Appendix B

Stratigraphy of the Subsurface at the Idaho National Technology and Engineering Center

ABSTRACT

The lithology and stratigraphy of the subsurface at the Idaho Nuclear Technology and Engineering Center (INTEC) will affect the potential migration of radioactive and chemical contaminants from INTEC to the Snake River Plain Aquifer (SRPA). This report evaluates data developed during the drilling of new wells over the past several years. The new data are used to develop several newer lithologic and stratigraphic correlation cross sections. These new data may provide for a better understanding and modeling of the INTEC subsurface. The new data may also be helpful in determining preferential flow pathways and provide updated values for the geologic parameters required to numerically model contaminant fate and transport from the ground surface to the SRPA.

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ACRONYMS

amsl	above mean sea level
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CPP	(Idaho) Chemical Processing Plant (now known as INTEC)
DOE	U.S. Department of Energy
DOE-ID	U.S. Department of Energy Idaho Operations Office
HLLW	high-level liquid waste
ICPP	Idaho Chemical Processing Plant
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
LDU	land disposal unit
ROD	record of decision
SRPA	Snake River Plain Aquifer
USGS	United States Geologic Survey
WAG	waste area group

Appendix B

Stratigraphy of the Subsurface at the Idaho National Technology and Engineering Center

B-1. INTRODUCTION

The Idaho National Engineering and Environmental Laboratory (INEEL) is divided into 10 waste area groups (WAGs) to better manage environmental operations mandated under a Federal Facility Agreement and Consent Order (DOE-ID 1991). The Idaho Nuclear Technology and Engineering Center (INTEC), formerly the Idaho Chemical Processing Plant (ICPP), is designated as WAG 3. Operable Unit (OU) 3-13 encompasses the entire INTEC facility.

OU 3-13 was investigated to identify potential contaminant releases and exposure pathways to the environment from individual sites as well as the cumulative effects of related sites. Ninety-nine release sites were identified in the OU 3-13 remedial investigation/feasibility study (DOE-ID 1997), 46 of which were shown to have a potential risk to human health or the environment. A new operable unit, OU 3-14, was created to specifically address activities at INTEC high-level liquid waste (HLLW) tank farm area, where special actions will be required. The 46 sites were divided into seven groups based on similar media, contaminants of concern, accessibility, or geographic proximity. The OU 3-13 record of decision (ROD) (DOE-ID 1999) identifies remedial design/remedial action objectives for each of the seven groups. The seven groups include:

- Tank Farm Soils (Group 1)
- Soils Under Buildings and Structures (Group 2)
- Other Surface Soils (Group 3)
- Perched Water (Group 4)
- Snake River Plain Aquifer (Group 5)
- Buried Gas Cylinders (Group 6)
- SFE-20 Hot Waste Tank System (Group 7).

The final ROD for OU 3-13 was signed in October 1999 (DOE-ID 1999). This comprehensive ROD presents the selected remedial actions for the seven groups, including Group 4 perched water instrumentation to assess the perched water drain out and potential contaminant flux into the Snake River Plain Aquifer (SRPA).

B-1.1 Project Purpose

This report describes the lithologic profiles of several wells and presents three stratigraphic correlations of the INTEC subsurface. This report also interprets and presents the geology from the ground surface to the SRPA, which has a top surface at approximately 137 m (450 ft) below ground surface (bgs) or at approximately 1,356 m (4,450 ft) above mean sea level (amsl).

The lithology and stratigraphy of the subsurface at INTEC will affect the potential migration of radioactive and chemical contaminants from INTEC to the SRPA. This interpretation may help to determine preferential flow pathways and provide updated values for the geologic parameters required to numerically model contaminant fate and transport from the ground surface to the SRPA.

Several additional wells and coreholes have been drilled at the INTEC facility since the previous attempts at stratigraphic correlations and geologic modeling have been conducted. The additional data that were collected during these drilling activities enable a more detailed and accurate reconstruction of the subsurface. These data, as well as ongoing tracer transport studies, should enable considerable updates of the INTEC site conceptual model.

B-1.2 Approach

The following steps outline the basic approach used to interpret the lithologic and stratigraphic subsurface geology at and near the INTEC facility:

1. A literature search was conducted to provide information about the regional and local geology of the INEEL and INTEC. Previous generalized lithologic and stratigraphic correlations have been constructed for the INEEL and, in some cases, more detailed correlations of the structure beneath the INTEC facility. These previous correlations were used as a basis or starting point for this report (Anderson 1991 and MSE 1995). The year 2000/2001 addition of data from an additional 21 boreholes will enable better correlations and greater detail in these subsurface reconstructions.

2. Previously existing and newly acquired data pertaining to the subsurface geology at INTEC were collected. The data were in the form of geologist's records recorded during various borehole drilling operations, core logs and photographs of core collected from coreholes drilled at INTEC, downhole video logs of boreholes drilled at INTEC, and borehole geophysical logs recorded in INTEC wells and boreholes.

3. Lithologic columns were constructed from the available data for selected boreholes at the INTEC facility, concentrating on the wells drilled during the years 2000 and 2001.

4. The lithologic information was compiled and entered into an electronic database.

5. Stratigraphic relationships between the lithologic columns were made, and cross sections of the subsurface showing the stratigraphic relations were constructed.

B-2. GEOLOGIC SETTING

B-2.1 Snake River Plain

The Snake River Plain is an arcuate basin of lower elevation and lower surface relief that extends for nearly 483 km (300 mi) across southern and southeastern Idaho. The plain truncates the northwest- to southeast-trending ranges, valleys, and faults of the surrounding basin and range province. The Snake River Plain is commonly divided into two regions, a western region and an eastern region. The western region trends in a generally northwest direction from near Boise, Idaho, and is a depositional basin. The eastern portion is a northeasterly trending volcanic plain terminating near Yellowstone National Park. The INEEL is located within this eastern region of the plain.

The elevation of the eastern Snake River Plain ranges from approximately 975 m (3,200 ft) amsl at the western boundary to 1,951 m (6,400 ft) amsl at the eastern boundary. The surrounding mountains rise between 914 and 1,828 m (3,000 and 6,000 ft) above the Snake River Plain.

Deep drilling and geophysical studies indicate that the eastern Snake River Plain is composed of three layers of volcanic or magmatic rocks. The upper portion of the plain is composed of a 610- to 1,524-m (2,000- to 5,000-ft) thick layer of iron-rich basalts. This is underlain by up to 3,048 m (10,000 ft) of silicic-rich rhyolite. The deepest drill hole at the INEEL has shown this unit to be composed of an upper portion of extrusive rhyolite and a lower portion of intrusive material. The third layer is known only from geophysical studies and appears to be an extremely dense rock that is even more iron rich than the surface basalts. This unit ranges in thickness from approximately 9.6 to 14.5 km (6 to 9 mi).

B-2.2 Origin of Snake River Plain

The Snake River Plain is believed to have originated with the passage of the continental crust over a deeply rooted mantle plume. This mantle plume, or "hot spot," is now located beneath Yellowstone National Park and, hence, has become known as the Yellowstone Hot Spot. Passage of the continental crust over this hot spot results in a specific sequence of different forms of volcanic activity that leaves in its wake the three distinct crustal layers beneath the Snake River Plain.

B-2.2.1 The Pre-Yellowstone Phase

This phase begins when a given location on the continental crust drifts across the location of the mantle plume. The actual genesis, workings, and life span of a mantle plume are not well known. It is believed that many hot spots have their roots as deep as the earth's core and lower mantle boundary. However, the roots of the Yellowstone plume and the origin of the extremely hot magma, which forms the ascending plume, may be as shallow as 200 km (125 mi) below the surface. The magma rises toward the surface due to buoyancy resulting from its higher temperature than surrounding rock. The magma rises to the base of the lithosphere at a depth of approximately 80.5 km (50 mi), where it pools. This magma causes dramatically increased heat flow to the surface and a substantial bulge in the earth's geoid for an area of up to 483 km (300 mi) in diameter.

B-2.2.2 The Yellowstone Phase

The Yellowstone Phase begins when portions of this material are sheared off of the plume and begin to rise through the earth's crust toward the surface. This rising molten material melts some of the overlying silica-rich continental crust and forms a secondary melt of a few tens of miles in diameter located 5 to 13 km (3 to 8 mi) below the surface. Large-volume rhyolite eruptions occur from this melt body, with some of the eruptions being cataclysmic in nature. These eruptions will typically leave calderas many tens of miles in diameter and produce eruption volumes measured in the hundreds of cubic miles. Caldera-forming eruptions are often followed by smaller localized rhyolitic volcanic flows. This is the type of volcanic activity now occurring in Yellowstone.

B-2.2.3 The Snake River Plain Phase

As the crust moves away from the hot spot, the Yellowstone Phase rhyolitic volcanism is replaced about one million years later with outpourings of basaltic lava flows. As the rhyolitic chamber cools and crystallizes, it allows deeper basalt magma to travel to the surface through fissures in the overlying crust. This phase is now beginning over the 1.2-ma Island Park caldera and has been active for four million to five million years on the Snake River Plain.

The three distinct layers of the Snake River Plain represent deposits of each of these phases. The basalts are located near the surface and were emplaced last. The rhyolitic volcanics are located in the middle and represent the huge silicic eruptions that preceded the basalt. The very dense, iron-rich rocks located deep beneath the plain are the remnants, or "slag," left in the magma chamber after the lighter minerals have been erupted.

B-2.3 Basalt Flow Structure

Greeley (1982) proposed the term basalt plain to describe the basaltic region of the eastern Snake River Plain. According to Greeley, a basalt plain combines elements of shield volcanoes and flood basalt plateaus.

The eastern Snake River Plain comprises multiple thin flows erupted from vents usually aligned along fissures. Two types of basalt are commonly erupted on the eastern Snake River Plain: (a) a form known as pahoehoe, which is a very fluid, low-viscosity magma that produces thin tongues and lobes, and (b) aa, which is a high-viscosity magma that results in blocky angular flows. A third hybrid type of basalt is also found among the lava flows of the eastern Snake River Plain. It is suggested it was formed by magma interacting with crustal rocks at depths of about 30 km (18.6 mi) (Malde 1991).

As suggested by Greeley (1982), pahoehoe is the dominant type of basalt erupted on the Snake River Plain; pahoehoe forms the long, low-angle flanks of the low-shield volcanoes. The eruption of an aa lava produces the higher-angle slopes found surrounding many of the volcanic vents. As the eruption of the basalt continued over time, several low-shield volcanoes formed, their flanks overlapping to produce the complex stratigraphy found within the Snake River Plain basalts.

B-2.3.1 Flows, Flow Units, and Flow Groups

A lava flow is generally defined as a solidified body of rock that has been extruded horizontally across the earth's surface from a fissure or vent. A lava flow may be described as a flow, which refers to the overall body of rock; a flow unit, which is a separate distinct lobe that issues from a flow; or a flow group, which is a sequence of petrographically similar flows that erupted from the same magma chamber (Anderson and Lewis 1989). Between lava flows, there is a contact that represents a cooling surface. The cooling surface is typically marked by an increase in the number of vesicles and fractures in the rock as well as a significant amount of oxidation. There may also be a layer of sediments between flows, which is referred to as an interbed.

The sediment or interbed sources may be other volcanic activity, such as an ash flow or alluvial, lacustine, or eolian types of sediments. The sediment thickness depends on the location of the deposition, the time between flows, and the method of sediment deposition. The sediments may not be continuous over an entire basalt flow.

B-2.3.2 Volcanic Vents

Volcanic vents and associated volcanic features of the Snake River Plain tend to be aligned along linear features associated with volcanic rift zones. These rift zones may be associated with regional northeast to southwest extension associated with the basin and range geologic province. Located to the west of the INEEL is the Arco Volcanic Rift Zone, and to the east is the Hell's Half Acre Rift Zone. Both of these features trend southeast to northwest. An additional zone of volcanic vents and rhyolitic domes is located to the south of the INEEL. This zone, known as the Axial Volcanic Zone, is located approximately on the axis of the hot spot track and the center of the Snake River Plain.

B-2.3.3 Surficial Sediments

Kuntz et al. (1990) provides the following summary of surficial sediments deposited on the surface of the Snake River Plain:

"The surficial sediments deposited on the surface of the plain in the vicinity of the INEEL are composed of alluvial, lacustrine, and eolian deposits. During the Pleistocene times, streams originating in the mountains north of the plain carried large volumes of sediments and deposited them in the mouths of the stream valleys as huge alluvial fans. Some sediments were carried out into the basins below the mountain ranges to form broad gravel plains. In addition to the sediments deposited by the regular workings of the mountain streams, some sediments were distributed through large floods that moved across the plain. There was also a large lake that formed during the Pleistocene time that covered much of the northeast portion of the INEEL. The lake has been named Lake Terreton. Sediment was also carried out over the plain by strong winds which deposited fine grained sands and silts."

B-2.3.4 Interbedded Deposits

Interbedded sediments can often be found between basalt flows within the subsurface. These sediment deposits likely have a similar origin to the current surficial deposits. The interbed sediments may have accumulated over periods of local volcanic quiescence or during periods of increased sediment deposition.

B-2.4 INTEC Geologic Data Summary

This report is based on data collected over many years of subsurface investigations at the INTEC facility. The data sources include published reports, geologist's logs recorded during drilling and coring operations, photographs of core material, downhole video logs of boreholes and wells, and corehole geophysical records of wells and boreholes.

B-2.4.1 Existing Reports

The existing reports on the subsurface at the INTEC facility include:

1. *Report of the Idaho Chemical Processing Plant Drilling and Sampling Program at the HLLW Tank Farm and LDU CPP-33*, Golder Associates Inc., September 1991.

2. *Report for the Idaho Chemical Processing Plant Drilling and Sampling Program at Land Disposal Unit CPP-37*, Golder Associates, Inc., March 1992.

3. *Report for the Idaho Chemical Processing Plant Drilling and Sampling Program at Land Disposal Unit CPP-55*, Golder Associates, Inc., March 1992.

4. *Report of Subsurface Soil and Rock Investigation 6th Set Calcined Solids Storage Facility at INEL, Idaho Falls, Idaho*, Northern Testing Laboratories, Inc., December 1980.

5. *Report of the Geotechnical Investigation for the 7th Bin Set at the Idaho Chemical Processing Plant, INEL*, Geosciences Section, Earth and Life Sciences Branch, EG&G Idaho, Inc., August 1984.

6. *Petrography, Age, and Paleomagnetism of Basalt Lava Flows in Coreholes Well 80, NRF 89-04, NRF 89-05, and ICPP-123, Idaho National Engineering Laboratory*, USGS Open-File Report 93-327, 1993.

7. *Statigraphy of the Unsaturated Zone and Uppermost Part of the Snake River Plain Aquifer at the Idaho Chemical Processing Plant and Test Reactors Area, Idaho National Engineering Laboratory, Idaho*, USGS Water Resources Investigations Report 91-4010, January 1991.

8. *Lithology and Stratigraphy at the Idaho Chemical Processing Plant, Idaho National Engineering Laboratory*, MSE, Inc., August 1995.

