PNNL-14586 Rev 1

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Geologic Data Package for 2005 Integrated Disposal Facility Waste Performance Assessment

S. P. Reidel

August 2002

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Summary

This data package is a compilation of existing geologic data from the Integrated Disposal Facility Site for use in the 2005 Performance Assessment. The data were compiled from both surface and subsurface geologic sources. The surface mapping has been published previously. The quality and uncertainty of the data are discussed. The 2004 report was modified to include results of studies of the shearwave velocity of sediments at and near the IDF site, which were performed for the Waste Treatment Plant and groundwater monitoring wells 299-E17-26 and 299-E24-24. The conclusions of the original report have not changed with the new data.

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1.0 Introduction

The Office of River Protection at the Hanford Site is responsible for the 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) and other mixed waste in a new facility, the Integrated Disposal Facility (IDF), in the south-central part of 200-East Area (Figure 1.1) (Mann et al. 1998).

This report is a compilation of the existing geologic data package for the Integrated Disposal Site. This data package is being assembled for the 2005 IDF Performance Assessment (PA).

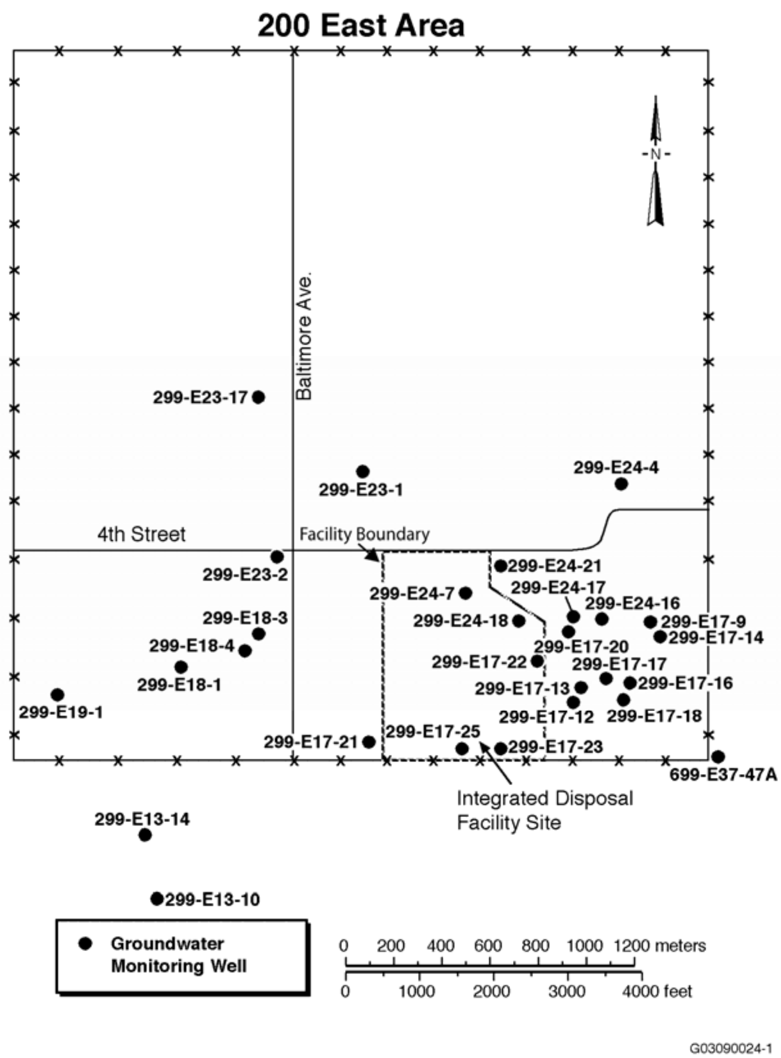

Figure 1.1. Location Map of the Integrated Disposal Facility

2.0 Source of Data

Data used in this compilation were obtained from surface geologic studies and from borehole data.

2.1 Surface Data

The surface geology and geomorphology of the Hanford Site has been mapped and published by Reidel and Fecht (1994a, 1994b, 2005). Reidel and Fecht (2005) mapped the geology exposed in the trench that was excavated during 2004 and 2005. These studies (Figure 2.1) have shown that the

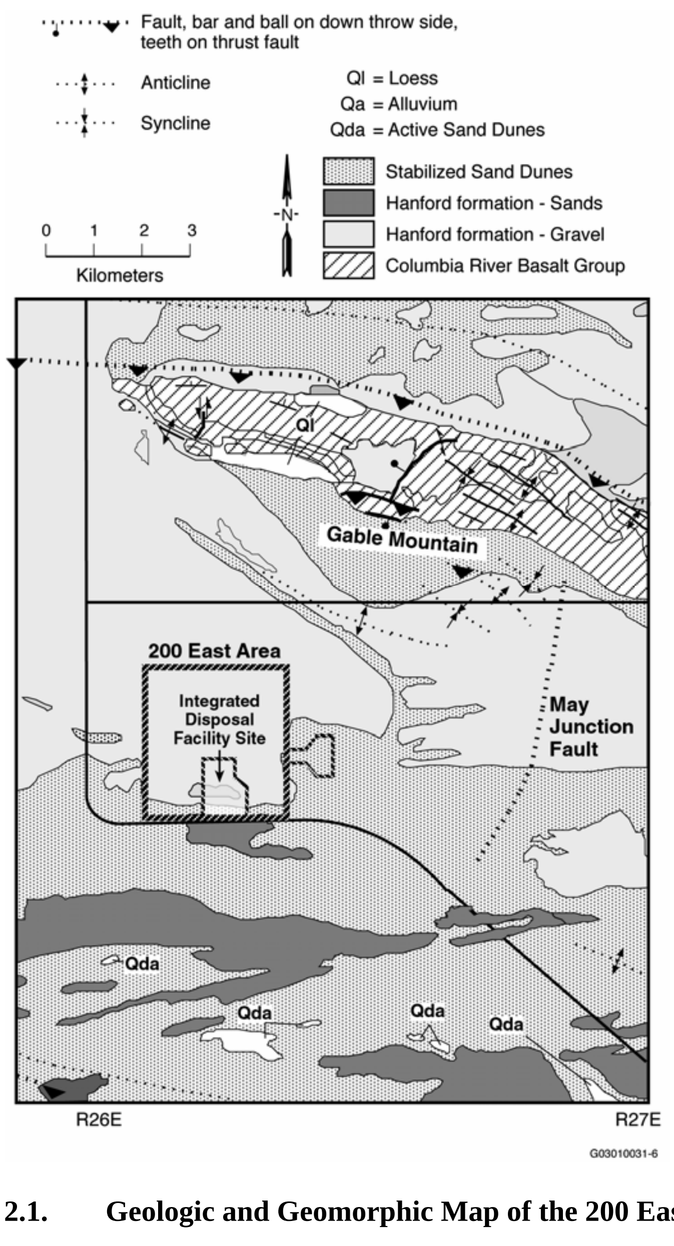

Figure 2.1. Geologic and Geomorphic Map of the 200 East Area

geomorphology of the 200 Areas is a flood bar (the 200 Areas plateau) that formed as sediments were deposited by the Missoula floods during the Pleistocene Epoch. A topographic low area immediately east of the 200 East Area is an erosional channel cut by the Missoula floodwaters that moved south through Gable Gap.

The principal geologic units exposed at the surface are fluvial and eolian sands (Reidel and Fecht 1994a, 1994b, 2005). The fluvial sands were deposited by the Missoula floods and have since been reworked by westerly winds to form a thin veneer of eolian deposits. The eolian deposits have been stabilized by vegetation in some areas but active sand dunes are present to the south.

2.2 Borehole Sources

Borehole data consisting of drilling logs, archived samples and geophysical logs are the principal data sets used to interpret the subsurface at the IDF. In addition, numerous reports describing the geology of the area and vicinity are available and are a valuable source of information (e.g., Tallman et al. 1979; DOE 1988; Connelly et al. 1992; Williams et al. 2000). During the course of this study, archived natural gamma geophysical logs from boreholes at the site and surrounding area were located and the logs were incorporated into the interpretations. These older geophysical logs included some from surrounding waste disposal sites obtained prior to discharge of effluent and provide an additional source of information for stratigraphic correlations.

Table 2.1 summarizes pertinent information about the wells and boreholes used in this report. The north-south and east-west coordinates listed in Table 2.1 were obtained from the well completion report for each borehole or, if no well completion report was available, from the well database maintained by Pacific Northwest National Laboratory (PNNL). For data obtained from the database, the most recent survey was used.

Elevation information listed in Table 2.1 was obtained from well completion reports, engineering surveys, as-built diagrams if available, from Chamness and Merz (1993), or from a well database maintained by Pacific Northwest National Laboratory. Because the boreholes are from so many vintages and because several different surveys have been used at the Hanford Site over the years, no attempt was made to assure consistency in the elevation survey data. However, differences among surveys are generally small (<3 feet; 1 m) with respect to other uncertainties associated with the data (see discussion on uncertainties). Except for water levels in areas with a relatively flat water table, the uncertainties will not affect significantly the geologic information presented in this database. The well completion dates for the boreholes, the total depths, and the types of boreholes were obtained from well completion reports, as-built diagrams, and Chamness and Merz (1993).

Particle size distribution and calcium carbonate content information are available for some boreholes from the ROCSAN database and studies on the IDF well samples. The ROCSAN database is a database of particle size distribution data that was maintained by Rockwell Hanford Operations and Westinghouse Hanford Company. The database is no longer maintained but is on file at Pacific Northwest National Laboratory and available through the *Virtual Library* maintained by the integrating contractor. Table 2.1 indicates the drilling and sampling method used for each borehole. ROCSAN data was only considered

Table 2.1. Borehole Information from the IDF Site and Adjacent Area

Borehole	Completion Date	Lambert Coordinates NS/EW (m)	Hanford Coordinates NS/EW (f)	Quality	Purpose	Casing Elevation (ft)	Ground Elevation (ft)	Total Depth (ft)	Type of Log	Drilling Method	Sieve	$CaCO_3$	Moisture	Gross Gamma-Ray Log	Neutron Log	Drill Cuttings
E13-10	1984	134249.07/ 573190.57	35348/-54798	Good	GW	733	NA	346	Geologist	Cable tool	N	N	N	N	N	N
E17-12	1986	135118.36/ 574902.94	38200/-49180	Good	GW	719	NA	340	Geologist	Cable tool	N	N	N	N	N	N
E17-13	1986	135164.69/ 574902.94	38352/-49039	Good	GW	719	NA	337	Geologist	Cable tool	N	N	N	N	N	N
E17-17	1988	135201.57/ 575044.06	38473/-48717	Good	GW	720	717	331	Geologist	Cable tool	N	N	N	Y	N	N
E17-18	1988	135115.31/ 575109.99	38190/- 48500.7	Good	GW	721	718	332	Geologist	Cable tool	N	N	N	Y	N	N
E17-20	1988	135407.71/ 574936.49	39149.3/- 49069.9	Good	GW	719	717	324	Geologist	Cable tool	N	N	N	Y	N	N
E17-21	1998	134894.21/ 574107.02	NA	Good	GW/V/C	737	735	480	Geologist	Becker	Y	Y	Y	Y SG	Y	Y Core
E17-22 C3826	2002	135195.921/ 574841.067	NA	Excellent	GW/V/C	737.01	723.7	363	Geologist	Becker	Y	Y	Y	Y SG	N	Y Core
E17-23 C3827	2002	134842.766/ 574694.485	NA	Excellent	GW/V/C	745.0	734.4	372	Geologist	Becker	Y	Y	Y	Y SG	N	Y Core
E17-25 C3926	2002	134845.913/ 574515.171	NA	Excellent	GW/C	751.5	738.3	382.5	Geologist	Becker	N	N	N	Y SG	N	Y
E17-26 C4648	2005	135025.06/ 574662.61	NA	Excellent	GW	738.6	736.3	379	Geologist	Becker	N	N	N	Y SG	N	Y
E18-1	1988	135197.30/ 573294.20	38459/-54458	Good	GW	720	716	332	Geologist	Cable tool	Y	Y	N	Y	N	N
E18-3	1988	135274.42/ 573426.85	38712/- 54022.8	Good	GW	722	718	330	Geologist	Cable tool	Y	Y	N	Y	N	N
E18-4	1988	135755.82/ 573426.48	38651/-54024	Good	GW	722	718	330	Geologist	Cable tool	Y	Y	N	Y	N	N
E19-1	1957	135083.31/ 572817.19	38085/-56023	Poor	GW	736	NA	370	Driller's log	Cable tool	N	N	N	Y	N	N
E23-1	1956	136011.73/ 574043.40	41131/-52000	Fair	C	710	NA	348	Driller's log	Cable tool	Y	Y	N	Y	N	Y
E23-2	1961	135667.00/ 573738.60	40000/-53000	Fair	GW	721	NA	456	Driller's log	Cable tool	N	N	Y	N	N	N

Table 2.1. (contd)

Borehole	Completion Date	Lambert Coordinates NS/EW (m)	Hanford Coordinates NS/EW (f)	Quality	Purpose	Casing Elevation (ft)	Ground Elevation (ft)	Total Depth (ft)	Type of Log	Drilling Method	Sieve	$CaCO_3$	Moisture	Gross Gamma-Ray Log	Neutron Log	Drill Cuttings
E24-4	1956	136027.24/ 575115.44	41181.9- 48482.8	Fair	GW	697	NA	330	Driller's log	Cable tool	N	N	Y	N	N	N
E24-7	1956	135554.38/ 574405.20	39630.5/- 50813	Poor	GW	716	NA	450	Driller's log	Cable tool	Y	Y	N	N	N	Y
E24-16	1988	135456.54/ 575016.14	39309.5/- 48808.6	Good	GW	718	715	329	Geologist	Cable tool	N	N	N	Y	N	N
E24-17	1988	135456.32/ 574936.34	39308.8/- 49070.4	Good	GW	719	716	329	Geologist	Cable Tool	N	N	N	Y	N	N
E24-18	1988	135463.0/ 574645.59	39330.7/- 50024.3	Good	GW	719	716	330	Geologist	Cable tool	N	N	N	Y	N	N
E24-21 C3177	2001	135698.200/ 574635.761	NA	Excellent	GW, C	727.7	724.7	335	Geologist	Becker	Y	Y	Y	Y SG	N	Y Core
E24-24 C4647	2005	135459.3/ 574179.77	NA	Excellent	GW	725.8	723.4	364	Geologist	Becker	N	N	N	Y SG	N	Y
E37-47A	1996	134893.26/ 575556.97	37430.58/ 47044.23	Good	GW	717	715	525	Geologist	Air Rotary	Y	Y	Y	Y SG	Y	Y
C3828	2002	134845.545/ 574518.125	NA	Excellent	C	NA	748.2	383	Geologist	Becker	Y	Y	Y	N	N	Y Core
C4562	2004	134894.21/ 574107.02	NA	Excellent	C (Seismic)	737	735	540	Geologist	Becker	N	N	N	N	N	Y

C = Characterization
GW = Groundwater
NA = not available
N = No
SG = Spectral Gamma-Ray
V = Vadose
Y = Yes

for intervals in boreholes sampled by drive barrel because hard tool drilling pulverizes the sediments so that results are not representative of actual particle size distribution. The drilling method was obtained from geologists logs, well construction reports, and as-built diagrams for most boreholes. Appropriate particle size distribution data from ROCSAN was used as supplemental textural information but because of the varying quality of the data, it is not included in this report. Khaleel (2004) reports particle size data from the disposal site and should be referred to for the best compilation of data.

Calcium carbonate and moisture contents are available for some boreholes. Available data are in the borehole packages on file at Pacific Northwest National Laboratory and reports on IDF samples. The data were obtained from discrete samples collected by the borehole geologist during drilling. The moisture data were used to supplement the geologists log and the gross gamma-ray log in determining lithologic variations. For obvious reasons, moisture data is only valuable for samples collected above the water table. Khaleel (2004) reports moisture data from the disposal sites and should be referred to for the best compilation of data from these sites.

Gross gamma-ray logs, spectral gamma-ray logs, and neutron moisture logs exist for many of the boreholes used for this database. Only logs obtained during drilling were used to supplement the geologists log because most of the geophysical logs obtained subsequent to borehole completion reflect the borehole construction materials more than they do the geologic materials. Available logs listed in Tables 2.1 and 2.2 are on file at Pacific Northwest National Laboratory. The newer RCRA (spectral gamma-ray) well logs are available electronically through the USDOE Grand Junction Office.

Finally, drill cuttings (e.g., chip samples) are available from most of the boreholes used for this database. The same precautions pertaining to the ROCSAN data pertain to the physical samples. That is, drill cuttings obtained from hard tool drilling methods will yield an unrepresentative particle size distribution; lithologies however, remain unchanged. All available physical samples are on file in the Hanford Geotechnical Sample Library under custody of Pacific Northwest National Laboratory.

2.3 Methodology

The process of building the database followed a series of steps that were designed to insure the data were used properly. First, the main stratigraphic units and contacts were identified in boreholes with geologists logs and geophysical data. Gross gamma-ray logs were examined with respect to the geologists logs for geophysical signatures of the stratigraphy. For many boreholes, chip samples (e.g., drill cuttings) from the Hanford Geotechnical Sample Library were examined to confirm stratigraphic units and lateral changes in the percentage of silt, sand and gravel. Next, boreholes with driller’s logs and gross gamma-ray logs were examined and compared to nearby wells and boreholes.

3.0 Uncertainty in Data

The principal source of uncertainty for the lateral continuity of the layers and thickness of the beds is borehole data. Surface mapping is well controlled at Hanford and has been done by geologists with extensive mapping experience at Hanford and in the Columbia Basin. The quality of borehole data is related to the drilling technique, the logging of the borehole, and the sample collection. Subtle differences between some stratigraphic units such as silty sandy layers of the Hanford formation and units of the underlying Ringold Formation (e.g., upper Ringold and intercalated silty units) make identification of the contact difficult. The quality of the driller's/geologist's log, and archived samples and use of geophysical logs become crucial to reducing this type of uncertainty.

In addition to the uncertainty in borehole data, there is uncertainty in the geometric shape of the sediment body. Because of the nature of the cataclysmic flooding that produced the Hanford formation, very few analogs are available for comparison to the Hanford Site. Borrow pits in the Pasco Basin and excavations at Hanford provide a glimpse into the geometric shape of a sediment body but often the nature of the sediment body must be interpreted from boreholes.

3.1 Drilling Techniques

Most boreholes near the proposed Integrated Disposal Site have been drilled using cable tool techniques and, less often, air rotary techniques. Five new IDF boreholes, 299-E17-21, 299-E24-21, 299-E17-22, 299-E17-23, and 299-E17-25, however, were drilled using the Becker-Hammer technique that allowed high quality core samples to be recovered. The principal source of uncertainty here is in the depth and thickness of the sedimentary beds due to straightness of the boreholes, which have not been surveyed for straightness. However, this is deemed to be minor because most boreholes have shown to have minor deviations when the groundwater pumps and risers were installed.

Cable tool drilling has been the standard technique from earliest drilling at Hanford because drilling can be done without adding water. Drilling advances by use of drive barrel or hard tool and driven temporary casing. However, drillers routinely added water when using hard tool. The technique generally provides acceptable sample control and has proven successful. More recently, in uncontaminated areas, air rotary has been the preferred technique. There are several disadvantages to the cable tool drilling:

- Samples can be difficult to retain in the drive barrel, especially samples from very dry zones.
- Gravels are not easily retrieved because they are not easily retained in the drive barrel;
- Cemented units or large gravels must be drilled with a "hard tool" which breaks up the sample and alters the grain size distribution of samples.

The disadvantages to air rotary drilling are:

- Samples can be difficult to retrieve. The quantity of sample is often related to the air pressure used.
- Low pressures of the air line can result in excessive grinding of particles by bits and thus, the sample may not be representative of the sediment body.

Most boreholes prior to the 1980s were drilled without a well-site geologist present to log the samples. Thus, the only records of early drilling are driller's logs that vary in the quality of the sample description. Driller's logs are extremely inconsistent because the driller's attention is focused on operating the rig and not on describing the samples. The quality of the geologist's logs also varies from borehole to borehole. For example, a geologist new to the site will recognize the major sediment changes in drill cuttings but may not recognize the subtler changes that also represent changes in stratigraphy.

Many boreholes at Hanford were completed without the benefit of being geophysically logged. Geo-physical logging can be an important tool for determining the depth of lithologic changes. Geophysical logs show subtle lithology differences stemming from of differing amounts of natural gamma-ray emitters (most commonly 40K). Gamma-ray logs typically are proportional to clay and silt abundance and can provide information on changes in grain size. When geophysical logs are used along with the well-site geologist's logs and archived samples, the uncertainty in the depth of lithologic changes is reduced.

3.2 Borehole Location and Coverage

Borehole coverage is usually dictated by factors other than addressing a geologic problem. Therefore the coverage of boreholes is generally inadequate to address many geologic problems. For the Integrated Disposal Site borehole coverage is good because of characterization studies for the Performance Assessment and the installation of groundwater wells.

3.3 Sampling

Sample retrieval is often difficult and sample quantities are limited. Vadose zone drilling is difficult for sample recovery because the samples are typically dry and are not easily retained in the drive barrel. As indicated above, the grain size of the sample can also be affected by the drilling technique such as in "hard tool" drilling which generates an increase in the fine-grained portion of the sediment samples.

In order to perform certain tests, samples from several depths often must be composited. Also, certain tests performed on samples in the past may also have destroyed the integrity of the sample. In the past particle size testing resulted in loss of fines when the samples were returned to the Hanford Geotechnical Sample Library.

3.4 Quality of Data

From the considerations discussed above, the quality of data available for the Hanford Site and the disposal site is variable. This section discusses how the uncertainty of the data was factored into the geologic models for the sites.

3.4.1 Drilling

Except for IDF Project boreholes, most boreholes were drilled using typically the cable tool and air rotary method. The Becker Hammer technique used on boreholes 299-E17-21, E17-22, E17-23, E17-25, and E24-21 provided typically undisturbed core samples. Table 2.1 provides a listing of the drilling techniques and information relevant to drilling and sampling activities for boreholes used in this report. The cable tool and air rotary techniques provided cuttings that can be logged. Both methods provide samples and if the drilling technique was recorded, then sample quality can be easily factored in to the geologic interpretations (e.g., cable tool uses a hard tool which breaks up gravel thus particle size distributions in gravels are in error and severely limits the use for geologic interpretations).

3.4.2 Geologist's and Driller's Logs

By far the main factor effecting quality of the data is the drilling log. Generally, prior to the late 1970s, geologists were not present during drilling. Thus, the logs available for this time period are poor to fair. It is apparent that some drillers were very good at describing the sediments so that the quality of driller's log is variable but even then only the major stratigraphic changes or properties are recorded. By far the best quality well logs are those prepared by experienced geologists. Most wells drilled after the late 1970s were logged by geologists. Table 2.1 provides a listing of which wells were logged by geologists.

3.4.3 Geophysical Logs

Geophysical logging techniques have improved over the years but even an older gross gamma-ray log from a borehole is an invaluable piece of information. Probably the poorest quality interpretation is from a borehole for which only a driller's log exists. A borehole with core, a geologist's log and a gross gamma-ray log offers the highest quality information for interpretation.

The older natural gamma-ray logs used in this study allowed older wells, for which only driller's logs were previously available, to be reinterpreted and correlated with newer wells for which geologist's logs and geophysical logs are available. This greatly increased the confidence in placing stratigraphic contacts. In addition, the signature of the geophysical response from the formations can provide an additional tool for correlating stratigraphy between boreholes.

4.0 Geology

4.1 General Hanford Stratigraphy

The site for the IDF is in a sequence of sediments (Figure 2.1) that overlie the Columbia River Basalt Group on the north limb of the Cold Creek syncline. These sediments include the upper Miocene to Pliocene Ringold Formation, Pleistocene cataclysmic flood gravels, sands and silt of the Hanford formation, and Holocene eolian deposits (Figure 4.1).

The main nomenclature employed 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; Lindsey 1996; DOE 2002) and IDF (Reidel and Horton 1999). Subdivision of the main units is inconsistent across the Hanford Site because of the difficulty in correlating beds over great distances. Following geologic convention, the

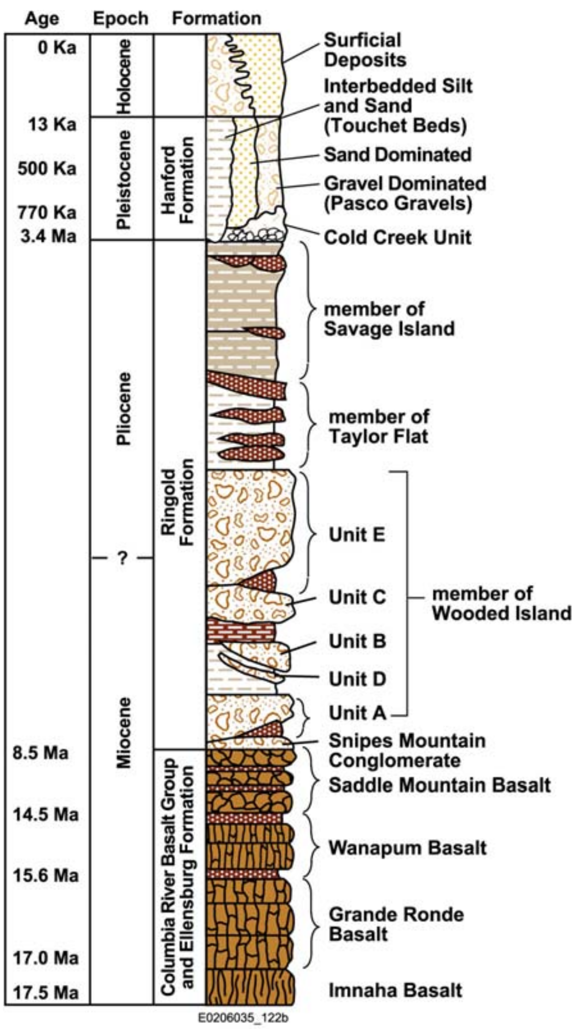

Figure 4.1. Generalized Stratigraphy of the Hanford Site and 200 East Area

discussion in this report proceeds from oldest to youngest units. In addition, this report will use feet rather than meters following the convention used in borehole data.

4.1.1 200 East Area

The geology of the 200 East Area consists of the Elephant Mountain Member of the Saddle Mountains Basalt, Columbia River Basalt Group overlain by the Ringold Formation and the Hanford formation. The Elephant Mountain Member is the uppermost unit of the Columbia River Basalt Group in this portion of the Hanford Site and forms the top of basalt throughout the area (Figure 4.2).

The Ringold Formation consists of fluvial and lacustrine sediments deposited by the ancestral Columbia and Clearwater-Salmon river systems between about 3.4 and 8.5 Ma (Fecht et al. 1987).

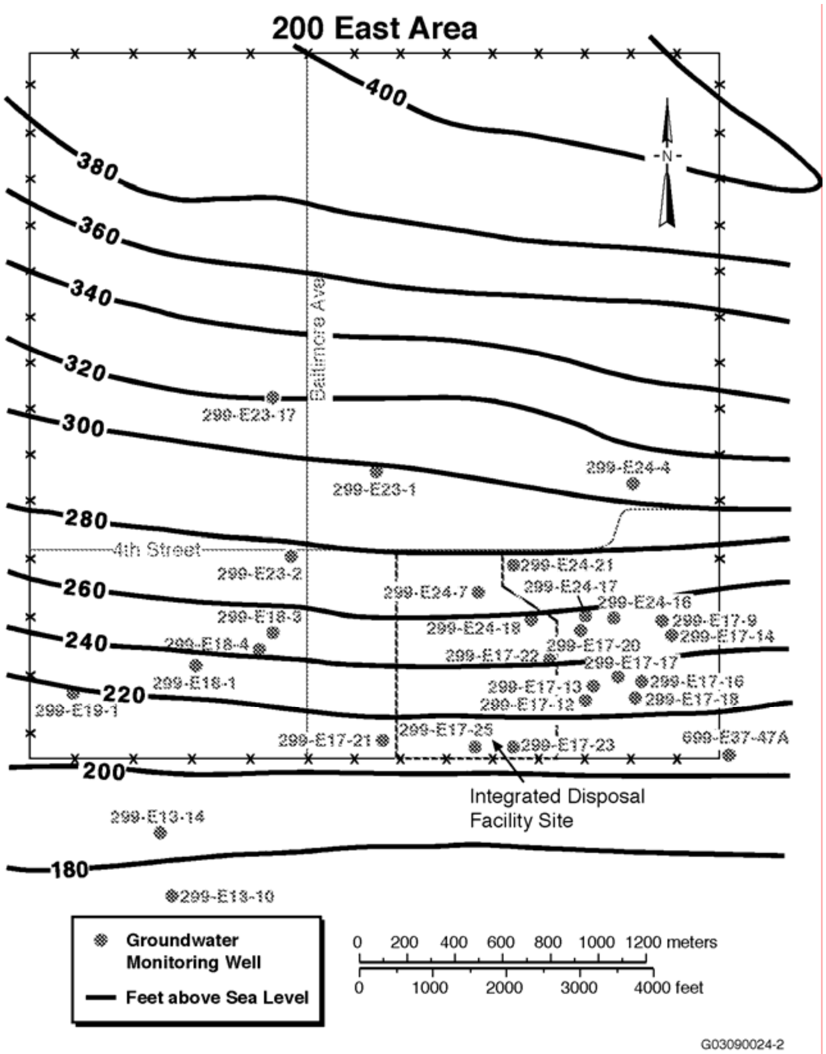

Figure 4.2. Elevation of the Surface of the Columbia River Basalt Group Under the 200 East Area and the IDF Site (from Williams et al. 2000)

Lindsey (1996) described the Ringold Formation in terms of three informal members: 1) the member of Wooded Island, 2) the member of Taylor Flat, and 3) the member of Savage Island. Of these, only the member of Wooded Island is present beneath the 200 East Area.

The member of Wooded Island consists of five separate units dominated by fluvial gravels. The gravels are designated (from bottom to top) as units A, D, B, C, and E. The gravel units are separated by fine-grained deposits typical of overbank and lacustrine environments. The lowermost of the fine-grained sequences is designated the lower mud unit. Only gravel units A and E are present beneath the 200 East Area and the Ringold Formation is entirely absent beneath the north and northeast parts of the 200 East Area (Williams et al. 2000) due to erosion.

The Ringold Formation gravels are clast- and matrix-supported, pebble to cobble gravels with a fine to coarse sand matrix (Fecht et al. 1987; Lindsey 1996). The most common lithologies are basalt, quartzite, and intermediate to felsic volcanics. Interbedded lenses of silt and sand are common. Cemented zones within the gravels are discontinuous and of variable thickness. In outcrop, the gravels are massive, planer bedded, or cross-bedded. Lying above the Ringold gravels are silts and sands of the member of Taylor Flat.

The Hanford formation overlies the Ringold Formation. The Hanford formation consists of glaciofluvial sediments deposited by cataclysmic floods from Glacial Lake Missoula, Glacial Lake Columbia, Pluvial Lake Bonneville, and ice-margin lakes. The Hanford formation sediments resulted from at least four major glacial events and were deposited between about 2 Ma and 13 Ka. The Hanford formation consists of pebble- to boulder-gravel, fine- to coarse-grained sand, and silt- to clayey-silt. These deposits are divided into three facies: 1) gravel-dominated facies, 2) sand-dominated facies, and 3) interbedded sand- and silt-dominated facies (DOE 2002). The Hanford formation is present throughout the Hanford Site and is up to 65 m thick (Delaney et al. 1991).

- Gravel-dominated facies - This facies generally consists of coarse-grained basaltic sand and granule to boulder gravel (DOE 2002). Many exposures on the Hanford Site (e.g., various burrow pits) show that these deposits typically have an open framework texture, massive bedding, plane to low-angle bedding, and large-scale planar cross bedding in outcrop. The gravel-dominated facies was deposited by high-energy floodwaters in or immediately adjacent to the main cataclysmic flood channel ways.

- Sand-dominated facies - This facies consists of fine- to coarse-grained sand and granule gravel with sparse layers of Cascade ash deposits. The sands typically have high basalt content and are commonly referred to as black, gray, or salt-and-pepper sands (DOE 2002). They may contain small pebbles and rip-up clasts, pebble-gravel interbeds, and silty interbeds less than 3 ft (1 m) thick. The silt content of the sands is variable, but where the silt is low a well-sorted texture is common. The sand facies was deposited adjacent to main flood channel ways during the waning stages of flooding. The facies is transitional between the gravel-dominated facies and the interbedded sand- and silt-dominated facies. Field studies have shown two subfacies. One is quartzofeldspathic sand with mainly plane-laminated or upward grading bedding with local cross bedding. The second subfacies is a highly basaltic sand to salt and pepper sand mostly related to scabland channel deposits and the lowermost glaciofluvial channel ways. Cross bedding and plane bedding is common.

- Interbedded Sand- and Silt-dominated facies - This facies consists of thin bedded, plane-laminated and ripple cross-laminated silt and fine- to coarse-grained sand (DOE 2002). Beds are typically a few centimeters to several tens of centimeters thick and commonly display normally graded-bedding (Myers et al. 1979; Bjornstad et al. 1987; DOE 1988; DOE 2002). Local clay-rich beds occur in the silt-dominated facies. Sediments of this facies were deposited under slack water conditions and in back flooded areas (DOE 1988).

Clastic dikes and pattern ground are a common features in the Hanford formation throughout the southern part of 200 West Area, the U.S. Ecology Site and the Grout Vault Area (now the Waste Treatment Plant) where the Hanford formation is not covered by younger sediments. Where covered by younger sediments, evidence for clastic dikes is not readily apparent but, never the less, clastic dikes are thought to be equally abundant as south of 200 West Area.

Holocene sediments at Hanford typically consist of active and stabilized sand dunes as well as localized alluvial fans and stream deposits. In the 200 East Area the dunes typically are parabolic. Mazama ash (6,000 years before present) is found in the dune deposits. The dunes have massive cross bedding indicating eastward transport. Active blowouts can occur in the dune fields. Regolith stabilized by vegetation is associated with shrub-steppe plant communities.

4.2 Integrated Disposal Site Geology

4.2.1 Previous Studies

The IDF is an area where no previous construction has been done so no major geologic studies have been carried out on the site. Studies relevant to the site are summarized in Reidel and Horton (1999). The first major activity was the drilling of borehole 299-E17-21 at the southwest end of the site and obtaining the first high-quality data from the area. This was followed by drilling of 299-E24-21 at the northwest corner of the site and then 299-E17-22, 299-E17-23, and 299-E17-25 (Figure 4.3). Finally, wells 299-E24-24 and 299-E17-26 were drilled during 2005.

4.2.2 Site Stratigraphy

The stratigraphy at the IDF site consists of the Hanford formation and Ringold Formation overlying the Columbia River Basalt Group. Surfacial sediments are mainly eolian deposits consisting of reworked Hanford sands and silts.

The stratigraphy and the stratigraphic model developed for this study is summarized in Figure 4.4 and Table 4.1. This diagram is based upon more detailed cross-sections (Figures 4.5, 4.6, 4.7, 4.8, and 4.9).

