subangular. 77′8″ to 78′3 1/2″ is a medium to coarse sand with scattered pebbles up to 7 mm (0.28 in.) in size. Sand is 50% basalt and 50% felsic, poorly sorted, slightly moist, and very compact. Silt on the edge of the lexan liner strongly effervesces. 78′3 1/2″ to 78′7 1/4″ is a bedded, medium grain sand (5YR6/2); beds are distinguished by color and hardness. Interpreted as paleosol layer. Grains are 0.25 to 0.5 mm (0.01 to 0.02 in.); 70% felsic and 30% basaltic. 78′7 1/4″ to 79′ is coarse sand, 50% basalt and 50% felsic, no compaction or cement, slightly disturbed due to filter paper.
80′6″ to 82′	The core section includes only 18″ of sediment with 6″ of bubble wrap. At 82 to 80′6″ is coarse grained sand (0.5 to 2 mm [0.02 to 0.08 in.] with some grains up to 5 mm [0.20 in.]), salt and pepper 50% basalt and 50% felsic; slightly moist. Larger grains are subround, most grains subangular. No compaction or cementation. About 1% silt; silt on edge of lexan liner effervesces strongly.
82 to 84′	Fining upward sequences about 3 1/2″ wide. Sand up to 2 mm (0.08 in.) in size; finer sand is 0.25 to 0.5 mm (0.01 to 0.02 in.). Sand is 50% basalt, 50% felsic with coarser material being mostly basalt. Sand is subangular and slightly moist, with no cement. Silt effervesces. Sediment is 99% sand.
85 to 86′	Fining upward sequences about 3 1/2″ wide. Sand up to 3 mm (0.12 in.) in size; finer sand is 0.25 to 0.5 mm (0.01 to 0.02 in.). Sand is 50% basalt, 50% felsic with coarser material being mostly basalt. Sand is subangular, slightly moist, and not cemented. Silt effervesces. Sediment is 99% sand.
87 to 89′	Core has a layered structure. Sand is coarse-grained (0.5 to 1 mm [0.02 to 0.04 in.]) with about 1% basalt and quartzite pebbles up to 5 to 7 mm (0.20 to 0.28 in.). Sand is 40% basalt and 60% felsic. Layer at 88′5 1/2″ is about 1/2″ thick and is coarser with more basalt. Core is slightly moist with no cement and no compaction. Less than about 1% silt on edges of lexan liner that effervesces.

Table 1. (contd)

Depth Below Surface (feet and inches)	Description of Core
90 to 92′	Core shows some bedding. Sand is coarse- to very coarse-grained (0.5 to 2 mm [0.02 to 0.08 in.]), subangular with about 5% pebbles up to 5 mm (0.20 in.). 50% basalt, 50% felsic. Bedding at 91′9″ is a fine-sequence (0.25 mm [0.01 in.]), well sorted, with very little moisture and no cementation. Silt reacts with HCl.
92 to 94′	Intact core. Bedding is present. Sand is 0.25 to 0.5 mm (0.01 to 0.02 in.) in size, 50% basalt and 50% felsic, subangular, and very little moisture. Core is compacted with no cementation. Bedding is defined by color. Silt effervesces.
95 to 97′	Upper 6″ of core are missing. Sediment is bedded, fining upward sequences about ~1 1/2″ thick. Sand is 0.25 to 0.5 mm (0.01 to 0.02 in.) in size with some grains up to ~2 mm (0.08 in.). Sand is subangular, dry, well sorted, and 60% basalt and 40% felsic. No cement and slight compaction. Silt effervesces.
97 to 99′	Intact core. Bedding is present and is about 2 to 5″ thick; fining upward sequences decreasing in size upward. Grains are 0.25 to 8.5 mm (0.01 to 0.33 in.) in size; 40% basalt and 60% felsic; well sorted, dry, and subangular. There is no cement but core is extremely compact. Silt effervesces.
100 to 102′	Upper 3″of core are missing. 100′3″ to 100′8″ is medium to fine grain (0.25 to 0.5 mm [0.01 to 0.02 in.]) sand with crude bedding. Sand is wet with the felsic component greater than the basalt component. Well sorted, no cement and no compaction. No HCl reaction. There is a curved (dragged?) distinct contact at 100′8″. 100′10″ to 102′ is very coarse sand (0.5 to 1 mm [0.02 to 0.04 in.]); fining upward. Fining upward sequences are 2 to 3″ thick. No cementation; coarser material is slightly more compact. Silt effervesces.
102 to 104′	Intact core. Fining upward sequences 4 to 5″ thick. Sand is 0.25 to ~1 mm (0.01 to ~0.04 in.) in size and is 50% basalt and 50% felsic. Sand is subangular to angular, slightly moist, very compact and well sorted; no cementation. Silt effervesces.
105 to 107′	Top 3 to 4″ of core are missing. Crude layering; fining upward sequences about 1″ thick. Sand is 0.25 to 1 mm (0.01 to 0.04 in.) in size; 30% basalt and 70% felsic. Sand is angular to subangular, well sorted, and moist. There is no cementation and no compaction. Silt on edges of lexan liner effervesces.
107 to 109′	Intact core. Bedding is fining upward sequences; about 1 1/2″ thick beds. Sand is 0.25 to 1 mm (0.01 to 0.04 in.) in size and 30% basaltic and 70% felsic. Sand is angular to subangular, well sorted, and slightly moist. Sediment is very compact but no cementation. Silt effervesces.
112 to 114′	Intact core. From 112 to 113′8″ is medium sand (0.25 to 0.5 mm [0.01 to 0.02 in.]) with 1/4 to 1/2″ bands defined by changes in grain size (0.1 to 0.25 mm [0.004 to 0.01 in.]). Finer bands are 40% basalt and 60% felsic, subangular, and compact with no cementation. Silt effervesces.

Table 1. (contd)

Depth Below Surface (feet and inches)	Description of Core
112 to 114′ (contd)	113′3″ to 113′5″ is fine to medium grained sand (0.25 mm [0.01 in.]) in 1/2″ thick bands. 113′5″ to 113′8″ is fine-grained sand (0.1 to 0.25 mm (0.004 to 0.01 in.] with some grains up to 1 mm [0.04 in.]) in 6 bands that are about 1/2″ thick. 70% felsic, 30% basaltic. Contacts are defined by very fine-grained material (maybe clay). 113′8″ to 114′ is medium sand as at 112 to 113′3″.
115 to 117′	Bedded, fining upward sequences on the 4″ scale with internal beds on the 1/2″ scale. Sand is medium- to coarse-grained (0.25 to 1 mm [0.01 to 0.04 in.]), slightly moist, 50% basalt and 50% felsic, well sorted and subangular; no pebbles and no cementation. Silt effervesces.
117 to 119′	Complete core section. Sediment has crude fining upward bedding. From 117 to 118′ is medium sand (0.25 mm [0.01 in.]) with crude bedding defined by color. From 118 to 118′5″ is coarser sand (up to 1 mm [0.04 in.]) with brown staining at 118′5″. Sand is angular to subangular. At 118′5″ to 119′ is medium sand (0.25 to 0.5 mm [0.01 to 0.02 in.]). Sand is 50% basalt and 50% felsic with a trace of quartzite pebbles (5 mm [0.20 in.]). Sand is well sorted and slightly moist. The center of this section is stained and may be slightly cemented (iron stain). Silt effervesces.
120 to 122′	Laminar bedding; fining upward sequences 3 to 4″ thick; coarse base is 2 to 10 mm (0.08 to 0.40 in.) in size and finer grained material is 0.5 to 1.5 mm (0.02 to 0.06 in.); angular to subangular. Sand is 40% basalt and 60% felsic, not very compacted and slightly moist. Silt effervesces. Clay zone at 120′2 1/2″ is 1/2″ thick with calcite cement.
122 to 124′	Complete core section. Bedding is defined by color and is about 1/2″ thick fining upward bands. Coarse part at base is about 1 mm (0.04 in.) in size and the darker fine-grained part is 0.25 to 1 mm (0.01 to 0.04 in.) in size. Sand is subangular, 40% basalt and 60% felsic, well sorted, fairly compacted, and dry. No cement. Silt effervesces.
125 to 127′	Complete core section. Crude 1/2″ bedding is defined by color. Sand is 0.25 to 1 mm (0.01 to 0.04 in.) in size, subangular, well sorted, and dry. 60% felsic, 40% basaltic. At 125′3″ is a contact with a coarse (1 to 2 mm [0.04 to 0.08 in.]) unit that fines upward. At 126′9″ is clay rich, stained band about 1/4″ wide. Sediment is well compacted and not cemented.
127 to 129′	Complete core section. Subtle fining upward sequences 6 to 9″ thick. Sand is 0.25 to 0.1 mm (0.01 to 0.004 in.) in size and contains distinct 1/8″ clay band and other color laminations. 70% felsic, 30% basaltic. Sand is angular to subangular, slightly moist, and compacted with no cementation. Silt effervesces.