9. *Core Logging and Fracture Analysis of ICPP and Other Boreholes*, Golder Associates, Inc., September 1995.

The HLLW tank farm report contains the core log reports for the CPP-33 series wells drilled around the perimeter of the HLLW tank farm from September 1990 to April 1991. These wells were cored and geophysically logged using a natural gamma tool, gamma-gamma tool, and neutron tool. A fence diagram that includes the wells was constructed for the report. The wells reach a maximum depth of 40.2 m (132 ft) bgs. The majority of the wells do not penetrate the first significant sedimentary unit found beneath the HLLW tank farm.

The report on Land Disposal Unit (LDU) Number 37 contains the core log report for well CPP-37-4. This hole was drilled as part of an investigation of an area northeast of the HLLW Tank Farm. Several shallow auger holes and a deep corehole were drilled, which reached a total depth of 39.7 m (130.3 ft).

The report on LDU Number 55 contains the core log for well CPP-55-06. This well was drilled as part of the investigation into possible paint thinner contamination of the subsurface at a location east of Bin Sets 2 and 3. The well was drilled to a depth of 37.5 m (123 ft) bgs.

The geotechnical reports for Bin Sets 6 and 7 contain core logs for the geotechnical borings done before construction of the bin sets. No geophysical logs were run for these boreholes; nor were wells constructed. The boreholes were drilled to the top of the first major sedimentary bed.

The United States Geologic Survey (USGS) report on coreholes Well-80, NRF 89-04, NRF 89-05, and ICPP-123 (USGS-123) provides a detailed description of the lithology and statigraphy penetrated by USGS-123.

The Anderson (1991) report on the stratigraphy of the unsaturated zone beneath INTEC provides a naming convention and general stratigraphic network on which the stratigraphy presented in this report is based.

The *Core Logging and Fracture Analysis of ICPP and Other Boreholes* was a detailed relogging of core from the INTEC facility once the core was removed from the Lexan tubes in which the core had been originally drilled and logged. The removal of the core and boxing in standard core boxes enabled a more thorough and detailed description of the rock and discontinuity data.

The MSE report, *Lithology and Stratigraphy at the Idaho Chemical Processing Plan*, was used extensively for this report. This report incorporates data from the additional wells drilled at the INTEC since the MSE report of August 1995.

B-2.5 Lithology of the Subsurface at the INTEC Facility

As discussed in Section B-2.3, the INTEC subsurface comprises a series of basalt flows that may be separated by sedimentary deposits. The generalized lithology of a basalt flow, starting from the base and moving vertically upward, begins with a zone of basal vesicularity and fracturing generally lacking sediment infilling. The next zone is often characterized by a fresh, minutely vesicular layer that may have some fracturing. The upper zone is generally a sediment-filled vesicular zone with sediment infilling and vesicularity increasing near the top of the flow. The top of the flow may be weathered and overlain by a sedimentary deposit or another flow. This sequence is repeated throughout the subsurface with little variation; therefore, detailed lithologic correlations between boreholes are difficult.

B-2.5.1 Methods Used to Characterize Lithology

The lithology penetrated by the wells at INTEC was determined by using geologic and geophysical data. The geologic data were obtained from drill rig geologist's records and, where available, downhole video logs and core or drill cuttings. The geophysical data were obtained from the USGS well logging program; natural gamma, neutron, density, and caliper logs are run for most of the wells at INTEC. When the geophysical data are combined with the geologic data, lithologic descriptions can be given with a good degree of confidence.

The lithologic features of particular interest are weathering, fracturing, vesicularity, color, grain or crystal size, bedding, sorting, and rock type. These features indicate position within a flow or sediment unit and may, in some cases, be correlated with similar features penetrated by other boreholes.

B-2.5.2 Geologic Methods

The geologic methods used to determine the lithologic features previously listed rely heavily on the geologist's descriptions of core and drill cuttings and on understanding how different geologic environments affect actual drilling operations.

The most reliable source of geologic data is from core. A geologist using a standardized method of rock description describes the core. Core collected at the INTEC facility during the tenure of Westinghouse Idaho Nuclear Company (WINCO) was logged to the WINCO Environmental Restoration Project Directive 1.33 "Geologic Logging," (ER PD 1.33) logging standard. The core descriptions include a complete and detailed description of weathering, structures, color, grain size, strength, and rock type, as well as core recovery, a rock quality index, and fracture density. The following summarizes the ER PD 1.33 method of describing core:

- Weathering is characterized as follows:

  a. Fresh (FR): No visible signs of rock material weathering.

    b. Slightly weathered (SW): Discoloration indicates weathering of rock material and discontinuity surfaces.

    c. Weathered (W): All the rock material is discolored by weathering and may be somewhat weaker than its fresh condition. Less than one-half of the rock material is decomposed.

- The structure descriptions apply to consolidated and unconsolidated materials. Structure descriptions include, but are not limited to, bedding, grading, sorting, foliation, lamination, flow banding, and vesicularity.

- Vesicularity is described as follows:

    a. Vesicular: 10 to 25% voids by volume.

    b. Slightly vesicular: 1 to 10% voids by volume.

    c. Minutely vesicular: Vesicles less than 1/32 in. and ordinarily less than 5% void by volume.

- Color is determined using a Geological Society of America Munsel color chart and color number.

- Grain size is recorded in millimeters or according to the Wentworth scale.

- Strength is a field estimate based on International Society for Rock Mechanics classification. Rocks are classified as weak, medium strong, and strong.

- Rock type is based on the Colorado School of Mines classification system.

- Core recovery is a record of the amount of core recovered over the interval drilled. Core loss is assigned to the most likely area of core loss; if it cannot be determined where core loss occurred, core loss is assigned to the end of the core run.

- The rock quality index is a measure of the total length of sound core over the length of the drill run. Rock quality index does not consider vertical fractures and is only used in solid materials (i.e., rock quality index is not recorded for unconsolidated sediments).

- The fracture density is a record of the number of fractures not caused by drilling per foot of core and is only applicable to solid materials. Fracture filling and fracture orientation with respect to the core axis are also recorded.

Other geologic data sources used include drill cuttings, observation of drilling, and the downhole video. Drill cuttings provide an estimate of weathering, color, vesicularity, fracture-filling materials, and rock type, all of which are recorded by the rig geologist. In addition to sample descriptions, observing the drill rig can provide information on fractures, rock strength and consolidation, and rock type (i.e., interbed sediments versus basalt). A downhole video log can provide information on fracture density and orientation. The information recorded by the drill rig geologist can be used in conjunction with a downhole video camera to provide a fair record of the lithology penetrated by the borehole.

B-2.5.2.1 Core Archive. Rock core from the various INTEC facility drilling programs is archived at the INEEL. Most of the core is available for examination or sub-sampling. Table B-2-1 lists the corehole number, the footage of core archived, and whether the core is stored at the USGS Lithologic Core Archive Library or at the INTEC Radiological Core Library.

Table B-2-1. Lithologic core available and storage location.

Well Number	Footage at Library	Archive Location
CPP 33-2	44–114.8	USGS
CPP 33-3	45–126.4	USGS
CPP 33-4	33.5–124.1	USGS
CCPP 33-4 (abandoned)	41–112.7	USGS
CPP 33-5L	35.5–131.5	USGS
CPP 37-4	34.1–106	USGS
PW-1	100–125	USGS
PW-2	110–135	USGS
PW-3	110–130	USGS
PW-4	Spot cores	USGS
PW-5	105–145	USGS
Pw-6	100–125	USGS
CPP 14-1	34.6–54.6	USGS
CPP 14-3	35.5–55.5	USGS
CPP 14-4A	38.7–55	USGS
CPP 14-8	38.5–55	USGS
CPP 14-10C	43.5–55.3	USGS
MW-14	98–102	USGS
MW-16	50–110	USGS
MW-17	96–103	USGS
USGS 121	34–746	USGS
USGS 123	35–	USGS
CH-AQ-01	40.7–738	USGS
USGS 82	10–120	USGS
CPP 33-1	48.2–114.8	INTEC
CPP 55-06	43.6–122.9	INTEC
MW-12	42–153	INTEC

B-2.5.3 Geophysical Methods

The borehole geophysical methods used to determine the lithologic features include natural-gamma logs, neutron logs, density or gamma-gamma logs, and caliper logs. The natural-gamma and neutron logs are the primary sources of geophysical data.

The term geophysical log refers to the record of the data produced during the measurement of a physical property by the geophysical sonde, which is the tool used to make the measurement.

Nuclear logging tools must be properly calibrated and standardized if quantitative results are to be obtained (Keys 1990, p. 9). The calibration must include factors such as the borehole diameter and well construction materials. To perform quantitative analysis of the porosity, the sonde must be calibrated to core from the area of interest that has undergone laboratory analysis of the porosity, or the sonde must be calibrated to the porosity of a known formation of similar geologic characteristics. The American Petroleum Institute in Houston, Texas, has established a standard scale calibration pit for the calibration of natural-gamma and neutron sondes. This provides a standard scale but does not provide calibration to a specific lithology or parameter such as porosity.

The volume of influence of a nuclear log is roughly a sphere centered at the detector for a natural-gamma sonde and between the detector and the source for sondes that contain sources, such as the gamma-gamma or neutron sondes. The volume of influence does not have definite boundaries, but it can be considered to be the volume that contributes approximately 90% of the total radiation measured (Keys 1990, p. 31). Because the radius of the volume of influence for a particular sonde may be greater than the thickness of some lithologic units, a smearing effect is observed; the anomaly may appear thicker than it is, and the radiation intensity may appear lower than the actual radiation count. A common method to determine unit thickness is to measure the thickness of the anomaly between the points of one-half the maximum amplitude of the anomaly. This provides some degree of correction for the smearing effect (Keys 1990, p. 31).

B-2.5.3.1 Natural-Gamma. The natural-gamma log is a record of the amount of natural gamma radiation emitted by the formation penetrated by the borehole. Gamma logs have been used heavily in previous correlation constructions. In addition to the natural gamma emissions of the formation, other environmental factors influence the level of natural gamma amplitude. These factors are items such as well construction materials and natural gamma-emitting contamination within the volume of influence of the natural gamma sonde. Cement grout with the addition of sand has been used extensively during drilling of many air rotary holes for hole stabilization. The sand included in the grout mixture and used to fill fracture zones has been observed to affect the natural gamma logs. The natural gamma sonde can measure the natural gamma radiation in open or cased boreholes that are either air- or liquid-filled (Keys 1990, p. 81).

Two classes of natural gamma sondes are typically used. The most common one measures the bulk gamma radiation; the second, a spectral gamma sonde, distinguishes the types of gamma radiation using the different emission energies of the sources. The common gamma-emitting isotopes are potassium-40 and the daughter products of the uranium and thorium decay series (Keys 1990, p. 79). Table B-2-2 summarizes the different emission rates and energies of potassium-40 and the uranium and thorium decay series (Keys 1990, p. 79).

Of the three naturally occurring gamma emitters listed, potassium-40 is by far the most common (potassium-40 makes up approximately 0.012% of all naturally occurring potassium); however, thorium and uranium have much higher emission rates (Keys 1990, p. 79). Natural gamma-emitting minerals are commonly found in rocks of granitic/rhyolitic compositions as aluminum silicates and phyllosilicates;

Table B-2-2. Potassium-40, uranium, and thorium decay series emission rates and energies.

Isotope	Emissions (g)	Emission Energies (MeV)
Potassium-40	3.4	1.46
Thorium series	12,000	2.62
Uranium series	26,000	1.76

potassium-bearing minerals are also found in metamorphic rocks of the chlorite facies as phyllosilictes. As the aluminum silicates and phyllosilicates weather to clays, potassium thus remains the close association of potassium to clay mineralogy. Basalts typically lack potassium except for some of the void-filling materials such as apphyllite, which is associated with zeolites and calcites.

Possible sources of rocks containing natural gamma-emitting minerals in the vicinity of the INEEL are the rhyolitic domes such as Big Southern Butte and the Island Park rhyolites and the siltstones, shales, and dolomitic limestones of the basin and range mountains surrounding the eastern Snake River Plain. Sediments derived from any of these sources and deposited on the developing Snake River Plain would cause the sediments found between the basalt flows to produce natural gamma anomalies.

Natural gamma anomalies detected in zones with no obvious sediment may be associated with zeolites or changes in the basalt mineralogy, which would include a change in the potassium content of the feldspars found in the basalt or, more likely, with gamma-emitting contamination caused by contaminated water moving through fractures in the basalt. Because natural gamma anomalies measured beneath INTEC are not always associated with interbedded sediment deposits, they must be carefully analyzed to determine the source of the anomaly. This typically requires considering other types of data to make a valid interpretation of the anomaly.

B-2.5.3.2 Neutron. A source within a neutron sonde emits neutrons. Elastic collisions occur when these emitted neutrons collide with the nuclei of substances in the formation being measured. These elastic collisions slow down the neutrons (Keys 1990, p. 94). The greatest energy loss during these collisions occurs when the neutron, and the nuclei it collides with, have approximately the same mass. Therefore, the most important element in terms of neutron energy retardation is hydrogen, because the nucleus of a hydrogen atom is approximately the same size as a neutron. Thus, the neutron log is a good indicator of hydrogen content regardless of what the hydrogen is associated with (i.e., water or hydrocarbons) and lends itself to the location of moisture. In saturated conditions, the neutron log provides a measure of porosity, and, in unsaturated conditions, the neutron log provides an indication of the moisture content of a formation (Keys 1990, p. 94).

Neutron sondes typically measure either the neutrons that have not been slowed by collisions with other nuclei or the backscatter of thermalized neutrons that result from the collisions between a neutron and nuclei. The type of sonde used by the USGS at the INEEL counts the number of uncaptured neutrons; therefore, higher moisture content is indicated by a lower value on the neutron log.

B-2.5.3.3 Gamma-Gamma. The gamma-gamma sonde measures the intensity of gamma radiation from a source in the probe after it has been backscattered and attenuated by the formation. Compton scattering is the main cause of attenuation of the gamma radiation on the formation, and the gamma radiation absorbed is proportional to the electron density of the material penetrated (Keys 1990, p. 90). Electron density is approximately equal to the bulk density of the formation. Bulk density can be determined for a formation from a properly calibrated and corrected log.

B-2.5.3.4 Caliper. The caliper log is a record of borehole diameter. The stability of the formation penetrated by the borehole is reflected in the caliper log. A borehole that penetrates solid material will show very little or no deflection on the caliper log, while boreholes that penetrate unconsolidated sediments show large deflections on the caliper log. The caliper log is ideal for locating unconsolidated sediments in basalt where the borehole is not cased. Borehole grouting masks the effects of unconsolidated zones on a caliper log. The caliper log does not distinguish between sediment and unconsolidated rock, such as a highly fractured basalt.

B-3. BOREHOLE LITHOLOGY

The lithology of individual coreholes was determined from first physically examining the core and specifically logging all fractures, weathering, interbeds, and inferred flow unit breaks. All cores from drilling projects prior to the year 2000 drilling project were physically relogged at the USGS Lithologic Core Archive Library located at the Central Facilities Area of the INEEL. Core from the Phase I drilling project was examined during drilling by the rig geologist for obvious flow unit breaks and was reexamined through the use of core photographs during this interpretation. The photos of the core from the Phase I drilling as well as photos of the core from the WWLAP well drilled at the INTEC sewage lagoons in 1995 are included as attachments.

