Nye County Early Warning Drilling Program
Phase V Drilling Report

NWRPO-2009-02

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DISCLAIMER

EXECUTIVE SUMMARY

Introduction

This report describes the methods and results of Phase V of the Nye County Early Warning Drilling Program (EWDP), performed as part of the Nye County Nuclear Waste Repository Project Office (NWRPO) Independent Scientific Investigations Program (ISIP). The ISIP was funded by a cooperative agreement with the U.S. Department of Energy (DOE) to support the evaluation of a high-level nuclear waste repository at Yucca Mountain, Nevada. Goals of the EWDP include a better definition of the potential risks of repository activities on Nye County drinking water supplies and the design of a groundwater monitoring network along potential flow paths between Yucca Mountain and populated areas of southern Nye County. A better understanding of the hydrogeologic flow system in this region is a necessary first step in achieving these goals and has been the primary focus of the EWDP to date.

Phase V activities were conducted from November 2004 through April 2006 and involved constructing 6 boreholes, 5 of which were completed as piezometers to:

- Help fill data gaps in hydrogeology along the southeastern edge of Crater Flat and in the area south of Highway 95 within the Fortymile Wash drainage.
- Support on-going groundwater tracer testing in both alluvium and fractured tuff in Fortymile Wash north of Highway 95.

The 6th borehole was abandoned due to drilling equipment failure at a relatively shallow depth of approximately 153 ft below ground surface (bgs). The 5 completed boreholes ranged in total depth from 657 to 1,569 ft bgs. Phase V activities included borehole drilling, drill cuttings and core collection, geologic logging and laboratory testing of selected samples, borehole geophysical logging, completion of single-screen and multiple string (i.e., nested) piezometers, water chemistry and water level monitoring, and limited aquifer testing. Water chemistry and water level monitoring will not be described in this present report, but will be addressed in future Nye County technical reports.

All EWDP borehole names have a formal "NC-EWDP-" prefix; in this report the names will be given by number only. Three of the Phase V piezometers were constructed in locations where boreholes had not previously been drilled; 13P was located along the southeastern edge of Crater Flat, 33P south of the Lathrop Wells cinder cone area and Highway 95, and 32P south of Highway 95 near the center of the braided channel of lower Fortymile Wash. Borehole 33P was drilled by DOE, and cleaned out and completed with piezometers by the NWRPO.

The two remaining Phase V piezometers were constructed to support groundwater tracer testing programs at locations already containing piezometers and wells. Both of these were located in Fortymile Wash approximately 3.5 miles north of Highway 95; 22PC was designed to support a Nye County tracer testing program in alluvium near the present day main channel of Fortymile Wash, and 24PB was located near the western boundary of Fortymile Wash to support a DOE Office of Science and Technology International (OSTI) tracer testing program in fractured tuff.

Drilling and Coring

The drilling methods employed in Phase V included: air-rotary reverse-circulation (AR-RC) drilling, dual-rotary casing-advance (DR-CA) drilling, and sonic coring. A variation of DR-CA method using a rotary under reaming bit system (Atlas Copco Symmetrix™) was also used. Drilling methods for each hole varied but generally included a combination of methods. For example, AR-RC methods were used to sample and advance boreholes 13P, 24PB, and 32P; and DR-CA methods were used to drill or ream (enlarge) and case primarily unsaturated alluvium sections of boreholes 22PC, 24PA, 24PB, and 32P. Sonic coring methods were used to collect nearly continuous core from the upper approximately 290 ft of the alluvial aquifer in 22PC.

AR-RC methods have been shown in previous EWDP Phases (NWRPO, 2003 and NWRPO, 2005) to yield drill cuttings samples from unsaturated alluvium with reasonably representative coarse (sand plus gravel) and fine (silt plus clay) fractions. Sonic core samples exhibit particle size distributions that are representative of both unsaturated and saturated alluvium (NWRPO, 2005). Sonic core from Phase V 22PC was suitable for logging (e.g., geologic, digital photographic, and video logs), laboratory testing of parameters independent of porosity, and produced coring-related data to permit calculation of in situ dry bulk density and porosity values.

DR-CA methods were used for the first time in the EWDP Phase V drilling program. Evidence is presented in this study that gravel and sand fractions in DR-CA samples from the unsaturated alluvium in 22PC are also reasonably representative of in situ conditions. Moreover, if the loss of fines as dust from unsaturated DR-CA drill cuttings samples in 22PC could have been reduced, the fines size fraction in the DR-CA drill cuttings would also likely have been in reasonable agreement with the fines in the formation alluvium.

Geologic Logging

Geologic logs indicate that alluvium penetrated during Phase V was composed solely of volcanic rocks, the only exception being in 32P where trace amounts of sandstone, limestone, and quartzite were observed in separate samples of fluvial deposits from 505 to 535 ft bgs and a white limestone layer was identified in the 750 to 755 ft bgs interval. Non-alluvium was composed primarily of volcanic rocks or sediment derived from these rocks.

The observed water contents of unsaturated alluvium drill cuttings from the vast majority of 2.5 ft sample intervals in Phase V boreholes were significantly decreased by the drilling process; that is, they were observed to be dry. The small numbers of wet or moist samples were generally artifacts of: drilling fluids used to condition borehole walls, cement grouting of surface casing, and/or lost drilling fluid circulation from previously drilled nearby boreholes.

Cementation was not observed in drill cuttings of unsaturated alluvium in Phase V boreholes. However, older and deeper saturated fluvial sediments exhibited strong cementation from 500 to 540 ft bgs in 32P. In addition, several weakly cemented thin intervals were observed in this borehole between 700 and 900 ft bgs in the same fluvial sediments.

HCl reaction for different sample intervals ranged from none to strong in Phase V boreholes. Since alluvium penetrated in Phase V boreholes does not contain carbonate rocks, HCl reaction indicates the presence of calcite, a potential cementing agent. However, because of the lack of visual evidence of cementation in alluvium, it is likely that calcite does not play a significant role in cementation. A similar conclusion regarding calcite as a cementing agent was reached in Phase IV boreholes (NWRPO, 2005).

Drilling penetration rates varied from less than 0.5 to greater than 3 feet per minute (fpm). Typically, the highest drilling rates (i.e., 1 fpm or greater) were recorded in alluvium, clastic sedimentary rocks (e.g., siltstone or claystone), volcaniclastic sedimentary rocks, and nonwelded intervals in volcanic tuffs. The lowest drilling rates (i.e., less than approximately 0.5 fpm) were recorded in the welded portions of most tuff units. Similar relations between drilling rate and rock type were observed in Phase IV boreholes (NWRPO, 2005).

Generally, water production increased with depth, especially in zones of sandstone, and moderately or densely welded tuff that are presumably highly fractured. In contrast, nonwelded tuffs and claystone generally appeared to slow water production.

The range in Munsell colors of sonic core from the upper approximately 290 ft of saturated alluvium suggests oxidizing conditions exist throughout upper portion of the saturated zone.

Laboratory Test Results on Sonic Core

In general, core samples are considered to exhibit flow- and transport-related properties more representative of in situ conditions than those of drill cuttings. However, sonic coring is much more expensive and has significant depth limitations compared to AR-RC and DR-CA methods. As a result, sonic coring in Phase V was limited to the upper alluvial aquifer in 22PC.

Bulk Density and Porosity

Average dry bulk densities for sonic core runs in 22PC ranged from 1.66 to 1.71 g/cm^3 depending on the core barrel diameter and amount of lost core. These average density values translate into average porosity values of 0.32 cm^3/cm^3 and 0.34 cm^3/cm^3 using an average laboratory determined particle density of 2.53 g/cm^3.

This range dry bulk density was significantly lower than the range (1.80 to 1.82 g/cm^3) determined for core runs in Phase IV sonic corehole 19PB (NWRPO, 2005). It is postulated that greater evaporative loss of water from core samples while processing them in the field at 19PB is likely responsible for the higher range in calculated bulk densities for core runs in this Phase IV corehole.

Particle Size Distribution (PSD) and Atterberg Limits

Summary statistics for PSD data from 22PC sonic grab core samples show that all samples are coarse-grained and, on the average, contain approximately 16 percent fines, 40 percent gravel, and 44 percent sand. The USCS group name for the average PSD composition is a silty or clayey sand with gravel.

A depth profile graph of major particle size fractions in 22PC sonic core determined by wet sieve analyses indicate that gravel varies more than the other fraction sizes with depth – as much as 40 to 50 percent by weight in adjacent depth intervals. This depth profile also shows a trend of slightly increasing percentages of fines and sand with depth and a corresponding decrease in percentages of gravel with depth.

Based on hydrometer particle size analyses, the fines fraction is composed of nearly identical proportions of clay and silt in sonic grab core samples over the entire cored interval in 22PC. There is a slight increase in fines and clay beginning at approximately 625 ft bgs and continuing to total depth at 763 ft bgs.

The Atterberg limits-based classification of the fines fraction in sonic grab core samples from 22PC shows that silt (ML) predominates over clay (CL) and silty clay (CL-ML) in the upper approximately 150 ft of the alluvial aquifer and the opposite is observed in the underlying approximately 150 ft. The predominance of clay over silt and silty clay below approximately 625 ft bgs corresponds to the slight trend in increasing clay mentioned previously based on hydrometer test data.

Little difference was observed in the average values of the major size fractions between 22PC sonic core and Phase IV 19PB sonic core. However, a slightly greater range in sand and gravel fractions was observed in 19PB than in 22PC. These relatively small differences in PSDs between coreholes suggests that the approximately 3 mile separation between 22PC and 19PB in the Fortymile Wash flow system does not appear to significantly impact the PSDs in the upper portion of the alluvial aquifer in lower Fortymile Wash.

Electrical Conductivity (EC)

Sonic core EC measurements on 1:1 soil-water extracts from the lower part of the unsaturated zone immediately above the present water table in 22PC shows only a single small spike or peak in EC that reaches 327 micromhos/cm at approximately 364 ft bgs. In contrast, Phase IV sonic corehole 19PB exhibits several large spikes or peaks of approximately 1,000 micromhos/cm and valleys (i.e., low values) between 200 and 400 micromhos/cm in the interval immediately above the water table. Numerous factors, including paleo-soils, paleo-recharge events, and variations in paleo-water tables may also play some role in the development and maintenance of these EC peaks and valleys in 19PB.

Laboratory Test Results on Drill Cuttings

Laboratory test results for alluvial drill cuttings from Phase V boreholes drilled by AR-RC and DR-CA methods include the following.

Spatial Trends in PSDs of Alluvium Drill Cuttings

- PSD profiles of unsaturated alluvium from 13P located on the eastern edge of Crater Flat are finer grained than profiles from the other Phase V boreholes in Fortymile Wash, which is consistent with a trend in fining of PSDs in Phase IV boreholes (NWRPO, 2005) west of Fortymile Wash.
- Very similar PSDs were measured for alluvium drill cuttings produced from approximately 60 to 150 ft bgs both in 24PA where the DR-CA Symmetrix™ method was used and in 24PB (located 37 ft from 24PA) where the AR-RC method was used. This suggests that the DR-CA Symmetrix™ method, like the AR-RC method, is also capable of producing unsaturated alluvium drill cuttings that are reasonably representative of formation conditions.

- Comparison of drill cuttings PSDs from unsaturated alluvium in 24PB and 24P (separated by approximately 150 ft) shows that the former is noticeably coarser grained than the latter. Higher water production rates observed in 24PB are consistent with the coarser sediments penetrated in the unsaturated portion of this borehole.
- A comparison of PSD profiles of unsaturated alluvium drill cuttings between Phase V boreholes 24PB and 32P, the latter located approximately 5 miles south (downgradient) of the former, shows that 32P is slightly finer in texture than the upgradient borehole 24PB. This is not unexpected given the relative position of the boreholes in the Fortymile Wash flow system.

Trends in Electrical Conductivity in Unsaturated Alluvium Drill Cuttings:

- Close agreement is observed in EC depth profiles of unsaturated alluvium between: 22PC and Phase III 22SA located approximately 60 ft apart, and in the upper 150 ft of 24PA and 24PB located 37 ft apart.
- A comparison of EC depth profiles for 24PB and Phase IV 24P shows significant differences even though they are separated by only approximately 150 ft. This observation is consistent with the differences in alluvial stratigraphy shown in PSD depth profiles mentioned previously.
- The relatively close agreement in EC depth profiles between 24PB and 32P, with the latter located approximately 5 miles downgradient in lower Fortymile Wash, may in part be related to similar PSD depth profiles described above.
- The magnitude of EC peaks in 13P depth profiles exceeds all peaks in other Phase V boreholes. The high values of EC in 13P are likely related to the basalt flow present from approximately 85 to 140 ft bgs and related weathering products, including clay minerals.

Comparison of Laboratory PSD Measurements on Core and Drill Cuttings with Field Logging Estimates

- Remarkably close agreement was found between field estimates and lab PSD measurements made on alluvium sonic core segments from 22PC and unsaturated alluvium drill cuttings from both 24PB and 32P.
- The excellent agreement in PSD measurements and estimates on drill cuttings samples permits using field estimates determined for every 2.5 ft sample interval to fill in data gaps between lab measurements made on every other 2.5 ft depth interval.
- These drill cuttings data show that alluvial sediments contain even more textural layers than previously observed using lab data alone. Moreover, these data are consistent with the high frequency of textural layering observed in sonic corehole 22PC and Phase IV sonic corehole 19PB (NWRPO, 2005).

Summary of Lithologic Logging Results

Borehole 13P

The alluvium from ground surface to a depth of 87 ft bgs is unremarkable and similar to other near-surface alluvium in Fortymile Wash and northern Amargosa Desert. A Pliocene basalt flow (~4.1 Ma) was penetrated from 87 to 140 ft bgs; samples were not recovered from 140 to 160 ft bgs, but are thought to be alluvium based on geophysical logs. Alluvial sediments penetrated between 160 and 260 ft bgs were primarily composed of silty sand with gravel and a layer of sandy clay from approximately 180 to 200 ft bgs. The gravel component of this alluvium includes unique clasts of weakly cemented and HCl reactive sandstone and more typical welded tuff lithologies. The sandy clay unit is similar to clay-rich horizons only encountered at depths greater than 500 ft bgs in the Fortymile Wash area at boreholes 2DB, 5S, 4PB and 23P. The nature of the clay-rich sediments suggests a playa depositional environment, probably of limited extent along a restricted drainage system prior to the eruption of the basalt flow.

Underlying the alluvium from 260 to 797 ft bgs are primarily volcaniclastic tuffaceous rocks with lacustrine-deposited tuffaceous claystone and sandstone likely deposited in a relatively lower energy environment. The water table was encountered at approximately 433 ft bgs. The interval from approximately from 797 to 1,550 ft bgs is a sequence of primarily fluvial sediments with altered tuff layers interpreted to represent preserved fault-related fan-sequences deposited in a relatively high energy environment during early post-Timber Mountain time (12.5 Ma - middle to late Miocene) during rapid extension along the Windy Wash fault. From 1,550 to 1,569 ft bgs the borehole penetrated an apparent welded tuff unit that may represent Bullfrog Tuff (member of the Crater Flat Group) or coarse clastic debris derived locally from Bullfrog Tuff (i.e. younger erosional material).

Boreholes 24PA and 24PB

Borehole 24P, drilled in 2003 (NWRPO, 2003) as part of EWDP Phase IV, indicated that the saturated zone stratigraphy at this drill site is similar to that at Yucca Mountain and the “C-wells” complex. The Phase V boreholes 24PA and 24PB were drilled to conduct geophysical investigations to measure in situ groundwater velocities and to support possible future natural gradient tracer testing.

Borehole 24PA was terminated at approximately 150 ft bgs as a result of downhole drilling system failure. Borehole 24PB intersected a nearly identical sequence of subsurface geological units as 24P. The alluvium-bedrock contact and groundwater was encountered at approximately 405 ft bgs, followed by Bullfrog Tuff from 405 to 900 ft bgs, pre-Bullfrog sedimentary rocks from 900 to 945 ft bgs, and Tram tuff from 945 to 1,377 ft bgs. The borehole was terminated in Pre-Tram sedimentary rocks at 1,395 ft bgs.

Borehole 32P

Borehole 32P encountered alluvial units from surface to 396 ft bgs, consisting of well-graded sand with silt and gravel (SW-SM), typical of alluvial units in the upper approximately 500 ft in Fortymile Wash boreholes. The water table was encountered at approximately 260 ft bgs, with the static water level rising to approximately 245 ft bgs. Between a depth of 396 and 496 ft bgs, a 4 Ma Pliocene basaltic lava flow was encountered. The basalt is underlain by a conglomeratic sandstone unit from 496 to 550 ft bgs. The sandstone grades downward into similar unconsolidated fluvial sediments from 550 to 940 ft bgs. Overall, the section of unconsolidated sediments shows a fining downward. Finally, underlying the unconsolidated sediments are lacustrine siltstone beds from 940 to 1,000 (TD) ft bgs.

Without the presence of a marker unit, except the Pliocene basalt, the age of the sediments below 496 ft bgs is uncertain. It is possible that this sequence is entirely “post-volcanic”, that is younger than the last large pyroclastic eruptions of the Timber Mountain Group volcanics at approximately 11.5 Ma. An alternative interpretation is that the sedimentary sequence (below 496 ft bgs) consists of pre-volcanic older sedimentary units overlain by Pliocene-aged basalt. This would imply a significant unconformity or non-deposition surface at the stratigraphic top of the sedimentary sequence (496 ft bgs). Unfortunately, few direct dating methods are available to determine ages of sedimentary sequences.

Borehole 33P

Borehole 33P was drilled by DOE contractors as one of several boreholes drilled in the Yucca Mountain area for analysis of volcanic hazards. Geologic data provided by the DOE indicates that the subsurface geologic units consist of 195 ft of alluvium overlying Tertiary conglomeratic sediments from 195 to 535 ft bgs. The open borehole water level was encountered in the upper portion of this conglomeratic unit at approximately 204 ft bgs. The borehole terminated in a Tertiary volcanic unit consisting of non-welded, bedded, and reworked tuff extending from 535 to at least 657.1 ft bgs. Preliminary identification suggests that these tuffaceous rocks are a member of the Paintbrush Group volcanics. The overlying conglomeratic sediments are similar in description to rocks in 13P from 1,140 to 1,315 ft bgs, as well as 10SA and 22SA (see discussion in 6.1.1). Overall, below the alluvium, the sequence at 33P appears to represent a post-volcanic Miocene section not seen at 32P.

Corehole 22PC

This corehole was located at site 22 to collect nearly continuous sonic core samples from the lowermost unsaturated and upper saturated zone alluvial sediments (460 to 763 ft bgs). Gravel units predominate in the upper approximate 170 ft (460 to 632.1 ft bgs), and sand units in lower approximate 130 ft (632.1 to 763.0 ft bgs). The mainly gravely units above 632.1 ft bgs generally contain less than or equal to 12% fines, and below 632.1 ft bgs the mainly sandy units generally contain more than 12%. That is, there is a slight fining in particle size distribution with depth.

Sonic corehole 19PB, located approximately 3 miles downstream from 22PC in the Fortymile Wash flow system, shows similar trends in gravel and sand units (NWRPO, 2003) as described above for 22PC. Finally, the major difference between boreholes appears to be the greater range in No. 4 sieve data (i.e., the basis for separating sand and gravel fractions) in 19PB compared to 22PC.

Borehole Geophysical Logging Results

Borehole geophysical logs were used for lithologic characterization and stratigraphic correlations. For the most part, only qualitative interpretations of rock properties were made from the logs. Significant findings include the following:

- Increasing amounts of clay in formation materials often correlate with increasing natural gamma counts, decreasing formation resistivity log values, decreasing density values, and decreasing neutron porosity log counts (increasing water filled porosity).
- In some cases, increasing amounts of clay correlate with all of the above, except increasing natural gamma counts. In these cases, natural gamma counts may decrease (rather than increase) as a result of a decrease in the concentration of gamma emitters with depth in the formation rock.

- In alluvium, valleys in natural gamma logs and peaks in density and neutron porosity logs can correspond to clean well-graded sand and/or gravel that produces clean water. These sand and/or gravel units can serve as preferential flow paths.
- Conglomeratic arkosic sandstone generally produces increases in natural gamma, density, and neutron porosity log values.
- In volcanic units, formation resistivity logs are useful for identifying the degree of welding within ash-flow tuffs, and therefore useful for stratigraphic correlation. Higher resistivity values correlate well with welded rocks identified in the geological cuttings described at the site and low resistivity values correlate with nonwelded rocks.
- Basalt flows exhibit lower natural gamma counts and higher density values than alluvium. These correlations permitted identifying the lower basalt alluvium contact in borehole 13P where drill cuttings were not returned to the ground surface.
- In most Phase V boreholes, fluid resistivity, fluid temperature, and caliper logs could be used to identify discrete intervals where groundwater flows into or out of the wellbore. In several cases, formation resistivity, density, and neutron porosity logs supported identification of water movement into/out of the borehole.
- Optical televiewer logs, though not always of usable quality, show that in some places, these discrete flow zones are open fractures. Discrete inflow zones were identified in 32P.
- In alluvial units in nearly every Phase V borehole, large peaks in caliper logs resulted from washout zones and corresponding decreases in natural gamma, density, and neutron porosity log values.
- Density and neutron porosity responses can be due to different clay contents, degree of cementation, grading of clasts, washout zones, and/or fractures.
- Several geophysical logs can yield meaningful results when run inside of multiple steel casings as demonstrated in 22S.
- In the uppermost alluvial unit in boreholes located in Fortymile Wash, there is generally a slight increase in natural gamma counts and a slight decrease in density values with depth. This reflects a slight increase in finer textured fractions with depth.
- At greater depths in Fortymile Wash alluvium, the natural gamma, density, and neutron porosity logs generally show gradual increases with depth in response to increasing amounts of fines, overburden pressure/compaction, and possibly grading.

Geologic Interpretations

New drilling data, deep-penetrating resistivity survey data, and gravity data were used to construct two geologic cross sections (Figures 6.3-5 and 6.3-6). These new cross sections replace conceptual cross sections presented in the Phase IV Drilling Report (NWRPO, 2005).

New interpretations provide different interpretations of the two largest features in the flow system south of Yucca Mountain, namely the Crater Flat-Jackass Flat Basin Structure (CJS) and Highway 95 Fault. Significant new geologic and hydrologic interpretations include:

- There is evidence that both the CJS and Highway 95 Fault impact or possibly control groundwater movement in the area, including upward hydraulic gradients observed in wells in close proximity to the Highway 95 Fault.
- The Highway 95 Fault location and strike is significantly different than in previous publications. The Highway 95 Fault has two sub-parallel strands, an older master fault to the south, and a slightly younger sympathetic hanging wall fault to the north. The fault is offset southwestward (approximately 3 km) along the CJS and reappears to the southwest of the Lathrop Wells Cone near well 3D, and continues with a similar west-northwest strike to terminate against the Bare Mountain Fault.
- The timing of displacement along the western portion of the Highway 95 Fault is different than the eastern portion.
- At sites 1, 7 and 9, the alternative conceptual model proposes that deep-seated faulting has breached the lowermost (and higher head) aquifers, and provided natural "piezometers" to the lower carbonate heads. This structurally controlled lower carbonate-sourced higher-head water discharges in the near subsurface environment (as leakance between normally isolated flow systems) above the regional (primarily volcanic) aquifer system, probably over very limited geographic extents at locations where deep-seated structures provide open pathways. These zones of upward leakance are now recognized along both the eastern and western strands of the buried Highway 95 Fault, and possibly along other similar structures.

Recommendations

- Do not use the DR-CA Symmetrix™ drilling system in future EWDP boreholes until the system is proven to be more robust.
- If conventional DR-CA systems are used in future EWDP boreholes, use a dust control system to capture dust and allow it to be sampled. In addition, use large enough air compressors to efficiently move drill cuttings to the ground surface.
- Evaluate the pros and cons of using 1.25-inch pipe in future EWDP boreholes requiring multiple-string nested piezometers in ≤ 6.5-inch diameter boreholes.
- Eliminate recording density related weights in alluvium geologic logging forms for drill cuttings.
- Continue recording field estimates of major particle size fractions in alluvium drill cuttings logging forms. These data are proving very useful in characterizing the textural layering in the alluvium downgradient from Yucca Mountain.
- Continue running natural gamma, caliper, formation resistivity, density, neutron porosity, sonic, fluid temperature, and fluid resistivity geophysical logs.

Introduction

This report describes the methods and results of Phase V of the Nye County Early Warning Drilling Program (EWDP), performed as part of the Nye County Nuclear Waste Repository Project Office (NWRPO) Independent Scientific Investigations Program (ISIP). The ISIP was funded by a cooperative agreement with the U.S. Department of Energy (DOE) to support the evaluation of a high-level nuclear waste repository at Yucca Mountain, Nevada. Goals of the EWDP include a better definition of the potential risks of repository activities on Nye County drinking water supplies and the design of a groundwater monitoring network along potential flow paths between Yucca Mountain and populated areas of southern Nye County. A better understanding of the hydrogeologic flow system in this region is a necessary first step in achieving these goals and has been the primary focus of the EWDP to date.

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FIGURES

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PLATES

ACRONYMS

amsl	above mean sea level
AR-RC	air-rotary reverse circulation
ASTM	American Society of Testing and Materials
ATC	Alluvial Testing Complex or Alluvial Tracer Complex
bgs	below ground surface
DOE	U.S. Department Of Energy
DR-CA	dual-rotary casing-advance
DTPS	disturbed thermal perturbation sensor
EC	electrical conductivity
EWDP	Early Warning Drilling Program
fpm	feet per minute
FEC	fluid electrical conductivity
ft	feet
GLS	Geophysical Logging Services
gpm	gallons per minute
HCl	hydrochloric acid
HFM	Hydrologic Framework Model
ISIP	Independent Scientific Investigations Program
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LCM	lost circulation material
mGal	1/1000th of a Gal
NTS	Nevada Test Site
NWRPO	Nuclear Waste Repository Project Office
OD	outside diameter
OSTI	Office of Science and Technology International
OTV	optical televiewer
PFD	phosphate free dispersant
PSD	particle size distribution
QA	quality assurance
QARC	Quality Assurance Records Center
RID	record index designator
SMF	Sample Management Facility
SP	spontaneous potential
TD	total depth
TP	technical procedure
TPN	test plan

USCS	Unified Soil Classification System
USGS	U.S. Geological Survey
WP	work plan
YMP	Yucca Mountain Project

1.0 INTRODUCTION

This report describes activities performed during Phase V of the Early Warning Drilling Program (EWDP), which include borehole drilling; geologic sampling, testing, and logging; and well completion. Phase V field work began in November 2004 and continued through April 2006. These activities were performed as part of the Nye County Nuclear Waste Repository Project Office (NWRPO) Independent Scientific Investigations Program (ISIP), which was funded by a cooperative agreement with the U.S. Department of Energy Yucca Mountain Project (DOE YMP) to support the evaluation of a high-level nuclear waste repository at Yucca Mountain, Nevada.

1.1 Program Background

The Yucca Mountain repository is located within Nye County. Because Nye County retains limited local jurisdiction over this site, the county has rights of participation, funding, and onsite representation in Yucca Mountain Project (YMP) policies and activities. Nye County began to exercise these rights in 1987 by creating the NWRPO. The major goals of the NWRPO are to provide an independent evaluation and review of activities and policies related to the transport, disposal, and storage of nuclear waste within Nye County, and to supplement federal studies about potential impacts of the repository.

The ISIP was initiated in 1994 with a technical grant from DOE YMP to provide an independent evaluation of selected site characterization and repository design and performance issues potentially affecting human health, safety, and the environment in southern Nye County. Since 1994, several additional grants and cooperative agreements have been obtained from DOE YMP to continue the ISIP.

The EWDP is a subregional-scale hydrogeologic study and monitoring program designed to help protect Nye County water supply interests. The program focuses primarily on the region between the Yucca Mountain repository and populated areas of the Town of Amargosa, referred to as Amargosa Valley in this report, in southern Nye County. The closest Amargosa Valley community to Yucca Mountain is Lathrop Wells, which is approximately 12 miles southeast of Yucca Mountain and downgradient along potential groundwater flow paths. Figure 1.1-1 shows the location of these areas, as well as the Nevada Test Site (NTS), areas of private land ownership, and the principal population centers within southern Nye County.

A major Nye County concern is whether future Yucca Mountain nuclear waste management activities have the potential to impact the groundwater and surface water supplies within the Amargosa Valley and, in turn, human health and the environment. Although Amargosa Valley is sparsely populated and largely undeveloped, significant economic development and population growth will likely occur as a result of the YMP. Amargosa Valley also contains important sensitive natural environments and habitats, including Ash Meadows National Wildlife Refuge, Devils Hole, the Amargosa River, and various springs and associated wetlands.

The first four phases of the EWDP, conducted October 1998 through August 2003, were funded by cooperative agreements with DOE YMP. Selected results from Phases I through IV are found on the NWRPO website (NWRPO, 2009). In addition, an overview of Phases I and II can be found in the NWRPO report for fiscal years 1996 through 2001 (NWRPO, 2001). Finally, details of Phase III and Phase IV methods and results are found in two NWRPO technical reports (NWRPO, 2003 and NWRPO, 2005). These technical report documents can also be found on the NWRPO website.

The work described herein was funded by a 5-year cooperative agreement between Nye County and DOE YMP begun on April 1, 2002. This report summarizes the methods and results of EWDP Phase V, which were conducted November 2004 through April 2006.

1.2 Program Objectives and Activities

The overall objectives of the EWDP include the following:

- A better definition of the potential risk to Amargosa Valley drinking water supplies from high-level nuclear waste handling and disposal at the Yucca Mountain repository
- The design of an appropriate “early warning” groundwater monitoring network between the repository and present and future populations in the Amargosa Valley area

A better understanding of the hydrogeologic system is a necessary first step toward achieving these objectives and has been the focus of all EWDP phases to date.

Before initiating the EWDP, an evaluation of existing hydrogeologic data revealed a significant data gap in the region downgradient from Yucca Mountain, including part of southern Jackass Flats, southern Crater Flat, western Rock Valley, and the northern Amargosa Desert. In short, there were few or no subsurface hydrogeologic data for these areas. The EWDP has targeted basic hydrogeologic data deficiencies in this region and continues to study the origin of spring deposits; geologic and hydraulic properties of valley-fill sediments; groundwater depths, gradients, and flow patterns; and baseline water chemistry.

Specific objectives of the EWDP include determining the following:

- Flow and transport parameters needed to refine and reduce uncertainty in groundwater and performance assessment models that incorporate groundwater modeling results
- Baseline water chemistry and water level data, and the capability to monitor trends in these data in strategically placed boreholes over time
- A better understanding of the hydraulic properties of the tuff/alluvium interface, the nature and continuity of alluvial textural layers, the hydrogeologic units underlying the alluvium, and hydraulic gradients within and between units.
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Phases I and II, completed in 2000 and 2001, respectively, provided hydrogeologic and baseline water chemistry data for the region south of the repository and along U.S. Highway 95, which traverses the northern edge of Amargosa Valley.

Phase III, completed in 2002, focused on filling data gaps for the region along the lower reaches of Fortymile Wash within and outside the NTS. Work in the region outside the NTS included establishing further testing and monitoring capabilities at the Alluvial Testing Complex (ATC) (Site 19) located just west of the present day braided channel area of Fortymile Wash approximately a mile north of Highway 95. The ATC was established for cooperative studies conducted by the DOE YMP; U.S. Geological Survey (USGS); Los Alamos National Laboratory (LANL); University of

Nevada, Las Vegas; and Nye County to characterize the hydraulic and transport properties of the saturated alluvium near the southwestern boundary of the NTS.

Phase IV, completed in August 2003, targeted southerly flow paths from Yucca Mountain in the drainage immediately to the west of Fortymile Wash, named Flat Tire flat in NWRPO (2005), and along the western edge of Fortymile Wash. In addition, it included a sonic corehole at Site 19.

Phase V activities were concluded in April 2006 and involved constructing 6 boreholes, 5 of which were completed as piezometers to help fill data gaps in hydrogeology along the southeastern edge of Crater Flat and in the area south of Highway 95 in the general area of Fortymile Wash, and to support on-going groundwater tracer testing in both alluvium and fractured tuff. Phase V activities included borehole drilling, drill cuttings and core collection, geologic logging and laboratory testing of selected samples, borehole geophysical logging, completion of single-screen and multiple string (i.e., nested) piezometers, water chemistry and water level monitoring, and limited aquifer testing.

This report focuses on the scope, methods, and results of these Phase V activities, with the exception of water chemistry and water level monitoring, which will be described in future Nye County technical reports.

1.3 Location of Phase V Boreholes

The locations of the Phase V boreholes that were completed as piezometers are shown on Figure 1.3-1; their coordinates are given in Table 1.3-1. All EWDP borehole names have an "NC-EWDP-" prefix; in this report the names will be given by number only. The six Phase V boreholes are listed as follows with the "P" in each number standing for a piezometer, which is defined in this report as a small diameter monitor well with a screen length generally less than 50 to 100 feet (ft).

- 13P
- 22PC
- 24PA
- 24PB
- 32P
- 33P

Due to failed equipment lost down hole in 24PA at approximately 150 ft below ground surface (bgs), it was necessary to abandon this borehole, and as a result it could not be completed as a water table piezometer. 24PB was constructed as a replacement for 24PA.

Three of the Phase V piezometers were constructed in locations where boreholes had not previously been drilled; 13P was located along the southeastern edge of Crater Flat, 33P south of the Lathrop Wells cone area and Highway 95, and 32P south of Highway 95 near the center of the braided channel of lower Fortymile Wash. The two remaining Phase V piezometers were constructed to support groundwater tracer testing programs at locations already containing piezometers and wells. Both of these were located in Fortymile Wash approximately 3.5 miles north of Highway 95; 22PC was designed to support a Nye County tracer testing program in alluvium near the present day main channel of Fortymile Wash, and the 24PB was located near the western boundary of Fortymile Wash to support a DOE Office of Science and Technology International (OSTI) tracer testing program in fractured tuff.

1.4 Pre-Phase V Knowledge

1.4.1 Geologic Setting

Borehole 13P is located on the eastern edge of Crater Flat approximately 6 miles north of the Lathrop Wells cinder cone. The five remaining Phase V boreholes (i.e., 22PC, 24PA, 24PB, 32P and 33P) are located either near the center or along the western margin of the lower portion of Fortymile Wash. This wash is the major topographic drainage system for Jackass Flats, the eastern side of Yucca Mountain, and the upland region of the southwestern corner of the NTS.

Locations of the Phase V boreholes with respect to surface geology are shown on a recent geologic map of the Yucca Mountain area by Potter and others (2002), which describes local stratigraphy and faults (Figure 1.4-1).

1.4.1.1 Borehole 13P

Borehole 13P is located in easternmost Crater Flat near the Windy Wash Fault, a major block bounding structure between Crater Flat and southern Yucca Mountain. No drilling had previously been conducted in the area. From geologic sections drawn by the USGS, the borehole is located in the hanging wall of the northeast striking Windy Wash Fault, approximately 2,000 ft west of the ridgeline of Paintbrush Group tuffs in the footwall of this fault. The area consists of well-drained alluvium and low outcrops of Pliocene basalt flows. Based on the USGS maps, it was expected that most of the volcanic units, including members of the Timber Mountain Group, would be preserved below a thin cover of alluvium.

1.4.1.2 Fortymile Wash Borehole 24PA and 24PB

The Fortymile Wash boreholes 24PA and 24PB were drilled at the existing site of Phase IV borehole 24P near the southern extent of Yucca Mountain, on the western flank of Fortymile Wash. The geology consists of relatively thick alluvium, possibly in a channel between ridges of predominantly Paintbrush Group tuffs surrounding the location, except to the east. In the subsurface, the alluvium unconformably overlies tuff units of the Crater Flat Group. The lack of younger Paintbrush Group rocks indicates that a structural high exists at the location and that earlier erosion had exposed the older rocks beneath the alluvium.

1.4.1.3 Fortymile Wash Boreholes 22PC, 32P, and 33P

Borehole 22PC was drilled at the existing site of Phase III boreholes 22S, 22PA and 22PB. The site is located in the thick alluvial sequence found along the main channel of Fortymile Wash. The borehole was designed to sample and characterize the saturated sediments of the upper approximately 300 ft of the alluvial aquifer.

Boreholes 32P and 33P were drilled in the area of the lower distributary channels of Fortymile Wash in the Amargosa Desert. The area has a thick cover of alluvium and no existing borehole information. Subsurface magnetic anomalies were the primary target.

1.4.2 Subsurface Geophysical Interpretations and Phase V Borehole Locations

Phase V boreholes 13P, 32P, and 33P were located in part based on previous geophysical surveys. Pertinent previous results and interpretations related to borehole locations are briefly described in the following.

1.4.2.1 Gravity Data

A regional gravity study of the area performed by the USGS (Blakely and Ponce, 2001) delineated several subbasins of the Crater Flat basin defined by higher (i.e., greater) depth to basement (i.e., Paleozoic age rocks). The subbasins, 4 kilometers or more deep, are thought to be filled with thick sections of Cenozoic volcanic and sedimentary rocks and alluvium.

Borehole 13P is located on the southeast edge of the Crater Flat basins and to the northeast of a large northeast trending gravity gradient described in NWRPO (2005) as beginning west of the Lathrop Wells Cone and passing between boreholes 16P and 27P located between Crater Flat and Fortymile Wash in a basin named Flat Tire Flat in the same NWRPO report. NWRPO (2005) also suggests that this northeast trending gravity gradient may be indicative of a steep contact between basin fill and basement rocks or a buried fault. Regardless of the origin of this feature, NWRPO (2005) notes that it could have significant control on groundwater flow paths in the area south of Yucca Mountain.

The work of Blakely and Ponce (2001) further shows a north-south-trending gravity gradient between low and moderate depths to basement on the east side of Fortymile Wash. This feature, which has long been recognized (Winograd and Thordarson, 1975) and is interpreted to be a buried normal fault, has been termed the Gravity Fault. All Phase IV and V boreholes are located west of the Gravity Fault on the down-dropped side.

1.4.2.2 Aeromagnetic Survey

An airborne magnetic survey was also performed by the USGS (Blakely et al., 2000) to identify younger volcanic rocks, which are more magnetic than other rock types. Three deep-seated east-west trending magnetic gradients (signatures) were identified between the south end of the repository and Highway 95; and a prominent magnetic lineament coincident with the northeast trending gravity gradient passing through Flat Tire Flat (mentioned previously in Section 1.4.2.1) was also identified. Figures showing these gravity and magnetic lineaments are presented in NWRPO (2005).

In addition, the Blakely et al. (2000) survey identified magnetic anomalies (areas of high magnetic values) that were interpreted as potential basalt flows in Crater Flat, Amargosa Valley, and lower Fortymile Wash. An even more detailed airborne magnetic survey of smaller aerial extent was completed by DOE YMP over the Yucca Mountain Region in 2005 (Kelley, 2005). In late 2005 and 2006 the DOE YMP drilled and sampled a number of the magnetic anomalies that were potential buried basalt flows.

Following the completion of DOE YMP drilling and sampling, Nye County assumed possession of two of these magnetic anomaly DOE YMP drill sites near the northern boundary of Amargosa Valley for EWDP water level and water chemistry monitoring. The DOE YMP exploratory borehole located south of the Lathrop Wells cone (VA-5) was developed and completed by Nye County and renamed 33P (Figure 1.3-1). Drilling contract constraints required DOE YMP to abandon a similar exploratory borehole VA-2 located approximately 2 miles southeast of 33P before Nye County could assume possession, develop, and complete it. As a result, Nye County drilled and completed a new borehole near the abandoned DOE YMP borehole, and named the former 32P (Figure 1.3-1).

1.4.3 Groundwater Flow System and Phase V Borehole Locations

The groundwater flow system in the Yucca Mountain/Amargosa Desert area is generally characterized by flow from north to south (Winograd and Thordarson, 1975). A potentiometric surface map of the area is shown on Figure 1.4-2 (DOE, 2003). The map shows a relatively steep potentiometric gradient north and west of Yucca Mountain as well as south of Yucca Mountain along Highway 95 and between Crater Flat and the basin to the east (Flat Tire Flat). The figure shows that there are no water level data to constrain the potentiometric contours and the high gradient between Crater Flat and Flat Tire Flat. Borehole 13P was located as shown on this map to help to better define these contours.

Figure 1-4.2 also shows little or no water level data southwest of borehole 19PB on the southern side of Highway 95. Water level data from boreholes 32P and 33P will help fill in this data gap.

1.5 Hydrogeologic Objectives of Phase V Boreholes

Phase V boreholes were sited to collect hydrogeologic information downgradient of Yucca Mountain, in both volcanic rocks and alluvium between Yucca Mountain and Amargosa Valley (Figure 1.3-1). Specifically, hydrogeologic objectives for Phase V include the following:

- Determine the role of the Windy Wash Fault on stratigraphy of subsurface geologic units penetrated in 13P
- Determine the stratigraphy and role of basin fill units including potential basalt flows and on groundwater levels and chemistry in 32P and 33P
- Drill, sample, log, instrument, and complete 24PB (replaces 24PA that was abandoned) to support single-well tracer tests in a fractured volcanic unit (Bullfrog Tuff), which is the same saturated unit that underlies the Yucca Mountain repository
- Provide continuous sonic core samples from the approximately upper 300 ft of saturated alluvium in 22PC and construct dual-string piezometers in the resulting core hole to support Nye County groundwater tracer studies in alluvium at Site 22
- Provide future monitoring points for water levels and water chemistry in the geologic unit spanning the water table in each of the Phase V monitor wells

1.6 Quality Assurance Plans and Procedures

The NWRPO Quality Assurance (QA) Program Plan and quality administrative procedures outline QA management procedures for the collection and documentation of scientific data. These documents help to ensure that NWRPO scientific investigations provide valid data that are useful to Nye County and other potential users associated with the YMP. The U.S. Nuclear Regulatory

Commission evaluated the Quality Assurance Program Plan in 1999 and issued a conditional acceptance statement (Reamer, 1999, personal communication).

Table 1.6-1 lists the specific work plans (WPs), technical procedures (TPs), and test plans (TPNs) pertinent to Phase V. The WPs included in this table outline technical objectives and describe methods and procedures for accomplishing these objectives (e.g., scopes of work). In addition, WPs reference applicable TPs, which in turn provide detailed instructions for performing routine technical activities or tasks. TPNs document technical objectives and detailed instructions for one-of-a-kind technical activities. Some deviations from these WPs, TPs, and TPNs were found to be necessary due to conditions encountered in the field. Major deviations were documented on field change approval forms filed in the NWRPO Quality Assurance Records Center (QARC). In general, these deviations did not affect the achievement of project objectives and goals.

1.7 Report Organization

Section 1.0 of this report provides pertinent background information and describes the purpose and scope of EWDP Phase V activities. Section 2.0 summarizes field drilling, sampling, logging, and laboratory testing methods and procedures. Section 3.0 describes well completion and development. Section 4.0 presents the results of geologic logging, Section 5.0 the results of laboratory testing, and Section 6.0 the results of geophysical and lithological logging and geologic cross-section interpretations. Section 7.0 summarizes major findings and recommendations.

2.0 DRILLING, CORING, SAMPLING, LOGGING, AND TESTING

This section describes Phase V drilling, coring, sampling, geologic logging, laboratory testing, and geophysical logging methods. Further details about these methods can be found in the QA documents listed in Table 1.6-1. The NWRPO On-Site Geotechnical Representative was responsible for program oversight and approval of procedural and scope changes necessitated by field conditions or findings. NWRPO field staff and contract geologists and technicians, referred to as NWRPO personnel in this report, were responsible for recording site management information, equipment calibrations, general observations, and progress notes in scientific field notebooks. Field forms were used by NWRPO personnel to record key drilling, sampling, and well completion data, including, but not limited to, depth control, geologic logging, and chain of custody. Completed forms and scientific notebooks are on file at the QARC.

2.1 Drilling and Coring

Under NWRPO oversight, drilling and coring were conducted by drilling contractors responsible for 1) implementation of the drilling/coring scope of work, 2) compliance with all applicable permit conditions and regulations, and 3) compliance with both their in-house health and safety plan and industry-standard work practices specified in contract documents. All contract documents are on file at the QARC.

Drilling and coring methods for Phase V boreholes were based on a number of objectives, including the ability of the methods to:

- Yield drill cuttings and core as representative as possible of in situ formation rock
- Minimize disturbance of the formation rock
- Achieve target depths
- Provide boreholes suitable for open-hole geophysical logging
- Yield boreholes suitable for single- or multiple-screen piezometer well completion

These objectives were previously used to select Phase III and IV drilling and coring methods. The methods employed in Phase V included: air-rotary reverse-circulation (AR-RC) drilling, dual-rotary casing-advance drilling (DR-CA), and sonic coring. A variation of DR-CA method using a rotary underreaming bit system (Atlas Copco Symmetrix™) was also used. Drilling methods for each hole varied but generally used a combination of methods to sample and advance the borehole and to enlarge and case open hole sections where required.

The target depths were achieved for all boreholes except 13P and 24PA where drilling problems limited the boreholes to depths of 1,569 and 152 ft bgs, respectively. Boreholes 24PB, 32P and 22PC were drilled to total depths of 1,395, 1,000 and 763 ft bgs, respectively.

Borehole 33P was previously drilled to 657 ft bgs by DOE YMP using polymer-based mud rotary methods. Nye County did not collect geologic samples from this boring; its role was limited to removing the polymer mud and constructing the well. Mud rotary drilling will not be discussed further in this report.

2.1.1 Overview of Methods

This section provides background information on Phase V drilling and coring methods including AR-RC drilling, DR-CA drilling, and sonic coring methods. As mentioned previously, most of the Phase V wells used more than one of these methods to meet the drilling objectives.

2.1.1.1 AR-RC Methods

AR-RC methods are commonly used in mineral exploration and are described in detail in NWRPO (2003) and (2005). These reports include a detailed discussion of drilling and drilling-related impacts that can potentially disturb the representativeness of drill cuttings and formation material. AR-RC methods are believed to provide reasonably representative drill cuttings for geologic logging from most formations, with the exception of saturated alluvium producing significant amounts of water. In this report the term “alluvium” refers to unconsolidated rock and “non-alluvium” to consolidated rock.

The NWRPO required that AR-RC method use compressed air exclusively as the drilling fluid. Generally, compressed air minimizes the disturbance to formation rock permeability and water chemistry. However, air often erodes borehole walls and can create caving conditions, especially in the unsaturated zone. In these cases, drilling mud (i.e., sodium bentonite and/or polymers and/or foamers) was used to stabilize the walls of AR-RC drilled boreholes. The method involved halting drilling, injecting drilling fluid using conventional circulation, and drying the borehole walls with compressed air before continuing the advancement of the borehole. This borehole conditioning method allowed AR-RC dry drilling to proceed to depths of 300 to 400 ft bgs in unconsolidated unsaturated alluvium and valley-fill deposits using only approximately 60 ft of surface casing. The use of organic drilling fluids and additives, including foams and polymers was minimized to the extent possible. More details about drilling fluids are presented in Appendix A. No lost circulation materials (LCM) were used in Phase V drilling.

In unsaturated alluvium, AR-RC generally produces drill cuttings where the total percent of fine particle sizes (silt plus clay) and the total percent of coarse particle sizes (sand plus gravel) are not significantly altered from in situ conditions. However, the method generally significantly reduces the gravel fraction and increases the sand fraction percentages compared to in situ conditions, while the percentages of silt and clay generally remain similar to in situ conditions (NWRPO, 2003).

2.1.1.2 DR-CA Methods

Conventional DR-CA drilling methods were used in 22PC and 32P and the recently developed Symmetrix™ version of DR-CA methods was used in 24PA and 24PB to case as much as 460 ft of unconsolidated alluvium and permit further borehole advancement using AR-RC or sonic coring methods. The conventional DR-CA method uses an outer drill casing with a fixed shoe bit and is advanced by rotating while the cuttings are “drilled-out” from inside the casing with tri-cone rotary bits or percussion hammer bits attached to a separate drill string. This separate inner drill string is independently rotated and advanced using one of several circulation methods including: dual-wall reverse-circulation and conventional circulation (circulation returns between the drill casing and the inner drill string). The drilling fluid circulation is controlled with the inner drill string and top head drive system.

The Symmetrix™ version of the DR-CA method is similar to the conventional DR-CA method, but employs a freely rotating bushed casing shoe bit and locking down-hole air percussion hammer that advances and rotates both bits while advancing drill casing. In addition, the air percussion hammer is deployed on dual-wall reverse-circulation drill pipe providing efficient and rapid return of drill cuttings to surface. This method has proven to be reasonably successful at moderate depths (<500 ft bgs) in alluvium, but is less effective in consolidated or bedrock units.

2.1.1.3 Sonic Coring Methods

Sonic coring methods collected nearly continuous samples with minimally disturbed particle size distributions (PSDs) from the lower portion of the unsaturated zone (approximately 460 to 470 ft bgs) and the upper approximately 293 ft of the saturated zone (470 to 763 ft bgs) in 22PC. Although this method disturbs the porosity and density of the alluvial samples, it maintains intact textural layering and provides representative samples suitable for detailed geologic logging and laboratory testing of selected flow and transport parameters. The method uses a dual-pipe system consisting of a core pipe (i.e., the core barrel) inside a larger diameter drill pipe (i.e., the drill casing). Both pipes are advanced using a combination of mechanically driven oscillations (i.e., vibrations), slow rotation, and hydraulic pull-down pressure. A top-mounted, hydraulically powered drill head is used to transmit the vibratory force and pull-down pressure on the core and drill pipes.

During typical sonic corehole advancement, the inner core pipe is advanced approximately 5 to 20 ft ahead of the outer drill pipe. The core pipe is then brought to the ground surface, where core is vibrated out of the pipe into polyethylene film tubing (i.e., a plastic sock) with a diameter slightly larger than the outside diameter (OD) of the core pipe. The outer drill pipe is then advanced to the bottom of the borehole and the inner core pipe is used to remove the disturbed fill material from the outer drill pipe. The above steps are then repeated to continue coring and advancing the borehole downward.

2.1.2 Details of Drilling/Coring Methods and Equipment by Borehole

Prior to discussing specifics for each borehole, it is important to note that for all Phase V boreholes, NWRPO personnel and drilling contractors maintained depth control during drilling by measuring/recording drill string and down-hole bit assembly lengths and, where practicable, depth sounding.

Surface casing was necessary in all Phase V boreholes to prevent caving of relatively unstable near-surface sediments, maintain annular borehole air pressure while drilling the remaining portion of each borehole, and provide a surface-well seal for later installation of one or more piezometers.

2.1.2.1 Borehole 13P

Borehole 13P was drilled by WDC Exploration and Wells (WDC) using a Speedstar SS-90K drill rig, 5.5-inch-diameter dual-wall drill pipe, and several down-hole bit assemblies, as summarized in Table 2.1-1.

The upper 62.5 ft of 13P was drilled and sampled using AR-RC methods with a 6.5-inch bit. The borehole was then reamed with an 11-inch reamer bit to 59.6 ft bgs, cased with an 8.625- inch OD surface casing, which in turn was grouted in place from 59.6 ft bgs to the ground surface.

With a surface casing in place, AR-RC drilling was continued using open-hole methods to total depth (TD) of 1,569 ft bgs. Much of the open-hole section was drilled in weakly-consolidated to unconsolidated alluvium, vesicular basalt, and fluvial sediments that eventually resulted in borehole stability and circulation problems. Below a depth of approximately 1,000 ft bgs, problems with drilling equipment failure compounded with drilling fluid circulation problems, caused progress to slow dramatically. At a depth of 1,569 ft bgs, progress stopped due to an inability to re-establish circulation.

Geophysical logging was first conducted in the dual-wall drill pipe and then in the open borehole after tripping out the drill pipe. Borehole bridging at 110 and 710 ft bgs prevented logging the entire borehole and only limited open hole-logs were obtained as summarized in Section 2.5.

Following geophysical logging, WDC and NWRPO agreed to condition the borehole with bentonite and polymer muds to attempt to stabilize the borehole walls and continue deepening the borehole. After two days of conditioning and attempting to circulate, the borehole was terminated at a depth 1,569 ft bgs and well completion began.

2.1.2.2 Boreholes 24PA and 24PB

Eklund Drilling Ltd. (Eklund) drilled boreholes 24PA and 24PB using a Foremost DR-24 drill rig, 5.5-inch diameter dual-wall drill pipe, and several downhole bit assemblies as summarized in Table 2.1-1. The same drill rig was used to drill 32P and to clean out 33P.

The upper 57.7 ft of 24PA was drilled and sampled using open-hole AR-RC methods with a 6.75-inch diameter drill bit. The 57.7 ft deep borehole was then overdrilled with a 16-inch DR-CA system. The 16-inch casing was left in place and the hole was advanced beyond 57.7 ft bgs using DR-CA Symmetrix™ downhole tools with a 10.75-inch OD outer casing and a dual-wall reverse-circulation inner string. Below a depth of approximately 150 ft bgs, the 10.75- inch casing string separated from the Symmetrix™ underreamer shoe bit and downhole hammer. The hole was abandoned after first recovering the inner string and hammer assembly, most of the 10.75-inch casing, and all of the 16-inch casing. The failure appeared to be the result of rocks locking the 16-inch surface casing and the 10.75-inch drill casings together and the drilling system pulling apart the drill casing as the hole was deepened.

After abandoning 24PA, 24PB was sited approximately 37 ft southwest of 24PA. The upper 57.5 ft of 24PB was drilled and sampled using AR-RC methods similarly to 24PA. Conventional DR-CA methods were then used to temporarily install an 8.625-inch OD casing to approximately 57.3 ft bgs. From 57.5 ft bgs, open-hole AR-RC methods with a 6.75-inch diameter drill bit were employed to drill and sample to a depth of 500 ft bgs.

The 8.625-inch OD surface casing was then removed and the borehole overdrilled by drilling and advancing a 10.75-inch casing using DR-CA methods with Symmetrix™ tools. The 10.75-inch casing with a dual-wall inner string was drilled to depth of 467.3 ft bgs using reverse circulation. At this depth, the Symmetrix™ casing underreamer shoe bit became separated from the casing. The casing advance aspect of the borehole was terminated at this depth. The borehole was then deepened and sampled from 500 ft bgs to a TD of 1,395 ft bgs using open-hole AR-RC methods with a 6.5-inch diameter drill bit. Drilling progressed smoothly and rapidly through this portion of the borehole, and after reaching the geologic objective of the bottom of the Tram Tuff drilling was terminated. Open-hole geophysical logging and fluid electrical conductivity (FEC) logging and testing were then conducted, followed by well completion activities.

2.1.2.3 Borehole 32P

The interval from ground surface to 57.5 ft bgs in 32P was drilled and sampled by Eklund using AR-RC methods with a 6.5-inch bit. The hole was then overdrilled and cased with a nominal 16-inch diameter conventional DR-CA rotary drilling system. The inner string of the DR-CA system was then removed and an 8.625-inch OD surface casing was installed inside the 16-inch casing. Cement grout was added to the annular space between the casings and 16-inch casing was removed to seal the 8.625-inch casing against the native unconsolidated sediments.