Table 1. (contd)

Depth Below Surface (feet and inches)	Description of Core
130 to 131′6″	One fining upward sequence; coarse sand is 0.5 to 2 mm (0.02 to 0.08 in.) in size and fine sand is 0.1 mm (0.004 in.) in size. 60% felsic, 40% basaltic. Sand is subangular, well sorted, dry, and not very compact. Silt on edges of lexan liner effervesces.
132 to 134′	Complete core section. 132 to 132′6″ is coarse-grained sand (0.5 to 1 mm [0.02 to 0.04 in.) with minor 1/2 to 3/4″ thick beds. 132′6″ to 134′ is coarse sand (0.5 to 1.5 mm [0.02 to 0.06 in.] with many grains over 2 mm [0.08 in.]). Sand is 40% basalt and 60% felsic, angular to subangular, well sorted, dry, very compact, but not cemented. Silt effervesces. This section contains rare rounded, basalt pebbles about up to 7 mm (0.28 in.) in size and oxidized.
135 to 137′	2″ of slough at the top. Sediment is 98% sand that is laminated, fining upward beds that are about 2 to 3″ thick. Sand is mostly coarse (up to 2 mm [0.08 in.]) with some fine sand 0.25 to 0.5 mm (0.01 to 0.02 in.) in size. Sand contains a few pebbles up to 8 mm (0.31 in.) in size. Sand is 40% basalt and 60% felsic, subangular, well sorted, and slightly moist; no cementation but well compacted. Silt effervesces.
137 to 139′	Intact except at the top. Laminated, fining upward sequences 1 to 2″ thick. Sand is coarse (1 mm [0.04 in.]) to medium (0.25 to 0.5 mm [0.01 to 0.02 in.]). Sand is angular to subangular, well sorted, slightly moist, and well compacted but no cementation. Slight HCl reaction on sand and medium reaction on silt. Sand is 40% basalt and 60% felsic. No gravel.
140 to 142′	Intact core except at the top. Fining upward lamination with sequences 1/2 to 1″ thick. Coarse sand is 1 mm (0.04 in.) in size and medium sand is 0.25 to 0.5 mm (0.01 to 0.02 in.) in size. Sand is subangular, well sorted, and very moist. Core is not well compacted and has no cementation. Sand is 30% basalt and 70% felsic. No gravel. Silt reacts strongly to HCl.
142 to 144′	Core contains 1/4 to 1/2″ laminations defined by color. Sand is 0.25 to 1 mm (0.01 to 0.04 in.) in size at the top of the core to 2 mm (0.08 in.) in size at the bottom of the core. 70% felsic, 30% basaltic. Sand is subangular, well sorted, and slightly moist. Silt effervesces.
145 to147′	Some lamination and color banding. Sand is 0.25 to 1 mm (0.01 to 0.04 in.) in size and forms fining upward sequences on a 6 to 9″ scale. Sand is well sorted, 40% basalt and 60% felsic, slightly damp, and subangular. Trace of pebbles up to 3mm (0.12 in.) in size. Silt effervesces.
147 to 149′	Intact core. Fining upward sequences about 2″ thick. Coarse sand is 1 mm (0.04 in.) in size and fine to medium sand is 0.1 to 0.5 mm (0.004 to 0.02 in.) in size. Sand is subangular, 40% basalt and 60% felsic, slightly moist, well sorted, and compact but not cemented. HCl reaction is strong on silt; no reaction on sand. Core is 99% sand with minor silt (1%); no gravel.

Table 1. (contd)

Depth Below Surface (feet and inches)	Description of Core
150 to 151′	Core contains layering defined by color banding. Medium grained sand (0.25 to 1 mm [0.01 to 0.04 in.]) is 40% felsic and 60% basaltic, well sorted, subangular, slightly moist, and poorly compacted. Moderate reaction to HCl.
152 to 154′	Upper 2″ of core are slough. Core is laminated. 152 to 152′6″ is fine-grained sand (0.25mm [0.01 in.]). From 152′6″ to 153′3″ is a fining upward sequence with the lower sand about 1 mm (0.04 in.) in size and the upper sand about 0.25 mm (0.01 in.) in size. 153′3″ to 154′ is fine sand that is layered in 1/2 to 1″ bands denoted by color. 0.25 to 1 mm (0.01 to 0.04 in.) with some grains up to 2 mm (0.08 in.). Sand is well sorted, 40% basalt and 60% felsic, subangular, and well compacted with no cementation. Silt effervesces. Some basalt pebbles (less than 7 mm [0.28 in.] in size) in coarser sand.
155 to 157′	Upper 5″ of core is missing. Loose, coarse sand; layered in lower part of core defined by color. 60% felsic, 40% basaltic. Sand is 1 to 2 mm (0.04 to 0.08 in.) in size with 10 to 15% finer grained (0.25 to 0.5 mm [0.01 to 0.02 in.]). Sand is moderately sorted, slightly moist, not cemented, and not compacted. Silt effervesces.
157 to 159′	Intact core. No noticeable structure. Medium (0.1 to 0.5 mm [0.004 to 0.02 in.]) and coarse sand (1 to 2 mm [0.04 to 0.08 in.]) is well sorted with minor pebbles up to about 7 mm (0.28 in.) in size; one 3 x 4″ quartzite cobble. Sand is 40% basalt and 60% felsic, fairly compact and slightly moist. Silt effervesces on edge.
160 to 162′	Upper 3″ of core are missing. 160′3″ to 160′9″ is coarse sand. 160′9″ to 162″ is a fining upward unit. The upper part is about 1 mm (0.04 in.) in size and is 50% basalt and 50% felsic. The lower part is 0.25 to 1 mm (0.01 to 0.04 in.) in size, moist, well sorted, compacted, subangular and is 40% basalt and 60% felsic. Silt on the edge of the lexan liner effervesces.
162 to 164′	Minor, 1/2″ thick banding at 162′7″ and 163′1″. Medium- to coarse-grained sand (0.25 to 1 mm [0.01 to 0.04 in.]) is 40% basalt and 60% felsic. Sand is subangular, slightly moist, and compacted. Minor rounded, basalt pebbles up to about 10 mm (0.40 in.) in size. Sediment is 99% sand with 1% gravel. Silt on edge of lexan liner effervesces.
165 to 167′	Medium- to coarse-grained sand (0.25 to 1 mm [0.01 to 0.04 in.]), well sorted, angular to subangular, no apparent silt except a little along the liner. Sand is 50% basalt and 50% felsic, moist, with no pebbles. There is a crude bedding at 165.5′ which is 1/2″ thick; the base of which is slightly finer grained. A second bed at 166.5’ is 1/2″ thick and finer grained at base. Coherent core; probably due to moisture. Separated silt effervesces strong. Sand shows no reaction with HCl. 1 to 2% silt shaken out along edges of lexan liner.

Table 1. (contd)

Depth Below Surface (feet and inches)	Description of Core
167 to 169′	Fine layering about every 1″ denoted by change in grain size. Sand is 0.25 to 1 mm (0.01 to 0.04 in.) in size, well sorted, 40% basalt and 60% felsic, slightly moist, compacted, and contains a few pebbles up to 5 mm (0.20 in.) in size. Silt on edge of lexan liner effervesces.
170 to 171′	Upper 3″ of core are missing. 170′3″ to 170′4″ is medium-grained sand (0.25 to 0.5mm [0.01 to 0.02 in.]) with clay; 50% basalt and 50% felsic. 170′4″ to 170′7″ is a fine sand to silt zone with pieces of dark brown mud. Mud is bioturbated and bleached with calcite cement (paleosols). 170′7″ to 171′8″ is laminated medium to coarse sand (0.25 to 1 mm [0.01 to 0.04 in.]) that is 40% basalt and 60% felsic, slightly moist, compacted, and well sorted. Some calcite in the sand below the paleosols; calcite drops off in amount about 5″ below the paleosol. Silt effervesces.
171′8″ to 173′8″	Upper 2″ of core are missing. 171′9″ to 172′7″ is coarse sand (1 mm [0.04 in.]); no bedding. At 172′7″, sand is finely laminated with fine sand and silt (6 silt layers) totaling 3/4″ thick. This zone is well cemented/compacted. Remainder of core is fining upward sequence. Coarse sand on the bottom is about 1 mm (0.04 in.) in size; finer sand is 0.25 to 1 mm (0.01 to 0.04 in.) in size. Crude laminations; possible silt layers, and 1/4″sand layer. Sand is 40% basalt and 60% felsic, well sorted, and slightly moist. Core section is 99% sand; no cement.
175 to 177′	Upper 3 1/2″ of core are missing. 175 to 176′ is coarse-grained sand. Sand is 1 to 3 mm (0.04 to 0.12 in.) in size, 50% basalt and 50% felsic, well sorted, angular to subangular, slightly moist, and not compacted. 176 to 176′5″ is laminated, finer grained sand in a fining upward sequence. 176′5″ to 177′ is a second fining upward unit. The fining upward units are 0.5 to 1 mm (0.02 to 0.04 in.) sand. The finer parts are laminated; the lower coarser parts are not. Sands are well sorted, slightly moist, and moderately compacted. Both silt and sand react to HCl. Some disseminated calcite.