This stratigraphic interpretation is based mostly on wells where physical core has been collected and examined. The core is stored at the USGS Lithologic Core Archive Library or at the INTEC Radiological Core Library. Table B-2-1 indicates the current physical location of core examined for this correlation.

Wells MW-1 through -11 were drilled by an air rotary system with a tri-cone bit in 1993. Lithologic details and logging of these wells were attempted through the use of the original geologist's logs, geophysical logs, and downhole video. The ability to differentiate the lithology varied greatly from one borehole to the other. Some boreholes, such as MW-4, were very clean and could easily be logged in great detail. Other boreholes had various degrees of mud coating on the borehole walls. It was common to run multiple downhole video runs as the drilling progressed. In many cases, one of the downhole videos allowed sufficient detail to differentiate individual flow units. The video log of USGS-50 below the casing at 109 m (357 ft) clearly shows specific lithologic detail. Other deeper USGS wells with open boreholes can also be easily logged for physical characteristics but were not included in this report.

Well MW-12 was cored during the 1994 drilling season. This core is located at the INTEC Radiological Core Library and has not yet been relogged in specific detail.

B-3.1 Lithology of Selected Coreholes

Coreholes USGS-121 and -123 are located at the northern and southern extremes of the INTEC facility. Detailed lithologic logs of these two wells are included to present stratigraphic controls for the INTEC cross sections. Additionally, extensive sub-sampling has been conducted on the core from USGS-123 and provides additional data for future correlations. Examination of the cores from USGS-121 and -123 reveal a very different stratigraphic sequence between the northern portion of the INTEC facility and the southern portion. The stratigraphic relationship of these two wells has become somewhat less vague with the addition of several coreholes between these first two wells.

B-3.1.1 Lithology of Corehole USGS-123

The lithology in corehole USGS-123 has been determined by carefully examining core and by using the geophysical logs to establish vertical control where core was not recovered. The core was examined to provide initial lithologic descriptions and relate the geophysical responses found in the natural gamma and neutron logs to the lithology in the corehole. The methods outlined in Section B-2.5 were used to describe the lithology. The location of corehole USGS-123 is shown in Figure B-3-1.

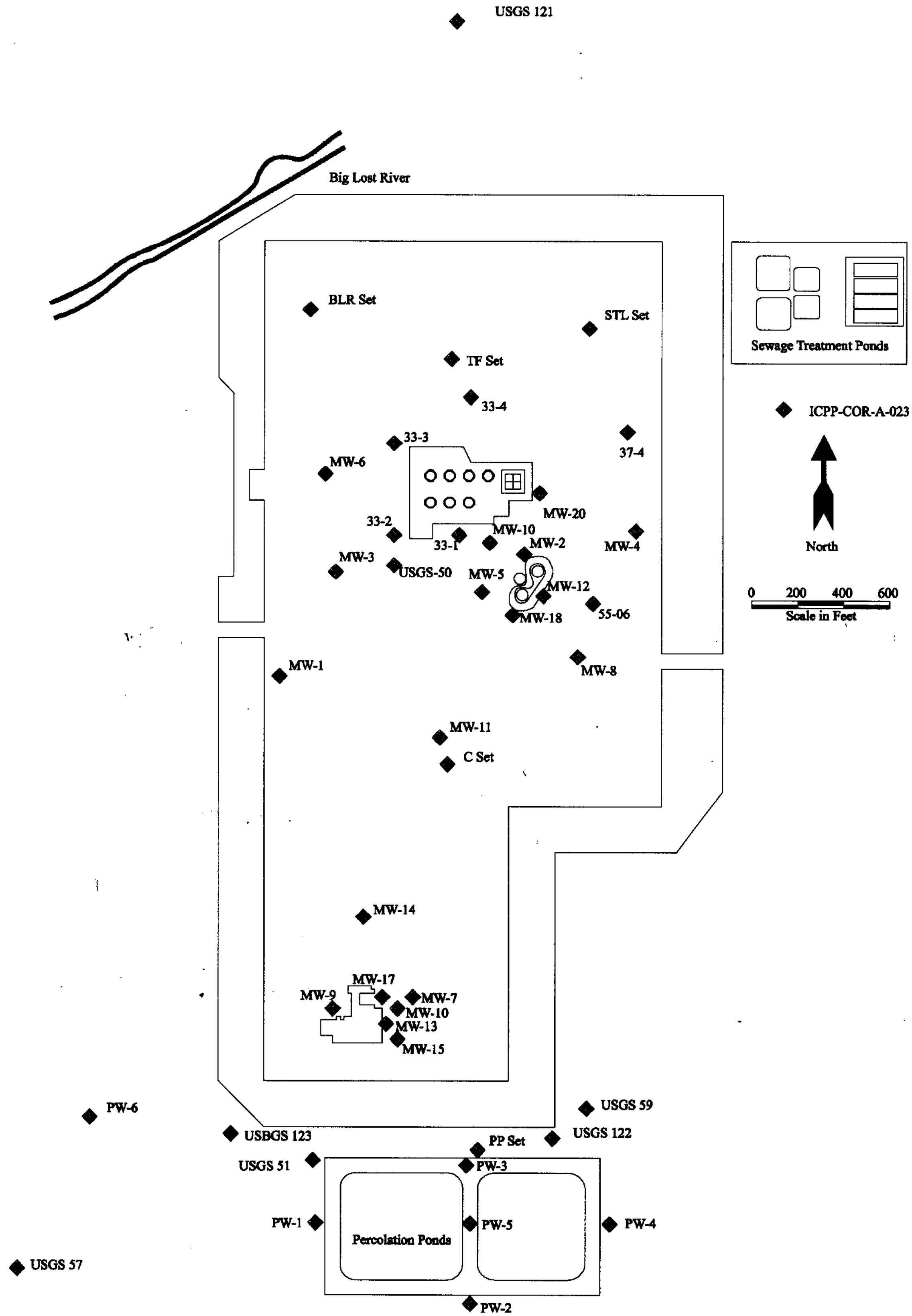

Figure B-3-1. Location of INTEC wells.

USGS-123 is located near the southwest corner of INTEC. The corehole was drilled in 1990 to a total depth of 226.8 m (744.2 ft) and was constructed as a monitoring well. The static water level in USGS-123 is approximately 142 m (465 ft) bgs. The hole was over-reamed to 11.875 in. and cased to 135 m (442 ft) bgs with an 8-in. carbon-steel casing. Stainless-steel casing was set into the well from 129.5 to 137 m (425 to 449.5 ft) bgs followed by 0.02-slot stainless screen from 137 to 145 m (449.5 to 475 ft) bgs and then stainless casing from 144.9 to 146.3 m (475.3 to 480 ft bgs). From 146.3 to 147.8 m (480 to 485 ft) bgs, a silica sand pack is set over a volclay plug, which is from 147.8 to 153 m (485 to 502 ft) bgs. The remainder of the hole, 153 to 226.8 m (502 to 744.2 ft) bgs, is filled with drill cuttings.

Marvin A. Lanphere, Duane E Champion, and Mel A. Kuntz have also examined the core for USGS-123 in great detail. Their report on the petrography, age, and paleomagnetism of the basalt in this corehole was useful in collaborating the field identification of flow unit bounds (Lanphere et al. 1993).

A generalized and also detailed lithologic column and core log is presented in Attachment B-1 for USGS-123. The detailed lithology was recorded to a depth of 460 ft bgs.

Unique lithologic sequences penetrated by USGS-123, as shown in Attachment B-1, are as follows:

1. The base of the surficial sediments arc is interpreted to be at 7 m (32) ft bgs. Because of core loss from 8.2 to 11 m (27 to 36 ft) bgs, the base of the sediments was determined from the natural gamma log and neutron log. Additionally, the geologist's log recorded during drilling states that the base of the sediments is at 7 m (32 ft) bgs.

   The natural-gamma count decreases significantly at 10.4 m (34 ft) bgs, which may be an indication of fracture and vesicle filling by sediments at the top of the flow between 7 and 10.4 m (32 and 34 ft) bgs. The neutron log shows an increase at 10 m (33 ft) bgs and then again at 10.4 m (37 ft) bgs, supporting the theory that the surface of the basalt may be fractured or have a significant number of vesicles infilled with sediments and retaining moisture. This unit is referred to as "Flow 1" in Lanphere et al. (1993).

2. Inspection of the core and original core log for the interval from 32.3 and 34.7 m (106 to 114 ft) is composed of sediments. The unit is described as a sand and silt that grades downward into a clayey silt. This unit corresponds well to an increase in the natural gamma count and a decrease in the neutron count.

   A thin basalt flow, described in the core log between 32.3 and 34.7 m (114 and 116 ft) bgs, correlates well with a decrease in the natural gamma log and an increase in the neutron log for this interval. The basalt is described as weathered, vesicular, medium gray (N5), aphanitic, medium strong basalt. This unit is referred to as "Flow 2" in Lanphere et al. (1993).

3. A zone of core loss and limited amount of recovery may indicate a thin interbed of silt from 35.4 to 35.8 m (116.3 to 117.4 ft) bgs. This may also be indicated by an increase in the natural gamma count and corresponding decrease in the neutron count for this zone.

   The basalt described in the core log between 35.8 and 47 m (117.4 and 154 ft) bgs is typically a medium gray, vesicular to minutely vesicular basalt. The unit shows typical vesicularity changes from top to bottom starting with a vesicular zone near the top, grading to slightly vesicular at 37.8 m (124 ft) bgs and to minutely vesicular at 39 m (128 ft). The natural gamma count shows an increase at approximately 42.7 m (140 ft bgs). This increase appears to be related to fractures with clay infilling at this depth. There is no increase in vesicularity or indication of disconformity to indicate a flow top at this point. This basalt is associated with a higher than normal natural gamma count for a basalt flow or unit. This higher than normal gamma count can be used to distinguish this flow in many other INTEC wells. This unit is referred to as "Flow 3" in Lanphere et al. (1993).

4. Another interbed is found in the interval from 47 to 49 m (154 to 161 ft). The unit grades from a fine sand at the top to a well sorted silt at the base.

5. The basalt described in the core log between 49 and 53.6 m (161 and 176 ft) bgs is typically a medium gray, vesicular to minutely vesicular basalt with some fracturing. This unit is referred to as "Flow 4 Unit 1" in Lanphere et al. (1993).

6. The next basalt flow unit extends from 53.6 to 62.8 m (176 to 206 ft) bgs. The unit is vesicular at the top and grades to slightly vesicular at 55.2 m (181 ft) bgs and to minutely vesicular at 57.2 m (187.5 ft) bgs. This unit is referred to as "Flow 4 Unit 2" in Lanphere et al. (1993).

7. A thin interbed is located from 62.9 to 63.6 m (206.3 to 208.8 ft) bgs. The unit is composed of a reddish orange clayey silt. This unit is associated with a significant increase in the natural gamma count and a decrease in the neutron count.

8. A thin basalt flow extends from 63.6 to 65.7 m (208.8 to 215.5 ft) bgs. This flow contains abundant 1- to 2-mm lath-shaped crystals of plagioclase. This flow is referred to as "Flow 5 Unit 1" in Lanphere et al. (1993).

9. Another thin basalt flow occurs between 65.7 and 67.2 m (215.5 and 220.4 ft) bgs. This flow is referred to as "Flow 5 Unit 2" in Lanphere et al. (1993).

10. Visual examination of the rock core indicates a basalt flow from 67.2 and 75.9 m (220.4 to 248.9 ft) bgs. Lanphere et al. (1993) separate this unit into two flow units based on a vesicle zone at 72.8 m (239 ft) exhibiting vesicles coated by oxidized glass. This is not an easily distinguished zone to be followed throughout other core logs, so this unit is listed as a single flow unit for core log correlation. This flow is referred to as "Flow 5 Unit 3 and 4" in Lanphere et al. (1993).

11. The next basalt flow begins at 75.9 m (248.9 ft) and extends in depth to 82.3 m (270 ft). The unit is slightly weathered and light brownish gray at its top, grading to fresh and light gray near its bottom. Vesiculartity also decreases with depth. This flow is referred to as "Flow 6 Unit 1" in Lanphere et al. (1993).

12. A basalt with clay infilling within the vesicles is found between 82.3 and 84.6 m (270 and 277.6 ft) bgs. This flow is referred to as "Flow 5 Unit 2" in Lanphere et al. (1993).

13. Core loss occurred in the interval between 84.7 and 86.6 m (278 and 284 ft) bgs. However, the cuttings recovered combined with the geophysical logs indicate a silt. The natural gamma count increases significantly between 69.5 and 91.4 m (228 and 300 ft) bgs, and the neutron log shows a significant decrease, suggesting the presence of a silt. The moisture associated with this interval appears to extend into the basalt below to a depth of 92.3 m (303 ft) bgs.

14. The next basalt flow is a very thick flow extending from 86.6 to 116.6 m (284 to 382.5 ft) bgs. There is a possibility of a flow break at 88.9 m (291.6 ft) bgs, where a 0.64-m (2.1-ft) long core loss occurred. The area of core loss had significant amounts of yellowish gray silty clay in fractures above and below the zone. If this represents a flow break, then the lower basalt is found from 89.5 to 116.6 m (293.7 to 382.5 ft) bgs, which is still an 27.1-m (88.8-ft) thick single flow unit. This flow is referred to as "Flow 7" in Lanphere et al. (1993).

15. The next basalt flow occurs in the interval from 116.6 to 127.9 m (382.5 to 419.5 ft). The top of the flow is very fractured and rubbly. Although no interbed or core loss was found in this area, a small natural gamma increase occurs here. Additionally, abundant sand began entering the corehole from this zone as drilling progressed. The very fractured upper portion of this unit probably contains abundant sand infilling of the fractures. During drilling of this well and also the nearby well MW-17, the drill bit became stuck at this depth and "twisted off" the drill string. This flow is referred to as "Flow 8" in Lanphere et al. (1993).

16. Core loss occurs in the zone of 127.9 to 129.1 m (419.5 to 423.5 ft) bgs. The natural gamma log shows a distinct increase in this zone, while the neutron log shows a count decrease. The small amount of material recovered indicated that this zone is likely composed of dense light brown clayey silt. While drilling below this depth, a piece of slough material was recovered between core runs. Between core runs at 135.6 m (445 ft) bgs, a 0.15-m (0.5-ft) piece of very light gray (n8) silicic tuff with obvious gall shards was required. The basalt core from above and below this piece of tuff fit exactly together, indicating that the recovered tuff is a cobble of slough from farther up the hole. As it is only normal to bring the drill string up a few tens of feet between runs, this piece of tuff probably came from this zone at 128 m (420 ft) bgs.

17. Additional basalt flows occur between 129.1 and 134 m (423.5 and 440 ft) bgs, 134 and 138.1 m (440 and 453 ft) bgs, and 138.1 and 151.2 m (453 to 496 ft) bgs.