The borehole was deepened and sampled again with a 6.5-inch bit using AR-RC open-hole methods to a total depth of 1,000 ft bgs. Except for some minor hole stability problems, drilling progressed smoothly and rapidly even though most of the interval consisted of unconsolidated material. Open-hole geophysical logs were obtained, including a digital optical televiewer log, followed by FEC geophysical logging and testing.

2.1.2.4 Borehole 33P

The AR-RC method with 5.5-inch dual-wall pipe with a 6.25-inch tricone drill bit was also used to re-enter borehole 33P that was previously drilled by DOE-YMP contractors as VA-5. The reverse circulation method was used to air-lift drilling fluids (in this case, thick polymer mud) and develop the borehole walls prior to well completion. Initially, the drill pipe was run into the borehole below the water table. A dilute mixture of Baroid AquaClear phosphate free dispersant (PFD) was then injected into the borehole at several levels and agitated. The following morning, the borehole was air-lifted and water quality EC measurements were used to monitor the removal of the polymer. After air-lifting for approximately 3 hrs and producing approximately 16,000 gallons of water, the borehole was geophysically logged and well completion was begun.

2.1.2.5 Borehole 22PC

The upper 460 ft of 22PC was drilled and sampled by Boart Longyear Company using a Foremost DR-24 drill rig and conventional DR-CA methods with conventional air circulation. Boart Longyear then advanced the borehole from 460 to 763 ft bgs using sonic coring methods and a GP24-300RS rig. The water table was encountered at approximately 472 ft bgs.

The DR-CA method was used primarily to sample and case the unsaturated alluvium to facilitate coring the underlying saturated alluvium. Initially, a 16-inch conventional DR-CA dual rotary method was used to drill, sample, and set 60.0 ft of 16-inch surface casing. The inner string of the DR-CA system consisted of 7-inch dual-wall drill pipe and a tricone bit assembly as summarized in Table 2.1-1. Conventional circulation return was conducted up the annular space between the outer drill casing and the inner drill string.

The hole was then deepened to 460 ft bgs using DR-CA methods with a 10.75-inch outer casing, the same inner string, and the same conventional circulation. Upon reaching 460 ft bgs, the 60 ft of 16-

inch casing was removed and the annular space between the formation sediments and 10.75-inch casing was cemented with Portland cement grout.

Following the cementing of 10.75-inch casing in place, the sonic drill rig was then moved to the hole and nearly continuous sonic core was collected from 460 to 763 ft bgs. Starting at 460 ft bgs, a 6.2-inch OD core barrel and 8.1-inch OD steel drill casing were advanced in 10-foot stages to 589.6 ft bgs. The core barrel was then advanced beyond the drill casing to 625.2 ft bgs, where advancement was no longer feasible. A switch was then made to a 4.5-inch OD core barrel and 5.8-inch OD drill casing. The smaller core barrel and drill casing were then advanced in 10-foot stages to 759.6 ft bgs, where the core barrel was advanced beyond the drill casing to a total depth of 763.0 ft bgs.

2.2 Geologic Sampling

Drill cuttings were collected using AR-RC methods for continuous field geologic logging and laboratory testing from all Phase V boreholes, except 22PC and a portion of 24PA (Table 2.2-1). The upper 460 ft of unsaturated alluvium in 22PC and the tertiary tuff interval from 57.5 to 151.8 ft bgs in 24PA were drilled and sampled using DR-CA methods.

Continuous sonic core samples were collected from 460 to 763 ft bgs in 22PC for field geologic logging and laboratory testing. This interval corresponds to the lower 10 ft of the unsaturated zone and the upper 293 ft of the saturated zone in 22PC.

Geologic sampling and sample handling methods generally conformed to the applicable WPs, TPs, and TPNs listed in Table 1.6-1. Exceptions to these methods are described in geologic log form comments and/or scientific field notebooks. Sampling related processes (e.g., heat generation at the drill or core bit) that may have disturbed samples further from in situ conditions and affected geologic, photographic, or video logging descriptions and/or laboratory testing are also described in Sections 4.0 through 6.0.

2.2.1 Drill Cuttings

Table 2.2-1 summarizes the number of drill cuttings samples, sample splits, and the number and types of laboratory tests conducted on drill cuttings from Phase V boreholes. Except as noted in Table 2.2-1 footnotes, continuous drill cuttings were collected at 2.5-foot intervals in unsaturated alluvium and 5-foot intervals in unsaturated and saturated non alluvium below the alluvium. A total of 1,234 drill cuttings samples were collected: 611 alluvial and 623 non-alluvial. With the addition of splits prepared for the NWRPO and DOE YMP approximately 4,041 cuttings samples were packaged, labeled, and handled.

Drill cuttings were collected at the ground surface in a cyclone separator. In the unsaturated portion of AR-RC boreholes, the entire alluvial sample from a particular depth interval was collected in 5-gallon buckets. Buckets from each depth interval were emptied onto a tarpaulin, mixed, and subsampled by the cone and quarter method.

Drill cuttings from the larger diameter DR-CA portion of 22PC were also collected in 5 gallon buckets, which were split in a Gilson splitter to reduce the sample weight to a manageable level. The smaller sample was then emptied onto a tarpaulin, mixed, and subsampled by the cone and quarter method.

Unsaturated zone alluvial drill cuttings were weighed in the field to provide data for calculation of in situ bulk density values. Samples were weighed on an electronic digital scale, which measures in 0.1-pound or 0.01-kilogram increments. A second small scale was used to measure field-sieved gravel for field calculations of gravel percentages.

In the saturated, non-alluvium portions of Phase V boreholes where significant amounts of water were produced during drilling, an Anaconda rotating wet splitter was attached beneath the cyclone separator to reduce the sample volume from a sample depth interval to a manageable number of 5-gallon buckets. The solid phase in the buckets was homogenized and subsampled over 5-foot depth intervals, except as noted in Table 2.2-1.

Unconsolidated fluvial sediments in 32P from 730 to 990 ft bgs were sampled by collecting one 5-gallon bucket full of sample and associated water per 20-ft drill rod (this sample interval was considered to be 0.1 ft). The exception to this method was the interval from 730.1 to 732.5 ft bgs, where the entire 2.4-ft sample interval was collected in twelve 5-gallon buckets, and the fines allowed to settle in order to collect a representative sample. Three split samples, each weighing approximately 5 pounds, were collected from each sample interval: two for the NWRPO and one for the DOE YMP. A fourth split sample was collected from every second 2.5-foot interval in alluvium for NWRPO laboratory analysis.

The first NWRPO split was collected for archival at the DOE YMP Sample Management Facility (SMF); the second NWRPO split was subsampled for field logging and the preparation of chip trays for future reference; the third NWRPO split was designated for NWRPO laboratory testing. The DOE YMP split was collected onsite by DOE YMP personnel. Both NWRPO and DOE YMP splits sent to the SMF were sealed in olefin bags; splits for laboratory testing were sealed in double plastic bags. All samples were labeled with appropriate identification and shipped to their destinations under chain of custody.

2.2.2 Sonic Core

After each sonic core run was brought to the ground surface, approximately 2-foot-long segments were vibrated from the core barrel into plastic socks with an ID slightly larger than the OD of the core. The core segments were then moved to the core logging trailer, where depth intervals were assigned. The expansion in the length of the recovered core due to the sonic vibrations was corrected to the approximate true in situ length by methods described in TP-8.0 (Table 1.6-1). Boundaries between alluvial layers with noticeably different PSDs were identified using visual-manual logging methods based on American Society for Testing and Materials (ASTM) D 2488-93. These layers often extended across adjacent segments and ranged in length from 0.3 to 6.8 ft.

Grab samples from the major textural layers present in sonic core were then collected in a manner to obtain representative PSDs by methods described in TP-8.0. Representative grab samples were collected by one of two permissible methods. The first involved splitting the core cylinder in half along its length (i.e., longitudinally). The second involved collecting a pie shaped wedge along the length of the core cylinder with the apex of the wedge at the center of the core. Both these methods ensured that the fines fraction, which was previously shown (NWRPO, 2005) to preferentially migrate towards the outside surface of the core during the coring process, was sampled in a representative manner. Table 2.2-2 lists the number of sonic core samples and summarizes the tests conducted by the NWRPO testing laboratory.

The representative grab samples of textural layers were geologically logged in the field by the NWRPO and transported to the NWRPO laboratory for testing. After the removal of NWRPO grab samples from core segments, digital photography, and DOE YMP video logging, the remaining portions of core segments were transferred to DOE YMP, who in turn transported the core to the SMF under DOE YMP chain of custody. The distribution of grab samples was controlled and documented with the NWRPO Transfer of Custody Form.

2.3 Geologic and Photographic Logging

Geologic logging and digital photography procedures are described in TP-8.0. Geologic logging data on drill cuttings collected from AR-RC or DR-CA portions of boreholes were recorded on the Alluvium and Non-Alluvium Drill Cuttings Logging Forms (Figures 2.3-1 and 2.3-2, respectively). Geologic logging data on sonic core collected from alluvium were recorded on the Alluvium Core Logging Form (Figure 2.3-3). Digital photographs of alluvial sonic core segments from 22PC were documented on the Field Digital Photography Log.

Procedures for geologic logging of alluvial samples are based on the visual-manual logging methods described in ASTM D 2488-93. The alluvium logging form records soil classification parameters, many of which are related to flow and transport properties of alluvial sediments. These parameters include color, moisture, PSD, cementation, hydrochloric acid (HCl) reaction, and other soil characteristics.

The non-alluvium logging form records parameters that support the identification of lithostratigraphic units, including color; moisture content in the unsaturated zone; rock unit; weathering; structure; matrix porosity; and color, size, and volume of phenocrysts and clasts. Since most rock units in the vicinity of Yucca Mountain are volcanic tuffs, additional descriptive tuff parameters include mode of deposition, degree of welding, and alteration. In addition, both alluvium and non-alluvium logging forms include sample bulk-density-related measurements, and rates of drilling, coring, and water production.

Field estimates of PSD in alluvial samples were used to estimate gross textural variability over the sample interval. Since these were field estimates, they were not used for quantitative purposes; instead, laboratory PSD measurements were used where quantitative data were required. In general, field logging observations were valuable for qualitatively identifying trends in logged flow related parameters in the saturated zone versus depth to support the location of well screens; as well as identify trends in color, clay content, and cementation that may indicate the presence of low permeability paleosols that may in part control flow in the unsaturated zone. Trends in several of these logged parameters are described in Section 4.0. Also, since field estimates of PSD were determined over each 2.5 ft interval and laboratory measurements of PSD were determined over every other 2.5 ft interval, field estimates that are reasonably accurate fill in data gaps between lab measurements.

2.4 Hydraulic Parameter Laboratory Testing

The number and type of hydraulic parameter related laboratory tests conducted on geologic samples collected during Phase V are summarized for drill cuttings in Table 2.2-1 and for sonic core in Table 2.2-2. The same tests were conducted on both drill cuttings and core samples. Most tests were conducted on every other 2.5 ft sample interval for drill cuttings and on each identified textural layer for sonic core samples. All laboratory tests were conducted in accordance with industry standard methods (Table 2.4-1).

Tests were not conducted on saturated non-alluvial samples. Tests on unsaturated non-alluvial drill cuttings collected over each 5-foot depth interval were limited to gravimetric water content measurements (Table 2.2-1).

2.5 Borehole Geophysical Logging

The primary geophysical logging contractor, Geophysical Logging Services (GLS) of Prescott, Arizona, was responsible for conducting downhole logging in all Phase V boreholes in accordance with industry-standard procedures (ASTM, 1995; API, 1997). Century Geophysical Corporation (Century) of Tulsa, Oklahoma was also contracted to conduct logging in several boreholes.

Descriptions of methods, specifications, and quality controls are presented in WP-6.0 and TP-11.0 listed in Table 1.6-1.

A comparison of GLS and Century density and moisture logs described in section 2.5.3 of NWRPO (2005) demonstrated that Century nuclear tools produced logs with higher signal-to-noise ratios than GLS non-nuclear tools. As a result, GLS moisture and density logs will not be discussed in this report.

2.5.1 Description of Borehole Geophysical Logs

Table 2.5-1 summarizes the types, properties measured, and applications of the geophysical logs performed in Phase V. Most of these logs were also run in EWDP Phase III and IV boreholes. A number of these logs measure similar or related parameters and have similar applications. These logs are run together in the same borehole to increase the level of confidence identified in logging data trends. Individual logs are discussed in relation to major categories of use or application in the following section.

Two additional new state-of-the-art logs to help measure formation fluid flow were run in selected EWDP Phase V boreholes for the first time. The first log, FEC, provided information on flowing intervals in open boreholes 24PB and 32P. FEC logging involved replacing groundwater within the well bore with deionized water, and then pumping the well at a constant rate from the upper part of the borehole while the hole was logged with an electrical conductivity probe. Logging was also conducted while pumping was not occurring. At locations where groundwater enters the borehole, the FEC log displays electrical conductivity peaks. By analyzing these logs at successive times it is possible to obtain flow rate and salinity data for the inflowing groundwater at different locations in the borehole. Nye County was responsible for conducting the electrical conductivity logging and the associated quality assurance of these logs. Lawrence Berkeley National Laboratory (LBNL) was responsible for supplying and operating the deionization equipment with support from Nye County.

Both Nye County and LBNL will produce separate technical reports describing and interpreting FEC logs. Nye County will present this information in a future report describing single-well push-pull tests in 24PB. A description and qualitative discussion of FEC logs in this report will be limited to those conducted in 32P.

The second new log run in EWDP boreholes was a thermal perturbation log in 24PB which utilized a distributed thermal perturbation sensor system (DTPS) to measure thermal responses due to formation fluid flow in the vicinity of the borehole after it was instrumented and subsequently backfilled with stemming materials. This method involved applying heat uniformly along the length of the borehole using a heating wire included in the Nye County borehole instrument package. A fiber optic temperature sensor, also included in the borehole instrument package, was then used to record the temperature profile along the borehole as a function of time. Cooler zones logged in the borehole may be related to lateral fluid flow in the formation. Nye County was responsible for installing a heater wire and a fiber optic cable (temperature sensor) as part of the Nye County instrument package in 24PB. LBNL was responsible for operating both the heater wire and DTPS. As in the case of FEC logging, both Nye County and LBNL will produce separate technical reports describing the DTPS logging and its significance. DTPS logging will not be discussed further in this report other than describing the installation of the heater and fiber optic cable in the 24PB borehole instrument package in Section 3.1.

2.5.1.1 Lithology Identification and Correlation

Gamma, density, moisture, sonic, spectral gamma, spontaneous potential, fluid resistivity, formation-related resistivity (i.e., R8, R16, R32, or R64), and optical televiewer logs can help identify and confirm formation contacts and properties in areas where sample recovery is poor, lithologic units are similar or indistinct, or where bedded lithologic units are thinner than the geologic sample interval. For example, density, moisture, and sonic log outputs are related to formation and/or layer porosity, which may vary between lithologic units.

Gamma logs help identify clay layers and indicate the natural changes in the gross radioactivity between differing volcanic units. Spectral gamma logs can be used to ascertain relative amounts of potassium, thorium, and uranium to aid in lithology identifications. Spectral gamma log data were obtained in all Phase V wells, with the exception of 32P.

Formation-related resistivity logs can indicate areas of increased welding in volcanic units, and also respond to the presence of clays. In addition, fluid resistivity, formation-related resistivity, and spontaneous potential log outputs may vary between formations and/or layers within a formation and can be used to identify and evaluate contacts between subsurface geologic units, thinly bedded sequences, and vertical facies changes in sedimentary sequences.

Caliper logs provide borehole diameter data necessary for the interpretation of many of the logs. For example, log responses to washout zones (i.e., intervals of borehole with significantly larger diameters) can be separated from actual responses to changes in formation and/or borehole fluid parameters. In addition, changes in borehole diameter are often related to lithology changes, especially contacts between unconsolidated and consolidated material.

Optical televiewer logs can provide a continuous 360-degree image of the reflection of the borehole wall via a prism mirror and camera, and can detect fractures, thin beds, and bedding dip. This log also provides caliper and deviation data.

2.5.1.2 Water Production Zone Identification

Several geophysical logs can provide information about water transmitting zones. For example, temperature (fluid temperature and differential temperature) logs can detect changes in subsurface temperature gradients at groundwater production zones (e.g., inflow from fractures). Fluid and formation resistivity logs can in some cases identify changes in salinity and total dissolved solids in water from different production zones. Formation resistivity logs can also potentially identify differences in groundwater chemistry at different distances outward from the borehole. Spontaneous potential logs can in some cases identify differences in borehole and formation fluid composition. Formation porosity information, which may be related to aquifer production, can be obtained from density, neutron moisture, and sonic logs. Finally, FEC and DTPS logs described briefly in Section 2.5.1 are relatively new and powerful tools to identify regions of fluid flow in open and backfilled boreholes, respectively.

2.5.1.3 Well Installation Support and Use

A number of logs also provide valuable information that can be used for well design, installation, verification, and use. Caliper logs yield borehole diameter data, which are useful for the design and placement of well screens and sampling ports. Deviation logs provide information about the locations of notable borehole deviations from the vertical (e.g., doglegs) that may complicate the completion process. Borehole deviation data are also necessary to provide accurate elevations of geologic contacts, screened intervals, and water table and piezometric surfaces. Following well installation, gamma and density logs can also help confirm the location and integrity of bentonite seals and well-screen sandpacks in completed wells.

2.5.2 Suites of Borehole Geophysical Logs

Table 2.5-2 summarizes the three suites of geophysical logs used in Phase V. Open-hole geophysical logs were run in open, uncased boreholes, where borehole stability was good and the drill pipe or casing could be removed before logging. In unstable boreholes, drill-string logs were run in drill pipe or drill casing in place of open-hole logs. After the completion of the well casing strings with sandpacks and seals, well-completion logs were run inside the well casing strings.

The drill-string logging suite generally includes neutron moisture, density, gamma, temperature, and deviation logs. These logs were run in the drill string of 13P, 22PC, 24PB, 32P, and 33P after reaching total depth and before open-hole and completion logs.

The open-hole geophysical log suite generally includes drill-string logs plus formation resistivity, fluid resistivity, spontaneous potential, caliper, magnetic susceptibility, sonic, and optical televiewer logs. Temperature and fluid resistivity logs are typically run downhole in the first tool run to capture undisturbed temperature and salinity gradients in the water column. These open-hole logs were run in 13P, 24PB, 32P, and 33P.

The well-completion suite generally includes drill-string logs plus magnetic susceptibility. This suite of logs was run in all wells following completion with well casing and screen. The well-completion suite was run in all boreholes except 32P and 33P where the small inner diameter of the triple-string piezometer tubing (approximately 1.38-inches) precluded running borehole geophysical logging tools.

3.0 WELL COMPLETION AND DEVELOPMENT

Well completion and development for Phase V were conducted by drilling contractors under oversight by the NWRPO in accordance with applicable QA drilling and well construction plans (Table 1.6-1), except where deviations from these plans were necessitated by field conditions and/or findings.

3.1 Well Completion

All Phase V boreholes, with the exception of 24PA (which was abandoned), were completed as piezometers and constructed in accordance with permit requirements and the Nevada Administrative Code (i.e., NAC 534.60–534.90). In addition, 24PB was completed with u-tubes and companion injection lines for sampling and injecting groundwater tracers, respectively. Table 1.3-1 summarizes completion data, including open-hole water levels, screened and sandpacked intervals, and formation units adjacent to these intervals. The completion diagrams in Appendix B contain the same information, with the exception of formation units. Table 3.1-1 contains reference point elevations (i.e., top of casing and ground surface) for water level measurements, as well as initial water level measurements. Depth data in Tables 1.3-1 and 3.1-1 and in Appendix B have not been corrected for borehole deviation.

WDC completed a single-string piezometer in 13P; Eklund completed a single-string piezometer and several u-tube/injection line systems in 24PB, and triple-string piezometers (i.e., nested) in 32P and 33P; and Boart Longyear completed dual-string piezometers in 22PC. Figure 3.1-1 shows the single-string completion in 13P, Figure 3.1-2 shows the dual-string completion in 22PC, Figures 3.1-3 and 3.1-4 show the triple-string completions in 32P and 33P, respectively, and Figure 3.1-5 shows a single-string piezometer in 24PB plus duplicate u-tube/injection line systems at two depth intervals below the piezometer screen.

The piezometer casing strings consisted of 2-inch Schedule 80 (i.e., 1.9-inch ID and 2.375-inch OD) flush joint PVC in 13P and 22PC, 2-inch Schedule 10 flush joint stainless steel (i.e., 2.157-inch ID and 2.375-inch OD) in 24PB, and 1.25-inch Schedule 40 flush joint PVC (i.e., 1.38-inch ID and 1.66-inch OD) in 32P and 33P. The piezometer screens consisted of the same casings as mentioned previously with machined 0.020-inch horizontal slots and the following corresponding open areas: an open area of 7.4 square inches per foot (in^2/ft) in 13P, 4.4 in^2/ft in 22PC, 1.7 in^2/ft in 24PB, and 4.0 in^2/ft in 32P and 33P.

An enlarged schematic picture of a u-tube/injection line system installed in 24PB is presented in Figure 3.1-6 (Freifeld, 2007). U-tubing consisted of 0.5- and 0.25-inch stainless steel tubing and the injection line comprised of 0.25-inch stainless steel tubing. Filters were attached to the inlet of the u-tube and the outlet of the injection line to minimize clogging while running the equipment into the borehole and while adding completion materials.

Single-string borehole piezometers were completed in Tertiary tuff with screens straddling the water table in 13P from 426.0 to 466.0 ft bgs, and between approximately 325 and 366 ft below the water table in 24PB (729.2 to 769.9 ft bgs).

Dual-string piezometer 22PC was completed in alluvium with one screen from 510.0 to 579.8 ft bgs and the other from 665.4 to 755.0 ft bgs. The depth intervals of these screens correspond approximately to the screens in Phase III well 22PA and the upper two screens in 22S located at Site 22.

Triple-string piezometers were completed in alluvium in 32P with screens from 238.7 to 277.9 ft bgs, 463.7 to 483.3 ft bgs, and 697.9 to 737.0 ft bgs; and in 33P with screens from 210.8 to 249.9 ft bgs, 484.5 to 523.6 ft bgs, and 600.9 to 640.0 ft bgs.

Depth control for the emplacement of sandpacks and grout seal material was monitored by estimating downhole annular volumes, tracking volumes of emplaced materials, and frequently checking depths of emplaced materials by manual sounding methods. In all cases, these materials were emplaced using tremmie pipes. During emplacement, the bottom of the tremmie pipe was maintained approximately 10 to 30 ft above the level of completion materials to minimize annular bridging and voids in the completion.

Sandpacks around the piezometer screens consisted of washed 8/12 mesh silica sand, except for 13P where 8/20 mesh silica sand was used. In all boreholes sand was tremmied to within 1 to 2 ft of the specified target depths, which were generally 5 to 10 ft above and below well screens.

Generally, grout seals in both the unsaturated and saturated zones of RC boreholes consisted of intervals of high-solids (i.e., more than 30 percent solids) bentonite grout and intervals of a mixture of 8/12 mesh silica sand and 8 mesh granular bentonite at a ratio of approximately 2 to 1 by weight. The NWRPO refers to this mixture as Bensand. Bensand was used to plug zones where large amounts of high solids grout were lost to the formation. Finally, Bensand was used to seal zones both below and above the sandpacks.

Both the sandpack and Bensand seal intervals were emplaced to the target depths using a tremmie pipe and centrifugal pump. Generally, water was initially pumped through the tremmie pipe at approximately 25 to 50 gallons per minute (gpm), followed by the addition of dry completion materials to the water stream via an open “tee” connection on the water intake side of the centrifugal pump. High solids bentonite grout was tremmied using a standard (i.e., diaphragm) grout pump.

To protect the piezometer string wellheads extending above the ground surface, approximately 3 ft of protective steel surface casing was welded to the existing conductor casing installed during drilling. The annular space between the outer conductor casing and the piezometer casing was sealed with dry granular bentonite that was emplaced by gravity free-fall methods. For further protection, an approximately 4- by 4-foot by 8-inch-thick concrete pad was set around the surface casing. Wellhead completions vary slightly among piezometer sites, as shown in the as-built details in Appendix B. All surface casings are capped with locking well caps. Each wellhead is labeled with the well name in the cement pad. The wells were surveyed by a DOE YMP contractor for location and elevation data according to QA standards (Table 1.3-1).

3.2 Well Development

Air was used as the drilling fluid during borehole advancement and reaming beneath the water table in all Phase V boreholes, except in 22PC where sonic coring methods did not require the use of drilling fluids and in 33P where the DOE YMP driller used bentonite mud and polymer to advance the borehole. Borehole conditioning beneath the water table was limited to the use of a foaming agent, polymer, and bentonite mud in 13P as described in Section 2.1.2.1 As a result, completed

Phase V wells, with the exception of 13P and 33P, contain no drilling fluids in the saturated zone that could impact well screen permeability and/or water chemistry measurements. Due to the absence of impacting drilling fluids in 24PB and 32P, there was no post-completion development conducted in these wells.

Drilling difficulties encountered at 13P below a depth of 1,569 ft bgs required the use of bentonite mud and polymer conditioning agents. Although the borehole was never advanced beyond this depth, the presence of these conditioning agents required borehole development prior to well completion. Air lifting in the open borehole, specifically in the screen interval of the completion was attempted as previously mentioned in Section 2.1.2.1.

After completion of 13P, the first attempt at well development consisted of 4.5 hours of airlifting. A second attempt included injecting approximately 150 gallons of water mixed with approximately 24 fluid ounces of Baroid Aqua-Clear® PFD, swabbing the well, and airlifting. This second attempt occurred over a two day period. After both attempts, the water remained grayish brown with zero clarity. Further development work included limited purging conducted with a small diameter piston pump. Forty gallons of diluted PFD was injected prior to pumping. Pumping was conducted on 3 separate occasions over a one-year period from 12/1/05 to 9/28/06 at approximately 0.4 gpm for a total of approximately 45 hours. After these development activities, water quality improved and water was successfully sampled during the water sampling event on 9/28/06.

Due to the drilling fluids used during the drilling of 33P by DOE YMP contractors, borehole development was attempted during the clean-out of the borehole and prior to completion. Borehole development included injecting diluted Baroid Aqua-Clear® PFD, followed by air-lifting in an attempt to produce water and remove polymer and bentonite. Produced water was monitored using EC measurements to provide an indication of improving water quality over time. After producing approximately 16,000 gallons of water over 3 hours, EC measurements indicated that development had stabilized the water quality.

Finally, development of 22PC included air-lifting for 4 hours in the deep string prior to the start of the Site 22 NWRPO tracer testing. This development was conducted to attempt to redistribute fine sediments into the sand pack that may have accumulated near the borehole wall due to the sonic coring method.

4.0 GEOLOGIC SAMPLE LOGGING

The results of field geologic and photographic logging activities on drill cuttings and core are presented in this section. The majority of data produced from these activities is technically defensible and of value to the scientific and engineering communities concerned with the Yucca Mountain repository. However, as in nearly all large hydrogeologic characterization efforts, some data were compromised or biased as a result of sampling, testing, and/or handling activities and are potentially confusing or not useful. To the extent possible, these data have been censored, are listed in Table 4.1-1, and will be discussed in more detail in Section 4.1.1. In addition, specific reasons for censoring various data types are listed in Table 4.1-1. Censored laboratory data are also presented in Table 4.1-1 and will be described in Section 5.0.

Censored data are a relatively small subset of the data; uncensored data are the primary focus of this section. The censored data will not be made publicly available except in this report where examples of censored data are presented in several summary tables and figures designed to illustrate the limitations of the data and the methods used to collect them. However, complete sets of Phase V data, both censored and uncensored, can be viewed at the QARC.

4.1 Geologic Logging of Drill Cuttings

Examples of geologic logging data from drill cuttings, and descriptions of their limitations, trends, correlations, and significance, are presented in this section. Where appropriate, the possible bias that drilling methods and sample handling procedures introduce into geologic logging data and the ability of such data to accurately characterize in situ formation conditions and properties are described.

Examples of geologic logging forms for alluvial and non-alluvial drill cuttings are presented on Figures 2.3-1 and 2.3-2, respectively. All alluvial and non-alluvial drill cuttings geologic logging forms for Phase V boreholes may be reviewed on the NWRPO website (NWRPO, 2009) or at the QARC. As mentioned in Section 2.3, alluvium logging forms primarily record soil classification parameters, many of which are related to flow and transport properties of alluvial sediments. The non-alluvium logging forms primarily record lithology-related parameters to support identification of lithostratigraphic units. In addition, both forms include sample density measurements and rates of drilling, coring, and water production.

4.1.1 Data Censoring

All geologic logging and drilling data on the logging forms are considered to be useful in characterizing approximate in situ hydrogeologic conditions and properties, with some exceptions. One exception is sample density data (e.g., sample, tare, and sample plus tare weights) for drill cuttings from the unsaturated zone in logged portions of boreholes drilled using AR-RC or DR-CA methods, which were censored because a significant and variably-sized portion of the total drill cuttings from each sample interval was not collected and weighed (Table 4.1-1). The portion not collected was lost in part as dust from the cyclone separator. The sample recovery data on Figures 2.3-1 and 2.3-2 illustrate the variably sized portions of drill cuttings that were lost. The lack of an accurate weight for the drill cuttings removed from a particular drilled interval precluded the calculation of meaningful in situ density values in cases where accurate water content and borehole volume values were known. Efforts to minimize sample material lost as dust, maximize sample recovery, and obtain more accurate estimates of borehole volume for meaningful sample density data in the unsaturated zone have largely been unsuccessful in EWDP Phases III, IV, and V. Also, sample density data are not collected from beneath the water table, due to the difficulty in separating water from the solid samples. For these reasons, consideration will be given in future EWDP phases to eliminate sample density measurements from the drill cuttings logging forms.

In previous EWDP drilling reports (NWRPO, 2003; NWRPO, 2005) field estimates of PSDs have been censored due to the difficulty in obtaining data that were reasonably consistent with laboratory PSD measurements. However, in Phase V field estimates generally agree closely with laboratory data, and as a result the field data have for the most part not been censored. Examples of the agreement between field estimated and laboratory measured PSD data are presented in Section 5. As mentioned previously, field PSD data, if reasonably accurate, help to fill in data gaps in the depth intervals between laboratory measurements and thereby help to provide a more realistic picture of variation in PSDs (i.e., textural layering) with depth.

4.1.2 Geologic Logging and Drilling Depth Profiles

Depth profiles of selected geologic logging and drilling data that illustrate important trends with depth are presented in this section. Examples of depth profiles for both alluvial and non-alluvial portions of the boreholes are presented, where applicable. Geologic logging parameter data for sample intervals of alluvial drill cuttings include field estimates of moisture content, cementation and HCl reaction; and for non-alluvial drill cuttings include HCl reaction and the degree of welding in tuff, if present. Drilling data are limited to measured drilling and water production rates.

The criteria used to describe geologic logging parameters are qualitative or semiquantitative at best, and are subject to human error and inconsistency. Therefore, trends in these parameters are considered approximations of in situ conditions. At the same time, geologic descriptions are useful for identifying drilling impacts and relative changes in hydrogeologic parameters with depth for both drill cuttings and the formation rock.

Drilling parameters recorded on logging forms are measured values; however, it should be noted that these measurements are in some cases approximate quantities. For example, water volumes are calculated from the number of nearly or partially full 5-gallon buckets containing varying amounts of drill cuttings sediment.

Finally, geologic logs from Phase V boreholes (NWRPO, 2009) indicate that alluvial drill cuttings are composed of 100% volcanic rock, and non-alluvial drill cuttings are composed primarily of volcanic rock or sediment derived from volcanic rocks. Similar observations had been made in geologic samples from Phase III and IV boreholes (NWRPO, 2003; NWRPO, 2005).

4.1.2.1 Moisture Content Depth Profiles

Core samples which are considered to exhibit moisture contents that are representative of in situ conditions have demonstrated in a previous study (NWRPO, 2005) that in situ alluvium is moist throughout most of the unsaturated zone; that is, in the region below the effect of near-surface evapotranspiration and above the effect of any capillary fringe near the water table. The fact that most AR-RC drill cuttings samples in Phase V boreholes were observed to be dry suggests that the drilling and sample collection processes were responsible for drying the cuttings. Drying is likely due to a number of factors including the heat generated at the drill bit, the elevated temperature of the compressed air, air movement around the drill cuttings as they were brought to the ground surface, and the drying that may have occurred on the ground surface before samples were packaged in air-tight plastic bags.

Narrow peaks in moisture content shown in the upper 150 ft of the unsaturated zone in 32P (Figure 4.1-1) are likely to be the result of the introduction of liquid drilling fluids during borehole conditioning procedures described in Section 2.1.2.3. In some cases a narrow peak in moisture content may be due to the presence of an underlying layer of significantly finer texture. This is likely the case for the peak from 62.5 to 67.5 ft bgs in 13P (Figure 4.1-2) where both sand and fines content increase significantly in underlying layers.

The broad step-like increases towards higher moisture contents in 32P beginning at approximately 230 ft bgs in Figure 4.1-1 indicates that the capillary fringe above the water table was likely penetrated at approximately 230 ft bgs. The fact that samples are only moist (i.e. not wet) in the upper 15 ft of the aquifer (245 to 260 ft bgs) indicates that drying also occurs in the upper portion of the aquifer where large volumes of water are not produced as shown in Section 4.1.2.4. This drying process in the upper portion of the water table was also observed in NWRPO (2005).

The broad moist peaks in moisture content shown between approximately 190 and 350 ft bgs in 22PC (Figure 4.1-3) are likely due to the lateral flow of drilling fluid from a nearby borehole (22S) which lost hundreds of thousands of gallons of liquid drilling fluid while penetrating the vadose zone (NWRPO, 2003).

4.1.2.2 Cementation and Hydrochloric Acid Reaction Depth Profiles

Cementation was not observed in drill cuttings of unsaturated alluvium in Phase V boreholes. However, older and deeper saturated fluvial sediments exhibited strong cementation from 500 to 540 ft bgs in 32P (Figure 4.1-4). In addition, several weakly cemented thin intervals were observed in this borehole between 700 and 900 ft bgs in the same fluvial sediments.

It should be pointed out that it is very difficult to identify degrees of cementation in drill cuttings. The drilling method, equipment, specific technique used by the driller, and related drilling rates can potentially affect evidence of cementation.

It was originally hypothesized that the difference in drilling rates in Phase IV borehole 24P and Phase V borehole 24PB was responsible for very different depth profiles of cementation (Figure 4.1-5) in the two boreholes, which are separated by approximately 150 ft, even though AR-RC drilling methods were primarily used in both boreholes. Borehole 24P drilled at an average rate of approximately 2 fpm in unsaturated alluvium while the 24PB alluvium was drilled at a rate of approximately 1 fpm (Section 4.1.2.3). It was hypothesized that the slower drilling rate disturbed the drill cuttings more (i.e., reduced particle sizes abraded more cement from clasts) than the faster rate. However, in Section 5.2.1.1 it will be shown that the opposite is true for the gravel fraction; that is, the slower drilling rate produced more gravel (average of 33 vs. 27%) than the faster drilling rate. The reason for this unexpected apparent effect of drilling rate on gravel content is unknown. It may simply be that drilling rate is not the important factor as expected, but that variations in stratigraphy between the boreholes, which are separated by approximately 150 ft, may be responsible for the observations in both cementation and PSD.

Because of the difficulty in observing evidence of cementation in drill cuttings and the possible effects of drilling related factors such as drilling rate and the other drilling parameters, consideration will be given to eliminating cementation from geologic logs of alluvium drill cuttings in future EWDP Phases.

HCl reaction is more easily observed than cementation and the reaction for different sample intervals ranged from none to strong in Phase V boreholes, the only exception being 13P, where the reaction remained strong throughout the unsaturated alluvium interval. In all Phase V boreholes there is little or no correlation between cementation and HCl reaction in unsaturated alluvium. Since alluvium penetrated in Phase V boreholes does not contain carbonate rocks, HCl reaction indicates the presence of calcium carbonate, a potential cementing agent. However, the lack of correlation between HCl reaction and cementation indicates that calcium carbonate does not play a major role in cementation. A similar lack of correlation between HCl reaction and cementation was observed in Phase IV boreholes (NWRPO, 2005).

In contrast to cementation data, a good correlation was observed between HCl reactions in nearby boreholes. This is illustrated in Figures 4.1-6 and -7, which show HCl reaction in Phase III borehole 22SA and Phase V borehole 22PC. These boreholes are located approximately 60 ft apart. A good correlation in HCl reaction is also observed between Phase IV borehole 24P (NWRPO, 2005) and Phase V borehole 24PB (Figure 4.1-8). As mentioned previously, these boreholes are separated from each other by approximately 150 ft.

Finally, it is interesting to note that HCl reaction is very similar in the upper 260 ft of alluvium in 24PB (Figure 4.1-8) and in 32P (Figure 4.1-9). For example, no HCl reaction was observed between depths of approximately 50 and 150 ft bgs in both boreholes. This may indicate that similar sediment deposition and soil forming processes have occurred over time at these two locations, which are separated by more than 5 miles in Fortymile Wash.

4.1.2.3 Drilling Rate Depth Profiles

Numerous formation- and drilling-related factors affected drilling rates in boreholes or portions of boreholes drilled using AR-RC or DR-CA methods. Drilling parameters include drill bit and drill casing diameters and types, drill bit weights, air pressures and flow velocities, and rotation rates. For the purpose of discussing drilling rates herein, it is assumed that drilling parameters remain approximately constant within a particular borehole, and that variations in drilling rates are due primarily to differing rock properties and the decrease in drilling efficiency with increasing penetration depth.

Drilling penetration rates in Phase V boreholes varied from less than 0.5 to greater than 3 fpm. Typically, the highest drilling rates (i.e., 1 fpm or greater) were recorded in alluvium, clastic sedimentary rocks (e.g., siltstone or claystone), volcaniclastic sedimentary rocks, and nonwelded intervals in volcanic tuffs. The lowest drilling rates (i.e., less than approximately 0.5 fpm) were recorded in the welded portions of most tuff units. These relations between drilling rate and rock type are most clearly illustrated in the upper approximately 1,000 ft of 24PB (Figure 4.1-10).

The effect of different drillers on drilling rate is illustrated by comparing Figure 4.1-10 with -11; that is, Phase V borehole 24PB and Phase IV borehole 24P (NWRPO, 2005), respectively. The trends in drilling rates vs. rock type vary similarly in both boreholes, but the magnitudes differ. As mentioned previously, these boreholes are separated by approximately 150 ft at the ground surface. Both boreholes were drilled by the same company (Eklund) using nearly the identical AR-RC equipment, but with different drillers. The driller of 24PB conditioned the borehole more often and drilled the borehole more slowly than the driller of 24P. This was in part due to Nye County requirements to keep 24PB as straight (i.e., near vertical) as reasonably possible to facilitate the installation of u-tube related instrumentation.

4.1.2.4 Water Production Depth Profiles

The rate of water production in RC boreholes is also a complicated function of a number of formation- and drilling-related parameters, including the variation in formation permeability with depth, depth below the water table, rate of drill bit advancement, drill bit diameter, air pressures and flow velocities, borehole conditioners and methods of conditioning, and the extent to which the drill bit and casing assembly sealed water off from the overlying formation. It is assumed herein that drilling-related parameters remain approximately the same for all boreholes, except the extent to which the drill bit and casing were sealed off.

Typically, water production increased with depth, especially in zones of sandstone, and moderately or densely welded tuffs that are presumably highly fractured. Moreover, nonwelded tuffs and claystone generally appeared to slow water production. These trends are illustrated in 13P (Figure 4.1-12) where nonwelded tuff and claystone inhibited the production of water from the water table (431 ft bgs) to a depth 745 ft bgs. At this latter depth, a sandstone layer began to produce sufficient water to be observable during drilling. Low water production rates (approximately 34 gpm) from 1,400 to 1,440 ft bgs were likely due to plugging of the drill bit and/or dual-wall casing primarily in claystone intervals. The highest water production rates (140 gpm) were from sandstone intervals beginning at 1,440 ft bgs and extending to 1,500 ft bgs. Nonwelded and moderately welded tuff units penetrated at approximately 1,500 ft bgs appear to have the effect of reducing water production.

Conglomerate and non- and weakly welded tuff intervals beginning at approximately 915 ft bgs in borehole 24PB appear to slow the rate of increasing water production slightly compared to overlying moderately and densely welded tuff units (Figure 4.1-13). The slope of the graph of water production vs. depth decreases from approximately 915 to 1,200 ft bgs. A similar trend was noted in nearby Phase IV borehole 24P from approximately 1,000 to 1,300 ft bgs (Figure 4.1-14). Finally, it is interesting to note that 24PB produces 20 to 25% more water than 24P at depths below 700 ft bgs even though they are separated by only approximately 150 ft. This may in part be due to the use of a slightly larger tricone center-return bit in 24PB (6.5-inch OD) than those used in 24P (6.125- and 6.25-inch OD) and/or proximity to faults and fractures.

4.2 Geologic and Photographic Logging Results on Core

As described in Section 2.2.2, continuous sonic core was collected from the lower approximately 10 ft of unsaturated alluvium and upper approximately 293 ft of saturated alluvium in 22PC. If collected using appropriate equipment and procedures, alluvial sonic core segments provide subsurface formation material that is much less disturbed from in situ conditions than drill cuttings (NWRPO, 2005). This section presents examples of geologic logging and coring-related data for these core samples and discusses limitations, trends, and correlations, where applicable. In addition, selected photographic logs are presented to illustrate examples of coring-related disturbance, textural layering, and selected mineral and rock components of sonic core samples.

Alluvial sonic core logging data (i.e., field estimated data) from 22PC were generally considered to be representative of similar data determined by laboratory tests on split core samples. As a result, field core logging data were not censored, as were selected drill cuttings logging parameters described in Section 4.1.1. In Section 5, PSD data (% gravel, sand, and fines) from field logging estimates and lab measurements will be shown to agree closely. However, it should be emphasized that related grading, plasticity, and Unified Soil Classification System (USCS) group symbols for field and lab data may not agree as closely because they depend on the shape of the PSD curve and Atterberg limits measurements, which can only be determined accurately in the laboratory.

4.2.1 Coring and Geologic Logging Data Trends

An example geologic logging form for drive and sonic core is presented on Figure 2.3-3. The complete set of logging forms for this core may be reviewed on the NWRPO website (NWRPO, 2009) or at the QARC. These logs include core recovery and density data, as well as geologic descriptions, and contain the same information found on the geologic logging forms for alluvial drill cuttings previously discussed in Section 4.1, with the exception of drilling fluid injection and water production rates. These rates are not applicable to the coring methods used and were not included on the core logging forms.

4.2.1.1 Sonic Core Bulk Density

Table 4.2-1 summarizes calculated dry bulk density for the nearly continuous sonic core runs in 22PC. Bulk density values shown in this table are weighted averages of core segment lengths making up each core run. Core runs were 10.4 ft long or less and contained as many as seven individual core segments. Details of sonic core bulk density calculations are presented in documents assigned to QA record index designator (RID) 7195.

Table 4.2-1 shows that core collected with the smaller diameter core barrel (i.e., 4.5-inch-OD) yields dry bulk density values that are slightly higher on the average than those on core collected with the larger diameter core barrel (i.e., 6.16-inch-OD). No other trends with depth are apparent. These slightly differing bulk density values may be due in part to the greater difficulty in determining the amount of lost core when using the smaller diameter core barrel. For example, Table 4.2-1 shows that if smaller diameter core runs containing more than 0.2 ft of lost core are excluded from the average calculation, the average dry bulk density values for runs generated from both core barrels are essentially the same (i.e., 1.66 versus 1.67 grams per cubic centimeter [g/cm^3]). TP-8.0 provides a detailed description of procedures for identifying lost core. These average density values for core runs with less than 0.2 ft of lost core translate into an average porosity value of 0.34 cm^3/cm^3, using an average laboratory determined particle density of 2.53 g/cm^3.

The representativeness of sonic core run density values in Table 4.2-1 may also be questionable, due to the assumptions required to make the density calculations. For example, the assumption made in

RID 7195 that the corehole diameter equals the OD of the core barrel may not be correct. Assuming a slightly smaller diameter (e.g., the ID plus one wall thickness) or a slightly larger diameter (e.g., the OD plus one wall thickness) significantly changes the calculated dry bulk density values shown in Table 4.2-1.

Finally, errors in measured and calculated gravimetric water contents (see RID 6142 for the method of calculating gravimetric water contents) can significantly affect dry bulk density calculations. Calculated densities for Phase IV 19PB sonic core presented in Table 4.2-2 (NWRPO, 2005) compared to Phase V 22PC sonic core densities in Table 4.2-1 show that the latter are significantly (nearly 8%) lower than the former densities. This is likely due in part to evaporative loss of water from 19PB core samples during sample handling and logging in the field. This was recognized when evaluating 19PB density data and gravimetric water content data, and steps were taken to minimize this water loss when logging and handling 22PC sonic core. The average calculated gravimetric water content for 19PB core segments was approximately 0.13, whereas the average value for 22PC core segments was 0.17. This difference of 0.04 in average water content translates into a difference of 0.04 or more in dry bulk density. That is, 19PB densities would decrease significantly, if a higher gravimetric water content was used (i.e., 0.17 instead of 0.13).

4.2.1.2 Sonic Core Composition, Cementation, and Hydrochloric Acid Reaction Trends

The geologic logs of the nearly continuous sonic core collected from saturated alluvium in 22PC allow the determination of trends of selected geologic parameters with depth in the upper alluvial aquifer. Geologic logs of alluvial core from 22PC (NWRPO, 2009) show that the alluvium is composed of 100% volcanic rocks. This observation is consistent with previous Site 22 observations based on geologic logs of drill cuttings from the entire alluvial sequence in exploratory Phase III borehole 22SA (NWRPO, 2003) and Phase IV boreholes 22PA and 22PB (NWRPO, 2005).

In contrast to the lack of variation in rock composition, geologic logs of sonic core in 22PC indicate some variation in cementation and HCl reaction with depth. Figure 4.2-1 shows that there are numerous weakly to moderately cemented zones from approximately 537 to 666 ft bgs in the saturated alluvium in 22PC. From 666 ft to TD (763 ft bgs) in 22PC, no evidence of cementation was observed. However, cementation observed in Phase III borehole 22SA (NWRPO, 2003) located approximately 60 ft from 22PC was not observed in drill cuttings below the water table until a depth of 670 ft bgs was reached (Figure 4.2-2). Moreover, cementation continued to be observed in most drill cuttings sample intervals until a total depth of 1,110 ft bgs was reached (Figure 4.2-2).

These differences do not indicate spatial variation in cementation between boreholes located at Site 22. Rather, as pointed out in the above paragraph, these differences (i.e., no correlation between cementation observed in 22PC sonic core samples and cementation in drill cuttings from 22SA between 537 and 763 ft bgs) illustrate the difficulty in identifying degrees of cementation in drill cuttings. In future EWDP Phases, cementation will not be recorded for drill cuttings; instead, it will be recorded only for core samples where evidence of cementation is more readily observable.

HCl reaction was not observed in 22PC sonic core samples (NWRPO, 2009) over the total coring interval from 460 to 763 ft bgs. Drill cuttings samples from 22SA over the same depth interval also showed no evidence of HCL reaction. In addition, HCl reaction in 22SA drill cuttings was only observed in approximately the upper 100 ft of the unsaturated zone and below approximately 760 ft bgs in the saturated zone (Figure 4.2-3). These findings indicate that significant calcic horizons are not present in the capillary fringe from above the water table to several hundred ft below the water table at Site 22. Moreover, the mechanism for precipitation of calcite at the water table in arid settings suggested by some workers, including Walvoord and others (2005), is not operative to a significant degree at 22PC.

4.2.1.3 Sonic Coring Rate and Run Length Trends

Figure 4.2-4 shows evidence of a weak correlation between coring rate and run length in 22PC; however, this correlation is slightly higher than in the Phase IV borehole 19PB. Some evidence for this correlation was expected because both parameters are related to the ease, or difficulty, of advancing the sonic core barrel. A number of related factors potentially affect core barrel advancement including: formation density, the amount of coarse gravel and cobbles present, gravel and cobble rock type, core barrel diameter, depth bgs and source of sonic vibration, and the specific coring methods used by the driller (NWRPO, 2005).

4.2.1.4 Sonic Core Expansion

The sonic coring process caused core to expand. Thus, the core run length measured in the logging trailer in all cases exceeded the field, or cut, core run length in the corehole. However, reasonably accurate depth intervals were assigned by assuming that expansion was constant throughout each core run and then systematically correcting for this expansion, as detailed in TP-8.0.

4.2.2 Photographic Logs and Sonic Core Layers and Disturbance

Some particle size segregation occurred during sonic coring. Specifically, some fines generally migrated from the interior of the core to the outside edge of the core. This disturbance is recorded in many of the digital and video photographic logs of the core, such as the one shown on Figure 4.2-5. This migration of fines to the outer edge of the core complicated the process of sampling major textural layers and possibly introduced error into laboratory PSD measurements on EWDP Phase IV sonic core from 19PB (NWRPO, 2005). However, in Phase V sonic core from 22PC, this potential sampling bias was avoided where possible by splitting samples in half horizontally. If this was not possible for 22PC core samples, pie shaped samples with their apex terminating in the center of the core, were collected.

There is no evidence from geologic or photographic logs that fines migrated along the length of the core. It was therefore assumed that textural layers remained intact in the sonic core, were representative of in situ conditions, and were suitable for detailed geologic logging and laboratory testing. Some good examples of textural layers present in approximately 2-foot-long core segments are illustrated on Figure 4.2-6.

Photographic logs also illustrate the effect of the heat generated from the coring process on the distribution of water in the core (Figure 4.2-7). Most heat was generated at the core bit, causing the temperature of the core adjacent to the core bit to increase more than core located further up the core barrel. This heat caused water to migrate from the region of the core bit upwards into core located in the uphole end of the core barrel. The additional water in the uphole portion of the core often resulted in colors darker in Munsell value, while the drier, downhole portion of the core exhibited colors lighter in Munsell value. Care was taken to air-dry the excessively wet core to a moist state and to consistently record only the Munsell colors of moist core.

Photographic logs can also illustrate minerals and rock types present in the alluvium as shown in Figure 4.2-8. For example, white zeolite and pink weathered zeolite clasts are easily identified in the photographic log in the depth interval form 502.5 to 504.2 ft bgs.

5.0 LABORATORY TEST RESULTS

The results of laboratory data collection activities for core and drill cuttings samples are described in this section. Data from laboratory hydraulic property tests of sonic core segments from 22PC are tabulated in Appendix C. Appendix C also contains laboratory hydraulic property test data from Phase V borehole drill cuttings. Censored laboratory test data and reasons for censoring are presented in Table 4.1-1.

5.1 Laboratory Tests of Sonic Core Samples

A summary of laboratory testing results on 22PC sonic core samples is presented below. These results include measurements that are independent of porosity, such as PSD (including USCS and Atterberg limits classifications), EC, and gravimetric water content. Since sonic grab core samples are not suitable for porosity-dependent tests, such as dry bulk density and saturated hydraulic conductivity, these latter tests were not conducted. Finally, it should be noted that laboratory tests on sonic core should be considered smaller in scale and possibly less representative of field conditions than larger scale field aquifer and tracer tests.

Continuous sonic core in 22PC was collected and tested to provide the detailed data necessary to characterize layering in the upper portion of the alluvial aquifer at Site 22. These data support the interpretation of much larger scale NWRPO single and cross-hole tracer tests and associated hydraulic testing at Site 22 begun in 2004 and ongoing as of fall 2008. Once tracer test data are collected and analyzed, additional evaluations will be done to determine if average laboratory parameter values of sonic core are appropriate for modeling thick intervals of these highly variable alluvial sequences, or if the more coarse-grained and poorly graded sequences represent fast pathways for groundwater flow that should be accounted for in the models.

Because core samples are generally more representative of in situ conditions than drill cuttings, they can be used as a standard for estimating the disturbing effects of drilling on drill cuttings. Conducting laboratory tests (e.g., PSD) on core samples and drill cuttings from the same or nearly the same depth interval in the same borehole or closely spaced boreholes provides a way to gauge such disturbance. In Section 5.2 several comparisons of PSD profiles of different geologic samples will be presented, including drill cuttings from Phase III borehole 22SA and sonic core from nearby Phase V corehole 22PC.

5.1.1 Particle Size Distribution Data in 22PC

Summary statistics for PSD data from 22PC sonic grab core samples are presented in Table 5.1-1. All samples are coarse-grained and, on the average, contain approximately 16% fines and approximately 40% gravel and 44% sand. The USCS group name for the average PSD composition is a silty or clayey sand with gravel.

Gravel varies more than the other fraction sizes with depth. For example, the range in gravel extends from 16 to 72% and in some cases differs by more than 40 to 50% in adjacent depth intervals, as shown on Figure 5.1-1. On this graph, the area to the right of the No. 4 sieve curve represents the amount of gravel, the area between this curve and the No. 200 sieve curve represents the amount of sand, and the area to the left of the curve represents fines. This figure also shows a trend of slightly increasing percentages of fines and sand with depth and a corresponding decrease in percentages of gravel with depth.

Figure 5.1-2 shows that the fines fraction is composed of nearly identical proportions of clay and silt in sonic grab core samples from 22PC based on hydrometer particle size analyses. The clay on this figure corresponds to material with a particle diameter of less than or equal to 0.005 millimeter, as determined from hydrometer data; fines were determined by wet sieve methods from the minus 200 mesh sieve fraction (Appendix C). Note that there is a slight increase in fines and clay beginning at approximately 625 ft bgs and continuing to total depth at 763 ft bgs.

The Atterberg limits-based classification of the fines fraction in sonic grab core samples from 22PC is summarized in Figure 5.1-3. This classification system is described in ASTM D 2487-00 (ASTM, 2000). In general, this figure shows that silt (ML) predominates over clay (CL) and silty clay (CL-ML) in the upper 150 ft of the alluvial aquifer and the opposite is observed in the underlying 150 ft. The predominance of clay over silt and silty clay below approximately 625 ft bgs corresponds to a slight trend in increasing fines as shown in Figure 5.1-2.

5.1.2 Electrical Conductivity Data in 22PC and 19PB

EC measurements of soil-water extracts from unsaturated zone alluvial sediments can provide an approximate estimate of the presence of readily soluble salts, and therefore a possible insight into the location of paleosols (i.e., geologically ancient soils), the terminus of wetting fronts from paleo-recharge events along Fortymile Wash, and/or the location of paleo-water tables.