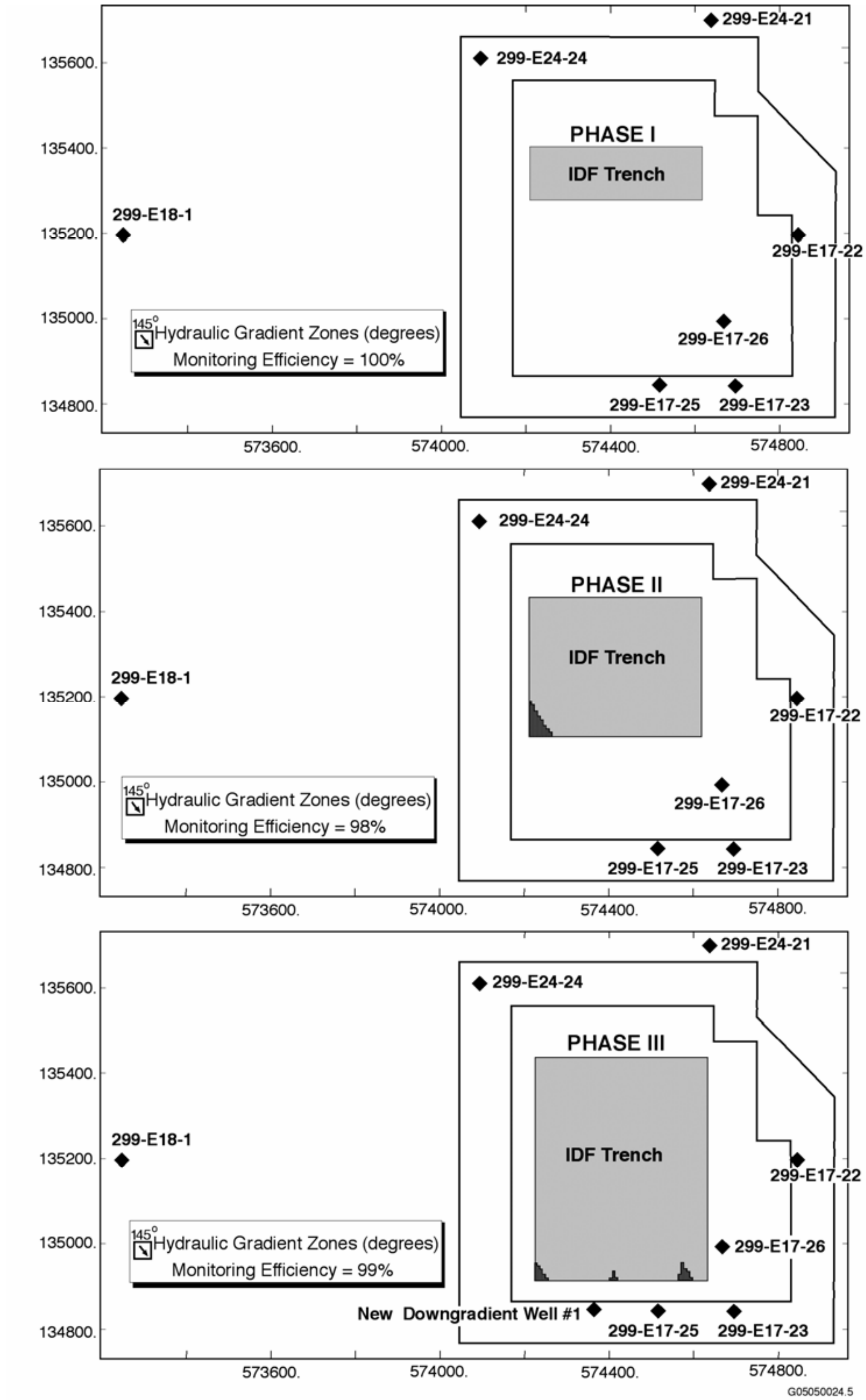

Figure 4.3. **Location of Ground Water Monitoring Wells at the IDF Site and Efficiency of the Monitoring Network**

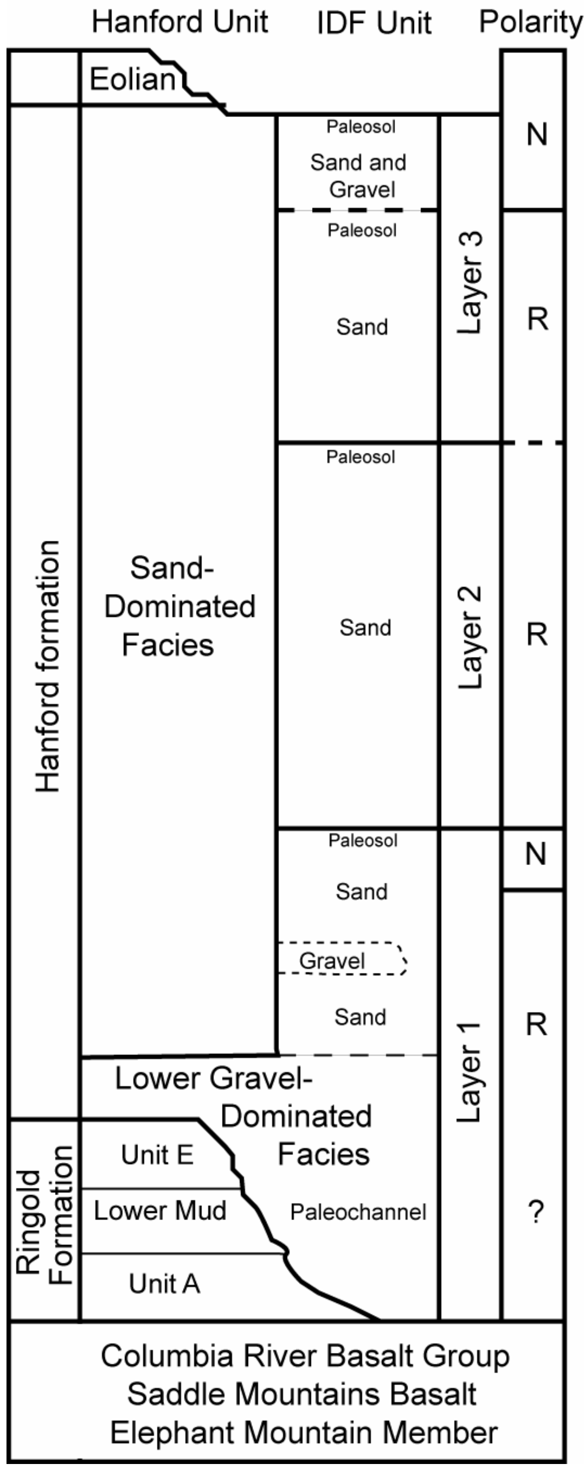

Figure 4.4. Integrated Disposal Site Stratigraphy

Table 4.1. Stratigraphic Information from Boreholes in the Integrated Disposal Site (ft [m])

Borehole	Surface Elevation [brass cap or casing (C)]	Back-fill	Surface Sand (S)	Top of Layer 3 (L3)	Top of Layer 2 (L2)	Top of Layer 1 (L1)	Top of Sandy Gravel 1 (G1)	Top of Sand 1 (S1)	Top of Sandy Gravel 2 (G2)	Top of Sand to Silty Gravelly Sand 2 (S2)	Top of Gravel 3 (G3)	Top of Sand to Silty Sand 3 (S3)	Top of Gravel 4 (G4)	Thickness of Hanford forma-tion	Top of Ringold	Top of Unit E	Top of Lower Mud	Top of Unit A	Thickness of Ringold	Basalt	Water Table Eleva-tion	Date of Water Level Measurement
E13-10	733(C) [223]	n	733 [223]	nd	nd	nd	np	733 [223]	713 [217]	705 [215]	537 [164]	514 [157]	494 [151]	239 [73]	449 [137]	449 [151]	np	np	nd	np	399.74 [121.8]	Mar-99
E17-12	719 (C) [219]	n	719 [219]	669 [204]	647 [197]	564 [172]	704 [215]	694 [212]	np	694 [212]	497 [151]	479 [146]	429 [131]	nd	np	np	np	np	nd	np	399.17 [121.7]	Mar-99
E17-13	719 (C) [219]	31	np	nd	647 [197]	nd	nd	689 [210]	np	689 [210]	494 [150]	469 [143]	424 [129]	nd	np	np	np	np	nd	np	399.56 [121.8]	Mar-98
E17-17	717 [219]	n	716 [219]	nd	651 [198]	nd	716 [218]	702 [214]	np	702 [214]	492 [150]	442 [135]	417 [127]	299 [91]	434 [130.4]	417 [150]	np	np	nd	np	399.8 [103.6]	Oct-98
E17-18	718 [219]	n	717 [219]	nd	648 [198]	nd	713 [217]	693 [211]	626 [191]	616 [188]	483 [147]	458 [140]	426 [130]	291 [89]	434 [130]	426 [147]	np	np	nd	np	399.27 [121.7]	Mar-99
E17-20	717 [219]	n	716 [219]	nd	646 [197]	nd	706 [215]	696 [[212]	676 [206]	671 [205]	497 [151]	436 [133]	416 [127]	nd	np	np	np	np	nd	np	400.55 [122.1]	Apr-97
E17-21	735 [224]	n	735 [224]	730 [223]	677 [206]	572 [174]	730 [223]	720 [219]	715 [218]	705 [215]	523 [159]	505 [154]	447 [136]	238 [73]	400 [151]	400 [122]	357 [109]	296	nd	nd	403 [122.8]	Apr-98
E17-22	723.7 [221]	n	723.7 [221]	722 [220]	650 [198]	nd	np	722 [220]	np	717.7 [219]	507 [155]	485.7 [148]	449 [137]	nd	np	np	np	np	nd	np	401.88 [122.5]	Apr.-02
E17-23	734.4 [224]	n	734.4 [224]	733 [223]	672 [205]	576 [176]	np	733 [223]	711 [217]	705.4 [215]	501 [153]	498.4 [152]	453 [138]	nd	np	np	np	np	nd	np	401.89 [122.5]	Apr.-02
E17-25	738.3 [225]	n	738.3 [225]	np	np	np	np	737 [225]	729 [222]	727.3 [222]	504 [154]	479 [146]	445 [136]	nd	np	np	np	np	nd	np	400.68 [122.1]	Apr.-02
E17-26	735.17 [224.08]	n	735.17 [224.08]	nd	nd	nd	np	np	np	np	505 [154]	485 [148]	455 [139	nd	-	-	np	np	nd	np	396.5 [121]	June-05
E18-1	716 [218]	n	nd	nd	nd	nd	720 [219]	700 [213]	675 [206]	660 [201]	545 [166]	535 [163]	np	215 [66]	505 [154]	505 [154]	np	np	nd	np	399.44 [121.8]	Mar-99
E18-3	718 [219]	n	718 [219]	nd	656 [200]	nd	715 [218]	703 [214]	nd	656 [200]	546 [166]	542 [165]	np	235 [72]	483 [147]	483 [147]	np	np	nd	np	401.1 [122.3]	Jun-96

Table 4.1. (contd)

Borehole	Surface Elevation [brass cap or casing (C)]	Back-fill	Surface Sand (S)	Top of Layer 3 (L3)	Top of Layer 2 (L2)	Top of Layer 1 (L1)	Top of Sandy Gravel 1 (G1)	Top of Sand 1 (S1)	Top of Sandy Gravel 2 (G2)	Top of Sand to Silty Gravelly Sand 2 (S2)	Top of Gravel 3 (G3)	Top of Sand to Silty Sand 3 (S3)	Top of Gravel 4 (G4)	Thickness of Hanford forma-tion	Top of Ringold	Top of Unit E	Top of Lower Mud	Top of Unit A	Thickness of Ringold	Basalt	Water Table Eleva-tion	Date of Water Level Measurement
E18-4	718 [219]	n	718 [219]	nd	nd	nd	715 [218]	699 [213]	668 [204]	658 [201]	nd	568 [179]	np	232 [71]	486 [148]	486 [148]	np	np	nd	np	401.17 [122.3]	Jun-96
E19-1	736 (C) [224]	n	736 [224]	nd	nd	nd	735 [224]	716 [218]	686 [209]	672 [205]	520 [159]	506 [154]	np	250 [76]	486 [148]	486 [148]	346 [105]	306	285 [285]	201	nd	nd
E23-1	710 (C) [216]	n	0 to 5 [0-1.5]	nd	665 [203]	nd	704 [215]	np	689 [210]	665 [203]	489 [149]	477 [145]	454 [138]	nd	417	409	np	np	nd	np	399.63 [121.8]	Mar-99
E23-2	721 (C) [220]	0	720 [220]	nd	nd	nd	np	720 [219]	np	605 [184]	520 [159]	500 [152]	484 [148]	290 [88]	460 [138]	430 [131]	np	nd	166 [51]	264	401.59 [122.4]	Dec-94
E24-4	697 (C) [212]	20 [6.1]	696 [212]	nd	646 [197]	nd	np	696 [212]	611 [184]	nd	nd	nd	472 [142]	270 [82]	nd	nd	np	np	nd	np	399.53 [121.8]	Aug-98
E24-7	716 (C) [218]	n	716 [218]	nd	652 [199]	nd	716 [218]	708 [216]	np	708 [216]	500 [152]	486 [148]	448 [137]	380 [116]	364 [106]	364 [106]	nd	nd	70 [21]	266	400.52 [122.1]	Jun-97
E24-16	715 [217]	n	715 [217]	nd	656 [200]	nd	714 [218]	706 [215]	626 [191]	616 [188]	460 [140]	425 [130]	410 [125]	nd	np	np	np	np	nd	np	399.41 [121.7]	Mar-99
E24-17	716 [218]	n	716 [218]	nd	659 [201]	nd	711 [217]	706 [215]	np	706 [215]	464 [141]	524 [160]	421 [128]	295 [90]	np	np	np	np	nd	np	399.59 [121.8]	Apr-97
E24-18	716 [218]	n	716 [218]	nd	664 [202]	nd	715 [218]	699 [213]	np	699 [213]	506 [154]	481 [147]	456 [139]	325 [99]	391 [119]	391 [119]	np	np	nd	np	399.3 [121.7]	Mar-99
E24-21	714 [218]	n	714.40 [218]	714 [218]	636 [194]	544 [166]	706 [215]	702 [214]	np	702 [204]	479 [146]	473 [144]	444 [135]	np	np	np	np	np	nd	np	404.88 [123.4]	Apr.-01
E24-24	721.46 [219.90]	n	721.46[219.90]	na	na	na	np	np	np	np	502 [153]	492 [150]	437 [133]	np	np	np	np	np	np	np	398.8 [121.6]	May-05
E37-47A	716 [218]	n	716 [218]	nd	nd	nd	np	716 [218]	np	716 [218]	526 [160]	np	474 [145]	284 [87]	432 [132]	412 [126]	350 [107]	304	231 [70]	201	405 [123.4]	Oct-96

Table 4.1. (contd)

Borehole	Surface Elevation [brass cap or casing (C)]	Back-fill	Surface Sand (S)	Top of Layer 3 (L3)	Top of Layer 2 (L2)	Top of Layer 1 (L1)	Top of Sandy Gravel 1 (G1)	Top of Sand 1 (S1)	Top of Sandy Gravel 2 (G2)	Top of Sand to Silty Gravelly Sand 2 (S2)	Top of Gravel 3 (G3)	Top of Sand to Silty Sand 3 (S3)	Top of Gravel 4 (G4)	Thickness of Hanford forma-tion	Top of Ringold	Top of Unit E	Top of Lower Mud	Top of Unit A	Thickness of Ringold	Basalt	Water Table Eleva-tion	Date of Water Level Measurement
C3828	737.5 [225]	n	737.53 [225]	nd	575 [175]	nd	np	737.5 [225]	np	728.5 [222]	503 [153]	475 [145]	460 [140]	nd	np	np	np	np	nd	np	396.2 [120.8]	Apr.-02
C4069	nd	n	Approx 725 [221]	710 [216]	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
C4070	nd	n	Approx 725 [221]	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
C4071	nd	n	Approx 725 [221]	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
C4562	735 [224]	n	735 [224]	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	238 [73]	400 [151]	400 [122]	356 [109]	296 [90.2]	204 [62.2]	196 [59.7]	396 [120.7]	May-04

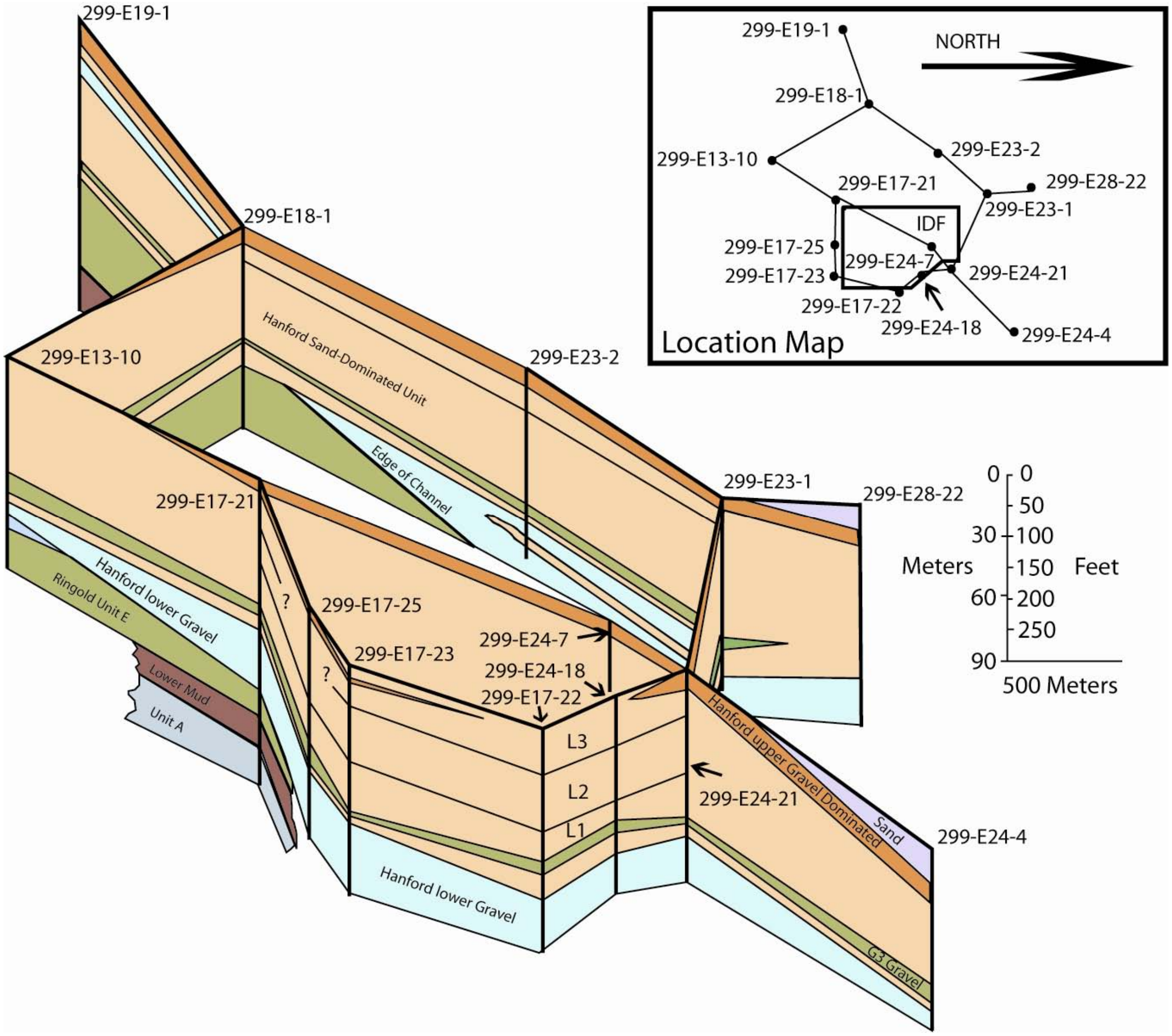

Figure 4.5. **Fence Diagram of the IDF Site and Vicinity**

The stratigraphy of the IDF site is divided from youngest to oldest into the following units:

- Eolian Deposits
- Hanford formation (informal), sand-dominated facies
  - Layer 3 (extends into upper gravel-dominated facies)
  - Layer 2
  - Layer 1

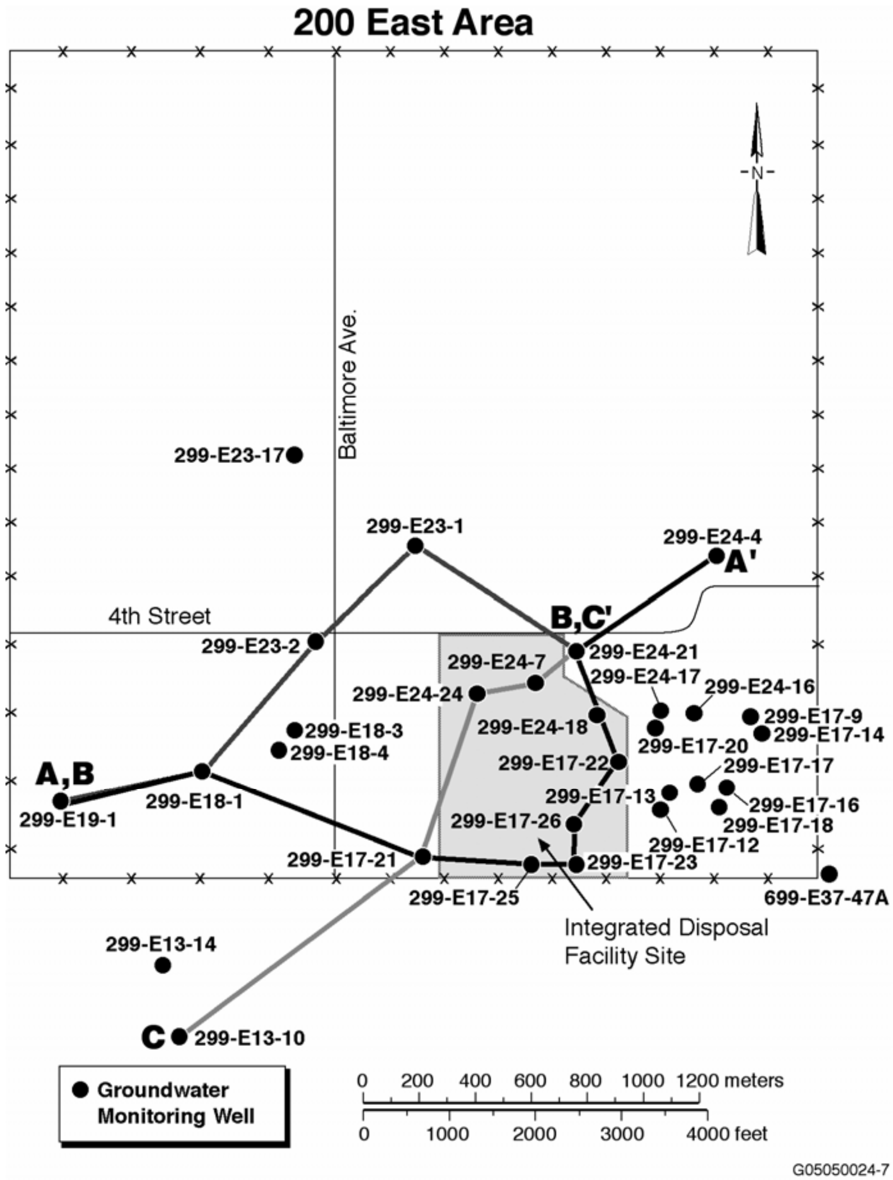

Figure 4.6. Map Showing the Locations of Cross-Sections A - A', B - B', and C - C'

- Hanford formation, lower gravel-dominated facies
- Ringold Formation
  - Unit E
  - Lower Mud
  - Unit A
- Columbia River Basalt Group.

The sequences of sandy gravels to gravelly sands (G1, G2, G3, G4) and sandy to silty sandy units (S, S1, S2, S3) can be recognized in the Hanford formation layers (Table 4.1). These units are not formally defined but are tentatively correlated across the site. Additional work will be necessary to verify these correlations. They are shown on the cross sections and in Table 4.1.

4.2.2.1 Columbia River Basalt Group

Previous studies (Reidel and Fecht 1994a) have shown that the youngest lava flows of the Columbia River Basalt Group at the 200 East Area are those of the 10.5 million-year old Elephant Mountain Member. This member underlies the entire 200 East Area and surrounding area and forms the base of the unconfined aquifer. No erosional windows are known or suspected to occur in the new IDF site area. Figure 4.2 shows the elevation of the top of the Columbia River Basalt Group under the 200 East Area and vicinity. Borehole C4562 adjacent to 299-E17-21 encountered the top of basalt (Elephant Mountain Member vesicular flow top) at 540 ft (165 m) below ground surface (195 ft [59.4 m] above mean sea level).

4.2.2.2 Ringold Formation

Because few boreholes penetrate much of the entire Ringold Formation at the IDF site, data are limited. The Ringold Formation reaches a maximum thickness of 285 ft (87 m) on the west side of the IDF site and thins eastward. It consists of three units of Lindsey’s (1996) Member of Wooded Island. The deepest unit encountered is the lower gravel, Unit A. Lying above unit A is the lower mud and overlying the lower mud is an upper gravel, unit E. The upper Ringold (sand and silt of the member of Taylor Flat) is not present at the IDF site but is present east of the site. Unit A and unit E are equivalent to mapping unit PLMcg, Pliocene-Miocene continental conglomerates of Reidel and Fecht (1994a, 1994b). The Lower Mud is equivalent the mapping unit PLMc, Pliocene-Miocene continental sand, silt, and clay beds of Reidel and Fecht (1994a, 1994b).

4.2.2.2.1 Unit A

Unit A underlies the lower mud and overlies the Columbia River Basalt Group. Only 3, possibly 4, boreholes penetrated Unit A in the study area (Table 4.1). New groundwater well 299-E17-26 may have penetrated this unit near the base of the well according the well-site geologist's log. If it did, then this would represent an isolated outcrop in the paleochannel that underlies the IDF site.

Unit A is 100 ft (30 m) thick on the west side of the IDF site but pinches out to the northeast (Figures 4.5, 4.7, 4.8, and 4.9). Unit A is sandy gravel consisting of both felsic and basaltic rocks. There are occasional yellow to white interbedded sand and silt with silt and clay lenses. One silt layer occurs at 465 to 475 ft (142 to 145 m) and a second was encountered in a borehole drilled next to E17-21 for shear wave velocity measurements (borehole C4562, Section 5) from 495 to 515 ft (151 to 157 m). Green-colored, reduced-iron stain is present on some grains and pebbles. Although the entire unit appears to be partially cemented, the zone produced abundant water in borehole 299-E17-21.

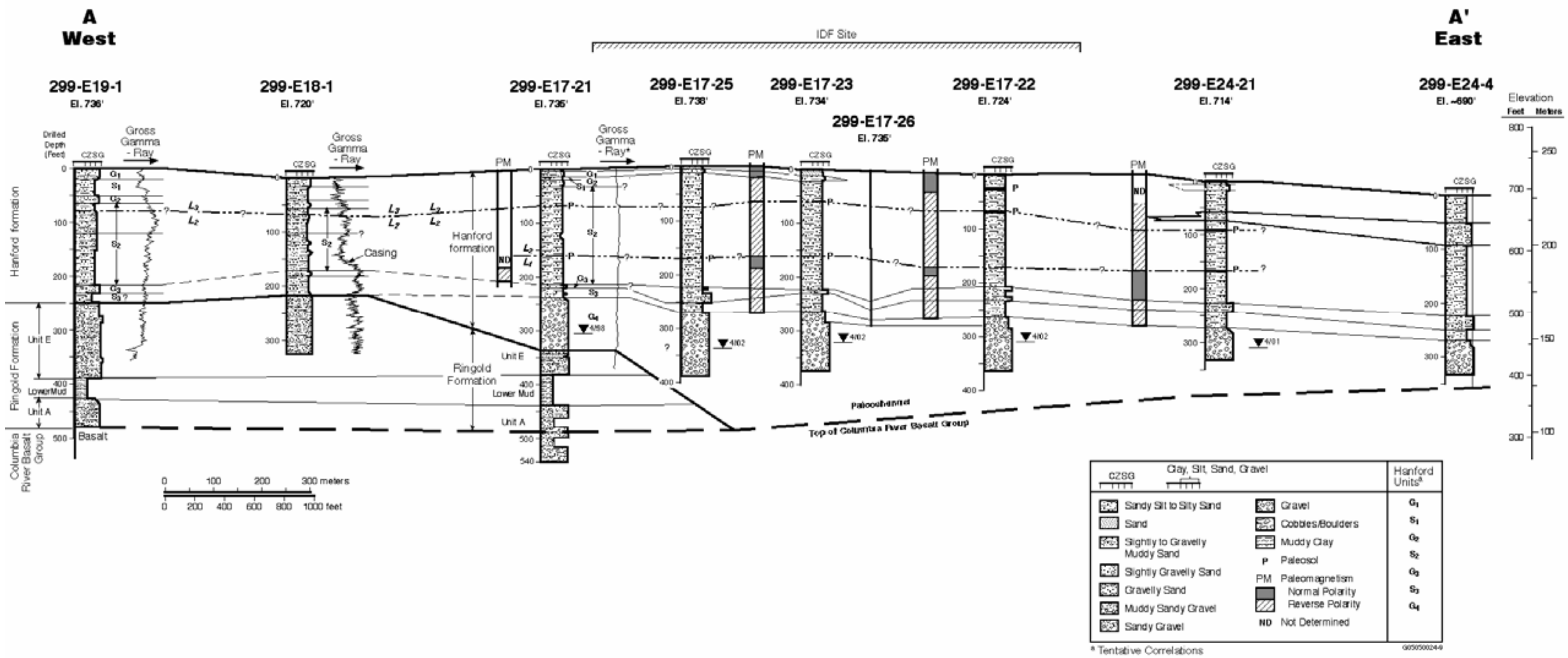

Figure 4.7. **Cross-Section A – A' Across the IDF Site. See Figure 4.6 for the location of the cross section.**

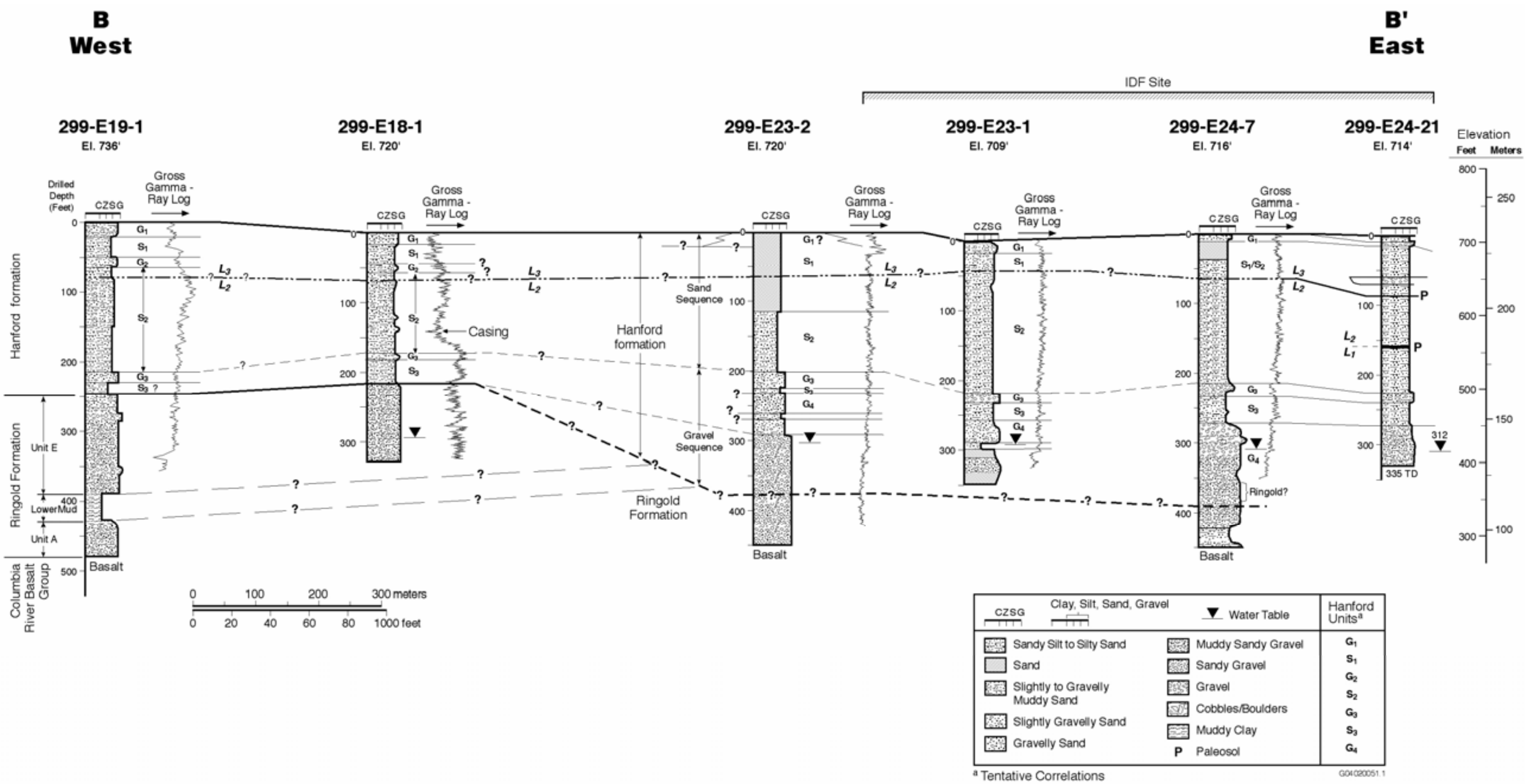

Figure 4.8. **Cross-Section B – B' Across the IDF Site. See Figure 4.6 for the location of the cross section.**

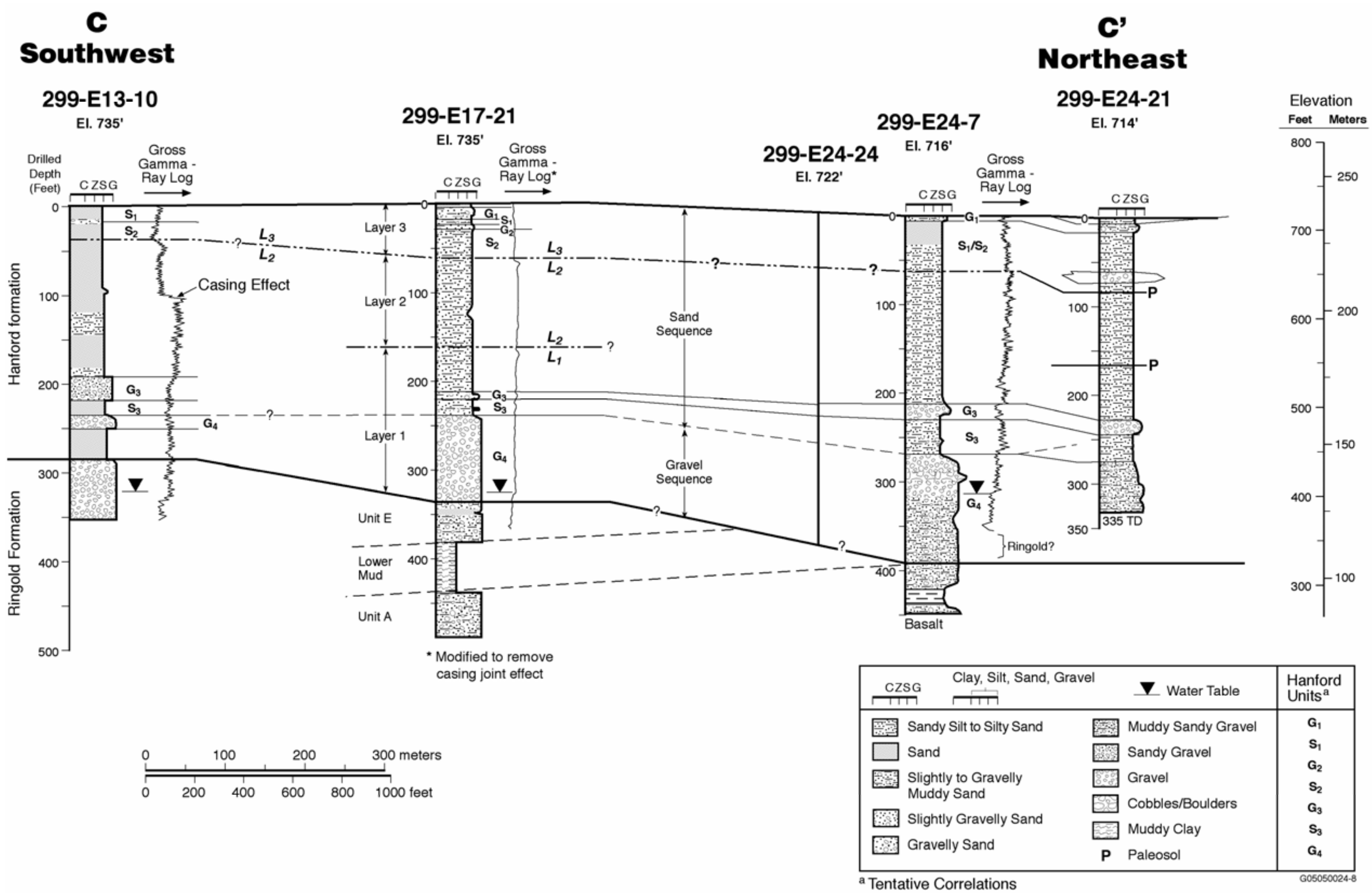

Figure 4.9. Cross-Section C – C' Across the IDF Site. See Figure 4.6 for the location of the cross section.