B-3.1.2 Lithology of Corehole USGS-121

USGS-121 is located north of the INTEC facility and was drilled to a total depth of 227.3 m (745.8 ft) bgs between 1989 and 1990 as an upgradient monitoring well. The static water level in USGS-121 is approximately 138.7 m (455 ft) bgs. The hole was over-reamed to 11.875 in. and cased to 131.7 m (432 ft bgs) with an 8-in. carbon-steel casing. Stainless-steel casing was placed with a downhole casing packer from 125.8 to 152.1 m (412.6 to 449 ft) bgs with 7.9 m (26 ft) of 0.02-slot stainless-steel screen and an additional 1.5 m (5 ft) of stainless casing to a depth of 146.3 m (480 ft) bgs. From 146.3 to 147.8 m (480 to 485 ft) bgs, a silica sand pack is set over a volclay plug, which is located from 147.8 to 150.9 m (485 to 495 ft) bgs.

A generalized and also a detailed lithologic column and core log for USGS-121 are presented in Attachment B-2. The detailed lithology was recorded to a depth of 140.2 m (460 ft) bgs.

Some unique lithologic sequences penetrated by USGS-121 and shown in the attachment are as follows:

1. The base of the surficial sediments at 10.4 m (34 ft) bgs is indicated by a sharp decrease in the natural gamma count. The neutron log does not show a significant change until the basalt becomes more competent and less fractured or vesicular. This was confirmed by inspection of the core.

2. Several thin basalt flows are found in the zone between the alluvium and above 25.9 m (85 ft) bgs. Flow breaks are visible at 13.5, 17.3, 18.7 m (44.2, 56.8, and 61.4 ft) bgs.

3. A zone of core loss with some silt recovered is found at 25.9 to 26.4 m (85 to 86.8 ft) bgs.

4. Another thin basalt flow occurs between 26.4 and 28.3 m (86.8 and 92.8 ft) bgs.

5. A zone of core loss indicates a probable interbed at 28.3 to 29.3 m (92.8 to 96.2 ft) bgs. This zone also shows an increase in the natural gamma count and a decrease in the neutron count.

6. A thicker basalt flow is found from 29.3 to 34.7 m (96.2 to 114 ft) bgs.

7. Core loss from 34.7 to 35.2 m (114 to 115.6 ft) bgs with a small recovery of silt indicates an interbed in this interval. An increase in the natural gamma count supports this interpretation.

8. A basalt sequence with an unusually high natural gamma count is located between 35.2 and 39.4 m (115.6 and 129.2 ft) bgs. This was confirmed as a basalt from inspection of the core. It appears to be a single unit with a thin sediment layer above and below, as indicated by the neutron log. The basalt is hard, medium gray, slightly vesicular to massive, with a limited amount of fracturing.

9. The neutron log shows a significant decrease between 39.6 and 40.5 m (130 and 133 ft) bgs. Core loss in these zones prevented a detailed description of the materials from these intervals, but silty sediments were found on the core above and below these intervals. The interval of core loss is from 39.4 and 40.6 m (129.2 to 133.2 ft) bgs.

10. A thin basalt flow occurs between 40.6 and 42.3 m (133.2 and 138.8 ft) bgs

11. A silt is indicated by the natural gamma and neutron logs between 42.7 and 44.2 m (140 and 145 ft) bgs. Because of a significant amount of core loss in this interval, a detailed description is unavailable; however, inspection of the core from above and below this interval revealed traces of silt, supporting the interpretation of the geophysical logs. The interval of core loss is 42.3 to 44.2 m (138.8 to 145.2 ft) bgs.

12. Six separate basalt flow units are found between 44.2 and 57.3 m (145.2 and 188 ft) bgs. Flow unit breaks occur at 46.9, 51.1, 53.2, 55.8, and 57.3 m (154, 167.8, 174.5, 183, and 188 ft) bgs. Several of these units may show features that resemble pyroclastic-deposited materials.

13. A thicker basalt flow is found from 57.3 to 72.4 m (188 to 237.5 ft) bgs. The flow appears to have an AA or pyroclastic top grading to more normal basalt at 58.8 m (193 ft) bgs. The basalt is aphanitic with 1- to 2-mm-long lath-shaped crystals of plagioclase. The flow has several distinct vesicle zones and some areas that appear to represent air-cooled "skins" incorporated into the flow body.

14. Several more thin basalt flow units or zones of core loss occur between 72.4 and 77.4 m (237.5 and 254 ft) bgs. Breaks in lithology are indicated at 74.2, 75.7, and 77.4 m (243.5, 248.5, and 254 ft) bgs. This lower unit from 75.7 and 77.4 m (248.5 to 254 ft) bgs again displays distinct lath-shaped plagioclase crystals.

15. A much more massive basalt unit extends from 77.4 to 95.1 m (254 to 312 ft) bgs. This basalt flow is grayish red at its surface but grades to medium gray by 80.8 m (265 ft) bgs. The vesicularity grades to minutely vesicular by above 85.3 m (280 ft) bgs and remains minutely vesicular and massive to the base of the flow at 95.1 m (312 ft) bgs.

16. Another flow with possible pyroclastic portions or inclusions is found between 95.1 and 98.4 m (312 and 323 ft) bgs.

17. A thin interbed is found in the core and indicated on the natural gamma log in an interval from 98.4 and 99.1 m (323 to 325 ft) bgs.

18. A series of basalt flows is found in the interval between 99.1 and 119.5 m (325 and 392 ft) bgs. Possible flow breaks are located at 103.8, 106.1, 111, 111.4, and 119.5 m (340.6, 348.2, 364.2,

365.5, and 392 ft) bgs. The thin interval from 97.8 to 98.4 m (321 to 323 ft) bgs is a highly weathered vesicular basalt that is likely a pyroclastic flow.

19. A zone of core loss from 119.5 to 122.1 m (392 to 400.7 ft) bgs is possibly basalt based on the lack of an increase in the natural gamma count.

20. The interval from 122.1 to 125.3 m (400.7 to 411 ft) bgs is a series of sands, silts, and clays. The sediment descriptions were obtained by inspection of the core. The geophysical responses of the sediments are used to confirm the intervals in which the sediments exist and provide clues as to the hydrogeologic significance of the sediments.

    a. The sediments between 122.2 to 122.5 m (401 to 402 ft) bgs are described in the core log as silt with basalt gravel. The natural gamma count is beginning to increase in this interval and the neutron log shows a significant low.

    b. From 122.5 to 123.4 m (402 to 405 ft) bgs a reddish brown, massive silty clay is described. The natural gamma count has significantly increased from the interval above. The neutron log increases in this interval, indicating moisture content decrease in these sediments.

    c. From 123.4 to 124.7 m (405 to 409 ft) bgs, a significant amount of core loss occurred; however, the geophysical data suggest a sand. This suggestion is based on the low natural gamma count combined with a decrease in the neutron count, indicating that the clay mineral content of the sediments decreased and porosity increased, which is typical of a sand.

    d. From 124.7 to 125 m (409 to 410 ft) bgs a pale yellow-brown, moist silt is described in the core log. This is accompanied by a high natural gamma count and a decrease in the neutron count.

    e. Based on the described observations, it appears water is perching on the fine clay-like sediments from 122.5 to 123.4 m (402 to 405 ft) bgs. The sediments above this zone appear to contain a significant amount of water, while the sediments below appear to be relatively dry.

21. The interbed is underlain by a basalt flow from 125.2 to 127.3 m (410.8 to 417.8 ft) bgs.

22. Core loss is indicated from 127.3 to 130.4 m (417.8 to 427.9 ft) bgs. An increase in the gamma count indicates that this interval is likely an interbed.

23. A thicker basalt flow is found from 130.4 m (427.9 ft) to a depth greater than the core was logged to at 460 ft.

B-3.1.3 Lithology of Corehole ICPP-SCI-P248

The Big Lost River Well Set and corehole were drilled in the northwestern section of the INTEC facility. The well was cored from the alluvium basalt interface at 12.1 m (39.6 ft) bgs to the total depth of 121.9 m (400 ft) bgs. A generalized lithologic section and photos of the core are included as Attachment B-3.

B-3.1.4 Lithology of Corehole ICPP-SCI-P249

The Central Well Set and corehole were drilled in the central part of the INTEC facility east of CPP-666. The well was cored from the alluvium basalt interface at 18.7 m (61.3 ft) bgs to a total depth of 122.5 m (402 ft) bgs. A generalized lithologic section and photos of the core are included as Attachment B-4.

B-3.1.5 Lithology of Corehole ICPP-SCI-P250

The Percolation Pond Well Set and corehole were drilled in the south central part of the INTEC facility just north of the INTEC percolation ponds. The well was cored from the alluvium basalt interface at 7.9 m (26 ft) bgs to a total depth of 126.4 m (414.8 ft) bgs. A generalized lithologic section and photos of the core are included as Attachment B-5.

B-3.1.6 Lithology of Corehole ICPP-SCI-P251

The Sewage Lagoon Well Set and corehole were drilled in the northeastern portion of the INTEC facility. The well was cored from the alluvium basalt interface at 10.5 m (34.6 ft) bgs to a total depth of 134.4 m (441 ft) bgs. A generalized lithologic section and photos of the core are included as Attachment B-6.

B-3.1.7 Lithology of Corehole ICPP-SCI-P252

The Tank Farm Well Set and corehole were drilled in the north-central part of the INTEC facility just north of the HLLW tank farm. The well was cored from the alluvium basalt interface at 11.6 m (38 ft) bgs to a total depth of 99.1 m (325 ft) bgs. A generalized lithologic section and photos of the core are included as Attachment B-7. Due to drilling difficulties, the hole was not advanced beyond the 99.1-m (325-ft) depth. The nearby tank farm aquifer well was cored from a depth of 96 to 120.4 m (315 to 395 ft) bgs to determine the specific lithology and recover sample material for testing.

B-3.1.8 Lithology of Corehole ICPP-COR-A-023

ICPP-COR-A-023 was cored in 1995 as part of the WWLAP for the INTEC sewage lagoons. The hole was cored from the alluvium basalt contact at 12.4 m (40.7 ft) to a depth of 225.1 m (738.6 ft) bgs. Photos of the core are included as Attachment B-8.

B-3.1.9 Lithology of Shallow Perched Water Wells

A number of coreholes have been cored through the upper basalts and into the uppermost interbed. Core logs and generalized lithologic sections for these wells are included in Attachment B-9.

B-3.2 Lithology of Selected Air Rotary and Cable Tool Boreholes

Wells in addition to the coreholes were required in order to provide a stratigraphic east-to-west section at the INTEC southern boundary. In order to provide data for this section, wells USGS-036, -51, -57, -59, and -122 were selected. Lithologic determinations were made for these wells from the original geologist's and driller's logs, a set of geophysical logs, and Anderson's inferred stratigraphy (Anderson 1991).

Well USGS-50 was also selected to provide additional control on the north-to-south stratigraphic section. Lithologic determination for USGS was also based on the original geologist's and driller's logs, a set of geophysical logs, and Anderson's inferred stratigraphy (Anderson 1991). However, additional data for USGS-50 were also obtained for the upper 39.6 m (130 ft) of the subsurface from core collected during the drilling of corehole CPP 33-2 located near USGS-50. Additional information was obtained from the numerous downhole video logs that clearly show lithologic conditions below the USGS-50 casing bottom at 108.8 m (357 ft) bgs.

This set of cable tool wells and air rotary wells was selected to provide additional east-west control for the subsurface geologic interpretation along the southern edge of the INTEC facility and additional points of control for the north-south interpretation presented in this report. The east-west section near the INTEC northern boundary is based entirely upon corehole data. The detail for the air rotary and cable tool wells is not quite as thorough as the detail for the coreholes because of differences in the methods used to drill the boreholes. The locations of these rotary and cable hole tools are shown on Figure B-3-1.

B-3.2.1 Lithology of USGS-36

The inferred lithology and geophysical logs of USGS-36 are included in Attachment B-10.

B-3.2.2 Lithology of USGS-50

The inferred lithology and geophysical logs of USGS-50 are included in Attachment B-10.

B-3.2.3 Lithology of USGS-51

The inferred lithology and geophysical logs of USGS-51 are included in Attachment B-10.

B-3.2.4 Lithology of USGS-57

The inferred lithology and geophysical logs of USGS-57 are included in Attachment B-10.

B-3.2.5 Lithology of USGS-59

The inferred lithology and geophysical logs of USGS-59 are included in Attachment B-10.

B-3.2.6 Lithology of USGS-122

The inferred lithology and geophysical logs of USGS-122 are included in Attachment B-10.

B-3.2.7 Lithology of Shallow Perched Air Rotary Boreholes

The inferred lithology of the MW series of wells drilled in 1993 with an air rotary drill rig utilizing a tri-cone bit are included as Attachment B-10.

B-4. STRATIGRAPHIC CORRELATIONS

A north-south and two east-west stratigraphic correlations and cross sections have been prepared from the data available. The stratigraphic correlations and cross sections extend from the ground surface at approximately 1,493.5 m (4,900 ft) amsl to the SRPA. The top of the SRPA is located at an approximate elevation of 1,356.4 m (4,450 ft) amsl in the vicinity of INTEC. Figure B-4-1 shows the location of the stratigraphic correlation and cross-section lines and the wells used for the correlations. The north-south and the two east-west stratigraphic correlations are shown as Figures B-4-2 through B-4-4.

The wells used for the north-south cross section are ICPP-SCI-P250 (Percolation Pond Well Set); MW-17 and ICPP-SCI-P249 (Central Well Set); MW-18, USGS-50, and ICPP-SCI-MON-252 (Tank Farm Well Set); and USGS-121. USGS-121 was cored in 1990, and the ICPP-SCI-MON-249, -250, and -252 wells were drilled during the Phase I drilling. USGS-50 was drilled with a cable tool drill rig in the late 1950s. Wells MW-17 and -18 were drilled with an air rotary rig utilizing a tri-cone bit. The coreholes were used for primary stratigraphic control on the cross section.

The wells used for the southern east-west cross section are USGS-036, USGS-57, USGS-123, USGS-51, ICPP-SCI-P-224, ICPP-SCI-P-250, USGS-122, and USGS-59. USGS-123 was cored in 1989 and 1990, and ICPP-SCI-P-250 was cored in 2001. These holes were used for primary stratigraphic control on the cross sections. USGS-122 and ICPP-SCI-P-224 were drilled with an air rotary rig utilizing a downhole hammer bit in 1990 and 2001, respectively. The remaining wells were drilled using a cable tool rig in the early 1950s and 1960s.

The wells used for the northern east-west cross section are ICPP-SCI-P-248, -252, -230, and -251 and ICPP-COR-A-023. Corehole ICPP-COR-A-023 was drilled in 1995, and coreholes ICPP-SCI-P-248, -252, and -251 were cored in 2001. Well ICPP-SCI-P-230 was drilled with an air rotary rig utilizing a downhole hammer bit in 2001.