Sonic core EC data from the lower part of the unsaturated zone immediately above the present water table in 22PC shows a small spike or peak in EC that reaches 327 micromhos/cm at approximately 464 ft bgs (Figure 5.1-4). This plot of EC in 22PC differs significantly from that determined for 19PB (Figure 5.1-5) at a similar location immediately above the water table, but approximately 3 miles downstream from 22PC in Fortymile Wash. 19PB exhibits several large spikes or peaks of approximately 1,000 micromhos/cm and valleys (i.e., low values) between 200 and 400 micromhos/cm (Figure 5.1-5). Given the locations of these data in the unsaturated zone alluvial profile, it is possible that paleo-water tables may be responsible in part for these great variations in EC values in 19PB. For example, each large EC spike and subsequent valley may indicate a very long period of water table stability followed by a relatively rapid decline. It is possible that salt could accumulate at the air/water interface during the stable water table period and not accumulate during the decline. It is important to note that numerous other factors, including paleosols and paleo-recharge events, may also play some role in the development and maintenance of these EC peaks and valleys.

For example, wetting fronts may have reached the water table more frequently at 22PC located further upstream and less frequently at the downstream location in 19PB. This could result flushing of salts from the unsaturated zone more often in 22PC compared to 19PB.

Finally, 22PC is located on a terrace approximately 800 ft from the incised main Fortymile Wash channel and 19PB is located on the edge of the braided channel network of Fortymile Wash. Because of the proximity of 19PB to portions of the wash that periodically transmit flow, it is possible that the spikes in EC may correspond to the terminus of different wetting fronts. At the same time, the present day large distance between 22PC and the main Fortymile Wash channel, which transmits all the wash flow at this location, may preclude wetting fronts from impacting the subsurface at 22PC.

5.2 Laboratory Tests of Drill Cuttings

Laboratory hydraulic-property related tests of drill cuttings from Phase V boreholes are presented in Appendix C. Selected data from this appendix are summarized in tables and figures, compared with sonic core results, and discussed in the following sections.

5.2.1 Particle Size Distribution Data from Alluvium

The following assumes that the PSDs of alluvial drill cuttings produced by AR-RC drilling methods from the unsaturated zone are reasonably representative of unsaturated zone in situ formation PSDs and core sample PSDs. Evidence for this assumption was presented in NWRPO (2003 and 2005). Evidence that unsaturated zone drill cuttings produced by DR-CA methods may also have the potential to be reasonably representative of in situ conditions is presented below.

5.2.1.1 Spatial Trends in Particle Size Distribution Data

Recent work (NWRPO, 2005) showed the PSDs of alluvial drill cuttings in Phase IV boreholes differed significantly between Fortymile Wash and the next north-south drainage located to the west (Flat Tire Flat). Boreholes in Fortymile Wash generally exhibited coarser-grained alluvium. Figure 5.2-1 also shows that alluvium in a typical Phase V Fortymile Wash borehole (24PB) is coarser-grained than in Phase V borehole 13P, located even further to the west along the eastern edge of Crater Flat (Figures 1.3-1 and 1.4-1). The 13P borehole is much finer-grained (contains more fines and less gravel) from approximately 160 to 260 ft bgs in the interval underlying a basalt flow (Figure 5.2-1). In fact, several 13P sample intervals contained approximately 80% fines; the largest amount of fines observed to date in EWDP boreholes. Moreover, several closely spaced sample intervals in 24PB contained more than 70% gravel compared to less than 20% gravel in similar intervals in 13P.

Summary statistics for PSD data listed in Table 5.2-1 shows the same trend in fines between 13P and 24PB. The average fines content in 13P is nearly twice the fines content in 24PB. This same table, as well as data in Table 5.2-2 show that average fines content in 13P is significantly higher than all other Phase V boreholes and several Phase III and IV boreholes.

In addition, a comparison of alluvium PSDs between Phase IV borehole 27P and Phase V borehole 13P suggests some similarities; that is, a similar trend in fining with depth (Figure 5.2-2). Borehole 27P is located a little more than a mile to the south east across a drainage divide from 13P as shown in Figures 1.3-1 and 1.4-1.

Figure 5.2-3 compares PSD alluvium drill cuttings data in 24PA and 24PB, which are located approximately 37 ft apart on the Site 24 drill pad. These boreholes were drilled using similar AR-RC methods, except for the interval from approximately 60 to 150 ft bgs in 24PA, where the DR-CA Symmetrix™ method was used. This latter method appears to produce drill cuttings samples with very similar PSDs to those produced by AR-RC methods. Summary statistical data in Table 5.2-1 confirms that average gravel, sand, and fines percentages are nearly the same for each borehole over the upper 150 ft of alluvial sediments.

Figure 5.2-4 shows that PSDs of alluvium drill cuttings differ slightly but follow the same trends for Phase IV borehole 24P (NWRPO, 2005) and nearby (i.e., located approximately 150 ft apart) Phase V borehole 24PB. Summary statistics in Table 5.2-2 confirm this observation. Borehole 24PB contains slightly more gravel (33 versus 27%) and slightly less fines (10 versus 14%) than 24P. Both boreholes were drilled with similar AR-RC methods and equipment, but by different drillers. Besides some differences in drilling related factors, differences in alluvial stratigraphy between the boreholes may be in part responsible for the differences in measured PSDs.

Finally, Figure 5.2-5 compares PSD profiles of drill cuttings between Phase V boreholes 24PB and 32P; the latter located approximately 5 miles south (downgradient) from the former. This graph shows that downgradient borehole 32P is slightly finer in texture than the upgradient borehole 24PB. That is, 32P contains more fines and sand, but less gravel than 24PB. This is not unexpected given the relative position of the boreholes in the Fortymile Wash flow system.

5.2.1.2 Core Versus Drill Cuttings Particle Size Distribution Data

Figure 5.2-6 compares PSD depth profile data for drill cuttings in Phase III borehole 22SA and Phase V sonic core in 22PC, located approximately 60 ft apart at Site 22. As mentioned in Section 5.1, core is generally considered more representative of in situ conditions than drill cuttings. Therefore, core may be used to characterize in situ conditions and to estimate the degree to which drill cuttings are disturbed by drilling. In the saturated zone, Figure 5.2-6 shows poor agreement in fines content between drill cuttings and sonic core, and even less agreement in gravel content. Agreement between fines and gravel content is much better when comparing 22PC core data from the saturated zone with 22SA drill cuttings data from the unsaturated zone (Figure 5.2-6). These trends in data were not unexpected, because previous studies (NWRPO, 2003; NWRPO, 2005) have shown that AR-RC drill cuttings PSDs (especially fines) are reasonably representative of in situ conditions in the unsaturated zone, but PSDs of AR-RC drill cuttings are highly disturbed in the saturated zone.

For example, significantly better agreement in fines content and slightly better agreement in gravel content was previously observed (NWRPO, 2003) between core and drill cuttings in the unsaturated zone in Phase III boreholes 10SA and 10P (Figure 4.3-7 from Phase III report). The grinding action of drilling clearly reduces larger, gravel-sized particles into smaller sand- and fines-sized particles. The grinding action of drilling is clearly enhanced beneath the water table. The potential impacts of AR-RC drilling methods on the PSD of drill cuttings are discussed in detail in NWRPO, 2003.

Figure 5.2-8 compares PSDs of drill cuttings from the unsaturated zone and sonic core from the saturated zone in 22PC. Conventional DR-CA drilling methods were used to drill the unsaturated zone in 22PC as described in Section 2.1.2.5. Good agreement in gravel content is shown in Figure 5.2-8, reasonable agreement in the sand fraction, and less agreement is observed in fines content. Slightly better agreement in fines content near the water table occurs where moisture contents were higher and loss of fines to dust was observed to decrease noticeably. If the loss of fines could have been reduced by a misting system, it is possible that DR-CA drilling with conventional circulation could have produced unsaturated zone drill cuttings with PSDs that were very similar to those produced from sonic core collected from the saturated zone. In summary, DR-CA drilling appears to have the potential to yield drill cuttings with PSDs that are reasonably representative of in situ formation conditions in the unsaturated zone.

5.2.2 Electrical Conductivity Data from Unsaturated Alluvium

Figure 5.2-9 shows that EC depth-profile values are almost identical for Phase V borehole 22PC and Phase III borehole 22SA. As mentioned previously, these boreholes are located approximately 60 ft apart on the Site 22 drill pad. Similar agreement in EC profiles to a depth of 150 ft bgs are shown in Figure 5.2-10 for Phase V boreholes 24PA and 24PB, which are located approximately 37 ft apart at the ground surface at Site 24. Note that it was necessary to abandon 24PA at 150 ft bgs.

Figure 5.2-10 also shows that soluble salts are concentrated in the upper 15 ft of alluvium with peak values near 1,000 micromhos/cm. EC values fall below 200 micromhos/cm until an approximate depth of 250 ft bgs in 24PB. From approximately 250 to 400 ft bgs in 24PB a number of minor EC peaks occur with values between 300 and 600 micromhos/cm.

Figure 5.2-11 compares EC plots for 24PB and Phase IV borehole 24P. In this plot, more EC peaks are shown between 50 and 250 ft bgs in 24P than in 24PB, and the opposite occurs between approximately 250 and 400 ft bgs. Even though these boreholes are separated by only approximately 150 ft, the differences in these EC plots is not surprising given the variation in alluvial stratigraphy suggested in PSD plots in Figure 5.2-4.

The close agreement in EC values in the upper 250 ft of alluvium between Phase V boreholes 24PB and 32P (Figure 5.2-12) may be in part also related to the agreement in PSD profiles observed in Figure 5.2-5, even though 32P is located approximately 5 miles downgradient from 24PB.

Finally, 13P located on the eastern edge of Crater Flat, exhibits a number of peaks between 400 and 800 micromhos/cm from approximately 75 to 260 ft bgs (Figure 5.2-13). These peak values generally exceed all subsurface peaks in the other Phase V boreholes, which are all located in Fortymile Wash. Higher EC values were also found in Flat Tire Flat boreholes compared to Fortymile Wash boreholes in EWDP Phase IV (NWRPO, 2005). Both Flat Tire Flat and Crater Flat are located to the west of Fortymile Wash.

The general lack of EC peaks with high values in Fortymile Wash may be related to the size of the drainage, the amount of water it transports, source rock of the alluvium, and possibly the relatively coarse PSD of the alluvium. The relatively high values in 13P are likely related to the basalt flow present from approximately 85 to 140 ft bgs and its weathering products, including significant amounts of clay.

5.2.3 Gravimetric Water Content Data in Unsaturated Alluvium

In previous EWDP reports (NWRPO, 2003; NWRPO, 2005) drive core samples were taken from unsaturated zone depth intervals immediately adjacent to drill cuttings samples in several representative boreholes. As a result, it was possible to compare gravimetric water contents of core and drill cuttings and to determine the disturbance (i.e., drying) of drill cuttings caused by AR-RC and DR-CA drilling methods used in Phase III and IV boreholes. These comparisons indicated that the gravimetric water contents of drill cuttings were generally less than 5% and ranged from 5 to 20% or more for adjacent core sample intervals. In short, drilling reduced gravimetric water contents of cuttings samples by as much as 0.15 g/g compared to core samples, which are more representative of in situ conditions.

In Phase V, core samples were not collected over the same or adjacent unsaturated depth intervals as drill cuttings in the same borehole. As a result it was not possible to determine the degree to which gravimetric water contents of drill cuttings were disturbed by AR-RC and DR-CA drilling methods. However, it is reasonable to assume that a reduction of 0.05 to 0.15 g/g is likely.

It is interesting to note that AR-RC drilling methods in Phase V produced drill cuttings water content profiles that were similar in cases where drill cuttings PSD profiles were similar. For example, 32P water content and PSD profiles were similar to those in 24PB to a depth of approximately 260 ft bgs (Figures 5.2-14 and -5, respectively). A peak in water content just above the water table in 32P (Figure 5.2-14) was probably due to water added as part of borehole conditioning.

Similarly, the PSD and water content profiles for drill cuttings from 24PA and 24PB agree closely (as shown in Figures 5.2-15 and -3, respectively). Note that 24PB was drilled with AR-RC methods to total depth; and 24PA was drilled with AR-RC methods from 0 to approximately 60 ft bgs and with Symmetrix™ casing advance methods from approximately 60 to 150 ft bgs.

5.3 Comparison of Laboratory Measurements with Field Logging Estimates

Figure 5.3-1 shows remarkable agreement between field estimates and lab measurements of PSDs for sonic core intervals in 22PC. There were only two notably significant differences between field and lab PSDs in Figure 5.3-1: first, field estimates were considerably less than lab measurements for fines data between approximately 575 and 625 ft bgs; and second, field estimated values in the No. 4 sieve data (the basis for separating the sand and gravel fractions) exhibited a greater range than lab measured values.

Summary statistics data for both field estimates and lab measurements over the entire cored interval in 22PC (Table 5.3-1) reflect a relatively small difference in average fines content (13% versus 16%), as well as showing that field estimates of gravel and sand, on the average, are slightly underestimated (39% versus 40%) and overestimated (48% versus 44%), respectively, compared to lab measurements. In addition, the greater standard deviation values for average field estimates in Table 5.3-1 are consistent with the larger range in values observed in Figure 5.3-1.

Even better agreement between field estimates and lab measurements of PSDs for drill cuttings is shown for 24PB in Figure 5.3-2. Summary statistics (Table 5.3-2) show that the difference between estimated and measured PSDs for drill cuttings samples was less than 2% for each of the major size fractions (gravel, sand, and fines). Similar results were observed for other Phase V boreholes including 32P, as shown in Figure 5.3-3 and Table 5.3-3.

The excellent agreement between field estimates and laboratory measurements of PSDs for drill cuttings permit using field estimates to fill in gaps between lab measurements. Field estimates were made on every 2.5 ft depth interval and lab measurements made on every other 2.5 ft depth interval. Field estimate data presented in Figure 5.3-4 for 24PB shows that the variations in PSDs observed in every 2.5 ft interval were at least as great as those determined by laboratory measurements on every second 2.5 ft depth interval. These drill cuttings data show that alluvial sediments contain even more textural layers than previously observed using lab data alone. Moreover, these data confirm the high frequency of textural layering observed in sonic coreholes 19PB and 22PC.

Finally, note that in previous plots of field estimated PSDs of drill cuttings in this report beginning in Section 5.2.1.1, sample data were taken from every other 2.5 ft depth interval to help make the plots more readable and to provide a direct comparison with lab measurements made on every other 2.5 ft sample interval.

5.4 Comparison of Sonic Core Particle Size Distributions in 22PC and 19PB

A comparison of Figures 5.4-1 and 5.4-2 indicates that the most noticeable difference in PSD profiles for 22PC and Phase IV 19PB is the range in the No. 4 sieve data, which is the basis for separating sand and gravel fractions. Summary statistics in Tables 5.4-1 and 5.4-2 confirm this observation. The standard deviations for the average values of the sand and gravel fractions are much greater for 19PB compared to 22PC.

In contrast, little difference is observed in the average values of the major size fraction in 22PC and 19PB. The average values for the sand and gravel fractions in 22PC are only approximately 1% lower than average values in 19PB, and the average value of the fines fraction for 22PC samples is only approximately 1.6% higher than in 19PB.

These similarities in PSD data between sonic coreholes 22PC and 19PB were not expected based on the relative positions of these boreholes in the Fortymile Wash flow system. Well 19PB is located approximately 3 miles downstream from 22PC. However, the offset of 22PC of approximately 800 ft from the present day incised Fortymile Wash channel, and the close proximity of 19PB to the western edge of the Fortymile Wash braided channels may override the expected differences resulting from location within the flow system.

It should be pointed out that the above-mentioned PSD major size fraction averages for the upper portion of the saturated zone in 22PC and 19PB in Tables 5.4-1 and 5.4-2 are not weighted by the variable lengths of the individual sonic core sample intervals. For the fines fraction, the depth-interval weighted averages for 22PC and 19PB equal 15.4 and 14.8 %, respectively. That is, the difference in the fines fraction average decreases even further (approximately 1.6 to 0.6 %) compared to the unweighted averages.

Even though the overall depth-interval weighted averages of the major PSD fractions for core samples from the two sonic coreholes are very similar, the weighted averages over depth intervals corresponding to sandpack and bentonite seal intervals exhibit greater differences. These differences are shown in Table 5.4-3. For example, the lower sandpack interval in 22PC averages 17.9% fines, while the lower sandpack interval in Phase IV corehole 19PB averages only 13.8 % fines. Moreover, the formation depth intervals corresponding to the bentonite seal intervals between the lower and upper sandpacks in 22PC and 19PB average 16.8 and 10.8 %, respectively. If it is assumed that saturated hydraulic conductivity is inversely related to fines content as proposed by Todd (1980), the lower screen in 22PC would be expected to exhibit a higher conductivity value than the lower screen in 19PB.

This hypothesis will be tested at some point in the future when Nye County tracer tests are completed at 22PC and constant head hydraulic conductivity tests can be conducted. Hydraulic conductivity tests have been completed in Phase IV corehole 19PB as described in NWRPO (2005).

6.0 BOREHOLE LITHOLOGY

Summary lithologic and borehole geophysical logs are presented and discussed in this section.

6.1 Summary Lithologic Logs

Summary lithologic logs from Phase V boreholes are presented in Appendix D. The alluvial section of each borehole is subdivided into major textural groups using the USCS group name classification system based on the particle size percentage criteria and the plasticity chart specified in ASTM D 2487-00, and the following laboratory tests on drill cuttings and sonic core samples: percentages of major particle size fractions determined by wet sieve analyses, percentages of clay by hydrometer methods, and Atterberg limits. ASTM procedures for generating these laboratory data are listed in Table 2.4-1 and the results of these tests are presented in Appendix C. The summary lithologic logs for alluvium also make use of geologic logging data included in alluvium drill cuttings and core logging forms included in Appendices C and D, respectively. Examples of these alluvium drill cuttings and core logging forms are shown in Figures 2.3-1 and 2.3-3, respectively.

The underlying volcanic and sedimentary rocks (non-alluvium) are subdivided, based first on lithology and second on recognized formation and member unit. These rocks are described in summary lithologic logs primarily using the lithologic related parameters recorded on non-alluvium logging forms for drill cuttings. An example form is presented in (Figure 2.3-2) and non-alluvium forms for all boreholes are included with alluvium forms on the NWRPO website (NWRPO, 2009) or at the QARC. Borehole geophysical logs are also used to help identify and confirm contacts primarily between non-alluvium rock units and/or between alluvium and non-alluvium rocks. These logs are described in Section 6.2, and were especially useful where geologic contacts were located within 2.5 ft and 5 ft sample intervals, where samples could not be collected, or the sample quality was poor.

This section will briefly describe the location of each new Phase V drill site including known nearby faults and surface outcrops and drainages. For all Phase V boreholes, the text will provide a narrative description of the summary lithologic logs and correlations, if any, with other wells in the area, including those within the main block of Yucca Mountain.

Finally, since 22PC is only one of two boreholes to produce nearly continuous core from the upper approximately 300 ft of the alluvial aquifer downgradient from Yucca Mountain, the description of its summary lithologic log will include a discussion of combining USCS units into hydrogeologic units suitable for modeling. In addition, the summary log of alluvium core from 22PC will be compared with a similar log from 19PB, the only other borehole that produced such core from approximately the upper 300 ft of the alluvial aquifer.

6.1.1 Borehole 13P

Borehole 13P is located in easternmost Crater Flat at the latitude of the Stagecoach Road (Figures 1.3-1 and 1.4-1). The borehole was sited within the Crater Flat basin to collect basic hydrologic data to better constrain the hydrologic conditions within this large hydrologic basin west of and possibly downgradient of Yucca Mountain. Existing geologic maps and cross- sections indicated that below a relatively thin cover of Quaternary alluvial valley fill west of the Windy Wash Fault, a relatively complete sequence of Miocene tuffs are preserved including tuff units of the Timber Mountain, Paintbrush and Crater Flat groups (Potter and others, 2002; Cross section B-B'). The well site is located in an alluvium-filled drainage along eastern Crater Flat, bounded to the west by low outcrops of the Pliocene basalt of Crater Flat and to the east by the footwall block of primarily welded Miocene Paintbrush tuffs along the Windy Wash fault. Pliocene basalt also occurs to the east of the site on the footwall in unconformable contact with the welded tuff units, indicating that the drainage is probably floored by Pliocene basalt and overlain by post-Pliocene alluvial sediments.

Borehole 13P penetrated a sequence of sandy alluvium from the ground surface to 87 ft bgs, underlain by Pliocene basalt from 87 to 140 ft bgs. The basalt is underlain by clay-rich and sandy alluvium from 140 to 260 ft bgs. The post-Pliocene alluvium from surface to a depth of 87 ft bgs is unremarkable and similar to other near-surface alluvium in Fortymile Wash and northern Amargosa Desert. The material consists primarily of well-graded sand with silt and gravel (SW-SM) and several layers of well-graded sand with gravel (SW) and silty sand with gravel (SM). Clasts are volcanic in origin and subangular to angular. The underlying Pliocene basalt consisted of two flows. The upper flow, from 87 to 107.5 ft bgs, has a vesicular top from 87 to 97 ft bgs, contains 5% altered mafic phenocrysts, and is weathered along contact zones. The lower flow, from 107.5 to 140 ft bgs, has a vesicular top from 110 to 122.5 ft bgs, contains 1 to 2% olivine phenocrysts, is weathered along contacts, and has apparent voids up to 2.5 ft wide near the base.

In open-hole conditions, the basalt commonly collapsed and bridged the borehole. During drilling, a void was encountered from 132.5 to 135 ft bgs and all sample recovery was lost until a depth of 162.5 ft bgs. From natural gamma log traces, it is evident that the base of the basalt occurs at approximately 140 ft bgs. The next recovered unit at 162.5 ft bgs is alluvium consisting of silty sand with gravel (SM) to a depth of 180 ft bgs. The gravel component includes unique clasts of weakly cemented and HCl reactive sandstone and less of the typical welded tuff lithologies. This unit is underlain by sandy lean clay (CL) from 180 to 197.5 ft bgs, locally with similar sandstone clasts. The sandy lean clay grades downward into sandy fat clay (CH) from 197.5 ft to 202.5 ft bgs. These fine-grained clay-rich sediments react strongly to 10% HCl.

Underlying the sandy clay are alluvial units consisting predominately of silty sand with gravel (SM) from 202.5 to 260 ft bgs. Gravel clasts consist primarily of welded tuff and locally of sandstone clasts similar to those found from 162.5 to 202.5 ft bgs.

The overall alluvial stratigraphy at 13P is similar to several other EWDP well locations. The sandy clay encountered between 180 to 202.5 ft bgs is similar to clay-rich horizons only encountered at depths greater than 500 ft bgs in the Fortymile Wash area in boreholes 2DB, 5S, 4PB and 23P. The nature of the sediments suggests a playa depositional environment, probably of limited extent along a restricted drainage system prior to the eruption of the basalt flow (approximately 4.1 Ma).

Between 260 ft bgs and TD (1,569 ft bgs), the borehole penetrated a highly variable sequence of primarily unconsolidated to weakly consolidated sediments including sandstones and conglomerates, volcaniclastic tuffs and sediments, and a fluvial sequence consisting of fine to coarse-grained clastic sediments interbedded with tuffaceous sediments. The hole is terminated in an apparent welded tuff unit that may represent Bullfrog Tuff or coarse clastic debris derived locally from Bullfrog Tuff (i.e., younger erosional material). No welded volcanic sequence was recognized, as the material encountered was comprised primarily of unconsolidated sediments with no easily recognizable volcanic strata.

The sediments encountered from 260 to 1,550 ft bgs are further divided into a lower sequence from 797 to 1,550 ft bgs of primarily fluvial sediments with altered tuff layers and a younger sequence from 260 to 797 ft bgs of primarily volcaniclastic tuffaceous rocks with lacustrine-deposited tuffaceous claystone and sandstone. The lower sequence is interpreted to represent preserved fault-related fan sequences deposited during early post-Timber Mountain time during rapid extension along the Windy Wash Fault. The units are roughly correlative to the Tgc unit (post-volcanic conglomerates, fanglomerates and rock-avalanche breccias [Miocene]) of Potter and others (2002). It is likely that these units record a reverse stratigraphic record as a result of rapid weathering or mass wasting with rapid denudation of up-thrown volcanic highlands to the north and northeast. The coarse clastic volcanic-source material likely accumulated as a clastic wedge or fan(s) in the trough formed by the hanging-wall block. Clasts of primarily welded tuff lithologies are supported in a matrix of primarily nonwelded tuff components.

The upper (younger) sequence from 260 to 797 ft bgs in the hole has a larger component of reworked tuffaceous deposits interbedded with lacustrine claystone. These tuffaceous deposits may correlate with Tvy (Younger Volcanic Rocks [Pliocene and Miocene]) of Potter and others (2002). The younger sequence records deposition in a lower energy environment, presumably after the rapid extension and deposition of coarse clastic debris recorded by the lower sequence. The presence of finely laminated claystone from 550 to 600 ft bgs and the nearly ubiquitous presence of calcium carbonate in the rocks suggest these rocks were deposited in a lake or playa.

The presence of a thick sequence of unconsolidated sediments, beneath alluvial cover, but above the Miocene volcanics indicates the uniqueness of the 13P section. The rocks record deposition of a relatively complete interval from post-Timber Mountain time to Quaternary time. The unique structural setting, in a topographic low on the hanging wall of a large normal fault, provides the structural basin to preserve this otherwise underrepresented sequence of rock units. In other EWDP boreholes, the time frame from post-volcanic to present is usually dominated by alluvium, likely with an unconformity (of undetermined magnitude) at the volcanic/alluvium contact. At 13P, although the top of the volcanic section is ambiguous, the completeness of the rock record likely preserves geologic products of this time frame (11.5 Ma to Quaternary).

One unit appears to roughly correlate between 13P and wells 10SA and 22SA drilled in Fortymile Wash. The unit from 1,140 to 1,315 ft bgs in 13P, logged as arkosic sand/sandstone and conglomerate, consists primarily of monolithic clasts of Paintbrush group rocks in a matrix of mostly volcanic quartz and feldspar. These rocks are very similar to rocks in 10SA and 22SA observed to occur beneath the alluvium but above the volcanics, and were interpreted to represent rapid weathering and reworking of welded tuff beds producing an immature conglomeratic sediment. If these units are roughly time correlative between 13P and 10SA/22SA, then there is possibly a paraconformity (non-deposition) of units in Fortymile Wash (above the conglomerate) that are well-represented in Crater Flat/Windy Wash section at 13P. Further geochronologic work is required to develop better chronostratigraphy of the 13P stratigraphy. Deeper drilling at all three sites is also needed to define the complete section.

6.1.2 Borehole 24PA and 24PB

Boreholes 24PA and 24PB were drilled at existing Site 24, on the southwest side of lower Fortymile Wash along the western boundary of the NTS. Site 24 was developed in 2003 with the drilling of

Phase IV well 24P as an exploratory borehole completed as a water table piezometer. The Phase V boreholes were drilled to conduct geophysical investigations to measure in situ groundwater velocities and to install “u-tube” sample apparatus for possible future natural gradient tracer testing. This site was chosen primarily because the saturated zone stratigraphy is similar to that at Yucca Mountain and the “C-wells” complex.

At Site 24, the saturated zone occurs within the upper few feet of Bullfrog Tuff beneath approximately 400 ft of unsaturated alluvium. Pre-Bullfrog sediments occur between 890 and 933 ft bgs, underlain by Tram Tuff to a depth of 1,356 ft bgs. Since the basic hydrogeologic system was known, the new well borehole was designed to allow testing and measurement of groundwater velocities using FEC and DTPS logging methods as described in Section 2.5.1.

The initial specification for 24PA called for drilling and casing the borehole to approximately 100 ft below the water table (at approximately 400 ft bgs), then drilling an open borehole in Bullfrog and Tram Tuffs for testing. During casing advance drilling of 24PA using Symmetrix™ downhole tools, at a depth of approximately 150 ft bgs, the drilling system failed and the borehole was lost. After abandoning the borehole by backfilling with bentonite grout, and recovering the drill casing, a replacement borehole (24PB) was located approximately 37 ft to the southwest of 24PA. It was drilled to total depth using conventional DR-CA and AR-RC methods as described in Section 2.1.2.2.

Borehole 24PB intersected a nearly identical sequence of subsurface geological units as 24P. The alluvium-bedrock contact and water table was encountered at approximately 405 ft bgs, followed by Bullfrog Tuff from 405 to 900 ft bgs, pre-Bullfrog sedimentary rocks from 900 to 945 ft bgs, and Tram tuff from 945 to 1,377 ft bgs. The borehole was terminated in Pre-Tram sedimentary rocks at 1,395 ft bgs.

6.1.3 Borehole 32P

Borehole 32P is located in northern Amargosa Valley, along the lower strands of western Fortymile Wash. The site was previously drilled to a depth of 475.2 ft bgs by DOE contractors as borehole USW VA-2, one of several boreholes drilled in the Yucca Mountain area for analysis of volcanic hazards. The VA-2 borehole encountered alluvial units to a depth of 390 ft bgs and basalt flows to a total depth of 475.2 ft bgs. The borehole was plugged with bentonite grout and abandoned. Nye County acquired the right-of-way and drilled borehole 32P at the same site, approximately 50 ft north of VA-2.

Borehole 32P encountered alluvial units from surface to 396 ft bgs, consisting of well-graded sand with silt and gravel (SW-SM), typical of alluvial units in the upper approximately 500 ft in Fortymile Wash boreholes. The water table was encountered at approximately 260 ft bgs, with the static water level rising to approximately 245 ft bgs.

Below a depth of 396 ft bgs, a basaltic lava flow was encountered. The flow consists of three zones including an upper weathered zone from 396 to 425 ft bgs, a massive flow core with fractures from 425 to 472.5 ft bgs, and a locally vesicular basal zone from 472.5 to 496 ft bgs. The basalt is hornblende porphyritic throughout and locally has calcite-filled fractures and fragment coatings.

The basalt is underlain by a conglomeratic sandstone unit from 496 to 550 ft bgs. The sandstone consists of a matrix of well-graded sand with heterolithic clasts of flow-banded rhyolite, quartzite, chert and limestone. The sandstone grades downward into unconsolidated sediments that are similar to the cemented unit above. The sediments consist of primarily well-graded sand with gravel (SW) from 550 to 752 ft bgs, silty sand (SM) and silt (ML) from 752 to 845 ft bgs, and primarily poorly graded sand with silt (SP-SM) and some layers of silty sand (SM) from 845 to 940 ft bgs. Gravel clasts within the sediments are predominately volcanic in origin with lesser quantities of sedimentary clasts. Overall, the section of unconsolidated sediments shows a fining downward trend. Finally, underlying the unconsolidated sediments are lacustrine siltstone beds from 940 to 1,000 (TD) ft bgs.

The geologic section drilled in borehole 32P has intervals of similar geologic sequences to other EWDP wells, but is unique in the juxtaposition of the units in the borehole. Starting from the lowermost unit, the sequence consists of a siltstone (1,000-940 ft bgs) overlain by an unconsolidated sequence of alluvial or fluvial sediments (940-550 ft bgs) capped by similar cemented sediments (550-496 ft bgs). This sedimentary sequence is interrupted by basaltic lava flows (496-396 ft bgs) and finally contains alluvial sediments from 396 ft bgs to the ground surface.

Without the presence of a marker unit, except the Pliocene basalt, the age of the sediments below 496 ft bgs is uncertain. It is possible that this sequence is entirely “post-volcanic” (i.e., younger than the last large pyroclastic eruptions of the Timber Mountain Group volcanics at approximately 11.5 Ma) and represents a relatively continuous and complete section of sediments beneath the approximately 4 Ma basalt. Moreover, these sediments were deposited in a basin similar to Fortymile Wash and Jackass Flat (as penetrated by boreholes 10SA, 22SA, 23P, 4PB, 5S), but without any substantial period of non-deposition or unconformities. In Fortymile Wash and Jackass Flat the correlative sequence consists entirely of alluvial sediments presumably overlying Miocene volcanic units. It is possible that at depth in 32P, the interval representing the Miocene volcanics of Yucca Mountain (13.5 to 11.5 Ma) would be intercepted.

An alternative interpretation is that the upper sedimentary sequence (below 496 ft bgs) consists of pre-volcanic older sedimentary units (Ts; Potter and others [2002]) overlain by Pliocene-aged basalt, followed by burial with alluvium. This would imply a significant unconformity or non-deposition surface at the stratigraphic top of the older sedimentary sequence (496 ft bgs) on which the Pliocene basalt was ultimately erupted, between approximately 14 Ma to approximately 4 Ma. The approximate 50 ft section of cemented sediments below the basalt may represent a deep soil horizon developed on a pedimented surface. Unfortunately, few direct dating methods are available to determine ages of sedimentary sequences.

6.1.4 Borehole 33P

Borehole 33P was drilled by DOE contractors as borehole USW VA-5, one of several boreholes drilled in the Yucca Mountain area for analysis of volcanic hazards. Nye County did not sample or log cuttings from the borehole. Nye County geologists observed drilling operations and collected archive chip samples under QA Test Plan 5.4 (Table 1.6-1). Under the data collection effort, daily operations activities and limited lithologic and hydrologic observations and data were recorded.

Borehole USW VA-5 was drilled using a modified drilling technique whereby a viscous polymer-based fluid was circulated using flooded-reverse circulation to improve borehole stability. Nye

County ultimately assumed the right-of-way for the site including the open and uncompleted borehole. The pre-completion activities are summarized in Section 2.1.2.4, which included re-entering the borehole, air-lifting, injecting dispersant, geophysical logging, and final air-lifting to remove polymer drilling fluid. The pre-completion water level in the open borehole was approximately 203 ft bgs.

Geologic data provided by the DOE (DOE, 2008) indicates that the subsurface geologic units consist of 195 ft of alluvium overlying Tertiary conglomeratic sediments from 195 to 535 ft bgs. The borehole ends in a Tertiary volcanic unit from 535 to 657.1 ft bgs, consisting of nonwelded, bedded and reworked tuff. Preliminary identification suggests that these tuffaceous rocks are a member of the Paintbrush Group volcanics. The overlying conglomeratic sediments are similar in description to rocks in 13P from 1,140 to 1,315 ft bgs, as well as 10SA and 22SA (see discussion in 6.1.1). Overall, below the alluvium, the sequence at 33P appears to represent a post-volcanic (Miocene) section not seen at 32P.

6.1.5 Corehole 22PC

Well NC-EWDP-22PC was drilled at Site 22 to collect nearly continuous sonic core samples of the lowermost unsaturated and upper saturated zone alluvial sediments. Data from these cores are used to support the analysis and interpretation of on-going tracer test results in the saturated zone at Site 22. The dual 2-inch piezometer well completion in the sonic corehole is used for tracer injection and recovery. The summary lithologic log for 22PC core (Appendix D) is based on laboratory PSD measurements made on sonic core split samples, including wet sieve, hydrometer, and Atterberg limits test (Appendix C).

The upper 460 ft of the unsaturated zone was drilled with conventional DR-CA whereby a 10.75-inch O.D. steel drill casing was advanced while a separate inner air-rotary drill string was advanced at approximately the same rate. Air circulation was conducted from the drill head down to the bit through the inner drill string and air and cuttings were returned through the annular space between the drill casing and the drill string to the surface.

This drilling and circulation method used in the 22PC unsaturated alluvium zone proved to yield drill cuttings with a coarse fraction that was similar to the coarse fraction measured in sonic core collected primarily from the underlying saturated zone. However, the amount of fines in drill cuttings produced by the DR-CA method (due to the production and loss of dust) was significantly less than the percentage of fines contained in sonic core as described in Section 5.2.1.2. Because the fines fraction produced by DR-CA methods in 22PC likely significantly underestimate the in situ fines fraction, and the fact that amount of fines is a key criteria for determining USCS groups, the unsaturated portion of 22PC drilled by DR-CA methods will not be discussed in terms of USCS groups in this summary. The following summarizes the lithology of sonic core samples collected from 460 to 763 ft bgs.

USCS group symbols were assigned to each core split sample. Wet sieve test data were used to determine grading as well as percentages of gravel, sand, and fine fractions. Hydrometer and Atterberg limits tests were used to determine whether silt or clay predominated in the fines fraction of the samples tested. Criteria for assigning USCS group symbols are specified in ASTM D 2487-00 (ASTM, 2000).

Figure 6.1-1 shows the distribution of the 16 USCS groups in the lower 10 ft of the unsaturated zone and the upper approximately 290 ft of the saturated zone. Also shown are lost core (no core recovered) intervals for which no split core sample data are available. This figure and the associated raw data served as the basis for developing the formal summary lithologic log for 22PC (Appendix D).

The log shows that gravel units predominate in the upper approximate 170 ft (460 to 632.1 ft bgs), and sand units in lower approximate 130 ft (632.1 to 763.0 ft bgs). This is well illustrated in Figure 6.1-2 whereby USCS units are mapped as two units: sand- or gravel-dominated. Figure 6.1-3 illustrates the same general trend and maps the predominance of the fines fraction in the core samples. Again, the upper section from 460 to 632.1 ft bgs consists predominantly of units with less than or equal to 12% fines and below 632.1 ft bgs the content of fines in units is predominantly greater than 12%.

Sonic corehole 19PB, located approximately 3 miles downstream from 22PC in the Fortymile Wash flow system, shows similar trends in gravel and sand units (NWRPO, 2003) as described above for 22PC. That is in 19PB, gravel units predominate in the upper approximately 135 ft of alluvium penetrated and sand units predominate in the lower approximately 145 ft of borehole. Moreover, a slight trend of an increasing amount of fines with depth is observed in both 19PB and 22PC. Also, the average percentages of gravel, sand, and fines measured in sonic core from each borehole differ by no more than several percent. Finally, the major difference between boreholes appears to be the greater range in No. 4 sieve data (i.e., the basis for separating sand and gravel fractions) in 19PB compared to 22PC.

6.1.6 Major Correlations

Boreholes drilled in Phase V were each drilled in very different geologic sections and therefore correlation to each other is problematic. Phase V boreholes are better correlated with boreholes from earlier phases of drilling. For example, borehole 13P is best correlated with EWDP Phase III wells drilled in Fortymile Wash (19IM2A, 22SA, 10SA) that cut a younger sequence of primarily alluvium and unconsolidated sediments overlying the Miocene volcanic sequence, than the most proximal well, 27P (Phase IV) that cuts a much thinner section of alluvium and mostly Miocene volcanic units. Likewise, borehole 32P is best correlated with Fortymile Wash boreholes and possibly boreholes with ‘pre-volcanic’ or older Tertiary section, such as boreholes 2DB, 1DX and 3D (Phase I and II). Borehole 24PB logically has a similar section to 24P (Phase IV). Corehole 22PC, with the detailed alluvial samples, is best correlated with 19PB (Phase IV), a similar hole in Fortymile Wash alluvial sediments.

6.2 BOREHOLE GEOPHYSICAL LOGS

Geophysical logs run in Phase V boreholes are classified into three logging suites: drill-string, open-hole, and well completion (Table 2.5-2). Selected logs from the GLS open-hole suite and/or the Century drill-string suite run in boreholes 13P, 22PC, 24PB, 32P, and 33P are presented on Plates 1 through 5, respectively. In addition, these plates include lithologic units, selected descriptive lithologic details, and borehole diameters illustrated in well completion diagrams. Correlations between lithologic log data and the responses of the borehole geophysical logs will be described for each borehole in the following sections.

Several logging tools produced inconsistent or unreasonable results. These logs were not used in interpretations and have been censored (Table 6.2-1). The GLS spectral gamma log, while shown on the plates, in general did not contribute to the interpretation process. The only gamma logs discussed further are the GLS and Century natural gamma logs.

Fluid electrical conductivity and distributed thermal perturbation sensor logging was conducted in several Phase V boreholes. These data are available at the NWRPO website and will be described in a separate report.

Drill-string and open-hole logs were run in exploratory boreholes drilled primarily with air; only very small amounts of bentonite, bentonite with polymer, and several synthetic-based drilling fluids were used to maintain stable borehole conditions during drilling, geophysical logging, and subsequent well completion activities (Appendix A). The exception is 33P, where large amounts of polymer were used during drilling. However, the borehole was circulated with phosphate-free dispersant and airlifted prior to geophysical logging and well completion.

Responses of both drill-string and open-hole logs to changes in formation conditions are likely affected only to a small degree by the relatively small amounts of bentonite and other drilling additives used to condition the boreholes. For example, the use of these drilling additives to condition the boreholes did not prevent the GLS open-hole suite from providing useful information such as water table location, water production zones, and confirmation of alluvium/tuff and other stratigraphic contacts, where present.

Several geophysical logs are considered to have meaningful responses only when run below the water table. These include formation resistivity, spontaneous potential (SP), sonic, fluid temperature, and fluid resistivity logs. Other logs, (i.e., induction resistivity [run only in 13P], natural gamma, compensated density, and compensated neutron) show meaningful qualitative responses in the unsaturated zone as well.

In addition to impacts from drilling fluids, responses of the Century drill-string suite are likely influenced by the size, type, and configuration of steel drill casing. For example, density logs run inside multiple steel casings have significantly higher responses than logs run only in drill pipe. In spite of this influence, logs in the drill-string suite clearly show the location of the water table, zones that may be producing or taking water, changes in water-filled porosity, changes in formation density, changes in textural properties, and the contacts between most lithologic units.

Although the well-completion suite helps to confirm the location and integrity of sandpacks placed across the well screens and bentonite seals above and below each sandpack, it shows few, if any, trends related to formation properties and/or water producing zones. As a result, these logs will not be discussed in this report, but may be viewed on the NWRPO website (NWRPO, 2009) or at the QARC.

6.2.1 Geophysical Log Signatures and Interpretations for 13P

Geophysical logs and lithologic log data from 13P are displayed on Plate 1.

Well-Graded Sand with Silt and Gravel (0-87 ft bgs)
This alluvial unit is characterized by increasing natural gamma counts and decreasing long-spaced compensated density (density) values with depth, indicating that the amount of fines in the unit also increases with depth. The sharp increase (i.e., peak) in natural gamma counts and sharp decrease (i.e., valley) (response is truncated) in density values from approximately 70 to 75 ft bgs corresponds with a layer of silty sand with gravel that contains significantly more fines than overlying and underlying alluvium.

Basalt (87-140 ft bgs)
The basalt is characterized by relatively constant lower natural gamma counts and higher density values from approximately 87 to 140 ft bgs. A valley in the density log within the basalt at approximately 115 ft bgs may be related to vesicles and/or fracturing. Due to problems with bridging in the upper part of the borehole, a temporary casing was set to 140 ft bgs prior to open-hole logging. Due to this casing, a caliper log was not run above 140 ft bgs, and therefore provides no evidence regarding of fractures or vesicles in the basalt zone.

Alluvium (140-160 ft bgs)
This interval is interpreted as alluvium based on the natural gamma log. The density log shows similar valleys from approximately 140 to 150 ft bgs as observed in the basalt section; however, no samples were recovered from 132.5 to 162.5 ft bgs, rendering interpretation of this section and the valleys in the density log difficult. Although the caliper log appears to respond correctly in the alluvium from 140 and 162.5 ft bgs, it shows no evidence of the presence of large voids as suggested in the density log.

Silty Sand with Gravel, Sandy Lean Clay, and Silty Sand with Gravel (160-260 ft bgs)
Natural gamma counts increase slightly and density values decrease slightly with depth throughout these units. The sandy lean clay unit logged from 180 to 202.5 ft bgs does not show a significant peak in natural gamma counts or a significant valley in density values as might be expected from clay layers. A small valley in the induction resistivity log in the lower portion of the 22.5 ft thick clay unit (geologically logged as a sandy fat clay subunit) is the only noticeable geophysical log response.

The periodic relatively small variations in natural gamma counts and to a lesser extent in induction resistivity values throughout the 100 ft interval of alluvium from 160 to 260 ft bgs may be a response to textural layering in the alluvium. The sharp peak in the natural gamma log and valley in the density log at approximately 248 ft bgs likely correlates with a lens of silt with some clay geologically logged from 250 to 252.5 ft bgs within the lower silty sand with gravel unit. The caliper log also indicates that the silty sand with gravel unit from 202.5 to 260 ft bgs “washes out” slightly, especially near the middle of the unit.

Reworked Tuffs and Related Volcaniclastic Rocks (260-797 ft bgs)

The valley in the induction resistivity log from 300 to 330 ft bgs may be due to increased moisture content of the top of the reworked air-fall tuff section. From 350 to 425 ft bgs, the natural gamma counts are significantly higher while the density values are lower than units above and below. The large change in natural gamma counts and the broad valley in density values may be due in part to increased argillization in this portion of the ash-fall tuff. A broad peak in induction resistivity correlates with the broad valley in density values. Another factor responsible for the very high natural gamma counts could be higher concentrations of elements emitting gamma radiation in the lower portion of the reworked ash-fall tuff unit.

The open-hole pre-completion water table occurs within the reworked tuff section at approximately 431 ft bgs. Natural gamma, induction resistivity, density, and fluid temperature logs respond to the water table.

Peaks in natural gamma, formation resistivity, neutron porosity (lower water filled porosity), and density logs characterize a less weathered ash-fall tuff at approximately 530 ft bgs. The claystone from 550 to 600 ft bgs is characterized by lower and relatively constant natural gamma, formation resistivity, and density values. An increase in SP and fluid resistivity as well as slope changes in fluid temp from 550 to 625 ft bgs may indicate a water production zone underlying the claystone unit.

A washout zone at 620 ft bgs shown on the caliper log correlates with small decreases in natural gamma, density, and neutron (indicating more water-filled porosity); and by a small peak in the formation resistivity logs. Deflections in the fluid temperature and fluid resistivity logs at 620 ft bgs also indicate that this particular washout may be related to inflow of formation water to the borehole. Similar correlations between the above logs, with the exception of fluid temperature and resistivity, are observed in the washout zone near 710 ft bgs. Washout zones shown in the caliper log from approximately 675 to 710 ft bgs do not show a consistent response in other logs.

Interbedded Fluvial Sediments and Tuffs (797-1,550 ft bgs)

This sequence comprises poorly consolidated fluvial sediments consisting primarily of sand, silt, and clay overlying sandstone interbedded with argillized tuffs and coarser sections of sand, gravel, cobbles, and boulders (conglomerate). Clasts within the sequence are volcanic in origin, consisting primarily of welded tuffs and lesser nonwelded tuff lithologies.

Just below the top of this interval, at 818 ft bgs, a sharp valley in natural gamma and sharp peaks in density and neutron (decrease in water-filled porosity) logs correspond to an interval of very clean, well rounded, well-graded sand with very little clay content. A change in slope of the fluid temperature log at this approximate depth suggests that water is entering the borehole from this interbed.

An increase in density values including several peaks in density logs from approximately 872 to 908 ft bgs likely results from cemented claystone and siltstone layers. The neutron log also shows several small peaks (decreases in water-filled porosity) over this interval.

From approximately 1,000 ft bgs to approximately 1,060 ft bgs density and neutron logs show a series of peaks and valleys. The largest peak occurs at approximately 1,035 ft bgs, where a clayey, weathered contact between sandstone/conglomerate and the underlying argillized tuff displays greater density and neutron log response (decrease in water-filled porosity) values compared to directly overlying and underlying intervals where the opposite responses occur; that is, the logs show lower density and neutron values. This latter response may be due to higher clay values and the former response may be due to sediments that include some clay, clasts that are well graded, and/or are more cemented. The decrease in natural gamma at the 1,035 ft bgs contact may be due to radioactive elements having been leached out of the clay that is present. A corresponding deflection in the fluid temperature also occurs at approximately 1,035 ft bgs.

From approximately 1,140 to 1,315 ft bgs (Arkosic Sand/Sandstone Conglomerate unit) a series of corresponding peaks and valleys in density and neutron logs is again observed. The sharpest peak in neutron counts occurs at several ft above the deeply weathered and argillized base of the argillized tuff (at 1,140 ft bgs). As in the interval from 1,000 to 1,060 ft bgs, these density and neutron responses may be due to different clay contents, cementation, grading of clasts and/or fractures/washout zones. The greatest variation in natural gamma counts occurs several tens of ft above and below the 1,140 ft bgs contact and may be related to geochemical composition changes across the contact tuff/sandstone contact.

Perhaps the sharpest valleys in density and neutron gamma values over the nearly 200 ft interval from 1,120 to 1,315 ft bgs occur in weakly consolidated sandstone at approximately 1,215 ft bgs. These valleys may result from a decrease in cementation and/or grading of clasts and/or the presence of fractures/washout zones.

From approximately 1,315 to 1,425 ft bgs the density, neutron, and natural gamma logs exhibit different signatures than overlying and underlying units. This depth interval corresponds approximately to the conglomeratic sandstone and conglomerate unit. The relatively narrow peaks and valleys observed mainly in the upper half of the 110 ft depth interval are interpreted to be the result of thin layers of cemented sediments alternating with thin layers of argillized tuff.

The conglomeratic arkosic sandstone, from 1,418 to 1,450 ft bgs, generally produces increased natural gamma, density, and neutron (decreased water-filled porosity) responses. These log signatures are consistent with a higher density, lower porosity unit containing larger, gravel-size clasts of welded tuff interbedded with ash-fall tuff and fluvial sediments, as noted in the drill cuttings. From 1,450 to 1,500 ft bgs these same logs show a consistent trend in decreasing values possibly related to increased weathering. Density and neutron logs were not run over the majority of the interval from 1,500 to 1,550 ft bgs and the natural gamma log shows only a slight response to different rock units geologically logged (argillized tuff and volcanic conglomerate) in this interval.

Lithic Ash-Flow Tuff (Possibly Bullfrog Tuff) (1,550-1,569 ft bgs)
No geophysical data, other than the drill-string fluid temperature log, are available in this unit. Therefore, no interpretations are made.

6.2.2 Geophysical Log Signatures and Interpretations for 22PC

Geophysical logs and lithologic log data from 22PC are displayed on Plate 2.

Alluvium Drilled by DR-CA methods (0-460 ft bgs)

From 0 to 460 ft bgs, lithologic descriptions are not included due to the interval being drilled with conventional DR-CA methods. This drilling approach produced drill cuttings samples containing gravel and sand percentages that are representative of in situ formation conditions; however, the percentage of fines in drill cuttings samples greatly underestimate in situ formation fines content. Consequently, it is not possible to correlate geophysical logs with stratigraphy in geologic logs in this 460 ft interval. However, the natural gamma log appears to represent a typical coarse grained layered alluvial sequence, with relatively small differences in PSDs. The very sharp peaks in natural gamma present between 190 and 300 ft bgs are likely due to noise from the tool.

<u>*Alluvium Cored by Sonic Methods (460-773 ft bgs)*</u>
Due to the sonic coring method (e.g., coring with a drill string inside multiple telescoping casings), only drill-string suite logs were run in borehole 22PC. All logs were run inside multiple steel casings from surface to approximately 585 ft bgs. At this depth, where the tools exit the multiple casings into drill pipe, the natural gamma log shows an increase in counts, and the density log shows a decrease. These log responses demonstrate the dampening effect of steel casings on these tools. At the same time logging within multiple casings did not prevent providing meaning geophysical logging data. For example, the natural gamma, density, and neutron logs all respond to the water table at approximately 472 ft bgs.

Below 585 ft bgs, the natural gamma, density, and neutron logs all show gradual increases with depth. These responses are consistent with the general interpretation of these units as clayey and silty sands and gravels with overburden pressure, compaction, and possibly grading increasing slightly with depth.

At a depth of 710 ft bgs, the fluid temperature log shows a sudden increase, and again at 760 ft bgs. These increases may represent zones of groundwater flow into the borehole. However, small peaks in the neutron log correspond to fluid temperature change in slope suggesting lower water filled porosity at these depths instead of the expected higher water filled porosity. Laboratory PSD test data indicate that these depths are dominated by gravel with a relatively small amount of fines. This may indicate that preferential flow paths are present through poorly-graded lower-porosity gravel layers at these depths.

6.2.3 Geophysical Log Signatures and Interpretations for 24PB

Geophysical logs and lithologic log data for 24PB are shown on Plate 3.

<u>*Alluvium (Well-Graded Sand with Silt and Gravel, Silty Sand with Gravel, Clayey Sand with Gravel and Well-Graded Sand with Clay and Gravel) (0-405 ft bgs)*</u>
Lithologic logs of alluvial drill cuttings from the ground surface to the top of the Bullfrog Tuff at 405 ft bgs indicate that the interval is a coarse-grained layered alluvial sequence that gets slightly finer with depth. More specifically, the lithologic log and laboratory particle size data show that the upper section from 0 to 255 ft bgs is primarily a well-graded sand with less than 12% fines, and the section from 255 to 405 ft bgs is mainly a silty or clayey sand with typically 12 to 20% fines and less gravel than the upper section.

The open-hole natural gamma geophysical log shows a trend of generally increasing counts from below the surface casing at 55 ft bgs to approximately 200 ft bgs, and relatively constant counts from 200 to 405 ft bgs.

<u>*Alluvium/Bullfrog Tuff Contact*</u>
The open-hole, pre-completion water table occurs at approximately 404 ft bgs, one foot above the contact between the alluvium and underlying Bullfrog Tuff. At the approximate water table/geologic contact, there is a very slight decrease in the natural gamma log response; however, the natural gamma tool is still logging inside a 10-inch surface casing at this depth, so its response is expected to be somewhat dampened.

<u>*Bullfrog and Pre-Bullfrog Sedimentary Rocks (405-945 ft bgs)*</u>
The Bullfrog Tuff intercepted in the borehole is a nonwelded to densely welded volcanic unit. The matrix is open and porous only in the nonwelded interval (405 to 460 ft bgs). The matrix in the remaining variably welded interval (460 to 900 ft bgs) is dense and non porous.

Of all geophysical logs run, the formation resistivity log correlates the most closely with the degree of welding. Highest resistivities are shown for the densely welded section and lowest resistivities for the nonwelded and weakly welded intervals. Natural gamma also correlates with the degree of welding in a number of cases. For example, decreases in natural gamma from 830 to 900 ft bgs correlates with the decrease in welding from densely welded to moderately welded, to weakly welded. Decreases in SP from 850 to 900 ft bgs correlate with the weakly welded basal section.

The increase in natural gamma response at 463 ft bgs is due to the natural gamma tool exiting the 10-inch surface casing into open borehole. A small washout zone shown as a peak in the caliper log at approximately 560 ft bgs correlates with relatively sharp valleys in natural gamma and formation resistivity values, and slight changes in the slope of fluid temperature and fluid resistivity logs. These log responses suggest that this washout zone results from a fracture system that conducts water into the borehole.

The underlying Pre-Bullfrog Tuff sandstone (900 to 945 ft bgs) has been geologically logged as argillized and possibly zeolitized. The unit displays an increase and peak in natural gamma and formation resistivity values, which correspond to the contact between the conglomerate sandstone/argillic fine volcaniclastic sandstone subunits at approximately 915 ft bgs. The caliper log also shows a peak at this depth, and together with a slight change in slope in fluid resistivity and temperature logs at approximately 925 ft bgs suggests that water may entering the borehole at and below this depth interval.