4.2.2.2.2 Lower Mud

A maximum of sixty-one feet (19 m) of the lower mud was encountered at the IDF site. The upper most part (about 4 ft, 1.2 m) consists of a yellow sandy to silty mud. The silty mud grades downward into about 34 ft (10 m) of blue mud with zones of silt to slightly silty mud. The blue mud, in turn, grades down into 23 ft (7 m) of brown silty mud with organic rich zones and occasional wood fragments. The lower mud, like unit A, is absent in the center of the IDF site (Figures 4.7, 4.8, and 4.9).

4.2.2.2.3 Unit E

Unit E overlies the lower mud and underlies the Hanford formation. Unit E is as much as 50 ft (15 m) of sandy gravel to gravelly sand with scattered large pebbles and cobbles up to 10 inches in size. The gravel consists of both felsic and basaltic clasts, which are well rounded with a sand matrix supporting the cobbles and pebbles. Cementation of this unit ranges between slight and moderate. The upper contact of unit E is not easily identified at the IDF site. In the western part of the study area, unconsolidated gravels of the Hanford formation directly overly the Ringold Unit E gravels, making exact placement of the contact difficult. The dominance of basalt in the Hanford formation and the general absence of any cementation are the key criteria used for distinguishing them here (Reidel et al. 1998). In the central and northeast part of the area, Unit E is interpreted to have been eroded (Figures 4.5, 4.7, 4.8, and 4.9). Unconsolidated gravels and sands typical of the Hanford formation replace them.

4.2.2.2.4 Upper Ringold

The upper Ringold is not present at the IDF site but has been identified in the southeast corner of 200 East Area in borehole 299-E37-47A (Lindberg et al. 1997). These sediments pinch out or were eroded before reaching the IDF site.

4.2.2.2.5 Unconformity at Top of Ringold Formation

The surface of the Ringold Formation is irregular in the IDF site area (Figure 4.11). A NW-SE trending erosional channel is centered along the northeast portion of the site. The deepest portion near boreholes 299-E24-7 and 299-E24-21 (Figure 4.2) is in the northern portion of the IDF site. This trough is interpreted to be a smaller part of a much larger trough under the 200 East Area resulting from scouring by the Missoula floods or post-Ringold fluvial incision prior to the Missoula floods.

4.2.2.3 Hanford formation

The Hanford formation is as much as 380 ft (116 m) thick in and around the IDF site. It thickens in the erosional channel cut into the Ringold Formation and thins to the southwest along the margin of the trough. The Hanford formation reaches its greatest thickness along a NW-SE trending trough under the eastern part of the IDF site (Figures 4.5, 4.7, 4.8, and 4.9).

The Hanford formation consists of poorly sorted pebble to cobble gravel and fine- to coarse-grained sand, with lesser amounts of interstitial and interbedded silt and clay. In previous studies of the IDF site, the Hanford formation was described as consisting of three units: an upper and lower gravelly facies and a sandy facies between the two gravelly units. The upper gravelly facies appears to be thin or absent in parts of the IDF area. The silt-dominated, slackwater facies (Touchet Beds) or interbedded sand- and silt-dominated facies is not present. In Table 4.1, the elevations of the tops of several of the more distinct and tentatively correlated units of the Hanford formation are given.

4.2.2.3.1 Basal Gravel-Dominated Facies

The lowermost part of the Hanford formation encountered in the IDF site consists of the gravel-dominated facies (Table 4.2). At the northeast end of the IDF site, the Hanford formation is over 109 feet (33m) thick in borehole 299-E24-21 and thins to the southwest (88 feet thick in 299-E17-21; Figure 4.9). The lower gravel decreases in elevation across the IDF site (Figure 4.10). Drill core and cuttings from these boreholes indicate that the unit is clast-supported pebble- to cobble-gravel with minor amounts of sand in the matrix. The cobbles and pebbles are almost exclusively basalt with no cementation. In outcroppings these deposits display massive bedding, plane to low-angle bedding and large-scale planar forset cross-bedding, but such features typically cannot be observed in borehole core. The gravel is interpreted to be Missoula flood gravels deposited in the erosional channel carved into the underlying Ringold Formation. The southwest part of the IDF site lies atop the western margin of this channel.

This basal gravel sequence is equivalent to the gravel-dominated facies of DOE (2002), and is equivalent to mapping unit Qfg1, Missoula Outburst flood gravel deposits of Reidel and Fecht (1994a, 1994b).

Table 4.2. Thickness of Basal Gravel-Dominated Facies at the IDF Site

Borehole	Thickness of Gravel Feet (Meters)
E17-21	88 (27)
E17-22	>86 (>26)
E17-23	>81 (>25)
E17-25/C3828	>63 (>19)
E17-26	>100? (>30?)
E24-21	>109 (>33)
E 24-24	>70 (>21)

4.2.2.3.2 Sand-Dominated Facies

The upper portion of the Hanford formation ranges from 270 (82 m) to 283 feet (186 m) (Table 4.3) of fine to coarse-grained sand with minor amounts of silt and clay and some gravelly sands. This sequence is equivalent to the sand-dominate facies of DOE (2002) and is equivalent to the following mapping units of Reidel and Fecht (1994a, 1994b): Qfs1, Qfs2, and Qfs3, Missoula Outburst Flood Deposits consisting of sand, silt, and clay.

The texture of the sand-dominated facies changes across the IDF site reflecting a higher energy environment for the floodwater to the northeast and east part of the site. In Figure 4.11 the percentage of

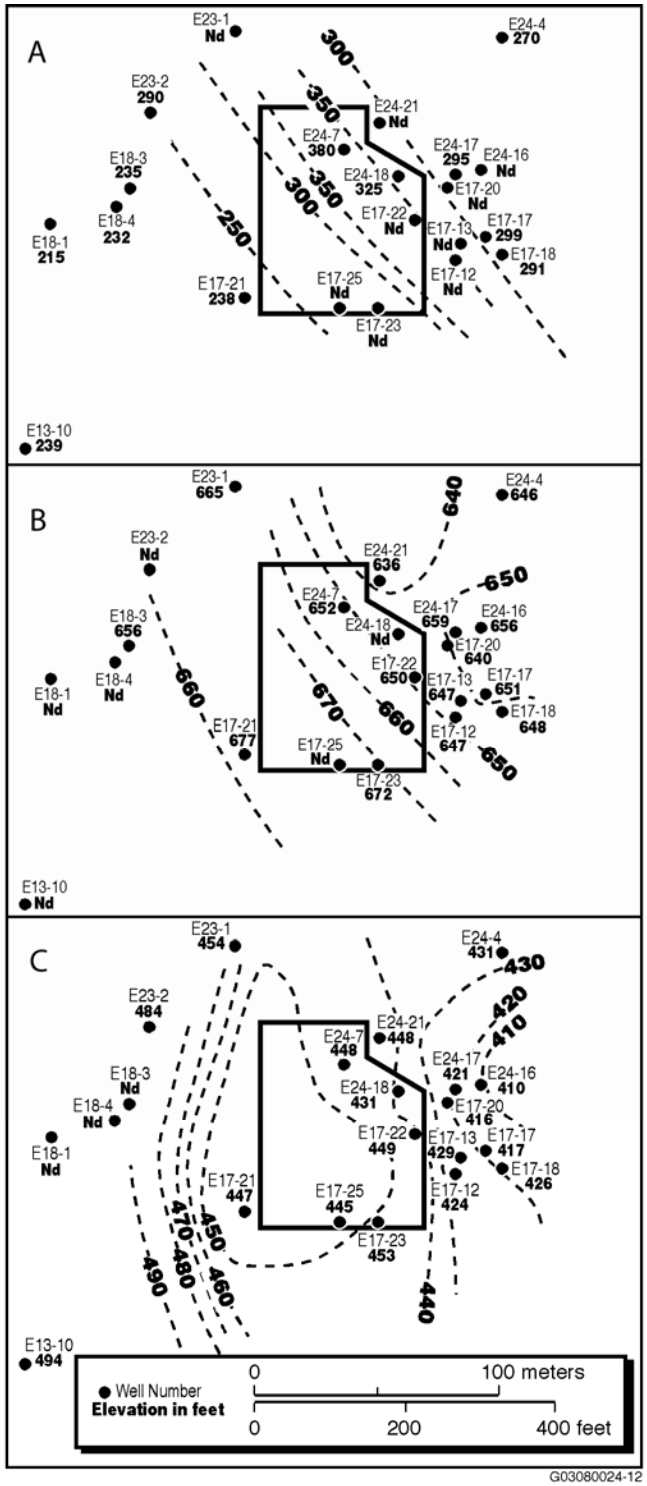

Figure 4.10. **A. Thickness of the Hanford formation Under the IDF Site. B. Elevation of Layer 2 under the IDF site. C. Elevation of the top of the lower-most gravel dominated under the IDF site. Dashed lines show approximate contour or isopleth.**

Table 4.3. Thickness of Sand-Dominated Facies in IDF Boreholes

Borehole	Thickness in feet (m)
299-E17-21	283 (86)
299-E17-22	273 (83)
299-E17-23	280 (85)
299-E17-25	277 (84)
299-E17-26	280 (85)
299-E24-21	270 (82)
299-E24-24	280 (85)

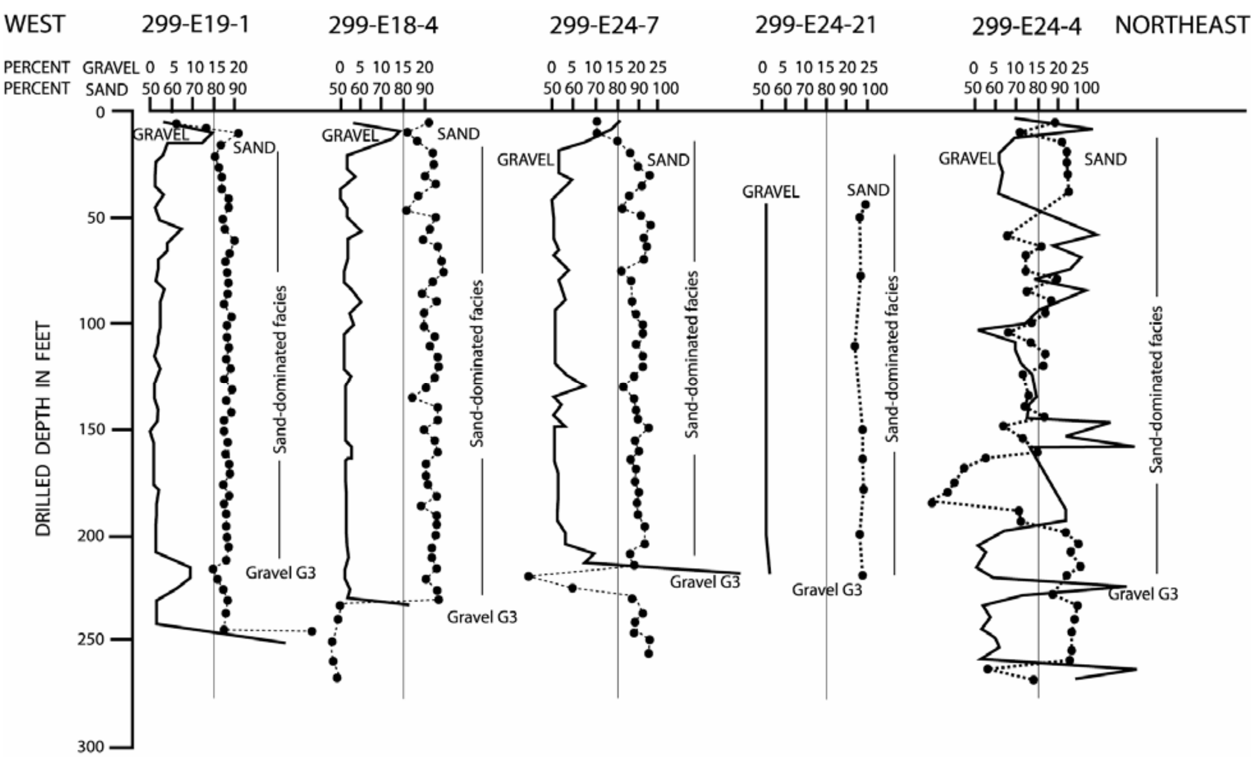

Figure 4.11. Percentage of Sand and Gravel Present in the Upper Part of the Sand-Dominated Facies in Selected Boreholes Near the IDF Site. For comparison a reference line is drawn at 80% sand and 15% gravel.

gravel and sand increase from the west (299-E19-1) to the northeast (299-E24-4). The percentage of sand in 299-E19-1 is around 85% but the percentage of sand increases to over 90% at the expense of silt and mud in 299-E18-4, 299-E24-7 and 299-E24-21. Borehole 299-E24-4 lies northeast of the IDF site and lies in the main part of the channel. Here sand decreases at the expense of increasing gravel.

4.2.2.3.3 Detailed Layer Stratigraphy of the Hanford formation

Stratigraphic studies at the IDF have defined three main layers: layer 1, layer 2, and layer 3 (Figure 4.4).

Layer 1. Layer 1 varies from 84 feet (26 m) thick in borehole 299-E17-21 to greater than 210 feet (64 m) in borehole 299-E24-21 (Table 4.4). This includes units Qh_1, Qh_2, and Qb (Figure C.1, Appendix C) of Reidel and Fecht (2005). A paleosol of sand and silt poorly cemented by $CaCO_3$ (Stage I or II carbonate development) forms a poorly developed layer at the top. Only the upper several inches have poor cementation but elevated concentrations of $CaCO_3$ extend to a depth or about 10 ft (3 m) below the top. $CaCO_3$ fragments and grain coatings were found at greater depths. A second paleosol is exposed in the IDF trench at the top of Reidel and Fecht's (2005) unit Qh_1.

The lower 20 feet (6.1 m) of Layer 1 consists of interbedded sands and gravels (Figures 4.7, 4.8, and 4.9). The basal gravel sequence underlying Layer 1 appears to grade upward into a sequence of interbedded sands and gravels. At least three upward fining zones of gravels to sands were recognized in Layer 1 (Reidel et al. 1998).

Planar-laminar sands with minor silt lenses dominate the upper part of Layer 1. This sequence consists of fining upward sands, well-compacted, slightly $CaCO_3$-cemented sands, and well-laminated sands. As noted above, $CaCO_3$ associated with development of the paleosol extends well down into this layer.

Layer 1 is part of the sand-dominated and lower gravel-dominated facies of DOE (2002) and is part of mapping unit Qfs1 of Reidel and Fecht (1994a, 1994b). Mapping unit Qfs1 are Missoula Outburst Flood Deposits consisting of sand, silt, and clay that have a reversed magnetic polarity capped by a normal polarity. Layer 1 may be as much as 1 to 1.7 million years old based on interpretation of the paleomagnetism (Appendix B) that suggests the normal polarity is equivalent to the Jaramillo subchron (0.99 to 1.07 Ma) (Pluhar et al. 2003).

Table 4.4. Elevation of Paleosols and Thickness of Stratigraphic Layers Capped by the Paleosols in IDF Boreholes

Borehole	Elevation of Paleosol 1 in feet (m)	Thickness of Layer 1 in feet (m)	Elevation of Paleosol 2 in feet (m)	Thickness of Layer 2 in feet (m)	Elevation of Paleosol 3a in feet (m)	Thickness of Layer 3a in feet (m)	Elevation of Surface (Paleosol 3b) in feet (m)	Thickness of Layer 3 in feet (m)
E17-21	572 (174)	84 (24.7)	677 (206)	105 (32.0)	ND	ND	730 (222)	53 (16)
E17-22	ND	ND	650 (198)	ND	693 (211)	43 (13)	723.7 (220.6)	73 (22)
E17-23	576 (175)	>204 (>62.2)	672 (204)	96 (29)	ND	ND	734.4 (223.7)	62 (19)
E17-25/C3828	575 (175)	>193 (>58.8)	ND	ND	ND	ND	738.3 (224.9)	ND
E24-21	545 (166)	>210 (>64.0)	636 (194)	91 (27.7)	ND	ND	714.4 (217.6)	78 (24)
C4069	ND	ND	ND	ND	ND	ND	Approx 710 (216)	ND

ND – Not detected.

Layer 2. Layer 2 is capped by a paleosol that occurs at approximately 650 feet (198 m) elevation under the IDF site but the surface of layer 2 decreases in elevation eastward under the site (Figure 4.10B). The upper 90 feet (27.4 m) of Layer 2 is principally fine- to medium-grained sand with minor amounts of interstitial silt. Throughout the sands are disseminated flakes of $CaCO_3$ and $CaCO_3$-cemented sand grains suggesting Stage II carbonate development. Several fining upward zones were recognized as well as well-compacted zones of sand and silt with faint laminations.

Layer 2 is also part of the sand-dominated facies of DOE (2002), and is part of mapping unit Qfs1 of Reidel and Fecht (1994a, 1994b). The mapping unit is a Missoula Outburst Flood Deposit consisting of sand, silt and clay that is older than 13 ka and younger than 720 ka. Mapping unit Qfs2 has a normal magnetic polarity. This layer is probably part of the Matuyama reversed polarity that began about 0.78 Ma.

Layer 3. Layer 3 is the upper most sediment sequence at the IDF site. Layer 3 thickens across the IDF site. It is 53 feet (16 m) thick at the southwest end of the site (299-E17-21) and thickens to 78 feel (24 m) thick at the northeast end of the site in borehole 299-E24-21. It consists of sand-dominated facies and has two polarity reversals – a reverse polarity at the base of the sequence and a normal polarity between the surface and the top of the reverse polarity (Appendix B). A paleosol at the top of the reverse polarity sediments was identified in borehole 299-E17-22 but was not recognized in any other borehole (Table 4.4, Appendix B). That paleosol is used to divide the layer into two parts where present.

A second paleosol was mapped in the IDF trench by Reidel and Fecht (2005). Preliminary paleomagnetic polarity measurements indicate that the paleosol formed during the normal polarity interval.

The upper-most paleosol is a 1.1-ft (3 m) thick, oxidized and leached zone of fine-grained sand and silt with some pebbles with a 4-in. (10-cm) caliche zone (sand and silt cemented by $CaCO_3$). Several distinct gravelly sands are present within several feet of the paleosol at the top of this layer. This forms the surface of much of the IDF site north of the eolian deposits.

The lower 25 to 30 ft (8 to 10 m) of Layer 3 consists principally of sand with interstitial silt and minor silt lenses. In borehole 299-E17-22, this layer is capped by a paleosol and is the top of the reversed polarity zone (Appendix B). Several minor silt lenses are locally present but are discontinuous.

Layer 3 is interpreted to consist of the upper gravelly sequence and the upper part of the sandy sequence defined in previous studies. It is part of the sand-dominated facies and the upper gravel dominated facies of DOE (2002). This is equivalent to mapping units Qfs 1,2, and 3 of Reidel and Fecht (1994a, 1994b) - Outburst Flood Deposits consisting of sand, silt and clay. An ash from the 13 ka eruption of Mt. St. Helens (Set S Ash) is typically found near the top of this unit in many places throughout the Pasco basin. The ash was not recognized in any of the boreholes near the IDF site but was identified in a pit excavated a few hundred feet west of borehole 299-E17-21 and in the PUREX tunnels east of the IDF site.

4.2.2.3.4 Paleosols

Three main paleosols (soils) were identified in the sand-dominated facies core and one gravel unit that allow the sand-dominated facies to be subdivided into at least three layers. Table 4.4 summarizes the elevations and drilled depths of the paleosols in IDF boreholes and Table 4.1 provides the elevations of these paleosols as determined from evaluation of existing boreholes from around the IDF site.

The paleosol horizons represent quiet time intervals when no sediments were deposited and soil development took place. They are interpreted to represent periods of non-deposition between Missoula flood deposition. The paleosols have abrupt upper contacts and less well defined lower contacts. The paleosols are typically 4-6 inches thick, bioturbated, a lighter color than the surrounding sediments, and slightly higher moisture content (e.g., C3177-170 5.26% in Horton et al. 2003). Calcium carbonate develop is also present suggesting that these paleosols represent the Stage I carbonate morphology of Birkeland et al. (1991).

4.2.2.4 Eolian Unit

Eolian deposits cover the southern part of the new IDF site (Figure 2.1). Borehole 299-E17-21 was sited on a stabilized sand dune. The eolian unit is composed of fine- to coarse-grained sands with abundant silt, as layers and as material mixed with the sand. Calcium-carbonate coating found on the bottom of pebbles and cobbles in drill core through this unit is typical of Holocene caliche development in the Columbia Basin. This unit is equivalent to mapping unit Qd, Holocene Dune Sand, of Reidel and Fecht (1994a, 1994b).

4.2.2.5 Clastic Dikes

Although there is no evidence for clastic dikes on the surface of the IDF site, clastic dikes were encountered during the drilling of well 299-17-24 between 155.5' and 157.5' (Reidel and Ho 2002, Figure 4.11) and in the IDF trench (see Reidel and Fecht 2005). This suggests that clastic dikes are present at the site although not readily apparent at the surface.

4.2.2.5.1 Clastic Dikes in the IDF Trench

Two clastic dikes were mapped in the trench (Reidel and Recht 2005; Figure C.1, Appendix C). One clastic dike crosses the trench from the south wall to the north wall and nearly bisects the trench. This clastic dike is approximately 1.2 m (4 ft) wide and trends approximately 35 degrees east of north. The second clastic dike is exposed along the west wall and trends approximately 70 degrees west of north. Both dikes exposed in the excavation are sheeted dikes composed of layers of sand segments bounded by layers of silt/clay. These dikes mainly cross cut the stratigraphic units exposed in the trench except locally where the dikes trend parallel to the bedding forming sill-like features. The sand segments and silt clay linings within the dikes that are composed of a mixture of quartzofeldspathic and basaltic sands commonly have limited vertical extent (up to 2 m). The upper and lower extend of these segments terminate either by pinching out against adjacent segments or abruptly at shears or slumps that were formed during dike emplacement. Exterior segments composed of basaltic sand represent the last segments of the dike to be emplaced. These basaltic sand segments generally extend vertically up to 2 m, however, the last basaltic sand emplacement can be traced at least several meters up the trench walls.

North-South Clastic Dike

The largest clastic dike exposed in the trench was mapped on the south and north walls and the floor of the trench. The dike is nearly vertical and its base is not exposed. The width remains nearly the same along its mapped length (approximately 1.2 m [4 ft]), varying by less than 0.1 m (0.5 ft). Two vertical branches to the main dike only several inches wide were mapped on the north wall. Both begin near the base of the trench (unit Qh_2 of Reidel and Fecht 2005) and trend 45 degrees west of north. Both branches terminate in the Qh_2 unit.

The primary clastic dike is composed of eight to nine segments on the north wall and five to six segments on the south wall. A segment is defined as silty sand to coarse sand bounded by clay margins or skins. The interior segments of the clastic dike are composed of sand having a brown color but the exterior segment on both sides is composed of dominantly black basaltic sand. Mapping relations suggest that the exterior basaltic sand is the youngest portion of the dike.

Overall, the sand component of the dike is compacted to partly cemented sand. This results in the dike being more resistant than the surrounding sediment in the trench. When rain or snow fell in the trench during the time the trench was being mapped, the clastic dike remained relatively dry compared to the host sediment. This suggested that the dike had a much lower permeability than the host sediment, probably due to the cement.

The vertical trace of the clastic dike up the walls of the trench is broken by sill-like deflections. This generally occurs where the nature of the host sediment changes (e.g., textural change from fine to coarse). For example, on the south wall the clastic dike is deflected about 1 m (3 ft) to the west at the contact between units Qh_1 and Qh_2 of Reidel and Fecht (2005). On the north wall a similar deflection occurs at the Qh_1-Qh_2 contact but it is only about 0.3 m (1 ft). A 1 m (3 ft) deflection occurs, however, at the top of the Qh_2 and the overlying sands. The deflection is to the east (relative to shallower depths from the floor of the trench) on the north wall and to the west on the south wall. In addition, on the south wall horizontal silt layers at the Qh_1-Qh_2 contact can be shown to feed into the clastic dike and are curved upward to make outer layers of the dike that terminate at this depth.

Several of the clastic dikes that occur in and are truncated at the top of the Qh_1 unit can be shown to feed into this clastic dike. This suggests that the primary clastic dike that can be traced to the top of the trench probably began to develop during the deposition of Qh_1 and formed the focus for later development of the clastic dike during and following deposition of unit Qh_2.

West-Wall Clastic Dike

The west-wall clastic dike is exposed only along the west wall and cannot be traced more than several meters east along the trench floor. It does not intersect the north wall-south wall clastic dike. Two branches of this clastic dike intersect the main dike at the Qh_1-Qh_2 contact. The southernmost clastic dike branch trends 35 degrees east of north and the northernmost clastic dike branch trends about 45 degrees east of north but intersects the main dike approximately 3 m (10 ft) higher up the trench wall. This is the same location where the main west wall clastic dike is deflected north about 1 m (3 ft) before continuing on strike with the lower portion of the dike.

A second deflection of the clastic dike occurs about 3 m (10 ft) higher than the first deflection. The deflection is to the north following the clastic dike from the floor of the trench to the top of the trench. At this deflection, the clastic dike appears to feed a sill that can be traced along the west wall and part of the north wall. The clastic dike can be traced upward to the eolian sediments.

Near the floor of the trench the clastic dike is approximately 1.2 m (4 ft) wide and narrows slightly upward. The southwest striking clastic dike is approximately 0.3 m (1 ft) wide near the intersection with the main clastic dike but thins gradually to its termination about 6.1 m (20 ft) higher in elevation.

The primary clastic dike is composed of six segments. Like to north-south clastic dike, the interior segments of the clastic dike are composed of brown sand but the exterior segment on both sides is composed of dominantly basaltic sand. Mapping relations suggest that the exterior basaltic sand is the youngest portion of the dike.

Unlike the north-south clastic dike, this clastic dike appears to originate in the sediment exposed along the floor of the trench. The clastic dike can be traced approximately 4 m (13 ft) out onto the floor of the trench but it then appears to end. The surface of the floor in the western part of the trench has many irregular clastic dikes that can be traced less than a meter. In addition, the sediment layers appear to be irregular as if the sediment had rapidly dewatered and the sediment backfilled the void space.

4.3 Mineralogy

Mineralogy was determined for sediment from two IDF boreholes: 299-E17-21 (Mattigod et al. 2000) and 299-E24-21 (Horton et al. 2003). This section summarizes those studies.

4.3.1 Borehole 299-E17-21

4.3.1.1 Introduction

This section summarizes the results of the mineralogical characteristics determined from borehole 299-E17-21 by Mattigod et al. (2000). The following is taken directly from their report.

4.3.1.2 Materials

Mattigod et al. (2000) selected eight representative core samples from the Hanford formation for analysis (Table 4.5). These samples consist mainly of sand-size material derived from roughly equal proportions of basaltic and felsic parent materials. Many of the samples contained calcium carbonate as coatings, discrete particles, and cement. Each sample was homogenized, and subsamples were drawn for particle size separation as described in Mattigod et al. (2000).

Table 4.5. Description of Selected Core Sample from Borehole 299-E17-21 (from Reidel et al. 1998)

Core Number	Core Interval (ft)	Layer	Description
7A	45.9 – 47.9	3	Medium to fine-grained sand with minor silts; sparse pebbles up to 1 inch; 50% basalt, 50% felsic. 45.9 $CaCO_3$ cementing sand into poorly consolidated nodules.
10A	57.8 – 59.8		57.8 – 58.1 Medium- to coarse-grained sand with some $CaCO_3$ 58.1 – 58.5 Cemented soil zone; fine- to medium-grained sand 58.5 – 59.8 Medium-grained sand
14A	80.3 – 82.8	2	Compacted medium- to fine-grained sand; some silt; 50% basalt, 50% felsic; minor $CaCO_3$ probably as grain coatings.
16A	100.5 – 103.0		Medium-grained sand; some $CaCO_3$ coating grains.
20A	129.7 – 132.2		Fine- to medium-grained sand, some silt; less than 50% basalt; some $CaCO_3$ as discrete particles and grain coatings.
24A		1	Fine- to medium-grained sand; uniform grain size; 50% basalt, 50% felsic; no bedding; well compacted, minor $CaCO_3$ cement.
31A			Fine-grained sand compacted by not cemented; faint bedding. 219.0 Pebbles of basalt and site; rounded.
35A	239.5 – 241.5		239.5 – 240.0 Granular to pebbly gravel (1/8 inch), mainly basalt; no sand matrix, open framework. 240.0 – 240.4 Grading into coarser gravel (1/4 to 1/2 inch); no sand matrix, open framework. 240.4 – 240.9 Coarse gravel with sand matrix; gravel up to 1 inch in diameter; coarse-grained sand; 50% basalt, 50% felsic.

4.3.1.3 Texture

The particle size analysis data indicated that the sand content of these soils ranged from about 79 to 98%, the silt content varied from about 1 to 15% and clay fraction constituted about 0.6 to 7% (Table 4.6). The textural data showed that all the sediment samples except 10A and 14A were sands. The samples 10A and 14A had sandy loam texture.

4.3.1.4 Mineralogy

The mineralogical composition of the sand, silt and clay fractions of the sediments are tabulated (Tables 4.7 to 4.9). About 5% by weight of corundum was detected in all sand samples which was contamination resulting from grinding the soil in a corundum containing mortar and pestle. The semiquantitative mineral contents of sand fractions therefore, were normalized to eliminate the corundum content.

Table 4.6. Particle Size Distribution of Selected Sediment Samples from Borehole 299-E17-21

Sample #	Layer	Sand >75 μm	Silt 75 – 2 μm	Clay <2 μm
7A	3	92.1	5.5	2.4
10A		82.1	14.6	3.3
14A	2	79.4	13.6	7.0
16A		94.7	3.8	1.4
20A		90.0	8.8	1.2
24A	1	91.3	6.1	2.6
31A		88.4	10.0	1.5
35A		98.3	1.1	0.6

Table 4.7. Semiquantitative Estimates (wt.%) of Minerals Identified in Sand Fractions of Selected Sediment Samples from Borehole 299-E17-21

Mineral Group	Mineral Species	Ideal Chemical Composition	Sample #							
			Layer 3		Layer 2			Layer 1		
			7A	10A	14A	16A	20A	24A	31A	35A
Quartz	Quartz	SiO_2	82	74	66	76	76	66	74	71
Feldspar	Plagioclase	$(Ca, Na)(Al, Si)AlSi_2O_8$	10	20	30	20	20	31	21	25
Feldspar	Orthoclase	$KalSi_3O_8$	5	5	1	1	1	1	1	1
Mica	Muscovite	$Kal_2(AlSi_3)O_{10}(OH)_2$	1	1	1	1	1	1	1	1
Chlorite		$(Fe, Al, Mg)_6(Al, Si)_4O_{10}(OH)_8$	1	1	1	1	1	1	1	1
Amphibole		$Ca_2Fe_3Al_2(Si_6Al_2)O_{22}(OH)_2$	--	--	1	1	1	--	1	1

The dominant minerals in the sand fractions of all samples were quartz (~66 to 82% by mass) and feldspars (~15 to 30%) (Table 4.7). These minerals (quartz, and plagioclase and orthoclase feldspars) constituted approximately 92 to 99% of the total mass of the sediment samples. Trace quantities of muscovite mica, chlorite and amphibole were also detected in the sand fractions (Table 4.7). The silt fractions of these samples were also dominated by quartz (~49–76%) and feldspars (~19–44%) (Table 4.8). Compared to the sand fractions, the silt fractions contained higher amounts of muscovite and chlorite (~1–5%), and amphibole (1–10%). Illitic mica, was the dominant mineral (~42 to 60% by mass) in the clay fractions of all the sediment samples (Table 4.9). About 14 to 25% chlorite and about 21 to 28% kaolinite were also found in clay fractions. Minor amounts (3 to 12%) of smectite (a high surface, high cation exchange capacity [CEC] mineral) were also detected in the clay fractions of all samples. Overall, quartz and feldspars dominated the sand fractions, whereas, the clay fractions were dominated by illitic mica and chlorite. These size-dependent mineral distributions are typical of primary (quartz and feldspars) and secondary (illite, chlorite, kaolinite and smectite) mineral occurrence in soils undergoing chemical weathering. The mineralogy of these sediments is typical of published mineralogy of other Hanford sediments (Schramke 1988).

Table 4.8. Semiquantitative Estimates (wt.%) of Minerals Identified in Silt Fractions of Selected Sediment Samples from Borehole 299-E17-21

Mineral Group	Mineral Species	Ideal Chemical Composition	Sample #							
			Layer 3		Layer 2			Layer 1		
			7A	10A	14A	16A	20A	24A	31A	35A
Quartz	Quartz	SiO_2	65	71	49	61	64	62	73	76
Feldspar	Plagioclase	$(Ca, Na)(Al, Si)AlSi_2O_8$	20	14	39	31	20	19	19	20
Feldspar	Orthoclase	$KAlSi_3O_8$	5	5	5	1	1	5	5	1
Mica	Muscovite	$KAl_2(AlSi_3)O_{10}(OH)_2$	5	5	5	5	1	5	1	1
Chlorite		$(Fe, Al, Mg)_6(Al, Si)_4O_{10}(OH)_8$	5	5	1	1	5	5	1	1
Amphibole		$Ca_2Fe_3Al_2(Si_6Al_2)O_{22}(OH)_2$	--	--	1	1	10	5	1	1

Table 4.9. Semiquantitative Estimates (wt.%) of Minerals Identified in Clay Fractions of Selected Sediment Samples from Borehole 299-E17-21

Mineral Group	Mineral Species	Ideal Chemical Composition	Sample #							
			Layer 3		Layer 2			Layer 1		
			7A	10A	14A	16A	20A	24A	31A	35A
Smectite	--	$(Ca, Mg, Na, K)_{0.33}Al_2(Al_{0.33}Si_{3.67})O_{10}(OH)_2$	8	5	4	3	8	8	12	8
Mica	Illite	$K_{0.75}Al_2(Al_{0.75}Si_{3.25})O_{10}(OH)_2$	56	60	60	59	55	51	44	42
Kaolinite	Kaolinite	$Al_4Si_4O_{10}(OH)_8$	22	21	22	21	22	26	28	25
Chlorite	--	$(Fe, Al, Mg)_6(Al, Si)_4O_{10}(OH)_8$	14	14	14	17	15	15	15	25

Based on the mineralogy data (Tables 4.7 to 4.9) and the mass distribution of particles in each size fraction (Table 4.6), the mineral distribution on the bulk soil basis were computed (Tables 4.10 and 4.11). As expected, in all samples (predominantly sandy in texture), the minerals which are dominant in the sand and silt fractions namely quartz and feldspars also dominate the mineralogy of bulk soils (~91–95%). All other minerals occur in minor to trace concentrations.