B-4.1 Stratigraphic Cross Section Correlations

B-4.1.1 South-to-North Section

The location of the north-south stratigraphic correlations between ICPP-SCI-P250 (Percolation Pond Well Set), ICPP-SCI-P249 (Central Well Set), USGS-50, ICPP-SCI-MON-252 (Tank Farm Well Set), and USGS-121 are shown on Figure B-4-2. The correlations are based on similar geophysical responses measured in the boreholes and the lithologic descriptions found in the driller's and geologist's logs or core logs. Nomenclature for flow units and sedimentary interbeds was taken from Anderson (1991) where available and applicable.

B-4.1.2 East-West (South INTEC) Stratigraphic Correlations

As with the north-south stratigraphic correlations described previously, the east-west stratigraphic correlations between boreholes USGS-036, USGS-57, USGS-123, USGS-51, ICPP-SCI-P-224, ICPP-SCI-P-250, USGS-122, and USGS-59 shown in Figure 4-3 are based on similar geophysical responses measured in the boreholes and the lithologic descriptions found in the driller's and geologist's logs or core logs. The stratigraphy shown for USGS-123 is based on the flow boundaries given in Lanphere et al. (1993) and the core log found in this appendix. Nomenclature for flow units and sedimentary interbeds was taken from Anderson (1991) where available and applicable.

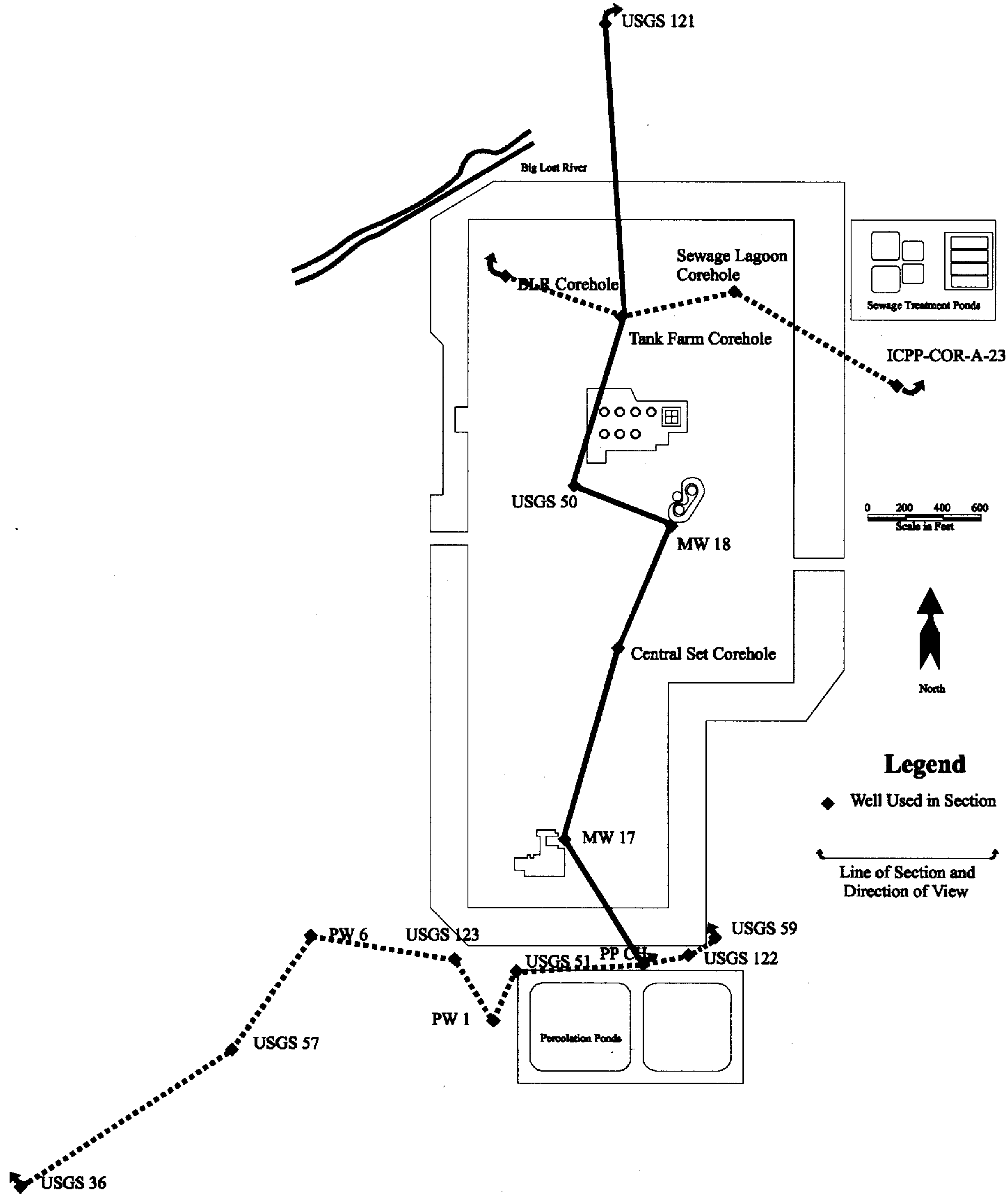

Figure B-4-1. Location of stratigraphic cross sections.

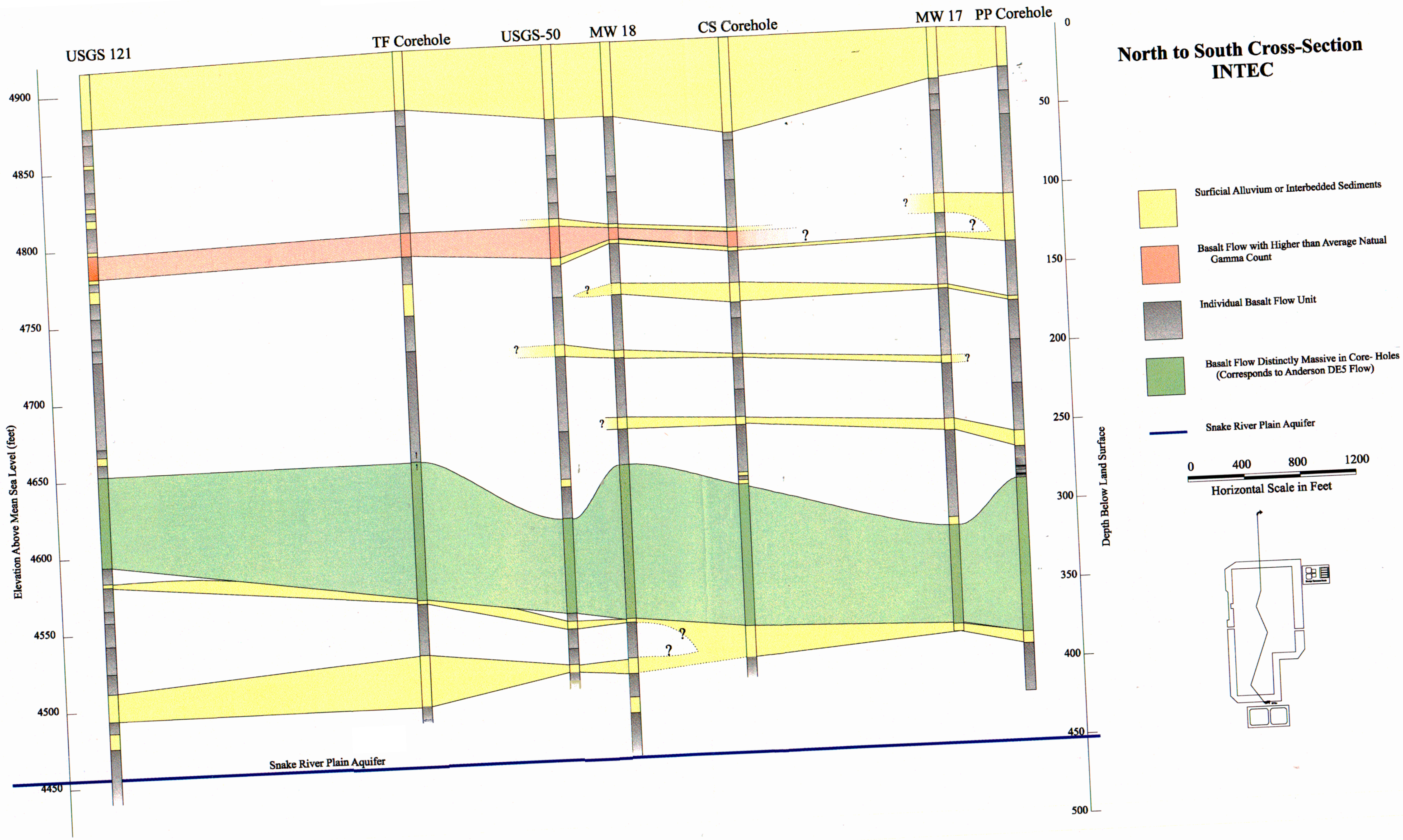

Figure B-4-2. North-to-south cross section.

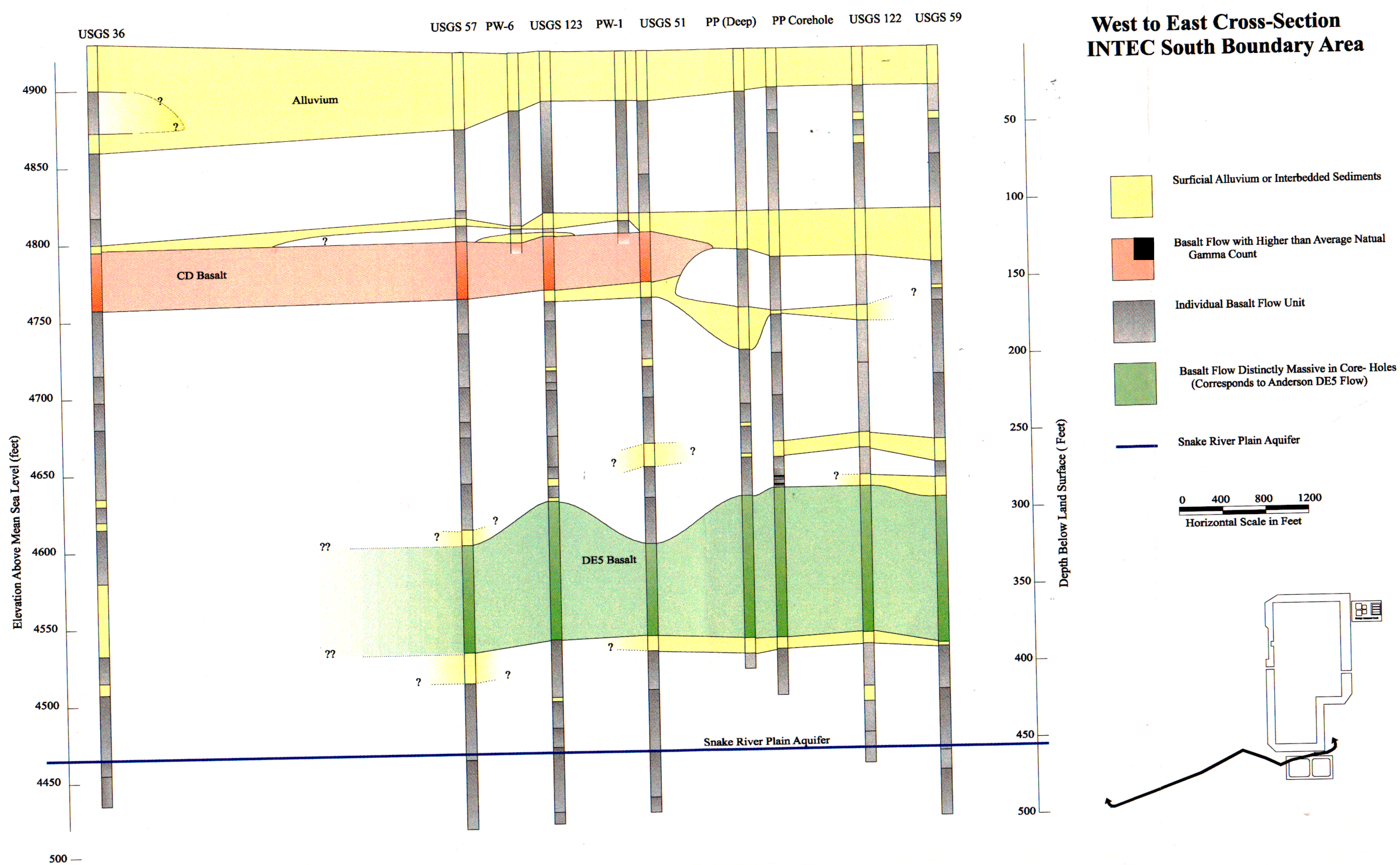

Figure B-4-3. West-to-east (south end) cross section.

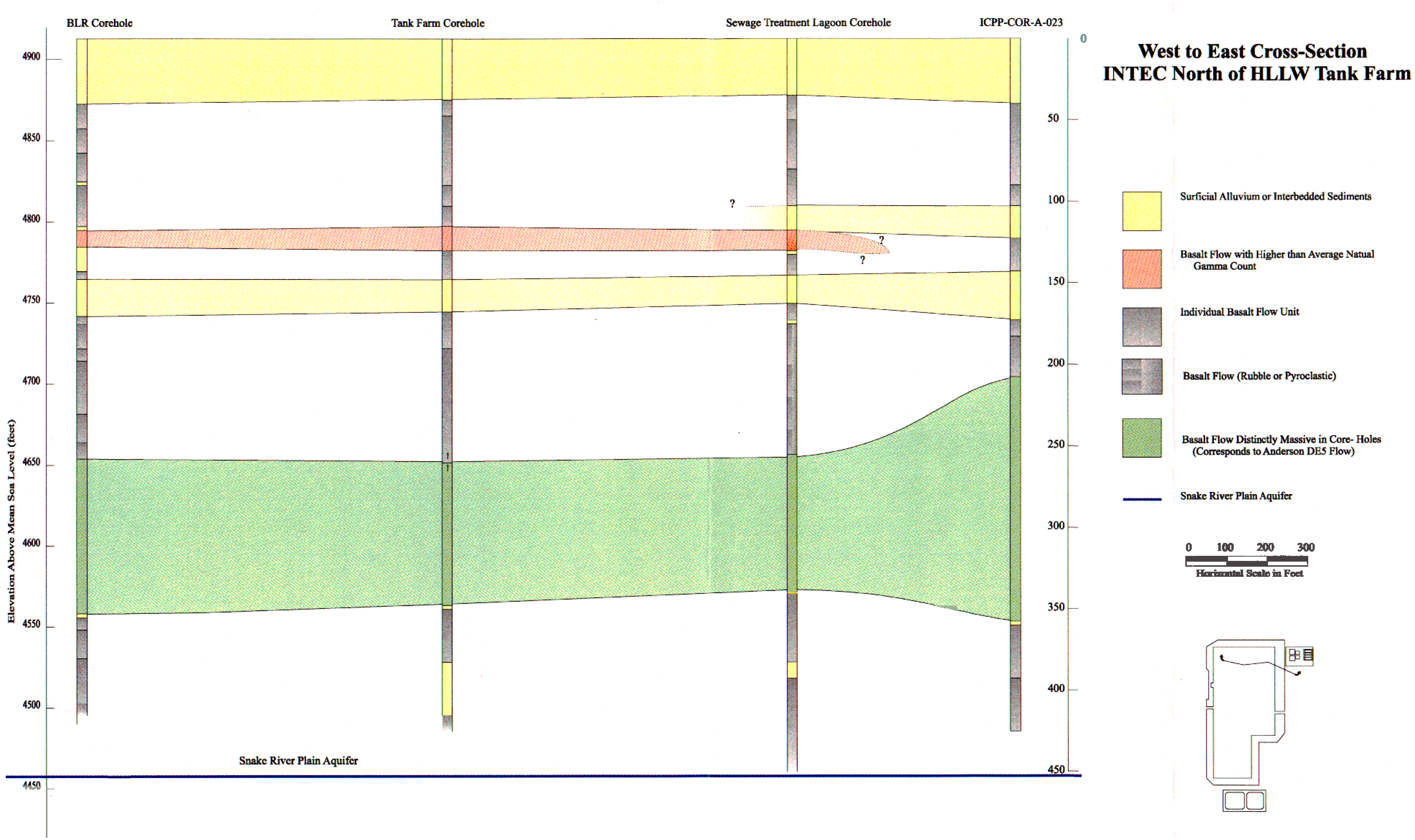

Figure B-4-4. West-to-east (north end) cross section.