Table 1. (contd)

Depth Below Surface (feet and inches)	Description of Core
177 to 179′	Some loose dry material lost from both ends of the core; top 2″ and bottom 3″ are lost. At 178′2″ to 178′3″ is a breccia with opal and charcoal grains up to 8 mm (0.31 in.). Host sand above is medium-grained (0.25 to 0.5 mm [0.01 to 0.02 in.]), 40% basalt and 60% felsic, well sorted, compacted, angular to subangular, and reacts mildly to HCl. Host sand below is coarser (1 mm [0.04 in.]), compacted and reacts with HCl.
180 to 181′	Coarse sand with gravel, 2 mm to 7 mm (0.08 to 0.28 in.) in size (10 to 20% of material is less then 2 mm [0.08 in.]), subrounded, 70% basalt, 30% felsic, poorly sorted, slightly moist, poor consolidation, slight reaction with HCl. No cementation.
182 to 184′	Missing upper 2″ and lower 1″ of core. 40% basaltic, 60% felsic. There is a series of color bands due to varying amounts of basalt. Possible upward fining, sequences 5 to 6″ thick. Sand is 0.1 to 0.75 mm (0.004 to 0.03 in.) (some up to 1.5 mm [0.06 in.]) in size, well sorted, subangular, and slightly moist. No cementation but there is compaction. Moderate reaction with HCl.
185 to 187′	Very coarse sand with no internal structure. Some larger grains up to 6 or 7 mm (0.24 to 0.28 in.). Sand is 1 to 2 mm (0.04 to 0.08 in.) in size, 50% felsic and 50% basalt, angular to subangular, slightly moist, and moderately sorted, with moderate compaction. Moderate reaction with HCl. Somewhat finer grained at top.
187 to 189′	Crude structure consisting of banding and upward fining sequences. Sand is 1.0 to 0.25 mm (0.04 to 0.01 in.) in sequence of upward fining (very poorly developed). Grain size is 1 mm (0.04 in.) average for core as a whole. Sand is 50% basalt and 50% felsic, subangular, moderately compacted, slightly moist. No pebbles. Moderate reaction to HCl.
190 to 192′	190 to 190′9″ is coarse-grained sand (1 to 2 mm [0.04 to 0.08 in.]) with some grains up to 5 mm (0.20 in.). 190′9″ to 192′ is finer-grain and consists of a series of 1 to 2″ thick upward fining sequences. Sand is 0.5 to 2 mm (0.2 to 0.08 in.) in size at the base and 0.5 mm (0.02 in.) in the upper part. 50% basalt, 50% felsic. Sand is moderately moist, very compacted, and well sorted. Moderate reaction to HCl. 190 to 190′9″ is 70% basalt, 30% felsic. 190′9″ to 192′ is 50% basalt, 50% felsic.
192 to 194′	Three upward fining sequences 6 to 9″ thick. Sand is 0.5 to 1 mm (0.02 to 0.04 in.) in size, 50% basalt and 50% felsic, poorly sorted, slightly moist, and compact. No cementation. Moderate reaction to HCl.

Table 1. (contd)

Depth Below Surface (feet and inches)	Description of Core
195 to 197′	One upward fining cycle. Grains at the bottom are up to 3 mm (0.12 in.) in size whereas those at the top are 0.5 mm (0.02 in.) in size. Sand is 50% basalt and 50% felsic, well sorted, slightly moist, and compact in finer-grained parts. No cementation. Moderate reaction to HCl.
197 to 199′	No apparent structure. Sand is coarse-grained with some (about 1%) larger granules up to 7 mm (0.28 in.). Composition is 40% basalt and 60% felsic. Sand is slightly moist, poorly sorted, and poorly compacted. Reacts moderately with HCl.
200 to 201′	Core sampled for hydrologic properties. 200 to 200′9″ is a coarse unit (7 to 6 mm [0.24 to 0.28 in.]) and fines upward (0.5 to 1 mm [0.02 to 0.04 in.]). 50% basalt, 50% felsic. Sediment below 200′9″ is finer grained than at 200 to 200′ 9″ and forms another upward fining unit. This unit is coarser grained than units at shallower depths in this core. Sand is moderately well sorted, slightly moist, poorly compacted, and consists of 70% basalt and 30% felsic. Moderate reaction to HCl.
202 to 204′	Faint color laminations. Coarse sand (1 to 2 mm [0.04 to 0.08 in.]) with 1 to 2% pebbles up to 10 mm (0.40 in.) in size. Sand is 50% basalt and 50% felsic. Pebbles and sand are subangular, slightly moist, moderately sorted, and slightly compacted. Silt on edge of lexan liner effervesces and sand shows a moderate reaction with HCl.
205 to 207′	No structure except finer grained band at 205′6″ that is 1/2″ thick and contains more silt. Sand is coarse-grained (0.5 to 1 mm [0.02 to 0.04 in.]), 50% basalt and 50% felsic, subangular, slightly moist, compact, and well sorted. A few (less than 1%) subround basalt pebbles up to 10 mm (0.40 in.) in size. No cementation. Reaction with HCl is moderate.
207 to 209′	Core shows color banding due to changes in the amount of basalt grains. Lighter layers are 50% basalt and 50% felsic; darker layers are 70% basalt and 30% felsic. Sand is 0.5 to 1 mm (0.02 to 0.04 in.) in size, angular to subangular, well sorted, and slightly moist. No cementation but well compacted. Moderate reaction to HCl.
212 to 214′	Top 2″ and bottom 3″ of core are missing. Color banding due to changes in percent of basalt and grain size. The overall sediment is well sorted and well compacted, slightly moist, and shows moderate reaction to HCl. 212 to 212′3 1/2″ is light colored, 0.5 to 1 mm (0.02 to 0.04 in.) in size, subangular, and is 50% basalt and 50% felsic. A few larger pebbles up to 7 to 8 mm (0.28 to 0.31 in.) in size. 212′3 1/2″ to 212′8″ is coarse sand 1 to 3 mm (0.04 to 0.12 in.) in size with grains reaching up to 7 mm (0.28 in.). Sand is 60 to 70 % basalt and 30 to 40 % felsic. 212′8″ to 214′ is 0.25 to 1 mm (0.01 to 0.04 in.) sand that is 50% basalt and 50% felsic.

Table 1. (contd)

Depth Below Surface (feet and inches)	Description of Core
217 to 219′	Material has been lost from both ends of core (lost 2″ from top and 3 1/2″ from bottom). Color bedding based on basalt content. Lighter layers are 40% basalt and 60% felsic; darker layers are 60 to 70% basalt and 30 to 40% felsic. Sand is coarse grained (0.25 to 1 mm [0.01 to 0.04 in.]). Basalt rich layers are coarser with grains up to 3 to 5 mm (0.12 to 0.20 in.) and some as large as 10 mm (0.40 in.). Sand is well sorted, slightly moist, and moderately compacted. Pebbles near bottom of core are up to 2 to 3 cm (0.79 to 1.18 in.) in size. Slight to moderate reaction to HCl.
220 to 222′	220 to 220′9 1/2″ is disturbed. 220′9 1/2″ to 221′4″ is coarse-grained sand (0.5 to 1 mm [0.02 to 0.04 in.]) with small, crude color bedding and 2 to 3% scattered basalt pebbles up to 10 mm (0.40 in.) in size. Sand is compacted, slightly moist, well sorted, and consists of 50% basalt and 50% felsic. Reaction to HCl is moderate. 221′4″ to 222′ is coarse-grained sand (0.5 to 1 mm [0.02 to 0.04 in.]) that is 60% basalt and 40% felsic, compacted, and slightly moist. One quartzite pebble at 4 cm (1.57 in.) in diameter. Slight reaction to HCl.
222 to 224′	222 to 222′2″ are missing. 222′2″ to 222′4″ is coarse-grained, bedded sand (0.5 to 1 mm [0.02 to 0.04 in.]) that is 50% basalt and 50% felsic. 222′4″ to 222′8 1/2″ is darker and coarser sand consisting of 60 to 70% basalt. Grain size is 1 to 2 mm (0.04 to 0.08 in.) with pebbles up to 10 mm (0.40 in.) in diameter. There is crude color bedding. 222′8 1/2″ to 223′3″ is coarse-grained sand (0.5 to 2 mm [0.02 to 0.08 in.]) with a few granules up to 3 mm (0.12 in.) in size. Sand is 60 to 70% basalt and has crude color bedding. 223′3″ to 223′5 1/2″ is finer grained sand (0.5 to 1 mm [0.02 to 0.04 in.]), light color, and 50% basalt and 50% felsic. 223′5 1/2″ to 224′ is very coarse-grained sand (1 to 2 mm [0.04 to 0.08 in.]) with a few granules up to 3 to 4 mm (0.12 to 0.16 in.) in diameter. 60% basalt and 40% felsic. All the above are slightly moist, well sorted, and compact with no cementation. Reaction to HCl is moderate to strong.
225 to 227′	Core shows a color zonation. 225 to 225′2″ are missing. 225′2″ to 225′5″ is light color sand (1 mm [0.04 in.]) that is 50% basalt and 50% felsic.