Table 4.10. **Calculated Mineral Distribution on Whole Soil Basis (wt.%) in Selected Sediment Samples from Borehole 299-E17-21**

Mineral Group	Layer 3						Layer 2									Layer 1								
	7A			10A			14A			16A			20A			24A			31A			35A		
	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
Quartz	62	12	--	63	8	--	59	3	--	66	6	--	65	6	--	59	5	--	53	17	--	68	1	--
Feldspar	12	5	--	21	3	--	28	2	--	19	3	--	18	2	--	28	5	--	16	5	--	25	--	--
Mica	1	1	3	1	Tr	2	1	Tr	3	1	Tr	2	1	Tr	2	1	Tr	2	1	Tr	2	1	--	1
Chlorite	1	1	1	1	1	Tr	1	Tr	1	1	Tr	Tr	1	1	1	1	Tr	1	1	Tr	1	1	--	1
Amphibole	--	--	--	--	--	--	1	Tr	--	1	Tr	--	1	1	--	--	Tr	--	1	Tr	--	1	--	--
Smectite	--	--	Tr	--	--	Tr	--	--	Tr	--	--	Tr	--	--	Tr	--	--	Tr	--	--	Tr	--	--	Tr
Kaolinite	--	--	1	--	--	1	--	--	1	--	--	1	--	--	1	--	--	1	--	--	2	--	--	1

Table 4.11. Calculated Mineral Distribution (wt.%) in Selected Sediment Samples from Borehole 299-E17-21

Mineral Group	Layer 3		Layer 2			Layer 1		
	7A	10A	14A	16A	20A	24A	31A	35A
	wt.%							
Quartz	74	71	62	72	71	64	70	69
Feldspars	17	23	30	22	20	30	22	25
Mica	4	3	4	3	3	2	3	2
Chlorite	3	2	2	1	3	2	2	1
Amphibole	--	--	1	1	2	Tr	1	1
Smectite	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Kaolinite	1	1	1	1	1	1	2	1

4.3.2 Borehole 299-E24-21

Horton et al. (2003) characterized the physical properties for five composite and seven discrete depth samples from the second IDF borehole, C3177 (299-E24-21) to augment data previously collected for recharge studies and from borehole 299-E17-21. The following is their discussion on mineralogy and is taken directly from their report.

Two types of samples were collected: composite samples and discrete depth samples. The composite samples were made so that large volumes of well characterized material would be available for future studies. Five composite samples were made by combining and mixing several 2 ft sections of core. Each composite was homogenized in 5 gallon buckets before subsampling for analyses. Composite samples are identified in Table 4.12 along with the other seven samples.

4.3.2.1 Mineralogy

X-ray diffraction (XRD) analysis of the IDF well 299-E24-21 (borehole C3177) sediments shows that all the samples are mineralogically similar. The bulk sediments are dominated by quartz and feldspar (both plagioclase and alkali-feldspar), with lesser amounts of mica, chlorite, and an amphibole.

Semi-quantitative analyses of the minerals in the bulk samples are provided in Table 4.13. Quartz concentrations range from 26 wt.% to 46 wt.%, with an average quartz concentration of 38 ± 6 wt.%. Plagioclase feldspar is present at concentrations between 15 to 40 wt.% and potassium feldspar concentrations are between 16 to 31 wt.%. Plagioclase feldspar was more abundant than potassium feldspar in all samples except C3177-45, C3177-80.3, C3177-113.3, and C3177-170.4. Over all the feldspar content (both plagioclase and alkali feldspars) averaged about 47 ± 5 wt.%. The amphibole phase comprised <4 wt.%, with the majority of samples having concentrations in the 2 to 4 wt.% range.

Samples from Layer 1 have higher plagioclase and lower quartz concentrations than do samples from Layer 2 or Layer 3. This reflects to the greater basalt content in Layer 1 than in the overlying layers (see the physical descriptions of samples in Table 4.12). Also, the paleosols and the silt lens have greater potassium feldspar concentrations than do the other samples.

Table 4.12. Samples Collected from Well 299-24-21 (C3177)

Sample Number[a]	Layer	Description
C3177-45	3	Composite sample; Hanford formation Layer 3
C3177-80.3	2	Sediment associated with a paleosol at the Hanford formation Layer 3/Layer 2 boundary; bedded, medium-grained sand; beds are distinguished by color and hardness
C3177-110		Composite sample; Hanford formation Layer 2
C3177-113.3		Silt lens in the Hanford formation Layer 2
C3177-150		Composite sample; Hanford formation Layer 2
C3177-168.5		Hanford formation Layer 2; bedded, medium-grained sand with a trace of silt; sample is from the base of the R2 (paleomagnetic) layer
C3177-170.4	1	Paleosol at the Hanford formation Layer 2/Layer 1 boundary; fine-grained sand to silt; bioturbated and bleached with calcite cement
C3177-200		Composite sample; Hanford formation Layer 1
C3177-215		Composite sample; Hanford formation Layer 1
C3177-223.5		Hanford formation Layer 1; coarse-grained sand; slight reaction to HCl; bottom of the N1 (paleomagnetic) layer
C3177-242.0		Hanford formation Layer 1; sandy gravel; near the top of the R1 (paleomagnetic) layer
C3177-251		Composite sample; Hanford formation Layer 1

(a) Sample numbers are the borehole designation followed by the depth below ground surface from where samples were collected.

Table 4.13. Semi-Quantitative XRD Results of Bulk Samples from Well 299-24-21 (C3177)

Sample Number	Mineral Phase (wt.%)						Goodness of Fit[a]
	Quartz	Amphibole	Plagioclase	K-Spar	Mica	Chlorite	
C3177-45	43	2	20	20	11	3	0.87
C3177-80.3	41	2	15	28	16	2	0.94
C3177-110	46	1	25	19	9	2	0.70
C3177-113.3	40	4	15	31	8	2	1.22
C3177-150	42	3	25	18	3	8	0.81
C3177-168.5	40	4	23	22	10	2	1.00
C3177-170.4	43	3	21	23	8	2	1.04
C3177-200	37	4	31	16	10	3	0.77
C3177-215	26	3	40	18	11	3	0.73
C3177-223.5	33	4	34	18	8	3	0.56
C3177-242.0	32	2	31	18	14	3	0.95
C3177-251	32	4	35	18	9	3	0.67

(a) Values closest to 1.0 represent an ideal refinement.

Calcite was identified in the physical description of most of the sediments by effervescence with HCl (Reidel et al. 2001). However, calcite was not identified in any of the sediments by XRD. This suggests that calcite makes up less than a few percent of the samples and that the major calcite reflections were masked by reflections from more abundant minerals in the diffraction analyses. The conversion of inorganic carbon to equivalent amounts of calcite also indicates that calcite is a minor phase (Horton et al. 2003).

Clay minerals identified in the bulk sediments include mica and chlorite. Mica concentrations range from 3 wt.% to 16 wt.% (the paleosol at 80.3 ft bgs), with an average concentration of 10 ± 3 wt.%. The specific type of mica present in the samples was not determined by XRD but both muscovite and biotite were identified during physical descriptions of the samples. Chlorite concentrations were <3 wt.% in all sediments analyzed with the exception of sample C3177-150, which had 8 wt.% chlorite.

The results of x-ray diffraction analysis of the <1.4 μm fraction of each sample are shown in Table 4.14. The clay fractions are dominated by four clay minerals: smectite, chlorite, illite, and kaolinite with minor amounts of quartz and feldspar.

No general trends are noted in the data in Table 4.14 from the twelve borehole samples. Smectite concentration ranges from 18 wt.% to 39 wt.%. Illite concentration varies from 43 to 54 wt.% with an average concentration of 48 wt.%. Chlorite and kaolinite are the least abundant of the clay minerals identified in the samples with concentrations equal to or less than 24 wt.% and 10 wt.%, respectively. Quartz and feldspar minerals were present as trace amounts in the clay fraction and therefore were not included in totals presented in Table 4.13.

The silt lens sample (C3177-113.3) has the highest smectite concentration and the lower paleosol sample (C3177-170.4) has the highest chlorite concentration. Overall, the mineralogy of the clay fractions from borehole C3177 are similar to clay fractions analyzed from clean boreholes and other composite samples of the Hanford formation sand-dominated sequence characterized by Serne et al. (2002).

Total clay recoveries are within ±15% of the "ideal" 100% for samples C3177-110, C3177-113.3, C3177-168.5, and C3177-242.0. Most other samples have recoveries within 30% of the "ideal" 100%. Factors affecting the semi-quantification procedure (preparation and condition of the clay filter cake) were generally controlled and not thought to be significant. Quantitative analysis is considered good if errors amount to approximately 10% of the amounts present for major constituents and approximately 20% for minerals whose concentrations are less than 20% (Moore and Reynolds 1989).

Table 4.14. Semi-Quantitative XRD Results of Clay Minerals Separated from the Samples Collected from 299-E24-21 (C3177)

Sample Number	Mineral Phase (wt.%)				Normalization Factor
	Smectite	Illite	Chlorite	Kaolinite	
C3177-45	24	54	14	8	0.67
C3177-80.3	34	44	14	9	0.78
C3177-110	26	51	16	7	0.89
C3177-113.3	39	43	12	6	0.90
C3177-150	25	50	18	7	0.77
C3177-168.5	27	47	19	6	0.90
C3177-170.4	18	50	24	9	1.40
C3177-200	27	50	16	8	1.36
C3177-215	30	46	20	4	1.50
C3177-223.5	NA	NA	NA	NA	-
C3177-242.0	27	44	18	10	1.16
C3177-251	NA	NA	NA	NA	-

NA – Not analyzed.

5.0 Hanford and Ringold Sediments Velocity Measurements

As part of the evaluation of earthquake ground motion response of the Waste Treatment Plant (WTP), measurements were made on shearwave velocities of sediment in 200 East Area (Rohay and Reidel 2005). This section is from that report and describes only that data collected near the IDF site.

The velocity measurements that were made at the IDF site included:

- Downhole shearwave velocity (Vs) and p-wave velocity (Vp) measurements in the 540-ft-deep borehole (named the Shear Wave Velocity Borehole, SWVB) adjacent to borehole 299-E17-21).
- Downhole Vs and Vp in boreholes 299-E17-21 and 299-E24-21 to the water table.
- In-hole suspension logging of the 540-ft-deep SWVB to confirm the results of the downhole method. This method required a water-filled borehole, and well construction failures limited the measurement depth range in this borehole to below 361 ft. A paired second borehole was constructed and logged, but the logging was not successful in completing measurements above this depth due to borehole casing resonances.
- Spectral analysis of surface waves (SASW) at the 299-E17-21 and 299-E24-21 borehole sites.

The locations of these measurements are summarized in Figure 5.1.

5.1 Downhole Velocity Measurements

A team from Northland Geophysical and Redpath Geophysics collected downhole seismic velocity surveys in six boreholes surrounding the WTP site in 2004 (Northland Geophysical 2004), two of which were at the IDF site. The locations of these measurements at the IDF site are shown in Figure 5.1. One of the boreholes (SWVB) was specially constructed to 540 ft deep, through the entire section of the Hanford and Ringold sediments to the top of the basalt, and completed using PVC casing.

A summary of the boreholes and measurements is shown in Table 5.1. Source offset was 12 ft (14 ft for the one compressional source). Interpreted velocities at comparable depth are subject to greater inaccuracy because of the potential for raypaths not to be straight geometrical paths as is assumed in the analysis. Travel times were measured every 3 ft in the top 100 ft, every 5 ft down to 300 ft depth, and every 10 ft below that.

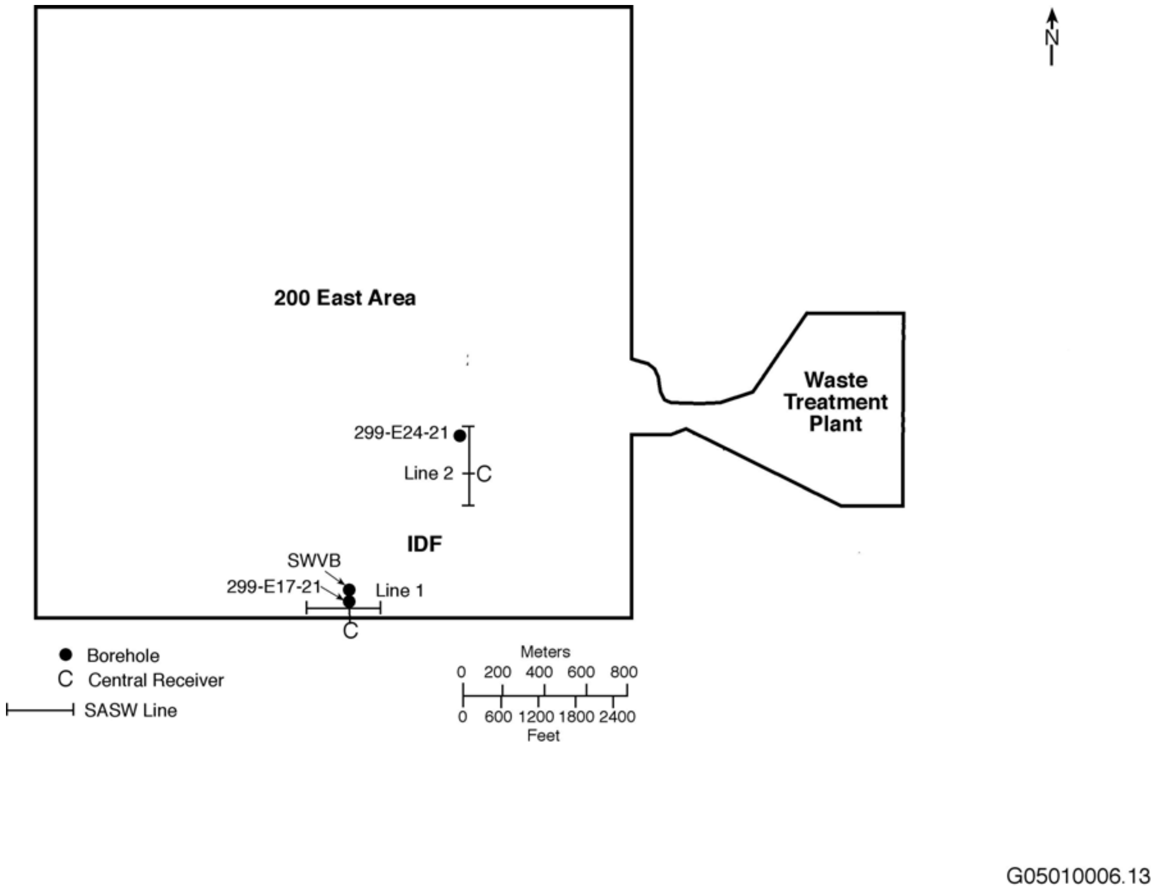

Figure 5.1. **Locations of Downhole and Suspension Log Velocity Measurements and SASW Measurements. The SASW profile sites, lengths, and map orientations are shown as lines, with the C indicating the location of the central receiver.**

Table 5.1. Summary of Downhole Velocity Measurements

Borehole Number	Survey Depth, ft	Remarks
299-E24-21	230	Stainless casing, oriented transducer Shear wave only
SWVB (C4562)	530	PVC-cased Shear-wave anisotropy investigated Compression-wave measured
299-E17-21	200	Stainless casing, oriented transducer Shear wave only (20 ft from SWVB)

An example of the interpreted Vs results, from the SWVB, is shown in Figure 5.2. The velocity change from near 2,000 to 2,700 feet per second (fps) at the 260-ft depth reflects the change from sand-dominated to gravel-dominated Hanford formation at 250 ft. There is no apparent change in velocity at a depth of 320 ft, the contact between the lower Hanford gravels and the upper Ringold gravels (Unit E). A low-velocity zone from 390 to 424 ft is detected and correlates with a fine-grained mud layer (lower mud). The velocity below this layer, 4,310 fps, corresponds again to gravel layer Unit A in the Ringold Formation.

Table 5.2 summarizes the results from the three boreholes. Velocity measurements made in the SWVB and in borehole 299-E17-21, located 20 ft from SWVB, are within 5% to 8% of each other. This suggests that there may be similar velocity variability over short distances at other locations such as in the WTP area. The shear wave onset signals do not appear to be significantly worse in the steel-cased borehole 299-E17-21 compared to the SWVB.

In general, velocities in the Hanford formation are 2,200 fps; velocities below this are associated with the Hanford sands, and velocities above 2,200 fps are associated with the lower Hanford gravel (and Unit E Ringold gravels). Ringold Unit A had a velocity of 4,000-fps at the bottom of the SWVB.

Table 5.2. Shear Wave Velocities from Downhole Measurements

Borehole	Location, NAD27	Depth Range, ft	Velocity, ft/sec
SWVB (C4562) 30°- Source	N46° 32.584' W119° 31.947'	0–11	830
		11–54	1,440
		54–135	1,705
		135–210	1,860
		210–260	2,045
		260–390	2,730
		390–424	1,940
		424–530	4,310
299-E17-21 (20' from SWVB)	N46° 32.583' W119° 31.955'	0–10	875
		10–50	1,430
		50–70	?
		70–140	1,645
		140–200	2,005
299-E24-21	N46° 33.016' W119° 31.535'	0–6	900
		6–36	1,160
		36–93	1,400
		93–186	1,665
		186–230	1,890
		14–90	1,145
		90–190	1,810
		190–250	2,565

Anisotropy was not an expected characteristic of sands and gravels, but measurements were made with four different polarizations of the shear waves, with one of the polarizations (138°) oriented parallel with the predominant southeastern flow directions that laid down the sediments. Travel times corresponding to the different polarizations agreed to within 1%, indicating no anisotropy. The velocities in the southeast and perpendicular directions are listed in Table 5.3.

Compressional wave measurements were made at the SWVB borehole only, because the metal casing in the other boreholes obscures the compression wave onset. Table 5.3 shows the resulting Vp values and calculated Poisson's ratio for the different depth intervals. Poisson's ratio (or the ratio Vp/Vs) in sedimentary materials becomes an important element in the development of the velocity model.

Table 5.3. SWVB Vs Anisotropy, Vp, and Poisson's Ratios. The two polarization orientations, 138° and 48°, are approximately parallel to and perpendicular to the depositional flow direction, respectively.

Depth Range, ft	Velocity, ft/sec			Poisson's Ratio (48° Source)
	Shear Wave		Compression Wave	
	48°	138°		
0 – 11	830	770	1,200	0.04
11 – 54	1,440	1,430	2,190	0.12
54 – 135	1,705	1,710	2,525	0.08
135 – 210	1,860	1,895	3,180	0.24
210 – 260	2,045	2,125	3,180	0.15
260 – 390	2,730	2,755	5,475	0.33
390 – 424	1,940	2,015	5,475	0.43
424 – 530	4,310	4,335	9,440	0.37

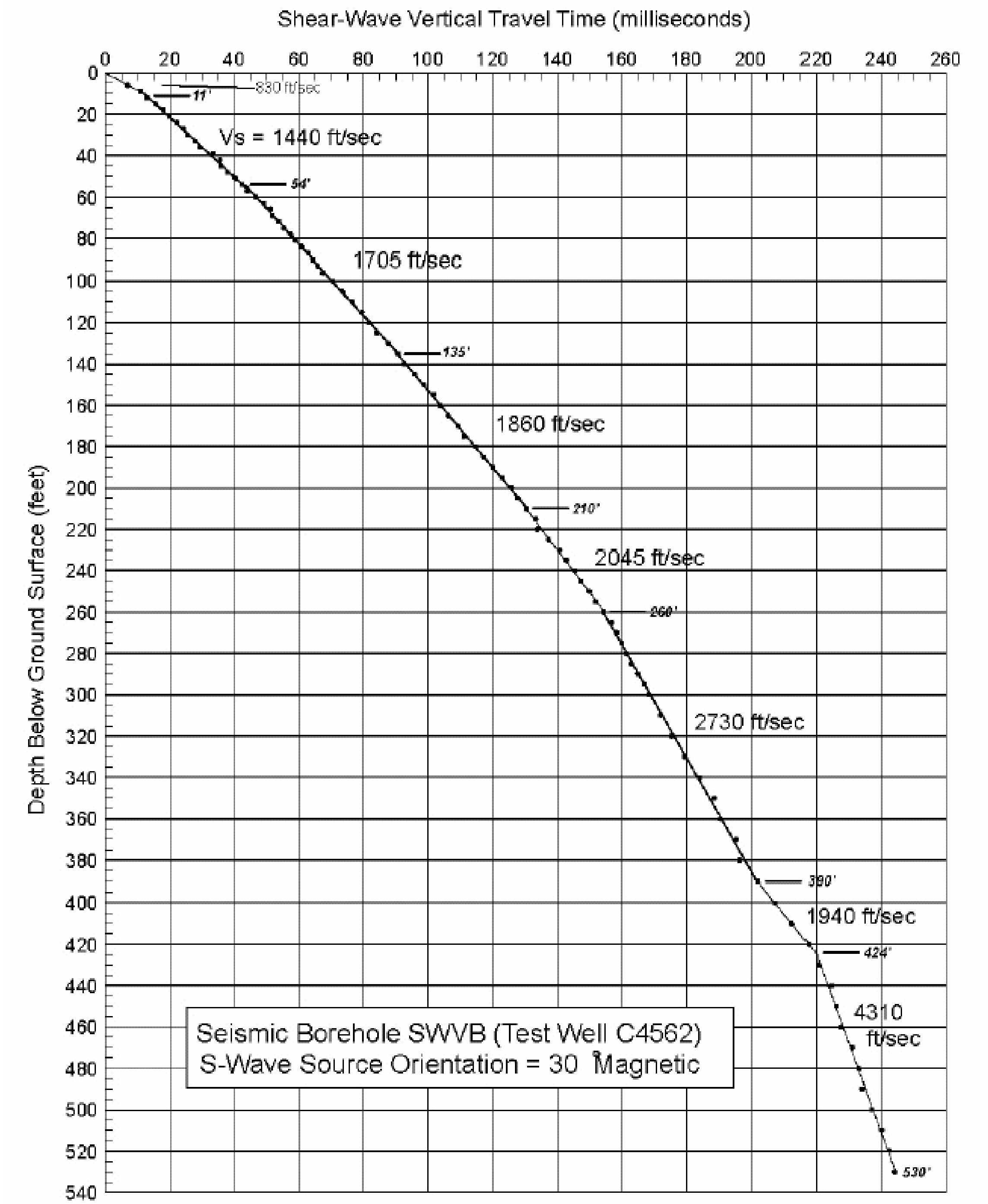

Figure 5.2. **Interpreted Shear Wave Velocity Profile at the Shear Wave Velocity Borehole (SWVB)**

5.2 Suspension Logging Measurements

Measurements were made in the SWVB (C4562; Figure 5.1) using a suspension logging system by Geovision Geophysical Services in 2004 (Geovision 2004). The SWVB PVC casing was cracked at the 360-ft depth and could not hold the water that is required to use this method. A second borehole (C4666) was drilled to 375 ft about 20 ft from the SWVB and completed watertight. The SWVB measurements were made from depths of 338 to 525 ft, and the measurements in the replacement borehole C4666 were made from 4 to 370 ft. The measurement interval was 1.64 ft (0.5 m). However, the waveforms for the data above a depth of 360 ft prevented a useful analysis and were not reported. It was thought that the well construction, cementing of the casing, and attempts to plug the leak at the 360-ft depth may have prevented obtaining clear signals using this method.

The results of the suspension logging from 360 to 525 ft are shown in Figure 5.3. The log begins with a 2,000 fps Vs between 360- and 430-ft depths. As noted for the downhole log, this interval is in the lower mud unit of the Ringold Formation, and the fine-grained mud has a low velocity. Below the 440-ft depth, the log detected layers with a relatively high Vs of 5,200 to 6,400 fps alternating with relatively low Vs of 2,000 to 2,500 fps. This is a different result from the SWVB downhole log, where an average velocity of 4,300 fps was determined, although the average velocities in this interval are comparable (see below). It is not surprising that the downhole logging did not detect the low-velocity layer near 465 ft; this layer is only 10 ft thick (the same as the downhole log spacing). The low-velocity layer between 495- and 515-ft depths could have been detected between only two or three measurements. Lithologic logs showed a silt layer in this interval, so this is an additional example of fine-grained Ringold layers having characteristic low velocity.

The accumulated travel times for the suspension log were compared to those from the downhole log (Geovision 2004) and are shown in Figure 5.4. The travel times differ by only 2%, reflecting the consistency of velocities determined by the two methods.

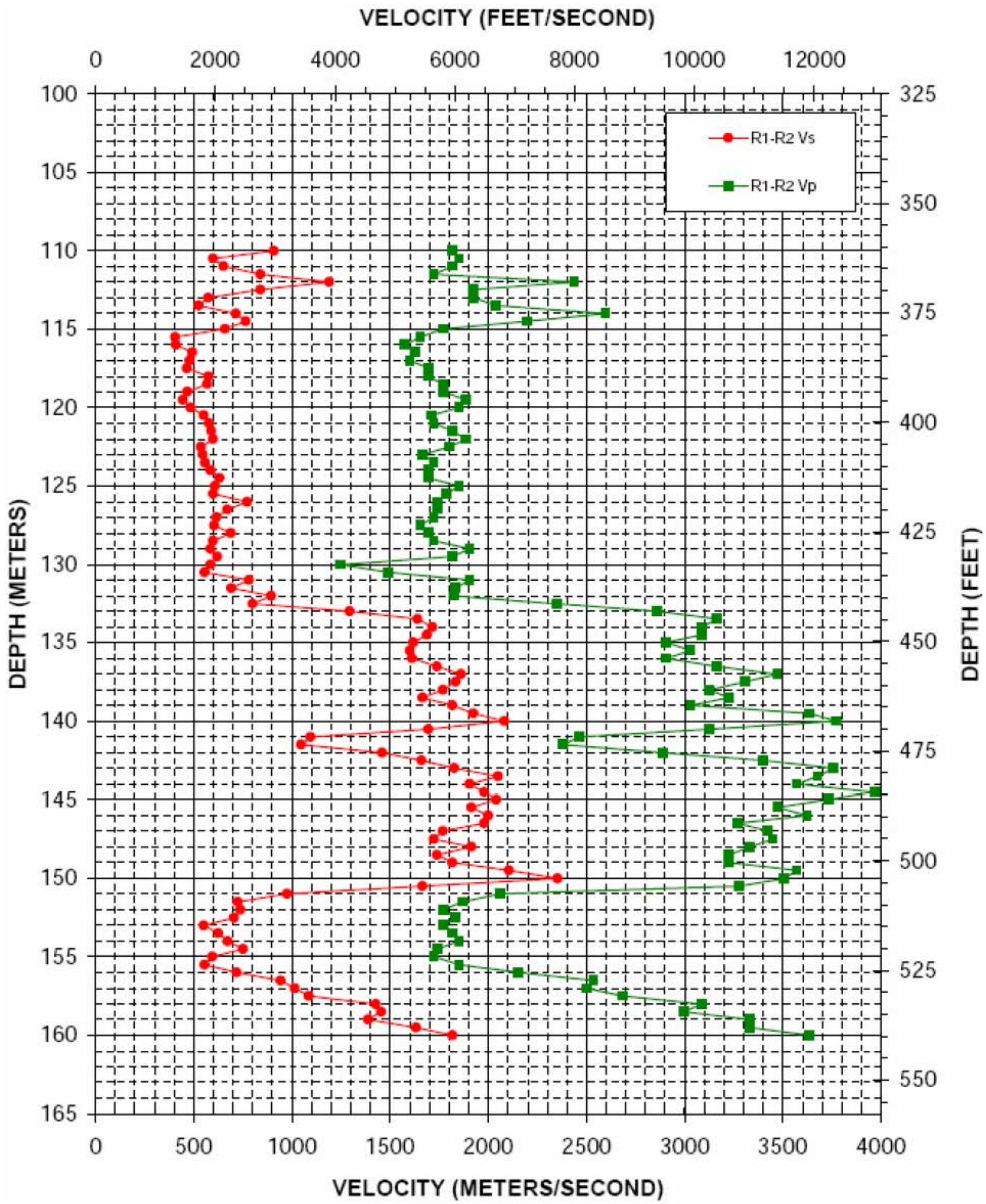

Figure 5.3. **Vs and Vp from Suspension Logging at the Shear Wave Velocity Borehole**

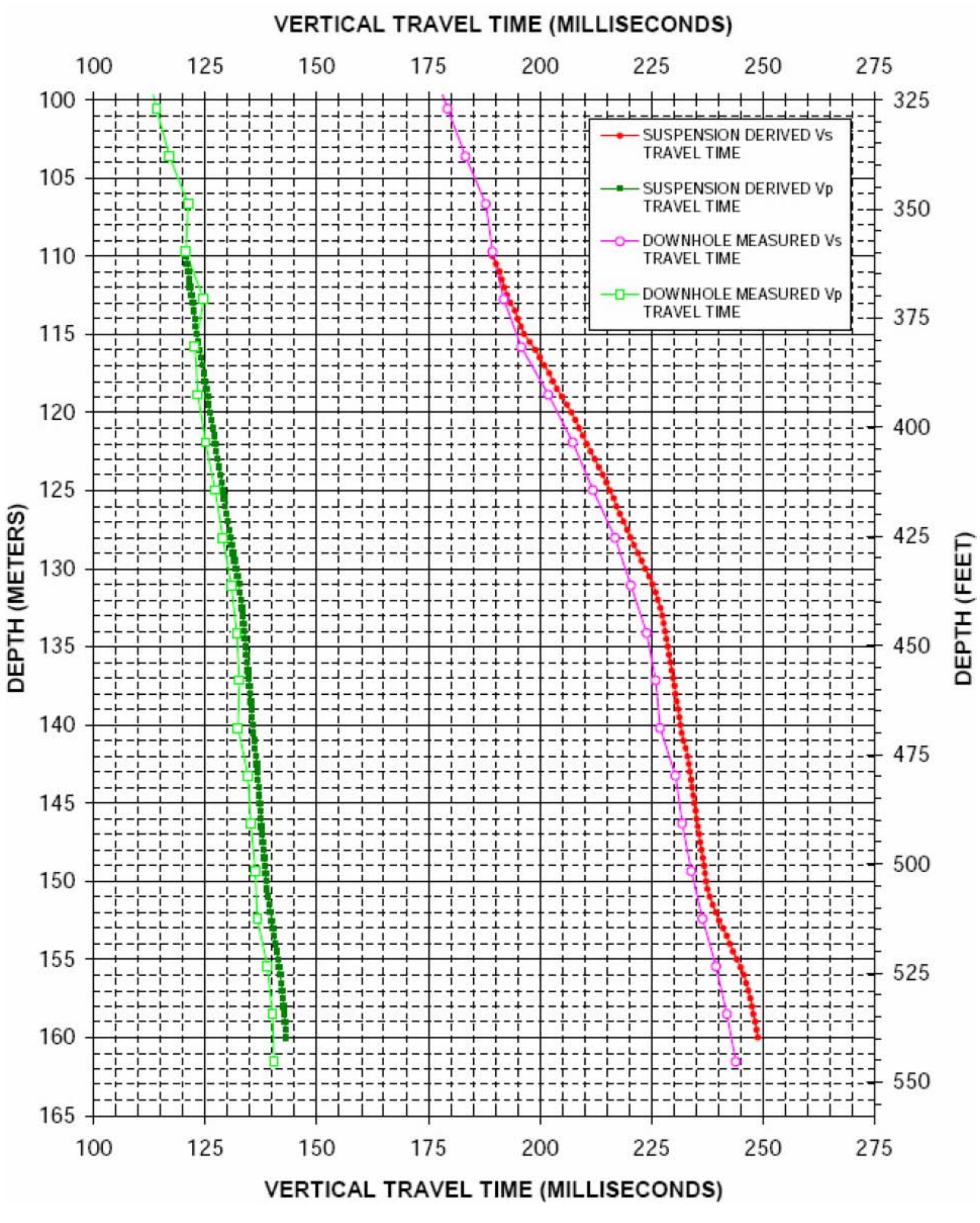

Figure 5.4. Comparison of Downhole and Suspension Travel Times for the Shear Wave Velocity Borehole

5.3 Spectral Analysis of Shear Waves (SASW) Measurements

Researchers from the University of Texas at Austin measured surface wave dispersion at 10 sites in 2004 (Stokoe et al. 2005). Two of these locations were within approximately 50 ft from boreholes 299-E17-21 and 299-E24-21 (Figure 5.1), that were logged using downhole methods. The SASW method was chosen because it provided a means to extend the Vs profiles below the approximately 250-ft depth of most of the borehole measurements using a surface technique. The orientations of the profiles were chosen based on geographic logistical considerations and not for any particular geologic reasons.

Figures 5.5 and 5.6 show the SASW-derived Vs profiles superimposed on the profiles from the downhole logs at the two IDF locations where both types of measurements were made. The SASW and the downhole logs give comparable results in the top 200 to 250 ft of the profiles (in the Hanford formation sands and gravels). However, at site 1 (299-E17-21), higher Vs are measured using the downhole method (near 2,600 fps) in the depth range of 200 to 250 ft, while the SASW Vs remain near 2,000 fps.

At the SWVB location (Line 1) where the downhole log extended through the Ringold Formation to the top of basalt, the SASW profile eventually increases to near 4,000 fps at the 450-ft depth, near the same depth where the downhole log Vs increases to 4,500 fps. However, it does not seem to respond to the upper Ringold Unit E present at this location. The SASW method is not capable of detecting thin low-velocity zones at depths within the Ringold, as were seen in the suspension logging.

The deeper parts of the SASW Vs profiles show increases in Vs to 4,000 to 5,000 fps. The depths to these velocity horizons are consistent with the depth to the top of the uppermost basalt flow.

In summary, the SASW gives results comparable to the downhole Vs surveys in the upper 250 ft where the Hanford sands and gravels represent the lithology. The Vs in the Hanford formation gradually increase from below 1,000 fps at the surface to near 2,000 fps at the bottom of the Hanford formation. The SASW variably detects the Ringold units below these depths. The Ringold Formation, where present, is variably represented by a Vs increase (relative to the Hanford formation) to a range between 2,500 and 4,000 fps. SASW-measured Vs in the basalt is also variable.