B-4.1.3 East-West (North INTEC) Stratigraphic Correlations

As with the other stratigraphic correlations described previously, the east-west stratigraphic correlations between boreholes are ICPP-SCI-P-248, -252, -230, and -251 and ICPP-COR-A-023 shown on Figure B-4-4 are based on similar geophysical responses measured in the boreholes and the lithologic descriptions found in the driller's and geologist's logs or core logs. The stratigraphy shown for this section was compared and matched to the previously constructed cross sections. Nomenclature for flow units and sedimentary interbeds was taken from Anderson (1991) where available and applicable.

B-4.1.4 Shallow Perched Water Well Cross Sections

Several cross sections were constructed showing the stratigraphy that may control the development of the shallow perched water systems at the INTEC facility. Four stratigraphic cross sections were constructed for the northern perched water area. The locations of these cross sections are shown in Figure B-4-5. The cross sections are shown as Figures B-4-6 through B-4-9.

B-4.1.5 Cross Sections

The stratigraphic relations shown on the cross sections depict the typical subsurface stratigraphy beneath INTEC. The basalt flows are characterized as overlapping lobes of basalt intermixed with larger basalt flows of relatively uniform thickness beneath INTEC. The sediments found between the basalt flows are often discontinuous and characterized by sequences of sands, silt, and clays. These changes in the sediment lithology are distinguished by the geologist's records from drilling and/or by the responses of the sediments on the geophysical logs.

Many of the basalt flows, as interpreted, appear to be relatively uniform in thickness beneath the INTEC facility. Some of the smaller and thinner flows, generally found in the northern portion of the facility, are local in extent and do not appear to cover the entire area. Significant changes in the flow thickness are often related to changes in the lithology of the flow or are caused by the flow margins in which the flow appears as a lobe of basalt.

B-4.2 Significant Stratigraphic Units

Several different methods have been used to correlate the stratigraphy of the Snake River Plain. These methods include chronostratigraphy using potassium argon age-dating methods, magnetostratigraphy using paleo-magnetic data to correlate units, and lithostratigraphy in which the physical character of a rock is used to correlate between units. The stratigraphic relations presented in this report are based on lithology and stratigraphic position. Where available, chronostratigraphic methods and magnetostratigraphic methods have been used to confirm the stratigraphic interpretation.

The stratigraphy from the ground surface to the SRPA beneath INTEC has been divided into several stratigraphic units. The names given the flow units are based on the naming convention established in Anderson (1991). This convention is used to maintain uniformity with similar work at the INEEL and use Anderson's work to define the regional setting for the stratigraphy presented in this report. An attempt was made to stratigraphically associate the sediments found between the basalt flows with the basalt flows. The names of the sediment units are based on the stratigraphic association (for example, DE2 basalt and the DE2 sands). The stratigraphic units were then further subdivided based on general lithology (for example, clay, silt, sand, gravel, and basalt).

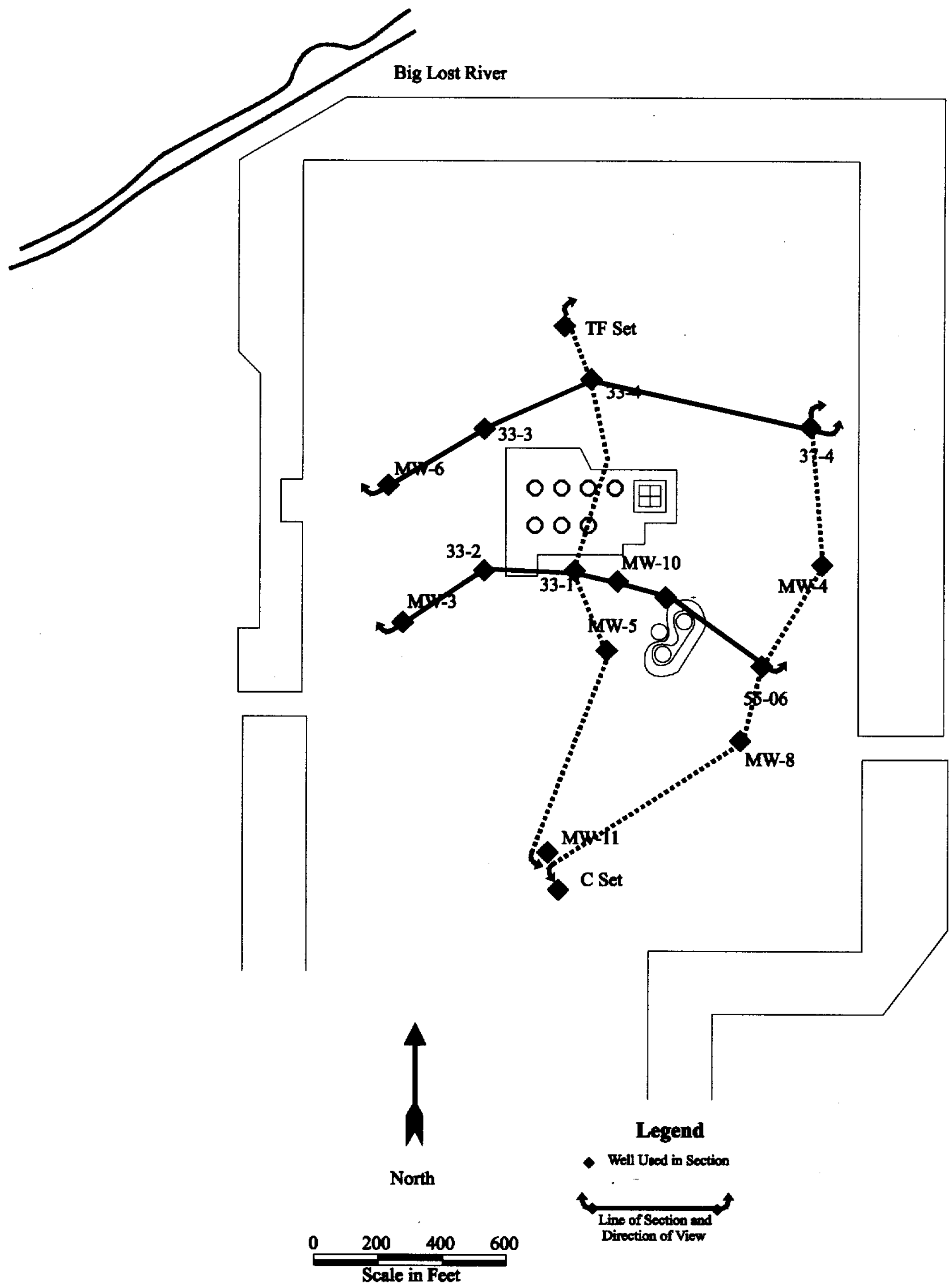

Figure B-4-5. Location of shallow well cross sections.

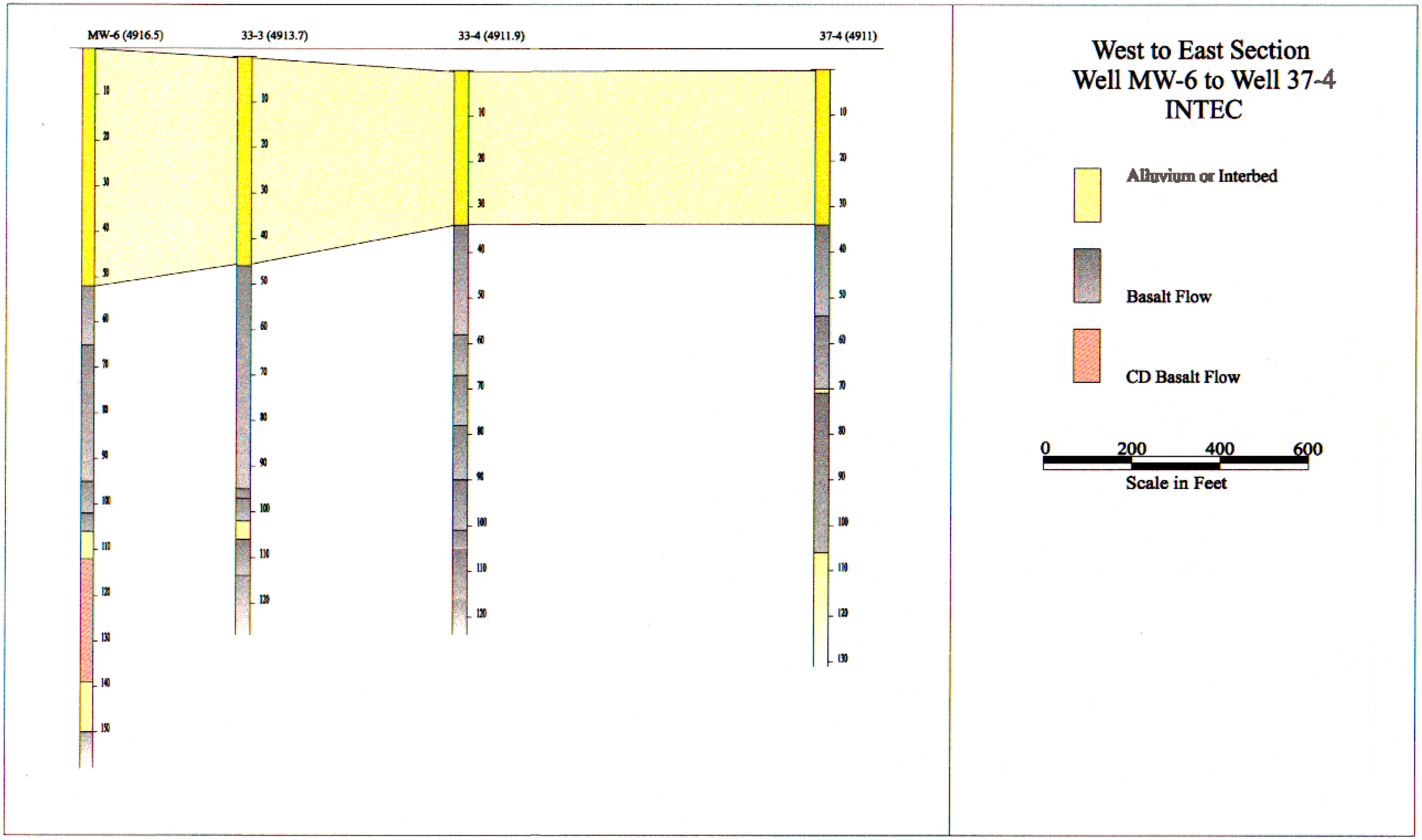

Figure B-4-6. West-to-east cross section (MW-6 to 37-4).

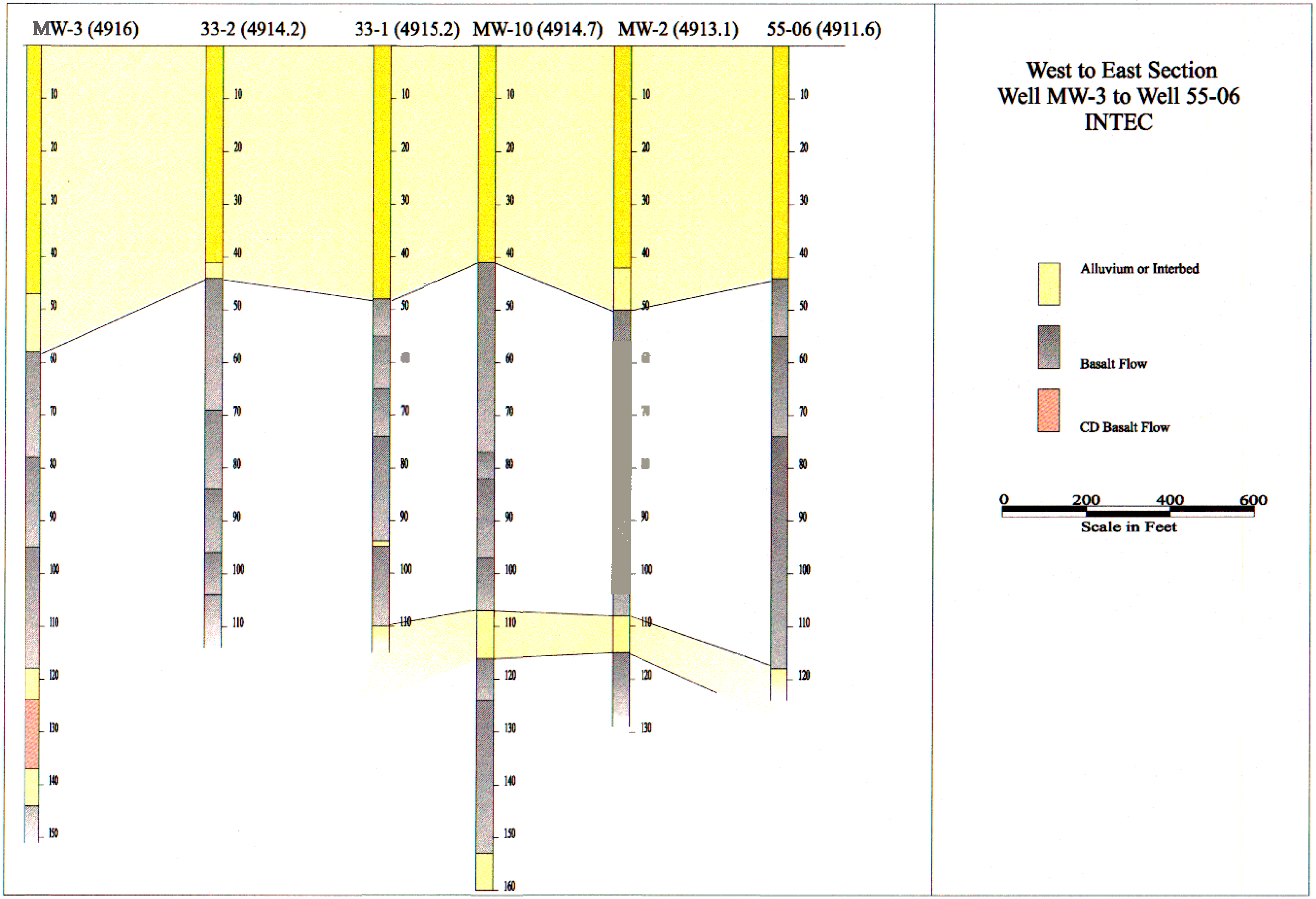

Figure B-4-7. West-to-east cross section (MW-3 to 55-06).