The contact with the underlying Tram Tuff is marked primarily by variable peak and valley type responses in the formation resistivity and sonic logs and a small valley in the SP log from approximately 935 to 955 ft bgs.

<u>*Tram Tuff (945-1,377 ft bgs)*</u>
The Tram Tuff at this location is logged as a nonwelded unit with an open porous matrix. It is highly weathered from 945 to 1,005 ft bgs and unweathered from 1,005 to 1,377 ft bgs. There is a slight increase in natural gamma and formation resistivity with depth from approximately 950 to 1,125 and 970 to 1,140 ft bgs, respectively. This suggests that clay content is not increasing with

depth; however, gamma emitting elements may be increasing with depth. However, peaks in gamma and valleys in formation resistivity at approximately 1,200, 1,350, and 1,375 ft bgs suggest increased clay contents at these depths. The latter depth corresponds with the Tram/Pre-Tram Sedimentary Rock contact at 1,377 ft bgs. Between approximately 950 and 1,060 ft bgs the caliper log indicates small washouts and perturbations are present in the fluid temperature and open-hole fluid resistivity logs, suggesting that water is moving into or out of the borehole over this interval.

Volcaniclastic Sedimentary Rock (Pre-Tram Sedimentary Rock) (1,377-1,395 ft bgs)
Only 18 ft of this unit was penetrated during drilling, and only natural gamma, formation resistivity, and sonic logs were run in the upper portion of this unit. However, geophysical log responses at the top of this interval correspond with the lithologic interpretation of the contact being clayey and weathered. For example, the natural gamma log shows an increase at the top of this unit, the formation resistivity log decreases, both indicating the presence of a clayey contact.

6.2.4 Geophysical Log Signatures and Interpretations for 32P

Geophysical logs and lithologic log data from 32P are displayed on Plate 4. The open-hole, pre-completion water table occurs at 244 ft bgs within an interval of well-graded sand with silt and gravel interbedded with well-graded sand with gravel.

Well-Graded Sand with Silt and Gravel Interbedded with Well-Graded Sand with Gravel (0-396 ft bgs)
Above the water table, this unit is characterized by variable gamma counts and variable responses in the density log, which are typical of alluvial sediments in the Fortymile Wash drainage. The caliper log shows several large washout zones from 100 to 115 ft bgs, and at 130 and 202.5 ft bgs corresponding to unconsolidated well-graded sand intervals. These washout zones are generally characterized by valleys both in natural gamma logs (usually both open-hole and drill-string logs) and density responses. At the water table, natural gamma counts decrease and the density log shows an increase. Between the water table (244 ft bgs) and the basalt zone (396 ft bgs) natural gamma, formation resistivity, and neutron log responses are relatively constant, whereas there is a trend towards decreasing density. The trend in density may be due in part to a slight increase in borehole diameter with depth as shown in the caliper log.

Basalt (396-496 ft bgs)
The basalt consists of 3 zones: and upper weathered zone from 396 to 425 ft bgs, a massive flow core with fractures from 425 to 472.5 ft bgs, and a locally vesicular basal zone from 472.5 to 496 ft bgs.

The contact between the overlying alluvial unit and the basalt is characterized by a sharp decrease in natural gamma to a lower and nearly constant value through the basalt layer. Bimodal peaks between approximately 425 and 472.5 ft bgs in the massive flow core are observed in the formation resistivity, density, and neutron logs. Near the base of the massive core at approximately 472 ft bgs, fluid temperature increases and fluid resistivity decreases sharply, and the differential temperature shows a sharp peak. These trends in logs near the contact between the massive core and the basal zone correspond to a large, open fracture zone in the basalt that “takes” water from approximately 468 to 476 ft bgs. This fracture is visible in both the video and optical televiewer (OTV) logs and the SP log shows a sharp increase.

The basal zone of the basalt, just below the open fracture, shows a trend in decreasing formation resistivity, whereas natural gamma, density and neutron values are relatively constant. An increase in clay content is lithologically logged in drill cuttings near the contact between the base of the basalt and the underlying conglomeratic sandstone. An increase in natural gamma, a decrease in formation resistivity immediately above the contact, and the slight increase in SP just below the contact may reflect this increase in logged clay content.

Conglomeratic Sandstone (496-550 ft bgs)
This unit is composed of poorly sorted, cemented, medium-sized sand grains. Formation resistivity and neutron logs show only very minor changes, natural gamma increases slightly, and density decreases slightly through this unit. In the vicinity of the contact with the underlying alluvial unit, natural gamma and formation resistivity increase sharply, SP and density decrease, while the neutron log shows little change.

Well-Graded Sand with Gravel (550-752 ft bgs)
This older alluvial sand unit contains thin interbeds of clay approximately 1 to 2 ft thick. The thin clay interbeds do not appear to show as peaks or valleys in any of the geophysical logs throughout this interval (approximately 575 to 750 ft bgs). For example, the natural gamma log, which often responds to clay layers, remains relatively constant throughout this interval. In addition, numerous sharp valleys (possibly indicative of clay layers) are not exhibited by density and neutron logs. In fact, these logs are characterized by more sharp peaks than sharp valleys. From 600 to approximately 690 ft bgs, the natural gamma, density, and neutron logs show fairly steady responses, indicating that the clast composition, density, and porosity are uniform throughout this interval.

At approximately 575 ft bgs, the caliper log shows a washout zone. Accordingly, the natural gamma, density, and neutron logs show sudden valleys in the responses. Formation resistivity and SP logs appear to be unaffected by the washout.

After the initial increase at the contact with the overlying conglomeratic sandstone, formation resistivity decreases steadily throughout the unit. The SP log shows a similar trend, except for a broad peak from approximately 660 to 700 ft bgs. Several minor deflections are shown on the fluid temperature, fluid resistivity, and differential temperature logs over this same depth interval. These deflections may be related to flow of groundwater through fractures into the borehole. This water likely moves upward in the borehole until it exits the borehole via the previously mentioned fracture zone from 468 to 476 ft bgs. The video log shows upward flow of water inside the borehole from approximately 475 to 600 ft bgs to these fractures in the basal basalt zone.

The small peaks in resistivity, density, and neutron logs together with the small valley in natural gamma logs at approximately between 700 and 710 ft bgs may be related to a small decrease in borehole diameter as shown in the caliper log and/or possibly a change in grading and/or mineralogy. Evidence suggesting an increase in grading includes censored data from geologic logs that show that drill cuttings from 700 to 710 ft bgs are described as well-graded and gravel content doubled from less that 15% in overlying and underlying intervals to 30% in the 10 ft interval of interest.

The base of this unit, from approximately 710 to 752 ft bgs, was logged as an interval of clean, non-clayey sediment, and return water was noted as being clear while drilling this interval. This corresponds to slightly increased natural gamma, density, and neutron log responses, as well as steadily decreasing (with depth) formation resistivity and SP log responses. The caliper log shows that the borehole was very close to being in gauge at the time it was logged.

Silty Sand with a layer of Sandy Silt (752-845 ft bgs)
This silty sand unit, from 752 to 845 ft bgs, represents lacustrine deposits with numerous washout zones as indicated in the caliper log. These washout zones are likely in part responsible for the relative wide swings in the natural gamma, density, and neutron logs. Formation resistivity is lower than overlying and underlying units and appears as a broad valley that extends over nearly the entire unit. A number of relatively narrow small peaks and valleys within the broad formation resistivity valley are likely due to variations in the borehole diameter. Both formation resistivity and SP log output increase across the contact with the underlying unit from approximately 835 to 860 ft bgs.

Poorly Graded Sand with Silt (845-940 ft bgs)
This unit is a poorly graded, granular sequence with a thin layer of silty sand or sandy silt from approximately 870 to 885 ft bgs. The sharp peaks in the caliper log from approximately 860 to 865 ft bgs and from approximately 890 to 895 ft bgs are likely primarily responsible for the valleys in natural gamma, density, and neutron logs at these same approximate depth intervals. Slightly elevated gravel contents, 15% and 19% respectively, shown in censored geologic logs at these depth intervals may be largely responsible for the washout zones.

Also, at the approximate depth interval from 860 to 865 ft bgs the differential temperature log exhibits a small peak and fluid resistivity and temperature logs exhibit small changes in slope. These log responses are interpreted to indicate that water is likely flowing into the borehole in this zone characterized by a slightly elevated gravel content. This water likely moves upward in the borehole until it exits the borehole via the previously mentioned fracture zone from 468 to 476 ft bgs.

A sharp valley in the formation resistivity log between 870 and 885 ft bgs corresponds to the thin layer of silty sand or sandy silt mentioned previously. Fluid resistivity and SP do not appear to respond to the presence of the silty layer.

In the lower portion of this unit from approximately 900 to 940 ft bgs natural gamma and formation resistivity exhibit a relatively constant increase and decrease, respectively, in log output suggesting a corresponding change in the mineral composition of the alluvial sediments. Fluctuations in differential temperature, fluid resistivity, and fluid temperature over this same interval suggest water may be entering the borehole from the formation.

Siltstone (940-1,000 ft bgs)
In general, natural gamma shows a trend in decreasing counts with depth and the formation resistivity log response is constant and shows the lowest values observed in the borehole. In the base of the laminated interval within this unit at approximately 975 ft bgs, the natural gamma log displays a small spike. Fluctuations in the fluid resistivity log and a weak broad peak in the differential temperature logs are observed over this depth interval, possibly suggesting water movement into the borehole.

6.2.5 Geophysical Log Signatures and Interpretations for 33P

Geophysical logs and lithologic log data from 33P are displayed on Plate 5.

It is not possible to correlate geophysical log responses in 33P to small-scale formational changes due to the lack of detail available in the lithologic log. This lithologic log only generally describes major stratigraphic units. Gross stratigraphy is well-represented in the geophysical logs, but without detail. Minor deflections in the geophysical logs are difficult to interpret with any degree of certainty. However, some generalities can be inferred from gross trends in the natural gamma and formation resistivity logs, and to a lesser degree, deflections in the SP, density, neutron, sonic, and fluid resistivity logs.

Alluvium – Predominantly Gravel and Sand (0-195 ft bgs)
The natural gamma and caliper logs show abrupt deflections as the tools exit the surface casing at approximately 55 ft bgs. From 55 ft bgs to the top of the volcanic conglomerate at 195 ft bgs, the natural gamma log shows a typical response to a coarse and layered alluvial sequence: the natural gamma counts are fairly constant with minor deflections (peaks and valleys) from approximately 55 to 160 ft bgs, then increases to a new roughly constant value from approximately 160 to 195 ft bgs, possibly due to increased clay content or a change in clast mineralogy and the presence of gamma emitting elements.

Volcaniclastic Conglomerate (195-535 ft bgs)
A close correlation between the formation resistivity, density, and neutron logs from the top of the volcaniclastic conglomerate at 195 ft bgs to the base of the upper altered ash bed at 342 ft bgs may indicate increasing clay alteration and increasing porosity with depth. A consistent trend of decreasing natural gamma counts over this same interval may result from decreasing concentrations of gamma emitters in the volcaniclastic sediments. The caliper log also shows that the borehole is in gauge within this interval, supporting the interpretation that the formation may contain some cohesive clayey materials.

The natural gamma, formation resistivity, density, and neutron logs all show little variation with depth from 342 to approximately 460 ft bgs. The density log shows the most variation, which may be due to washout zones indicated in the caliper log from approximately 340 to 400 ft bgs. From approximately 460 to 515 ft bgs the formation resistivity log generally shows a constant positive slope with depth (except for peaks at 460 and 515 ft bgs) while the fluid resistivity log shows a large broad peak over this interval. These trends in resistivity suggest that water quality is increasing significantly, possibly due to higher quality water cleaner entering the borehole in or below this interval.

Natural gamma remains remarkably constant with depth over the 460 to 535 ft bgs interval while density and neutron logs remain nearly constant with depth except for peaks near 460 and 515 ft bgs. These density and neutron peaks correspond to peaks in formation resistivity. This correspondence in peak depths may indicate that high quality water is preferentially flowing in lower porosity paths (e.g., fractures or in poorly-graded coarse grain layers) within the conglomerate unit.

<u>*Bedded and Reworked Tuff (535-657 ft bgs)*</u>
In this unit, from 535 to 610 ft bgs formation resistivity values decrease nearly continuously and from 610 to 657 ft bgs increase nearly continuously. This suggests that clay alteration and/or water salt content is a maximum at approximately 610 ft bgs. Valleys in density and neutron logs are centered at approximately 610 ft bgs and peaks at approximately 590 ft bgs. This may indicate that clay alteration with increased porosity may be concentrated at approximately 610 ft bgs. Slight increases in natural gamma between 590 and 610 ft bgs may support this clay alteration hypothesis.

From 610 to 657 ft bgs, the density log generally increases slightly, but the neutron and gamma logs remain nearly constant with depth. The increase in density may be due to the decrease in the borehole diameter over this interval as shown in the caliper log. The corresponding decreases in sonic travel times support the interpretation that this interval is denser than the overlying interval.

6.3 Geologic Cross Sections

Two geologic cross sections were constructed using: 1) summary lithologic logs from EWDP boreholes; 2) borehole data from previous EWDP drilling phases; 3) geophysical data and maps from published and ongoing geophysical studies; and 4) published geologic information from the USGS and YMP. The locations of the two geologic sections are shown in Figure 1.4-1. These cross sections update the conceptual cross sections that were presented in NWRPO (2005).

Geologic cross section A-A' (RID 7576) is constructed between boreholes 16P and 24P and includes extensions to the north-northwest and south-southeast that incorporate data projected from nearby boreholes 13P, 27P and 22SA (Figure 6.3-4). Section A-A' intersects the southernmost part of Yucca Mountain, extending eastward across Fortymile Wash in Jackass Flats. The section is approximately perpendicular to the strike of faults and potentiometric contours of the uppermost volcanic aquifers (Figure 6.3-3).

Geologic cross section B-B' (RID 7577) is constructed south from borehole 24P to 19D where the section bends westward continuing to 32P. Data from nearby borehole 2DB is projected onto the southwest-trending segment (Figure 6.3-5). The northerly segment of the section is approximately parallel to strike of normal faults except the Highway 95 Fault. The section updates and expands on the conceptual cross section (C-C') constructed for the Phase IV Drilling Report (NWRPO, 2005).

Information from geophysical surveys including interpretive gravity survey maps (Figure 6.3-1), aeromagnetic surveys (Blakely, 2000; Perry et al., 2005; Figure 6.3-2), a deep penetrating resistivity survey conducted by the NWRPO in conjunction with USGS Water Resources Division in 2006 (RID 7242) and a limited seismic reflection survey along a portion of the B-B' geologic section has been incorporated into the sections. Profiles of the interpretive gravity survey, "depth to Pre-Cenozoic" (Blakely and Ponce, 2001) are plotted on the cross sections.

Cross sections A-A' and B-B' are presented in Figures 6.3-4 and 6.3-5, respectively. Textural variations within the alluvium are not distinguished on the cross sections. Volcanic units are identified only to the group level. Newly recognized sedimentary units are differentiated as formations. Geologic relationships are generalized between areas of sparse borehole data where they are inferred from geophysical information.

Two types of faults are identified based primarily on previous mapping (Potter et al., 2002) and data from earlier drilling phases (NWRPO, 2005). Early faults represent basin bounding growth faults that are buried by the thick volcanic ash-flows tuffs of the Paintbrush Group and younger tuff units. Later faults are the more familiar and well-mapped Miocene faults of Yucca Mountain. The locations of the buried older faults are based primarily on basin thickness changes identified in the gravity survey interpretations (Ponce and Blakely, 2001; Figure 6.3-1). On the cross sections, early faults are identified as "pre-13 Ma" faults that generally provide for the depositional thickening of Pre-Crater Flat Group Sedimentary Rocks (Tvo/Ts). The younger faults are identified as "post-13 Ma" faults that offset the major ash flow tuff units of the Crater Flat and Paintbrush Group and locally the Timber Mountain Group. Several older faults are likely re-activated by younger faulting.

6.3.1 Cross Section A-A'

Section A-A' is constructed across the southeastern-most part of Yucca Mountain between eastern Crater Flat and lower Fortymile Wash (Figure 6.3-4). This is an update of the conceptual section B-B' from the Phase IV Drilling Report (NWRPO, 2005). New Phase V information from borehole 13P at the eastern margin of Crater Flat provides data on the Windy Wash Fault in that area. This section is also close to part of the B-B' cross section by Potter, et al., (2002). Depth to pre-Cenozoic rocks from the interpretive gravity map of Blakely and Ponce (2001) are plotted on both cross sections A-A' and B-B'.

Overall, the section presented is similar to the section published by Potter et al., (2002). The relatively late closely spaced domino-style Miocene normal faulting, similar to the structural pattern observed at Yucca Mountain in the repository area, is maintained across this section. The major north-south trending faults including Windy Wash, Stagecoach Road and Paintbrush Canyon Faults are shown to have the largest throws. The cross section also illustrates structural relationships first suggested by results from Phase IV drilling (NWRPO, 2005) including buried growth faults, paleotopographic highs, and the extent and thickness of several major ash flow tuff groups near their farthest southern extents in the Highway 95 area. In the central part of the cross section, in the area of Phase IV drill holes 27P, 16P and 28P, the cross section shows a prominent northeast trending gravity "high" where the depth to the pre-Cenozoic rocks is relatively shallow. This interpretation is supported by the intersection of Pre-Crater Flat Group Sedimentary Rocks (Tvo/Ts) underlying Paintbrush group volcanic rocks at shallow depth in borehole 28P.

The gravity feature is described by Potter, et al., (2002) as follows: "A buried northeast-striking fault is interpreted beneath southern and central Yucca Mountain and the Calico Hills from regional gravity data". Furthermore, the fault is marked by "a steep northeast-trending gravity gradient that tracks a 20-mGal northwest-side-down step in the isostatic residual gravity anomaly map" . . . and . . ." the southwest end of this trend is near Lathrop Wells Cone; it crosses Fortymile Wash near Fran Ridge and passes to the northwest of the exposures of Paleozoic rocks in the Calico Hills". This unnamed fault, referred to herein as the Crater Flat-Jackass Flat Basin Structure (CJS), separates the larger and deeper Miocene Crater Flat basin of Fridrich (1999) into the Crater Flat basin proper (which includes central and northern Yucca Mountain) from the smaller and shallower Miocene basin beneath much of Jackass Flat and southern Yucca Mountain. Cross section A-A' illustrates this structure as an approximately 4 km wide zone of west-northwest-dipping buried faults defined by the steep gravity gradients. The Crater Flat basin can be characterized by thick pre-volcanic deposits (>1 km thick) overlain by a complete sequence of middle Miocene tuffs. The Jackass Flat basin is characterized by thin pre-volcanic deposits (<1 km thick) with thinner and less complete sequence of middle Miocene tuffs. Figure 6.3-1 shows the thickness relationships of the two basins that are separated by the CJS. Figure 6.3-4 illustrates the stratigraphic relationships across the CJS. The westernmost part of the footwall block of the CJS has an angular unconformity between the Topopah Springs Tuff (not differentiated) of the Paintbrush Group and lower Tvo/Ts units intersected in borehole 28P. The "fault zone" or CJS comprises a series of buried pre-13 Ma growth faults in which the hangingwall blocks preserve greater thicknesses of the depositional units of the upper section of "older volcanics and older sediments" (Tvo/Ts) and all members of the Crater Flat Group. The eastern strand of the CJS (east of 28P) is likely reactivated as the Stagecoach Road Fault presumably after the eruption of the Paintbrush tuffs.

The initial recorded Tertiary (Oligocene-early Miocene?) extension accommodated by the north-northeast trending CJS is substantial, with at least 1,600 ft of down-to-the-northwest throw between boreholes 28P and 16P and substantially more (at least 3 km) across the entire CJS. The section also illustrates the potential relationship between the growth faults inferred to be the cause of the thickness variations in Tvo/Ts units, that are inferred from Blakely and Ponce (2001), and later, more northerly-striking, middle Miocene normal faults of Yucca Mountain, specifically, the Stagecoach Road Fault, which likely developed along an older, reactivated fault among those included as part of the CJS.

The difference between "depth to Pre-Cenozoic" and the base of Tvo/Ts rocks shown for the section line A-A' at the 28P location may be attributed to the distance, approximately 5,100 ft, across which drill hole data is projected. The line of projection of the drill hole data is nearly perpendicular within a south-southwest plunging basin based on gravity data. Unit thickness of the Crater Flat volcanics as shown on the CJS footwall thicken in the area the A-A' section relative to the 28P location, but the 28P data is projected to demonstrate the variability of preservation of Crater Flat units in the basin, probably at the thinnest section of Crater Flat volcanic units (Figure 6.3-1).

At the location of 28P along the CJS, the top of Tvo/Ts is encountered at depths as shallow as 1,340 ft bgs. The section includes calcareous mudstone and sandstone (Ts), locally containing pyrite, interbedded with units of "older tuffs" (Tvo). In borehole 28P the deepest strata between 1,974 ft and TD at 2,080 ft bgs comprise mainly mudstone and claystone locally containing green clay beds, gypsum layers and pyrite. These rocks are equivalent to the "older sedimentary rocks" discussed in EWDP Phase IV report.

In light of the shallow depth of the older rocks beneath units of the Paintbrush Group, a substantial unconformity exists between older sedimentary rocks (Ts) and Paintbrush tuffs along the easternmost extent of the footwall block of the CJS. It is also evident from the cuttings collected from 28P (NWRPO, 2005, Plate 3), that these Ts rocks are deeply weathered, indicating that the footwall block was likely uplifted , tilted and eroded prior to burial by the Paintbrush Group volcanics. Furthermore, although the exact age of the Ts units encountered in 28P is unknown (NWRPO, 2005), the timing of the extension along this fault is assumed to be prior to the eruption of Crater Flat Group volcanic from approximately 16 to approximately 13 Ma and possibly earlier based on the thickness of older sedimentary rocks (Ts). Burial began during eruption of Paintbrush Group about 12.8 Ma.

At the western end of section A-A’ data from borehole 13P provides new information about the stratigraphy in eastern Crater Flat. The borehole was drilled in the hangingwall area of the Windy Wash Fault west-northwest of 27P. Based on the geologic interpretations presented in Section B-B’ of Potter et al., (2002), volcanic units of the Timber Mountain Group would be encountered at less than 100 m. During drilling no middle Miocene volcanics units (Tc, Tp, Tm) were penetrated in the 1,559-foot-deep borehole. Based on the complete sections intersected in other parts of Crater Flat and the likelihood of preservation of the middle Miocene section in the hangingwall of the Windy Wash Fault, it is interpreted that these rocks occur beneath the total depth reached in 13P.

Information from 13P indicates that Windy Wash Fault has a larger throw and is longer lived than previously thought. Borehole 13P intersects a section of post-Timber Mountain units including volcanics (Tvy) with interbeds of volcaniclastic units and lower sedimentary units (Tsy_1 and Tsy_2). The throw and timing of the Windy Wash Fault in this area is unknown; movement along the fault is assumed to be younger than Timber Mountain tuffs (< 11.5 Ma). The preservation of a thick section of post-Timber Mountain units suggests that the fault is long-lived, possibly from middle Miocene to post-4 Ma as suggested by local offsets in the Pliocene (~4 Ma) basalt flows. If Timber Mountain Group volcanics do actually exist below the TD of 13P, the throw on the fault is approximately 3,300 ft, based on the offset of the Paintbrush Group tuffs between the hangingwall exposures east of 13P and the expected intercept below the TD in 13P.

Current models of groundwater/hydrogeology (i.e., Hydrologic Framework Model for the Saturated Zone Site-Scale Flow and Transport Model [HFM], Sandia National Laboratories [SNL], 2007.) do not address the stratigraphic and structural relations described herein. Based on the hydrogeologic definitions used in the HFM model, the footwall block of the CJS in the 28P area at A-A’ is comprised of units within the Paintbrush Volcanic Aquifer (PVA) and upper Crater Flat aquifer units (CFPPA), not the fine-grained lacustrine and volcaniclastic rocks of the lower volcanic and sedimentary units (Lower VSU) intersected in 28P. In the HFM, the Lower VSU (aquitard) is located approximately 1,000 ft below the intercept of LVSU in 28P. Flow models derived from the HFM (i.e., Saturated Zone Site-Scale Flow Model, SNL, 2007) would contain a large degree of hydraulic connectivity in the volcanic aquifer units above the Lower VSU that does not exist in the area of 28P. Similarly, structural offsets and juxtaposition of tuff aquifer units against Lower VSU units at the Windy Wash, Stagecoach Road and Paintbrush Canyon Faults are not reflected in the HFM surfaces. These offsets are primary impediments to west-to-east flow. The HFM surfaces also do not model the outcrops of Paintbrush tuffs located in the footwall blocks of these faults, instead, substituting alluvial aquifers in their place.

6.3.2 Cross Section B-B’

Geologic cross section B-B’ is constructed south from borehole 24P to 19D; where the section bends westward continuing to 32P (Figure 6.3.-5). Data from nearby borehole 2DB is projected onto the southwest-trending segment. The northerly segment of the section is approximately parallel to the strike of normal faults except the Highway 95 Fault. The section has been updated with data derived from the drilling of borehole 32P in northern Amargosa Valley. Deep-penetrating resistivity surveys (RID 7242) provide control on the extent of large-scale subsurface units, centered primarily near the Highway 95 fault. The survey resolved the depth and extent of contrasting resistivity units (interpreted as gross geologic units) along the section line to depths of 3,000 to 5,000 ft bgs.

The new borehole data, deep-penetrating resistivity survey data, and gravity data are used to improve earlier interpretations of the structural relationships first presented in the Phase IV Drilling Report (NWRPO, 2005), add to geologic information from earlier phases (NWRPO, 2001; NWRPO, 2003), to interpret the discontinuous geology between wells and identify major bounding faults, and to resolve the depth of the post-volcanic basin-fill to help resolve the complex nature of the Highway 95 Fault. The cross section replaces the conceptual cross section C-C' from the Phase IV Drilling Report (NWRPO, 2005).

The southern margin of the Yucca Mountain area coincides with the northeastern boundary of Amargosa Valley that is the locus of paleospring deposits. This discontinuity also coincides with the Highway 95 Fault which may have accommodated right-lateral movement during opening of the Crater Flat basin (Fridrich, 1999). Potter et al. (2002) depict the Highway 95 Fault as a nearly east-west right-lateral oblique fault with a down-to-the-north dip-slip component. The Highway 95 Fault (NWRPO, 2005, Conceptual Cross Section C-C') is shown as a north-dipping growth fault bounding a volcanic basin to the north, cut by a younger right lateral oblique fault (slightly to the north).

In this updated interpretation, the Highway 95 Fault is a complex series of faults (i.e., fault zone) that form a roughly symmetrical graben-like feature (or sag) (Figure 6.3-5). This feature is bounded by an older master fault as the southern north-dipping right lateral oblique structure acting as a growth fault, a similar smaller parallel fault to the north (~2,500 ft), and younger and steeper graben faults again to the north that down-drop and preserve the thin volcanic units and produce a basin in which younger sedimentary rocks were deposited. The younger graben features preserve post-Paintbrush sedimentary basin-fill units and the unique younger tuff encountered in borehole 19D.

The Highway 95 Fault is a steep right-lateral strike-slip fault zone that may have been modified during subsequent deformation. The graben-like feature (or sag) shown on section B-B' may reflect uplift of the Paintbrush tuff on the north side of the Highway 95 Fault caused by contraction orthogonal to the strike of Miocene normal faults. The sag is bounded on the south by the main strike-slip fault.

Within the fault zone, post-volcanic sedimentary basin-fill rock units identified based on drilling data are designated as Tsy_1, Tsy_2, and Tsy_3, based primarily on stratigraphic relationships in borehole 2DB, the most complete section drilled, and less complete sections in nearby boreholes 19D1, 22SA and 10SA in western Fortymile Wash.

Unit Tsy_1 is comprised primarily of fine-grained interbedded poorly to well-sorted sandstone, laminated siltstone and claystone, and locally containing gravel or conglomeratic beds of fluvial and shallow lacustrine origin. These rocks are penetrated by borehole 2DB (see Summary Lithologic Log [RID 7196], and Cuttings Sample Logs [RID 4466]) where Tsy_1 occurs from 1,010 to 1,155 ft bgs. In 2DB Tsy_1 consists of interbedded poorly sorted sandstone with beds of clay/claystone and siltstone. The rocks are weakly cemented and have limited reaction to HCl, indicating little carbonate component. Locally conglomeratic beds are present with clasts exclusively of volcanic origin. In borehole 19D1 (see Summary Lithologic Log [RID 2569], and logs [RID 2565]), Tsy_1 occurs from 1,245 to 1,438 ft bgs (TD) and consists of interbedded gravelly sands, sand, clay, and silt.

Overlying the fine-grained volcaniclastic Tsy_1 unit are coarser-grained volcaniclastic conglomeratic sandstone and conglomerates designated as Tsy_2, intersected in boreholes 2DB from 925 to 1,010 ft bgs, 22SA (see Summary Lithologic Log, RID 5472 [22SA]) from 1,110 to 1,200 ft bgs (TD), and 10SA (see Summary Lithologic Log, RID 5471 [10SA]) from 790 to 1,200 ft bgs (TD). The unit is comprised primarily of cobble to boulder volcanic conglomerate. Clasts are composed primarily of Paintbrush welded tuff in a matrix of clayey sand containing volcanic crystals. This unit is more than 400 ft thick in Fortymile Wash at site 10S.

The highest unit in the sequence, Tsy_3, identified in 2DB from 670 to 925 ft bgs, consists of light colored sandy and silty clay with gravel, lean clay/claystone and silt/siltstone with a significant carbonate component. This unit is interpreted to represent shallow lacustrine deposits possibly with spring deposits developed over the Highway 95 Fault(s). Tsy_3 underlies alluvium in lower Fortymile Wash. Previous interpretations (Phase III Drilling Report, A-A', NWRPO, 2003 or RID 5613) had included the Tsy_2 and Tsy_3 units as part of the alluvial section. However, the sedimentary units did correlate northward with alluvial units in borehole 19IM2A. In the new interpretation, the Tsy_3 unit is shown as being deposited in a small, structurally controlled basin. Tsy3 overlies older sediments (Ts) south of the southern strand of the Highway 95 Fault and younger sediments (Tsy_1 and Tsy_2) to the north. These fine-grained sediments were not intersected in the wells to the north (19D1, 22SA and 10SA) or southwest in 32P. Additionally, the Tsy_3 depositional units are relatively elevated with respect to the underlying depositional surface (~60m, see Phase III Drilling Report, A-A', NWRPO, 2003 or RID 5613), indicating the possibility that the Tsy_3 forms a constructional landform. This observation may suggest that either the unit is a deeply eroded remnant of larger or more widespread depositional unit, or that the deposits formed a constructional feature such as spring mounds. Further work, including sediment mesh analysis and paleobotany of selected samples is being conducted to better understand the Tsy_3 sediments.

Gravity survey data (and the interpreted "depth to pre-Cenozoic") support the general sag-like form of the Highway 95 Fault zone at this location, but appears to be offset to the north approximately 3,300 ft, compared with the resistivity data. Nye County has proposed the collection of higher density gravity and seismic reflection data to resolve this discrepancy.

Borehole 32P is near the end of the section in northern Amargosa Valley. At this location, unsaturated and saturated alluvial layers are underlain by Pliocene-age basalt flows that were apparently extruded on to the land surface. Sediments below the basalt are strongly cemented and grade downward in to uncemented sediments of primarily volcanically derived detritus. These volcaniclastic sediments are correlated with post-volcanic sediments (Tsy_1) in boreholes 2DB and 19D. Below 940 ft bgs, the volcaniclastic sediments are underlain by homogeneous siltstone units correlated with pre-volcanic sedimentary rocks (Ts). A northwest-striking growth fault between wells 2DB and 32P is interpreted to exist where the gravity-based "depth to pre-Cenozoic" increases toward the southwest.

6.3.3 Cross Section Interpretations

New subsurface data provides the opportunity to reinterpret stratigraphic and structural relationships to depths of 1,600 to 3,300 ft bgs with additional geologic constraints. The interpretations benefit from drilling information supplemented with targeted geophysical surveys. The new geologic insights are also useful for developing models of groundwater flow. The new interpretations provide a substantially different interpretation of the two largest features in the flow system south of the Yucca Mountain, namely the CJS and the Highway 95 Fault. There is evidence that both of these features impact or possibly control groundwater movement in the general area. Large upward hydraulic gradients are observed in wells in close proximity to the Highway 95 Fault (wells 19D, 2DB, 33P and 3D), presumably as a result of upward leakance along faults from the higher head zone in the underlying Paleozoic carbonate rock aquifers.

In the eastern section of the Highway 95 Fault (intersected by B-B'), east of Windy Wash, uncertainty exists where the thick ash-flow tuff sheets of the Southwest Nevada Volcanic Field and Yucca Mountain terminate at or near this feature. The area is obscured by thick alluvial cover, and without the benefit of drill data and/or targeted deep-penetrating geophysical methods, the nature of this feature is speculative. Magnetic surveys (Perry et al., 2005) indicate that the magnetic volcanic rocks terminate rather abruptly at approximately the latitude of 19D, either as an abrupt pinch out, or as a southward-dipping package below younger basin-fill, in an apparent basin that should preserve these units. This would suggest that the Highway 95 Fault forms a growth fault (as in NWRPO, 2005 Conceptual Cross Section C-C') with a deeper basin to the north of the fault, as suggested by the gravity surveys (Figure 6.3.3), and that by Paintbrush age (~12.8 Ma), forms a buttress feature that restricts the extent of welded ash-flow tuffs.

Drilling at 2DB, south of the Highway 95 Fault, confirms that volcanic units are not present in the subsurface south of the fault. If these tuffs were deposited, they were eroded prior to deposition of alluvium Figure 6.3-5. In post-volcanic time (after ~11.5 Ma), the region south of the fault, was structurally elevated, leading to a nonconformity between pre-volcanic rocks and deposition of the first alluvial cover. The alluvial cover thickness is relatively uniform in the area near 2DB (compared with other boreholes in western Fortymile Wash [19D, 22S, and 10S]), also suggesting that the area south of the fault was structurally stable during alluvial deposition (presumably after ~10 Ma). Based on this new data and interpretation, the Highway 95 Fault can be described as a complex fault zone (approximately 2 miles wide) with progressively younger structures toward the north as illustrated in Figure 6.3-5. These younger faults form grabens (or, on a large scale, a sag) that through time are in filled with progressively younger sedimentary basin-fill units toward the center. The oldest volcanic units terminated against the oldest and southernmost fault (a growth fault) and subsequent younger grabens formed north of this, which allowed the thickening and preservation of post-volcanic sedimentary units (Tys), younger volcanic (Tmt) and alluvium. The magnetic ash flow tuff units (primarily the Paintbrush Tuffs) are preserved at depth and magnetically muted by the younger cover.

Based on the new data and interpretation, the extent of the Highway 95 Fault can be extrapolated along strike to the east and west from the B-B' section. It would appear that previous interpretations of the location and strike (Potter et al., 2002) were based primarily on the newer magnetic data available at the time (Blakely, 2000). Using the gravity maps (and interpretive Depth to Pre-Cenozoic Map, Figure 6.3-1, Blakeley and Ponce, 2001), the Highway 95 Fault would be better traced by a "line" following the northern side of the gravity "high" in northernmost Amargosa Valley, north of Highway 95. This line, or fault trace, trends west-northwest (not east-west) and terminates against the northeast-trending fault(s) depicted on Section A-A' (CJS; Figure 6.3-4), near the Stagecoach Road Fault (a younger feature), northeast of the Lathrop Wells Cone. This interpretation suggests left-lateral movement along the CJS Fault and related structures. The movement may have offset the Highway 95 Fault.

Evidence from the resistivity geophysical surveys indicates that the Highway 95 Fault has two sub-parallel strands, an older master fault to the south, and a slightly younger sympathetic hangingwall fault to the north (approximately 2,620 ft). Using the same criteria to extend the fault westward, it would appear that the fault is offset southwestward (approximately 2 miles) along the CJS and reappears to the southwest of the Lathrop Wells Cone near well 3D, and continues with a similar west-northwest strike to terminate against the Bare Mountain Fault. Distribution of paleosprings and abrupt changes in the potentiometric surface also provide objective indications of a possible fault at depth. Based on this interpretation, the Highway 95 location and strike is significantly different than in previous publications, but is consistent with the updated geophysical data sets. These strands of the Highway 95 Fault are shown on the aeromagnetic survey map in Figure 6.3-2 which also shows boreholes that will be discussed in connection with the fault strands.

The western portion of the fault also has a similar structural character, whereby the extent and thickness of Miocene-aged tuffs are abruptly terminated southward at this fault. However, along this western section of the Highway 95 Fault, the termination of tuff units are relatively elevated, end more abruptly than similar units in the eastern section, and dip northward at approximately 10°, in contrast to the eastern section where the tuff units terminate more gradually and are buried by younger sedimentary and alluvial materials. Also, some magnetic volcanic units (probably Paintbrush group) extend southward “over” the Highway 95 Fault, mostly in the far western section in the area of wells 9SX and 12PA (Figure 6.3-2). This relationship would suggest that the timing of displacement along the western portion of the fault is different than the eastern portion. Using this new interpretation, the western Highway 95 Fault would be better characterized as a fault system oriented similarly to the eastern Highway 95 Fault, but displaced left laterally by the CJS bounding fault. These two separate faults systems, an eastern and western fault (zone) could be described as “West Highway 95 Fault” and “East Highway 95 Fault” as illustrated in Figure 6.3-1.

Studying the depth to pre-Cenozoic and magnetic maps, three dominant features (East and West Highway 95 Faults and the CJS) are evident at the southern extent of the Southwest Nevada Volcanic Field south of Yucca Mountain. Collectively, these features are similar, as they represent concealed growth faults, which roughly define the terminus of the voluminous ash flow tuff sheets (carapaces from the calderas to the north), and control the thickness of Tertiary basin-fill and/or greatly modify the nature of deposition, either sedimentary or volcanic in nature. These faults (or fault zones) define the boundaries of structural domains in which the “style, timing and magnitude of extension change abruptly,” as discussed by Fridrich (1999). Therefore, these faults are similar to and can be compared with, the other bounding faults of the Crater Flat basin, namely, the Bare Mountain Fault, Yucca Wash Fault, and the Gravity Fault (Fridrich, 1999).

6.3.4 Hydrologic Significance of the Highway 95 and CJS Fault Zones

Previous workers have recognized the hydrologic significance of the Highway 95 Fault and CJS, but the exact nature of these structures was poorly understood and only very general interpretations could be drawn from this incomplete knowledge. With the new geologic and geophysical data, combined with the results of EWDP drilling and testing, the hydrogeologic significance of these features can be updated substantially.

One of the perplexing problems discovered as part of the EWDP is the potentiometric head relationships observed between wells 1S and 1DX (deep) and between 7S and 7SC (zone 4). At these two well sites (Sites 1 and 7), large downward hydraulic gradients (125-135 ft) are observed between shallow aquifer zones and deeper aquifer zones. In addition, both of these sites have anomalously shallow heads relative to the regional potentiometric surface. Shallow heads are also observed in well 9SX, but without the large downward gradient. Many explanations for this phenomenon have been proposed (summarized in BSC, TDB No. 11, 2003), including perched water in the shallow zone or low permeability confining layers in the shallow subsurface (impeding downward migration of shallow groundwater). It should also be noted that all these well sites are located on paleospring discharge areas. Pumping tests in wells 1S (RID 1661), 7SC (RID 4919) and 9SX (RID 919) indicate moderate to very high permeabilities, limited boundary conditions, and moderate specific capacities. These aquifer test data indicate that explanation of these shallow head zones as perched zones is problematic and hydrologically unlikely.

The downward gradients observed at sites 1 and 7 can be addressed with an alternative explanation or conceptual model. The shallow heads observed at these sites maybe a result of the decay of “spring” level heads that discharged to surface in the past, as evidenced by the spring mounds at all three sites. These anomalous heads are likely connected directly to the deepest sections of the layered aquifer system in the Crater Flat basin; more specifically, the regional lower carbonate aquifer that presumably underlies all of the volcanic aquifers in the basin, and has a substantially higher head. The regional potentiometric head (the “potentiometric surface” used by all YMP site scale flow models) is measured primarily in the overlying volcanic aquifers that are isolated from the heads in the lower carbonate aquifer (LCA) by the extensive older fine-grained sedimentary and volcanic rocks. This extensive aquitard isolates the horizontally stratified aquifers, their respective recharge areas, and presumably the hydraulic gradients of each.

At sites 1, 7 and 9, the alternative conceptual model proposes that deep-seated faulting has breached the lowermost (and higher head) aquifers, and provided natural “piezometers” to the lower carbonate heads. Upward hydraulic gradients observed in wells close to the Highway 95 Fault (wells 19D, 2DB, 33P and 3D), probably record the upward movement of water along the fault. This structurally controlled lower carbonate-sourced higher-head water discharges in the near subsurface environment (as leakance between normally isolated flow systems) above the regional (primarily volcanic) aquifer system, probably over very limited geographic extents at locations where deep-seated structures provide open pathways. These zones of upward leakance are now recognized along both the eastern and western strands of the buried Highway 95 Fault, and possibly along other similar structures. Adding to the complexity is that these leakant zones also occur near the terminus of welded tuff aquifers at the lateral transition to basin-fill aquifer flow. Much of the eastern strand of the Highway 95 Fault is more deeply buried by thick saturated alluvial deposits. Using this conceptual model, hydrogeologic drilling and testing programs can provide physical validation of this leakance-controlled model.

This conceptual model envisions the flow system as two isolated north-south panels (a western Crater Flat geographic domain and an eastern Yucca Mountain and Jackass Flat domain). Flow in these panels is relatively independent and is bounded to the south by the two separate zones of leakance at the Highway 95 Fault(s). It is also postulated that the two flow panels are separated into the western and eastern flow domains by the CJS or related structural feature (possibly the Windy Wash Fault), that have separate base level discharge points. These base level discharge points can be envisioned as the top "edge" of the subcropping Highway 95 Faults where both the faults and the surrounding hydrogeologic unit are transmissive and able to capture the leakance into a "mixing" zone. Flow entirely within the volcanic aquifers, encountering these planar upward leakant zones in a geometrically normal arrangement would have to flow "over" the higher head leakant zones, a hydraulically impossible scenario. In lower angle relationships, flow from the volcanic aquifers would be diverted to parallel the higher head leakant zones along an approximately vertically oriented pressure gradient and be diverted in a direction of smaller pressure gradients. These smaller pressure gradient zones will occur along these planar features where either the fault zone is hydraulically inefficient (plugged) and the pressure gradient zone is neutralized, or where high permeability units are connected and the pressure gradient is lower and more diffuse in high-flow zones through or across the structure. These relationships probably occur as discontinuous zones along or on the planar leakant feature(s), or as "spring lines" both in the near subsurface or under saturated alluvial cover.

To further complicate this hydrologic phenomenon, discharge from the volcanic aquifers can entirely avoid the hydraulic barriers in areas, if they discharge into saturated alluvial materials at higher elevations than the Highway 95 Faults. These areas are coincident with those recognized as the "alluvial uncertainty zones", primarily in lower Fortymile Wash.

The best method to visualize this flow barrier relationship is to project the Highway 95 Faults onto a vertical longitudinal section oriented along the strands of the Highway 95 Faults, and: 1) identify where upward leakance is evident (those areas with paleosprings in proximity and areas of upward gradient) project those to the plane; 2) identify areas where erosion and saturated alluvial fill truncate the upward projection of the faults into saturated sediments; 3) identify where highly transmissive saturated volcanic units project into areas on the plane where no upward leakance is detected or suspected. Next, interpolate the probable heads (and head differences) between the lower carbonate aquifer and the overlying volcanic aquifer and project these as profile lines onto the projection. Effective flow from the volcanic aquifers through or "around" the planar flow barrier will occur only where head profile lines become equal or cross, and only in areas where erosion and saturated alluvial fill truncate the upward projection of the faults into saturated sediments or where highly transmissive saturated volcanic units project into areas on the plane where no upward leakance is detected or suspected. These areas likely exist in lower Fortymile Wash and possibly west of well 3D in Windy Wash. In areas where upward leakance is evident and head profiles are greatly separated, discharge from the lower carbonate aquifer will occur and effectively displace all discharge from the volcanic aquifer. These areas occur on the western strand of the Highway 95 Fault, generally west of well 9SX. This western domain is both geographically and structurally elevated without obvious gaps where erosion and saturated alluvial fill truncate the upward projection of the faults or where highly transmissive saturated volcanic units project into areas on the plane, so little discharge likely occurs from the volcanic rocks in western Crater Flat. Evidence for this relationship would be the geochemical signature of wells to the south of the barrier having a "mixed" water source, for example wells 12PA, 12PB, and 12PC.

The deeper zones encountered in 1DX (deep) and 7SC (zone 4) are at lower heads (approximately 2458 ft [749 m] and 2586 ft [788 m] amsl, respectively) and are more consistent, but still substantially higher than heads observed in nearby regional potentiometric levels in wells 12PA and 12PB (2372 ft [723m] amsl) (Figure 6.3-3). Interpreting these deeper heads as part of regional potentiometric surface would provide for a more realistic interpretation of the potentiometric surface than the use of “mixed” heads from the shallow zones that reflect the higher heads of the lower carbonate aquifer. The new potentiometric surface will still have a large southward-directed deviation in the otherwise gentle southeastward gradient to accommodate the higher heads, but without new data, this deviation would be approximately one-half as large as that currently modeled (Figure 6.3-3).

These deeper zones better reflect the regional head, and their higher elevations may reflect that discharge from these volcanic-dominated aquifers is not occurring and that water is mounding behind the higher head hydraulic barrier. Further, based on the similarities of other deep-seated structures that are less well exposed (primarily to the east of well 9SX), extrapolations as to the impacts of the structures on the flow system can be made. It would not be unrealistic to assume that the gentle horizontal gradients observed between Yucca Mountain and Highway 95 (from about 2390 to 2310 ft [730 m to 705 m] amsl) could not be strongly influenced by upward leakance of heads of higher absolute elevation, sampled at sites 1DX (shallow) and 7S (approximately 2582 ft [787 m] and 2724 ft [830 m] amsl, respectively). In this eastern area, wells specifically targeted at potential upwelling zones can confirm whether this phenomenon exists in the subsurface.

7.0 FINDINGS AND RECOMMENDATIONS

This section summarizes major findings from Phase V drilling, logging, and testing of geologic deposits at several locations in the lower portion of Fortymile Wash and at a location on the eastern edge of Crater Flat.

7.1.1 Drilling, Coring, and Well Construction

AR-RC drilling methods used to drill and sample the vast majority of footage in Phase V produced drill cuttings from unsaturated alluvium and from both unsaturated and saturated non-alluvium that were reasonably representative of in situ formation rock, minimized the disturbance of the formation rock and groundwater chemistry, and produced boreholes suitable for completing piezometer screens across and beneath the water table. AR-RC methods produced similar results in EWDP Phase III (NWRPO, 2003) and Phase IV (NWRPO, 2005) boreholes.

DR-RC methods used to drill larger diameter portions of several Phase V boreholes primarily in unsaturated alluvium produced drill cuttings with PSDs similar to RC methods for most size fractions. A relative new and innovative DR-CA drilling method (Symmetrix™ drilling system) using a percussion hammer and reverse circulation in 24PA produced gravel, sand, and fines fractions that were very similar to those produced by AR-RC methods from Phase IV borehole 24P and Phase V borehole 24PB from approximately 58 to 152 ft bgs. However, more downhole equipment problems were encountered with the Symmetrix™ method compared to AR-RC and conventional DR-CA methods.

A more conventional DR-RC method using a tricone bit and standard circulation in the upper 460 ft of unsaturated alluvium in 22PC produced drill cuttings where the gravel and sand fractions were similar to those produced by sonic core methods in 22PC from the lower 10 ft of unsaturated alluvium and the upper 293 ft of saturated alluvium. In contrast, the amount of fines produced by the DR-RC method in 22PC was much less than produced by sonic core, due to the significant amount of fines that was lost as dust from the cyclone separator. If this dust was captured by misting or other dust control systems, it is likely that the fines fraction from the conventional DR-RC method would also have been similar to that measured in sonic core from the underlying saturated alluvium.

Borehole conditioning methods successfully stabilized borehole walls both above and below the water table using small amounts of bentonite-based drilling mud, polymer, and foam in Phase V boreholes. The only exception was 13P, where these methods failed to prevent caving, to re-establish circulation, and to advance the borehole beyond a depth of 1,569 ft bgs.

Sonic coring in 22PC was an unqualified success and produced nearly continuous core from the lower 10 ft of unsaturated alluvium and the upper approximately 293 ft of saturated alluvium. This core was suitable for logging (e.g., geologic, digital photographic, and video logs), laboratory testing of parameters independent of porosity, and produced coring-related data to permit calculation of in situ dry bulk density and porosity values.

The sonic coring process resulted in some disturbance of the core samples from in situ conditions, including the following:

- Core expansion, resulting in higher core porosity and lower density values, although textural layers remained intact.
- Some migration of silt and clay from the interior of the core to the outside surface of the core; however, there was no evidence of migration of fines along the length of the core.
- Some migration of water from core in the lower region of the core barrel to core in the upper region, due to heat produced primarily at the core bit.

Borehole drilling and well installation resulted in the emplacement of piezometer screens, sandpacks, and grout seals at or near target depths for all boreholes. In addition, u-tube sampling and tracer injection lines were successfully installed at target depths in 24PB to support future single well tracer tests planned by OSTI.

Borehole development was not conducted in 24PB and 32P because drilling fluids that could impact water quality were not used in saturated zone depths near piezometer screens. However, recently the uppermost screen in 32P has become clogged with bentonite, and efforts to remove this material have been unsuccessful to date. This finding indicates that bentonite material that was emplaced in the unsaturated zone has migrated downward to the upper-screened interval in 32P following well completion activities.

Development in sonic corehole 22PC was limited to 4 hours of air-lifting from the lower piezometer screen to attempt to redistribute fine sediment that likely accumulated in near the borehole wall during sonic coring operations. In 13P air lifting with was conducted in the region of the piezometer screen both before and after piezometer completion to attempt to remove drilling fluids added in the saturated zone during drilling. In addition, a low flow-rate piston pump (0.4 gpm) was used on 3 occasions for a total of 45 hours over a 1-year period to remove suspended sediment. Finally, 33P, which was drilled with polymer by the DOE YMP, was injected with a polymer dispersant and air lifted for 3 hours and produced 16,000 gallons before water quality parameters stabilized. It is important to note that polymer has move back into the screens at 33P and will likely require additional development.

7.1.2 Geologic Logging

Geologic logs indicate that alluvium penetrated during Phase V was composed solely of volcanic rocks, the only exception being in 32P where trace amounts of sandstone, limestone, and quartzite were observed in separate samples of fluvial deposits from 505 to 535 ft bgs and a white limestone layer was identified in the 750 to 755 ft bgs interval. Non-alluvium was composed primarily of volcanic rocks or sediment derived from these rocks.

<u>Data Censoring</u>

As observed in EWDP Phase III and IV, sample density related data collected from weights of unsaturated alluvium drill cuttings from 2.5 ft sample intervals was censored due to the loss of sample material during drilling. In contrast to the Phase III and IV, field logging estimates and laboratory measurement of the PSDs (i.e., major size fractions of gravel, sand, and fines) of both alluvium drill cuttings and core agree remarkably well; as a result, field estimates of PSDs were not censored in Phase V.

Alluvial Drill Cuttings
Findings regarding PSD data from geologic logging will be discussed below in relation to results from laboratory tests on drill cuttings (Section 7.1.6).

The observed water contents of drill cuttings from the vast majority of 2.5 ft sample intervals from the unsaturated zone of Phase V were significantly decreased by the drilling process; that is, they were observed as dry. Most narrow wet peaks in water content were due to drilling fluids used to condition the borehole walls and/or from cement grouting of the surface casing. Some broader peaks of moderate and wet cuttings were observed in 22PC near the capillary fringe of the water table and where lateral flow resulted from lost circulation of liquid drilling fluids in a previously drilled Phase III borehole (22S) located nearby. Finally, drill cuttings collected from 32P from immediately below the water table (245 ft bgs) showed evidence of drying 15 ft into the saturated zone.

Cementation was not observed in drill cuttings of unsaturated alluvium in Phase V boreholes. However, older and deeper saturated fluvial sediments exhibited strong cementation from 500 to 540 ft bgs in 32P. In addition, several weakly cemented thin intervals were observed in this borehole between 700 and 900 ft bgs in the same fluvial sediments.

It should be pointed out that it is very difficult to identify degrees of cementation in drill cuttings. The drilling method, equipment, specific technique used by the driller, and related drilling rates can potentially affect evidence of cementation. Because of the difficulty in observing evidence of cementation in drill cuttings and the likely disturbing effects of drilling on cementation evidence, consideration will be given to eliminating cementation from geologic logs of alluvium drill cuttings in future EWDP Phases.

HCl reaction was more easily observed than cementation and the reaction for different sample intervals ranged from none to strong in Phase V boreholes. Since alluvium penetrated in Phase V boreholes does not contain carbonate rocks, HCl reaction indicates the presence of calcite, a potential cementing agent. However, because of the lack of visual evidence of cementation, it is likely that calcite does not play a significant role in cementation. A similar conclusion regarding calcite as a cementing agent was reached in Phase IV boreholes (NWRPO, 2005).

Drilling Rates and Water Production in Alluvium and Non-Alluvium
It is assumed in this report that drilling parameters remain approximately constant within a particular borehole and variations in drilling rates are due primarily to differing rock properties and the decrease in drilling efficiency with increasing penetration depth. Drilling penetration rates varied from less than 0.5 to greater than 3 ft per minute. Typically, the highest drilling rates (i.e., 1 per minute or greater) were recorded in alluvium, clastic sedimentary rocks (e.g., siltstone or claystone), volcaniclastic sedimentary rocks, and nonwelded intervals in volcanic tuffs. The lowest drilling rates (i.e., less than approximately 0.5 per minute) were recorded in the welded portions of most tuff units. Similar relations between drilling rate and rock type were observed in Phase IV boreholes (NWRPO, 2005).

Generally, water production increased with depth, especially in zones of sandstone, and moderately or densely welded tuff that are presumably highly fractured. Moreover, nonwelded tuffs and claystone generally appeared to slow water production. Lowest water production rates (approximately 34 gpm) in Phase V boreholes below 1,000 ft bgs were observed at the base of several relatively thin claystone layers in 13P where clay likely caused the plugging of the drill bit and/or dual wall drill pipe. The highest water production rates (140 gpm) in this same borehole were from sandstone intervals immediately underlying the claystone layers.

Finally, it is interesting to note that 24PB produced 20 to 25% more water than 24P at depths below 700 ft bgs even though they are separated by only approximately 150 ft. This may in part be due to the use of a slightly larger tricone center-return bit in 24PB (6.5-inch OD) than those used in 24P (6.125- and 6.25-inch OD) and/or closer proximity to faults and fractures in 24PB.