Table 1. (contd)

Depth Below Surface (feet and inches)	Description of Core
225 to 227′ (contd)	225′5″ to 225′7″ is like the above sand but includes larger pebbles about 2 cm (0.79 in.) in diameter. 225′7″ to 225′9″ is sand that is 1 to 2 mm (0.04 to 0.08 in.) in size and 60 to 70% basalt and 30 to 40% felsic in composition. 225′9″ to 226′8″ is light color sand that is 50% basalt and 50% felsic with a layer of pebbles at 225′10″. 226′8″ to 227′ is coarser grained granules (3 to 5 mm [0.12 to 0.20 in.]) and is 60 to 70% basalt. All of the above are very compacted, well sorted and moderately moist. Reaction to HCl is moderate to strong.
227 to 229′	Upper 1″ of core is missing. 227 to 228′1″ is very coarse grained (0.5 to 7 mm [0.02 to 0.28 in.] and greater in size) with pebbles up to 4 cm (1.57 in.). Unit is 60 to 70 % basalt and 30 to 40% felsic, well compacted, slightly moist, and poorly sorted. 228′1″ to 229′ is coarse sand and granules (1 to 3 mm [0.04 to 0.12 in.]) that are 60 to 70% basalt and 30 to 40% felsic. Sand is 20 to 30% of the sample. The sediment is moderately sorted and slightly moist. Fines show strong reaction with HCl.
229 to 232′	Not logged – archive.
232 to 234′	No apparent internal structure. Entire core is coarse grained, poorly sorted, subangular, moderately compacted, and 50% basalt and 50% felsic. 50% of the sediment is 1 to 2 mm (0.04 to 0.08 in.) in size and 50% is greater then 2 mm (0.08 in.) in size. Sand is subangular and pebbles are rounded. Some basalt pebbles up to 3 cm (1.18 in.). Moderate reaction to HCl.
234 to 241′	Not logged – archive.
241 to 243′	Coarse sand (0.5 to 2 mm [0.02 to 0.08 in.]). Sand is 50% basalt and 50% felsic, subangular, slightly moist, well compacted, and well sorted. Slight reaction with the HCl.
243 to 255′	Not logged – archive.
255 to 256′	255 to 255′2″ is banded, fine- to medium-grained sand (0.1 to 0.5 mm [0.004 to 0.02 in.]) with 20% silt. 255′2″ to 256′ is sand (0.25 to 0.5 mm [0.01 to 0.02 in.]) that is 50% basalt and 50% felsic, slightly moist, and well sorted. No compaction or cementation. Moderate reaction with the HCl.
256 to 259′6″	Not logged – archive.

Table 1. (contd)

Depth Below Surface (feet and inches)	Description of Core
259′6″ to 261′6″	Upper 6″ of core are slough. At 260′4″ is a 1″ thick, basalt rich zone. This entire cored interval is medium to coarse sand (0.25 to 1 mm [0.01 to 0.04 in.]) that is well sorted, subangular to subrounded, and slightly moist. Sand is compacted but not cemented. No pebbles. Moderate reaction with HCl.
261′6″ to 265′	Not logged – archive.
265 to 266′6″	Bedding – 1 bed at 265′6″ to 265′8″ and another at 266′2″ to 266′4″. Except for the two beds, overall grain size is 0.25 to 0.5 mm (0.01 to 0.02 in.) with a few grains up to 1 mm (0.04 in.). Sand is angular to subangular, well sorted, slightly moist, and not very compacted. No cementation. Strong reaction with HCl. 265′8″ to 265′6″ is compact and slightly cemented with calcite (strong reaction with HCl). Grain sizes are as described above. 266′2″ to 266′4″. This layer is also cemented with calcite (reacts with HCl). Base of 266′5″ has rounded, basalt pebbles with some sand grains cemented on them. Pebbles are up to 4 cm (1.57 in.) in size.
266′6″ to 268′6″	266′6″ to 266′10″ is medium to coarse sand (0.25 to 1 mm [0.01 to 0.04 in.]) and gravel up to 4″ in diameter. 40 to 50% gravel. Sand shows moderate reaction with HCl. 60% felsic, 40% basalt. 266′10″ to 268′3″ is a sand and gravel sequence. 266′10″ to 266′11″ is calcite-cemented sand. Sand is 50% basalt and 50% felsic; gravel is 30% basalt and 70% felsic. Gravel ranges in size from 10 mm to 5 cm (0.40 to 2 in.). Sand has a strong reaction with HCl and contains some 2 mm (0.08 in.) pieces of calcite. Bottom 268′5″ to 268′7″ is sand.
270 to 272′	270 to 270′6″ is basalt gravel, up to 12 cm (4.72 in.) in diameter with some smaller, felsic gravel. 270′6″ to 271′10″ is gravelly sand, 60 to 70% sand, 30 to 40% gravel. Sand is (0.1 to 1 mm [0.004 to 0.04 in.]), angular to subangular, and contains caliche stringers. Gravel is rounded, poorly sorted, slightly moist, and consists of 60% basalt and 40% metamorphic rock fragments. Gravel is slightly cemented with calcite.

3.1.2 Sand Sequence

The upper 262 ft of the Hanford formation encountered in the borehole consists dominantly of fine- to coarse-grained sand with traces of silt and fine gravel. One zone, from 237 to 241 ft bgs, is sandy gravel with 40 to 50% fine to very fine pebbles. The sand sequence is equivalent to unit H2 of Lindsey et al. (1994) and may be equivalent to the following mapping units of Reidel and Fecht (1994a, b): Qfs_1, Qfs_2, and Qfs_3, Missoula Outburst Flood Deposits consisting of sand, silt, and clay.

The sands range in composition from about 75% felsic and 25% basaltic to 30% felsic and 70% basaltic. Generally, there is a tendency for the composition of the sands to become more basalt rich with depth. The sands are generally subround to subangular and moderate to well sorted. The degree of compaction varies within the sand-dominated sequence with some samples being loose, uncompacted sediment and others being compacted, competent sediment. That part of the sand-dominated sequence below the sandy gravel at 237 to 241 ft bgs is more compacted than the sands above the sandy gravel zone.

Cementation is rare throughout the sand-dominated sequence. Two palesols (78 and 170 ft bgs, respectively) are calcite cemented, as is a clay-rich layer at 120 ft bgs. A thin zone at about 118 ft bgs is iron stained and may contain some iron cementation. Above about 175 ft bgs, the silt fraction of the samples generally effervescence with HCl whereas the sand fraction does not. However, below 175 ft depth, effervescence of the sand fraction is common.

The dominant sedimentary feature existing in the sand-dominated sequence is bedding. Generally, bedding is fairly subtle and defined by slight color changes (that reflect slight changes in composition) or changes in grain size. Bedding defined by grain size changes reflects fining upward sequences that are generally on the order of about 5 to 15 cm (2 to 6 in.) thick.

Two paleosols (ancient soil zones) were identified in the drill core. The first was encountered at about 78 ft bgs and the second at about 170 ft bgs (see Table 1). These two paleosols are between 3 and 4 in. thick and are in the same relative stratigraphic positions as the paleosols for layers 1 and 2 that were encountered in borehole 299-E17-21 on the southwest side of the ILAW site (Reidel et al. 1998). If they are the same paleosols as those encountered in 299-E17-21, then these paleosols and the layers below them could form continuous layers across the ILAW site.

The two palesols provide reliable horizons to subdivide the Hanford formation sand sequence. The terminology used to describe the subdivisions in this report is consistent with that used by Reidel et al. (1998) for the subdivisions encountered in 299-E17-21.

Layer 1 is that part of the Hanford formation sand-dominated sequence extending from 170 ft bgs to the top of the gravel-dominated sequence at 270 ft bgs. Thus, layer 1 is 100 ft thick in this area. Layer 1 was found to be 84 ft thick in borehole 299-E17-21, which is about 900 meters (2953 ft) to the southwest. The paleosol defining the top of this layer is a silt zone with dark brown, bioturbated mud and calcite cement.