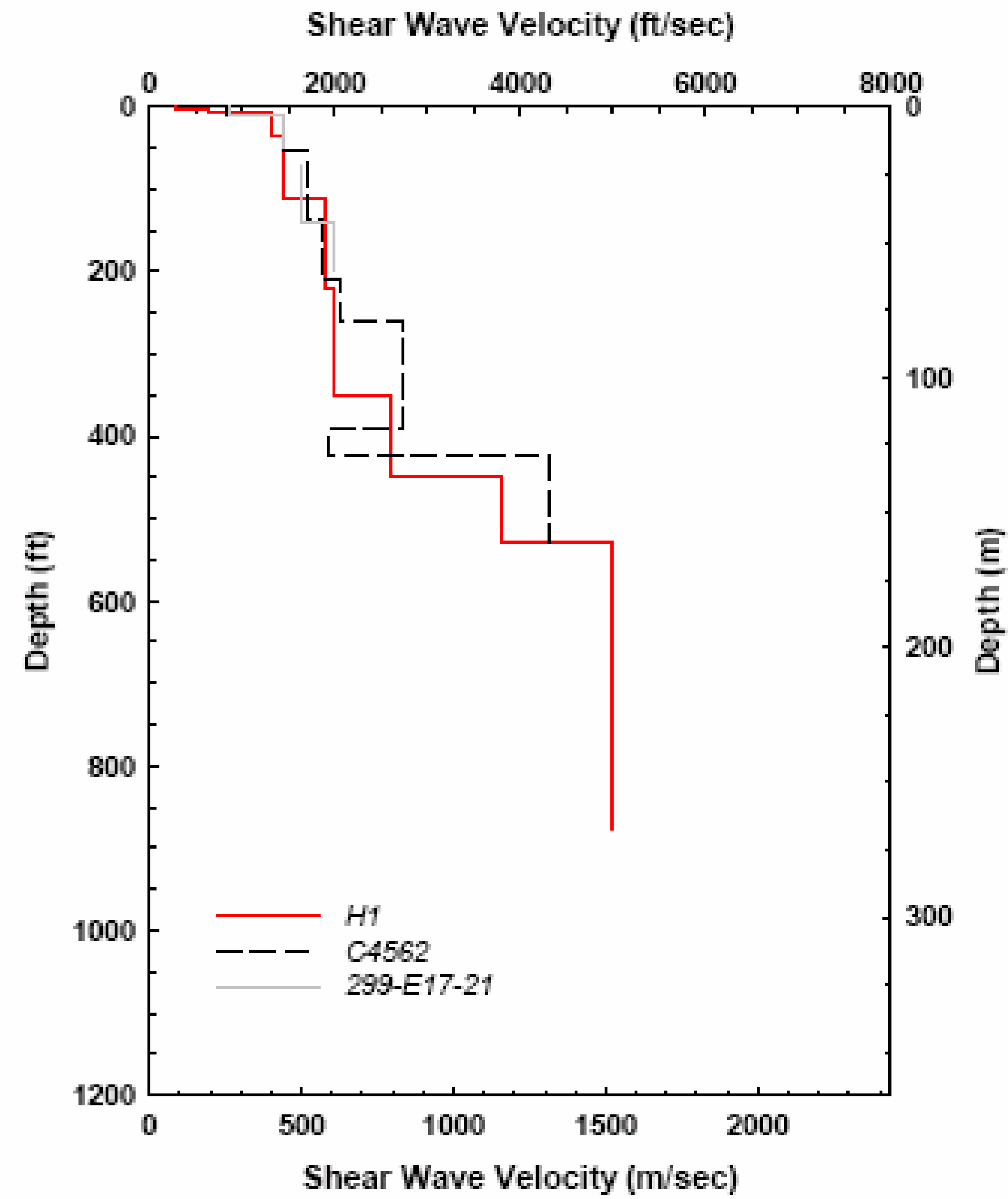

Figure 5.5. **Comparison of SASW Profile H1 and Downhole Logs at Site 1 (SWVB)**

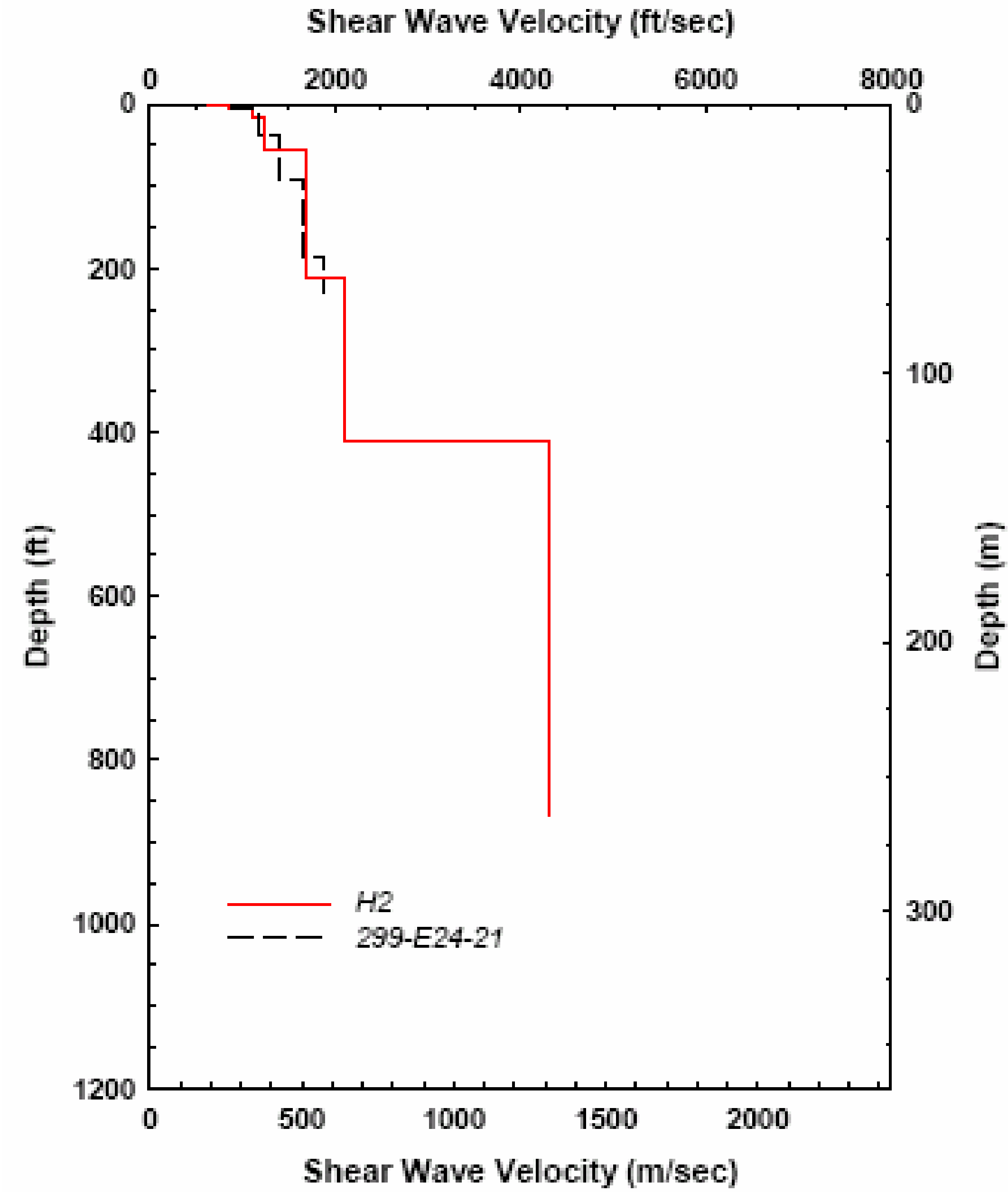

Figure 5.6. **Comparison of SASW Profile H2 and Downhole Log at Site 2**

6.0 Water Table and Aquifer Characterization

Figure 6.1 shows the water table at the site as of 2003. The principal characteristic of the water table is its relatively flat nature across the site. Appendix A provides the results of slug tests performed at the wells.

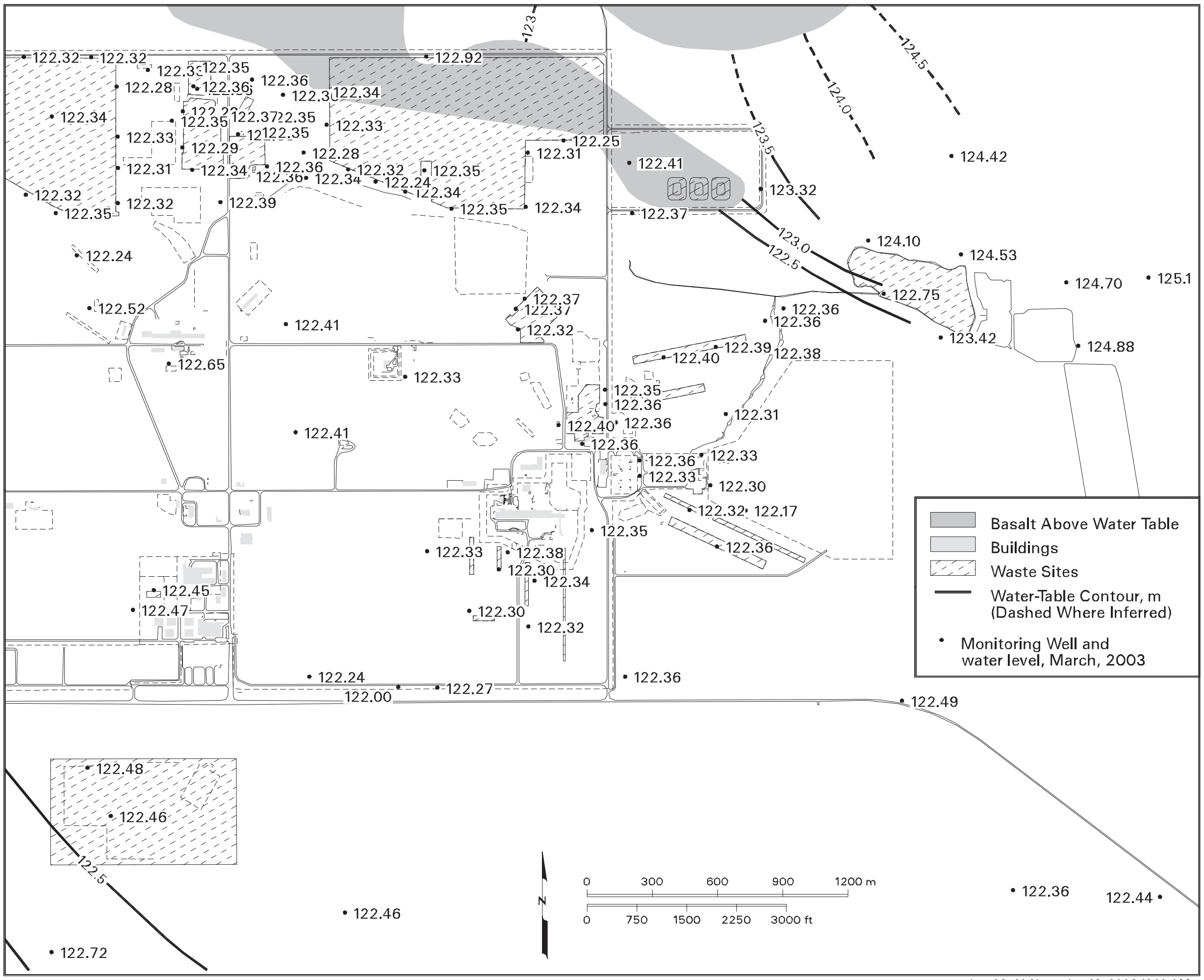

Figure 6.1. Water Table Map for the Hanford Site 200 East Area

7.0 Seismic Data

Figure 7.1 shows the earthquake activity that has occurred since seismic monitoring began at Hanford in 1969. This map shows that no earthquakes have been recorded at the existing disposal site or the new IDF site. The closest earthquakes are of magnitude 2.0 or less. A comparison of the geologic map (Figure 2.1) and the earthquake map show that there are no earthquakes occurring on known geologic faults.

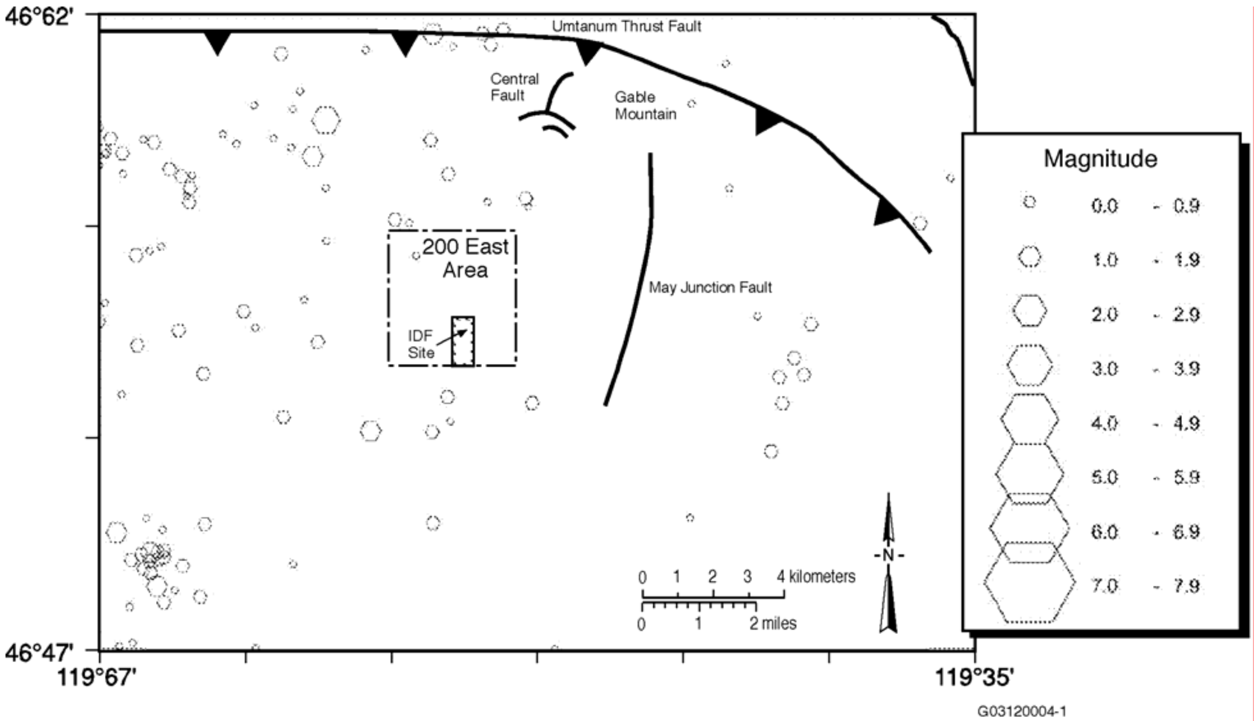

Figure 7.1. Map Showing the Location of Earthquakes Detected Since 1969

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Appendix A

Slug Test Characterization Results

Appendix A

Slug Test Characterization Results

Frank Spane

This report section provides the analytical results and description of slug tests conducted at five Integrated Disposal Facility (IDF) site monitor well locations. The location of the test wells surrounding the IDF site is shown in Figure A.1, and include: wells 299-E17-21, 299-E17-22, 299-E17-23, 299-E17-25, and 299-E24-21.

A.1 Test Method Description

Because of their ease of implementation and relatively short duration, slug tests are commonly used to provide initial estimates of hydraulic properties (e.g., range and spatial/vertical distribution of hydraulic conductivity, K). Because of the small displacement volumes employed during slug tests, hydraulic properties determined using this characterization method are representative of conditions relatively close to the well. For this reason, slug-test results are commonly used to design subsequent hydrologic tests having greater areas of investigation (e.g., slug interference [Novakowski 1989; Spane et al. 1996], constant-rate pumping tests [Butler 1990; Spane and Wurstner 1993]). Results provided in Spane et al. (2001a, 2001b, and 2002) indicate a relatively close correspondence between reported hydraulic properties derived from slug test and pumping tests conducted at Hanford Site locations (i.e., estimate values generally within ±30%). As noted in Butler (1998), the close correspondence between slug and pumping test hydraulic property estimates indicates that the formation being tested can be represented as a homogeneous unit at the slug test or larger scale.

Slug tests conducted as part of the IDF site slug test characterization program were performed by removing a slugging rod (withdrawal test) of known displacement volume. Slug-withdrawal tests are preferred over 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). At one test site location, however, (well 299-E17-25) a number of slug injection tests were conducted as a means of test response comparison. At all test sites, two different size slugging rods were used to impart varying stress levels for individual slug tests. The slug tests were repeated at each stress level to assess reproducibility of the test results. Comparison of the normalized slug-test responses (i.e., for the two stress levels) is also useful assessing the effectiveness of well development and the presence of near-well heterogeneities and dynamic skin effects, as noted in Butler et al. (1996). Dynamic skin conditions refer to the non-repeatability of test responses conducted at a particular stress level. This non-repeatability of test response is commonly associated with changing formational conditions near the well due to incomplete well development activities. All IDF site wells tested, however, exhibited repeatable slug test response behavior indicating a stable or static formation condition surrounding each well, and suggests that the wells had been effectively developed prior to testing.

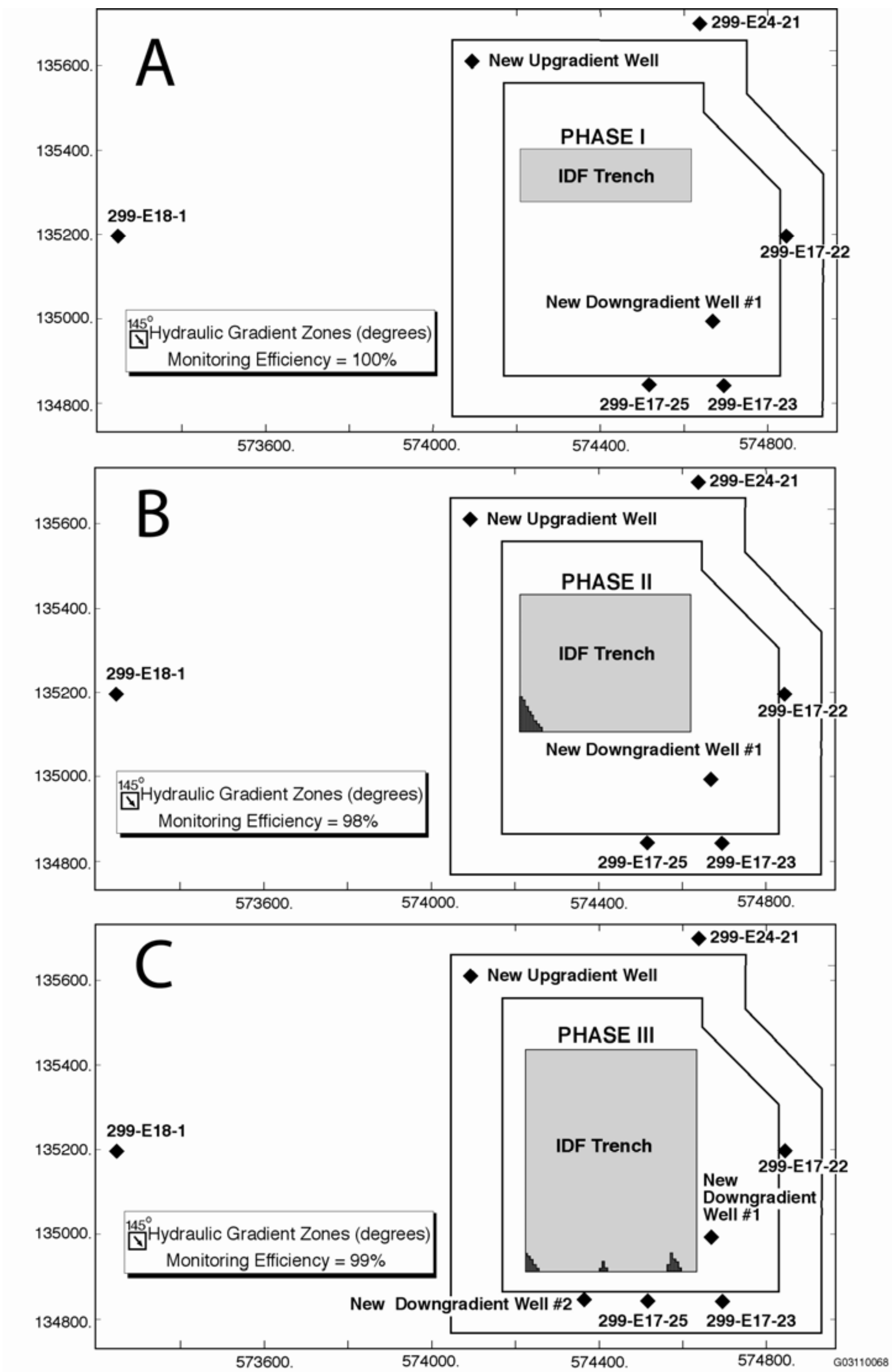

Figure A.1. **Location Map of Integrated Disposal Facility (IDF) Site Monitoring Network Wells and Phases of Installation**

Based on volumetric relationships, the two different size slugging rods theoretically impart a slug-test stress level of 0.458 meter (low-stress tests) and 1.117 meters (high-stress tests) within a 0.102-meter inside diameter well. However, due to the relatively high aquifer permeability conditions that exist in the IDF site area and the fact that the slug tests could not be initiated in an *instantaneous* manner, the actual stress level imposed on the test formation were (in some cases) significantly lower than the theoretical stress level. This is due to the rapid and concurrent formation response during the time for slug test initiation (i.e., slugging rod removal ≈1 second). For these high-permeability test situations, the actual slug-test stress level is determined by projecting the observed early test response back to the time of test initiation (i.e., test time = 0).

A.1.1 Test Response Characteristics

As shown in Figure A.2, water levels within wells can respond in one of three ways to the applied initial stress of the slug test. These response model patterns are: 1) an over-damped response, where the water levels recover in an exponentially decreasing recovery pattern; 2) an under-damped response, where the slug test response oscillates above and below the initial static, with decreasing peak amplitudes with time; and 3) critically damped, where the slug test behavior exhibits characteristics that are transitional between the over- and under-damped response patterns. Factors that control the type of slug test response model that is exhibited within a well include a number of aquifer properties (hydraulic conductivity, storativity) and well-dimension characteristics (well-screen length, well casing radius, well radius, aquifer thickness).

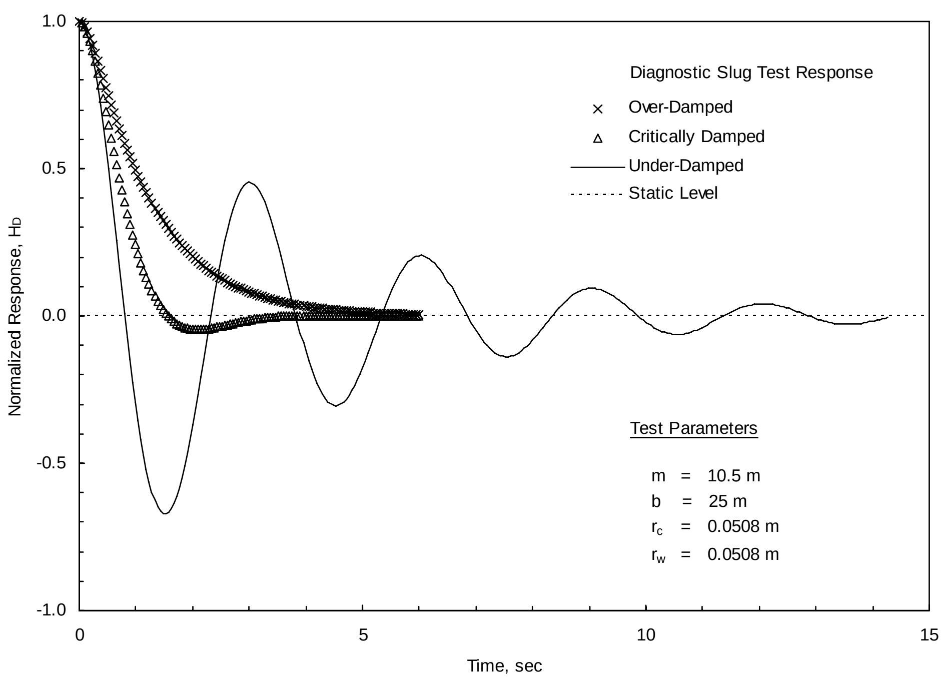

Figure A.2. Diagnostic Slug Test Responses

Over-damped test response behavior occurs within wells monitoring test formations of low to moderately high hydraulic conductivity (e.g., K less than ~30 m/d for L = 10 m), and are indicative of test conditions where frictional forces (i.e., resistance of groundwater flow from the test interval to the well) are predominant over test system inertial forces. It is the most frequently displayed response pattern exhibited for wells tested on the Hanford Site, particularly for tests conducted within the 200-West Area. Standard methods used for the analysis of over-damped slug-tests include: the semi-empirical, straight-line analysis method described in Bouwer and Rice (1976) and Bouwer (1989), and the type-curve-matching method for unconfined aquifers presented in Butler (1998). A detailed description of these slug-test analysis methods, as they relate to unconfined aquifer tests conducted on the Hanford Site, is presented in Spane et al. (2001a, 2001b, 2002).

Under-damped test response patterns are exhibited within wells where inertial forces are predominant over formation frictional forces. This commonly occurs in wells with extremely long well fluid columns (i.e., large water mass within the well column) and/or within wells that penetrate highly permeable aquifers. As noted in Butler (1998), unconfined aquifer tests exhibiting under-damped behavior should be analyzed using the model presented in Springer and Gelhar (1991), which has been modified by Butler and Garnett (2000) to include partially penetrating well conditions. Tests exhibiting under-damped behavior should be conducted using very small stress level applications. If too high of a stress is applied, the slug test response will commonly exhibit oscillatory behavior superimposed on either an over- or critically damped recovery response. Methods are currently not available for the analysis of slug tests exhibiting this type of composite slug test response. For test sites exhibiting composite oscillatory behavior, the tests should be re-run at lower stress levels to allow analysis and quantitative hydraulic property determination using the appropriate, individual, analysis model method (under-, over-, or critically damped).

As mentioned previously, critically damped test responses are indicated by well water level responses that are transitional to the over- and under-damped test conditions, as shown in Figure A.2. They typically occur in wells that monitor test formations exhibiting high hydraulic conductivity. As noted in Butler (1998), distinguishing between over- and critically damped slug test response may be difficult in some cases (i.e., due to test signal noise) when examined on arithmetic plots. Proper model identification may be enhanced when semi-log plots are utilized, i.e., log head versus time. Critically damped slug tests exhibit a diagnostic concave-downward pattern when plotted in semi-log plot format. This is in contrast to over-damped response behavior, which displays either a linear or concave upward pattern. Appropriate methods that can be used to analyze critically damped slug tests are discussed in Butler (1998). A particularly useful spreadsheet method that is valid for the analysis of a variety of critically damped well/test response conditions is presented in Butler and Garnett (2000).

Table A.1 lists the diagnostic assessment of test response characteristics exhibited at the five IDF site monitor well test sites. As indicated in the table, all tests exhibited extremely rapid recovery times, and exhibited either over-damped or composite response model behavior. These diagnostic test response characteristics are indicative of test formations exhibiting high to very high permeability characteristics. Slug tests exhibiting these high permeability characteristics cannot be analyzed quantitatively using the Bouwer and Rice (1976) or type-curve methods, even if over-damped response patterns are exhibited (e.g., well 299-E24-21). Methods that can be employed for analyzing unconfined aquifer tests exhibiting

Table A.1. Diagnostic Assessment of Slug-Test Response

Test Well	Test Parameters					Comments
	Test Date	Test Response Recovery Time[a], sec	Projected Stress Level[b], m	Test Response Type[c]	Applied Analysis Method[d]	
299-E17-21	06/10/98	4.5	0.25	Composite: Under- and Over-Damped	High-K	Well-developed oscillatory characteristics exhibited in slug withdrawal recovery curve – particularly for low-stress tests
299-E17-22	07/31/02	5	0.04 - 0.05	Over-Damped	High-K	No oscillatory characteristics exhibited in slug withdrawal recovery curve
299-E17-23	08/01/02	5	0.04	Over-Damped	High-K	No oscillatory characteristics exhibited in slug withdrawal recovery curve
299-E17-25	08/05/02	3.5	0.28 - 0.38	Composite: Under- and Critically Damped	High-K	Minor oscillatory characteristics exhibited in slug withdrawal recovery curve; dominant oscillatory pattern exhibited for slug injection tests
299-E24-21	06/12/01	7.5	0.0366	Over-Damped	High-K	No oscillatory characteristics exhibited in slug withdrawal recovery curve

Note: For all test wells, r_c = 0.051 meter; r_w = 0.110 meter.
(a) Time required for test recovery (i.e., within 0.001 m of pre-test static level).
(b) Estimated applied stress-level for high-stress slug tests; note: theoretical applied stress = 1.117 m.
(c) Diagnostic test response characteristics exhibited for slug withdrawal tests.
(d) High-K analysis method presented in Butler and Garnett (2000) and Butler et al. (2003). Standard analytical methods include type-curve and Bouwer and Rice methods described in Spane et al. 2002.

high permeability characteristics include, methods described in Springer and Gelhar (1991), Butler (1998), McElwee and Zenner (1998), Butler and Garnett (2000), Zurbuchen et al. (2002), and Butler et al. (2003). Because of the ease provided by a spreadsheet-based approach, the test analysis method presented in Butler and Garnett (2000) was used for the analysis of all IDF site tests, which exhibited high permeability response characteristics. Analysis results for individual test well sites are discussed in Section A.2.

A.2 Test Results

Description and analytical results for slug tests conducted in IDF site monitor wells are provided in the following sections of the report. Table A.2 lists pertinent test and analysis results for the respective well sites. As indicated, test results for wells 299-E17-21 and 299-E24-21 were previously reported in Spane (1998) and Spane (2001), respectively. These test results, however, were analyzed using standard analytical methods, which are not appropriate for the analysis of high-permeability formations or tests not exhibiting over-damped test response. As was noted and recommended in Spane (1998), these slug test results should be reanalyzed when more appropriate analytical methods for analysis of slug tests exhibiting high permeability and/or critically damped behavior became readily available. Table A.2, then, lists the re-analysis of these two well sites, as well as the results for recently conducted slug tests at the other three IDF site monitor well sites using the High-K analysis method described in Butler and Garnett (2000) and Butler et al. (2003), which is appropriate for high permeability tests exhibiting either over-, under- or critically damped response behavior.

Table A.2. Slug-Test Analysis Results

Test Well	Test Parameters			High-K[c] Type-Curve Analysis Method		Previously Reported Horizontal Hydraulic Conductivity, $K_{h,}$[d] (m/day)
	Test Date	Aquifer Thickness[a] (m)	Test Interval Saturated Thickness (m)	Horizontal Hydraulic Conductivity, $K_{h,}$[b] (m/day)	Damping Factor, C_D	
299-E17-21	06/10/98	13.3	7.83	40.3-45.7 (≥43)	3.0-5.0	69
299-E17-22	07/31/02	25	10.41	27.3-30.0 (≥29)	2.75-2.90	-
299-E17-23	08/01/02	25	10.63	23.0-23.9 (≥24)	2.50-3.75	-
299-E17-25	08/05/02	25	10.15	38.2-51.1 (≥45)	1.30-1.33	-
299-E24-21	06/12/01	25	6.1	39.9 (≥40)	10.0	75

Note: For all test wells, r_c = 0.051 meter; r_w = 0.110 meter.
Number in parentheses is best estimate value for the test interval.
(a) Determined, in most cases, from projection from neighboring wells.
(b) Assumed to be uniform within the well-screen test section.
(c) Results based on High-K analysis method presented in Butler and Garnett (2000) and Butler et al. (2003).
(d) Previously reported values based on standard slug test analysis methods (i.e., type-curve and Bouwer and Rice methods as discussed in Spane et al. 2002), which are not valid for tests exhibiting High-K conditions

A.2.1 Well 299-E17-21

A total of seven slug withdrawal tests (three high and four low stress) were conducted on June 10, 1998. Very rapid recoveries (~99% recovery within ~4.5 seconds) were exhibited for all tests, and are indicative of extremely high permeability conditions (Table A.1). A comparison of the normalized, low- and high-stress slug-test responses indicates essentially identical behavior, which suggests that the well had been fully developed. Examination of the individual slug-test responses also indicates a high permeability, nonlinear-inertial slug test response. Of particular note, is the well-defined oscillatory pattern exhibited in Figure A.3, which is superimposed on the general, rapid, slug withdrawal recovery pattern (particularly on low-stress tests). As noted previously, such a superimposed pattern is indicative of a composite model response pattern (i.e., under-damped on over-damped). This composite pattern is attributed to the application of too high of a stress level to initiate the test. The existence of composite response behavior was not recognized at the time of testing; and consequently, no subsequent slug tests were performed at lower stress levels that would insure single-model response behavior. As noted previously, such tests exhibiting composite response patterns are not currently analyzable with available analytical methods. In an attempt to provide a qualitative hydraulic conductivity estimate for the test, a High-K over-damped response curve was fit through the test response data, projecting approximately through the mid-points of the data exhibiting oscillatory behavior. This is similar to the filtering analysis

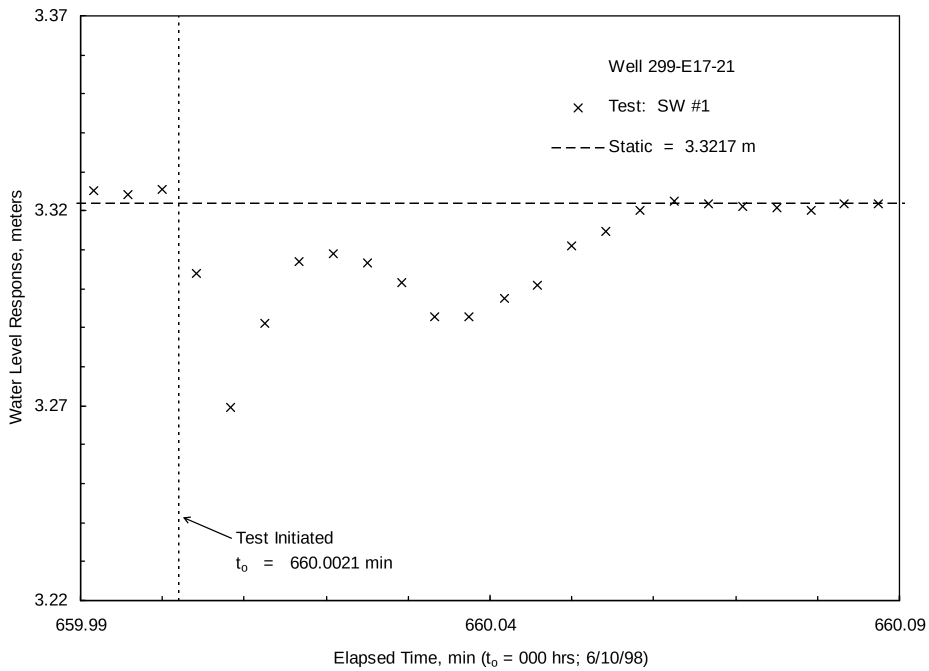

Figure A.3. Test Response for Well 299-E17-21 Showing Oscillatory Response Superimposed on Over-Damped Slug Withdrawal Test Recovery

approach taken by Giffin and Ward (1989) for analyzing pumping test pumping test data exhibiting similar early-time oscillatory responses that are superimposed on a general recovery water-level buildup pattern. Figure A.4 shows an analysis plot for a selected high-stress test for this well.

As noted previously, such a superimposed pattern is indicative of a composite model response pattern (i.e., under-damped on over-damped). This composite pattern is attributed to the application of too high of a stress level to initiate the test. The existence of composite response behavior was not recognized at the time of testing; and consequently, no subsequent slug tests were performed at lower stress levels that would insure single-model response behavior. As noted previously, such tests exhibiting composite response patterns are not currently analyzable with available analytical methods. In an attempt to provide a qualitative hydraulic conductivity estimate for the test, a High-K over-damped response curve was fit through the test response data, projecting approximately through the mid-points of the data exhibiting oscillatory behavior. This is similar to the filtering analysis approach taken by Giffin and Ward (1989) for analyzing pumping test pumping test data exhibiting similar early-time oscillatory responses that are superimposed on a general recovery water-level buildup pattern. Figure A.4 shows an analysis plot for a selected high-stress test for this well.