Continuous Sonic Core

Geologic logs of alluvial core from 22PC from 460 to 763 ft bgs show that the alluvium is composed of 100 % volcanic rocks. This observation is consistent with observations based on geologic logs from Phase III and IV boreholes previously drilled and logged at Site 22.

In contrast to the lack of variation in rock composition, geologic logs of sonic core in 22PC indicate some variation in cementation with depth. However, the cemented core intervals observed in 22PC did not correlate with drill cuttings intervals observed to be cemented Phase III borehole 22SA, which was located approximately 60 ft from 22PC. These differences do not indicate spatial variation in cementation between boreholes located at Site 22. Rather, as pointed out previously, these differences illustrate the difficulty in identifying degrees of cementation in drill cuttings. In future EWDP Phases, cementation will not be recorded for drill cuttings; instead, it will be recorded only for core samples where evidence of cementation is more readily observable.

HCl reaction was not observed in 22PC sonic core samples over the total coring interval from 460 to 763 ft bgs. Drill cuttings samples from 22SA over the same depth interval also showed no evidence of HCL reaction. These findings indicate that significant calcic horizons are not present in the capillary fringe above the water table and to depths of several hundred ft below the water table at Site 22. Moreover, the mechanism for precipitation of calcite at the water table in arid settings suggested by some workers, including Walvoord and others (2005), is not operative to a significant degree at 22PC.

A weak correlation ($r^2 = 0.41$) between coring rate and run length was observed in 22PC. Some evidence for this correlation was expected because both parameters are related to the ease, or difficulty, of advancing the sonic core barrel. Formation density is expected to be a key factor controlling core barrel advancement. However, the errors inherent in the approach used to calculate formation density mentioned previously, preclude finding a meaningful correlation between formation density and coring rate and run length.

The Munsell colors of sonic core from the upper approximately 290 ft of saturated alluvium range in hue from 2.5YR to 10YR, value from 4 to 6, and chroma from 2 to 8. The most common color is 5YR 5/6. This range of colors suggests oxidizing conditions throughout upper portion of the saturated zone.

7.1.3 Photographic Logging

Both digital photographs taken by the NWRPO and video taken by DOE SMF personnel showed evidence that particle size segregation occurred during sonic coring in 22PC, as was previously observed in Phase IV corehole 19PB. Specifically, some fines generally migrated from the interior of the core to the outside edge of the core. Potential sampling bias was avoided in 22PC by splitting core samples in half horizontally or by collecting pie shaped samples with their apex terminating in the center of the core.

There is no evidence from geologic or photographic logs that fines migrated along the length of the core. It was therefore assumed that textural layers remained intact in the sonic core, were representative of in situ conditions, and were suitable for detailed geologic logging and laboratory testing.

Photographic logs also illustrated the effect of the heat generated from the coring process on the distribution of water in the core. Most heat was generated at the core bit, causing the temperature of the core adjacent to the core bit to increase more than core located further up the core barrel. This heat caused water to migrate from the region of the core bit upwards into core located at the uphole end of the core barrel.

7.1.4 Dry Bulk Density and Porosity Values for Sonic Core Runs

Field measurements were made to determine the mass and volume of each sonic core run. These measurements, together with laboratory measurements of gravimetric water content, were used to determine the dry bulk density of each core run based on depth-weighted averages of core segment lengths making up each core run.

Sonic core collected with the smaller diameter core barrel (i.e., 4.5-inch-OD) yields dry bulk density values that are slightly higher on the average (1.71 g/cm^3 vs. 1.66 g/cm^3) than those on core collected with the larger diameter core barrel (i.e., 6.16-inch-OD). No other trends with depth are apparent. These average density values translate into average porosity values of 0.32 cm^3/cm^3 and 0.34 cm^3/cm^3 using an average laboratory determined particle density of 2.53 g/cm^3 as shown in Table 4.2-1.

These slightly differing bulk density and porosity values may be due in part to the greater difficulty in determining the amount of lost core when using the smaller diameter core barrel. Other possible sources of error in these bulk density calculations include the estimated corehole diameter as well as the measured gravimetric water content. Regarding the latter, it was recognized during data analysis of density data from Phase IV corehole 19PB that significant evaporative loss of water occurred during sample handling and logging in the field. As a result steps were taken to minimize this water loss when logging and handling 22PC sonic core. The average calculated gravimetric water content for 19PB core segments was approximately 0.13, whereas the average value for 22PC core segments was 0.17. This difference of 0.04 in average water content translates into a difference of 0.04 or more in dry bulk density. Evaporative losses from 19PB core samples in the field may in part be responsible for the higher average dry bulk densities (1.80 to 1.82 g/cm^3) calculated for 19PB core runs.

7.1.5 Laboratory Tests on Sonic Core

In general, core samples are considered to exhibit flow- and transport-related properties more representative of in situ conditions than those of drill cuttings. Because core samples are generally more representative of in situ conditions than drill cuttings, they can be used as a standard for estimating the disturbing effects of drilling on drill cuttings samples. For example, conducting laboratory tests (e.g., PSD) on core samples and drill cuttings from the same or nearly the same depth interval in the same borehole or closely spaced boreholes provides a way to gauge such disturbance. Finally, it should be noted that laboratory tests on sonic core are smaller in scale and possibly less representative of field conditions than larger scale field aquifer and tracer tests.

PSD and Atterberg Limits Data

Summary statistics for PSD data from 22PC sonic grab core samples show that all samples are coarse-grained and, on the average, contain approximately 16 percent fines and approximately 40 percent gravel and 44 percent sand. The USCS group name for the average PSD composition is a silty or clayey sand with gravel.

A depth profile graph of major particle size fractions in 22PC sonic core determined by wet sieve analyses indicate that gravel varies more than the other fraction sizes with depth. For example, the range in gravel extends from 16 to 72 percent and in some cases differs by more than 40 to 50 percent in adjacent depth intervals. This depth profile also shows a trend of slightly increasing percentages of fines and sand with depth and a corresponding decrease in percentages of gravel with depth.

The fines fraction is composed of nearly identical proportions of clay and silt in sonic grab core samples over the entire cored interval in 22PC based on hydrometer particle size analyses. There is a slight increase in fines and clay beginning at approximately at approximately 625 ft bgs and continuing to total depth at 763 ft bgs.

The Atterberg limits-based classification of the fines fraction in sonic grab core samples from 22PC shows that silt (ML) predominates over clay (CL) and silty clay (CL-ML) in the upper 150 ft of the alluvial aquifer and the opposite is observed in the underlying 150 ft. The predominance of clay over silt and silty clay below approximately 625 ft bgs corresponds to the slight trend in increasing clay mentioned previously based on hydrometer test data.

Little difference was observed in the average values of the major size fractions between 22PC sonic core and Phase IV 19PB sonic core. The average values for the sand and gravel fractions in 22PC are only approximately 1 percent lower than average values in 19PB, and the average value of the fines fraction for 22PC samples is only approximately 1.5 percent higher than in 19PB. Calculated averages of PSD fractions for 22PC and 19PB that are weighted by the variable lengths of the individual sonic core sample intervals agree even more closely than unweighted averages. However, a slightly greater range in sand and gravel fractions was observed in 19PB than in 22PC. Taken together these relatively small differences in PSDs between coreholes suggests that the approximately 3 mile separation between 22PC and 19PB in the Fortymile Wash flow system does not appear to significantly impact the PSDs in the upper portion of the alluvial aquifer in lower Fortymile Wash.

Significant differences between these coreholes are however found in major particle size fractions when the weighted averages over depth intervals corresponding to sandpack and bentonite seal intervals are calculated, rather than taking the average over the entire cored interval. For example, the lower sandpack interval in 22PC averages 17.9% fines, while the lower sandpack interval in Phase IV corehole 19PB averages only 13.8 percent fines. If it is assumed that saturated hydraulic conductivity is inversely related to fines content as proposed by Todd (1980), the lower screen in

22PC would be expected to exhibit a lower conductivity value than the lower screen in 19PB. This hypothesis will be tested when tracer test activities are completed at 22PC.

Electrical Conductivity Data
Sonic core EC data from the lower part of the unsaturated zone immediately above the present water table in 22PC shows only single a small spike or peak in EC that reaches 327 micromhos/cm at approximately 364 ft bgs. In contrast, Phase IV sonic corehole 19PB exhibits several large spikes or peaks of approximately 1,000 micromhos/cm and valleys (i.e., low values) between 200 and 400 micromhos/cm in the interval immediately above the water table. It is possible that variations in paleo-water tables may be responsible in part for these great variations in EC values in 19PB. Numerous other factors including paleo-soils and paleo-recharge events may also play some role in the development and maintenance of these EC peaks and valleys in 19PB.

Regarding paleo-recharge events, wetting fronts may have reached the water table more frequently at 22PC located further upstream and less frequently at the downstream location in 19PB. This could result flushing of salts from the unsaturated zone more often in 22PC compared to 19PB. Alternatively, the fact that 22PC is presently located on a terrace approximately 800 ft from the incised main Fortymile Wash channel may preclude wetting fronts from impacting the subsurface at 22PC. In contrast 19PB is presently located on the edge of the braided channel network in lower Fortymile Wash that periodically transmits flows that result in infiltration/percolation wetting fronts, where the spikes in EC may correspond to the terminus of these different wetting fronts.

7.1.6 Laboratory Tests on Drill Cuttings

Spatial Trends in PSDs of Alluvium Drill Cuttings
Results from wet sieve and hydrometer PSD tests for alluvial drill cuttings from Phase V boreholes drilled by AR-RC and DR-CA methods include the following:

- Comparison of PSDs of unsaturated alluvium from 24PB and 24P (separated by approximately 150 ft) shows that the former is noticeably coarser grained than the latter. Both boreholes were drilled using similar AR-RC methods and equipment, but by different drillers. Besides some differences in drilling related factors, differences in alluvial stratigraphy between the boreholes are likely in part responsible for the differences in measured PSDs. Higher water production rates in 24PB mentioned previously, is consistent with the coarser sediments penetrated in the unsaturated portion of this borehole.
- A comparison of PSD profiles of unsaturated alluvium drill cuttings between Phase V boreholes 24PB and 32P, the latter located approximately 5 miles south (downgradient) of the former, shows that 32P is slightly finer in texture than the upgradient borehole 24PB. This is not unexpected given the relative position of the boreholes in the Fortymile Wash flow system.

Trends in Electrical Conductivity of Unsaturated Alluvium Drill Cuttings
EC tests on a one-to-one by weight ratio of water to alluvium drill cuttings extracts show the following:

- Close agreement is observed in EC depth profiles of unsaturated alluvium between: 22PC and Phase III 22SA located approximately 60 ft apart, and in the upper 150 ft of 24PA and 24PB located 37 ft apart.

- A comparison of EC depth profiles for 24PB and Phase IV 24P shows significant differences even though they are separated by only approximately 150 ft. This observation is consistent with the differences in alluvial stratigraphy shown in PSD depth profiles mentioned previously.
- The relatively close agreement in EC depth profiles between 24PB and 32P, with the latter located approximately 5 miles downgradient in lower Fortymile Wash, may in part be related to similar PSD depth profiles described above.
- The magnitude of EC peaks in 13P depth profiles exceeds all peaks in other Phase V boreholes. The high values of EC in 13P are likely related to the basalt flow present from approximately 85 to 140 ft bgs and basalt weathering products, including clay minerals.

Gravimetric Water Content of Alluvial Drill Cuttings

- In Phase III and Phase IV it was found that AR-RC drilling reduced the gravimetric water content of alluvium drill cuttings compared to core by as much as 0.15 g/g. Similar reductions are expected in Phase V, although core was not collected to verify the magnitude of drying of drill cuttings by AR-RC and DR-CA methods.
- Although not representative of in situ conditions, drill cuttings water content profiles are useful in identifying relative water content differences between boreholes, and depth intervals where excess drilling fluids were used to condition the borehole.
- As expected, AR-RC drilling methods produced similar water content depth profiles in Phase V boreholes with similar PSD depth profiles. These borehole pairs included 24PB and 32P, and 24PA and 24PB. Under drained predrilling conditions, water content profiles are expected to be similar in boreholes with similar PSD profiles. In addition, it is expected that drilling impacts on water contents would be similar for boreholes with similar PSDs.

7.1.7 Comparison of Laboratory PSD Measurements on Core and Drill Cuttings with Field Logging Estimates

Remarkably close agreement was found between field estimates and lab PSD measurements made on alluvium sonic core segments from 22PC. Summary statistic averages (Table 5.3-1) for field estimates and lab measurements of major size fractions are as follows: fines content, 13% estimated versus 16% measured; gravel content, 39% estimated versus 40% measured; and sand content, 48% estimated versus 44% measured. Even closer agreement was found between field estimates and lab measurements for unsaturated alluvium drill cuttings from both 24PB and 32P (Tables 5.3-2 and 5-3.3 respectively).

The excellent agreement between field estimates and laboratory measurements of PSDs for drill cuttings permit using field estimates determined for every 2.5 ft sample interval to fill in data gaps between lab measurements made on every other 2.5 ft depth interval. A comparison of these data shows that the variations in PSDs observed in every 2.5 ft interval was at least as great as that determined by laboratory measurements on every second 2.5 ft depth interval. These drill cuttings data show that alluvial sediments contain even more textural layers than previously observed using lab data alone. Moreover, these data are consistent with the high frequency of textural layering observed in sonic corehole 22PC and Phase IV sonic corehole 19PB (NWRPO, 2005). This textural layering is discussed in greater detail in the following.

7.1.8 Summary Lithology Logs

Borehole 13P

Borehole 13P, located on the edge of Crater Flat near the Windy Wash Fault, penetrated a sequence of sandy alluvium from the ground surface to 87 ft bgs, underlain by Pliocene basalt from 87 to 140 ft bgs. The post-Pliocene alluvium from surface to a depth of 87 ft bgs is unremarkable and similar to other near-surface alluvium in Fortymile Wash and northern Amargosa Desert. During drilling of the lower portion of the Pliocene basalt, a void was encountered from 132.5 to 135 ft bgs and all recovery was lost until a depth of 162.5 ft bgs. The natural gamma log indicated that the base of the basalt occurs at approximately 140 ft bgs.

The next recovered unit at 162.5 ft bgs is alluvium consisting of silty sand with gravel (SM) to a depth of 180 ft bgs. The gravel component includes unique clasts of weakly cemented and HCl reactive sandstone and less of the typical welded tuff lithologies. This unit is underlain by sandy clay from 180 to 202.5 ft bgs. This sandy clay unit is similar to clay-rich horizons only encountered at depths greater than 500 ft bgs in the Fortymile Wash area at boreholes 2DB, 5S, 4PB and 23P. The nature of the sediments suggests a playa depositional environment, probably of limited extent along a restricted drainage system prior to the eruption of the basalt flow (~4.1 Ma).

Underlying the sandy clay are alluvial units consisting predominately of silty sand with gravel (SM) from 202.5 to 260 ft bgs. Gravel clasts consist primarily of welded tuff, and locally sandstone clasts similar to those found from 162.5 to 202.5 ft bgs.

The sediments encountered from 260 to 1550 ft bgs are divided into two sequences. Sediments from 260 to 797 ft bgs consist primarily of volcaniclastic tuffaceous rocks with lacustrine-deposited tuffaceous claystone and sandstone, with a water table at approximately 433 ft bgs. These rocks are underlain by an older sequence from 797 to 1,550 ft bgs of primarily fluvial sediments with altered tuff layers. The lower sequence is interpreted to represent preserved fault-related fan-sequences deposited during early post-Timber Mountain time (12.5 Ma - middle to late Miocene) during rapid extension along the Windy Wash Fault. The younger sequence records deposition in a lower energy environment, presumably after the rapid extension and deposition of coarse clastic debris recorded by the lower sequence. The borehole is terminated at 1,569 ft bgs in an apparent welded tuff unit that may represent Bullfrog Tuff or coarse clastic debris derived locally from Bullfrog Tuff (i.e., younger erosional material).

The unit from 1,140 to 1,315 ft bgs in 13P, logged as arkosic sand/sandstone and conglomerate, consists primarily of monolithic clasts of Paintbrush group rocks in a matrix of mostly volcanic quartz and feldspar, which are very similar to rocks in 10SA and 22SA observed to occur beneath the alluvium but above the volcanics. If these units are roughly time correlative between 13P and 10SA/22SA, then there is possibly a paraconformity (non-deposition) of units in Fortymile Wash (above the conglomerate) that is well-represented in Crater Flat/Windy Wash section at 13P. Further geochronologic work in 13P and deeper drilling in Fortymile Wash are required to test this hypothesis.

Boreholes 24PA and 24PB

Borehole 24P drilled in 2003 (NWRPO, 2003) indicated that the saturated zone stratigraphy at this drill site is similar to that at Yucca Mountain and the "C-wells" complex. The new boreholes 24PA and 24PB were drilled to conduct geophysical investigations to measure in-situ groundwater velocities and to support possible future natural gradient tracer testing.

Borehole 24PA was terminated at approximately 150 ft bgs as a result of downhole drilling system failure. Borehole 24PB intersected a nearly identical sequence of subsurface geological units as 24P. The alluvium-bedrock contact and groundwater was encountered at approximately 405 ft bgs, followed by Bullfrog Tuff from 405 to 900 ft bgs, pre-Bullfrog sedimentary rocks from 900 to 945 ft bgs, and Tram tuff from 945 to 1,377 ft bgs. The borehole was terminated in Pre-Tram sedimentary rocks at 1395 ft bgs. Volcanic units younger than Bullfrog were either eroded away or not deposited at this location.

Borehole 32P

Borehole 32P encountered alluvial units from surface to 396 ft bgs, consisting of well-graded sand with silt and gravel (SW-SM), typical of alluvial units in the upper approximately 500 ft in Fortymile Wash boreholes. The water table was encountered at approximately 260 ft bgs, with the static water level rising to approximately 245 ft bgs. Between a depth of 396 and 496 ft bgs a basaltic lava flow was encountered.

The basalt is underlain by a conglomeratic sandstone unit from 496 to 550 ft bgs. The sandstone consists of a matrix of well-graded sand with heterolithic clasts of flow-banded rhyolite, quartzite, chert and limestone. The sandstone grades downward into unconsolidated fluvial sediments from 550 to 940 ft bgs. Overall, the section of unconsolidated sediments shows a fining downward. Finally, underlying the unconsolidated sediments are lacustrine siltstone beds from 940 to 1,000 (TD) ft bgs. Without the presence of a marker unit, except the Pliocene basalt, the age of the sediments below 496 ft is uncertain. It is possible that this sequence is entirely "post-volcanic"; that is, younger than the last large pyroclastic eruptions of the Timber Mountain Group volcanics at approximately 11.5 Ma. In this case, it is possible that the sequence in 32P beneath the approximately 4 Ma basalt is a relatively continuous and complete section of sediments. If 32P were deepened the interval representing the Miocene volcanics of Yucca Mountain (13.5 to 11.5 Ma) would be intercepted.

An alternative interpretation is that the upper sedimentary sequence (below 496 ft bgs) consists of a pre-volcanic older sedimentary unit overlain by Pliocene-aged basalt, followed by burial with alluvium. This would imply a significant unconformity or non-deposition surface at the stratigraphic top of the sedimentary sequence (496 ft bgs) on which the Pliocene basalt was ultimately erupted. The approximate 50 ft section of cemented sediments below the basalt may represent a deep soil horizon developed on a pedimented surface. Unfortunately, few direct dating methods are available to determine ages of sedimentary sequences.

Borehole 33P

Borehole 33P was drilled by DOE contractors as one of several boreholes drilled in the Yucca Mountain area for analysis of volcanic hazards. Geologic data provided by the DOE indicates that the subsurface geologic units consist of 195 ft of alluvium overlying Tertiary conglomeratic sediments from 195 to 535 ft bgs. The borehole terminated in a Tertiary volcanic unit consisting of non-welded, bedded, and reworked tuff extending from 535 to at least 657.1 ft bgs. Preliminary identification suggests that these tuffaceous rocks are a member of the Paintbrush Group volcanics. The overlying conglomeratic sediments are similar in description to rocks in 13P from 1140 to 1,315 ft bgs, as well as 10SA and 22SA (see discussion in 6.1.1). Overall, below the alluvium, the sequence at 33P appears to represent a post-volcanic Miocene section not seen at 32P.

Corehole 22PC

This corehole was located at Site 22 to collect nearly continuous sonic core samples of the lowermost unsaturated and upper saturated zone alluvial sediments from 460 to 763 ft bgs. The summary log shows that gravel units predominate in the upper approximate 170 ft (460 to 632.1 ft bgs), and sand units in lower approximate 130 ft (632.1 to 763.0 ft bgs). The cored mainly gravelly units above 632.1 ft bgs generally contain less than or equal to 12% fines, and below 632.1 ft bgs the mainly sandy units generally contain greater than 12% fines.

Sonic corehole 19PB, located approximately 3 miles downstream from 22PC in the Fortymile Wash flow system, shows similar trends in gravel and sand units (NWRPO, 2003) as described above for 22PC. That is in 19PB, gravel units predominate in the upper approximately 135 ft of alluvium penetrated and sand units predominate in the lower approximately 145 ft of borehole. Moreover, a slight trend of an increasing amount of fines with depth is observed in both 19PB and 22PC. Also, the average percentages of gravel, sand, and fines measured in sonic core from each borehole differ by no more than several percent. Finally, the major difference between boreholes appears to be the greater range in No. 4 sieve data (i.e., the basis for separating sand and gravel fractions) in 19PB compared to 22PC

7.1.9 Borehole Geophysical Logging

Borehole geophysical logs were used for lithologic characterization and stratigraphic correlations. For the most part, only qualitative interpretations of rock properties were made from the logs. Significant findings include the following.

- Increasing amounts of clay in formation materials often correlate with increasing natural gamma counts, decreasing formation resistivity log values, decreasing density values, and decreasing neutron porosity log counts (increasing water filled porosity).
- In some cases increasing amounts clay correlate with all of the above, except increasing natural gamma counts. In these cases, natural gamma counts may decrease (rather than increase) as a result of a decrease in the concentration of gamma emitters with depth in the formation rock.
- In alluvium, valleys in natural gamma logs and peaks in density and neutron porosity logs can correspond to clean well-graded sand and/or gravel that produces clean water. These sand and/or gravel units can serve as preferential flow paths.
- Conglomeratic arkosic sandstone generally produces increases in natural gamma, density, and neutron porosity log values.

- In volcanic units, formation resistivity logs are useful for identifying the degree of welding within ash-flow tuffs, and therefore useful for stratigraphic correlation. Higher resistivity values correlate well with welded rocks identified in the geological cuttings described at the site and low resistivity values correlate with nonwelded rocks.
- Basalt flows exhibit lower natural gamma counts and higher density values than alluvium. These correlations permitted identifying the lower basalt alluvium contact in borehole 13P where drill cuttings were not returned to the ground surface.
- In most Phase V boreholes, fluid resistivity, fluid temperature, and caliper logs could be used to identify discrete intervals where groundwater flows into or out of the wellbore. In several cases, formation resistivity, density, and neutron porosity logs supported identification of water movement into/out of the borehole.
- Optical televiewer logs, though not always of usable quality, show that, in some places, these discrete flow zones are open fractures. Discrete inflow zones were identified in 32P.
- In alluvial units in nearly every Phase V borehole, large peaks in caliper logs resulted from washout zones and corresponding decreases in natural gamma, density, and neutron porosity log values.
- Density and neutron porosity responses can be due to different clay contents, degree of cementation, grading of clasts, washout zones, and/or fractures.
- Several geophysical logs can yield meaningful results when run inside of multiple steel casings as demonstrated in 22S.
- In the uppermost alluvial unit in boreholes located in Fortymile Wash, there is generally a slight increase in natural gamma counts and a slight decrease in density values with depth. This reflects a slight increase in finer textured fractions with depth.
- At greater depths in Fortymile Wash alluvium natural gamma, density, and neutron porosity logs generally show gradual increases with depth in response to increasing amounts of fines, overburden pressure/compaction, and possibly grading.

7.1.10 Geologic Interpretations from Drilling and Geophysical Data

New drilling data, deep-penetrating resistivity survey data, and gravity data were used to construct two geologic cross sections (Figures 6.3-4 and 6.3-5). These new cross sections replace conceptual cross sections presented in the Phase IV Drilling Report (NWRPO, 2005).

New interpretations provide different interpretations of the two largest features in the flow system south of Yucca Mountain, namely the CJS and Highway 95 Fault. Significant new geologic and hydrologic interpretations include:

- There is evidence that both the CJS and Highway 95 Fault impact or possibly control groundwater movement in the area, including upward hydraulic gradients observed in wells in close proximity to the Highway 95 Fault.
- The Highway 95 Fault location and strike is significantly different than in previous publications. The Highway 95 Fault has two sub-parallel strands, an older master

fault to the south, and a slightly younger sympathetic hanging wall fault to the north. The fault is offset southwestward (approximately 3 km) along the CJS and reappears to the southwest of the Lathrop Wells Cone near well 3D, and continues with a similar west-northwest strike to terminate against the Bare Mountain Fault.

- The timing of displacement along the western portion of the Highway 95 Fault is different than the eastern portion.
- At sites 1, 7 and 9, the alternative conceptual model proposes that deep-seated faulting has breached the lowermost (and higher head) aquifers, and provided natural “piezometers” to the lower carbonate heads. This structurally controlled lower carbonate-sourced higher-head water discharges in the near subsurface environment (as leakance between normally isolated flow systems) above the regional (primarily volcanic) aquifer system, probably over very limited geographic extents at locations where deep-seated structures provide open pathways. These zones of upward leakance are now recognized along both the eastern and western strands of the buried Highway 95 Fault, and possibly along other similar structures.

7.2 Recommendations

- Do not use the DR-CA Symmetrix™ drilling system in future EWDP boreholes until the system is proven to be more robust.
- If conventional DR-CA systems are used in future EWDP boreholes, use a dust control system to capture dust and allow it to be sampled. In addition, use large enough air compressors to efficiently move drill cuttings to the ground surface.
- Evaluate the pros and cons of using 1.25-inch pipe in future EWDP boreholes requiring multiple-string nested piezometers in ≤ 6.5-inch diameter boreholes.
- Eliminate the recording of density related weights in alluvium geologic logging forms for drill cuttings.
- Continue recording field estimates of major particle size fractions in alluvium drill cuttings logging forms. These data are proving very useful in characterizing the textural layering in the alluvium downgradient from Yucca Mountain.
- Continue running natural gamma, caliper, formation resistivity, density, neutron porosity, sonic, fluid temperature, and fluid resistivity geophysical logs.

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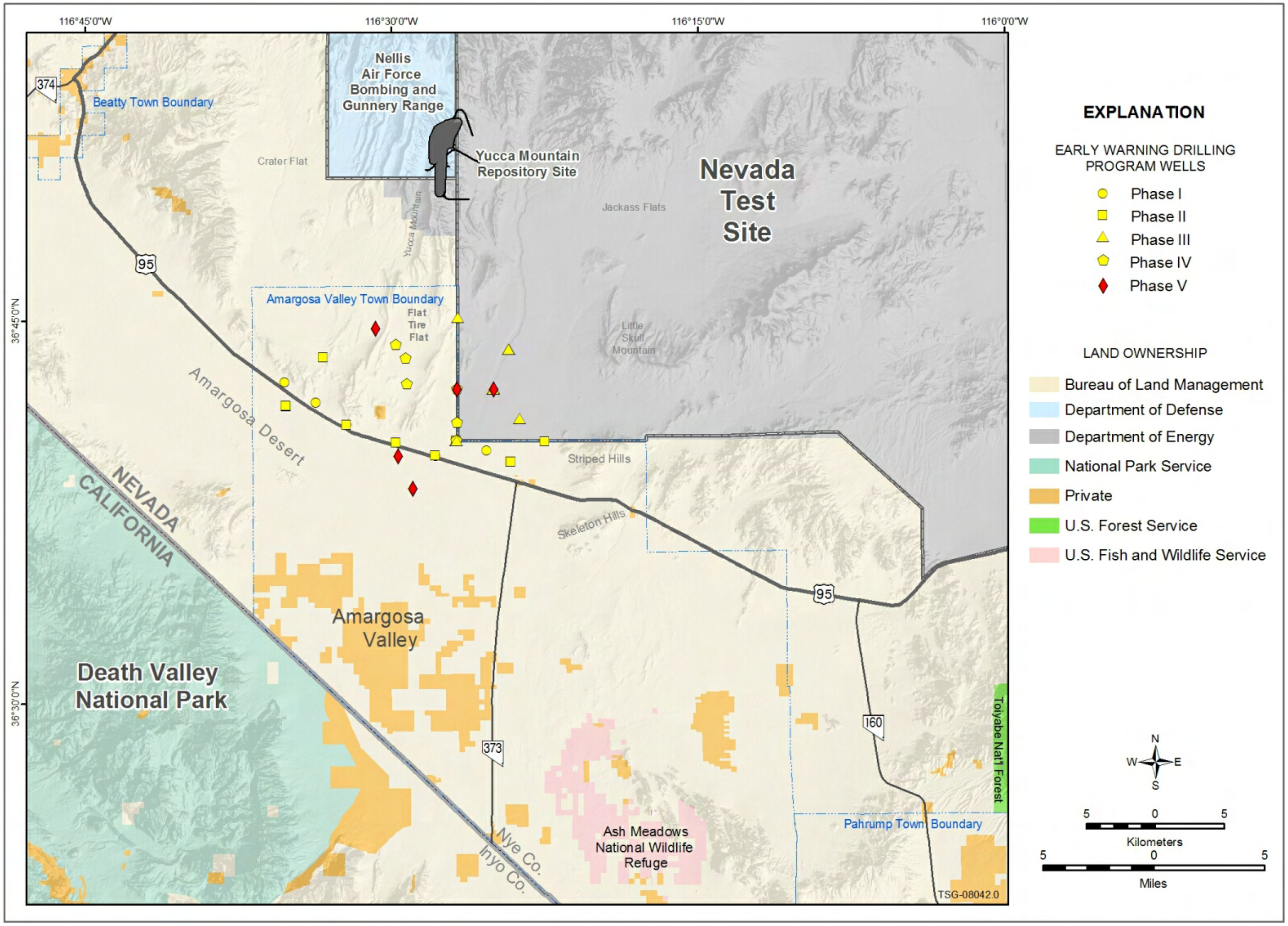


Figure 1.1-1
Early Warning Drilling Program Region

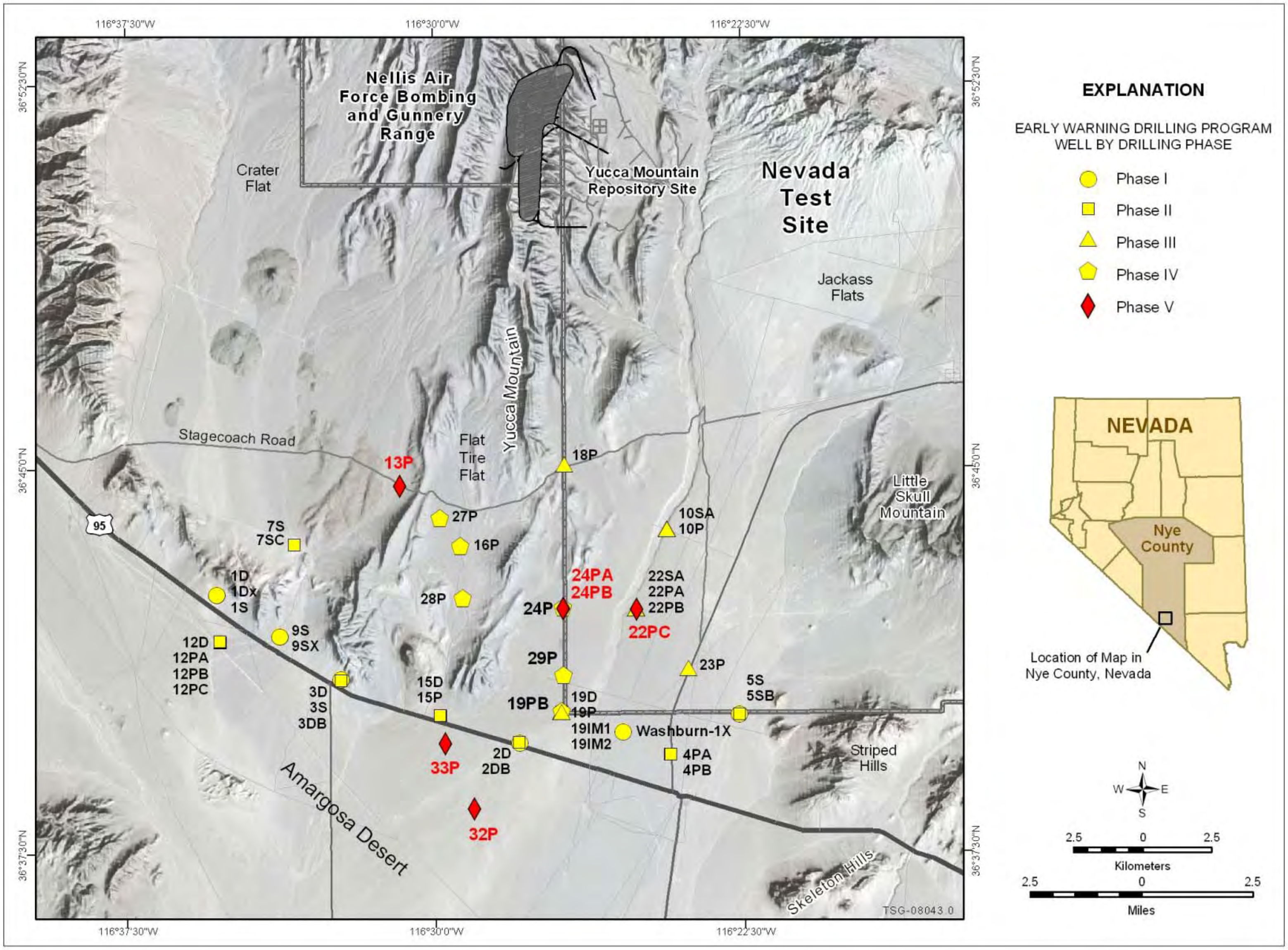
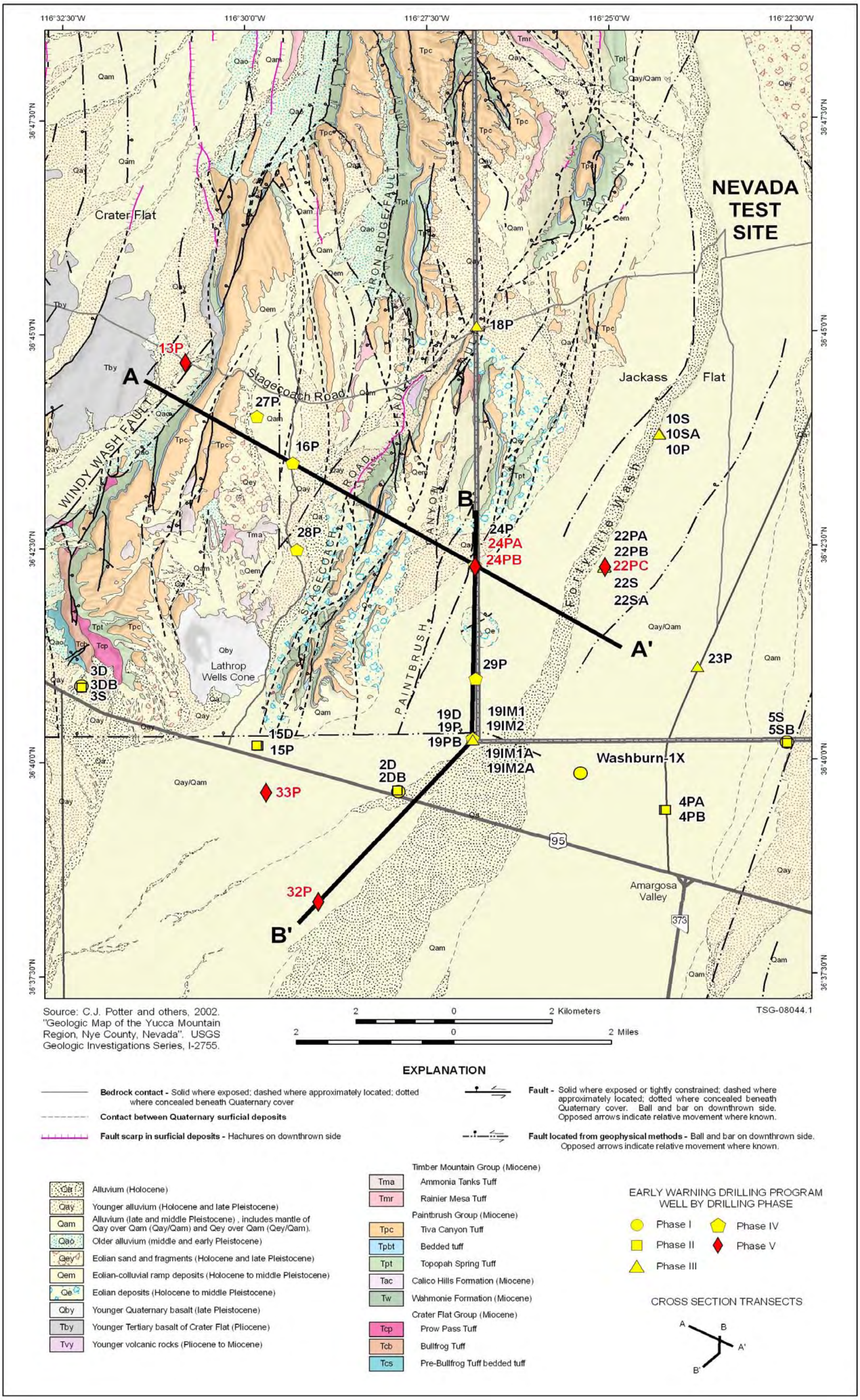


Figure 1.3-1
Early Warning Drilling Program Well Locations by Phase



Figures 1.4-1
Geologic Map of the Yucca Mountain Area

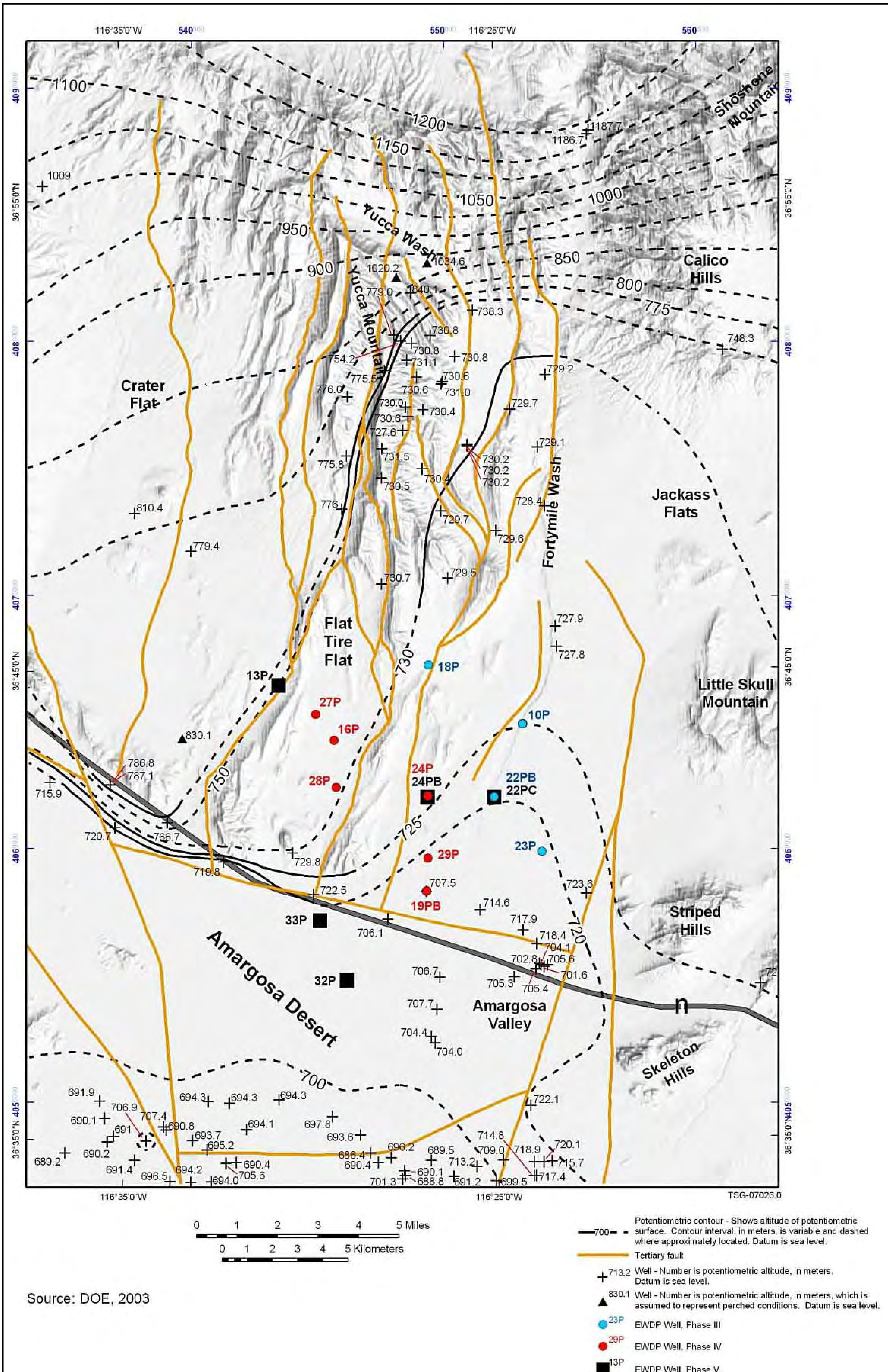


Figure 1.4-2
Potentiometric Surface Map of Yucca Mountain/Amargosa Desert Area

Alluvium Drill Cuttings Logging Form - Nye County Nuclear Waste Repository Project Office

Borehole ID: NC-EWDP-13P (Phase 5) Driller/Drilling Company: Chris Bufkin/WDC Drilling Method: Air-Rotary Reverse Circulation Alluvium Depth (ft bgs): 0 to 260 Start Date: 6/16/2005 End Date: 6/19/2005 Page 1 of 3

Date Logged	Logged By (Initials)	Date Checked	Checked By (Initials)	Sample Number	Depth Interval (feet bgs) From	Depth Interval (feet bgs) To	Drilling Data: Liquid Drilling Fluid Injection Rate (gpm)	Drilling Rate (feet/min)	Water Production (gpm)	Sample Recovery (gallons)	Borehole Diameter (inches)	Sample Density Measurements: Tare Weight (kg)	Sample Plus Tare Weight (kg)	Sample Weight (kg)
6/16/2005	EJH	6/18/2005	DD	13P-0.0-2.5-D	0.00	2.50	0.00	2.20	0.00	2.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-2.5-5.0-D	2.50	5.00	0.00	2.20	0.00	2.50	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-5.0-7.5-D	5.00	7.50	0.00	2.20	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-7.5-10.0-D	7.50	10.00	0.00	2.20	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-10.0-12.5-D	10.00	12.50	0.00	2.20	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-12.5-15.0-D	12.50	15.00	0.00	2.20	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-15.0-17.5-D	15.00	17.50	0.00	2.20	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-17.5-20.0-D	17.50	20.00	0.00	2.20	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-20.0-22.5-D	20.00	22.50	0.00	2.50	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-22.5-25.0-D	22.50	25.00	0.00	2.50	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-25.0-27.5-D	25.00	27.50	0.00	2.50	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-27.5-30.0-D	27.50	30.00	0.00	2.50	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-30.0-32.5-D	30.00	32.50	0.00	2.50	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-32.5-35.0-D	32.50	35.00	0.00	2.50	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-35.0-37.5-D	35.00	37.50	0.00	2.50	0.00	2.50	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-37.5-40.0-D	37.50	40.00	0.00	2.50	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-40.0-42.5-D	40.00	42.50	0.00	1.90	0.00	2.50	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-42.5-45.0-D	42.50	45.00	0.00	1.90	0.00	2.50	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-45.0-47.5-D	45.00	47.50	0.00	1.90	0.00	3.00	6.500			
6/16/2005	EJH	6/18/2005	DD	13P-47.5-50.0-D	47.50	50.00	0.00	1.90	0.00	2.50	6.500			
6/16/2005	EJH	6/29/2005	DD	13P-50.0-52.5-D	50.00	52.50	0.00	1.90	0.00	3.00	6.500			
6/16/2005	EJH	6/29/2005	JSW	13P-52.5-55.0-D	52.50	55.00	0.00	1.90	0.00	2.50	6.500			
6/16/2005	EJH	6/29/2005	JSW	13P-55.0-57.5-D	55.00	57.50	0.00	1.90	0.00	1.50	6.500			
6/16/2005	EJH	6/29/2005	JSW	13P-57.5-60.0-D	57.50	60.00	0.00	1.90	0.00	2.00	6.500			
6/16/2005	EJH	6/29/2005	JSW	13P-60.0-62.5-D	60.00	62.50	0.00	1.90	0.00	2.50	6.500			
6/17/2005	EJH	6/29/2005	JSW	13P-62.5-65.0-D	62.50	65.00	0.00	1.90	0.00	2.50	6.500			
6/17/2005	EJH	6/29/2005	JSW	13P-65.0-67.5-D	65.00	67.50	0.00	1.90	0.00	4.00	6.500			
6/17/2005	EJH	6/29/2005	JSW	13P-67.5-70.0-D	67.50	70.00	0.00	1.90	0.00	3.00	6.500			
6/17/2005	EJH	6/29/2005	JSW	13P-70.0-72.5-D	70.00	72.50	0.00	1.90	0.00	1.00	6.500			
6/17/2005	EJH	6/29/2005	JSW	13P-72.5-75.0-D	72.50	75.00	0.00	1.90	0.00	4.00	6.500			
6/17/2005	EJH	6/29/2005	JSW	13P-75.0-77.5-D	75.00	77.50	0.00	1.90	0.00	1.00	6.500			
6/17/2005	EJH	6/29/2005	JSW	13P-77.5-80.0-D	77.50	80.00	0.00	1.90	0.00	2.00	6.500			

Sample Number	Munsell Color Symbol	Moisture Content: Dry	Moist	Wet	Particle Size Distribution (%): Gravel	Sand	Silt	Clay	Fines (Silt plus Clay)	Grading: Well Graded	Poorly Graded	Estimated Plasticity: None	Low	Moderate	High	USCS Group Symbol	Gravel/Sand GrainShape: Angular	Subangular	Subrounded	Rounded	Cementation: None	Weak	Moderate	Strong	HCL Reaction: None	Weak	Strong	Major Rock Type (%): Volcanics	Carbonates	Other
13P-0.0-2.5-D	5YR 6/1	☑	☐	☐	26	70	4	0	4	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-2.5-5.0-D	5Y 6/1	☑	☐	☐	52	45	3	0	3	☑	☐	☑	☐	☐	☐	GW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-5.0-7.5-D	N5	☑	☐	☐	26	69	5	0	5	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-7.5-10.0-D	5YR 4/1	☑	☐	☐	20	75	5	0	5	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-10.0-12.5-D	5YR 4/1	☑	☐	☐	16	78	6	0	6	☑	☐	☑	☐	☐	☐	SW-SM	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-12.5-15.0-D	5YR 4/4	☑	☐	☐	33	65	2	0	2	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-15.0-17.5-D	5YR 4/4	☑	☐	☐	40	58	2	0	2	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-17.5-20.0-D	5YR 3/4	☑	☐	☐	33	64	3	0	3	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-20.0-22.5-D	5YR 3/2	☑	☐	☐	21	75	4	0	4	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-22.5-25.0-D	5YR 4/4	☑	☐	☐	24	72	4	0	4	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-25.0-27.5-D	5YR 4/4	☑	☐	☐	15	79	6	0	6	☑	☐	☑	☐	☐	☐	SW-SM	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-27.5-30.0-D	10YR 4/2	☑	☐	☐	24	71	5	0	5	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-30.0-32.5-D	5YR 3/2	☑	☐	☐	22	73	5	0	5	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-32.5-35.0-D	5YR 3/2	☑	☐	☐	29	67	4	0	4	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-35.0-37.5-D	5YR 5/2	☑	☐	☐	21	72	7	0	7	☑	☐	☑	☐	☐	☐	SW-SM	☐	☑	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-37.5-40.0-D	5YR 5/2	☑	☐	☐	22	76	2	0	2	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-40.0-42.5-D	10YR 6/2	☑	☐	☐	10	80	10	0	10	☑	☐	☑	☐	☐	☐	SW-SM	☐	☑	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-42.5-45.0-D	5YR 5/2	☑	☐	☐	22	73	5	0	5	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-45.0-47.5-D	5YR 4/4	☑	☐	☐	26	72	2	0	2	☑	☐	☑	☐	☐	☐	SW	☐	☑	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-47.5-50.0-D	10YR 5/4	☑	☐	☐	21	73	6	0	6	☑	☐	☑	☐	☐	☐	SW-SM	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-50.0-52.5-D	5YR 3/2	☑	☐	☐	8	84	8	0	8	☑	☐	☑	☐	☐	☐	SW-SM	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-52.5-55.0-D	5YR 3/2	☑	☐	☐	44	52	4	0	4	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-55.0-57.5-D	5YR 3/2	☑	☐	☐	48	49	3	0	3	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-57.5-60.0-D	5YR 4/2	☑	☐	☐	40	55	5	0	5	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-60.0-62.5-D	5YR 3/2	☑	☐	☐	32	63	5	0	5	☑	☐	☑	☐	☐	☐	SW	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-62.5-65.0-D	10YR 6/2	☐	☐	☑	27	67	4	2	6	☑	☐	☐	☑	☐	☐	SW-SM	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-65.0-67.5-D	10YR 4/2	☐	☑	☐	11	77	7	5	12	☑	☐	☐	☑	☐	☐	SW-SM	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-67.5-70.0-D	10YR 5/4	☑	☐	☐	11	78	6	5	11	☑	☐	☑	☐	☐	☐	SW-SM	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-70.0-72.5-D	10YR 4/2	☑	☐	☐	18	70	7	5	12	☑	☐	☑	☐	☐	☐	SW-SM	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-72.5-75.0-D	10YR 4/2	☑	☐	☐	7	82	7	4	11	☑	☐	☑	☐	☐	☐	SW-SM	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-75.0-77.5-D	10YR 4/2	☑	☐	☐	25	65	10	0	10	☑	☐	☑	☐	☐	☐	SW-SM	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		
13P-77.5-80.0-D	10YR 4/2	☑	☐	☐	18	75	7	0	7	☑	☐	☑	☐	☐	☐	SW-SM	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	100		

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Figure 2.3-1
Example of Alluvium Drill Cuttings Geologic Logging Form

Non-Alluvium Logging Form - Nye County Nuclear Waste Repository Project Office

Borehole ID: NC-EWDP-13P (Phase 5) Driller/Drilling Company: Chris Bufkin/WDC Drilling Method: Air-Rotary Reverse Circulation Non-Alluvium Depth (ft bgs): 87 to 1569 Start Date: 6/17/2005 End Date: 7/23/2005 Page 1 of 10

Logged (date)	Logged (by)	Checked (date)	Checked (by)	Sample	Depth Interval (feet/bgs) from	Depth Interval (feet/bgs) to	Drilling/Coring Data: Liquid Drilling Fluid Injection Rate (gpm)	Drilling/Coring Rate (feet/min)	Water Production (gpm)	Sample Recovery (gallons)	Sample Density Data: Borehole Diameter (inches)	Tare Weight (kg)	Sample Plus Tare Weight (kg)	Sample Weight (kg)	Munsell Color Symbol
06/17/05	EJH	06/18/05	DD	13P-87.0-90.0-D	87.00	90.00	0.00	0.20	0.00	5.50	6.50				N1
06/17/05	EJH	06/18/05	DD	13P-90.0-95.0-D	90.00	95.00	0.00	0.20	0.00	6.00	6.50				N1
06/17/05	EJH	06/18/05	DD	13P-95.0-100.0-D	95.00	100.00	0.00	0.20	0.00	6.00	6.50				N1
06/18/05	EJH	06/29/05	JSW	13P-100.0-105.0-D	100.00	105.00	0.00	0.10	0.00	5.00	6.50				N1
06/18/05	EJH	06/29/05	JSW	13P-105.0-110.0-D	105.00	110.00	0.00	0.10	0.00	1.00	6.50				N1
06/18/05	EJH	06/29/05	JSW	13P-110.0-115.0-D	110.00	115.00	0.00	0.10	0.00	4.00	6.50				N1
06/18/05	EJH	06/29/05	JSW	13P-115.0-120.0-D	115.00	120.00	0.00	0.10	0.00	4.00	6.50				N1
06/18/05	EJH	06/29/05	JSW	13P-120.0-125.0-D	120.00	125.00	0.00	0.10	0.00	4.50	6.50				N1
06/19/05	EJH	06/29/05	JSW	13P-125.0-130.0-D	125.00	130.00	0.00	0.10	0.00	6.00	6.50				N1
06/19/05	EJH	06/29/05	JSW	13P-130.0-132.5-D	130.00	132.50	0.00	0.10	0.00	1.50	6.50				N1
06/19/05	EJH	07/20/05	BW	13P-260.0-265.0-D	260.00	265.00	0.00	2.90	0.00	2.00	6.50				10YR 5/4
06/19/05	EJH	07/20/05	BW	13P-265.0-270.0-D	265.00	270.00	0.00	2.90	0.00	5.50	6.50				5YR 7/2
06/19/05	EJH	07/20/05	BW	13P-270.0-275.0-D	270.00	275.00	0.00	2.90	0.00	5.00	6.50				10YR 5/4
06/19/05	EJH	07/20/05	BW	13P-275.0-280.0-D	275.00	280.00	0.00	2.90	0.00	6.00	6.50				10YR 5/4
06/19/05	EJH	07/20/05	BW	13P-280.0-285.0-D	280.00	285.00	0.00	1.40	0.00	5.50	6.50				10YR 5/4
06/19/05	EJH	07/20/05	BW	13P-285.0-290.0-D	285.00	290.00	0.00	1.40	0.00	4.50	6.50				10YR 6/2
06/19/05	EJH	07/20/05	BW	13P-290.0-295.0-D	290.00	295.00	0.00	1.40	0.00	4.00	6.50				10YR 6/2
06/19/05	EJH	07/20/05	BW	13P-295.0-300.0-D	295.00	300.00	0.00	1.40	0.00	7.00	6.50				10YR 6/6
06/20/05	EJH	07/20/05	BW	13P-300.0-305.0-D	300.00	305.00	0.00	1.10	0.00	8.00	6.50				10YR 6/6
06/20/05	EJH	07/20/05	BW	13P-305.0-310.0-D	305.00	310.00	0.00	1.10	0.00	5.50	6.50				10YR 6/6
06/20/05	EJH	07/20/05	BW	13P-310.0-315.0-D	310.00	315.00	0.00	1.10	0.00	2.00	6.50				10YR 6/6
06/20/05	EJH	07/20/05	BW	13P-315.0-320.0-D	315.00	320.00	0.00	1.10	0.00	2.00	6.50				10YR 6/6
06/20/05	EJH	07/20/05	BW	13P-320.0-325.0-D	320.00	325.00	0.00	1.40	0.00	2.00	6.50				10YR 6/6
06/20/05	EJH	07/20/05	BW	13P-325.0-330.0-D	325.00	330.00	0.00	1.40	0.00		6.50				10YR 6/6
06/20/05	EJH	07/20/05	BW	13P-330.0-335.0-D	330.00	335.00	0.00	1.40	0.00		6.50				10YR 6/6
06/20/05	EJH	07/20/05	BW	13P-335.0-340.0-D	335.00	340.00	0.00	1.40	0.00		6.50				10YR 6/6
06/20/05	EJH	07/20/05	BW	13P-340.0-345.0-D	340.00	345.00	0.00	1.70	0.00	4.50	6.50				10YR 6/6
06/20/05	EJH	07/20/05	BW	13P-345.0-350.0-D	345.00	350.00	0.00	1.70	0.00	4.00	6.50				10YR 6/6

Sample	Moisture Content: Not Applicable	Dry	Moist	Wet	HCL Reaction: None	Weak	Strong	Rock Unit: Tuff: Deposition: Ash Fall	Ash Flow	Reworked	Welding: Dense	Moderate	Weak	None	Alteration: Vitric	Devitrified	Matrix	Vapor Phase	Spherulitic	Sedimentary: Claystone	Mudstone	Siltstone	Sandstone	Conglomerate	Chert	Carbonate: Limestone	Dolomite	Other	Weathering: Fresh	Slight	Moderate	High	Decomposed	Structure: None Observed	Stratified	Laminated	Fractured	Other	Matrix: Dense/Non-porous	Open/Porous	Other
13P-87.0-90.0-D		✔					✔																								✔			✔					✔		
13P-90.0-95.0-D		✔				✔																								✔				✔					✔		
13P-95.0-100.0-D		✔				✔																								✔				✔					✔		
13P-100.0-105.0-D		✔					✔																						✔					✔					✔		
13P-105.0-110.0-D		✔			✔																											✔		✔					✔		
13P-110.0-115.0-D		✔				✔																									✔			✔					✔		
13P-115.0-120.0-D		✔				✔																								✔				✔					✔		
13P-120.0-125.0-D		✔			✔																								✔					✔					✔		
13P-125.0-130.0-D		✔				✔																							✔					✔					✔		
13P-130.0-132.5-D		✔				✔																							✔					✔					✔		
13P-260.0-265.0-D		✔					✔			✔				✔		✔																✔		✔						✔	
13P-265.0-270.0-D		✔					✔			✔				✔		✔																✔		✔						✔	
13P-270.0-275.0-D		✔					✔			✔				✔		✔																✔			✔					✔	
13P-275.0-280.0-D		✔					✔			✔				✔		✔																✔			✔					✔	
13P-280.0-285.0-D		✔					✔			✔				✔		✔																✔		✔						✔	
13P-285.0-290.0-D		✔					✔			✔				✔		✔																✔		✔						✔	
13P-290.0-295.0-D		✔					✔			✔				✔		✔																✔		✔						✔	
13P-295.0-300.0-D		✔					✔			✔				✔		✔																✔		✔						✔	
13P-300.0-305.0-D		✔					✔			✔				✔		✔																✔		✔						✔	
13P-305.0-310.0-D		✔					✔			✔				✔		✔																✔		✔						✔	
13P-310.0-315.0-D			✔				✔			✔				✔		✔																✔		✔						✔	
13P-315.0-320.0-D			✔				✔			✔				✔		✔																✔		✔						✔	
13P-320.0-325.0-D			✔				✔			✔				✔		✔																✔		✔						✔	
13P-325.0-330.0-D		✔					✔			✔				✔		✔																✔		✔						✔	
13P-330.0-335.0-D		✔					✔			✔				✔		✔																✔		✔						✔	
13P-335.0-340.0-D		✔					✔			✔				✔		✔																✔		✔						✔	
13P-340.0-345.0-D		✔					✔			✔				✔																		✔		✔						✔	
13P-345.0-350.0-D		✔				✔				✔				✔																	✔			✔						✔	

Sample	Phenocrysts: Mafics % by Vol.	Mafics Munsell Color Symbol	Mafics Max. Size (mm)	Quartz % by Vol.	Quartz Munsell Color Symbol	Quartz Max. Size (mm)	Feldspar % by Vol.	Feldspar Munsell Color Symbol	Feldspar Max. Size (mm)	Clasts: Pumice % by Vol.	Pumice Munsell Color Symbol	Pumice Max. Size (mm)	Lithics % by Vol.	Lithics Munsell Color Symbol	Lithics Max. Size (mm)
13P-87.0-90.0-D	5	5YR 5/6	1.5												
13P-90.0-95.0-D	8	5YR 5/6	1.5												
13P-95.0-100.0-D	8	5YR 5/6	1.5												
13P-100.0-105.0-D	2	5YR 5/6	1												
13P-105.0-110.0-D	1	5YR 5/6	1												
13P-110.0-115.0-D	2	5YR 5/6	1												
13P-115.0-120.0-D	1	5YR 5/6	1												
13P-120.0-125.0-D	2	10Y 6/6	2												
13P-125.0-130.0-D	2	5Y 5/6	1												
13P-130.0-132.5-D	1	5Y 5/6	1												
13P-260.0-265.0-D															
13P-265.0-270.0-D															
13P-270.0-275.0-D															
13P-275.0-280.0-D															
13P-280.0-285.0-D															
13P-285.0-290.0-D															
13P-290.0-295.0-D															
13P-295.0-300.0-D															
13P-300.0-305.0-D													1	10R 2/2	1
13P-305.0-310.0-D													1	10R 2/2	1
13P-310.0-315.0-D													1	10R 2/2	1
13P-315.0-320.0-D													1	10R 2/2	2
13P-320.0-325.0-D															
13P-325.0-330.0-D															
13P-330.0-335.0-D															
13P-335.0-340.0-D															
13P-340.0-345.0-D										3	10YR 8/2	10			
13P-345.0-350.0-D										5	10YR 8/2	20	1	10R 2/2	1

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Figure 2.3-2
Example of Non-Alluvium Drill Cuttings Geologic Logging Form

Alluvium Core Logging Form - Nye County Nuclear Waste Repository Project Office

Key for Sample Number: SC = Sonic core; SCA = Sonic core duplicate interval; C = Drive core. Key for Sample Type: L = Logging; D = Density; F = Fill; LC = Lost core; R = Entire run; X = End of run (overlaps with next run).