Layer 2 is between 170 and 78 ft bgs and is 92 ft thick. The paleosol defining the top of this layer is a zone of banded and bedded medium-grained sand. Layer 2 was found to be 105 ft thick in well 299-E17-21.

Layer 3 occurs above the upper paleosol. The thickness of layer 3 is at least 70 ft thick because the paleosol defining the top of the layer was not noted either in the core or drill cuttings in the field.

3.1.3 Eolian Unit

Up to about 7.5 ft of eolian silty sand overlies the Hanford formation at borehole 299-E24-21. The sand is fine- to very fine-grained and well sorted. This deposit represents reworked, windblown Hanford formation sand deposited since the last cataclysmic flood less than 13,000 years ago. These sediments are consistent with those described by Bjornstad (1999) in a trench excavated near the site of borehole 299-E24-21.

3.2 Passive Gamma Spectral Results

Duratek Federal Services logged the borehole on April 5, 2001 using a spectral gamma ray tool to verify the absence of man-made radionuclides. Previous experience from geophysical logging at 299-E17-21 showed that the vadose zone at the ILAW site does not exhibit significant stratigraphic changes that can be detected during geophysical logging. Well 299-E24-21 was logged after it had been completed and developed as a groundwater well. The results of this survey are presented in Appendix B. There are four logs: total gamma, potassium-40, uranium, and thorium. No man-made gamma emitting contamination was detected.

The resulting logs for total gamma, natural uranium, and thorium are not indicative of the vadose zone but, instead, reflect the sealing material. The slight drop in gross gamma count rate at approximately 20-foot intervals throughout the well is the result of changes in casing thickness where two adjacent pieces of casing screw together. Potassium-40 appears to reflect the presence of gravel. There is a slight decrease in potassium-40 values at approximately 237 ft bgs where the upper conglomerate appears and again at 270 ft bgs at the top of the lower gravel sequence.

4.0 Conclusions

Results from the second ILAW borehole are consistent with results from the first ILAW borehole (299-E17-21). These results indicate that the ILAW site is situated above an erosional channel cut into the Ringold Formation and filled with unconsolidated, open-framework gravel of the Hanford formation. Stratigraphy above the channel appears to consist of sediments representing three, individual Lake Missoula cataclysmic flooding events. These events that deposited the sediment are found to be continuous across the site.

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Appendix A

Results of Aquifer Testing in Borehole 299-E24-21

Appendix A

Results of Aquifer Testing in Borehole 299-E24-21

Frank Spane

A.1 Background

This letter report presents the analysis results for a series of slug tests conducted at well 299-E24-21. The field tests were performed in support of the TWRS Immobilized Low-Activity Disposal Complex (ILAWDC). The purpose of the slug tests was to provide initial hydraulic property estimates for the unconfined aquifer, specifically the Gravel Sequence – Layer 1 of the Hanford formation, in proximity to well 299-E24-21. The depth interval tested represents the upper 6.1 m (20 ft) of the unconfined aquifer, from approximately 95.2 to 101.3 m (312 to 332 ft) bgs. Preliminary geologic information indicates that the Layer 1 – Gravel Sequence unit of the Hanford formation occurs below a depth of 82.6 m (271 ft) bgs. The thickness of the unconfined aquifer is uncertain, but based on projection of information from nearby wells and a depth to water of ~95.2 m (312 ft) bgs, it is estimated to be approximately 25 m (82 ft) thick. This thickness is reflective of the projected top-of-basalt at this location. It is uncertain whether units of the Ringold Formation are present below Layer 1 of the Hanford formation and above the top-of-basalt contact. Information pertaining to well drilling, completion, development, and geologic description of materials encountered at the well are provided in Walker (2001).

The slug tests were conducted on June 12, 2001 following well completion and development activities that were concluded on March 28, 2001. The well has a 0.1016-m (4-in.) diameter well-screen completion, which is surrounded by an annular well sandpack out to a borehole diameter of 0.248 m (9.75-in.). Slug testing was conducted by removing a slugging rod (slug withdrawal test) of known displacement volume. Slug withdrawal tests were employed rather than slug injection tests (i.e., by rapidly immersing the slugging rod), because of their reported superior results for unconfined aquifer tests where the water table occurs within the well screen section (e.g., Bouwer 1989). In total, five slug withdrawal tests were conducted. For the first and last test (#1 and #5), the slugging rod displacement volume was 0.0037 m^3 (0.13 ft^3). For tests #2, #3, and #4, a larger slugging rod with a displacement volume of 0.0091 m^3 (0.32 ft^3) was utilized. Different sized slugging rods were used during testing to impart varying stress levels during testing, which are useful for assessing the effectiveness of well development and the presence of dynamic skin effects (Butler et al. 1996). The similarity in test responses and rapid test recoveries for the two different slug rod sizes used indicate that the well had been adequately developed and that skin effects did not adversely effect the slug test response.

A.2 Diagnostic Test Responses

All five slug tests exhibited extremely rapid recovery patterns (i.e., 99% recovery) within 6 sec of test initiation. The extremely rapid recovery behavior is indicative of highly permeable test formation conditions. Because of the existing high permeability, the test formation was likely recovering during slugging rod removal (implemented to initiate the test), so a “full” stress level associated with the slugging rod volume was not applied to the well/test interval during the test. Based on back-projection of early-time test data, only about 1/10th of the theoretical stress (i.e., observed = 0.101 m [0.33 ft]; theoretical = 1.117 m [3.7 ft]) is estimated to have been applied during the high stress tests. Because of the higher observable test responses, only the high-level stress tests (i.e., Tests #2, #3, and #4) were selected for detailed hydraulic test analysis.

A.3 Analysis Methods

As discussed in Spane et al. (2001a, 2001b), the two analytical methods used for the analysis of unconfined aquifer slug tests for Hanford Site investigations include the type-curve matching method as presented in Hyder et al. (1994), Hyder and Butler (1995), and Spane and Wurstner (1993), and the semi-empirical straight-line analysis method described in Bouwer and Rice (1976) and Bouwer (1989). Because the type-curve analytical methods can use all or any part of the slug test response in the analysis procedure, they are particularly useful in the analysis of high permeability, unconfined aquifer tests (e.g., as exhibited at well 299-E24-21). They also do not have any of the inherent analytical weaknesses of the commonly used Bouwer and Rice method (e.g., assumption of steady-state flow, isotropic conditions, inelastic response, etc.), as originally described in Bouwer and Rice (1976) and Bouwer (1989) for unconfined aquifer slug tests. These analytical limitations are discussed in Hyder and Butler (1995), Brown et al. (1995), and Bouwer (1996).

Although slug tests provide a rapid and economical hydraulic test method for acquiring site-specific estimates of hydraulic conductivity, they have limitations for characterizing high permeability aquifers such as the Hanford formation at well 299-E24-21. To illustrate this limitation, predicted slug test responses (in standard type-curve format) are shown in Figure A.1 for hydraulic conductivity values (K) of 25, 50, and 100 m/d. The test responses were calculated using the KGS model described in Liu and Butler (1995) for the listed parameters, which are reflective of well/aquifer conditions at the well 299-E24-21. As shown, for most practical applications, slug test analysis using the type-curve method would be limited for aquifer materials exhibiting K values of ≤100 m/d. Figure A.2 shows the same test responses expressed in the graphical format commonly used for Bouwer and Rice analysis. Because of this method’s dependence on early-time response analysis, its practical limit would be for aquifer material exhibiting K values of approximately 25 m/d or less.