As indicated Table A.2, hydraulic conductivity estimates ranged between 40.3 and 45.7 m/day for all tests using this approximate analytical approach. Because of the qualitative nature of the analysis method utilized (i.e., using a single response model to analyzed a test exhibiting composite model behavior), a best estimate value of ≥43 m/day (based on the average for high- and low-stress tests) can only be

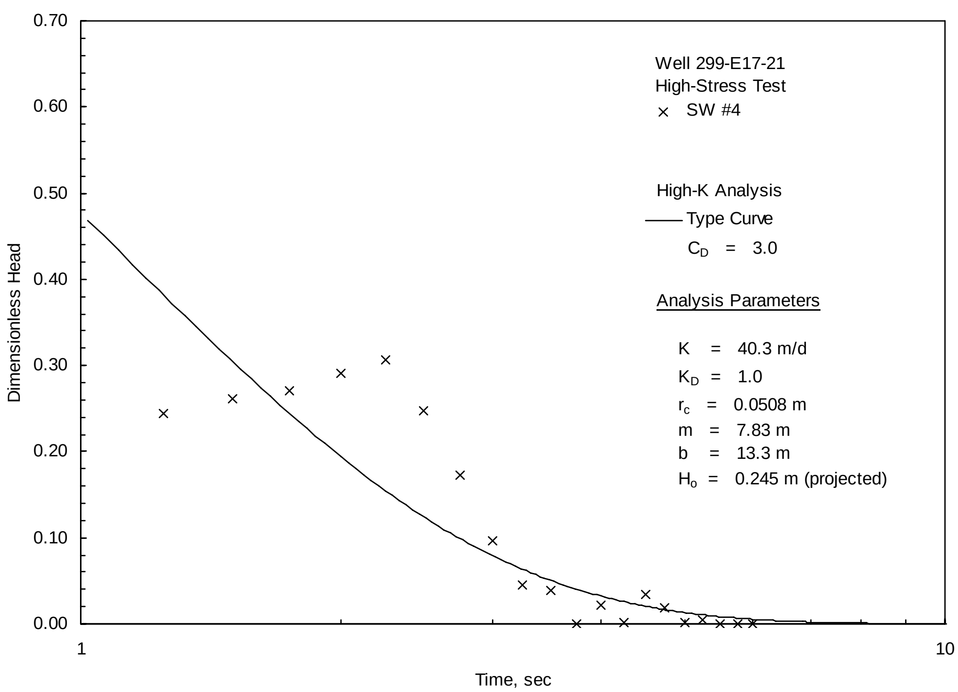

Figure A.4. High-K Slug Withdrawal Test Analysis Plot for Well 299-E17-21

specified at this time for the test formation monitored at this site. A more quantitative estimate can obtained for this well location by conducting additional low-level stress tests, and incorporating the test suggestions presented in Section A.3 of this report. For comparison purposes, Table A.2 also shows that a higher estimate for hydraulic conductivity of 69 m/day was reported earlier in Spane (1998) for the slug tests performed at this site. As previously discussed, however, this earlier results was determined based on analytical methods not appropriate for high permeability formation conditions.

A.2.2 Well 299-E17-22

A total of five slug withdrawal tests (three high and two low stress) were conducted on July 31, 2002. Very rapid recoveries (~99% recovery within ~5 seconds) were exhibited for all tests, and are indicative of extremely high permeability, over-damped conditions (Table A.1). A comparison of the normalized high-stress slug-test responses indicates essentially identical behavior, which suggests that the well had been fully developed. Due to the relatively small test responses exhibited for low-stress test results, only test data obtained for high-stress tests were subjected to quantitative analysis. Because the high-stress test responses were nearly identical, analysis results would be expected to be quite comparable. Figure A.5 shows the results of a selected high-stress slug test analysis. As indicated in Table A.2, hydraulic conductivity estimates ranged between 27.3 and 30.0 m/day for all high-stress tests using the High-K analysis method. Because of the extremely rapid recovery response and low projected stress levels (0.04 to 0.05 m; Table A.1), a best estimate value of ≥29 m/day (based on the average for high-stress tests) can only be specified at this time for the test interval monitored at this site. A more quantitative

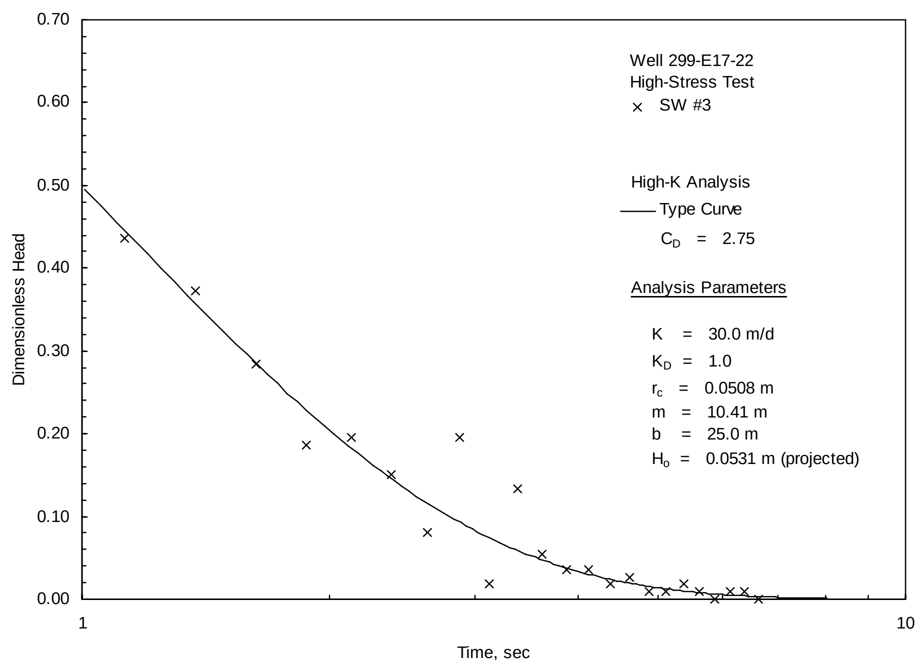

Figure A.5. High-K Slug Withdrawal Test Analysis Plot for Well 299-E17-22

estimate might be obtained for this well location by conducting additional stress tests that incorporate test suggestions presented in Section A.3 of this report.

A.2.3 Well 299-E17-23

A total of five slug withdrawal tests (three high and two low stress) were conducted on August 1, 2002. Very rapid recoveries (~99% recovery within ~5 seconds) were exhibited for all tests, and are indicative of extremely high permeability, over-damped conditions (Table A.1). A comparison of the normalized high-stress slug-test responses indicates essentially identical behavior, which suggests that the well had been fully developed. Due to the relatively small test responses exhibited for low-stress test results, only test data obtained for high-stress tests were subjected to quantitative analysis. Because the high-stress test responses were nearly identical, analysis results would be expected to be quite comparable. Figure A.6 shows the results of a selected high-stress slug test analysis. As indicated in Table A.2, hydraulic conductivity estimates ranged between 23.0 and 23.9 m/day for all high-stress tests using the High-K analysis method. Because of the extremely rapid recovery response, low projected stress levels (0.04 m; Table A.1), and scatter in test data, a best estimate value of ≥24 m/day (based on the average for high-stress tests) can only be specified at this time for the test formation monitored at this site. A more quantitative estimate might be obtained for this well location by conducting additional stress tests that incorporate test suggestions presented in Section A.3 of this report.

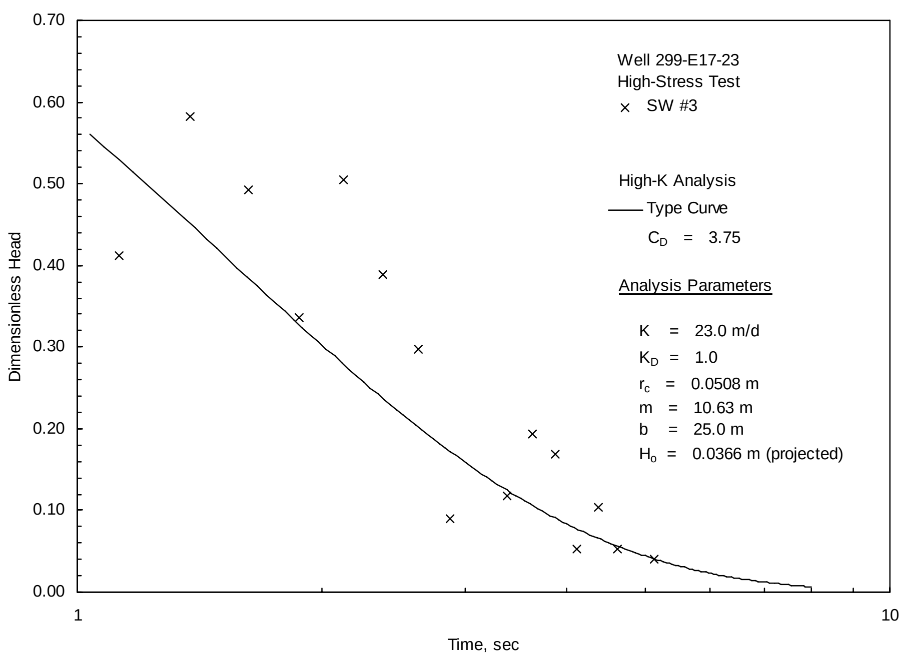

Figure A.6. High-K Slug Withdrawal Test Analysis Plot for Well 299-E17-23

A.2.4 Well 299-E17-25

A total of five slug withdrawal tests (three high and two low stress) were conducted on August 5, 2002. Very rapid recoveries (~99% recovery within ~3.5 seconds) were exhibited for all tests, and are indicative of extremely high permeability, critically damped conditions (Table A.1). A comparison of the normalized high-stress slug-test responses indicates essentially identical behavior, which suggests that the well had been fully developed. Of particular note, is a consistent, over-recovery of water-levels during the early stages of the test (i.e., beyond the pre-test static water level), which then recovers back to equilibrium conditions. Test responses exhibiting this type of pattern are indicative of critically-damped test behavior as shown in Figure A.2. In addition, to these tests, three slug injection tests were conducted for comparing test response behavior. The slug injection tests exhibited an oscillatory, under-damped slug test response as shown in Figure A.7. The reason for the change in response behavior (i.e., from critically damped to under-damped), is due the presence of the slugging rod, which effectively changes the inside well casing radius (i.e., where the water-level response occurs). As discussed in Section A.3, decreasing the well casing radius, r_c, lowers the well-response damping factor, C_D, which can cause a shift in test behavior from over-damped to → critically damped or to → under-damped behavior. Unfortunately, the slug injection oscillatory tests can not be analyzed using standard, High-K underdamped, analytical methods. This is due to the fact that the effectively reduced well casing radius occurs in only part of the well-screen section (i.e., slugging rod is ~1.8 m). As a result, the oscillatory test response occurred in well-screen sections of varying radius (i.e., early peaks within the open well casing, with the oscillatory troughs occurring within the annular area surrounding the slugging rod and well casing).

Because of the difficulties presented with analyzing the slug injection oscillatory response, analysis efforts for this test well focused on analyzing the critically damped slug withdrawal tests. Due to the relatively small test responses exhibited for low-stress test results, only test data obtained for high-stress tests were subjected to quantitative analysis. Figure A.8 shows the results of a selected high-stress slug test analysis. As indicated in Table A.2, hydraulic conductivity estimates ranged between 38.2 and 51.1 m/day for all high-stress tests using the High-K analysis method. Because of the extremely rapid recovery response, a best estimate value of ≥45 m/day (based on the average for high-stress tests) can only be specified at this time for the test formation monitored at this site. A more quantitative estimate might be obtained for this well location by conducting additional stress tests that incorporate test suggestions presented in Section A.3 of this report.

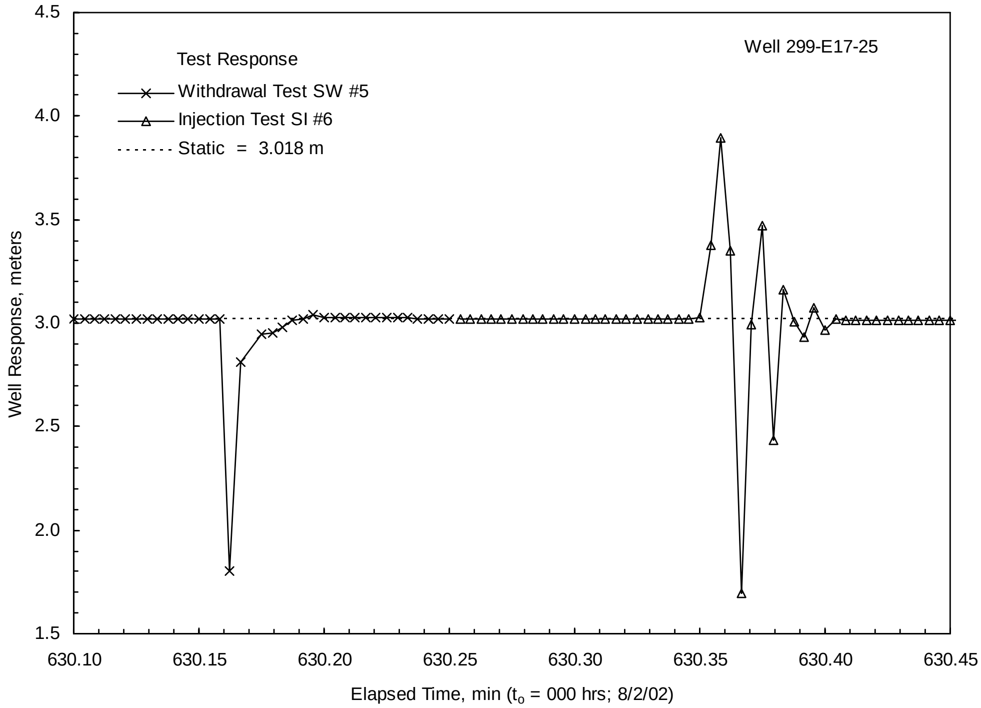

Figure A.7. **Test Response for Well 299-E17-25 Showing Over-Damped Slug Withdrawal Test Response and Oscillatory, Under-Damped Slug Injection Test Response**

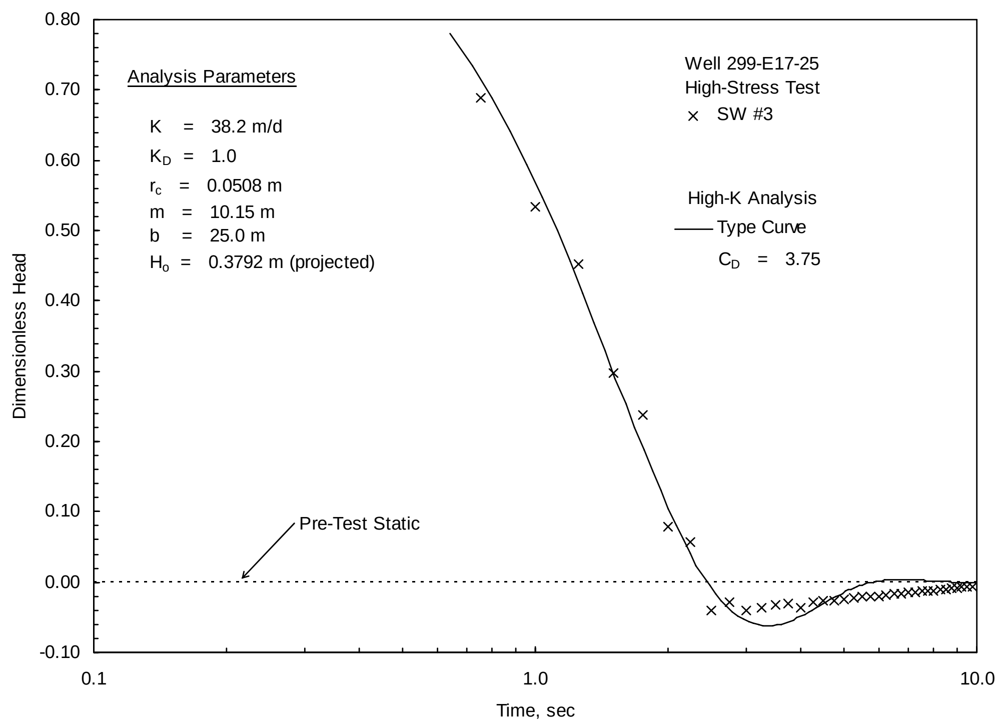

Figure A.8. **High-K Slug Withdrawal Test Analysis Plot for Well 299-E17-25**

A.2.5 Well 299-E24-21

A total of five slug withdrawal tests (three high and two low stress) were conducted on June 12, 2001. Very rapid recoveries (~99% recovery within ~7.5 seconds) were exhibited for all tests, and are indicative of extremely high permeability, over-damped conditions (Table A.1). A comparison of the normalized high-stress slug-test responses indicates essentially identical behavior, which suggests that the well had been fully developed. Due to the relatively small test responses exhibited for low-stress test results, only test data obtained for high-stress tests were subjected to quantitative analysis. To facilitate the analysis process, selected high-stress test responses were combined. Figure A.9 shows the results of a composite analysis of three combined high-stress tests. Because of the additional test data available from the combined tests, the analysis plot shows a composite dimensionless head and head derivative plot, which is commonly employed in standard, type-curve analysis of lower permeability slug tests exhibiting over-damped behavior (e.g., Spane et al. 2001a, 2001b, 2002). As indicated in the analysis figure, the type curve and derivative plot match yielded a hydraulic conductivity estimate of 39.9 m/day for the combined high-stress tests using the High-K analysis method. Because of the exhibited rapid recovery response and low projected stress levels (0.04 m; Table A.1), a best estimate value of ≥40 m/day can only be specified at this time for the test formation monitored at this site. A more quantitative estimate might be obtained for this well location by conducting additional stress tests that incorporate test suggestions presented in Section A.3 of this report.

A.3 Test Recommendations

Results from analysis of slug tests conducted at five IDF site monitor wells indicates high permeability conditions, with best estimate hydraulic conductivity ranging from ≥24 m/day to ≥45 m/day. There is a degree of uncertainty to these calculated hydraulic properties, however due to:

- an upper-K characterization limit for slug tests exhibiting over-damped slug test response behavior (at three well sites)
- rapid test response recoveries (from ≤3.5 to ≤7.5 secs)
- extremely low projected stress levels (three well sites ≤0.05 m)
- composite model response behavior (at two well sites)

High permeability well sites exhibiting over-damped or composite model response behavior is particularly limiting in the ability to define hydraulic properties greater than ~30 m/day (i.e., for a test interval section, L, of ~10 m). The ability to characterize test intervals having significantly higher hydraulic properties could be enhanced by manipulating the well test to ensure oscillatory, under-damped

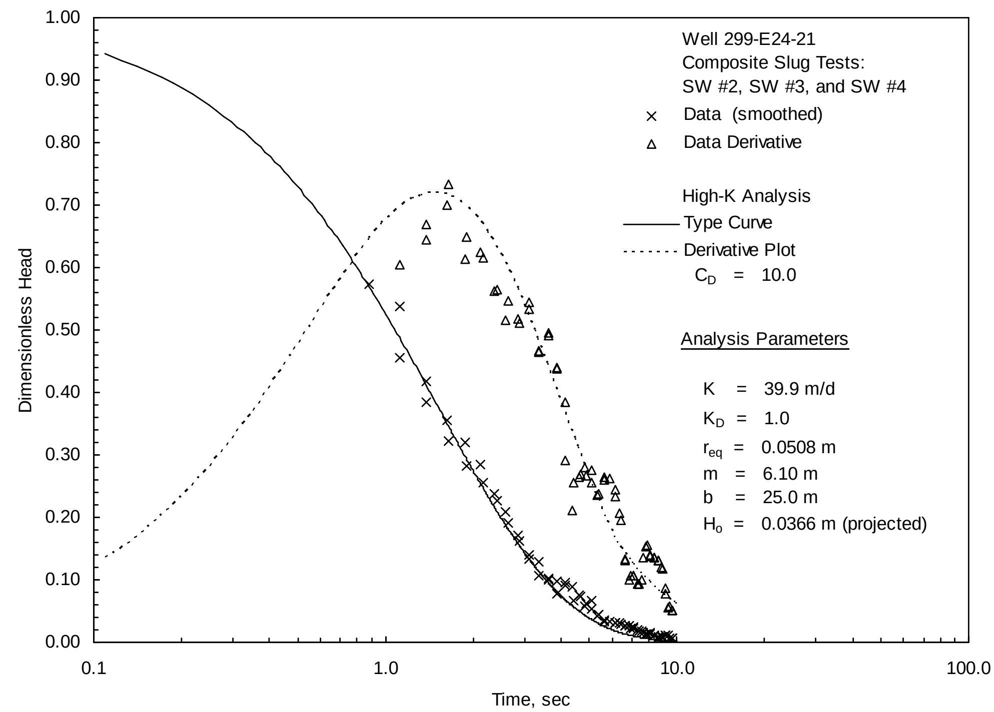

Figure A.9. High-K Composite Slug Withdrawal Test Analysis Plot for Well 299-E24-21

behavior. Well-test response behavior can be manipulated by adjusting one of the parameters controlling the response damping parameter, C_D, which Butler (1998) reports for unconfined aquifer tests as:

$$C_D = (g/L_e)^{1/2}\, r_c^2 \ln (R_e/r_w)/(2\, K\, m) \quad \text{(A.1)}$$

where g = acceleration due to gravity

L_e = effective well water-column length

r_c = well casing radius; i.e., radius of well water-column that is active during testing

R_e = effective test radius parameter; as defined by Bouwer and Rice (1976)

r_w = well radius

K = hydraulic conductivity of test interval

m = well-screen length.

Of the equation parameters, the well casing radius, r_c, is one parameter that can be modified relatively easily, and because it is a squared term, reductions in well casing radius can have a significant effect on C_D, and subsequent well response behavior. Figure A.10 illustrates the predicted well response behavior for a standard 4-inch diameter well exhibiting over-damped response behavior (base case), and predicted oscillatory, under-damped slug test responses for various reduced r_c well radii. As indicated, increased oscillatory behavior is produced by decreasing the r_c well dimension parameter. Also shown, is that the ability to resolve the hydraulic conductivity is significantly improved (i.e., in contrast with the over-damped response) when oscillatory, under-damped test conditions are produced by decreasing r_c. An effective reduction in r_c can be realized a number of ways, but perhaps most simply by using a slugging rod that exceeds the well screen length, L. The produced oscillatory response using a slugging rod to effectively reduce the existing well-casing radius was demonstrated by the slug injection test response exhibited for well 299-W17-25, as shown in Figure A.7. To facilitate ease of test analysis, however, the manipulated under-damped test response should occur solely within the reduced well-casing radius section, preferably extending across the entire well-screen length.

Figure A.11 illustrates the ability to extend the range for hydraulic conductivity characterization of a test interval, if the r_c is reduced from 4 inches to 1.25 inches (for the same test conditions specified in Figure A.10). As indicated, hydraulic conductivity characterization limits can be readily ***extended by a factor of 3*** or more by reducing r_c, to produce oscillatory test behavior within the well (i.e., for this example: over-damped characterization limit, K ~30 m/day; for under-damped response, K ≥90 m/day). Lower and higher characterization levels may be realized by increasing and decreasing r_c, well dimension, respectively.

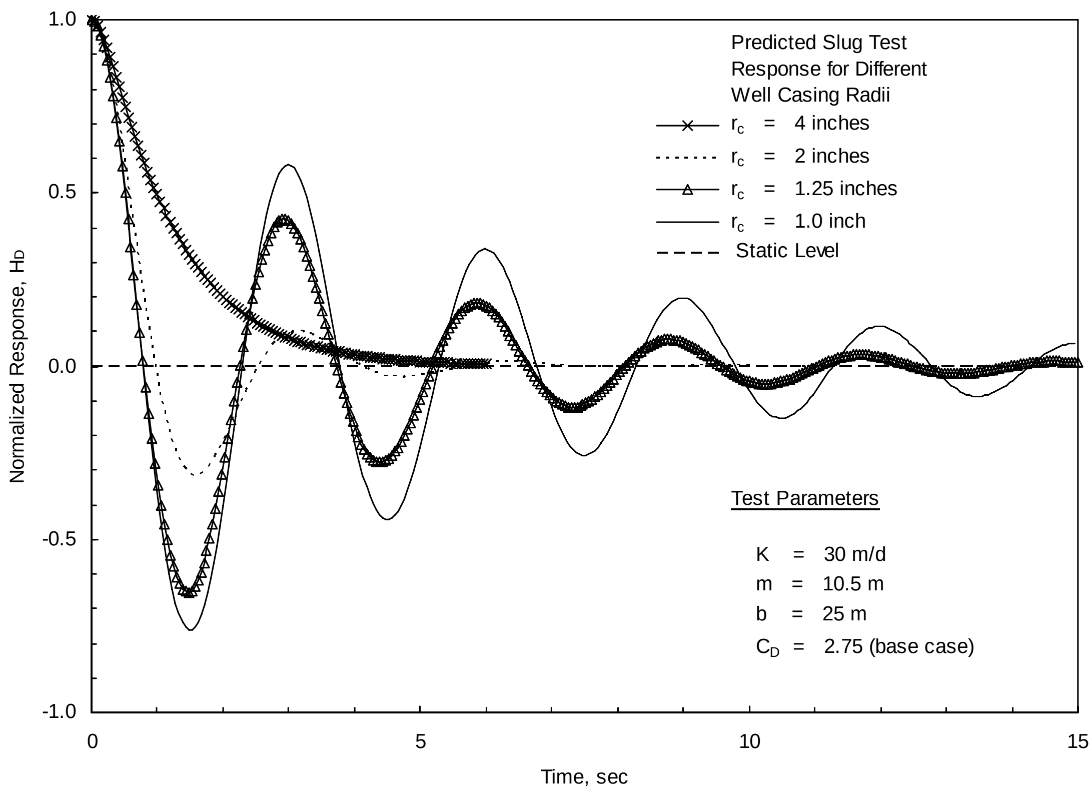

Figure A.10. Predicted Slug Test Response, as a Function of Varying Well Casing Radius, r_c

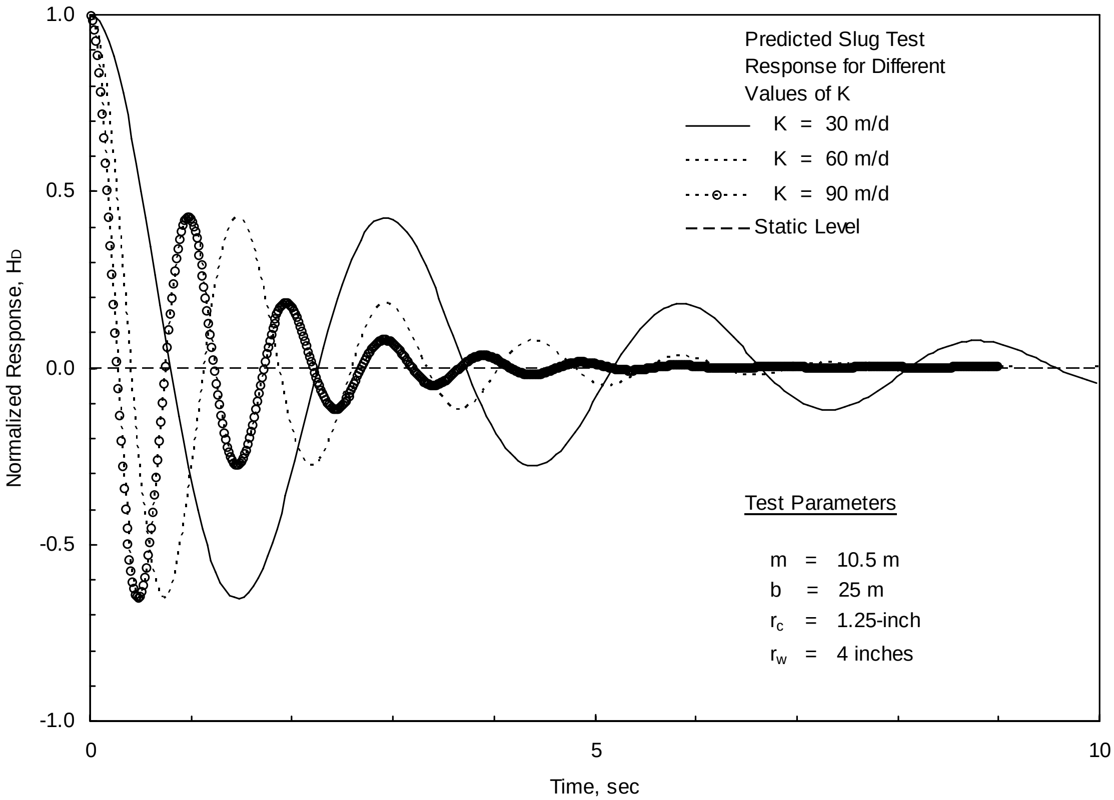

Figure A.11. Predicted Slug Test Response, as a Function of Varying Test Interval Hydraulic Conductivity, K

In addition to modifying r_c to enhance and extend slug test analysis characterization for high-permeability formations, several other recommendations can be implemented to improve the quality of test results. For well/aquifer systems exhibiting under-damped or composite model response behavior, tests should be conducted with very low stress levels to insure linear response behavior (i.e., non-turbulent, Darcian flow conditions). The appropriate lower stress level is indicated when normalized test response behavior for tests with different applied stress levels, are equivalent.

For improving the *instantaneous* application of stress for slug tests, pneumatic stress applications (rather than using slugging rod methods) should be considered, as discussed in Spane et al. (1996) and Butler (1998). For test well situations where the water table is within the well-screen section, this requires the use of highly elastic sealing equipment (e.g., packer system) to isolate the water table from the well water column. The equipment sealing length would also have to extend below anticipated slug stress levels for initiated tests.

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Appendix B

Descriptions of Core Collected from Boreholes at the IDF Site

Appendix B

Descriptions of Core Collected from Boreholes at the IDF Site

Table B.1. Summary Description of Core from Borehole 299-E17-21 (Reidel et al. 1998)

Core Number	Polarity (Reidel and Horton 1999)	Core Interval (feet)	Description
01A	ND	0 – 2.0	0.0 – 0.6 Pad construction fill. 0.6 – 2.0 Medium- to fine-grained sand; 60% basalt, 40% felsic.
		3.0 – 5.0	No recovery.
02C	ND	9.6 – 11.6	9.6 – 11.6 Very fine- to coarse-grained sand; 1% pebbles up to 0.5 inch.
02B	ND	11.6 – 12.8	11.6 – 12.6 Coarse- to very coarse-grained basaltic sand; 1-2% subrounded pebbles up to 1 inch in diameter; some bedding present.
02A	ND	12.8 – 14.6	12.8 – 12.9 Fine-grained sand with silt. 12.9 – 14.2 Medium- to coarse-grained sand; 70% basalt, 30% felsic. 14.2 – 14.6 Finely bedded medium- to fine-grained sand up to 20%. 14.3 – 14.6 Silt; fine scale bedding.
		15.0 – 18.5	No recovery.
03B	ND	18.7 – 19.7	18.7 – 19.5 Medium sand; 60% basalt, 40% felsic; sparse 0.5 inch diameter pebbles. 19.5 – 19.7 Brown, fine-grained sand with minor silt.
03A	ND	19.7 – 21.7	19.7 – 19.8 Fine-grained sand. 19.8 – 20.0 Brown, silty sand with 5-10% silt. 20.0 – 20.9 Medium-grained sand; 60% basalt; 40% felsic; rare mica. 20.9 – 21.1 Very fine-grained sand with silt; sharp upper contact. 21.1 – Silty, fine-grained sand, slightly moist; 50% basalt, 50% felsic. 21.5 – Coarse-grained sand; 50% basalt; 50% felsic; minor pebbles. 21.5 – 21.7 Gravely, coarse-grained sand.
		22.0 – 24.0	No recovery.
04B	ND	28.1 – 28.5	Coarse-grained sand with minor gravel; 50-60% basalt; 40-50% felsic.
04A	ND	28.5 – 30.5	Slightly silty fine- to medium-grained sand; minor gravels up to 1 inch in diameter; grain size decreases slightly downward.
	ND	30.5 – 31.6	No recovery.
05A	ND	31.6 – 33.0	Silty coarse-grained sands; minor basaltic gravel; contains loosely $CaCO_3$ cemented sand grains.
06C	ND	35.7 – 37.0	Silty, coarse-grained sands; minor basaltic gravel; contains loosely $CaCO_3$ coating on sand grains.
06B	ND	37.0 – 38.0	Coarse-grained sand; granular; salt and pepper.
06A		38.0 – 40.0	38.0 – 38.2 Silty coarse-grained sand; minor basaltic gravel; contains $CaCO_3$ coating on sand grains. 38.2 – 40.0 Medium-grained sand, slightly moist.
07B	ND	45.3 – 45.9	Coarse-grained sand; contains some fine- to medium-grained sand.
07A	ND	45.9 – 47.9	Medium- to fine-grained sand with minor silts; sparse pebbles up to 1 inch; 50% basalt, 50% felsic. 45.9 – $CaCO_3$ cementing sand into poorly consolidated nodules.

Table B.1. (contd)

Core Number	Polarity (Reidel and Horton 1999)	Core Interval (feet)	Description
08A	ND	49.3 – 50.5	Medium- to coarse-grained sands; 50% basalt, 50% felsic; top 2 inches are fine- to medium-grained sand with less than 50% basalt.
09A	ND	50.1 – 52.5	50.1 – 51.0 Medium-grained sand; 25-50% basalt, remainder felsic. 51.0 – 51.5 Layered medium-grained sand and thin silt lenses; 25-50% basalt. 51.5 – 52.2 Medium-grained sand; 25-50% basalt. 52.2 – 52.5 Coarse-grained sand.
10C	ND	55.9 – 56.8	Medium- to coarse-grained sand; 35-50% basalt, 50-65% felsic; 1-2% gravel; core is disturbed.
10B	ND	56.8 – 57.8	Medium-grained sand; 25-50% basalt, 50-75% felsic.
10A	ND	57.8 – 59.8	57.8 – 58.1 Medium- to coarse-grained sand with some $CaCO_3$. 58.1 – 58.5 Cemented soil zone; fine- to medium-grained sand. 58.5 – 59.8 Medium-grained sand.
11B	ND	59.6 – 60.6	Medium-grained sand; 50% basalt, 50% felsic.
11A	ND	60.6 – 63.1	Medium-grained sand; 50% basalt, 50% felsic; minor caliche flakes present but not as cemented sand.
12A	ND	69.4 – 70.95	69.4 – 70.0 Sloughing 70.0 – 70.4 Coarse-grained sand; 50% basalt, 50% felsic. 70.4 – 70.7 Clay/silt lens. 70.7 – 70.95 Coarse-grained sand; less than 50% basalt.
13B	ND	75.3 – 75.9	Medium- to coarse-grained sand; 50% basalt, 50% felsic; upper 4 inches is slough.
13A	ND	75.9 – 78.4	Silty, medium- to fine-grained sands; 50% basalt, 50% felsic; minor $CaCO_3$ coating on sand grains.
14B	ND	79.2 – 80.3	Medium-grained sand; 50% basalt, 50% felsic.
14A	ND	80.3 – 82.8	Compacted medium- to fine- grained sand; some silt; 50% basalt, 50% felsic; minor $CaCO_3$ probably as grain coating.
15B	ND	89.4 – 90.5	Medium- to coarse-grained sand fining downward to medium-grained sand; 50% basalt, 50% felsic; grains of $CaCO_3$ apparent; top of the interval is slough and wet.
15A	ND	90.5 – 93.0	Medium- to fine-grained sands; some silt; minor pebbles less than 0.2 inch; $CaCO_3$ cementing sand grains in places.
16B	ND	99.2 – 100.5	Medium- to coarse-grained sand.
16A	ND	100.5 – 103.0	Medium-grained sand; some $CaCO_3$ coating grains.
17B	ND	109.4 – 109.8	Medium- to coarse-grained salt and pepper sand; 50-70% basalt, 30-50% felsic; top half of interval is slough.
17A	ND	109.8 – 112.2	Fine- to medium-grained sand; some silt.
18B	ND	115.6 – 116.4	115.6 – 116.3 Coarse-grained sand as slough. 116.3 – 116.4 Coarse- to medium- to fine-grained sand; 50% basalt, 50% felsic.
18A	ND	116.4 – 118.9	Medium- fine-grained sand, some silt; 50% basalt, 50% felsic; less than 1% basalt pebbles.
	ND	118.9 – 119.5	No recovery.
19B	ND	119.5 – 121.0	Medium-grained sand; 50% basalt, 50% felsic; very minor $CaCO_3$ coating sand grains.
19A	ND	121.0 – 123.5	Medium- to fine-grained sand, some silt; 50% basalt, 50% felsic; bottom 0.3-inch silty fine-grained sand.
20B	ND	129.2 – 129.7	Medium- to coarse-grained sand; 50% basalt, 50% felsic; entire interval is disturbed.