Borehole ID: NC-EWDP-22PC (Phase 5) Driller/Drilling Company: Shawn Cain/Boart Longyear Drilling Method: Sonic Coring Alluvium Depth (ft bgs): 460 to 763 Start Date: 10/26/2004 End Date: 11/11/2004 Page 1 of 24

Date Logged	Logged By (Initials)	Date Checked	Checked By (Initials)	Core Run Number	Sample Type	Sample Number	Depth Interval (feet bgs) From	Depth Interval (feet bgs) To	Coring Data: Coring Rate (feet/min)	Coring Data: Sample Recovery (feet)	Coring Data: Core Diameter (inches)	Sample Density Data: Tare Weight (kg)	Sample Density Data: Sample Plus Tare Weight (kg)	Sample Density Data: Sample Weight (kg)	Munsell Color Symbol
10/26/2004	DD/BW	10/27/2004	BW	1	D	22PC-460-460.5-SC	460.00	460.50			6.20	0.20	6.00	5.80	
10/26/2004	DD/BW	10/27/2004	BW	1	L	22PC-460-460.5-SCA	460.00	460.50				0.82	6.40	5.58	5YR 4/6
10/26/2004	DD/BW	10/27/2004	BW	1	R	22PC-460-463.7-SC	460.00	463.70	0.80	3.70					
10/26/2004	DD/BW	10/27/2004	BW	1	D	22PC-460.5-461.3-SC	460.50	461.30			6.20	0.20	13.75	13.55	
10/26/2004	DD/BW	10/27/2004	BW	1	L	22PC-460.5-461.1-SC	460.50	461.10				0.81	9.65	8.84	10YR 4/3
10/26/2004	DD/BW	10/27/2004	BW	1	L	22PC-461.1-461.8-SC	461.10	461.80				0.85	6.75	5.90	5YR 4/6
10/26/2004	DD/BW	10/27/2004	BW	1	D	22PC-461.3-462-SC	461.30	462.00			6.20	0.20	11.30	11.10	
10/26/2004	DD/BW	10/27/2004	BW	1	LX	22PC-461.8-463.7-SC	461.80	463.70				0.85	9.40	8.55	10YR 4/3
10/26/2004	DD/BW	10/27/2004	BW	1	D	22PC-462-462.9-SC	462.00	462.90			6.20	0.20	13.95	13.75	
10/26/2004	DD/BW	10/27/2004	BW	1	D	22PC-462.9-463.7-SC	462.90	463.70			6.20	0.20	12.05	11.85	
10/26/2004	DD/BW	10/27/2004	BW	2	D	22PC-463.7-464.9-SC	463.70	464.90			6.20	0.20	12.55	12.35	
10/26/2004	DD/BW	10/27/2004	BW	2	R	22PC-463.7-471.4-SC	463.70	471.40	1.70	7.70					
10/26/2004	DD/BW	10/27/2004	BW	2	LX	22PC-463.7-464.2-SC	463.70	464.20				0.82	4.75	3.93	5YR 5/6
10/26/2004	DD/BW	10/27/2004	BW	2	L	22PC-464.2-466.3-SC	464.20	466.30				0.86	10.85	9.99	5YR 6/4
10/26/2004	DD/BW	10/27/2004	BW	2	D	22PC-464.9-466.5-SC	464.90	466.50			6.20	0.20	18.85	18.65	
10/26/2004	DD/BW	10/27/2004	BW	2	L	22PC-466.3-468.1-SC	466.30	468.10				0.81	9.95	9.14	5YR 6/4
10/26/2004	DD/BW	10/27/2004	BW	2	D	22PC-466.5-468.2-SC	466.50	468.20			6.20	0.20	20.20	20.00	
10/26/2004	DD/BW	10/27/2004	BW	2	L	22PC-468.1-469.1-SC	468.10	469.10				0.82	10.50	9.68	5YR 6/4

Sample Number	Moisture Content: Dry	Moist	Wet	Particle Size Distribution (%): Gravel	Sand	Silt	Clay	Fines (Silt plus Clay)	Grading: Well Graded	Poorly Graded	Not Applicable	Estimated Plasticity: None	Low	Moderate	High	USCS Group Symbol	Gravel/Sand GrainShape: Angular	Subangular	Subrounded	Rounded	Cementation: None	Weak	Moderate	Strong	HCL Reaction: None	Weak	Strong	Major Rock Type (%): Volcanics	Carbonates	Other
22PC-460-460.5-SC																														
22PC-460-460.5-SCA		✓		37	47	6	10	16			✓			✓		SC		✓			✓				✓			100		
22PC-460-463.7-SC																														
22PC-460.5-461.3-SC																														
22PC-460.5-461.1-SC		✓		46	40	4	10	14		✓			✓			GP-GC		✓			✓				✓			100		
22PC-461.1-461.8-SC		✓		52	36	5	7	12	✓				✓			GW-GC		✓			✓				✓			100		
22PC-461.3-462-SC																														
22PC-461.8-463.7-SC		✓		44	36	6	14	20			✓			✓		GC		✓			✓				✓			100		
22PC-462-462.9-SC																														
22PC-462.9-463.7-SC																														
22PC-463.7-464.9-SC																														
22PC-463.7-471.4-SC																														
22PC-463.7-464.2-SC		✓		13	61	8	18	26			✓				✓	SC		✓			✓				✓			100		
22PC-464.2-466.3-SC		✓		59	32	3	6	9	✓				✓			GW-GC		✓			✓				✓			100		
22PC-464.9-466.5-SC																														
22PC-466.3-468.1-SC		✓		64	29	2	5	7	✓				✓			GW-GC		✓			✓				✓			100		
22PC-466.5-468.2-SC																														
22PC-468.1-469.1-SC		✓		24	54	7	15	22			✓			✓		SC		✓			✓				✓			100		

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Figure 2.3-3
Example of Alluvium Core Geologic Logging Form

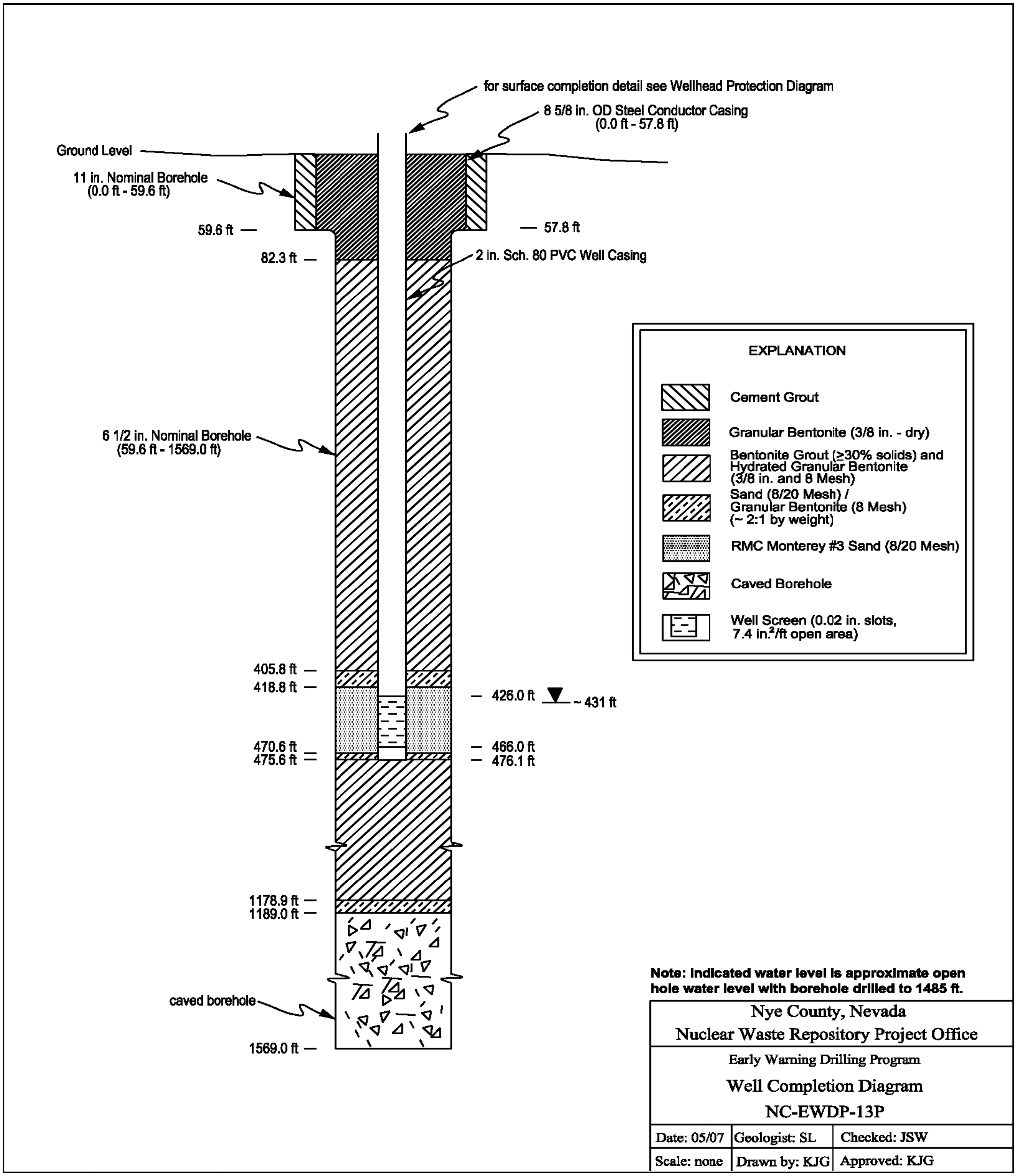


Figure 3.1-1
Single-String Piezometer Completion Diagram for 13P

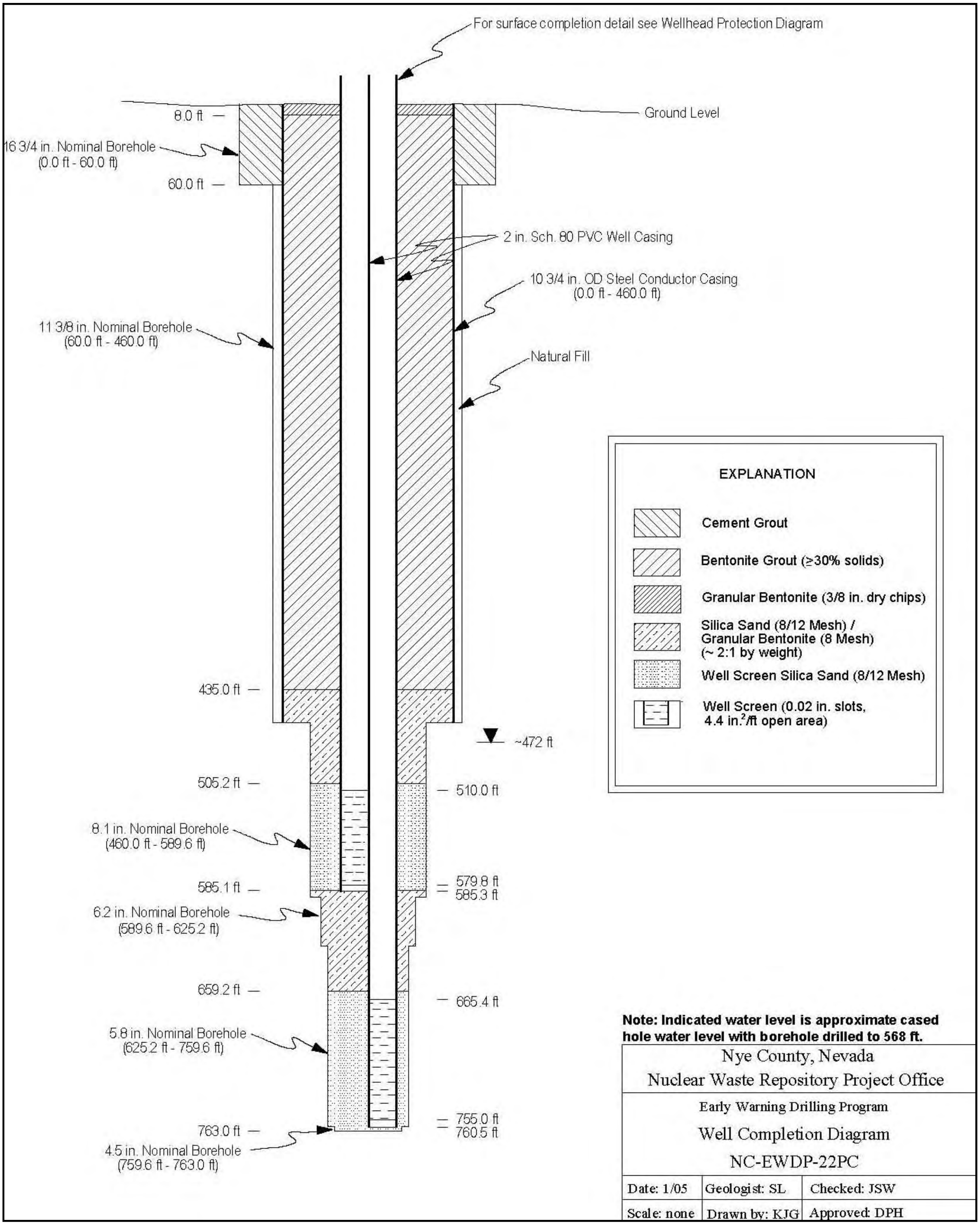


Figure 3.1-2
Dual-String Piezometer Completion Diagram for 22PC

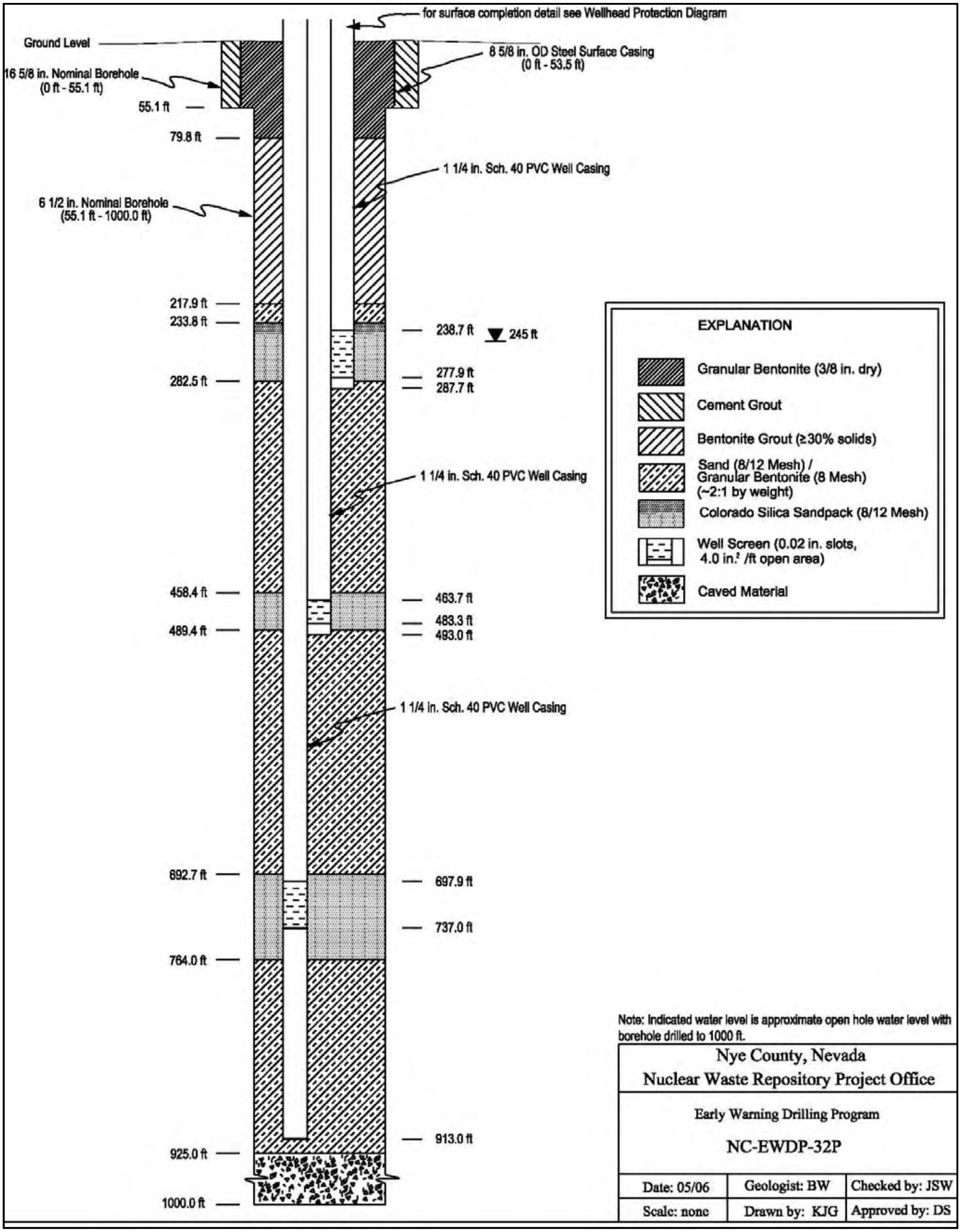


Figure 3.1-3
Triple-String Piezometer Completion Diagram for 32P

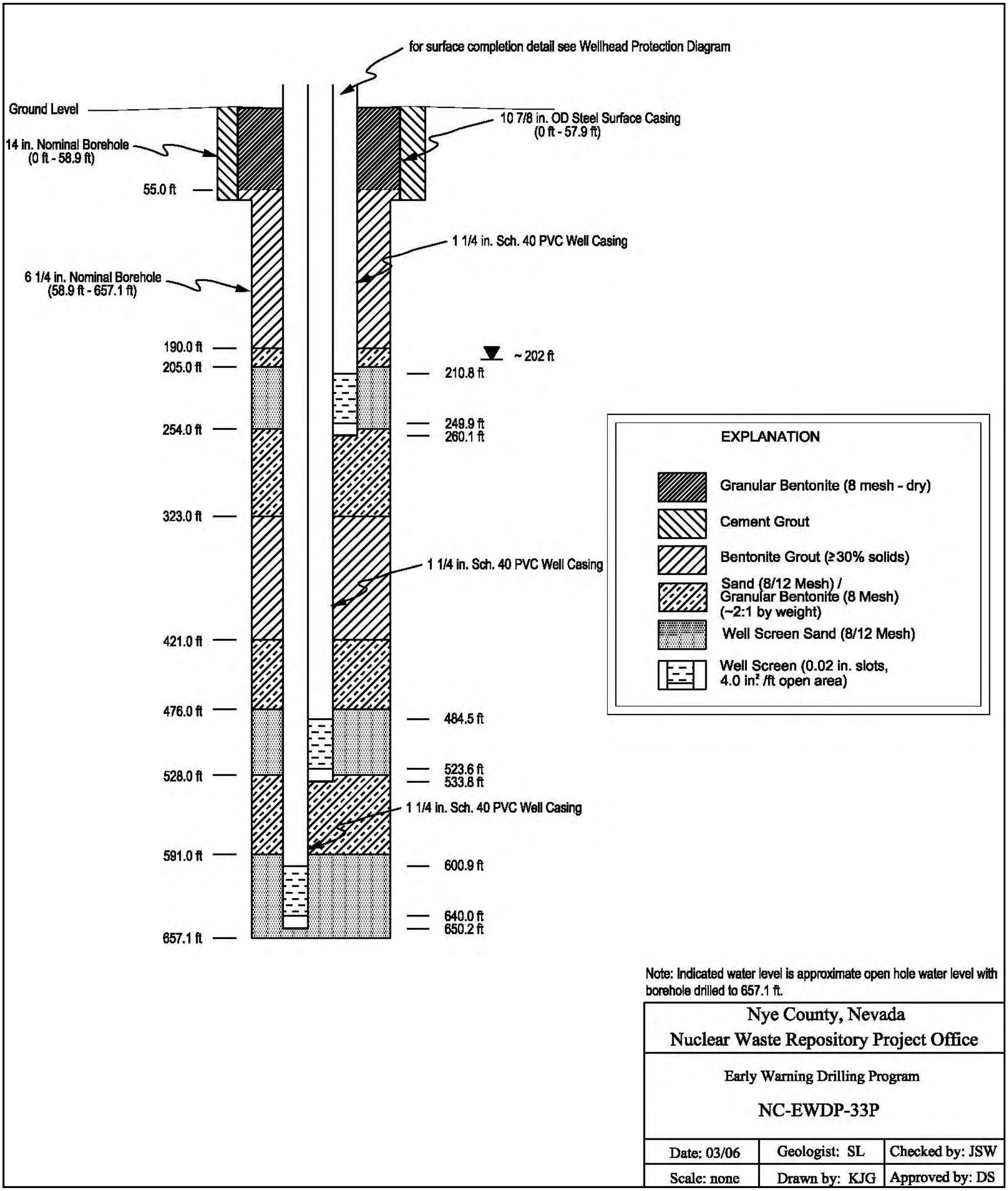


Figure 3.1-4
Triple-String Piezometer Completion Diagram for 33P

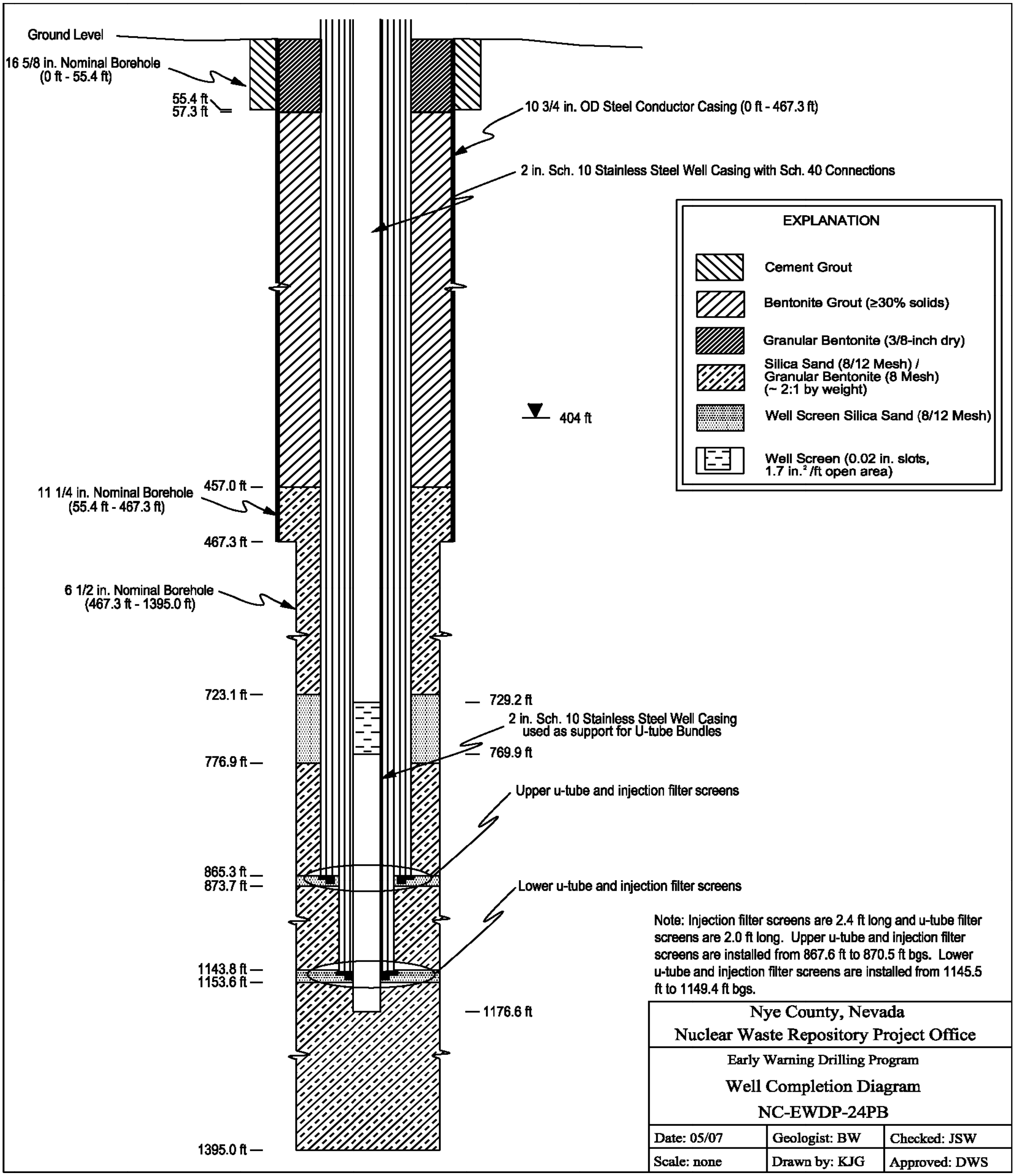
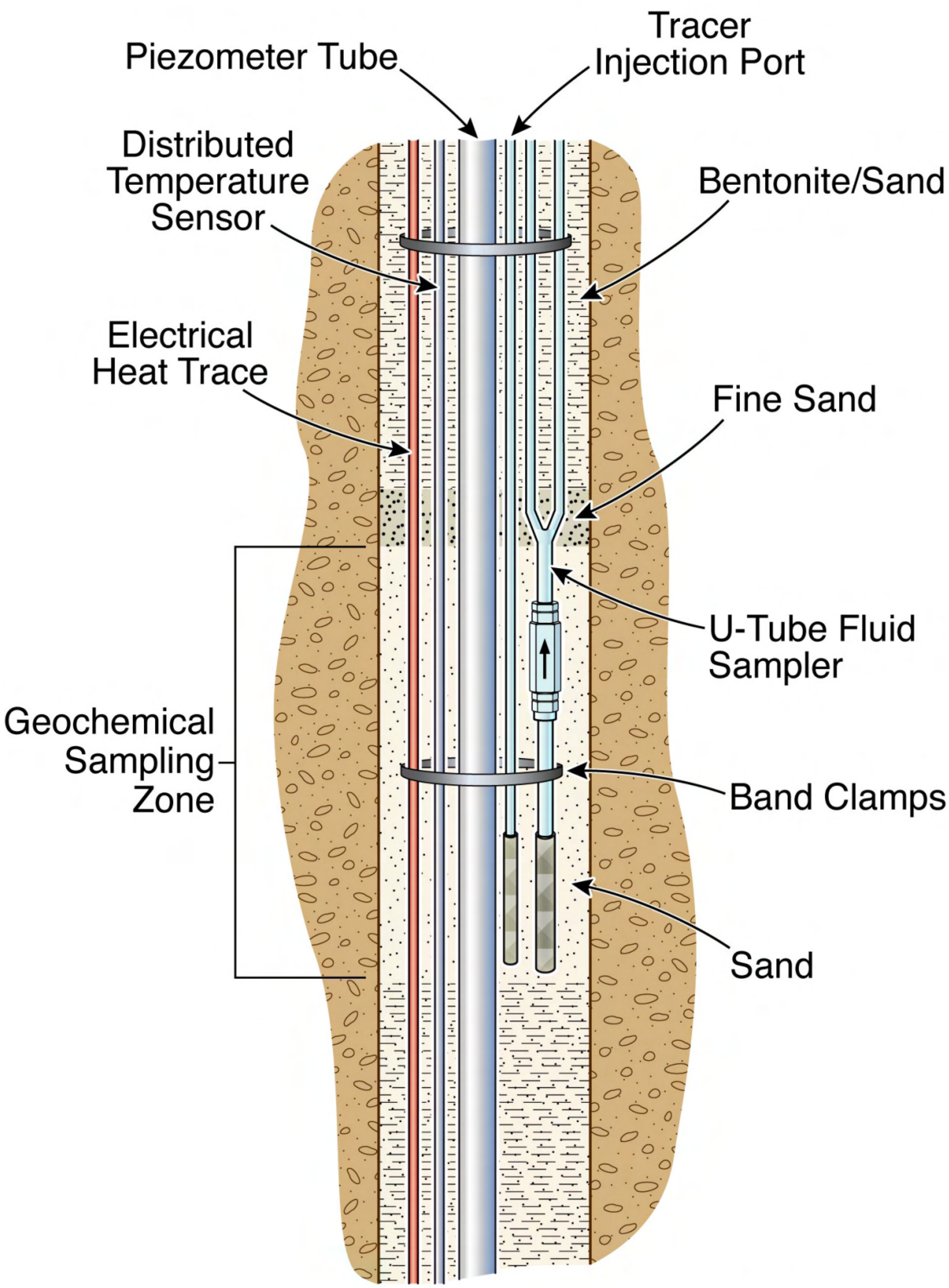


Figure 3.1-5
Single-String Piezometer, U-Tube, and Injection Instrumentation Completion Diagram for 24PB



Freifeld, B., 2007. Monitoring CO2 Geosequestration Using Distributed Thermal Measurements, Sixth Annual Conference on Carbon Capture and Sequestration, Pittsburg, Pennsylvania. pp 9.

Figure 3.1-6
Schematic Diagram of Monitoring System in 24PB

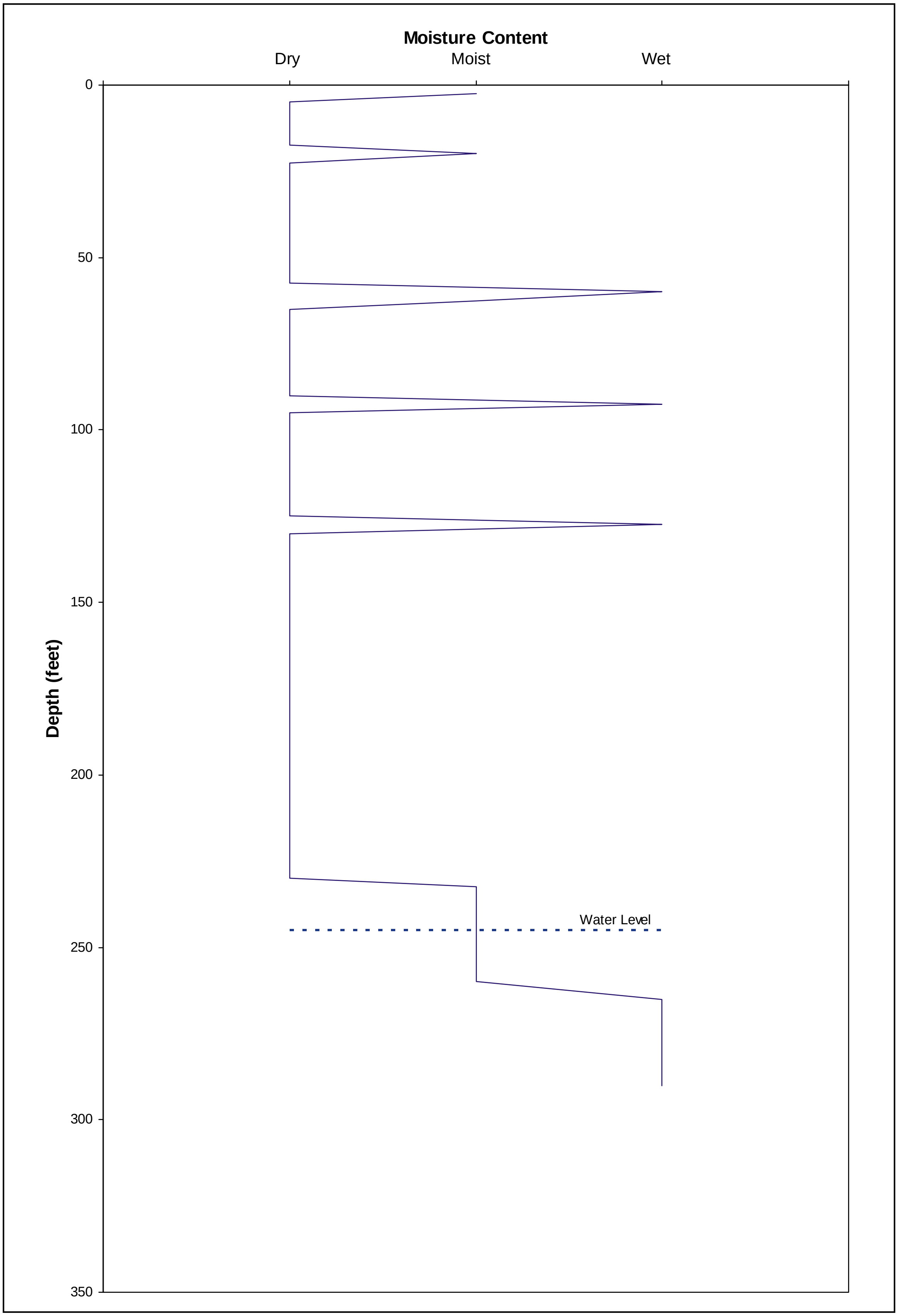


Figure 4.1-1
Moisture Content versus Depth in Alluvium for 32P (0 to 290 Feet)

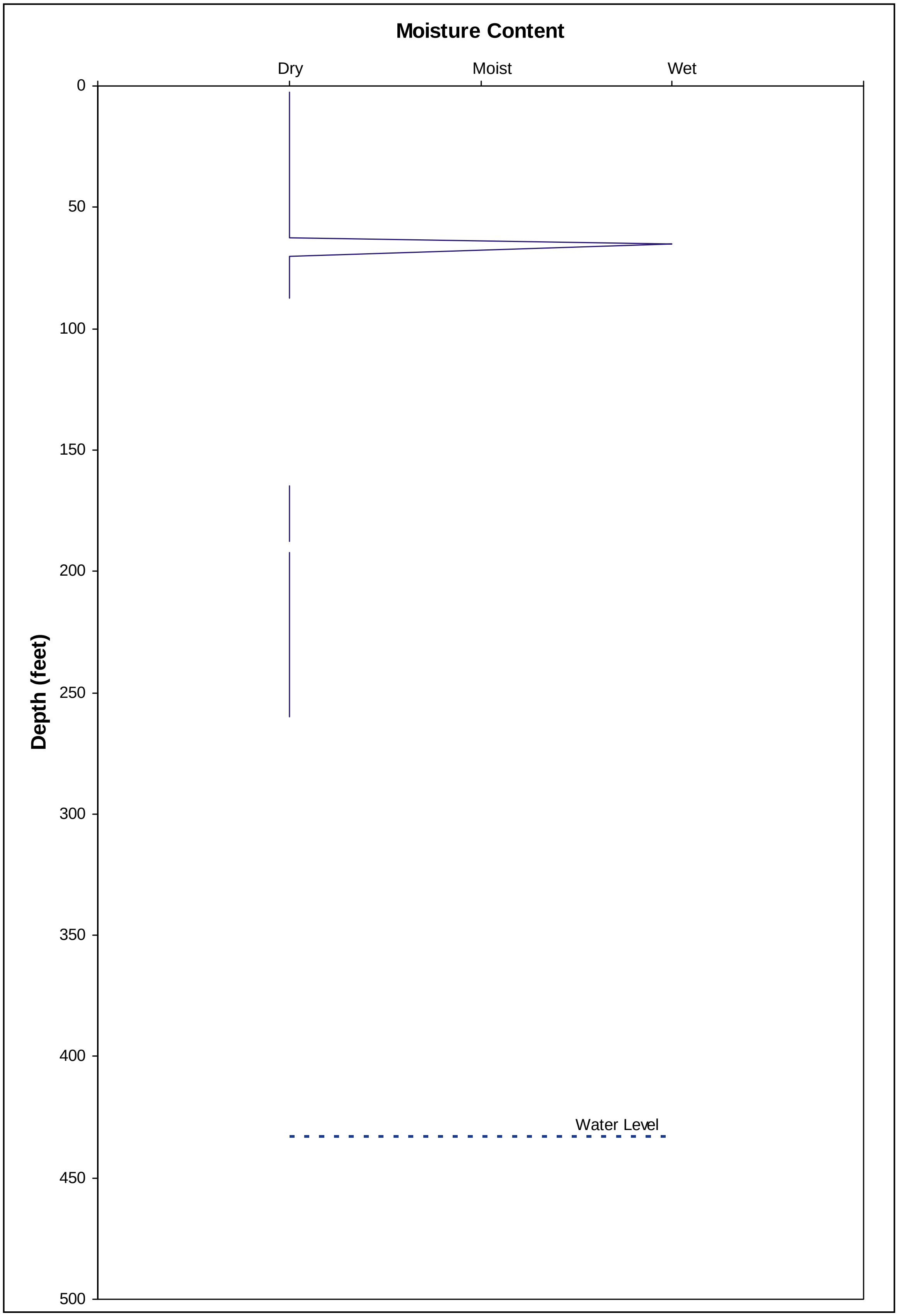


Figure 4.1-2
Moisture Content versus Depth in Alluvium for 13P (0 to 260 Feet)

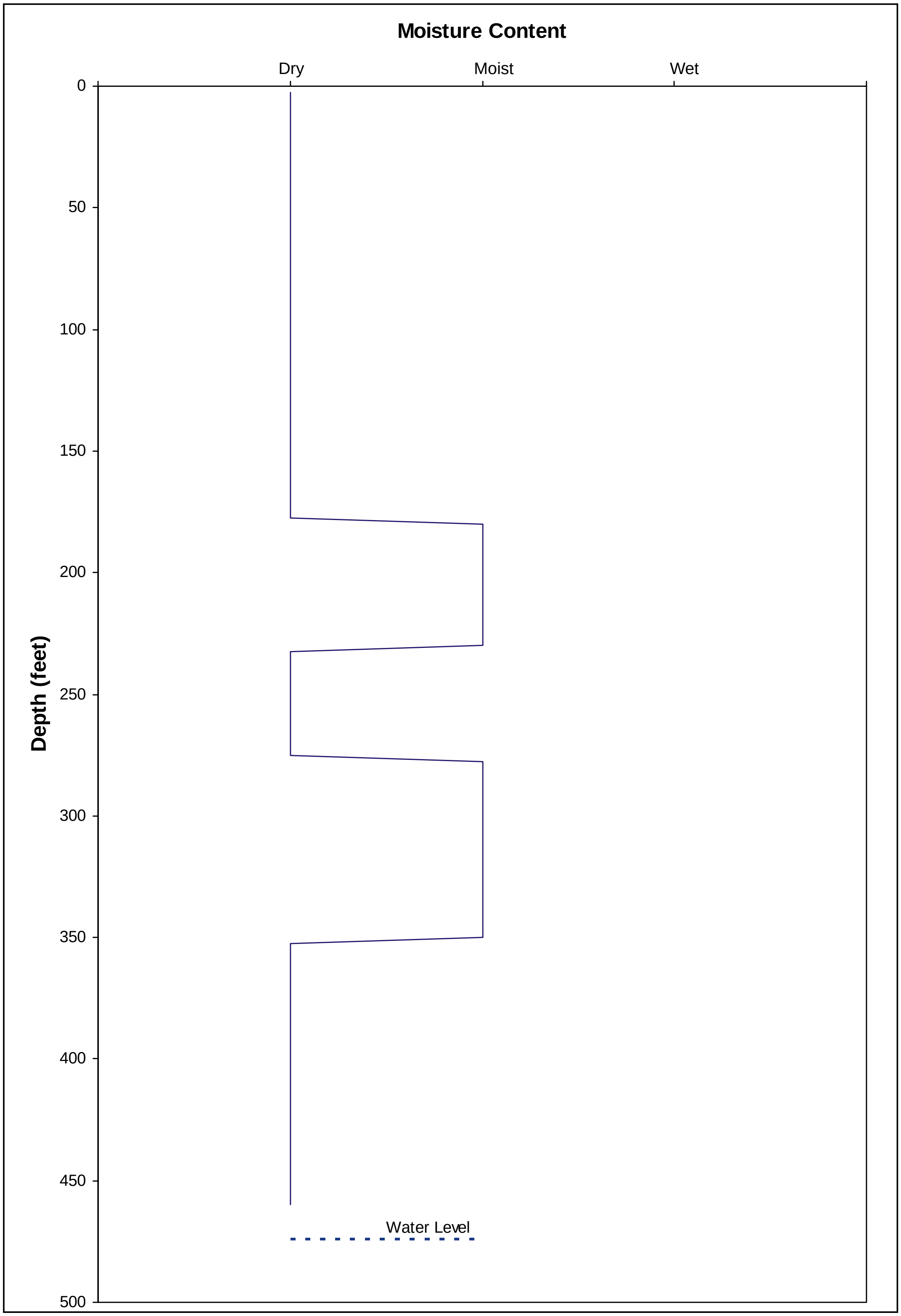


Figure 4.1-3
Moisture Content versus Depth in Alluvium for 22PC (0 to 460 Feet)

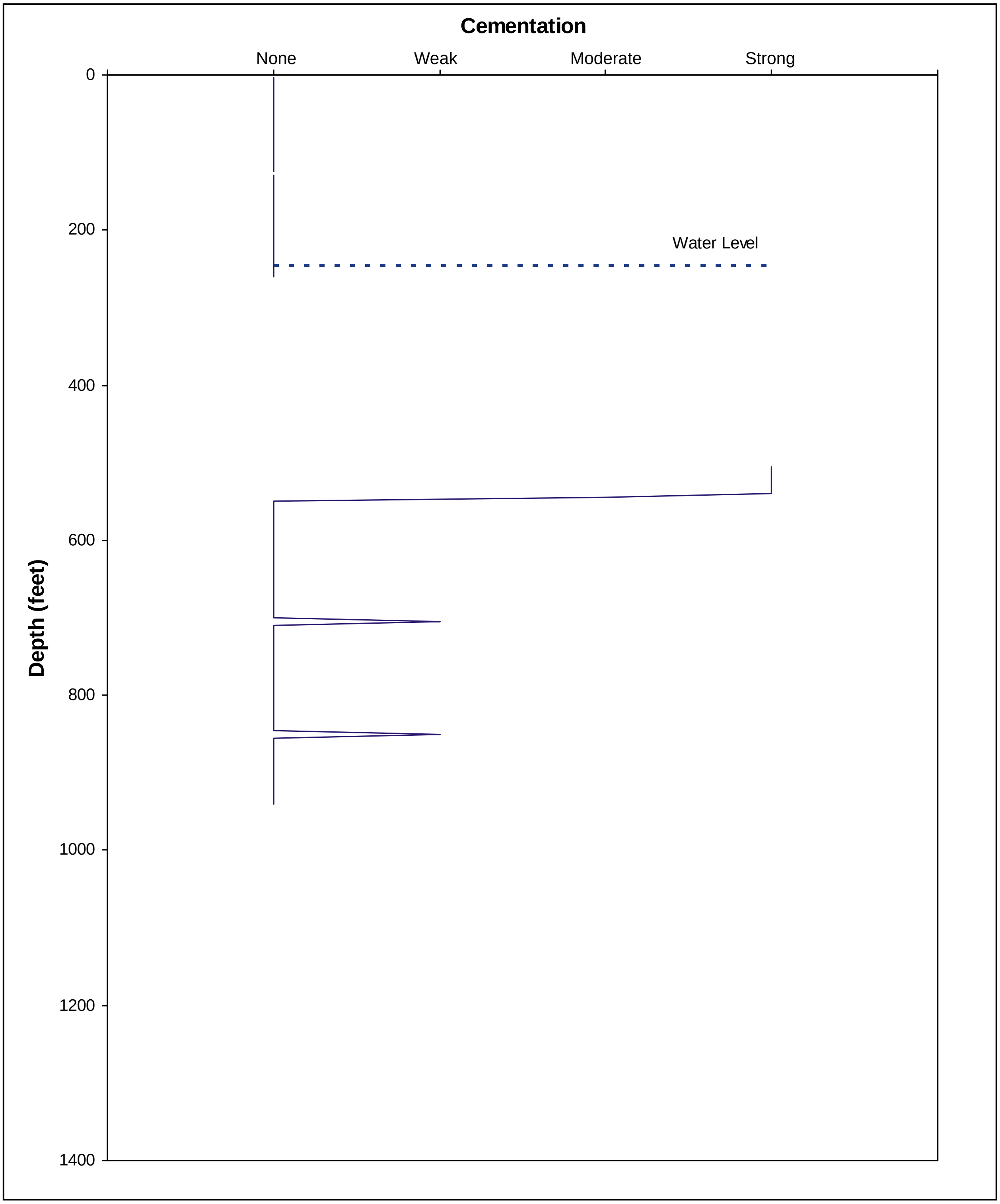


Figure 4.1-4
Cementation versus Depth in Alluvium for 32P (0 to 990 Feet)

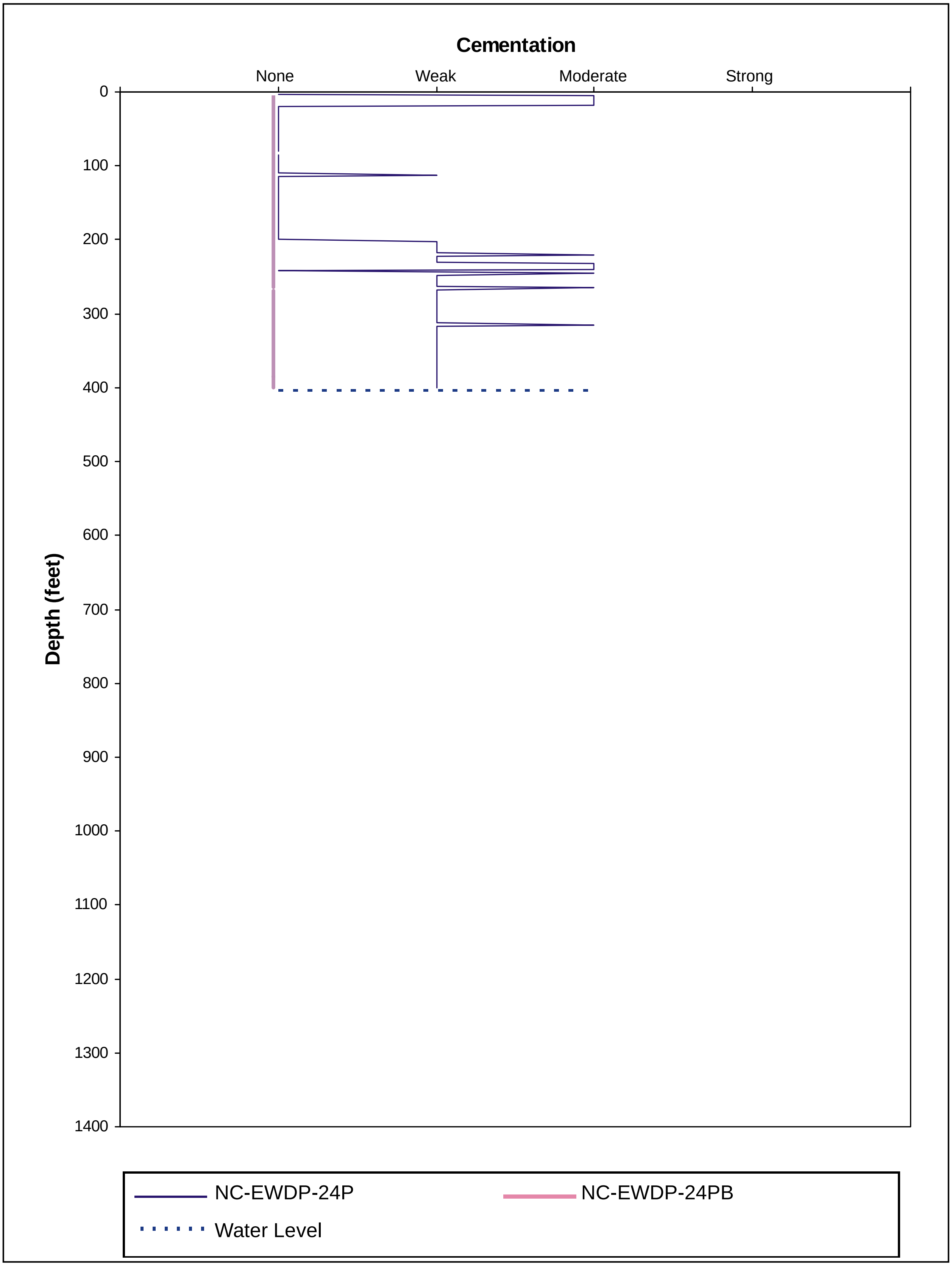


Figure 4.1-5
Cementation versus Depth in Alluvium for 24P and 24PB (0 to 400 Feet)