As noted previously because the type-curve method can use all or any part of the slug-test response in the analysis procedure, it provides the best opportunity for analyzing the rapid/elastic slug-test responses

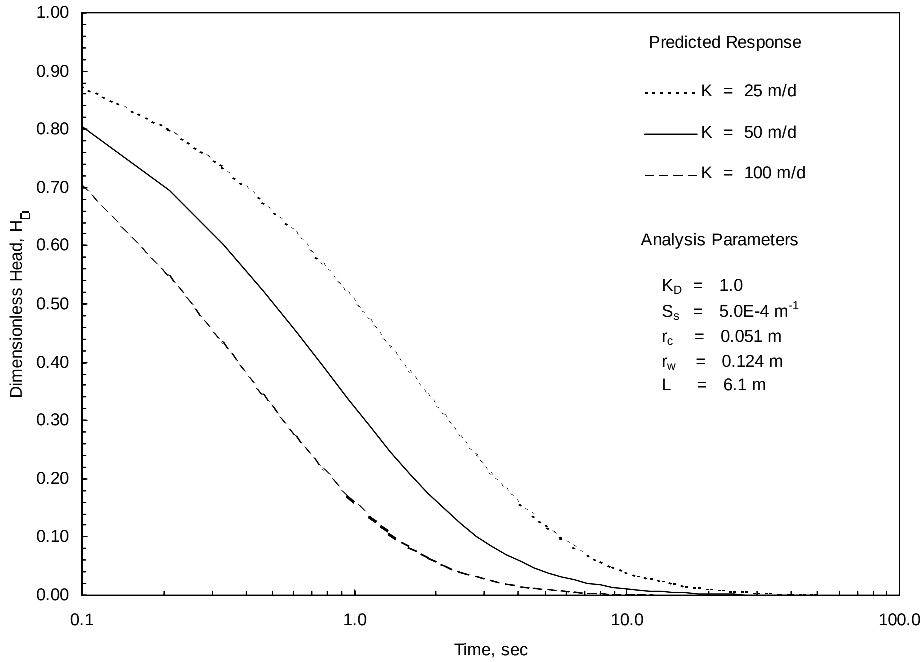

Figure A.1. Predicted Slug Test Response Characteristics at Well 299-E24-21 for Selected Aquifer Conditions

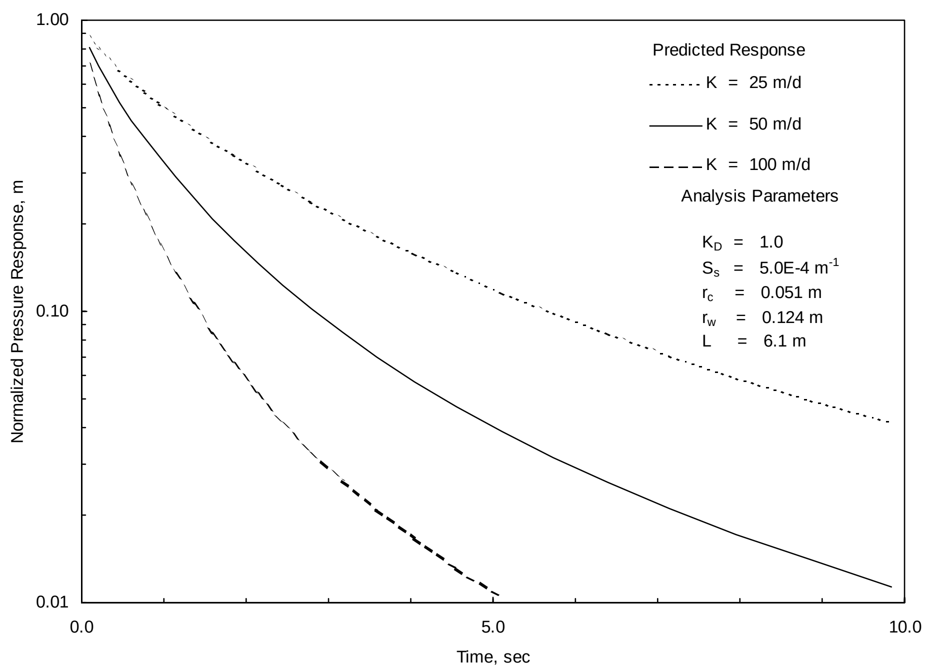

Figure A.2. Predicted Bouwer and Rice Method Slug Test Response Characteristics at Well 299-E24-21 for Selected Aquifer Conditions at well 299-E24-21. To facilitate the slug-test type-curve analysis, the standard set of initial analysis parameters specified in Spane et al. (2001a, 2001b) was assumed:

- a vertical anisotropy, K_D, value of 1.0
- a specific storage, S_s, value of 0.00001 m^{-1}
- the well-screen interval below the water table was assumed to be equivalent to the test-interval section.

As noted in Butler (1998), a K_D value of 1.0 is recommended for slug-test analysis when setting the aquifer thickness to the well-screen length. Previous investigations by the author have indicated that single-well slug-test responses are relatively insensitive to K_D; therefore, the use of an assumed (constant) value of 1.0 over a small well-screen section (i.e., <10 m long) is not expected to have a significant impact on the determination of hydraulic conductivity, K_h, from the type-curve-matching analysis.

To facilitate the slug-test type-curve analysis, a S_s value of 0.00001 m^{-1} was used for all initial analysis runs. After initial matches were made through adjustments of K, additional adjustments of S_s were then attempted to improve the overall match of the test-response pattern. Because the tests exhibit elastic response behavior, the input S_s values were increased to improve the final analysis type-curve matches. It should be noted, however, that other factors influence the shape of the slug-test curve (e.g., skin effects, K_D). For this reason, the S_s estimate obtained from the final slug-test analyses is considered to be of only qualitative value and should not be used for quantitative applications.

For the slug-test analysis, the saturated well-screen interval (rather than the sandpack interval) was used to represent the test interval. This was based on the assumption that the formation materials within the screened interval have a higher permeability than the sandpack; therefore, test-response transmission is expected to propagate faster laterally from the well screen to the surrounding test formation than vertically within the sandpack zone. In reality, only small differences exist between individual well-screen and sandpack-interval lengths (i.e., compared to the aquifer-thickness relationship) and, subsequently, no significant differences in analysis results would be expected. This assumption is consistent with recommendations listed in Butler (1996).

A.4 Analysis Results

Although all individual, normalized slug tests exhibited similar response characteristics, the high stress-level tests (i.e., Test #2, #3, and #4) generally exhibited less noise and larger test responses, which facilitates their analysis. For this reason, the high stress tests were the only tests selected for detailed analysis. Because of the uniform, rapid recovery rate exhibited by the tests (i.e., within 6 sec), the high-stress responses were combined to produce a more complete data record over the test recovery period. The composite test response (i.e., for Test #2, #3, and #4) was smoothed using a five-point moving average scheme (central), to support the type-curve matching procedure. Figure A.3 shows the type-curve and derivative plot match to the high-stress, composite test response. As indicated, a relatively good test data and data derivative match was obtained for a hydraulic conductivity value of 75 m/d. For

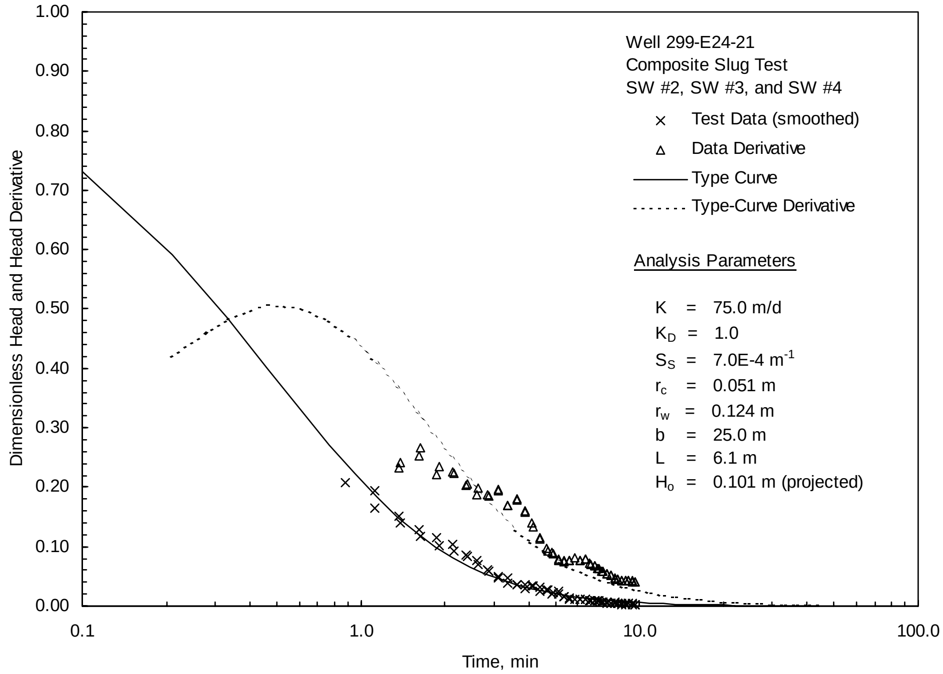

Figure A.3. Analysis Plot for Composite High-Stress Slug Tests Conducted at Well 299-E24-21

comparison purposes, Figure A.4 shows the composite test response in relation to the predicted slug test behavior (in Bouwer and Rice response format) shown in Figure A.2. As illustrated, the composite response is bracketed by the predicted 50 and 100 m/d K profiles.

It should be noted that the K estimate value of 75.0 m/d is considered to be a lower bound value for the Hanford formation (Layer 1) at this well location. This is due to turbulent flow conditions that likely occurred during the first second of the test. As noted previously in Spane and Thorne (1994) for slug tests conducted in highly permeable formations, the effects of turbulence may cause additional friction losses that are independent of the aquifer, causing a slower water-level recovery during the tests. Analysis of tests that are significantly affected by friction, therefore, will give results for K that are lower than the actual hydraulic conductivity of the test interval.