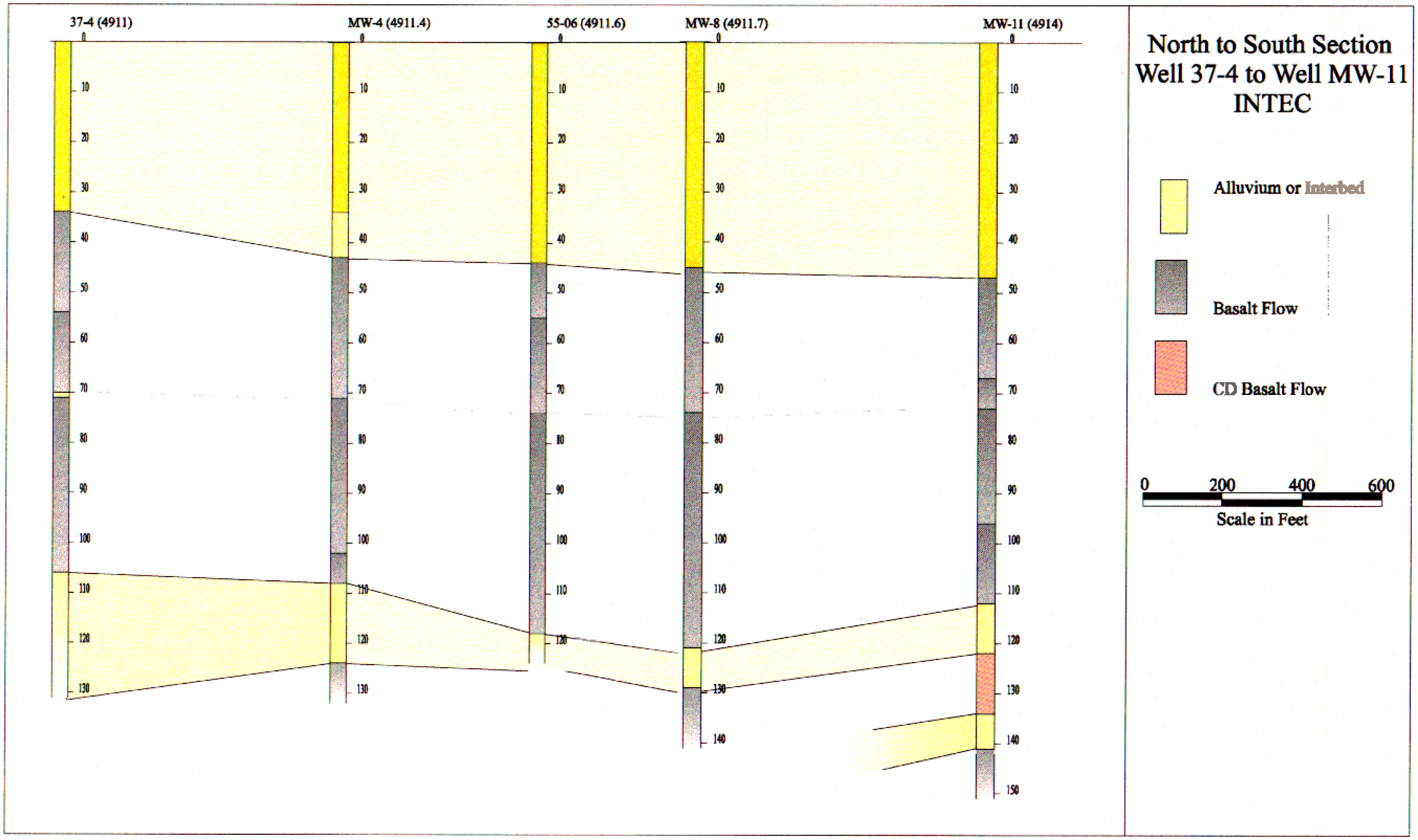

Figure B-4-8. North-to-south cross section (37-4 to MW-11).

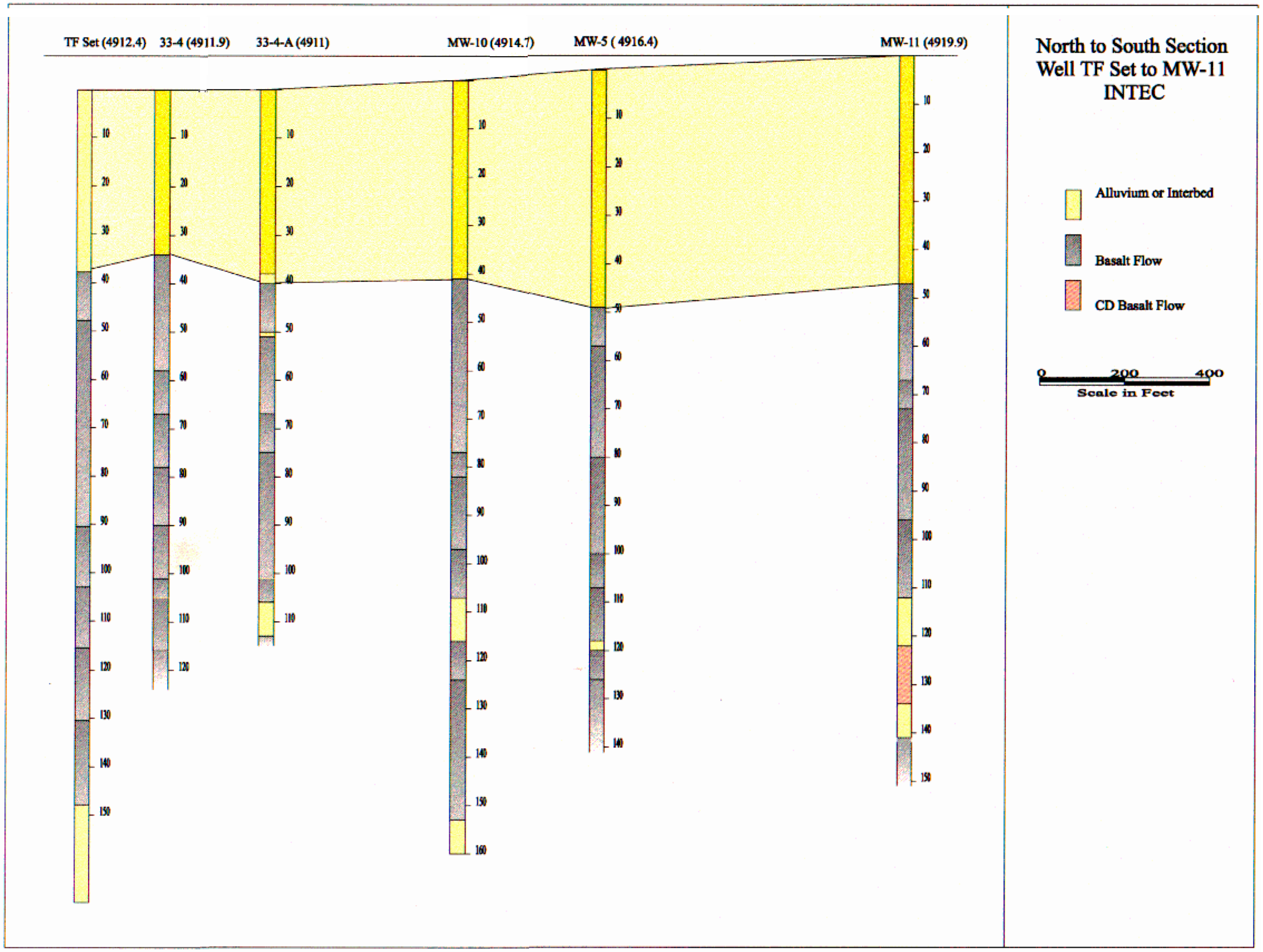

Figure B-4-9. North-to-south cross section (TF Set to MW-11).

The stratigraphic units shown in individual well lithologic constructions are not always present in all boreholes. A description of important stratigraphic horizons used as markers for the stratigraphic interpretation follows.

B-4.2.1 The Base of the Surface Sediments

The base of the surface sediments is included, because it is easily identified in all boreholes from the driller's and geologist's logs and geophysical logs. The base of the surface sediments provides an upper bound for the stratigraphic interpretation. It is defined as the contact between the uppermost basalt flow and the overlying sediments.

B-4.2.2 BC Basalts

The number of flow units located between the alluvium basalt contact and the upper interbed is significantly different from the northern portion of INTEC to the southern portion. USGS-123 has a single flow unit between the depths of 9.7 and 32 m (32 and 105 ft) bgs. USGS-121 has six flow units over the same interval. The number of individual flows in the upper 30.5 m (100 ft) of the subsurface decreases from north to south, as the individual well lithologic columns included as Attachments B-1 through B-10 show. Corehole ICPP-COR-A-023 is similar in flow stratigraphy to USGS-123, with a single basalt flow in this zone. These thinner, more numerous flows that likely were implaced from the north may impact the occurrence and movement of the upper perched water.

B-4.2.3 CD Flow

The CD basalt is characterized by a high natural gamma count in the upper portion 33.5 to 45.7 m (110 to 150 ft) bgs of the subsurface. The CD basalt flow is typically absent from the east and southeast extremes of INTEC. But where this flow is present, it is easily distinguished by an unusually high natural gamma signature (for a basalt) and provides a marker horizon in the upper regions of the stratigraphic column. This basalt flow appears to be important in relation to the perched water in the top 45.7 m (150 ft) of the stratigraphic column and may potentially affect the movement of groundwater within the vadose zone. An examination of the natural gamma logs of any of the wells occurring to the west of the present and absent boundary line shown in Figure B-4-10 will reveal the distinct signature of this unit. The geophysical logs are provided in Attachments B-1 through B-10.

B-4.2.4 DE3 Sands and Silts

The DE3 sands and silts are defined as the sand and silt unit that typically occurs below the D basalt. A clay layer that is often described above the DE3 sands and silts is defined as the DE2 clay. The DE3 sands and silts are among the thickest sediments found in the INTEC subsurface. This unit is more prevalent in the northern portion of the INTEC facility.

B-4.2.5 DE5 Basalts

The DE5 basalt is among the thickest and most massive basalt flows found in the INTEC subsurface, with a typical thickness of nearly 30.5 m (100 ft). The base of the unit appears to be relatively flat-lying, while the upper surface of the unit has a south-to-southwest slope. The unit is distinguishable in coreholes by its massive structure and in geophysical logs by its generally low moisture neutron signature. The unit is greatest in thickness near the INTEC sewage lagoons. The base of the DE5 basalts overlies a series of thin basalt flows and sediments that make up the DE6 and DE7 stratigraphic units. These sediments are the last significant set of sediments in the stratigraphic column above the top of the SRPA.

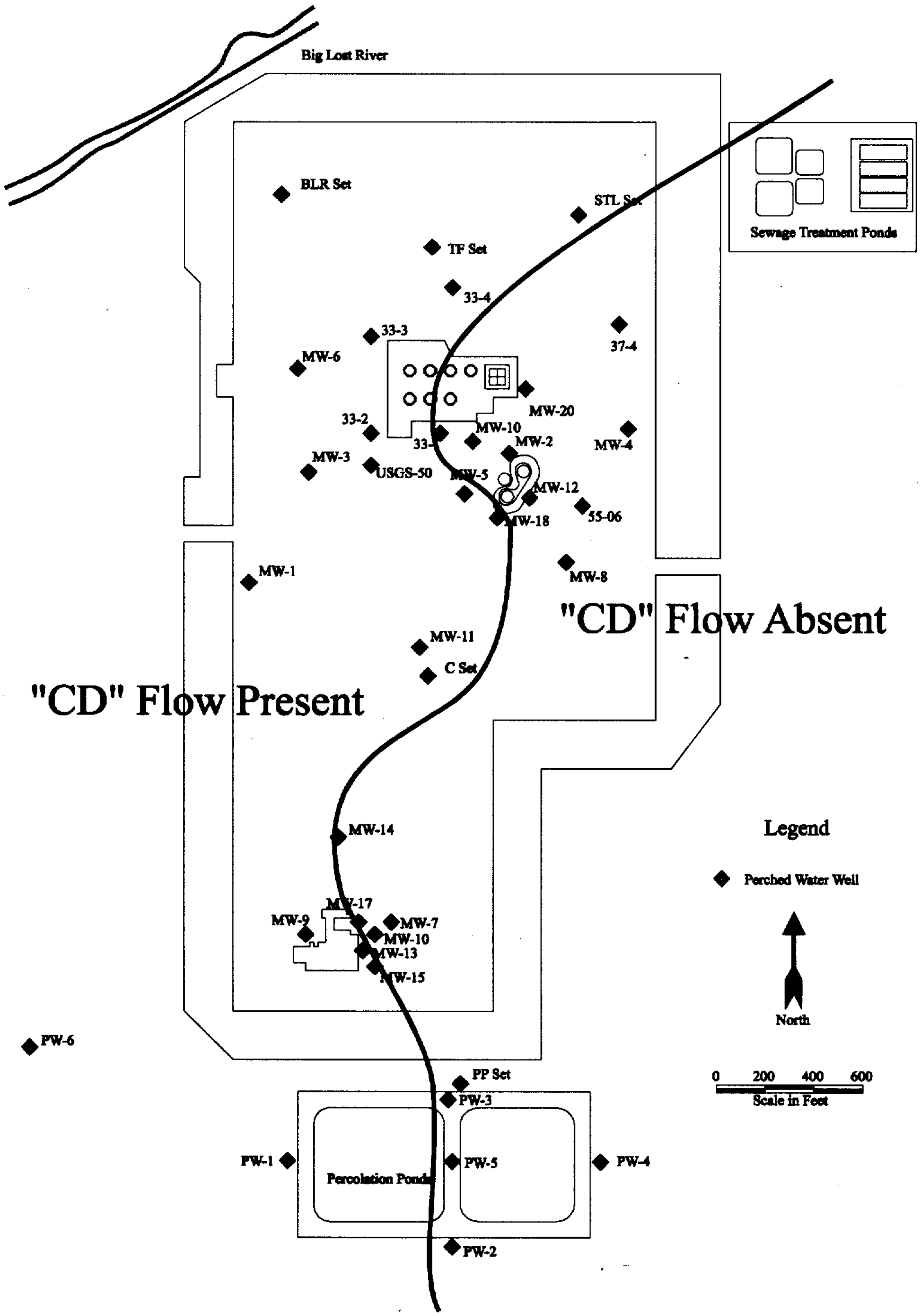

Figure B-4-10. Occurrence of the CD basalt flow.