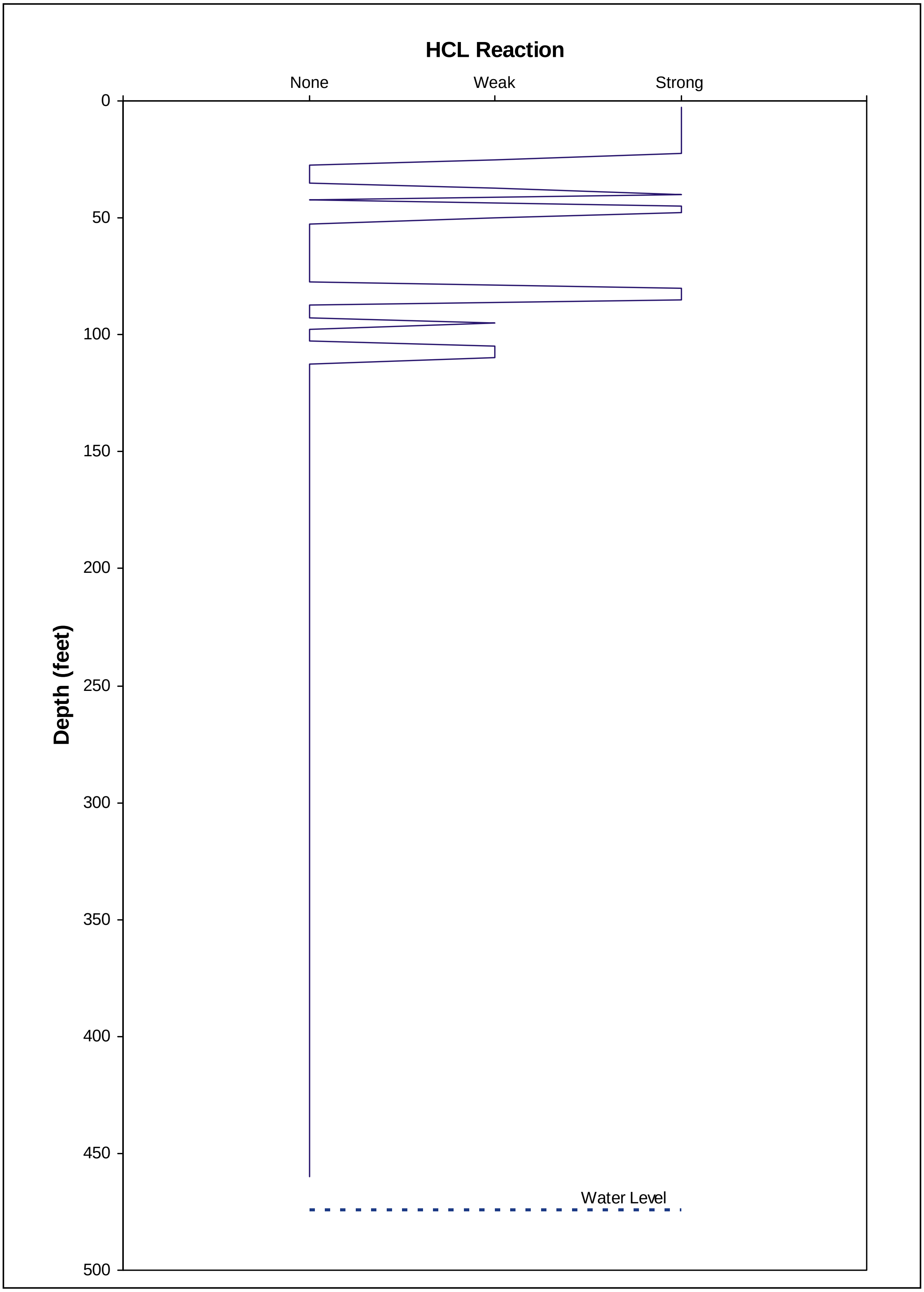


Figure 4.1-6
HCL Reaction versus Depth in Alluvium for 22SA (0 to 460 Feet)

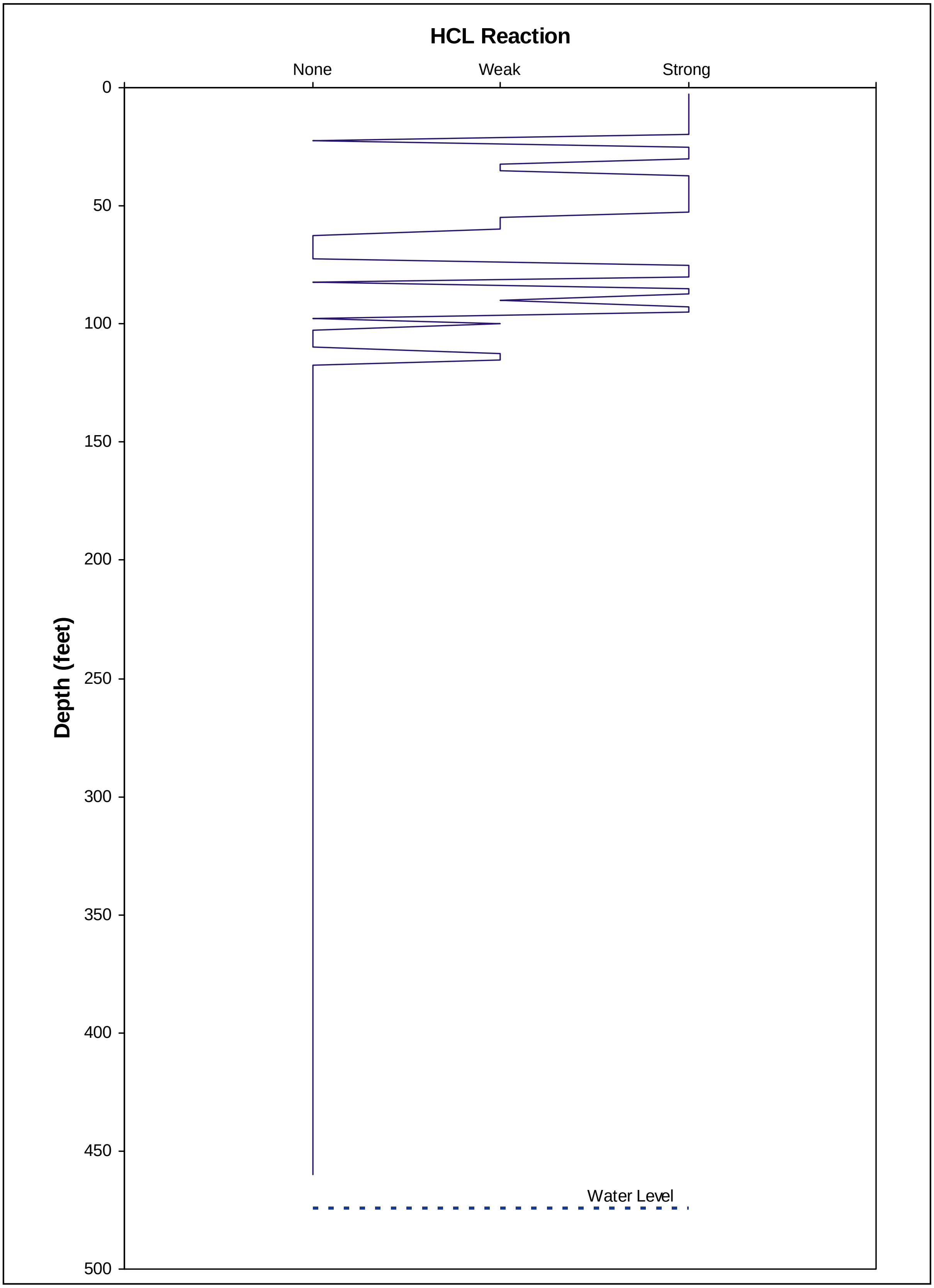


Figure 4.1-7
HCL Reaction versus Depth in Alluvium for 22PC (0 to 460 Feet)

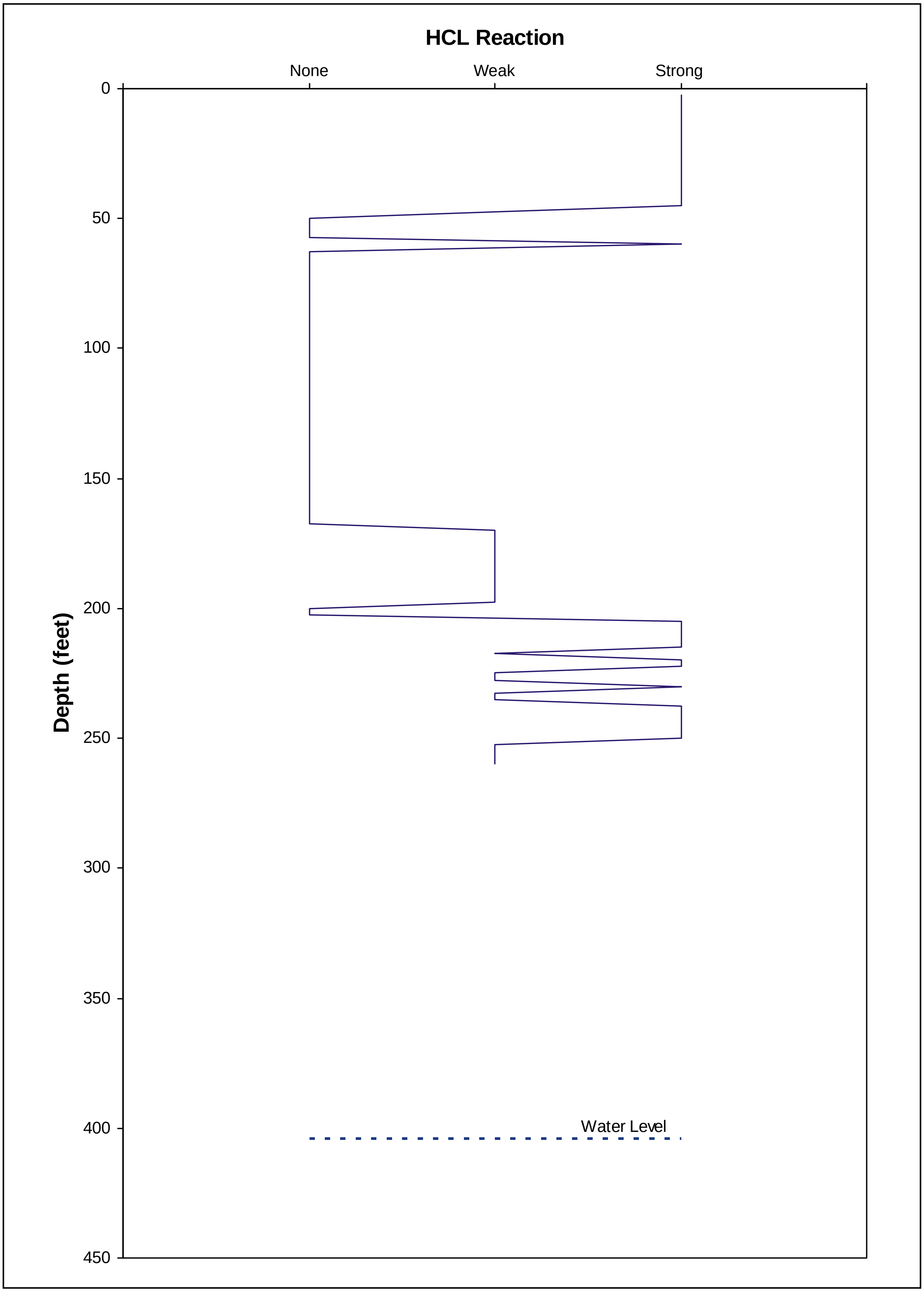


Figure 4.1-8
HCL Reaction versus Depth in Alluvium for 24PB (0 to 260 Feet)

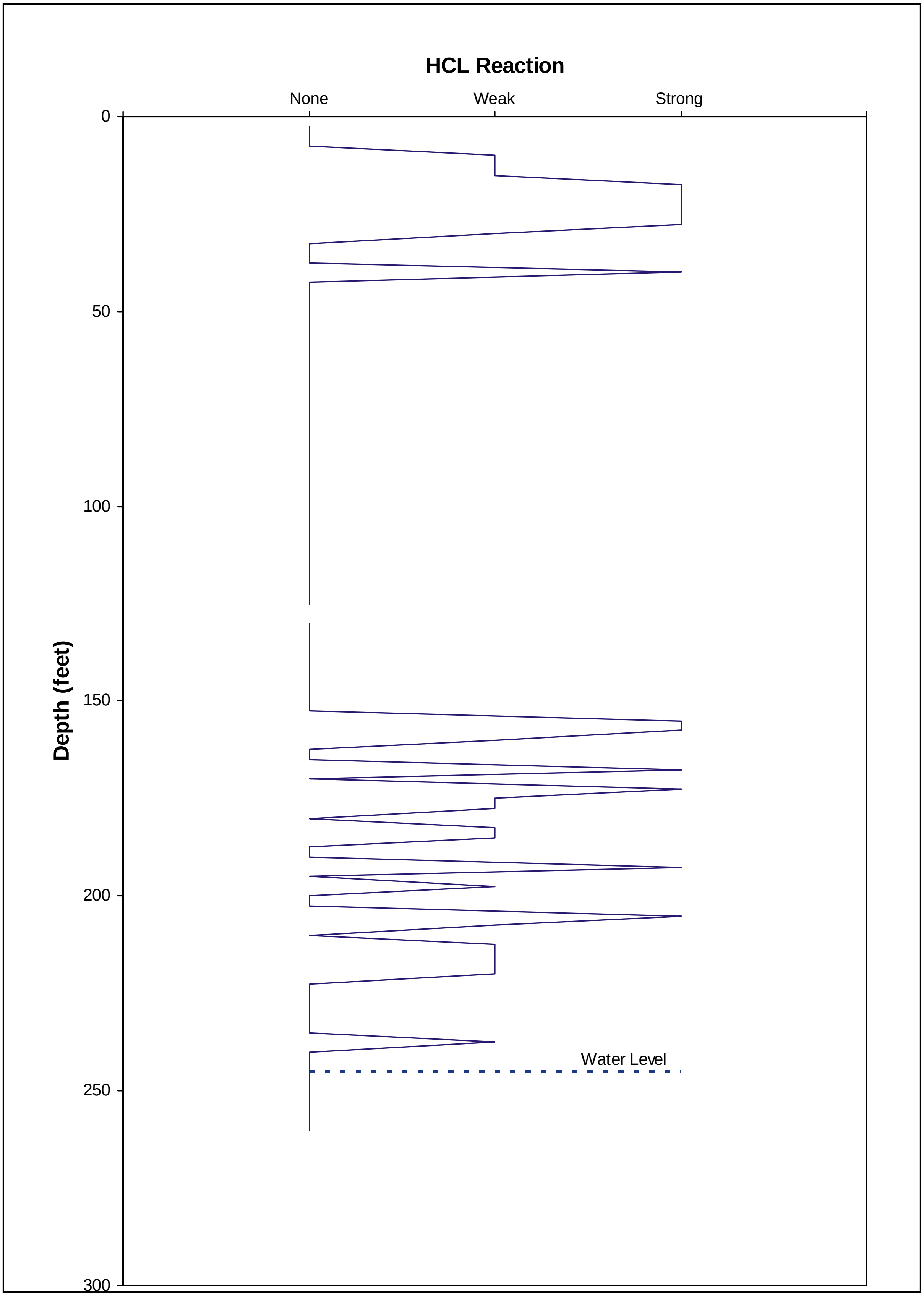


Figure 4.1-9
HCL Reaction versus Depth in Alluvium for 32P (0 to 260 Feet)

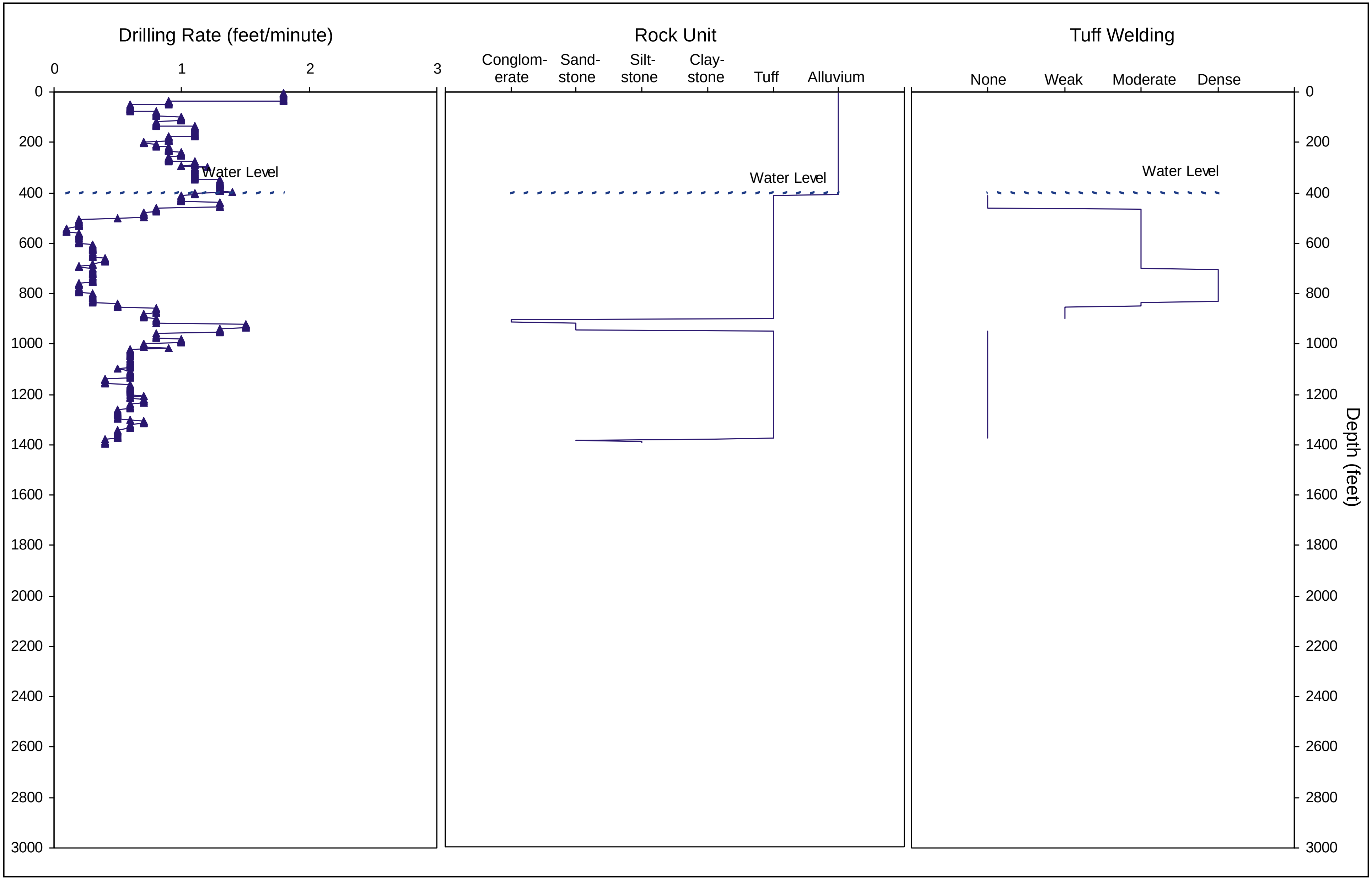


Figure 4.1-10
Drilling Rate, Rock Unit, and Tuff Welding versus Depth for 24PB (0 to 1,395 Feet)

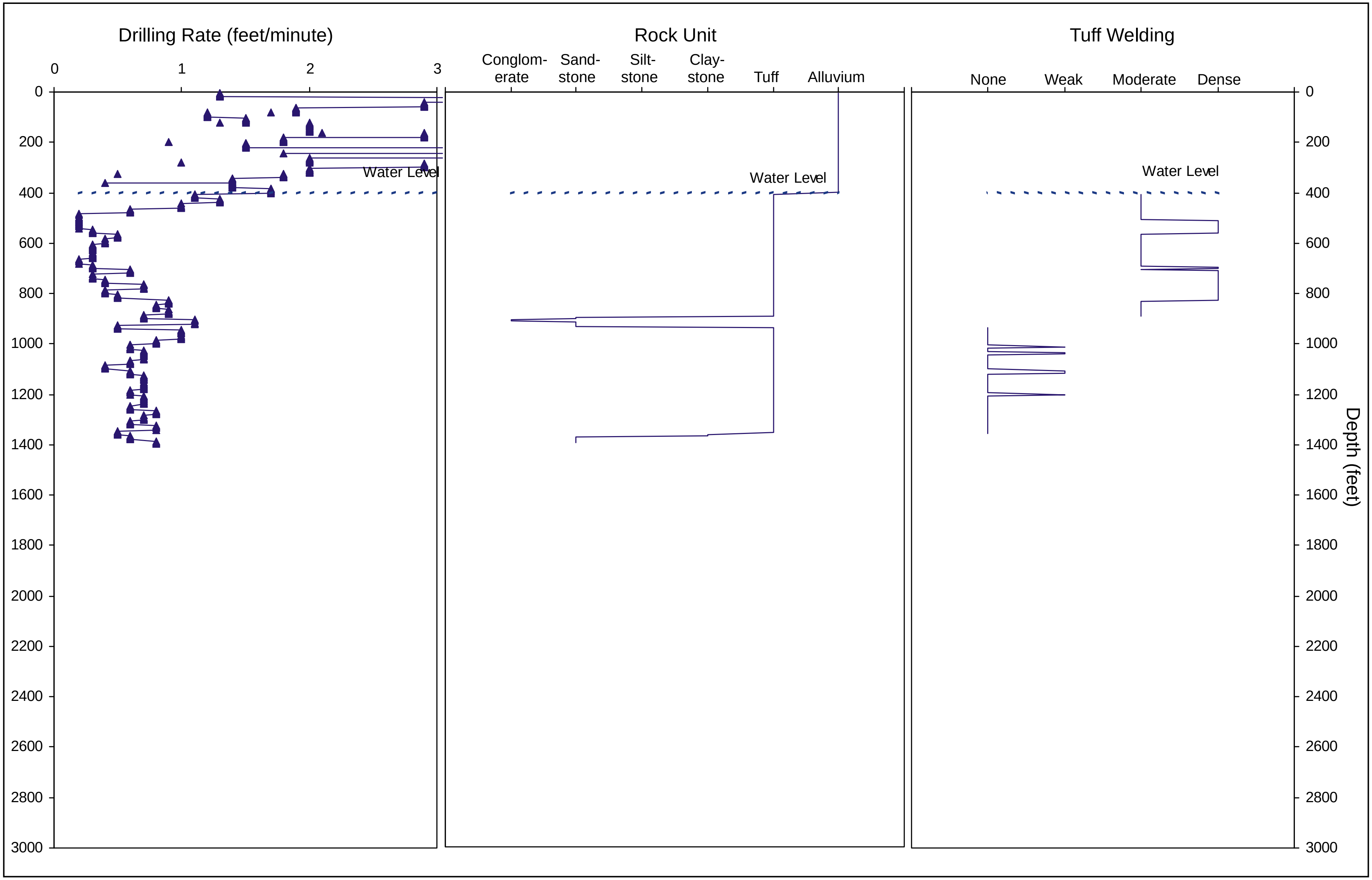


Figure 4.1-11
Drilling Rate, Rock Unit, and Tuff Welding versus Depth for 24P (0 to 1,395 Feet)

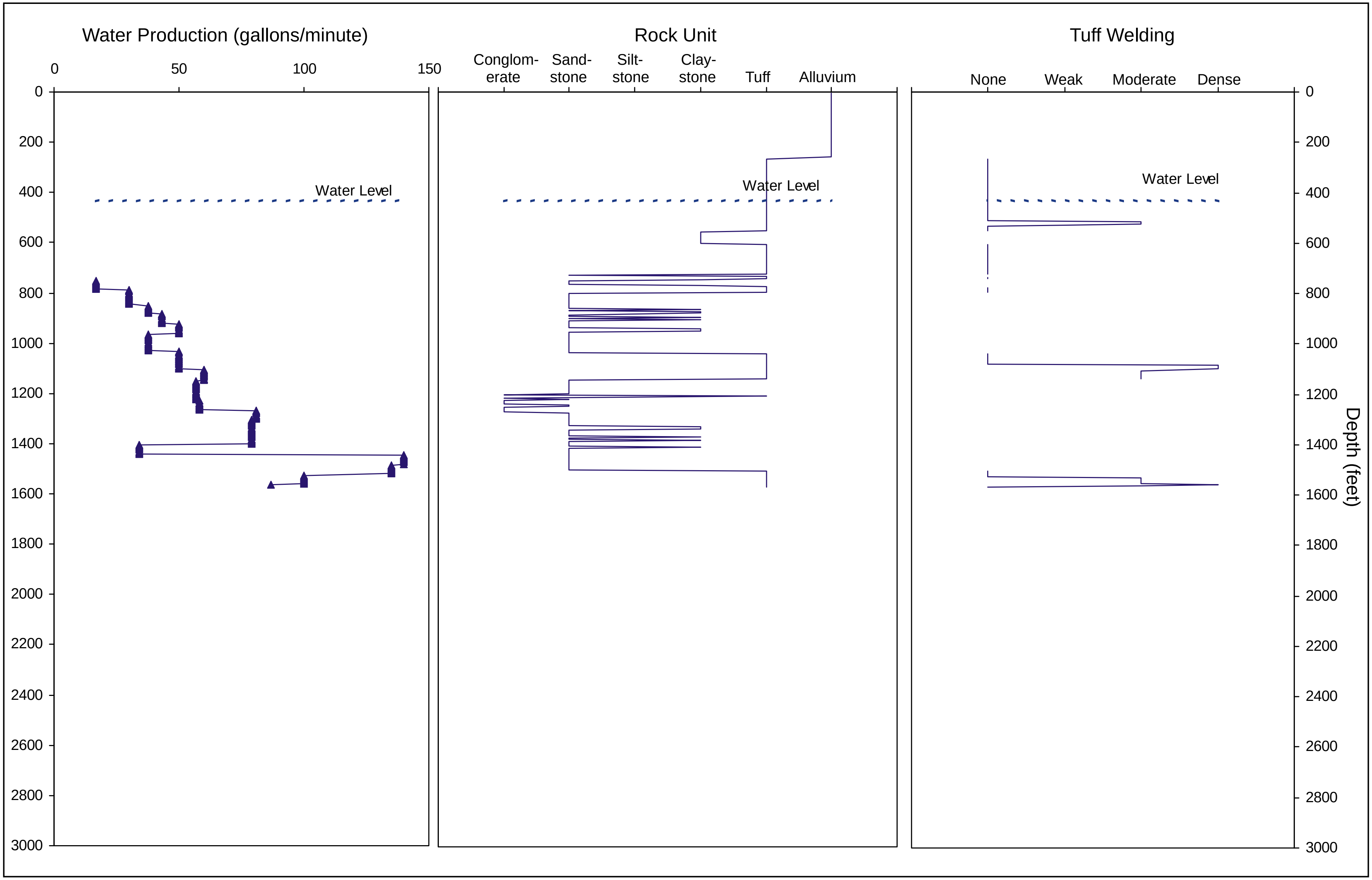


Figure 4.1-12
Water Production, Rock Unit, and Tuff Welding versus Depth for 13P (0 to 1,569 Feet)

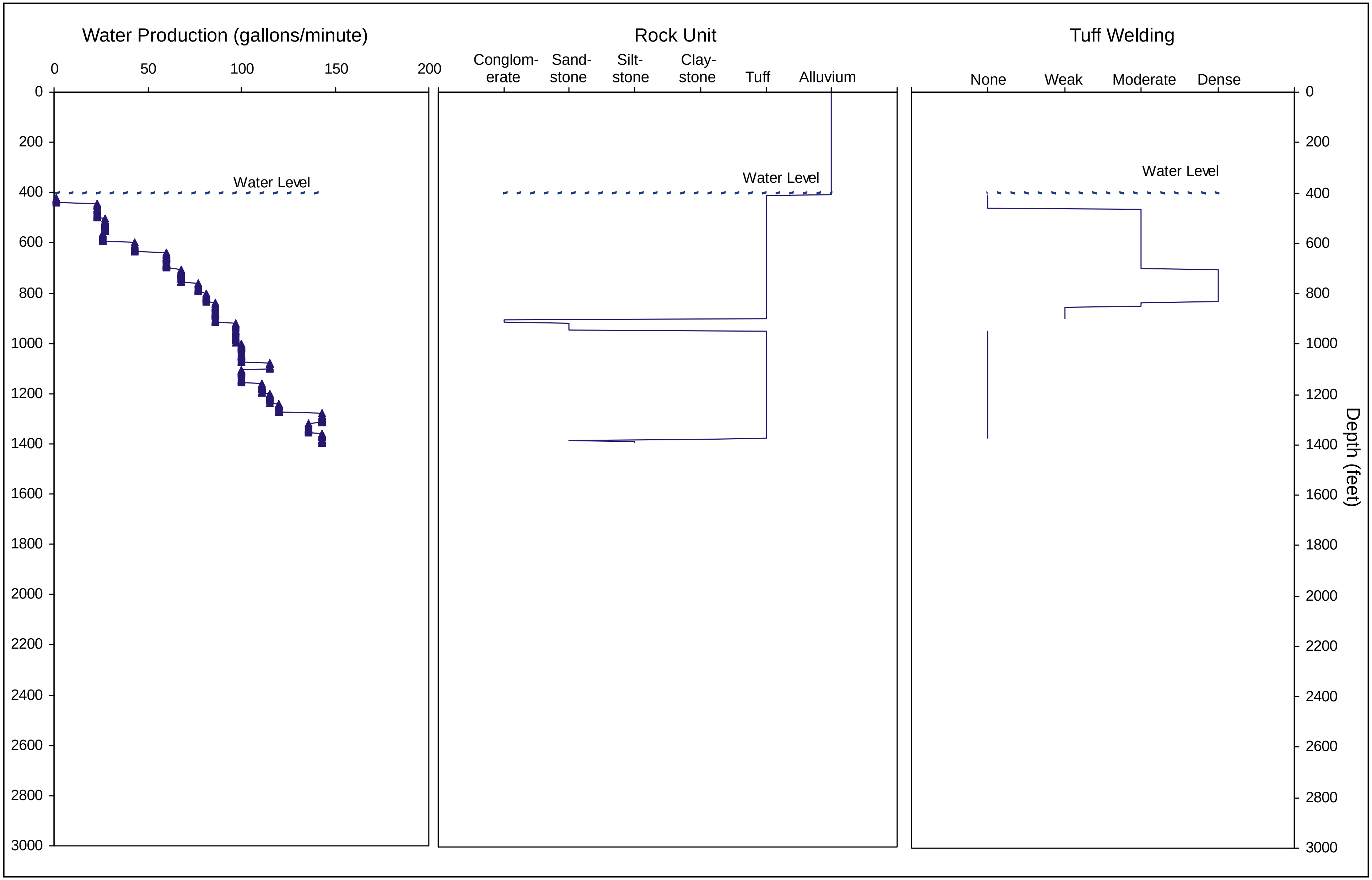


Figure 4.1-13
Water Production, Rock Unit, and Tuff Welding versus Depth for 24PB (0 to 1,395 Feet)

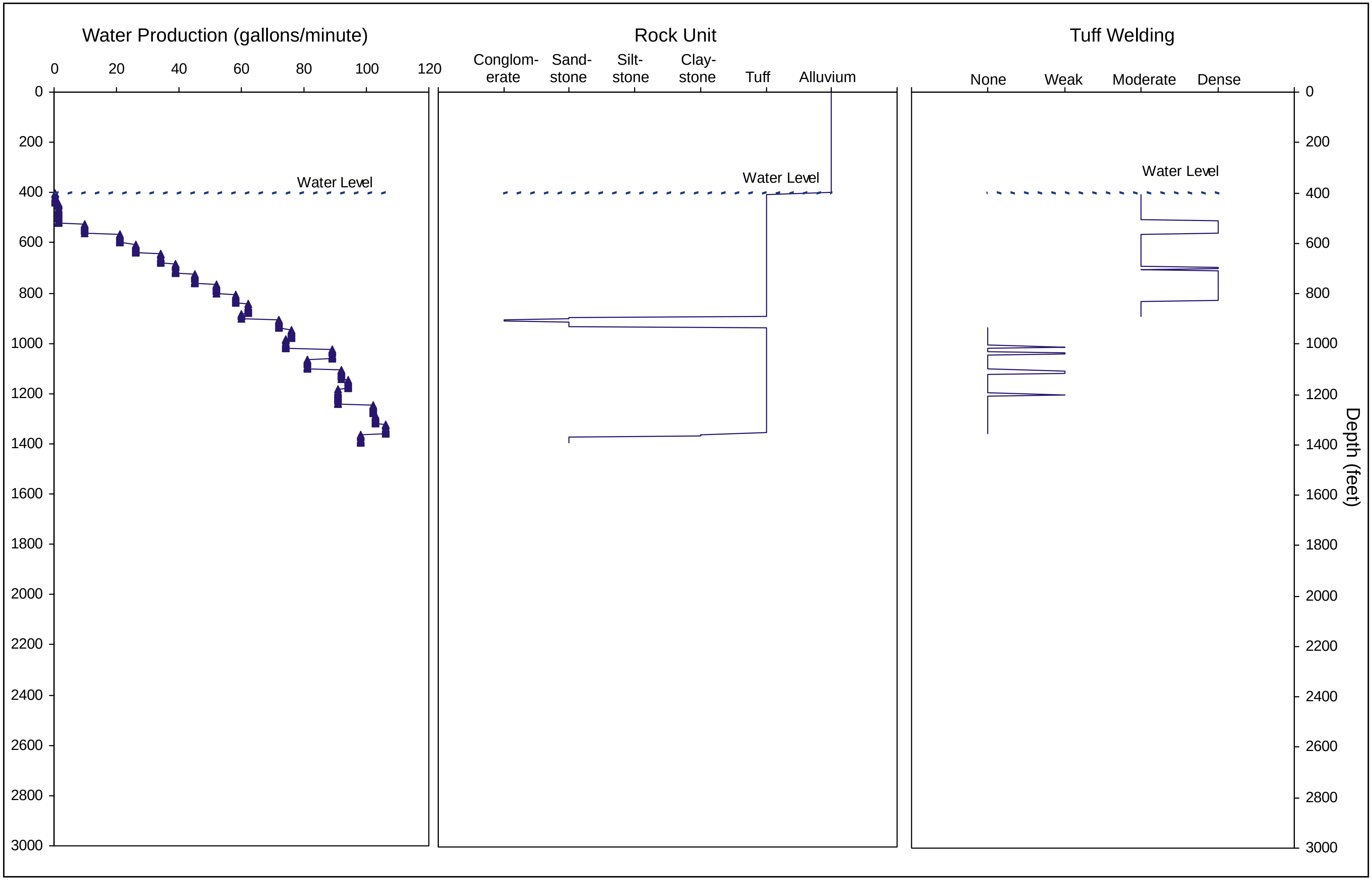


Figure 4.1-14
Water Production, Rock Unit, and Tuff Welding versus Depth for 24P (0 to 1,395 Feet)

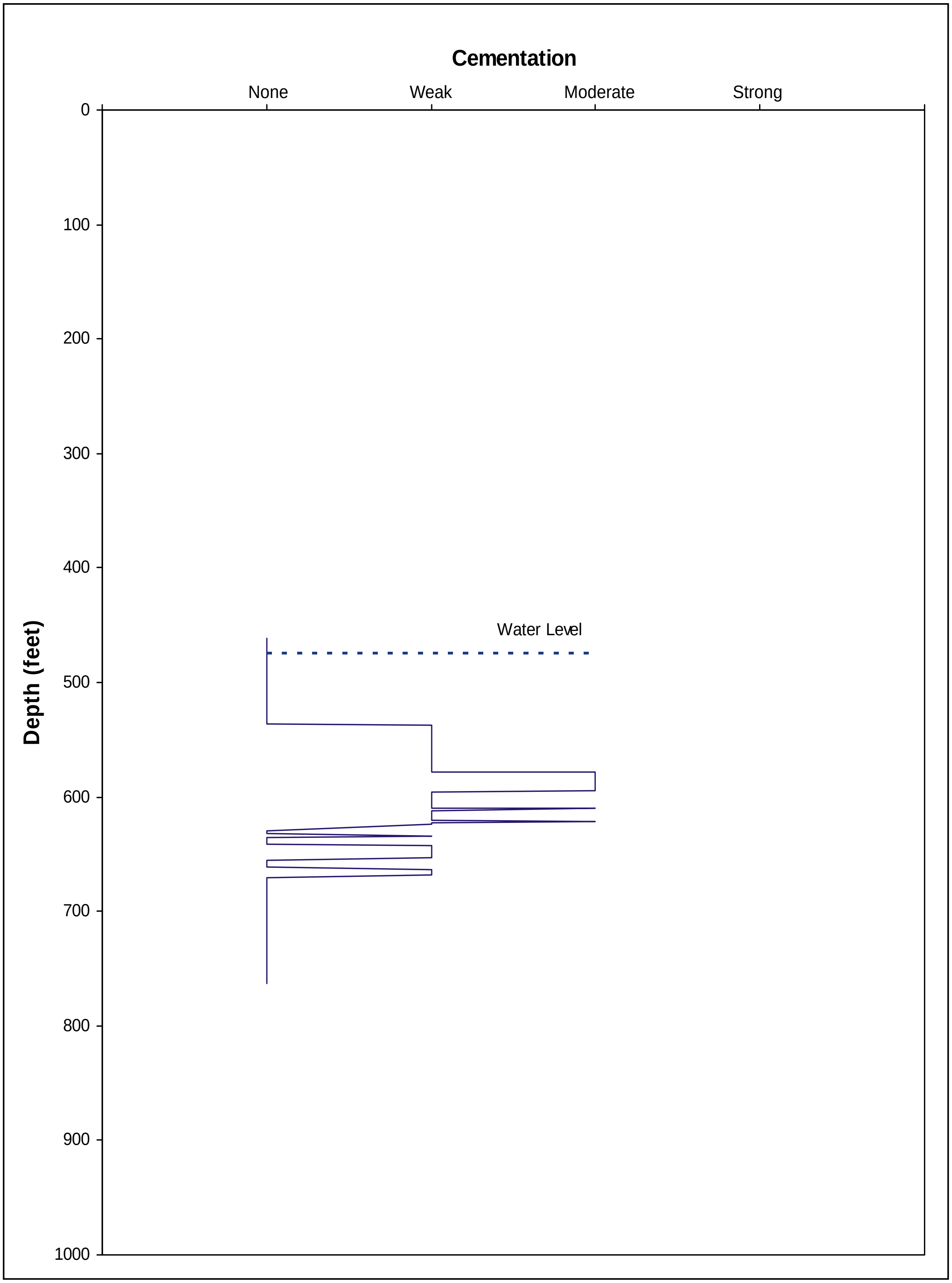


Figure 4.2-1
Cementation versus Depth for Sonic Core in Alluvium for 22PC (460 to 763 Feet)

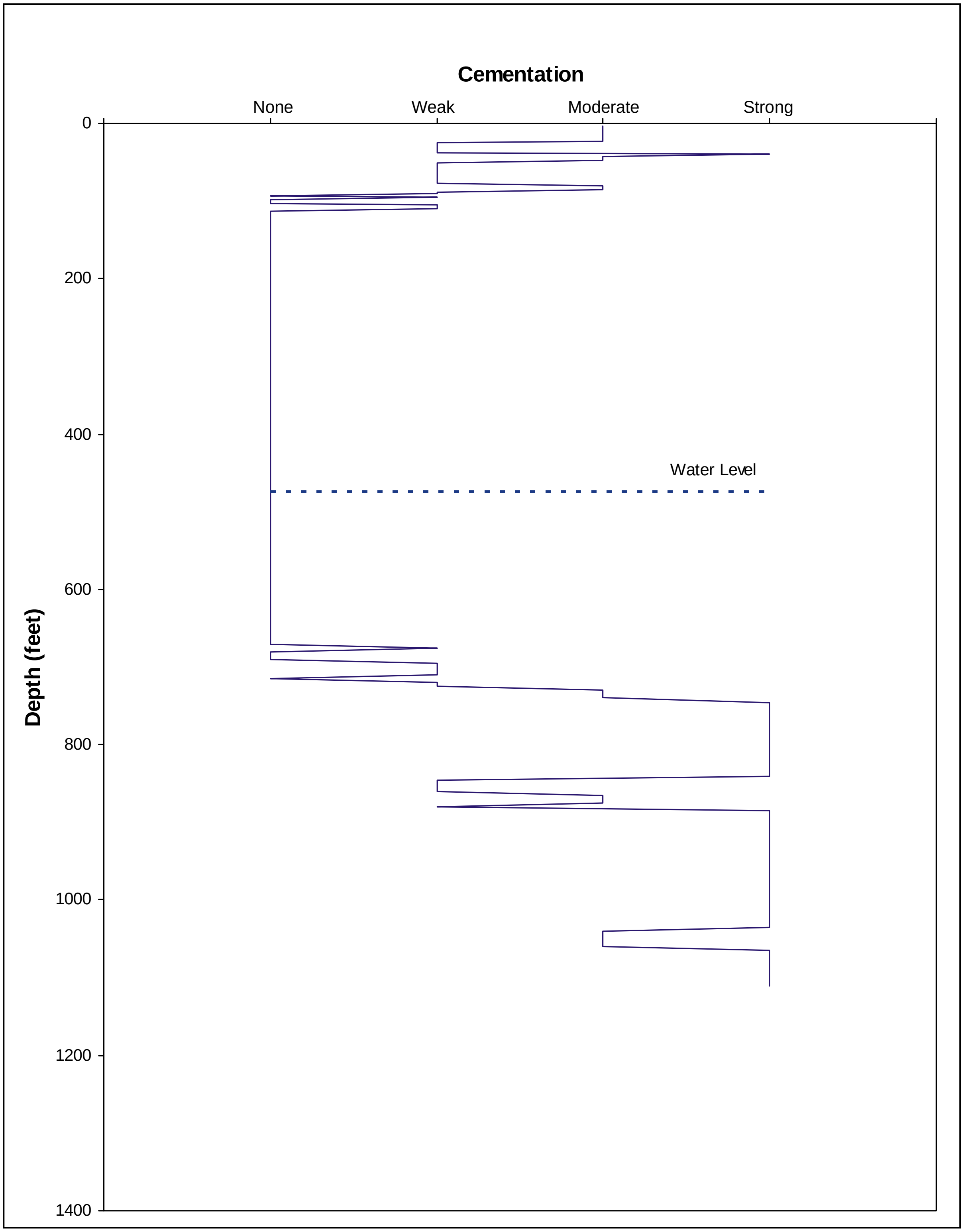


Figure 4.2-2
Cementation versus Depth in Alluvium for 22SA (0 to 1,110 Feet)

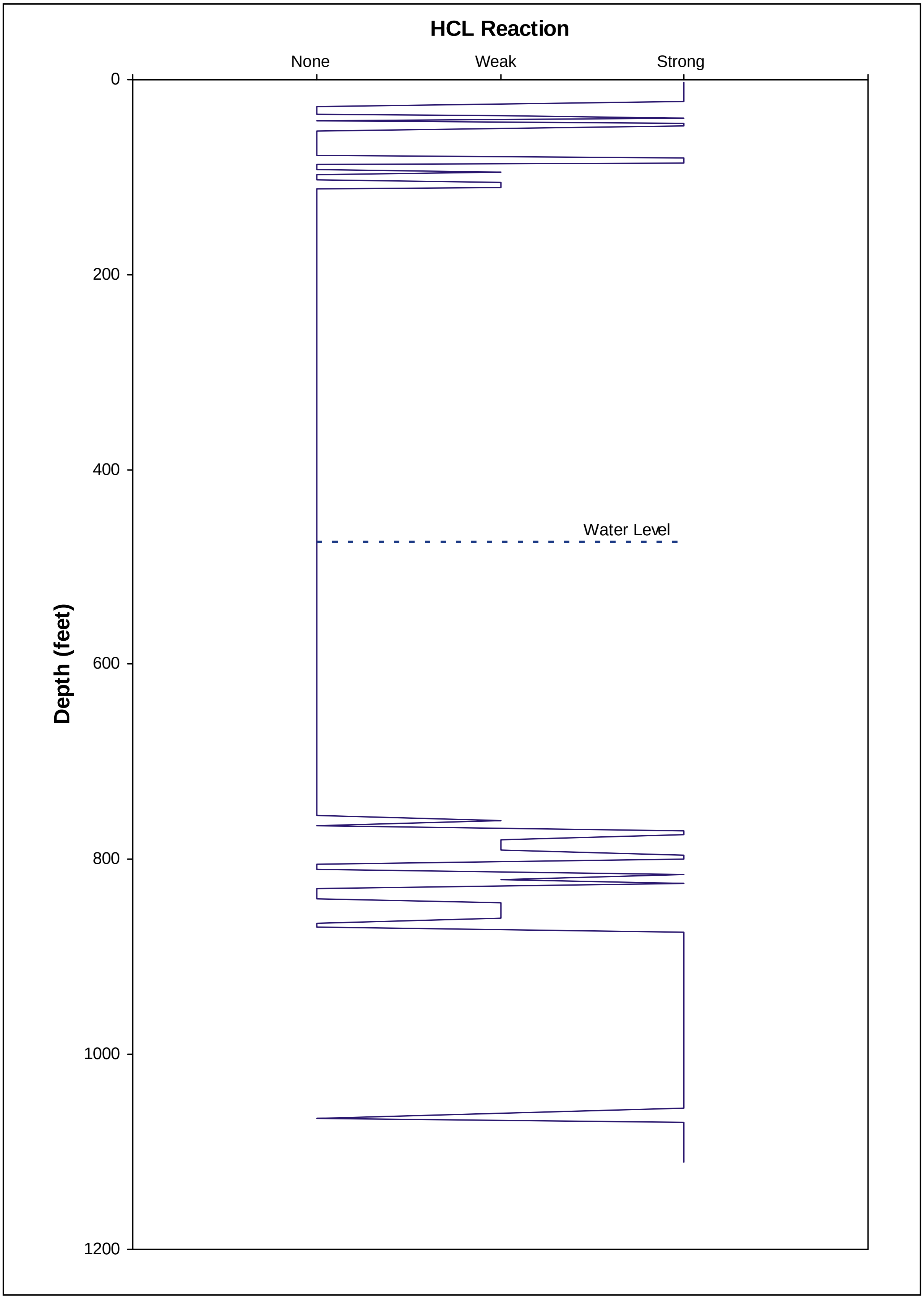


Figure 4.2-3
HCL Reaction versus Depth in Alluvium for 22SA (0 to 1,110 Feet)

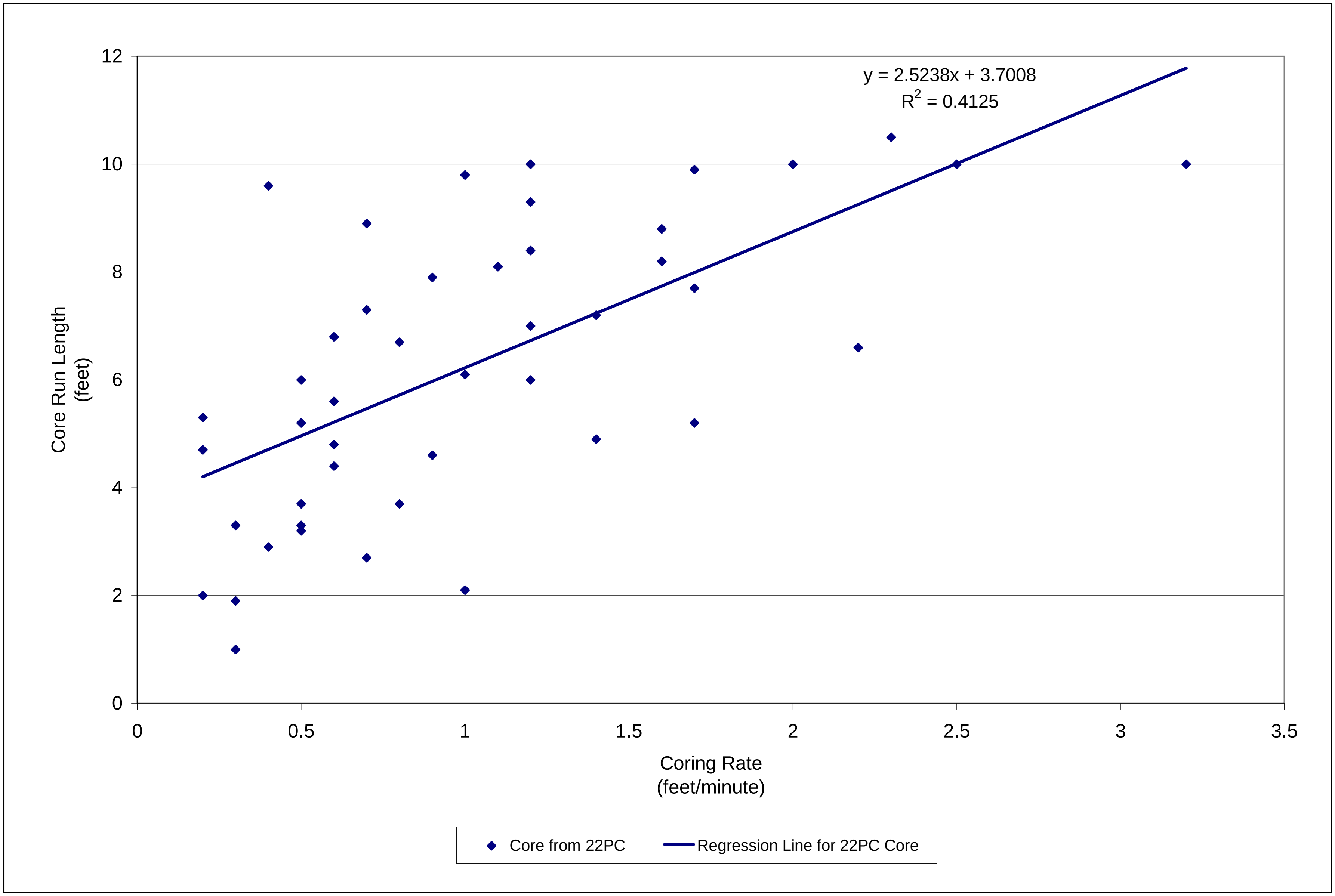
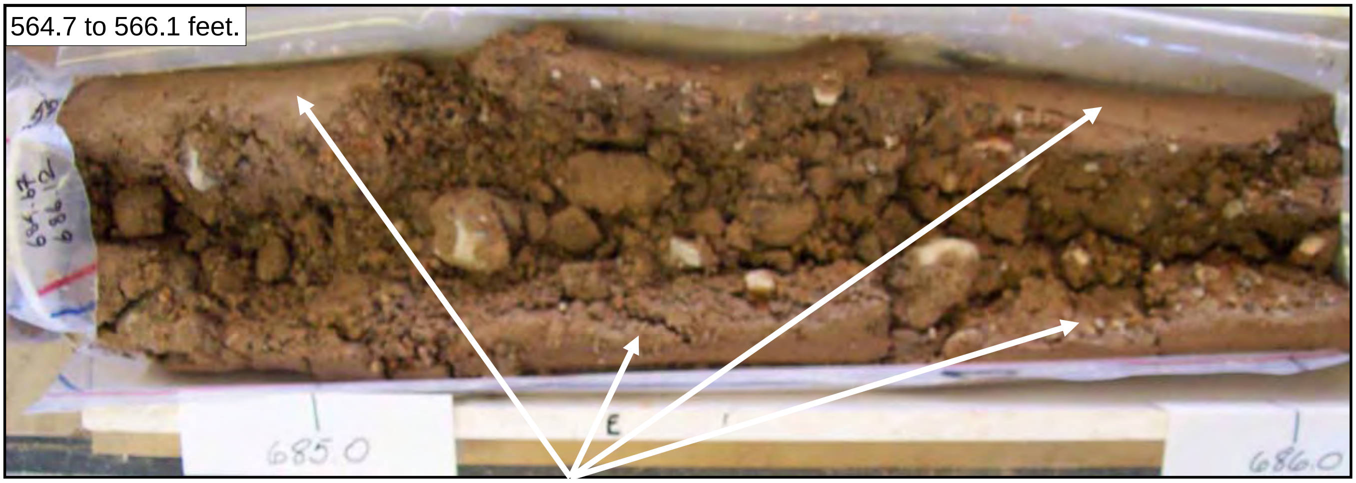
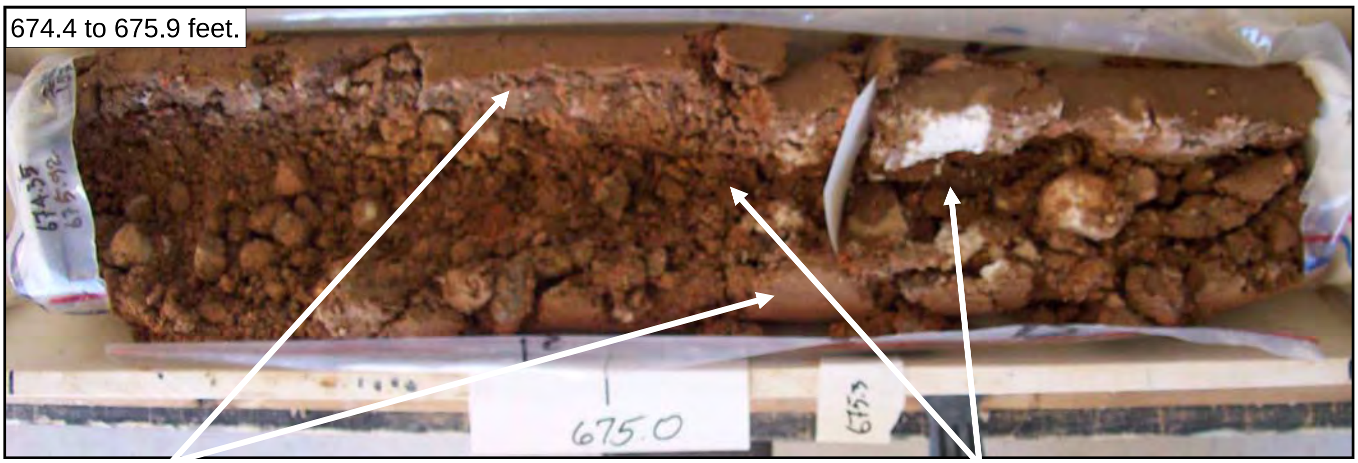


Figure 4.2-4
Coring Rate versus Run Length for 22PC

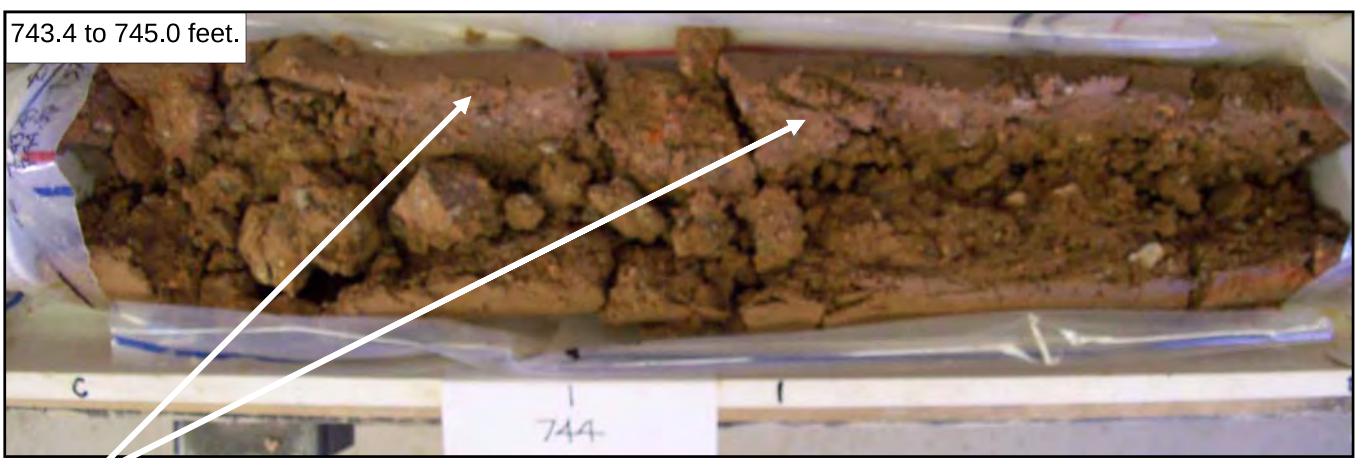


Fines migrated to outside surface of clayey sand with gravel core.