For future tests conducted at well sites like well 299-E24-21 that are completed in highly permeable test formations, it is recommended that the slug tests be conducted pneumatically to apply the test stress instead of mechanically using a slugging rod. The use of pneumatic slug tests may improve data acquisition for test responses during the first second of the test, and extend characterization capabilities to higher permeability formation conditions. (Note: for the performance of pneumatic slug tests at wells where the water table is within the well screen, an installation of a blank test tubing section a short distance below the water table would be required). A description of the performance of pneumatic slug interference tests on the Hanford Site is provided in Spane et al. (1996).

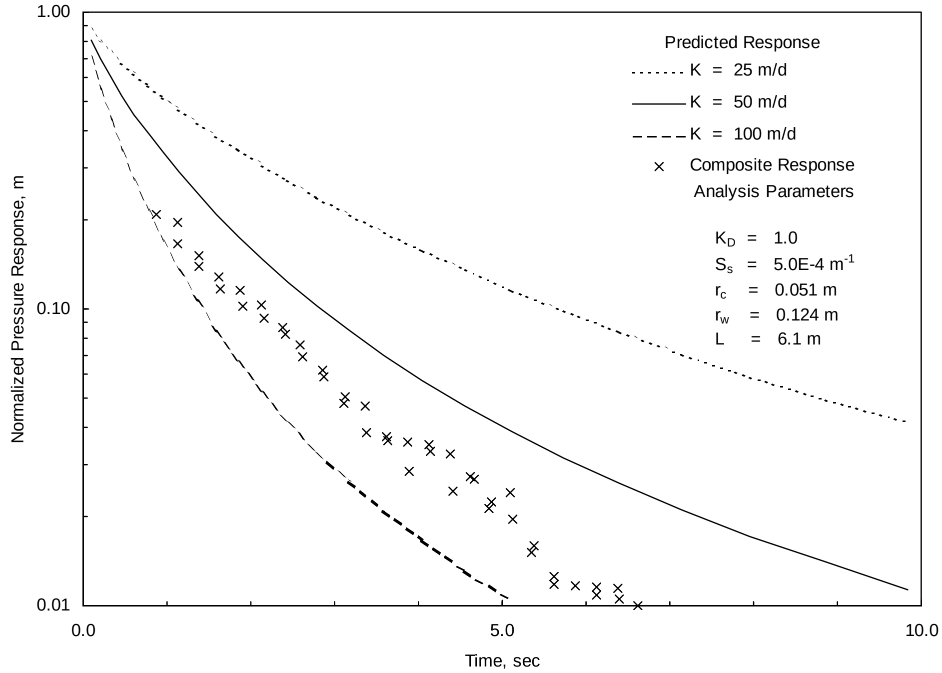

Figure A.4. Comparative Analysis Plot for Composite High-Stress Slug Tests Conducted at Well 299-E24-21 (Bouwer and Rice Method)

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Appendix B

Geophysical Logging Results for Borehole 299-E24-21

RLS Spectral Gamma Ray Borehole Survey

Duratek Federal Services

Log Header

Project: ILAW — Well: **299-E24-21**

Log Type: HPGe Spectral Gamma Ray (Figure B.1)

Borehole Information

Well # C3177	Water Depth 313 ft	Total Depth 335 ft
Elevation Reference n/a	Elevation n/a ft	
Depth Reference Ground Surface	Casing Stickup 2.79 ft	
Casing Diameter 6 ID in	Depth Interval 0 to 10 ft	Thickness 0.125 in
Casing Diameter 4 ID in	Depth Interval 0 to 335 ft	Thickness 0.083 in

Logging Information

Log Type:	HPGe Spectral Gamma Ray		
Company	Duratek Federal Services		
Date/Archive File Name	April 5, 2001	H2E24021	
Logging Engineers	J. Kiesler		
Instrument Series	RLSG07000S01.0		
Logging Unit	RLS-1		
Depth Interval	0 to 170 ft	Prefix	A715
	140 to 300 ft		A716
Instrument Calibration Date	Oct 6, 2000		
Calibration Report	WHC-SD-EN-TI-292, Rev 0.		

Analysis Information

Company	Three Rivers Scientific
Analyst	Russ Randall
Date	April 23, 2001

Notes No man-made contamination was detected. The KUT levels are a response to sealing material and not common to Hanford vadose conditions.

Spectral Gamma Ray Log Analysis & Summary

Waste Management Federal Services

Project:	ILAW	Well:	**299-E24-21**
Log Type:	HPGe Spectral Gamma Ray	Log Date:	April 5, 2001

General Notes:

Total gamma is a response to wellbore sealing material and not to the geologic conditions of the vadose zone.

Log data collected with a depth reference of ground surface.

System Performance Verify: The pre- and post-log verification passed performance standards; a –14% change was observed in the gross, (based upon borehole survey data sheet). The FWHM of the 583 keV photo peak was also within specifications for pre- and post-log verification.

Repeat Interval: Based on the repeat interval, the logging system performed as per specifications.

Environmental Corrections: All radionuclide concentrations have been corrected for casing attenuation (entire well). Water correction was not applied, since logging did not enter water.

Radionuclides:

No man-made radionuclide contamination was detected. This observation was confirmed using a summing technique for the spectral data.

The natural uranium and thorium concentrations are not indicative of the vadose zone. The sealing material generates the majority of the signal for KUT results. From ground surface to 10 feet, there is little sealing material, and from 10 to 15 feet larger diameter sealing is present surrounding the casing. From 268 to 272 feet, the sealing material is again more prominent suggesting this sealed interval is also larger diameter than other depths. A lack of sealing material is also evident from 289 to 292 feet.

Slight drops in gross gamma occur at approximately 20-foot intervals indicating the presence of collar thickness changes over the thin wall casing. No change in attenuation correction was applied for these collar thickness changes, since the depth intervals are too short to make adequate corrections.