Table B.1. (contd)

Core Number	Polarity (Reidel and Horton 1999)	Core Interval (feet)	Description
20A	ND	129.7 – 132.2	Fine- to medium-grained sand, some silt; less than 50% basalt; some $CaCO_3$ as discrete particles and grain coatings.
		135.2 – 138.0	No recovery.
21B	ND	139.3 – 141.5	Medium- to fine-grained sand, some silt; 50% basalt with scattered basalt pebbles up to 0.1 inch in diameter. 139.8 $CaCO_3$ weakly cemented zone.
21A	ND	141.5 – 144.0	Medium-grained sand, 10-20% fine-grained sand; 50% basalt, 50% felsic.
22B	ND	149.4 – 151.9	149.4 – 150.2 Medium-grained sand; slightly moist. 150.2 – 150.9 Compacted, slightly cemented, bedded medium-grained sand and silt; layers are 0.25 inch thick. 150.9 – 151.9 Medium-grained sand; minor $CaCO_3$, probably as coatings on grains.
22A	ND	151.9 – 154.4	Medium-grained sand with minor silt; 50% basalt, 50% felsic; well developed fine-scale laminations; laminations appear to be due to light/dark minerals; minor $CaCO_3$ disseminated throughout, probably as grain coatings; not compacted but very loose.
23B	ND	159.4 – 160.4	Medium- to fine-grained sand, some silt; less than 50% basalt; $CaCO_3$ is present but probably as grain coatings; upper 4 inches is slough.
		160.4 – 160.4	No recovery.
23A	ND	160.4 – 162.9	Fine-grained sand to silt with well developed fine-scale laminations; laminations appear to be due to light/dark minerals; 50% basalt, 50% felsic; well compacted; $CaCO_3$ probably as grain coatings.
	ND	169.6 – 174.2	No recovery.
24B	ND	179.6 – 180.7	Medium-grained sand; 50% basalt, 50% felsic; $CaCO_3$ cemented fragments up to 1.2 inch long; entire core is disturbed.
24A	R	180.7 – 182.7	Fine- to medium-grained sand; uniform grain size; 50% basalt, 50% felsic; no bedding; well compacted, minor $CaCO_3$ cement.
25A	R	189.7 – 191.9	Medium- to fine-grained sand, some silt; 50% basalt, 50% felsic; 1-inch layer of poorly cemented ($CaCO_3$) sand grains.
26A	R to N	196.0 – 198.0	Medium- to fine-grained sand; 50% basalt, 50% felsic.
27A	R	199.3 – 201.3	199.3 – 199.9 Fining upward sequence of coarse pea gravel (1/8 inch diameter) to fine-grained sand; 50% basalt, 50% felsic; well compacted with $CaCO_3$ coating grains and as minor cement between grains. 199.9 – 200.2 very fine- to fine-grained sand. 0.5 inch thick silt lens. 200.25 – 200.4 Medium-grained sand.
28A	R	206.0 – 208.0	Medium-grained sand with minor pebbles; slightly compacted; minor $CaCO_3$ probably as grain coatings.
29A	ND	210.9 – 211.4	Four inch of pea gravel (1/8 inch) grading upward into medium-grained sands; sand is 50% basalt, 50% felsic; no bedding; well-compacted sands with minor $CaCO_3$ cement.
30A	ND	216.1 – 218.1	Pebbly, 4 inches of pea gravel (1/8 inch) grading into coarse-grained sand; 2 inch partly $CaCO_3$ cemented zone at 216.2 feet.
31A	R	219.6 – 221.6	Fine-grained sand compacted but not cemented; faint bedding. 219.0 – Pebbles of basalt and site; rounded.
32A	ND	226.1 – 228.1	Medium- to coarse-grained sand; well-compacted with $CaCO_3$ coating grains; minor moisture.

Table B.1. (contd)

Core Number	Polarity (Reidel and Horton 1999)	Core Interval (feet)	Description
33A	ND	229.2 – 231.2	229.2 – 229.8 Pebbly, coarse-grained sand; 50-60% basalt, remainder felsic. 229.8 – 230.0 Gravel up to 1.5 inches; 75% basalt. 230.0 – 230.3 Coarse-grained sand some fine-grained sand and silt; 60-70% basalt. 230.3 – 231.2 Compacted, medium- to coarse-grained sand some silty, fine-grained sand; 60-70% basalt; moist.
34A	ND	236.1 – 238.1	Coarse-grained sand to pea gravel (up to 1/8 to 1/4 inch); some compaction but no cementation; damp.
35A	ND	239.5 – 241.5	239.5 – 240.0 Granular to pebbly gravel (1/8 inch), mainly basalt; no sand matrix, open framework. 240.0 – 240.4 grading into coarser gravel (1/4 to 1/2 inch.); no sand matrix, open framework. 240.4 – 240.9 Coarse gravel with sand matrix; gravel up to 1 inch in diameter; coarse–grained sand; 50% basalt, 50% felsic.
		245.6 – 248.0	No recovery.
36A	ND	268.1 – 270.1	Top 10 inch slough composed of 3 inch of clean gravel over sandy gravel; remainder of core is gravel with medium-grained sand; 15% gravel, 50% basalt, 50% quartzite and metamorphic pebbles.
37A	ND	349.6 – 350.6	Gravels.
38A	ND	379.7 – 381.7	Ringold Formation, Lower Mud unit.

Table B.2. Descriptions of Core from Borehole 299-E17-22 (C3826) (Reidel and Ho 2002)

Depth Below Surface (feet and inches)	Polarity Preliminary	Description of Core (C3826)
0’ to 8’	ND	No core recovered.
8’ to 9’	ND	25% recovered—not opened. Moist, loose, no internal structure preserved. Medium- to coarse-grained sand; 75% basalt and 25% felsic; subrounded to subangular; poorly sorted; color 10YR5/2.
9’-10’	ND	55% recovered. Slightly moist, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Coarse to medium-grained sand: 50% coarse, 40% medium-grained, 7% fine-grained, 3% very coarse, with pebbles up to 0.4 in (diameter); well-cemented zone 1.2 to 1.6 in wide (previously wider?) in the middle of the core (at 9’6”); material above this zone is also slightly cemented with $CaCO3$; material below this zone is slightly more moist, finer-grained, and shows only a moderate reaction to HCl; 40% basalt and 60% felsic; subangular to subrounded; color 10YR5/2.
10’ to 11’	ND	70% recovered. Dry, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Coarse to very coarse sand: 5-10% gravel, with rounded to subrounded pebbles up to 1 in (diameter), 30% very coarse, 45% coarse, 15% medium-grained, trace of silt; 50% basalt and 50% felsic; subangular to angular; color 10YR5/2.
11’ to 12’	ND	95% recovered. Moist, loose, undisturbed. Coarse-grained sand with minor silt, grains up to 0.15 in (diameter); 50-60% basalt and 40-50% felsic; subangular; fairly sorted; color 10YR5/2. At 11’7” is a 0.8-in--thick layer of silt and clay (possible soil?), separating coarse material above from finer material below.
12’ to 13’	ND	50% recovered—not opened. Moist, loose, no internal structure preserved. Medium- to coarse-grained sand; 50-70% basalt and 30-50% felsic; subrounded to subangular; poorly sorted; color 10YR5/2.
13’ to 14’	ND	75% recovered. Dry, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Coarse- to medium-grained sand: 45% coarse, 45% medium- and fine-grained, 10% very coarse, with grains up to 0.16 in (diameter); 45% basalt and 55% felsic; angular to subangular (large grains mostly angular); color 10YR5/2.
14’ to 15’	N	95% recovered. Slightly moist, undisturbed, compact. Three color bands apparent. From 14’ to 14’2”: color band of medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; unsorted. From 14’2” to 14’7.5”: fine- to medium-grained sand; compacted, with graded bed fining upwards, each ~0.8 in thick; subangular to subrounded, well-sorted. At the base of this band is a very fine clay zone 0.08 in thick that effervesces. From 14’7.5” to the bottom of the core: coarse sand, with grains up to 0.2 in (diameter); 60% basalt and 40% felsic; subangular; poorly sorted. Color 10YR5/2.
15’ to 16’	N	95% recovered. Dry, slightly compact. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; 10YR5/2. Bands of fine- to medium-grained sand are apparent, and spaced every 1 to 2 in. The most prominent bands are at 15’8” and 15’9”. A fairly compact zone is found between 15’6.5” and 15’9.5”.
16’ to 17’	ND	50% recovered. Dry, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Medium- to fine-grained sand: 55% fine-grained, 40% medium-grained, 5% coarse, 2% very coarse, with grains of basalt up to 0.16 in (diameter); 30-35% basalt and 65-70% felsic; subangular to subrounded; 10YR5/2.
17’ to 18’	ND	90 to 95% recovered. Dry, loose, undisturbed. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; 10YR5/2. Pebble layers ~0.5 in thick are found at 17’2.5” and 17’5.5”; both are basalt-dominated, with pebbles up to 1 in (diameter).

Table B.2. (contd)

Depth Below Surface (feet and inches)	Polarity Preliminary	Description of Core (C3826)
18' to 19'	N	90 to 95% recovered. Dry, uncompacted, slightly disturbed. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; 10YR5/2. Layers of coarser sand present.
19' to 20'	ND	60% recovered. Dry, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Medium-grained sand: 75% medium-grained, 10% fine-grained, 10% coarse, 5% very coarse, with granitic pebbles up to 0.1 in (diameter); 30 to 40% basalt and 60 to 70% felsic; angular to subangular; moderately well-sorted; 10YR5/2.
20' to 20'6"	ND	No recovery.
20'6" to 21'6"	ND	30% recovered—not opened. Dry, loosely packed, internal structure not preserved. Medium-grained sand, grains up to 0.15 in (diameter); 50% basalt and 50% felsic; subrounded to subangular; color 10YR5/2.
21'6" to 22'6"	ND	90% recovered. Dry, partially disturbed, uncompacted. Medium- to coarse-grained sand with minor silt, grains up to 0.6 in (diameter); 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2. Some coherent silty nodules present.
22'6" to 23'6"	ND	80% recovered. Dry, disturbed, loose. Medium-grained sand with some silt present; 50% basalt and 50% felsic; subangular to subrounded; poorly sorted; color 10YR5/2.
23'6" to 24'6"	N	90% recovered. Very slightly moist, loose, undisturbed. Medium- to coarse-grained sand, grains up to 0.15 in (diameter); 50% basalt and 50% felsic; subangular to subrounded; fairly well-sorted; color 10YR5/2. Color band at 23'7" composed of a 0.4-in thick silt-rich (up to 50% silt) layer; effervesces.
24'6" to 25'	ND	No recovery.
25' to 26'	ND	Partially recovered. Dry, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Medium- to coarse-grained sand: 58% coarse, 40% medium-grained, 2% very coarse; 50% basalt and 50% felsic; subangular to angular; color 10YR5/2.
26' to 27'	ND	85% recovered. Dry, loose. Medium-grained sand with minor silt; 50% basalt and 50% felsic; subangular to subrounded; poorly sorted; color 10YR5/2.
27' to 28'	ND	85-90% recovered. Dry, loose. Medium- to coarse-grained sand, grains up to 0.07 in (diameter); 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2. From 17'8.8" to 17'9.5" is a light color band that is finer (contains more silt) than the rest of the core, and is not compact or coherent.
28' to 29'	ND	Partially recovered. Dry, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Medium- to coarse-grained sand: 55% medium-grained, 40% coarse, ~2% very coarse, ~2% fine-grained; 40% basalt and 60% felsic; subangular to angular; moderately well-sorted; color 10YR5/2.
29' to 29'6"	ND	No recovery.
29'6" to 30'6"	ND	80-85% recovered—not opened. Dry, loose, disturbed. Medium- to coarse-grained sand with minor silt; subangular to subrounded; poorly sorted; color 10YR5/2.
30'6" to 31'6"	I	95% recovered. Dry, undisturbed, well-compacted. From 30'6" to 30'10": calcareous zone, cemented, fine-grained silt to sand with sparse coarse sand, layered; paleosol? From 30'10" to 31'7.5": medium-grained sand with some coarse bands (apparent at 31' and 31'0.5"); 50% basalt and 50% felsic (fine-grained zones are more felsic); subangular to subrounded; well-sorted. From 31'7.5" to 31'8.2": silt layer. Color 10YR5/2

Table B.2. (contd)

Depth Below Surface (feet and inches)	Polarity Preliminary	Description of Core (C3826)
31’6” to 32’6”	ND	100% recovered. Dry, but slightly moist in silty layers, relatively undisturbed. Medium- to coarse-grained sand; 50% basalt and 50% felsic; well-sorted; color 10YR5/2. Coherent layers of silt and sand are at 31’7.1”, 31’8”, 31’8.8” to 31’11.9”, 32’0.5” to 21’1”, 32’2.5”, and 32’3.5”. These layers are silty with sand, and are each ~0.4 in thick. Silty layers are calcareous, as is silt along the core rim, and barely cemented.
32’6” to 33’6”	ND	75% recovered. Dry, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Medium- to coarse-grained sand: 60% medium-grained, 35% coarse, 5% fine-grained; 40% basalt and 60% felsic; subangular to angular; moderately well-sorted; color 10YR5/2.
33’6” to 34’		No recovery.
34’ to 35’	ND	85% recovered. Dry, loose, uncompacted. Coarse to very coarse sand: 30% very coarse, 60% coarse, 10% medium-grained; 50% basalt and 50% felsic; subangular to angular; moderately well-sorted; color 10YR5/2.
35’ to 36’	R	85% recovered. Dry, loose. Coarse sand: 10% very coarse, 80% coarse, 10% medium-grained; 40% basalt and 60% felsic; moderately well-sorted; 10YR5/2 color 10YR5/2.
36’ to 37’	ND	90% recovered. Dry, very loose. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well sorted; 10YR5/2 color 10YR5/2.
37’ to 38’	ND	85% recovered. Dry, loose, uncompacted. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
38’ to 39’	N	85% recovered. Dry, compacted. Fine- to medium-grained sand; 50% basalt and 50% felsic; well sorted; 10YR5/. Numerous layers of CaCO3-rich zones, from 0.1 to 1.5 in wide. Color 10YR5/2
39’ to 40’	N	90% recovered. Fairly compacted. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well sorted. Layer of silt and $CaCO_3$ about 0.4 in thick at 39’5.5” separating darker (more black and fresh?) material above from more brownish-reddish (more clayey and weathered?) material below. Color 10YR5/2
40’ to 41’	N	100% recovered. Intact, not disturbed, well compacted. Medium- to coarse-grained sand with trace of silt; 50% basalt to 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
41’ to 42’	ND	90% recovered. Very slightly moist, moderately compact in the middle of core. Medium- to coarse-grained sand: 5% very coarse, 75% coarse, 20% medium-grained. Between top of core and 41’3.1”, disturbed and loose, mostly medium-grained sand; between 41’3.1” and 41’6.7” is a fining-upwards sequence (mostly coarse sand between 41’3.1” and 41’4.7”, and an obvious band of very coarse sand between 41’4.7” and 41’6.7”, with angular to subangular grains up to 0.2 in (diameter); between 41’6.7” and 41’10.6” is another upwards-fining sequence, from medium-grained to medium- and coarse-grained sand; core from 41’10.6” to the bottom is empty. 40 to 50% basalt and 50 to 60% felsic; subangular to angular; moderately well-sorted; color 10YR5/2.
42’ to 42’6”		No recovery.
42’6” to 43’6”	ND	60% recovered. Dry, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Medium- to coarse-grained sand: 30% coarse, 60% medium-grained, 10% very coarse; 40 to 50% basalt and 50 to 60% felsic; subangular to angular; fairly well-sorted; color 10YR5/2.
43’6” to 44’6”	I	90% recovered. Slightly moist, slightly compact. Coarse sand: 70% coarse, 20% medium-grained, 10% very coarse; possible color bands ~1.2 to 1.6 in wide (upwards-fining sequences from very coarse to medium-grained sand); distinct pebble layer between 43’11.7” and 44’0.6”, with grains up to 0.24 in (diameter); 50% basalt and 50% felsic; mostly angular, with some subangular grains; fairly well-sorted; color 10YR5/2.
44’6” to 47’		No recovery.

Table B.2. (contd)

Depth Below Surface (feet and inches)	Polarity Preliminary	Description of Core (C3826)
47' to 48'	ND	90% recovered. Slightly moist, slightly compact. Medium-to coarse-grained sand: 15% very coarse (mainly in the upper half of core, with grains up to 0.1 in diameter), 35% coarse, 50% medium-grained; 40 to 50% basalt and 50 to 60% felsic; angular to subangular; fairly sorted; color 10YR5/2.
48' to 49'	R	95% recovered. Compact. Medium-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well sorted; color 10YR5/2. Silty CaCO3-rich layer from 48'6.7" to 48'8.7".
49' to 50'	R	80% recovered. Very slightly moist, very slightly compact, disturbed. (Opened previously for LBL oxygen isotope study.) Medium- to coarse-grained sand, with grains up to 0.16 in (diameter); 50% basalt and 50% felsic; angular to subangular; moderately sorted; color 10YR5/2.
50' to 51'	I	95% recovered. Compact. Medium-grained sand, with basalt clasts up to 0.4 in (diameter); 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2. Some color banding, with basalt-rich layers appearing slightly darker.
51' to 58'		No recovery.
58' to 59'	I	85% recovered. Loose, uncompacted. Medium-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well sorted; color 10YR5/2.
59' to 60'	ND	90% recovered. Loose, uncompacted. Medium-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
60' to 61'	ND	85% recovered. Moderately compact. Medium-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2. Color bands and fining-upward sequences 0.4 to 0.8 in thick.
61' to 62'	I	90% recovered. Compact. Medium-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2. Faint color banding.
62' to 64'6"		No recovery.
64'6" to 65'6"	ND	80% recovered. Slightly moist, slightly compact in middle of core, disturbed. (Opened previously for LBL oxygen isotope study.) Fine- to medium-grained sand: 55% medium-grained, 40% fine-grained, 5% coarse; 35 to 40% basalt and 60 to 65% felsic; subangular to angular; well-sorted; color 10YR5/2.
65'6" to 66'6"		No recovery.
66'6" to 67'6"	I	90% recovered. Loose, not compact. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well sorted; color 10YR5/2.
67'6" to 68'		No recovery.
68' to 69'	ND	85% recovered. Not compact. Medium-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2. Contains $CaCO_3$-rich nodules up to 0.8 in (diameter) between 68'2" and 68'4".
69' to 70'	I	85% recovered. Fairly compact. Between 69' and 69'4", medium-grained sand in 0.2-in-thick bands; from 69'4" to 70' is medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
70' to 71'	ND	90% recovered. Dry, loose, uncompacted. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
71' to 72'	ND	90% recovered. Moderately compact. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2. From 71'7" to 71'9" is a silty layer containing color bands ~0.4 in wide.

Table B.2. (contd)

Depth Below Surface (feet and inches)	Polarity Preliminary	Description of Core (C3826)
72' to 73'	ND	85% recovered. Dry, loose. Medium- to coarse-grained sand; fine- to medium-grained sand with silt between 72'10' and 73'; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
73' to 74'	N	90% recovered. Moderately compacted. Medium- to fine-grained sand, cemented with $CaCO_3$ between 73' and 73'4"; lower part of core is composed of medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
74' to 75'	ND	85% recovered. Loose, uncompacted. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
75' to 76'	I	95% recovered. Fairly compact. Medium- to coarse-grained sand (mostly coarse), with fining-upwards bands about 0.8 to 1.2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
76' to 76'6"		No recovery.
76'6" to 77'6"	I	80% recovered. Uncompacted. Uppermost 2.5 in is empty; from 76'8.5" to 77'3" is medium- to fine-grained, $CaCO_3$-cemented sand, poorly sorted; from 77'3" to the bottom of the core is medium- to coarse-grained sand. All material is fairly well-sorted; subangular to subrounded; color 10YR5/2.
77'6" to 78'6"	ND	80% recovered. Dry, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Medium- to coarse-grained sand: 65% medium- to fine-grained; 35% coarse; 30% basalt and 70% felsic; angular to subangular; moderately sorted; color 10YR5/2.
78'6" to 79'6"	ND	X% recovered. Very compact. Medium- to coarse-grained sand, with bands of fining-upwards sequences 1.2 to 1.6 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
79'6" to 80'6"	N	95% recovered. Well-compacted. Medium- to coarse-grained sand, with subtle fining-upwards sequences ~0.8 in wide each; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
80'6" to 96'		No recovery.
96' to 97'	N	80% recovered. Slightly moist, uncompacted. Medium- to coarse-grained sand (mainly medium-grained); subangular to subrounded; well-sorted; color 10YR5/2.
97' to 98'	ND	85% recovered. Slightly moist, not compact. Medium- to fine-grained sand, with fining-upward sequences about 1.2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
98' to 99'	ND	85-90% recovered. Dry, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Medium- to fine-grained sand: 50% medium, 50% fine; 40% basalt and 60% felsic; angular to subangular; well-sorted; color 10YR6/2.
99' to 100'	I	90% recovered. Moderately compact. Fine- to medium-grained sand between 99' and 99'8.7"; medium- to coarse-grained sand between 99'8.7" to 99'11.8"; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
110' to 119'		No recovery.
119' to 120'	R	90% recovered. Not compact. One large fining-upward sequence: medium-grained sand in lower part, fine-grained sand in uppermost 2.4 in of core; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
120' to 121'	N	95-100% recovered. Medium-grained sand, with 0.8-in-wide fining-upwards bands apparent; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; 10YR5/2.

Table B.2. (contd)

Depth Below Surface (feet and inches)	Polarity Preliminary	Description of Core (C3826)
121' to 122'	ND	85% recovered. Dry, slightly compact, disturbed. (Opened previously for LBL oxygen isotope study.) Fine to very fine sand, thin (<0.1 in wide) coherent layers visible between 121'2.4" and 121'8.3" of very fine-grained sand between darker, basalt-rich medium-grained layers; 60% fine-grained, 40% medium-grained; very fine-grained loose sand between 121'8.7" and 121'11"; lowermost 1 in of core empty; no HCl reaction; 45% basalt and 55% felsic; well-sorted; color 10YR5/2.
122' to 123'	N	98% recovered. Compact. From the top of the core to 122'0.6" is fine-grained sand; from 122'0.6" to 122'3.5" is very coarse sand with color banding; from 122'3.5" is a 0.08-in-wide very fine clay layer, iron-stained at the top; from 122'3.5" to 122'10.2" is the top of another fining-upwards sequence, medium-grained sand; from 122'10.2" to 122'11.8" is coarse-grained sand at the bottom of this sequence; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
123' to 149'		No recovery.
149' to 150'	ND	90% recovered. Slightly compact. Medium- to coarse-grained sand, with fining-upwards sequences about 0.8 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2. A transition from sand above to more silt below occurs at 149'10.2". Pebbles about 0.8 in (diameter) occur at 149'4".
150' to 151'	I	90% recovered. Well-compacted. Medium- to coarse-grained sand, some coarse basalt-rich layers fining upwards in layers ~0.8 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted. Color 10YR5/2
151' to 152'	ND	90% recovered. Dry, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Sand: 70% medium-grained, 30% fine-grained, coarse layer with grains up to 0.12 in (diameter) between 151'5.5" and 151'5.9"; 40% basalt and 60% felsic; subangular to subrounded; moderately sorted; color 10YR6/2.
152' to 153'	ND	90% recovered. Moderately compact. Medium- to fine-grained sand, with subtle fining-upwards sequences ~3.5 in wide; subangular to subrounded; well-sorted; color 10YR5/2.
153' to 163'6"		No recovery.
163'6" to 164'6"	R	80% recovered. Loose, uncompacted, poorly consolidated. Medium- to fine-grained sand, one fining-upwards sequence; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
164'6" to 165'6"	ND	95 recovered. Compact. Medium- to fine-grained sand, with subtle upward-fining sequences ~2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
165'6" to 166'6"	N	95% recovered. Compact. Fine- to medium-grained sand, with fining upward sequences ~3 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
166'6" to 167'6"	ND	90% recovery. Moderately compact. Medium- to fine-grained sand; with fining upward sequences ~2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted. The zone between 167'2.5" and 167'2.9" is lined at the top and bottom by brownish silt stringers <0.04 in wide. Color 10YR5/2
167'6" to 168'		No recovery.
168' to 169'	N	85% recovered. Compact. Mainly medium- to coarse-grained sand; at 168'4.7" is a caliche zone ~1.1 in thick showing soft-sediment deformation, with a lobe protruding 3 to 7.5 in out of the band; at 168'10.6" is a 0.11-in-wide clay layer at the top of an upward-fining sequence; fine sand between 168'10.6" to 168'11.8".

Table B.2. (contd)

Depth Below Surface (feet and inches)	Polarity Preliminary	Description of Core (C3826)
169’ to 170’	ND	98% recovered. Well-compacted. Medium- to fine-grained sand, one large fining-upwards sequence; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2. Contact between one fining-upwards sequence above and another below at 169’10.6”.
170’ to 171’	N	95% recovered. Compact. Medium- to coarse-grained sand, with fining-upward sequences 1-2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
171’ to 172’6”		No recovery.
172’6” to 173’6”	ND	80% recovered. Loose, uncompacted, poorly consolidated. Coarse- to medium-grained sand, mostly coarse, with pebbles up to 0.4 in (diameter) in a layer between 173’0.3” to 173’1.9”; subangular to subrounded; fairly sorted; color 10YR5/2.
173’6” to 174’6”	R	95% recovered. Compact. Medium- to coarse-grained sand, with fining upwards sequences (coarse to fine) each ~0.8 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
174’6” to 175’6”	ND	95% recovered. Well-compacted. Medium- to coarse-grained sand, with upward fining sequences ~0.8 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
175’6” to 176’6”	R	95% recovered. Compact. Medium- to coarse-grained sand, with color bands of upward-fining sequences about 1.2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
176’6” to 179’		No recovery.
179’ to 180’	I	90% recovered. Moist, moderately compact. Medium- to coarse-grained sand, with fining-upwards sequences ~3.5 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
180’ to 181’	ND	95% recovered. Well-compacted. Medium- to coarse-grained sand, with upwards-fining sequences 2 to 2.8 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2. At 180’1.6” is a layer of clay ~0.04 in wide.
181’ to 182’	R	90% recovered. Well-compacted. Medium- to coarse-grained sand, containing fining-upwards sequences mostly ~1 in but up to 5.5 in wide, with 0.4-in-wide sequences within the thicker bands; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
182’ to 183’	R	85% recovered. Dry, loose, disturbed. (Opened previously for LBL oxygen isotope study.) Sand: 75% medium- and fine-grained, 25% coarse; 40% basalt and 60% felsic; subangular to subrounded; moderately well-sorted; color 10YR6/2.
183’ to 219’		No recovery.
219’ to 220’	ND	95% recovered. Moderately compact. Coarse- to very coarse-grained sand, with a pebbly zone between 219’4.7” and 219’6.3” containing pebbles mainly of basalt up to 0.8 in (diameter); 60% basalt and 40% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
220’ to 221’	R	90% recovered. Compact. Medium- to very coarse-grained sand, with pebbles up to 0.4 in (diameter) and fining-upwards sequences ~3 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
221’ to 222’	ND	95% recovered. Compact. Coarse- to very coarse-grained sand, with clasts up to 0.8 in (diameter); coarse basalt-rich bands and upward-fining sequences 2 to 2.5 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.

Table B.3. Descriptions of Core from Borehole 299-E17-23 (C3827) (Reidel and Ho 2002)

Depth Below Surface (feet and inches)	Polarity Preliminary	Description of Core (C3827)
0' to 53.5'		No recovery.
53'6" to 54'6"	R	45% recovered. Moist, compact. Medium- to coarse-grained sand: 15% very coarse, 30% coarse, 60% medium-grained, with grains up to 0.1 in (diameter); 50% basalt and 50% felsic; angular to subangular; moderately well-sorted; color 10YR5/2.
54'6" to 55'6"	ND	95% recovered. Moist, compact. Medium- to coarse-grained sand, with upwards-fining sequences ~0.8 in wide; 50% basalt and 50% felsic, subangular to subrounded; well-sorted; color 10YR5/2.
55'6" to 56'6"	R	100% recovered. Moist, compact. Medium- to coarse-grained sand with crude, subtle upwards-fining sequences ~ 2 in wide; medium- to coarse-grained sand between 56'5.4" and 56'5.8"; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2. A fine-grained sand to silt lens between 56'4.2" and 56'5.4" has a 0.04 in layer of clay at the bottom and top.
56'6" to 57'6"	ND	93% recovered. Moist, compact. Coarse sand from top of core to 56'7.8"; very coarse sand between 56'7.8" and 56'11.5"' medium-grained sand between 56'11.5" and 57'0.3", a dark band containing ~60% basalt; continued coarsening downward, from 57'0.3" to 57'5.8"; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
57'6" to 58'		No recovery.
58' to 59'	ND	95% recovered. Moist, moderately compact. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
59' to 60'	ND	96% recovered. Moist, moderately compact. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
60' to 61'	R	99% recovered. Moist, compact. Medium-grained sand from the top of core to 60'6.7", with color bands 0.8 to 1.2 in wide; coarse to very coarse sand between 60'6.7" and 60'9.4", with pebbles up to 0.8 in (diameter) at 60'9.4"; coarse sand between 60'9.4" and bottom of core; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
61' to 62'	ND	95% recovered. Slightly moist, compact. Medium- to coarse-grained sand, with upwards-fining sequences (very coarse to medium-grained sand) ~2.8 in wide and pebbles up to 0.6 in (diameter); 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
62' to 62'6"	ND	No recovery.
62'6" to 63'6"	ND	95% recovered. Compact. Moist, medium-grained sand from top of core to 62'8"; bioturbated, calcareous **paleoso**l, medium- to fine-grained between 62'8" and 62'11.9"; dry, coarse-grained sand with disseminated $CaCO_3$ and pebbles up to 0.2 in (diameter) between 62'11.9" and 63'5". Color 10YR5/2.
63'6" to 65'6"	ND	No recovery.
65'6" to 66'6"	ND	92% recovered. Moist, compact. Very coarse-grained sand from the top of core to 65'11.5"; coarse sand between 65'11.5" and the bottom of core; subangular to subrounded; well-sorted; color 10YR5/2.
66'6" to 76'		No recovery.
76' to 77'	ND	100 recovered. Moist, slightly compact (more compact near the bottom of core). Medium- to coarse-grained sand, with faint color banding 0.8 to 1.2 in wide in the bottom half of core; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
77' to 78'	ND	100% recovered. Moist, compact. Medium- to coarse-grained sand, with upwards-fining sequences 1.2 to 2.8 in wide; a prominent upwards-fining sequence between 77'7.9" and 77'11.8"; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.

Table B.3. (contd)

Depth Below Surface (feet and inches)	Polarity Preliminary	Description of Core (C3827)
78' to 79'	ND	100% recovered. Moist, compact. From the top of core to 78'3.5", coarse to very coarse sand at the top to medium-grained sand at the bottom, with color bands ~0.4 in wide; from 78'3.5" to 78'5.3", a fine sand-silt band; from 78'5.3" to 78'9.1", coarse to very coarse sand; from 78'9.1"to the bottom of core, coarse sand at the top to medium-grained sand at the bottom, with a band of fine material at 78'9.4"; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
79' to 80'	ND	95% recovered. Moist, compact. Two prominent fining-upwards sequences: between 79'0.4" and 79'7.7", a sequence of medium- to fine-grained sand; between 79'7.7" and 79'11.8", a sequence of medium- to very fine-grained sand; color banding due to basalt between 79'4.7" and 79'7.5"; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
80' to 98'		No recovery.
98' to 99'	ND	95% recovered. Moist, coarse to very coarse sand from the top of core to 98'7"; drier, medium- to coarse-grained sand fining upwards between 98'7" and the bottom of core; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
99' to 100'	ND	100% recovered. Slightly moist, compact. Medium-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
100' to 101'	I	100% recovered. Slightly moist, compact. Fine- to coarse-grained sand, in one large fining-upwards sequence; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
101' to 102'	ND	95% recovered. Slightly moist, well-compacted. Medium-to coarse-grained sand, with a band of finer-grained sand between 101'7.5" and 101'8.7"; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
102' to 119'		No recovery.
110' to 120'	ND	100% recovered. Moist, compact. Medium- to coarse-grained sand, with the uppermost 2.8 in of core slightly more coarse, and containing color bands 1.5 to 2 in wide, probably upwards-fining; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
120' to 121'	R	100% recovered. Slightly moist, compact. Medium- to coarse-grained sand, with color bands ~0.8 in wide and subtle upwards-fining sequences(?); 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
121' to 122'	ND	100% recovered. Slightly moist, compact. Medium- to coarse-grained sand, with color bands ~0.8 in wide and subtle upwards-fining sequences(?); 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
122' to 123'	ND	90% recovered. Slightly moist, compact. Medium- to coarse-grained sand, with color bands ~0.8 in wide and subtle upwards-fining sequences(?); 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
123' to 149'		No recovery.
149' to 150'	ND	93% recovered. Dry, slightly compact, fairly loose. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
150' to 151'	ND	90% recovered. Dry, moderately compact. Medium-grained sand, with grains up to 0.2 in (diameter); subangular to subrounded; well-sorted; color 10YR5/2.
151' to 152'	ND	90% recovered. Dry, moderately compact. Medium- to fine-grained sand, with upwards-fining bands ~1.2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
152' to 153'	ND	90% recovered. Dry, moderately compact. Medium- to fine-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
153' to 153'6"		No recovery.

Table B.3. (contd)

Depth Below Surface (feet and inches)	Polarity Preliminary	Description of Core (C3827)
153’6” to 154’6”	ND	95% recovered. Moderately moist, uncompacted. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
154’6” to 155’6”	R	95% recovered. Dry, moderately compact. Medium- to coarse-grained sand from the top of core to 154’11.5”; from 154’11.5” to the bottom of core, very coarse sand with pebbles up to 1 in (diameter); most pebbles are found in a layer at 155’3.8”; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
155’6” to 156’6”	ND	95% recovered. Dry, slightly compact. Coarse sand with pebbles up to 0.4 in (diameter) from the top of core to 155’11.5” ; medium- to coarse-grained sand between 155’11.5” and 156’5.8”; pebbles up to 1.6 in (diameter) at 156’3.8”; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
156’6” to 157’6”	ND	95% recovered. Dry, slightly compact. Fine- to medium-grained sand, with fining-upwards sequences ~1.2 in side; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
157’6” to 158’		No recovery.
158’ to 159’	I	95% recovered. Dry, slightly compact. Uppermost 1.6 in of core is empty; fine-grained, compact paleosol cemented with $CaCO3$ between 158’1.6” to 158’5.1”; less cemented medium- to fine-grained sand between 158’5.1” and 158’8.7”; from 158’8.7” to the bottom of core, slightly cemented, compact medium- to fine-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
159’ to 160’	ND	98% recovered. Moist, compact. Medium- to coarse-grained sand with upwards-fining sequences 0.8 to 1.2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
160’ to 161’	ND	97% recovered. Dry, moderately compact. Medium- to fine-grained sand, with fining-upwards sequences ~0.8 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
161’ to 162’	ND	96% recovered. Dry, slightly compact. Medium- to fine-grained sand, with fining-upwards sequences (possibly fining-downwards?) 0.8 to 1.2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
162’ to 162’6”		No recovery.
162’6” to 163’6”	ND	90-95% recovered. Dry, slightly compact. Fine- to medium-grained sand: 65% fine-grained, 35% medium-grained, trace of coarse sand. From the top: to 162’8” down, disturbed and loose; between 162’7.2” and 162’8” down, possible layer of well-cemented (with $CaCO3$), fine- to very fine-grained sand, but mostly disturbed; between 162’8” and 163’0.9”, mainly fine-grained sand with faint color bands 0.8 to 1.6 in wide; between 163’0.9” and 163’4.2”, mainly medium-grained sand with faint color bands 0.4 to 0.8 in wide; between 163’4.2” and bottom of core is disturbed and loose. 40% basalt and 60% felsic; subangular to angular; well-sorted; slight HCl reaction; color 10YR6/2.
163’6” to 164’6”		No recovery.
164’6” to 165’6”	ND	95% recovered. Dry, loose, uncompacted. Medium- to fine-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
165’6” to 166’6”	ND	90% recovered. Dry, moderately compact. Fine-to medium-grained sand, with upwards-fining sequences ~0.8 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
166’6” to 179’		No recovery.