B-4.3 Departures from Anderson

Differences in lithologic constructions occurred in some units in some wells from the lithology established by Anderson (1991). It should be noted that Anderson's lithology is based on natural gamma logs of wells from the entire INEEL. The Anderson stratigraphy was developed to provide reference for sitewide occurrence of flow groups and may not be absolutely accurate when it comes to the smaller detail required to model water and contaminant flow on a more local scale. This stratigraphic reconstruction is only intended to provide the local detail necessary to model flow beneath the INTEC facility in the vadose zone and is not intended to reflect nomenclature over a larger or sitewide area. Figures B-4-11 and 4-B-12 illustrate the differences in the footage of flow breaks used in this reconstruction compared to the sitewide flow group stratigraphy of Anderson. In most cases, examination of the actual core enabled larger basalt flow groups to be divided into individual flow units. In some cases, however, examination of the core revealed no flow break where the Anderson data indicated one.

The specific details of departures from Anderson stratigraphy can be found in the attachments included with details of each of the wells. Listed below are the significant departures from the Anderson data.

B-4.3.1 CD Basalt Flow

A basalt flow with a distinctly above-normal natural gamma signature was found in most boreholes at the INTEC facility. This flow was found in nearly all boreholes (including USGS wells not included in cross sections) at a depth ranging from approximately 33.5 to 39.6 m (110 to 130 ft) bgs. Anderson's nomenclature variously describes this marker bed basalt as several different units. Most commonly, he refers to this flow as either the C or D flow. Because of this reference, it will be referred to as the CD flow in this reconstruction. Several natural gamma logs are included in the attachments, which clearly show this unit. This unit is also readily apparent in both USGS-121 and -123 natural gamma logs. The real extent of this flow is illustrated in Figure B-4-10.

B-4.3.2 DE5 Basalt Flow

A basalt flow of unusual thickness is apparent in the core for several of the coreholes at a typical depth of 76.2 m (250 ft) to approximately 115.8 m (380 ft). This unit often overlays the lower vadose zone interbed at approximately 116 to 119 m (380 to 390 ft). Anderson attempts to split this unit into separate flows in several of the wells. However, examination of the core from these wells often indicates that not even fractures are present in the core at the specified depths. Lanphere et al. (1993) also list this unit as a single flow unit (Flow 7) in USGS-123. This unit is especially thick in corehole ICPP-COR-A-023.

Well USGS-123 with Anderson Units

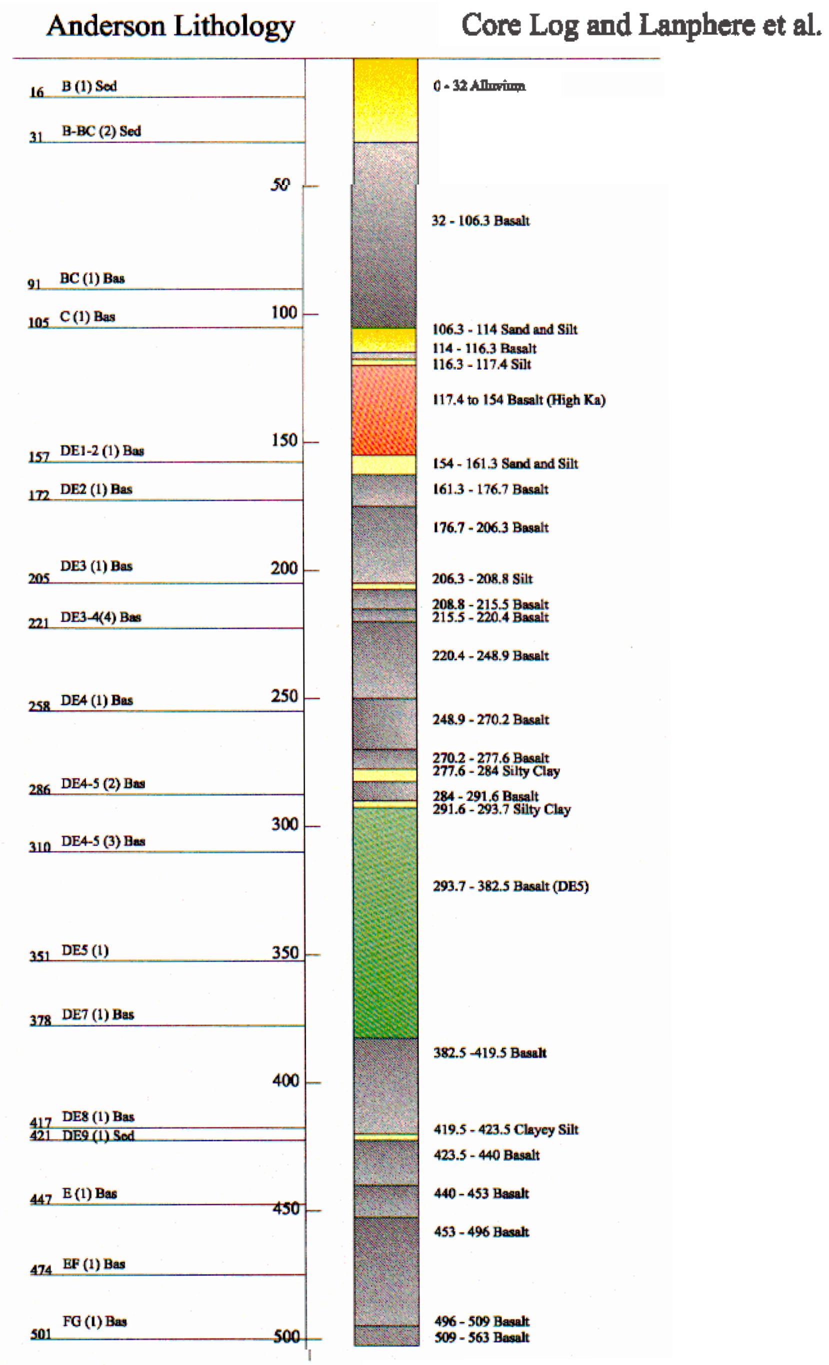

Figure B-4-11. USGS-123 core lithology and Anderson nomenclature.

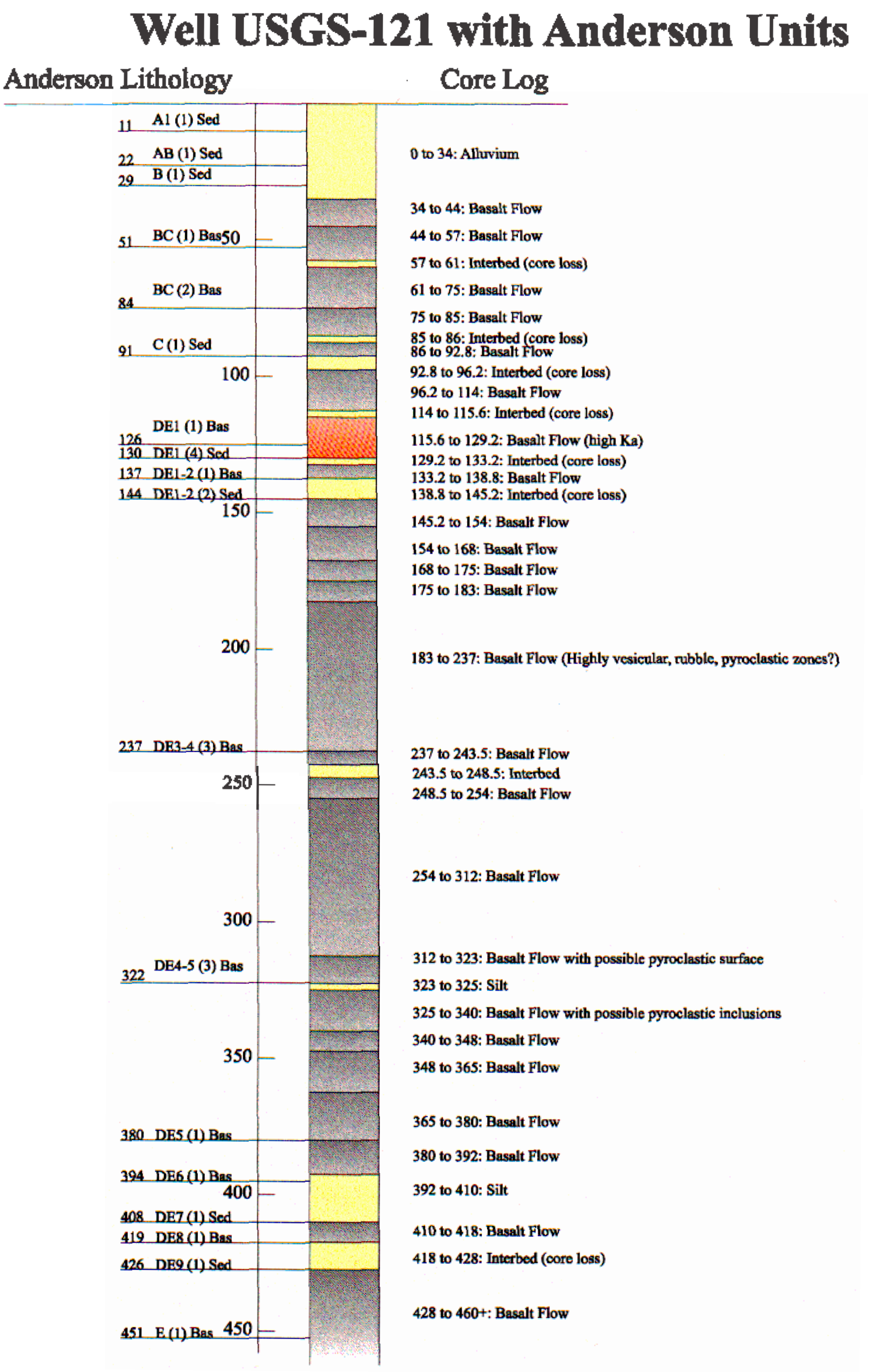

Figure B-4-12. USGS-121 core lithology and Anderson nomenclature.

B-4.3.3 USGS-123

A representation of differences between physical logging of the rock core from USGS-123 and the lithologic intervals from Anderson is shown in Figure B-4-11. The physical logging of the core closely approximates the divisions identified by Lanphere et al. (1993) based on petrography, age, and paleomagnetism within the corehole. Anderson's lithology follows quite closely with a few notable exceptions.

Anderson misses both of the upper interbeds and, in this case, identifies the high gamma signature basalt flow as DE1-2 (1) Basalt. In other wells, he identifies this high gamma signature flow as Flow DE-1 (1), Flow C, or Flow D.

Anderson also splits the basalt flow located from 89.5 to 116.6 m (293.7 to 382.5 ft) bgs into three separate units. He places flow unit breaks at 94.5 and 107 m (310 and 351 ft) bgs within this unit. Lanphere et al. believe this unit to be a single flow. Examination of the core at 94.5 and 107 m (310 and 351 ft) bgs reveals no flow break within the core. The core at these locations is very slightly to minutely vesicular and unfractured. Therefore, this unit will be represented as a single flow in this reconstruction.

B-4.3.4 USGS-121

USGS-121 is lithologically quite different from USGS-123. The core from this well reveals numerous small flows that in many cases appear to be more vent proximal than flows within USGS-123. Examination of the core reveals additional flow breaks not indicated within the Anderson framework. Major differences with the Anderson stratigraphy again center around the high natural gamma basalt flow and the deeper massive DE5 flow. The high natural gamma flow is found from 35.2 to 39.4 m (115.6 to 129.2 ft) bgs in this corehole and for the purposes of this reconstruction will again be referred to as the CD basalt flow.

Anderson indicates that the depth of the DE5 flow within USGS-121 is at a depth of 98.1 to 115.8 m (322 to 380 ft) bgs. Examination of the core from this zone indicates that this interval is composed of numerous distinct flow units. This interval does not appear to have the same characteristics as the nearly 30.5-m (100-ft) thick flow located in well USGS-123 that is referred to as the DE5 flow. However, very dense and massive basalt does occur within USGS-121 just above this interval. The basalt flow found from 77.4 to 95.1 m (254 to 312 ft) bgs is very similar to the "Flow 7" of Lanphere et al. (1993) in USGS-123. Additionally, new coreholes drilled between these wells over the past year indicate that the contacts of the upper and lower portions of this flow trend directly to the upper and lower contacts of the flow in USGS-123. Therefore, for the purposes of this reconstruction, the massive basalt found between 77.4 to 95.1 m (254 and 312 ft) bgs will be considered to be the DE5 unit.

B-5. DISCUSSION AND CONCLUSIONS

B-5.1 Correlation Limitations

After extensive review of the available geologic data for the INTEC subsurface, the following points should be considered:

1. A detailed and accurate stratigraphic correlation of the basalt flows beneath INTEC may not be feasible given the data available. Collection of sufficient data to enable this accurate correlation would probably be cost-prohibitive. However, a well-by-well mapping of the gross lithology may be possible and would provide some insight into the overall stratigraphy and characteristics of the vadose zone and upper aquifer. A detailed search of archived data, such as video logs, geologist's logs, other investigations conducted on INTEC core, and geophysical logs, may provide additional data at a lower cost than additional drilling.

2. Sediment type can be determined from the existing geologic data within the boreholes and can be correlated between boreholes with some degree of confidence. The major sediment types found within the borehole are gravels, sands, silts, and clays. The dominant sediment types are silt and sand. Clay and gravel appear to be relatively rare but do occur.

B-5.2 Generalized Geologic Framework

Even though it may be impossible to correlate all individual flows between coreholes, some general trends can be recognized within the data.

Coreholes located in the northern portion of the INTEC facility contain a significantly higher number of basalt flows than coreholes located in the southern portion or to the east of the facility. Many of these thinner flows appear to have pyroclastic materials incorporated into the flow body and may represent a more vent proximal flow regime. Distinctly rubbly units are present at depths of approximately 45.7 to 85.3 m (150 to 280 ft) in the northern portion of the facility. These deposits have resulted in considerable drilling difficulty in the coreholes of the Tank Farm and Sewage Treatment Lagoon well sets. These smaller units tend to dip gently to the south and may abut thicker flows to the south.

Corehole ICPP-COR-A-023, located slightly to the southwest of the INTEC sewage lagoons, has exceptionally thick basalt flow groups. These units also have contacts slightly higher than contacts between flows found in other wells. This may indicate a source vent somewhere in the vicinity of this corehole. It could also mean that this corehole is located at just the perfect distance from a source vent so as to not receive the small minor flows but then receives large surges of magma from large flows that "pool" against the already emplaced minor flows.

Figures B-4-2 through B-4-9 present cross sections based on the data recovered from coreholes at the INTEC facility and reflect the trends listed above.

B-6. RECOMMENDATIONS

If a more detailed construction of the subsurface at the INTEC facility is required, several different approaches may be attempted or needed:

1. Additional data could be collected during future drilling operations. For accurate stratigraphic control, it would be greatly beneficial to include coreholes in future drilling projects.

2. A great amount of data could be recovered from currently existing cores, reports, video logs, and chemical analysis. Before any attempt is made to core new wells, it may be well advised and more cost effective to make a concerted effort to gather this data.

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