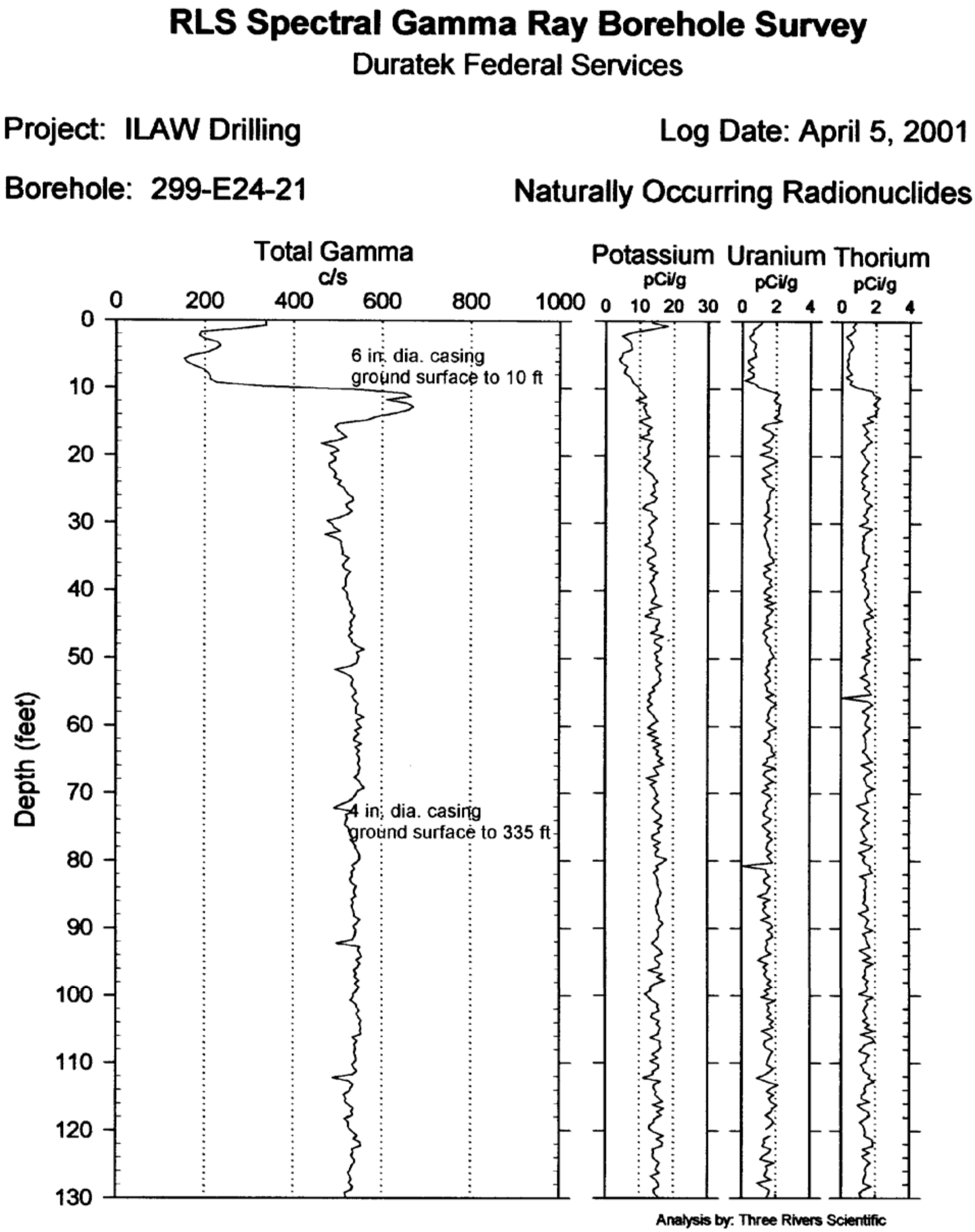

Figure B.1. Wireline Geophysical Logs for Borehole 299-E24-21

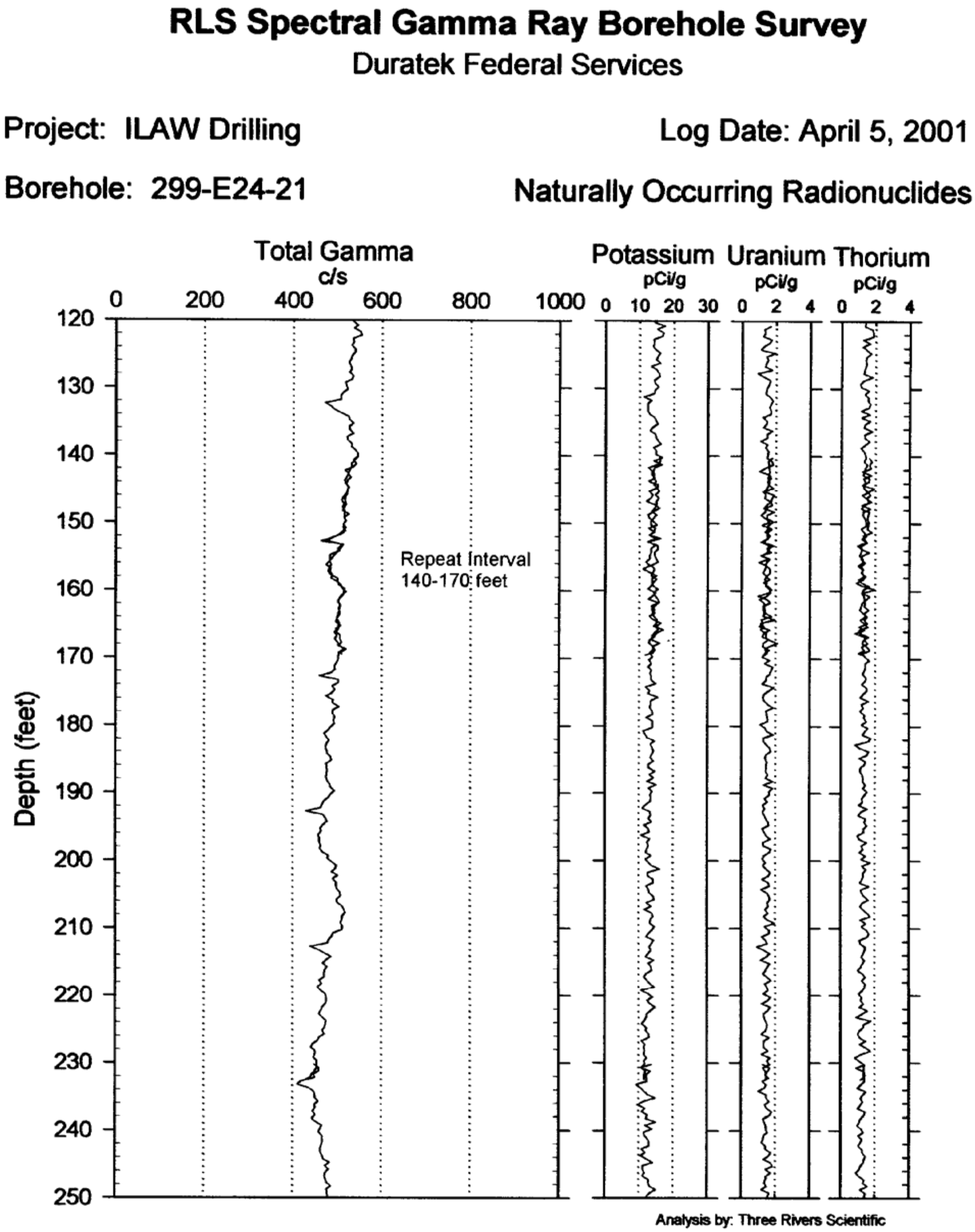

Figure B.1. (contd)

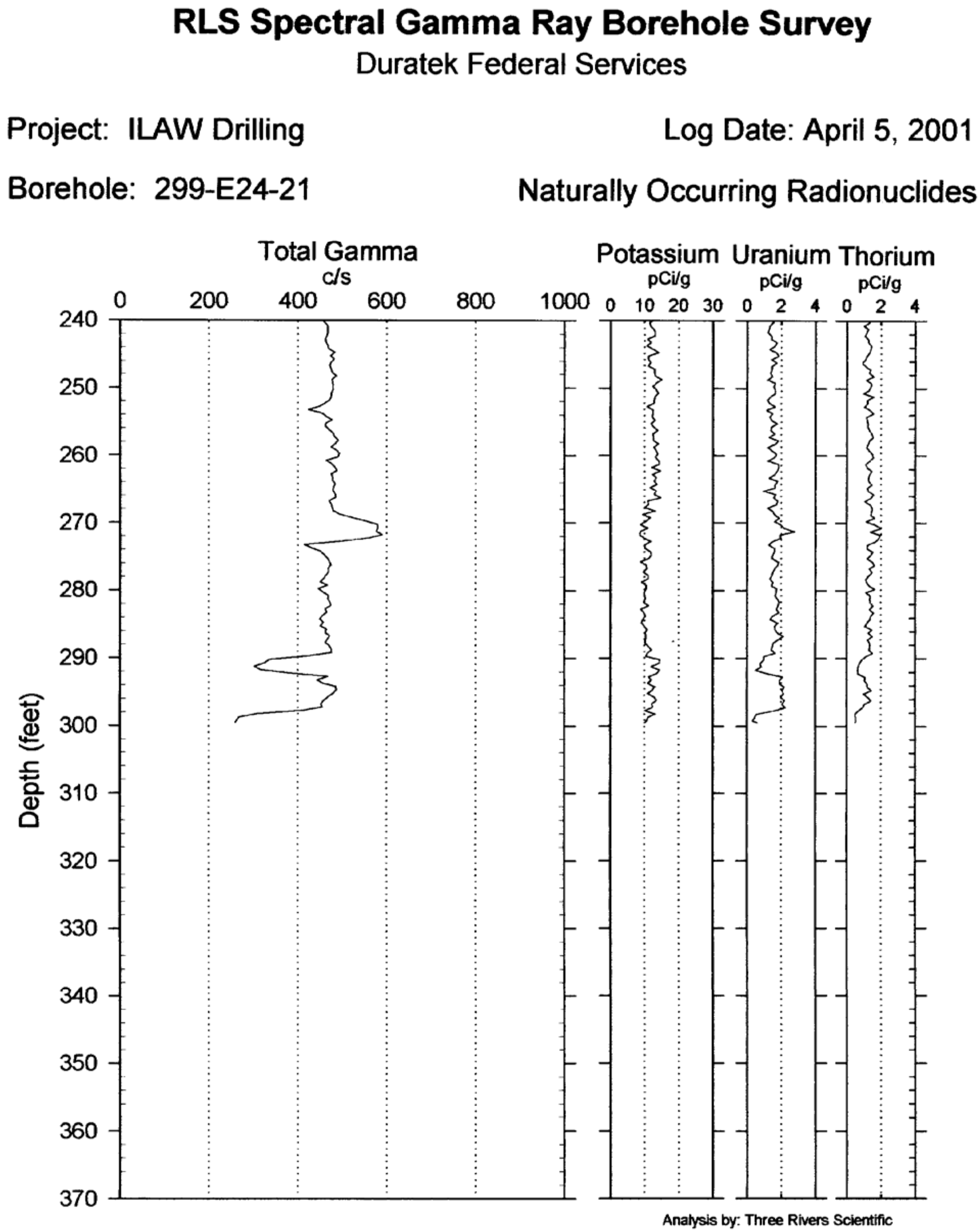

Figure B.1. (contd)

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