Table B.3. (contd)

Depth Below Surface (feet and inches)	Polarity Preliminary	Description of Core (C3827)
179' to 180;	ND	95% recovered. Dry, loose. Uppermost 1.2 in of core empty; coarse to very coarse sand between 179'1.2" and 179'2.8"; very coarse sand between 179'2.8" and 179'6.5"; medium- to coarse-grained sand from 179'6.5" to bottom of core; pebbles up to 0.8 in (diameter) in upper 6.5 in of core; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
180' to 181'	R	98% recovered. Dry, compact. Medium- to coarse-grained sand, with color bands (upwards-fining sequences) 0.8 to 1.2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
181' to 182'	ND	96% recovered. Dry, well-compacted. Medium- to coarse-grained sand, with color bands (upwards-fining sequences) 0.8 to 1.2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
182' to 183'	ND	99% recovered. Dry, well-compacted. Medium- to coarse-grained sand, with color bands (upwards-fining sequences) 0.8 to 1.2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
183' to 219'		No recovery.
219' to 220'	ND	75% recovered. Dry, not compact. Coarse to very coarse sand, with pebbles, mainly of basalt, up to 0.8 in (diameter); 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
220' to 221'	ND	96% recovered. Dry, compact. Uppermost 1.2 in of core is empty; between 220'1.2" to 220'6.3", very coarse sand; between 220'6.3" and 220'7.1", medium- to coarse-grained sand; between 220'7.1" and bottom of core is coarse and very coarse sand; pebbles mostly 0.8 in (diameter) but up to 0.8 in; subtle color bands (fining-upwards sequences) ~1.2 in wide throughout core; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
221' to 222'		95-100% recovered—not opened.
222' to 223'	ND	85% recovered. Dry, moderately compact (especially in lower part of core). Uppermost 0.8 in of core is empty; between 222'0.8" and 222'6.3", very coarse sand, with pebbles up to 0.8 in (diameter), containing a 0.2-in-wide medium-grained sand layer at 222'5.1"; between 222'6.3" and 222'10.6", medium- to coarse-grained sand; core is empty between 222'10.6" and the bottom; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.

Table B.4. Descriptions of Core from Borehole 299-E17-25 (Reidel and Ho 2002)

Depth Below Surface (feet and inches)	Polarity Preliminary	Borehole 3828 Description of Core
0’ to 53’6”		No recovery.
53’6” to 55’6”	ND	99% recovered. Moist, compact. Medium- to coarse-grained sand, with a 0.2-in-wide silt band at 54’0.7” and subtle upwards-fining sequences ~1.2 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
55’6” to 57’6”	ND	90% recovered. Moist, compact. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
57’6’” to 58’		No recovery.
58’ to 60’	ND	95% recovered. Moist, compact. Medium- to coarse-grained sand; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
60’ to 62’6”		No recovery.
62’6” to 64’6”	ND	97% recovered. Moist, compact. Medium- to coarse-grained sand, with subtle upwards-fining sequences; 50% basalt and 50% felsic; well-sorted; color 10YR5/2.
64’6” to 65’6”	ND	97% recovered. Moist, compact. Medium- to coarse-grained sand, with upwards-fining sequences ~1.1 in wide, scattered pebbles up to 0.8 in (diameter) and a silt layer 0.11 in wide at 65’4”; 50% basalt and 50% felsic; subangular to subrounded; color 10YR5/2.
65’6” to 153’		No recovery.
153’ to 155’	ND	60% recovered. Moist. Empty between 153’ and 153’9.4”; silt layer from 153’2” to 153’2.4” separating medium- to fine-grained sand below from medium- to coarse-grained sand above; silt lens ~0.4 in wide at 153’11”. Medium- to coarse-grained sand’ 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
155’ to 158’		No recovery.
158’ to 160’	ND	100% recovered. Moist, compact. Layered: 158’ to 158’3.5”, silt lens; 158’3.5” to 159’1.8”, upwards-fining sequence; 159’1.8” to 159’3”, banded layers of finer and coarser material; 159’3” to 159’4.1”, band of sand with fine-grained clay at the top and bottom; 159’4.1” to 159’8”, upwards-fining sequence; 159’8” to 159’8.3”, layer of clay at the top of the lowermost upwards-fining sequence; 159’8.3” to the core bottom, fine- to medium-grained sand. Color 10YR5/2.
160’ to 162’	ND	96% recovered. Moist, compact. Medium- to coarse-grained sand, with a possible paleosol between 161’5.7” and 161’9.7”’ 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
162’ to 162’6”		No recovery.
162’6” to 164’6”	ND	100% recovered. Moist, compact. Medium-grained sand, with crude banding ~0.8 in wide; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.
164’6” to 166’6”	ND	96% recovered. Moist, compact. Medium- to fine-grained sand, with subtle upwards-fining sequences; 50% basalt and 50% felsic; subangular to subrounded; well-sorted; color 10YR5/2.

Table B.5. Descriptions of Core From 299-E24-21 (Reidel et al. 2001)

Depth		Polarity	Interval Description
45’ to 45’11 ½’’ 46’7’’ to 47’		(47) Reversed 2	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 to opening for hydrologic properties. Core is disturbed, coarse sand (0.5 to 1 mm); sparse pebbles up to about 4 cm; 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	R2	No data	100% full. Silt shaken to surface; some compaction. Sediment shows layering with a contact at 48.5’. 48.5’ to 49’ is fine sand, ~0.1 to 1.5 mm in size with some subtle bedding and some upward fining. 47’ to 48.5’ is coarse (1.5 to 1.0 mm) sand with few sparse pebbles up to 7 mm (metamorphic). Sand is subangular, salt & 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 crystals. The sample was coherent when opened. Core is drying out as it is describe. Good potential for paleomagnetic sample. Core is 26" long.
50’ to 51.5’		(51) Reversed 2	Core was disturbed when sampled for hydrologic properties. Coarse sand (1.5 to 1 mm), subangular to subrounded, moist but not wet, no cementation or compaction. Some grains up to 2-3 mm (sparse). Core is 30% basalt, 70% felsic. Silt along edge of liner effervesces.
52 to 54.2’		(53) Indeterminate	A 1/8’’ thick clay seam at 52' 6". Coarse sand (0.5 to 1 mm) above the seam; sand is approximately 50% basalt, 5% felsic, subangular, and moist; slight compaction but no cementation. Rare pebbles to ~ 5 mm. Silt on edges effervesces strongly. Core is 99% sand. Below the seam is fine sand (0.1 to 0.25 mm) with a series of seams at 52’8’’ resulting in crude bedding. Sparse basalt pebbles (up to 8 mm). Silt on edges shows strong fizz. Banding is 1/8 to ¼’’ thick. 53’ 0.5 to 1 mm; subangular; 60% felsic, 40% basalt. 54.2’ Fine grained (0.1 mm) with larger (0.5 to 1 mm) grains; 60% felsic, 40% mafic.
60 to 62’	R2	No data	Upper 3’’ of this core was lost in the field during sampling. From 60' to 60’8’’ is coarse sand up to 1 mm. Sand shows fining down structure, slightly moist, no cement. Rare pebbles up to 10 mm consisting of quartzite. Silt on edges 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 with some grains as large as 2 mm; smaller grains are subangular; larger grains subrounded; 70 felsic, 30% mafic.
62 to 64’		(63) Reversed 2	Liner is full, sample not disturbed. Core is 95% sand and 5% silt. Sand is coarse (0.5 to 1 mm), angular, salt & 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. Sand is poorly sorted. 63’ 0.5 to 1 mm; subangular to subrounded; 60% felsic, 40% mafic; some calcite crystals. Silt portion effervesces strongly. Silt shakes to surface of core. 2’ section is uniform throughout. 22 ½’’ long core

Table B.5. (contd)

Depth		Polarity	Interval Description
65 to 67’	R2	(66) Indeterminate	Lost material at 67’ when dropped in field. Sand is ~0.25 to 0.5 mm in size; 40% basalt; 60% felsic; angular to subangular. Some granules up to ~ 2 mm. Core shows no sorting, no cementation and no compaction. Core is dry. Silt on edge effervesces strongly.
67 to 69		(68) Indeterminate	Core is composed of sand that is 0.25-0.5 mm in size; 40% basalt 60% felsic; and subangular in larger grains. A few basalt pebbles up to 10 mm. Core shows no sorting, is slightly moist, and has some faint bands 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’		(71.5) Reversed 2	70' to 70’6’’ lost in the field. Core is medium sand (~0.5 mm up to 1.5 mm) 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 that effervesces strongly.
72 to 74’	R2	No data	Core shows fining upward sequences ~ 2’’ thick. Sediment is 99.9% sand from about 0.25 to 0.6 mm in size, subangular, and 50% felsic 50% basaltic. Small pebble layer at 73’ 7 ½’’ that is ¼’’ thick with pebbles ~ 5 mm 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 strongly effervesces.
75 to 77’		(77.5) Reversed 2	Core shows no geologic structure. Core consists of coarse, subangular sand (1 to 7 mm), 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 that effervesces.
77 to 79		(77.5) Reversed 2 (78) Reversed 2 (78.6)	77 to 78’ 3 ½’’= unit 1 coarse sand 78’7’’- 78 3 ½’’= fine unit 78’7’’ to 79’= unit 3 77’ 1 ½’’ is well compacted, coarse sand (up to 1 mm) with up to 5% pebbles up to 7 mm; unit is fining upward. 77’6’’ to 77’8’’ is finer grained (<1 mm) with fewer pebbles. 77’8’’ is a fine pebble band ~ ¼’’ thick (basalt pebbles); pebbles are rounded and sand is subangular. 77’8’’ to 78’ 3 ½’’ is a medium to coarse sand with scattered pebbles up to 7 mm in size. Sand is 50% basalt and 50% felsic, poorly sorted, slightly moist, and very compact. Silt on the edge strongly effervesces. 78’ 3 ½’’ to 78’ 7 ¼’’ is a banded, bedded, fine grain section (5YR6/2); bands are distinguished by color and hardness. Possible paleosol layer. Grains are 0.25 to 0.5; 70% felsic and 30% basaltic. 78’ 7 ¼’’ to 79’ is coarse sand, 50% basalt and 50% felsic, no compaction or cement, slightly disturbed due to filter paper.
80.5 to 82’	R2	No data	The core section includes only 18’’ of soil with 6’’ of bubble wrap. At 82’ to 80.5’ is coarse grained sand (0.5 to 2 mm with some grains up to 5 mm), salt & 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’		(83) Reversed 2 (?)	Fining upward sequences about 3 ½’’ wide. Sand up to 2 mm in size; finer sand is 0.25 to 0.5 mm. Sand is 50% basalt, 50% felsic with coarser material being mostly basalt. Sand is subangular, slightly moist, with no cement. Silt effervesces. Sediment is 99% sand.

Table B.5. (contd)

Depth		Polarity	Interval Description
85 to 86'		No data	Fining upward sequences about 3 ½'' wide. Sand up to 3 mm in size; finer sand is 0.25 to 0.5 mm. Sand is 50% basalt, 50% felsic with coarser material being mostly basalt. Sand is subangular, slightly moist, with no cement. Silt effervesces. Sediment is 99% sand.
87 to 89'		(88) Indeterminate	Core has a layered structure. Sand is medium grained (0.5 to 1 mm) with about 1% basalt and quartzite pebbles up to 5 to 7 mm. Sand is 40% basalt and 60% felsic. Layer at 88' 5 ½'' is about ½'' thick and is coarser with more basalt. Core is slightly moist with no cement and no compaction. Less than about 1% silt on edges that effervesces.
90 to 92'		No data	Core shows some bedding. Sand is medium to coarse grained (0.5-2.0 mm), subangular with about 5% pebbles up to 5 mm. 50% basalt, 50% felsic. Bedding at 91.'9'' is a fine-sequence (0.25 mm), well sorted, with very little moisture and no cementation. Silt reacts with HCl along edge.
92 to 94		(91) Indeterminate	Intact core. Bedding is present. Sand is 0.25 to 0.5 mm 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'		No data	Upper 6'' of core is missing. Sediment is bedded, fining upward sequences about ~ 1 ½'' thick. Sand is 0.25 to 0.5 mm in size with some grains up to ~ 2 mm. Sand is subangular, dry, well sorted, and 60% basalt and 40% felsic. No cement and slight compaction. Silt on the edges effervesces.
97 to 99		(89) Indeterminate	Intact core. Bedding is present and is about 2'' to 5'' thick; fining upward sequences decreasing in size upward. Sand is 0.25 to 8.5 mm 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	R2	(100.5) Indeterminate	Upper 3'' of core is missing. 100'3'' to 100'8'' is medium to fine grain (0.25 to 0.5 mm) sand with crude bedding. Sand is wet with the felsic component greater than the basalt component. Well sorted, no cement and no compaction. 50% basaltic, 50% felsic. 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); fining upward. Fining upward sequences are 2-3'' thick. No cementation; coarser material is slightly more compact. Silt on edges effervesces.
102 to 104		No data	Intact core. Fining upward sequences 4 to 5'' thick. Sand is 0.25 to about 1 mm in sized and is 50% basalt and 50% felsic. Sand is subangular to angular, slightly moist, very compact and well sorted; no cementation. Silt on edges effervesces.
105 to 107		No data	Top 3 to 4'' of core is missing. Crude layering; fining upward sequences about 1'' thick. Sand is 0.25 to 1 mm 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 effervesces.
107 to 109		(108) Indeterminate	Intact core. Bedding is fining upward sequences; about 1 ½'' thick beds. Sand is 0.25 to 1 mm 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 on edges effervesces.
112 to 114	R2	No data	Intact core with 2 zones. From 112' to 113'8'' is medium sand (0.25-0.5 mm) with ¼'' to ½'' bands defined by changes in grain size (0.1-0.25 mm). Finer bands are 40% basalt and 60% felsic, subangular, and compact with no cementation. Silt on edges effervesces 113'.3'' to 113'5'' is fine to medium grained sand (0.25 mm) in ½'' thick bands. 113'5'' to 113'8'' is very fine-grained sand (0.1 to 0.25 mm so up to 1 mm) in 6 bands that are about ½'' 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''.

Table B.5. (contd)

Depth		Polarity	Interval Description
115 to 117		(116) Indeterminate	Bedded, fining upward sequences on the 4’’ scale with internal beds on the ½’’ scale.. Sand is coarse (0.25 to 1 mm), slightly moist, 50% basalt and 50% felsic, well sorted and subangular; no pebbles and no cementation. Silt on edge effervesces.
117 to 119		No data	Complete core section. Sediment has crude fining upward bedding. From 117 to 118' is medium sand (0.25 mm) with crude bedding defined by color. From 118’ to 118’5’’ is coarser sand (up to 1 mm) with brown staining at 118’5’’. Sand is angular to subangular. Back to medium sand (0.25 to 0.5 mm) at 118’5’’-119’. Sand is 50% basalt and 50% felsic with a trace of quartzite pebbles (5 mm). Sand is well sorted and slightly moist. The center of the section is stained and may be slightly cemented (iron stain). Silt effervesces.
120 to 122’	R2	(121) Reversed 2 (?)	Laminar bedding; fining upward sequences 3 to 4’’ thick; coarse base is 2 to 10 mm in size and finer grained (0.5 to 1.5 mm); angular to subangular. Sand is 40% basalt and 60% felsic, not very compacted and slightly moist. Silt effervesces. Clay zone at 120’ 2 ½’’ is ½’’ thick with caliche cement.
122 to 124’		(123.5) Normal (overprint?)	Complete core section. Bedding is defined by color and is about ½’’ thick bands fining upward. Coarse part at base is about 1 mm in size and the darker fine part is 0.25 to 1 mm in size. Sand is subangular, 40% basalt and 60% felsics, well sorted, fairly compacted, and dry. No cement. Silt on edges effervesces.
125 to 127’		No data	Complete core section. Crude ½" bedding is defined by color. Sand is 0.25-1.0 mm in size, subangular, well sorted, and dry. 60% felsic, 40% basaltic. At 125’3’’ is a contact with a coarse (1 to 2 mm) unit above that fines upward. At 126’9’’ is clay rich, stained band about ¼’’ wide. Sediment is well compacted and not cemented.
127 to 129		No data	Complete core section. Subtle fining upward sequences 6 to 9’’ thick. Sand is 0.25 to 0.1 mm 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.
130 to 131.5		(130.5) Indeterminate	One fining upward sequence; coarse sand is 0.5 to 2 mm in size and fine sand is 0.1 mm in size. 60% felsic, 40% basaltic. Sand is subangular, well sorted, dry, and not very compact. Silt on edges effervesces.
132 to 134	R2	No data	Complete core section. 132’ to 132.6’’ is fine-grained sand (0.5-1 mm) with a couple ½’’ to ¾’’ wide beds. 132’6’’ to 134’ is coarse sand (0.5 to 1.5 with many grains over 2 mm). Sand is 40% basalt and 60% felsic, angular to subangular, well sorted, dry, very compact, and not cemented. Silt effervesces. Section contains rare rounded, basalt pebbles about up to 7 mm in size and oxidized.
135' to 137'		No data	2’’ of sluff 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) with some fine sand 0.25-0.5 mm in size. Sand contains a few pebbles up to 8 mm in size. Sand is 40% basalt and 60% felsic, subangular, well sorted, and slightly moist; no cementation but well compacted. Silt on edge effervesces.
137’ to 139'		(138) Indeterminate	Intact except at the top. Laminated, fining upward sequences 1’’ to 2’’ thick. Sand is coarse (1.0 mm) to fine (0.25 to 0.5 mm). 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'		No data	Intact core except at the top. Fining upward lamination with sequences ½’’-1’’ thick. Coarse sand is 1.0 mm in size and fine sand is 0.25 to 0.5 mm 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 along band reacts strongly to HCl.

Table B.5. (contd)

Depth		Polarity	Interval Description
142' to 144'		(143) Indeterminate	Core contains ¼ to ½'' laminations defined by color. Sand is 0.25 to 1 mm in size at the top of the core to 2 mm in size at the bottom of the core. 70% felsic, 30% basaltic. Sand is subangular, well sorted, and slightly moist. Silt effervesces.
145' to 147'		No data	Some lamination and color banding. Sand is 0.25 to 1 mm 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 3 mm in size. Silt effervesces
147' to 149'		No data	Intact core. Fining upward sequences about 2" thick. Coarse sand is 1.0 mm in size and fine sand is 0.1 to 0.5 mm 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.
150' to 151'		No data	Core contains layering defined by color banding. Medium grained sand (0.25 to 1 mm), is 40% felsic and 60% basaltic, well sorted, subangular, slightly moist, and poorly compacted. Moderate reaction to HCl.
152' to 154'		(153.5) Indeterminate	Upper 2'' of core is sluff. Core is laminated. 152 to 152'6'' is fine-grained sand (0.25 mm). From 152'-6'' to 153'3'' is a fining upward sequence with the lower sand about 1 mm in size and the upper sand about 0.25 mm in size. 153'3'' to 154' is fine sand that is layered in ½'' to 1'' bands denoted by color. 0.25 to 1 mm with some grains up to 2 mm. 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 in size) in coarser sand.
155' to 157'		No data	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 in size with 10 to 15% finer grained (0.25 to 0.5 mm). Sand is moderately sorted, slightly moist, not cemented, and not compacted. Silt effervesces.
157' to 159'		(158) Indeterminate	Intact core. No noticeable structure. Medium (0.1 to 0.5 mm) and coarse sand (1 to 2 mm) is well sorted with minor pebbles up to about 7 mm 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'		(161) Normal	Upper 3'' of core is 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 in size and is 50% basalt and 50% felsic. The lower part is 0.25 to 1 mm in size, moist, well sorted, compacted, subangular and is 40% basalt and 60% felsic. Silt effervesces on edge.
162 to 164'		Reversed (2?)	Minor, ½'' thick banding at 162'7'' and 163'1''. Medium to fine-grained sand (0.25 to 1 mm) is 40% basalt and 60% felsic. Sand is subangular, slightly moist, and compacted. Minor rounded, basalt pebbles up to about 10 mm in size. Sediment is 99% and with 1% greater than 2 mm in size. Silt on edge effervesces.
165' to 167'		No data	24" long core. Medium-grained sand (0.25 to 1 mm), 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 a ½" band (bed) the base of which is slightly finer grained. A second band at 166.5' is ½" wide and finer at base. Coherent core; probably due to moisture. Separated silt effervesces strong. Sand doesn't fizz. 1 to 2% silt shaken out along edges.
167' to 169'		Indeterminate	Fine layering about every 1" denoted by grain size. Sand is 0.25 to 1 mm in size, well sorted, 40% basalt and 60% felsic, slightly moist, compacted, and contains a few pebbles up to 5 mm in size. Silt on edge effervesces.

Table B.5. (contd)

Depth		Polarity	Interval Description
170’ to 171’		(171) Normal	Upper 3” of core is missing. 170’3” to 170’4” is fine sand (0.25 to 0.5) 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 coarse sand (0.25 to 1 mm) 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’	N1	(172.7) Reversed (2)	Upper 2” of core is missing. 171’9” to 172’7” is coarse sand (1 mm); no bedding. At 172’7” sand is finely laminated with fine sand and silt (6 silt layers) totaling ¾” thick. This zone is well cemented/compacted. Remainder of core is fining upward sequence. Coarse sand on the bottom is about 1 mm in size; finer sand is 0.25 to 1 mm in size. Crude laminations; possible silt layers, and ¼” sand layer. Sand is 40% basalt and 60% felsic, well sorted, and slightly moist. Core section is 99% sand; no cement.
175’ to 177’		No data	Upper 3 ½” of core are missing. 175’ to 176’ is coarse-grained sand. Sand is 1 to 3 mm 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 composing a fining upward sequence. 176' 5" to 177' is a second fining upward unit. The fining upward units are 0.5 to 1 mm 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.
177’ to 179’	N1	Indeterminate	Some lose dry material lost from both ends of the core; top 2” and bottom 3” lost. At 178’2”-178’3” is a breccia with opal and charcoal with grains up to 8 mm. (Sample taken.) Host sand above is medium-grained (0.25-0.5 mm), 40% basalt and 60% felsic, well sorted, compacted, angular to subangular, and reacts mildly to HCl. Host sand below is coarser (1 mm) fizz with HCl, compacted.
180’ to 181’		No data	Coarse sand, 2 mm to 7 mm in size (10-20% of material is less then 2 mm), subrounded, 70% basalt, 30% felsic, poorly sorted, slightly moist, poor consolidation, slight reaction with HCl. No cementation.
182’ to 184’		(183) Normal	Missing upper 2” and lower 1” of core. 40% basaltic, 60% felsic. There is a series of color banding due to varying amounts of basalt. Possible upward fining, sequences 5” to 6” thick. Sand is 0.1 to 0.75 mm (some up to 1.5 mm) in size, well sorted, subangular, and slightly moist. No cementation but compaction. Moderate reaction with HCl.
185’ to 187’		No data	Coarse sand with no internal structure. Some larger grains up to 6 or 7 mm. Sand is 1 to 2 mm 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’	N1	Indeterminate	Crude structure consisting of banding and upward fining sequences. Sand is 1.0 mm to 0.25 mm in sequence of upward fining (very poorly developed) moderately coarse. Grain size is 1.0 mm average for core as a whole. Sand is Sand is 50% basalt and 50% felsic, subangular, moderately compacted, slightly moist. No pebbles. Moderate reaction to HCl .

Table B.5. (contd)

Depth		Polarity	Interval Description
190' to 192'		Indeterminate	190' to 190'9" is coarse-grained sand (1 to 2 mm) with some grains up to 5 mm. 190'9"-192' is finer-grain and consists of 1 to 2 ' thick upward fining sequences. Sand is 0.5 to 2 mm in size at the base and 0.5 mm in the upper part. 50% basalt, 50% mafic. Light color due to felsic content. 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'		Indeterminate	Three upward fining sequences 6 to 9" thick. Sand is 1 to 1 mm in size, 50% basalt and 50% felsic, poorly sorted, slightly moist, and compact. No cementation. Moderate reaction to HCl.
195' to 197'		No data	One upward fining cycle. Sand at the bottom is up to 3 mm in size whereas that at the top is 0.5 mm 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'		Indeterminate	No apparent structure. Sand is coarse-grained with some (about 1%) larger granules up to 7 mm. Composition is 40% basalt and 60% felsic. Sand is slightly moist, poorly sorted, and poorly compacted. Reacts moderately with HCl.
200' to 201'	N1	(201) Indeterminate	Core sampled for hydrologic properties. 200 to 200'9" is a coarse unit (7 to 6 mm) and fines upward (0.5 to 1 mm). 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 that units at shallower depths. Sand is module well sorted, slightly moist, poorly compacted, and consists of 70% basalt and 30% felsic. Moderate reaction to HCl
202' to 204'		No data	Faint color laminations. Coarse sand (1-2 mm) with 1 to 2% pebbles up to 10 mm in size. Sand is 50% basalt and 50% felsic. Pebbles and sand are subangular, slightly moist, moderately sorted, and slightly compacted. Silt on edge effervesces and sand shows a moderate reaction with HCl.
205' to 207'		(205.5) Normal (1?)	No structure except finer grained band at 205' 6" that is ½" thick and contains more silt. Sand is medium grained (0.5 to 1 mm), 50% basalt and 50% felsic, subangular, slightly moist, compact, and well sorted. A few (less than 1%) subround basalt pebbles up to 10 mm in size. No cementation. Reaction with HCl is moderate.
207' to 209'		Indeterminate	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 1.0 mm in size, angular to subangular, well sorted, and slightly moist. No cementation but well compacted. Moderate reaction to HCl.
212' to 214'	N1	Normal (1?)	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'-212'3 ½" is light colored, 0.5 to 1 mm in size, subangular, and is 50% basalt and 50% felsic. A few larger pebbles up to 7-8 mm in size. 212'3 ½" - 212'8" is coarse sand 1 mm to 3 mm in size with grains reaching up to 7 mm. Sand is 60-70% basalt and 30-40% felsic. 212'8"- 214' is 0.25 to 1 mm sand that is 50% basalt and 50% felsic.

Table B.5. (contd)

Depth		Polarity	Interval Description
217 to 219’	N1	No data	Material has been lost from both ends of core (lost 2” from top and 3 ½” 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). Basalt rich layers are coarser with grains up to 3 to 5 mm and some as large as 10 mm. Sand is well sorted, slightly moist, and moderately compacted. Pebbles near bottom of core are up to 2 to 3 cm in size. Slight to moderate reaction to HCl.
220’ to 222’		Indeterminate	220’- 220’9 ½” is disturbed. 220’9 ½” - 221’4” is medium grained sand (0.5 to 1 mm) with small, crude color bedding and 2 to 3% scattered basalt pebbles up to 10 mm in size. Sand is compacted, slightly moist, well sorted, and consists of 50% basalt and 50% felsic. Reaction to HCl is moderate. 221’4”-222’ is coarse grained sand (0.5 to 1 mm) that is 60% basalt and 40% felsic, compacted, and slightly moist. One quartzite pebble at 4 cm in diameter. Slight reaction to HCl.
222’ to 224’		(223.5) Normal (1?)	222’-222’2” is missing. 222’2”-222’4” is fine-bedded sand (0.5 to 1 mm) that is 50% basalt and 50% felsic. 222’4”- 222’81/2” is darker and coarser sand consisting of 60 to 70% basalt. Grain size is 1 to 2 mm with pebbles up to 10 mm in diameter. There is a crude color bedding. 222’8 ½”- 223’3” is coarse-grained sand (0.5 to 2 mm) with a few pebbles up to 3 mm in size. Sand is 60 to 70% basalt and has a crude color bedding. 223’3” –223’5 ½” is finer grained sand (0.5 mm to 1 mm), light color, and 50% basalt and 50% felsic in composition. 223’5 ½” –224’ is coarser-grained sand (1 to 2 mm) with a few pebbles up to 3 to 4 cm in diameter. Composition is 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’		(226) Normal (1?)	Core shows a color zonation. 225’-225’2” is missing. 225’2”-225’5” is light color sand (1 mm) that is 50% basalt and 50% felsic. 225’5”-225’7” is like the above sand but includes larger pebbles about 2 cm in diameter. 225’7”-225’9” is sand that is 1 to 2 mm in size and 60-70% basalt and 30-40% felsic in composition. 225’9”-226’8” is light color sand that is 50% basalt and 50% felsic with a layer of pebbles at 225’10” 226’8”-227’ is coarser grained granules (3 to 5 mm) and is 60% to 70% basalt. All of the above are very compacted, well sorted moderately moist. Reaction to HCl is moderate to strong.

Table B.5. (contd)

Depth		Polarity	Interval Description
227’ to 229’	?	No data	Upper 1" of core is missing. 227’- 228’1” is very coarse grained (0.5 to 7 mm and greater in size) with pebbles up to 4 cm. Unit is 60 to 70% basalt and 30 to 40% felsic, well compacted, slight moist, and poorly sorted. 228’1”-229’ is coarse sand and granules (1-3 mm) that are 60 to 70% basalt and 30 to 40% felsic. Sand is 20-30% of the sample. The sediment is moderately sorted and slightly moist. Fines show strong reaction with HCl.
229' to 232'		No data	Not logged - archive
232’ to 234’	R1	(233) Reversed 1	No apparent internal structure. Entire core is coarse grained (0.5 to 2 mm), poorly sorted, subangular, moderately compacted, and 50% basalt and 50% felsic. 50% of the sediment is 1 to 2 mm in size and 50% is greater then 2 mm in size. Sand is subangular and pebbles are rounded. Some basalt pebbles up to 3 cm. Moderate reaction to HCl.
234' to 241'		No data	Not logged - archive
241’ to 243’		(242) Reversed 1	Coarse sand (0.5 to 2 mm). Sand is 50% basalt and 50% felsic, subangular, slightly moist, well compacted, and well sorted. Slight reaction with the HCl.
243' to 255'		No data	Not logged - archive
255’ to 256’		(255) Reversed 1	255’-255’2” is banded, fine-grained sand (0.1-0.5) with 20% silt. 255’2”-256’ is sand (0.25-0.5 mm) that is 50% basalt and 50% felsic, slightly moist, and well sorted. No compaction or cementation. Moderate reaction with the HCl.
256' to 259.5'	R1	No data	Not logged - archive
259.5’ to 261. 5’		(261) Reversed	Upper 6” of core is sluff. At 260’4” is a 1” thick, basalt rich zone. This entire cored interval is medium sand (0.25 to 1 mm) that is well sorted, subangular to subrounded, and slightly moist. Sand is compacted but not cemented. No pebbles. Moderate reaction with HCl.
261.5' to 265'		No data	Not logged - archive
265’ to 266. 5’	R1	(265.5) Indeterminate	Bedding – 1 bed at 265’6”-265’8” and another at, 266’2”-266’4”. Except for the two beds, overall grain size is 0.25 to 0.5 mm with a few grains up to 1 mm. Sand is angular to subangular, well sorted, slightly moist, and not very compacted. No cementation. Strong reaction with HCl. 265’8”-265’6” is compact and slightly cemented with $CaCO_3$ (strong reaction with HCl). Grain sizes are as described above. 266’2”- 266’4” The layer is also cemented with $CaCO_3$ (reacts with HCl). Base of 266’5” has rounded, basalt pebbles with some sand grains cemented on them. Pebbles are up to 4 cm in size.

Table B.5. (contd)

Depth		Polarity	Interval Description
266.5' to 268.5'		(267) Indeterminate (268) Indeterminate	266.5'- 266'10" is medium sand (0.25 to 1 mm) and gravel up to 4" in diameter. 40-50% gravel. Sand moderate reacts with HCl. 60% felsic, 40% basalt. 266'10"- 268'3" is a sand and gravel sequence. 266'10"- 266'11" is caliche-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. Sand has a strong reaction with HCl and contains some 2 mm pieces of $CaCO_3$. Bottom 268'5"-268'7" is sand.
270' to 272'		No data	270'- 270'6" is basalt gravel, up to 4" in diameter with some smaller, felsic gravel. 270'6" – 271'10" is gravelly sand, 60 to 70% sand, 30 to 40% gravel. Sand is (0.1 to 1 mm), 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.

Appendix C

Geologic Map of the Integrated Disposal Facility Trench

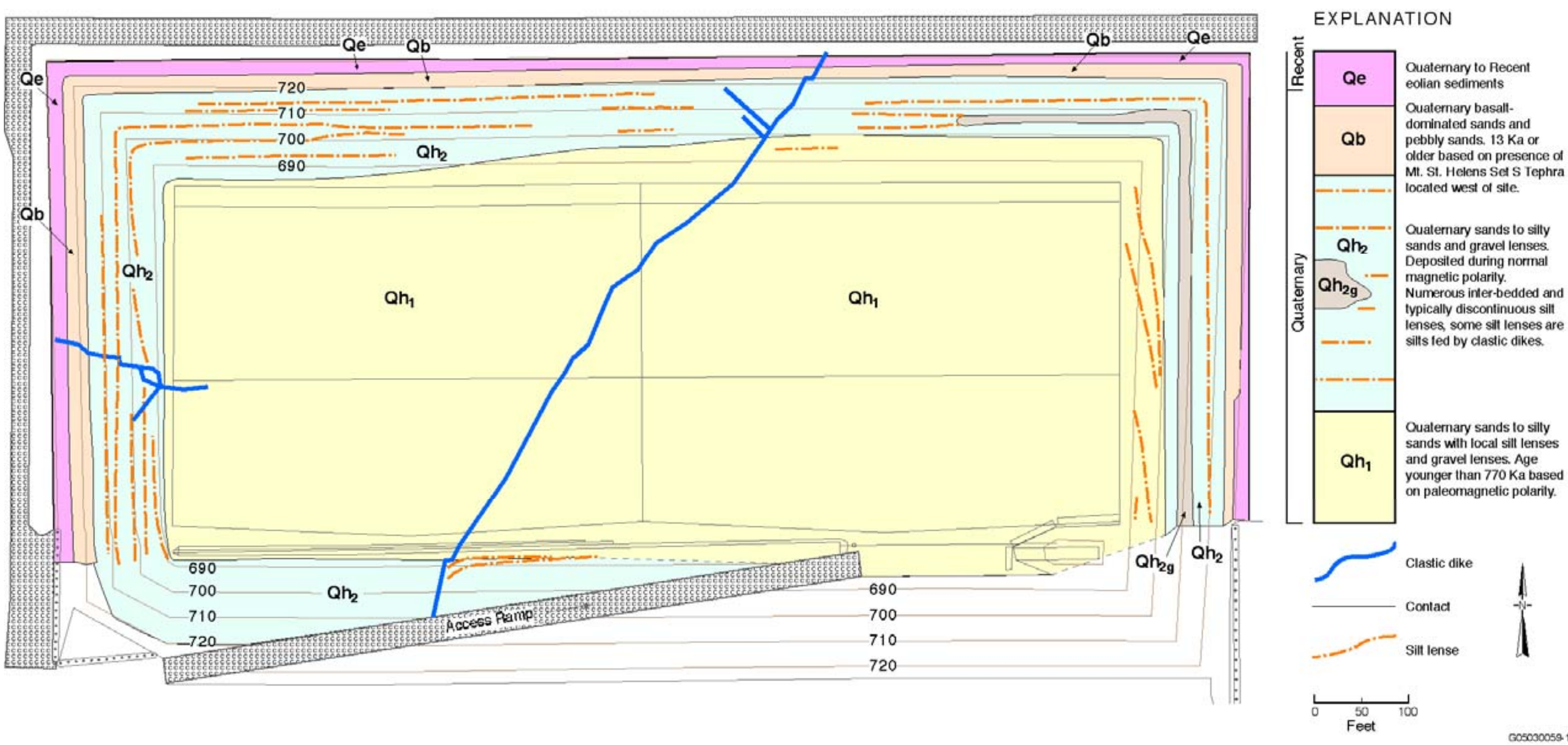

Figure C.1. Geologic Map of the Integrated Disposal Facility Trench (from Reidel and Fecht 2004)

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