Fines migrated to outside surface of core.

Transition from sand with clay and gravel to clayey gravel.



Pink fines migrated to outside surfaces of clayey sand with gravel core.

Figure 4.2-5
Example of Fines Migration in 22PC Sonic Core Segments

Figure 4.2-6
Examples of Textural Layers in 22PC Sonic Core Segments

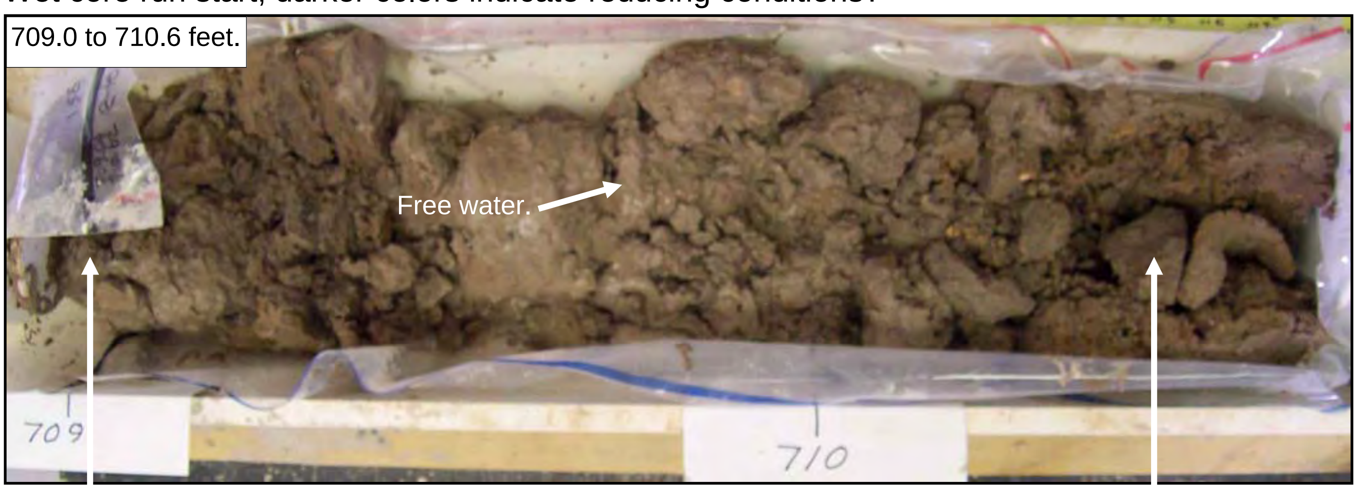
Water table encountered at 471 feet; water content decreases in first core segment of core run.

Higher water content.

Lower water content.

Dry near end of 7-foot core run.

Wet core run start; darker colors indicate reducing conditions?



Start of run.

Slightly dryer core.

Figure 4.2-7
Examples of Water Redistribution in 22PC Sonic Core Due to Heat

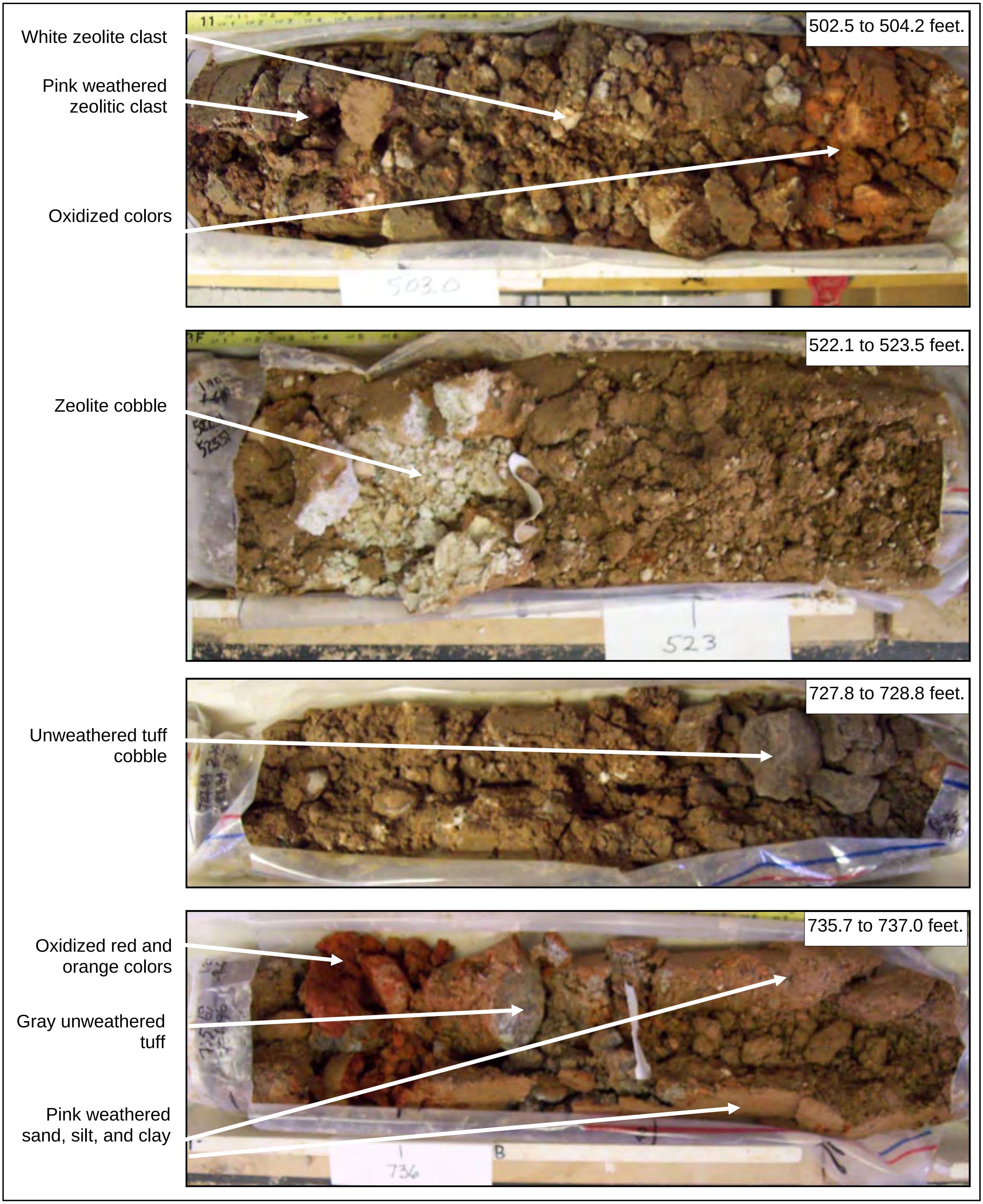


Figure 4.2-8
Examples of Minerals and Rock Type in Alluvium

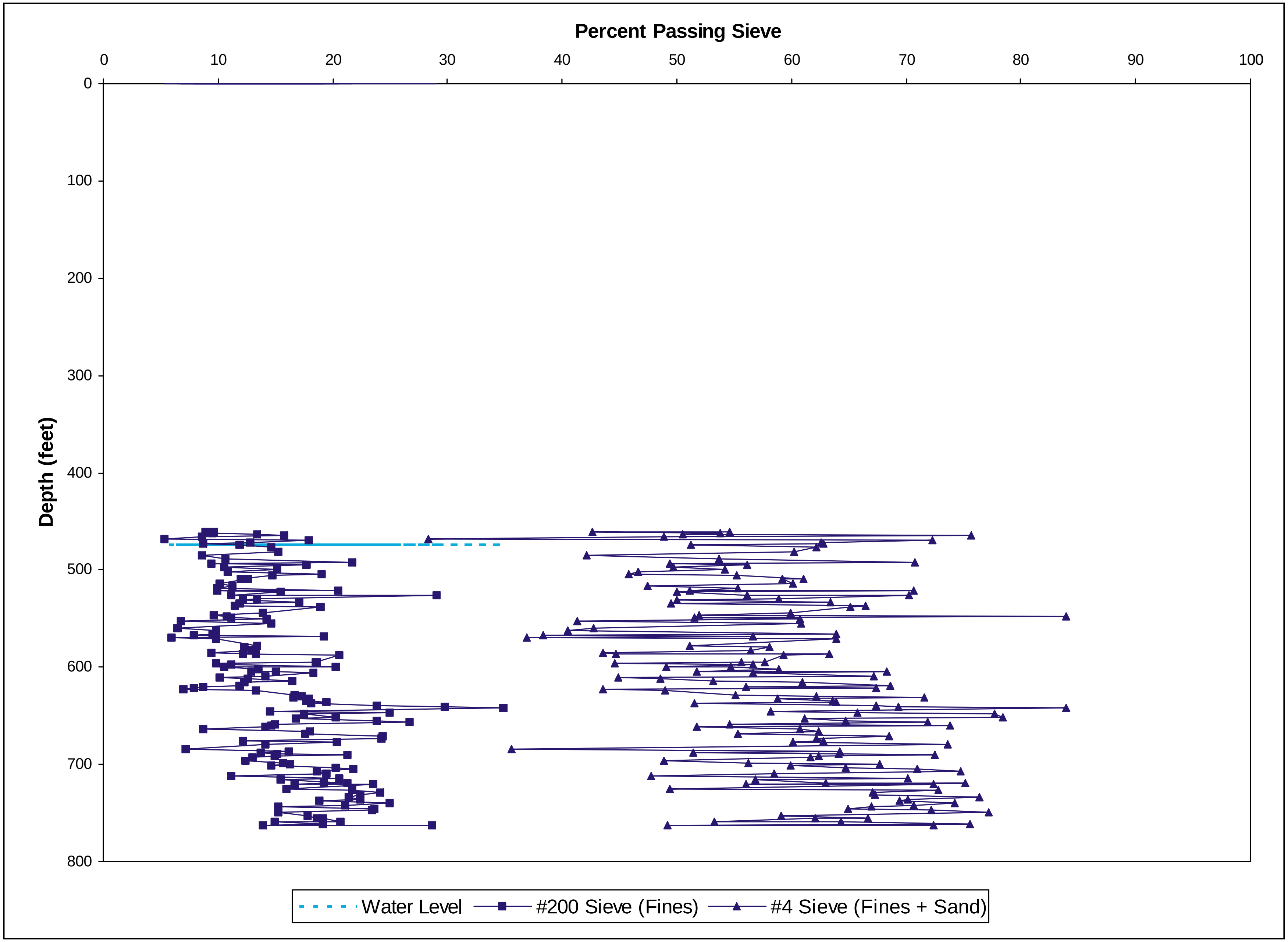


Figure 5.1-1
Laboratory Particle Size Distributions of Sonic Core versus Depth in Alluvium for 22PC (460 to 763 Feet)

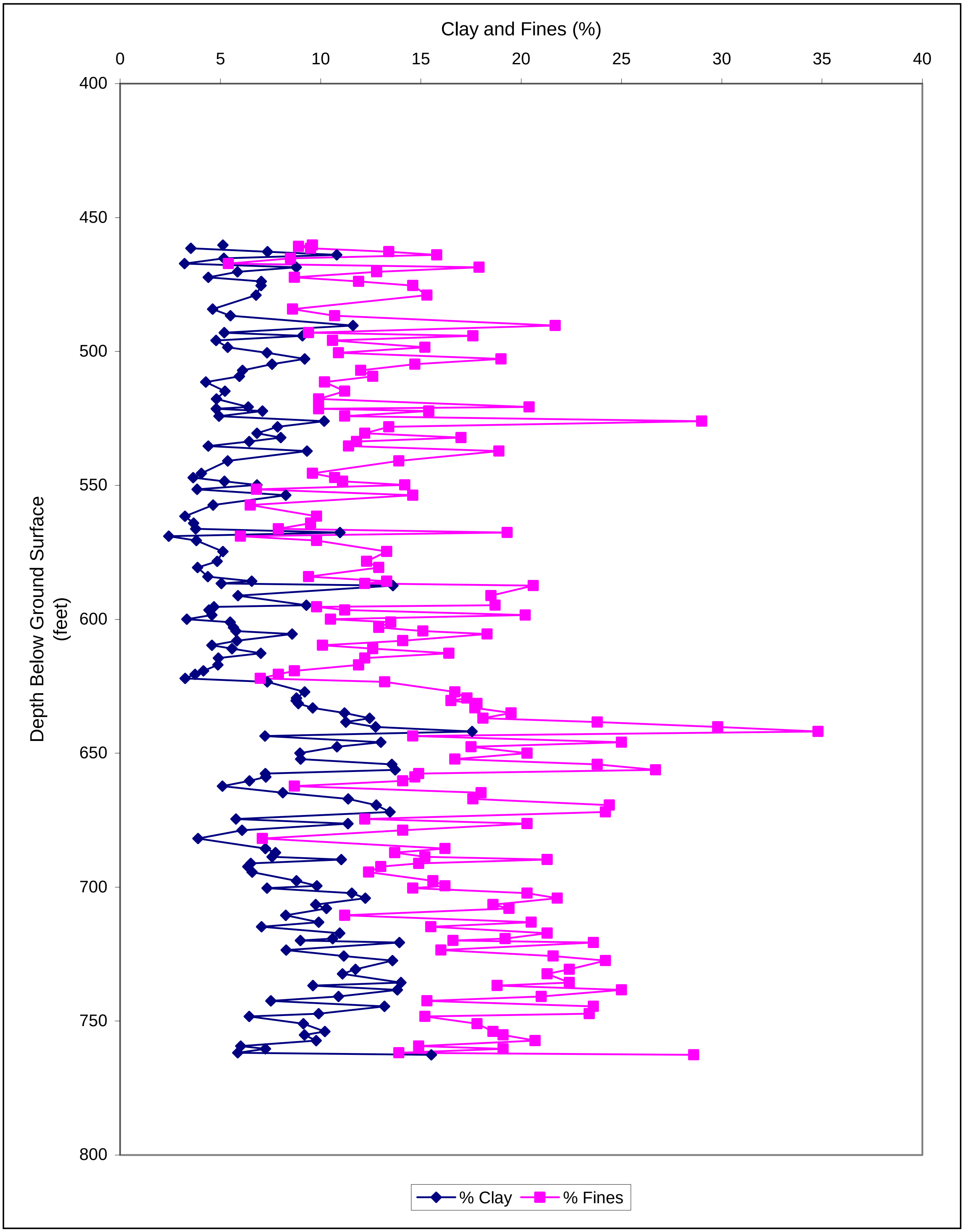


Figure 5.1-2
Clay and Fines Fraction for Sonic Core Grab Samples from 22PC, based on Hydrometer and Wet Sieve Particle Size Distribution Data, respectively

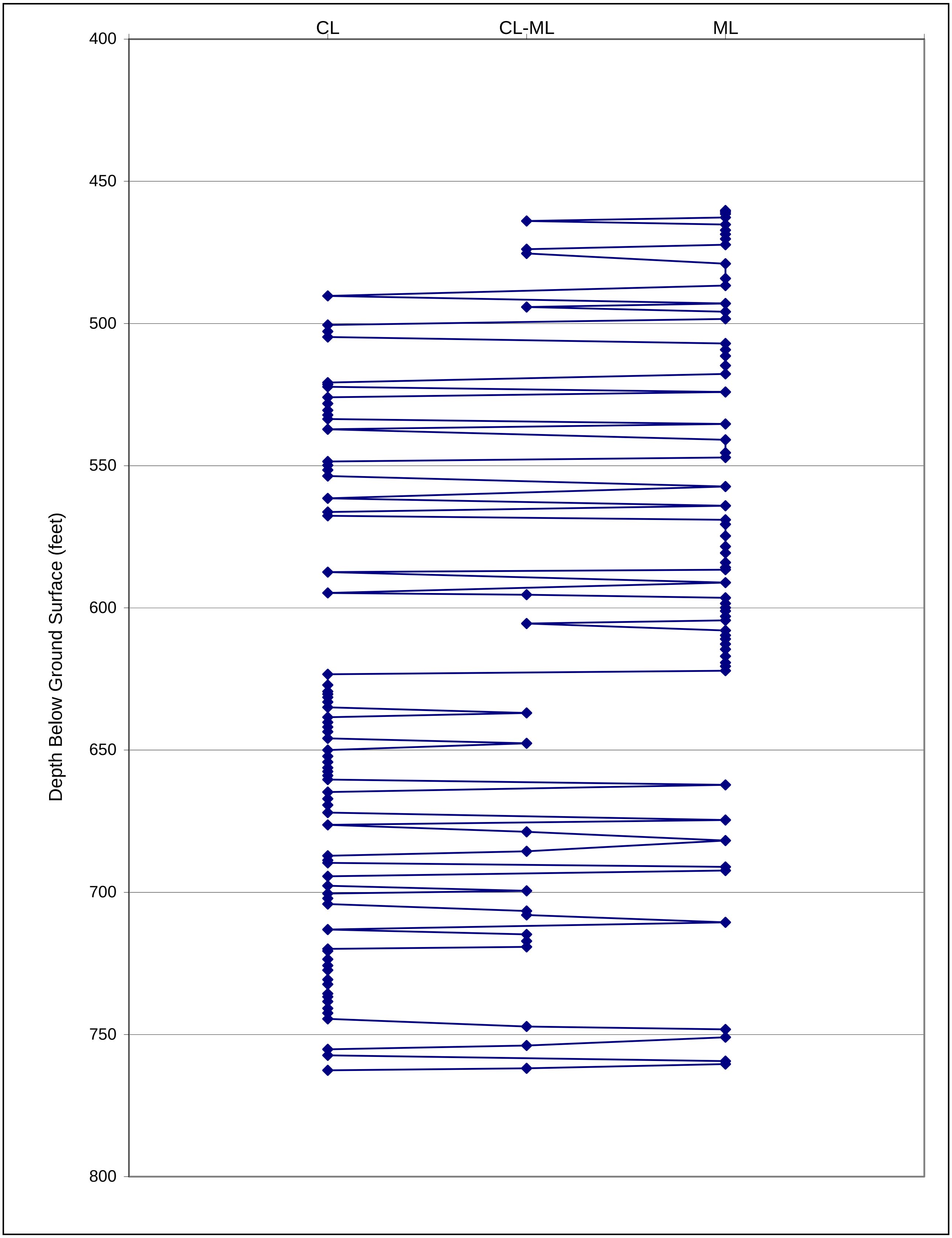


Figure 5.1-3
Classification of Fines Fraction for Sonic Core Grab Samples from 22PC, based on Atterberg Limits Data

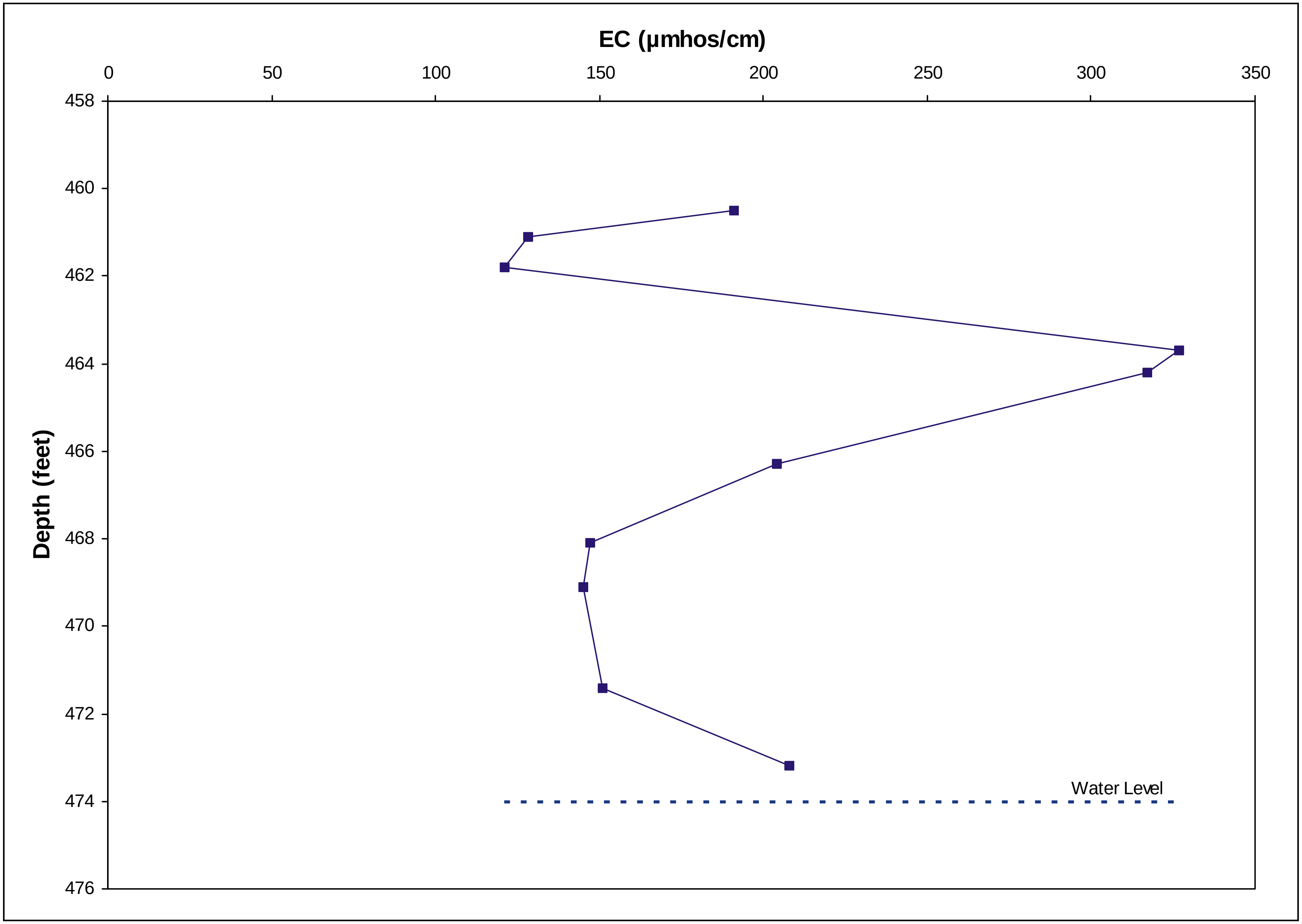


Figure 5.1-4
Electrical Conductivity versus Depth for Sonic Core in Alluvium for 22PC (460 to 473.2 Feet)

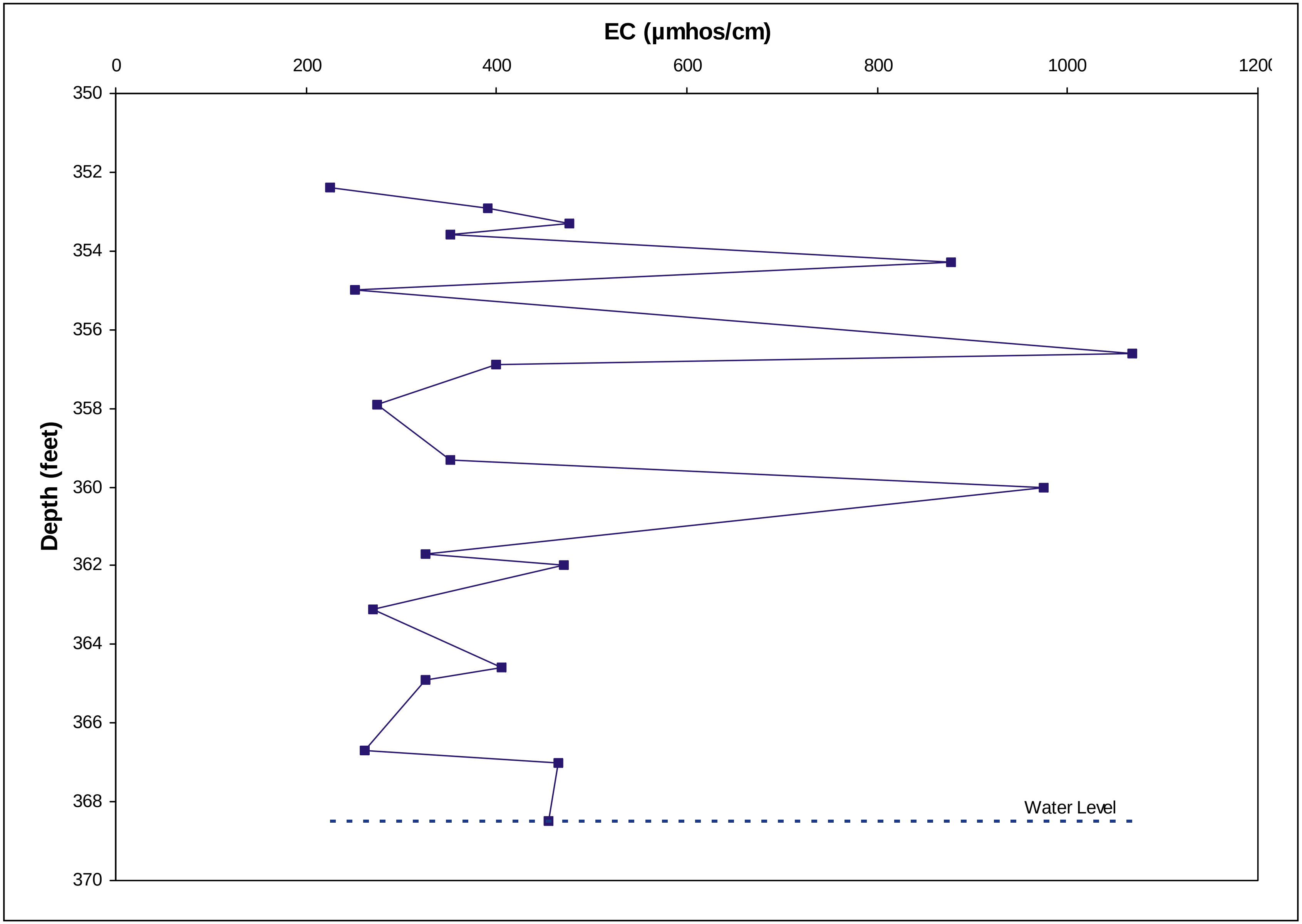


Figure 5.1-5
Electrical Conductivity versus Depth for Sonic Core in Alluvium for 19PB (350 to 368.5 Feet)

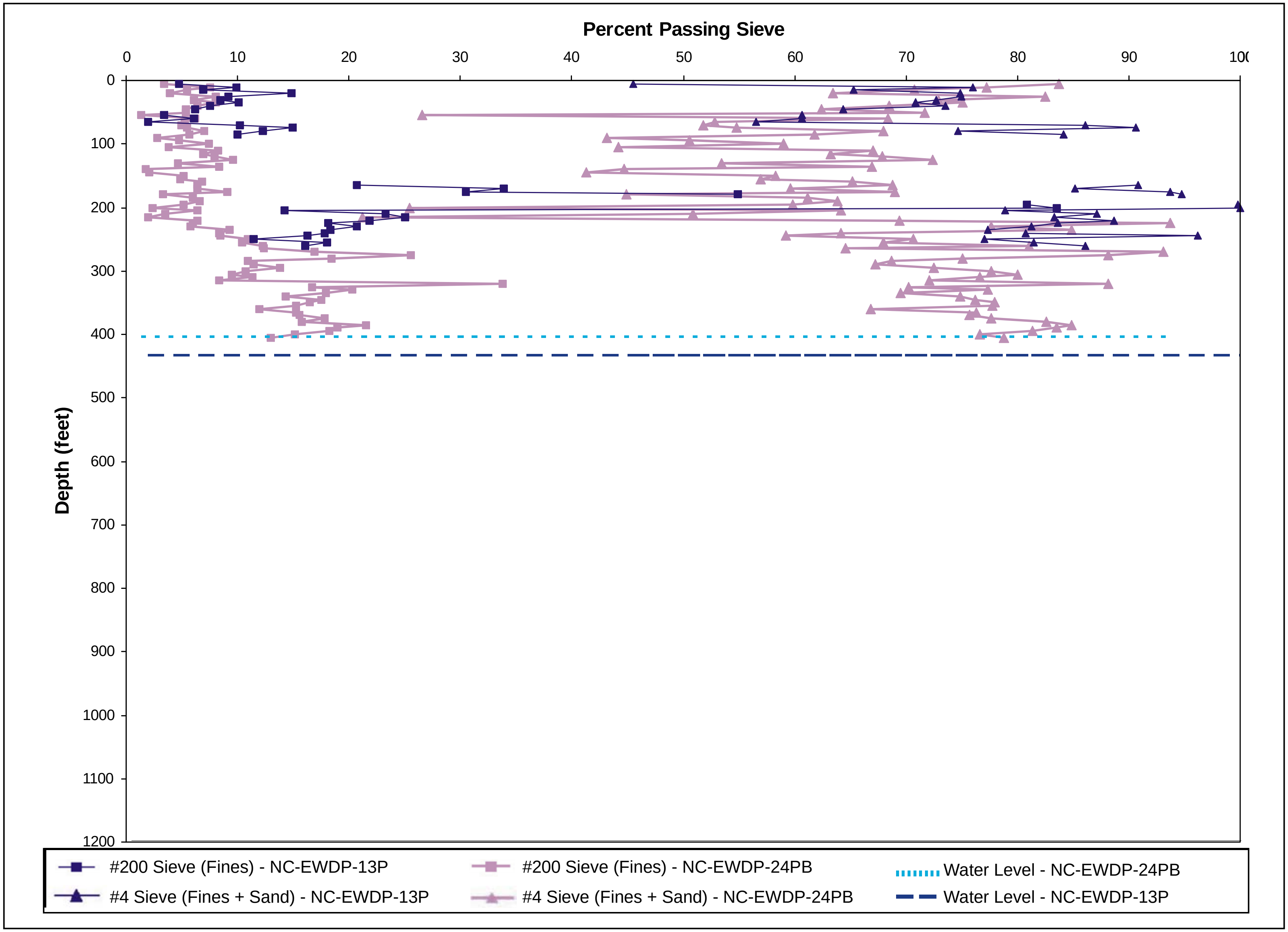


Figure 5.2-1
Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for 13P and 24PB (0 to 405 Feet)

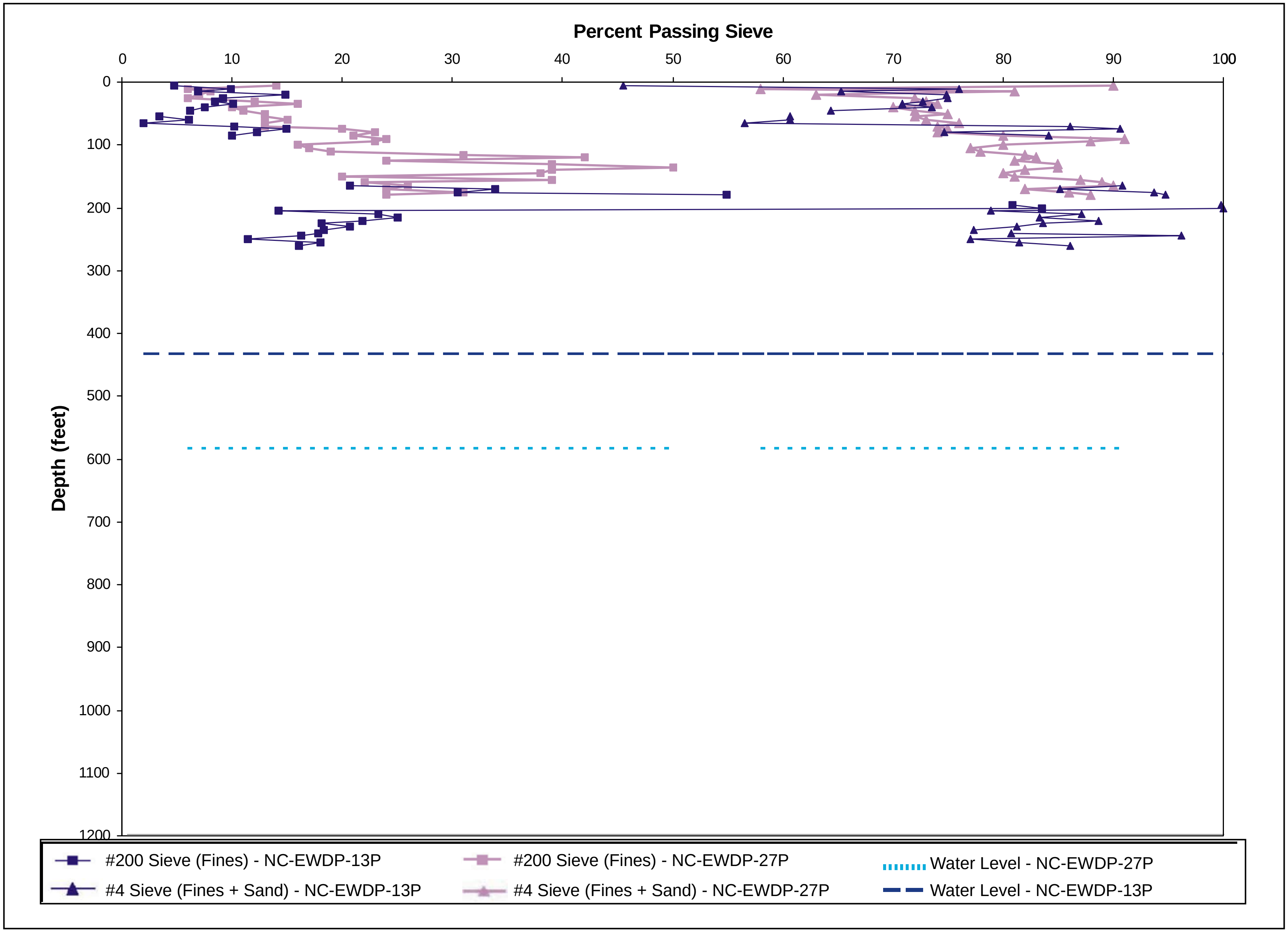


Figure 5.2-2
Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for 13P and 27P (0 to 260 Feet)

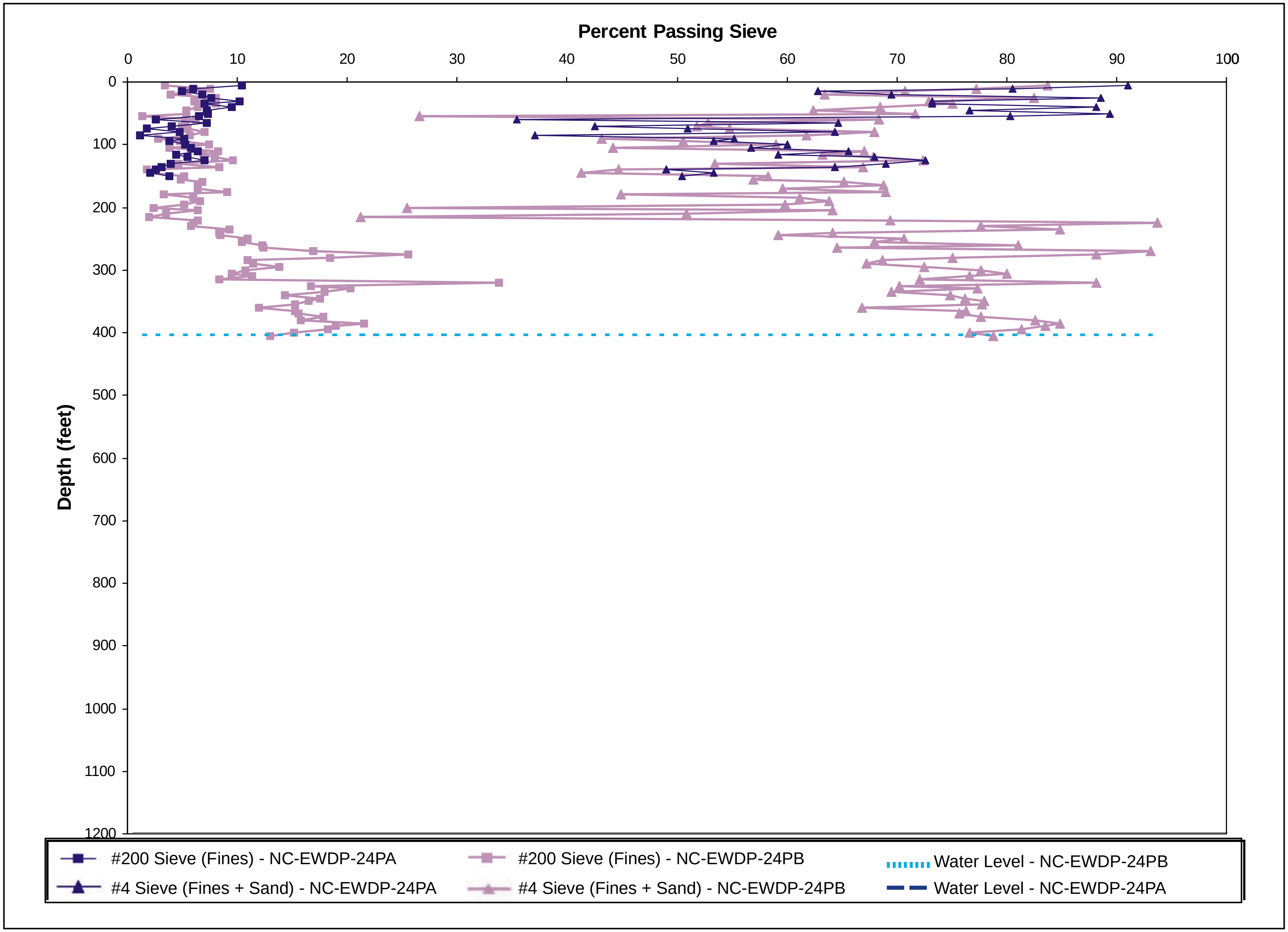


Figure 5.2-3

Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for 24PA and 24PB (0 to 405 Feet)

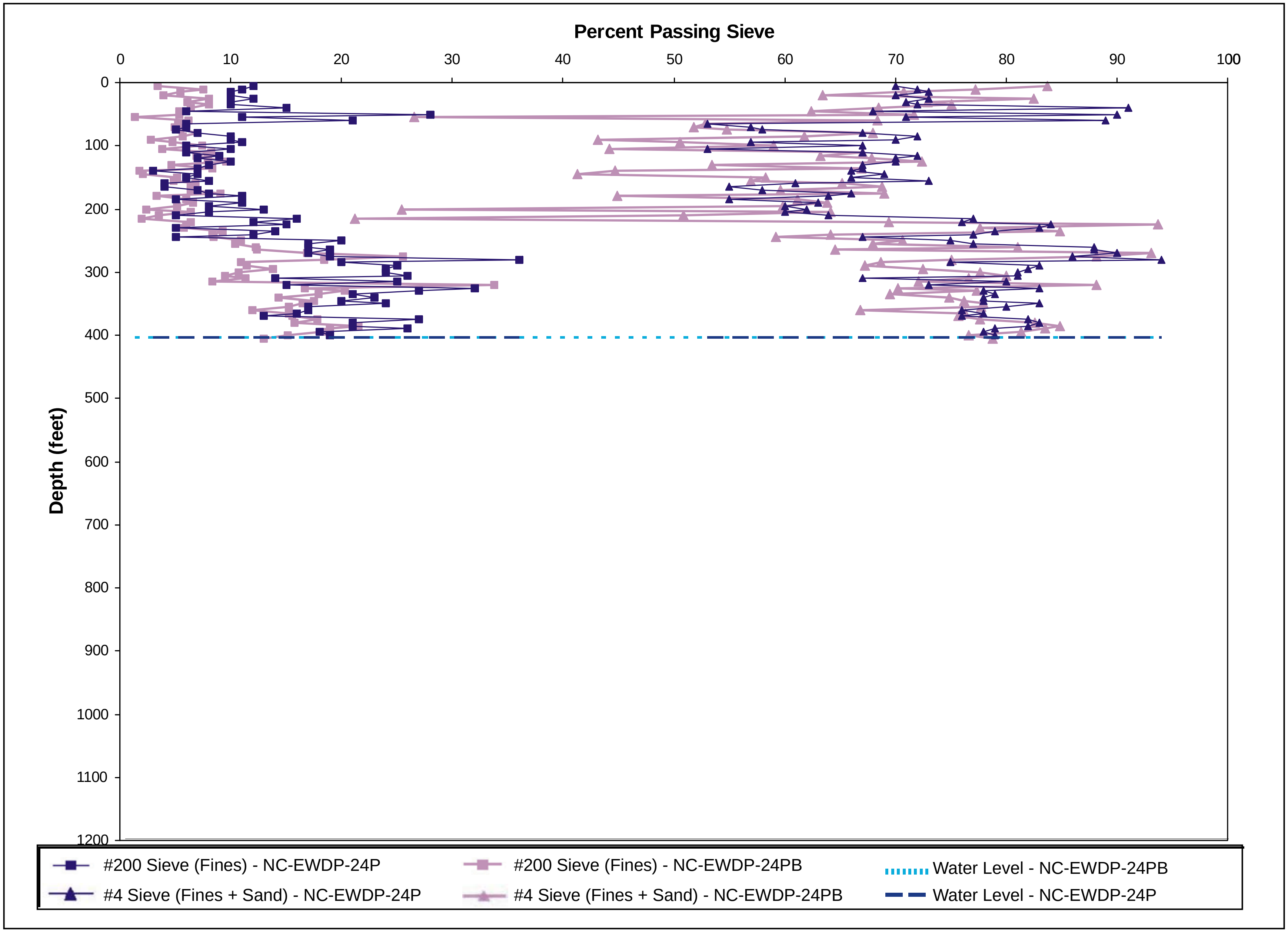


Figure 5.2-4
Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for 24P and 24PB (0 to 405 Feet)

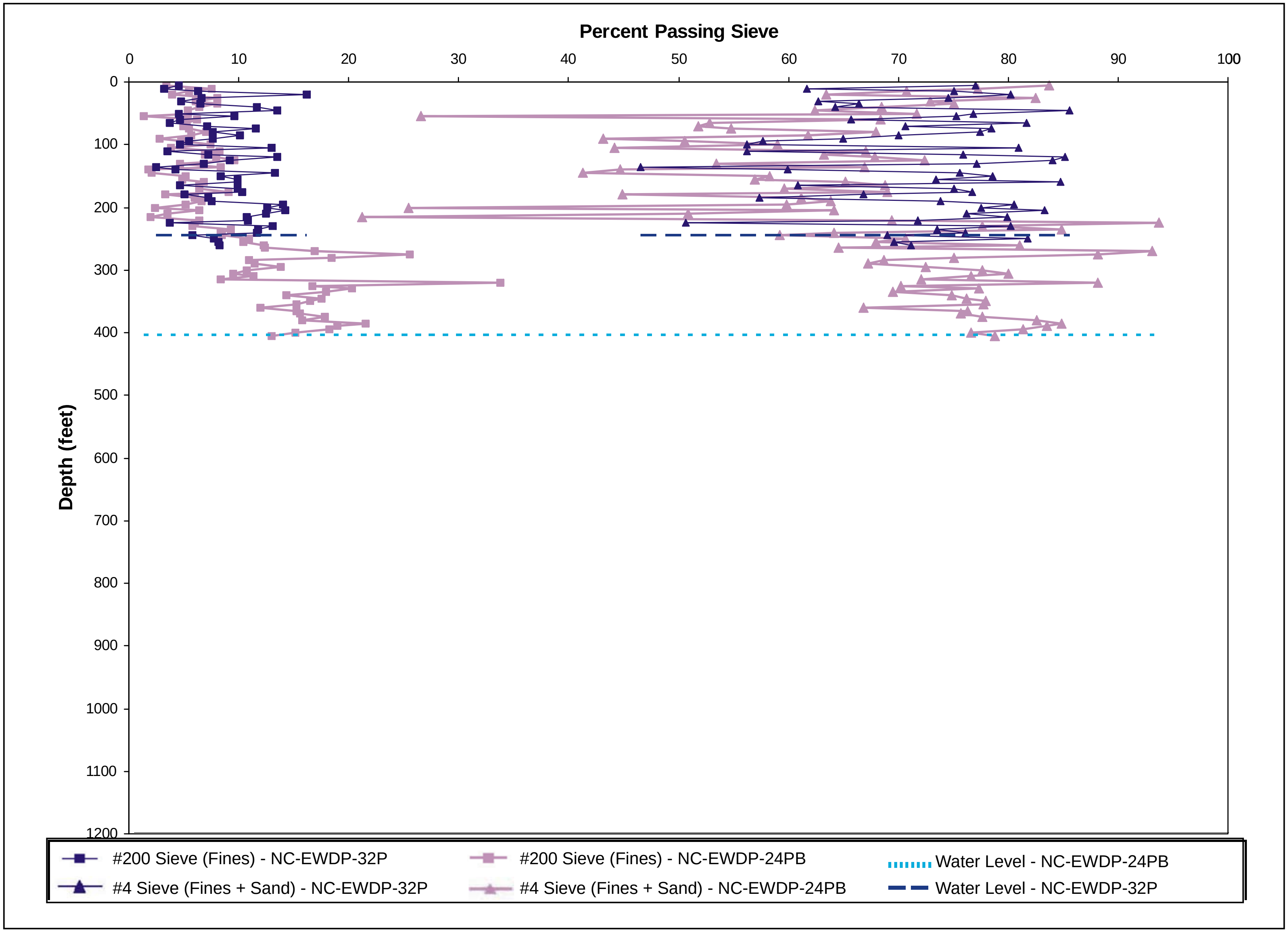


Figure 5.2-5
Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for 32P and 24PB (0 to 405 Feet)

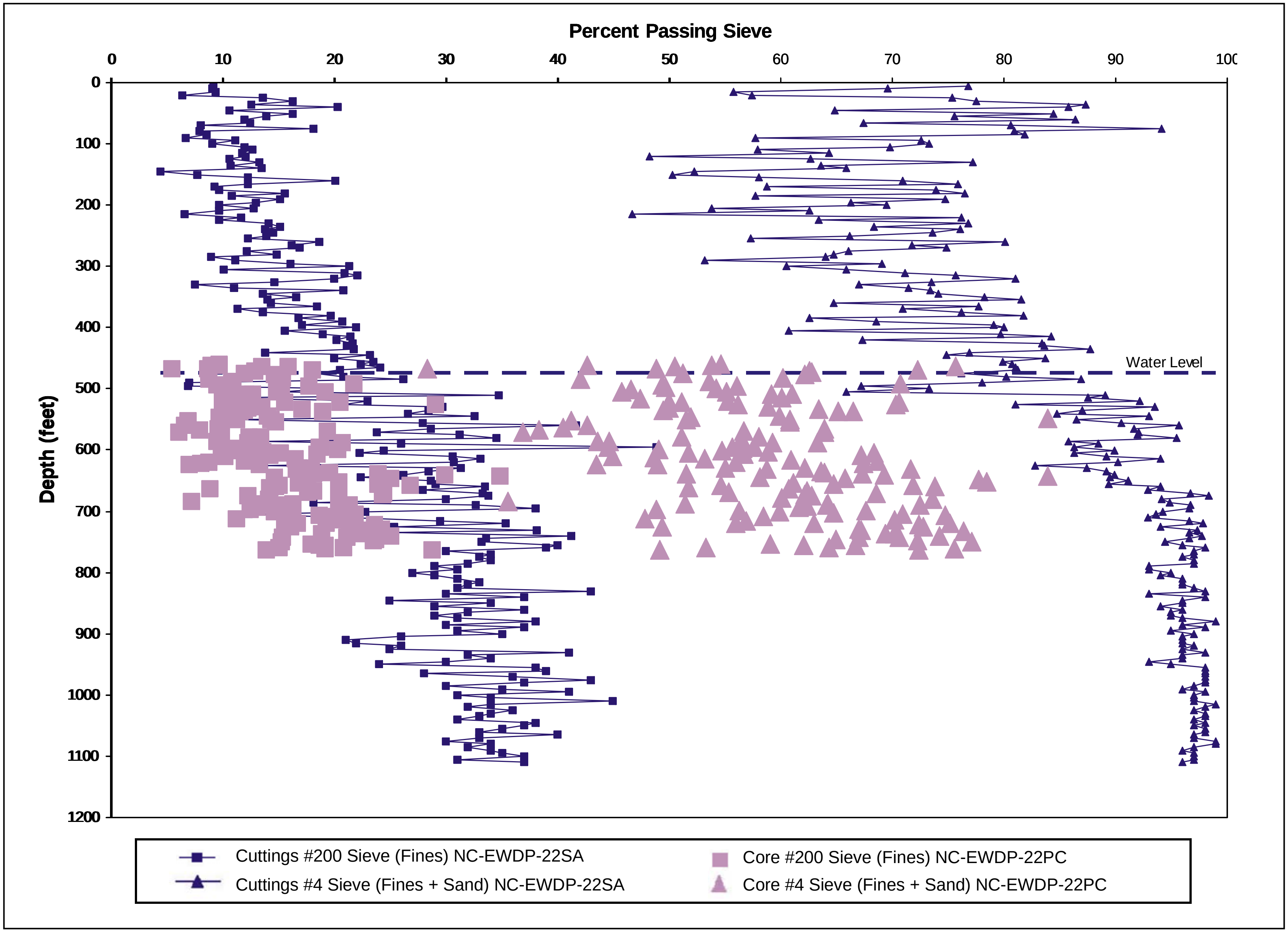


Figure 5.2-6
Laboratory Particle Size Distributions of Drill Cuttings and Core versus Depth in Alluvium for 22SA and 22PC, respectively

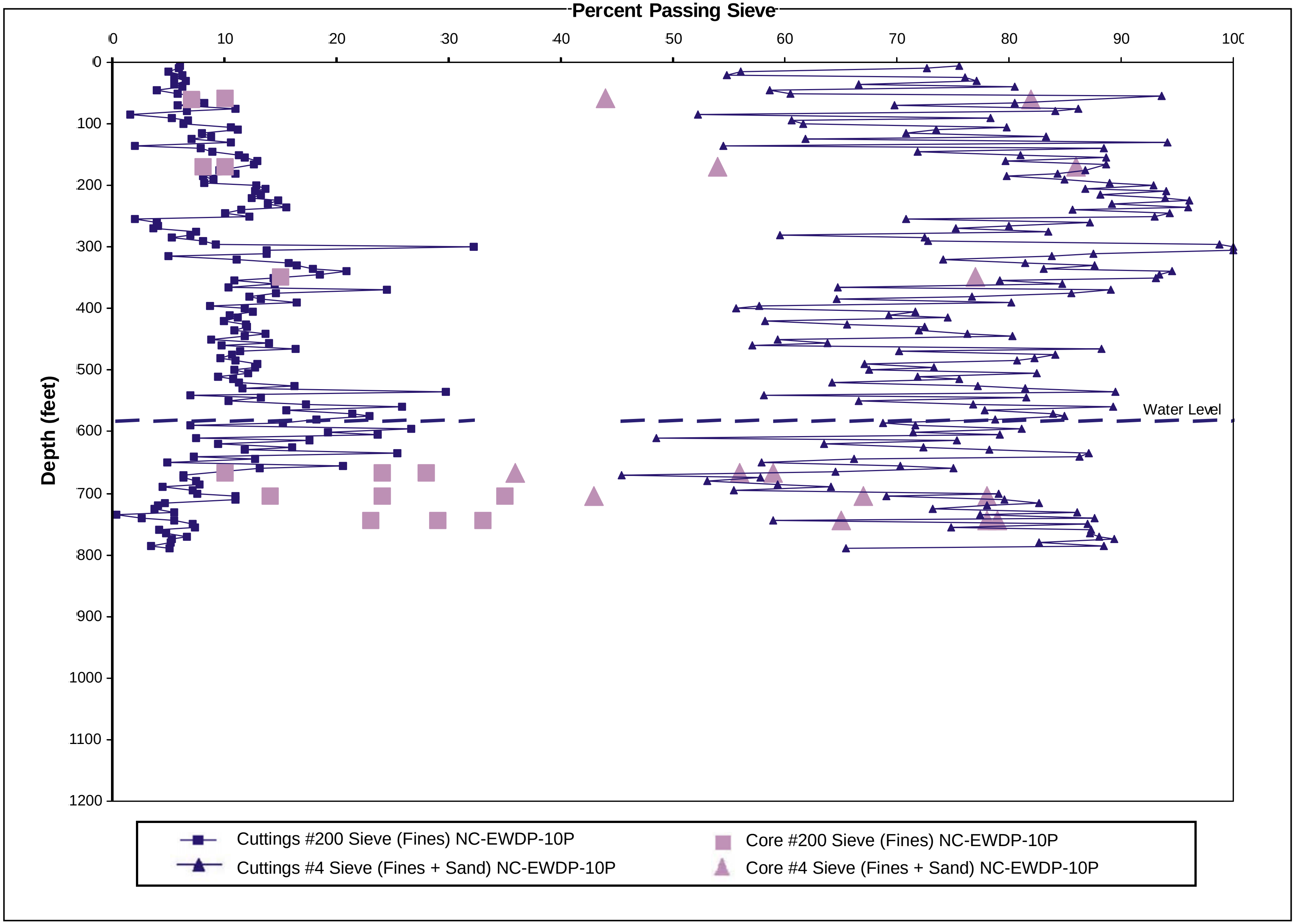


Figure 5.2-7
Laboratory Particle Size Distributions of Drill Cuttings and Core, including Core Shoes, versus Depth in Alluvium for 10P

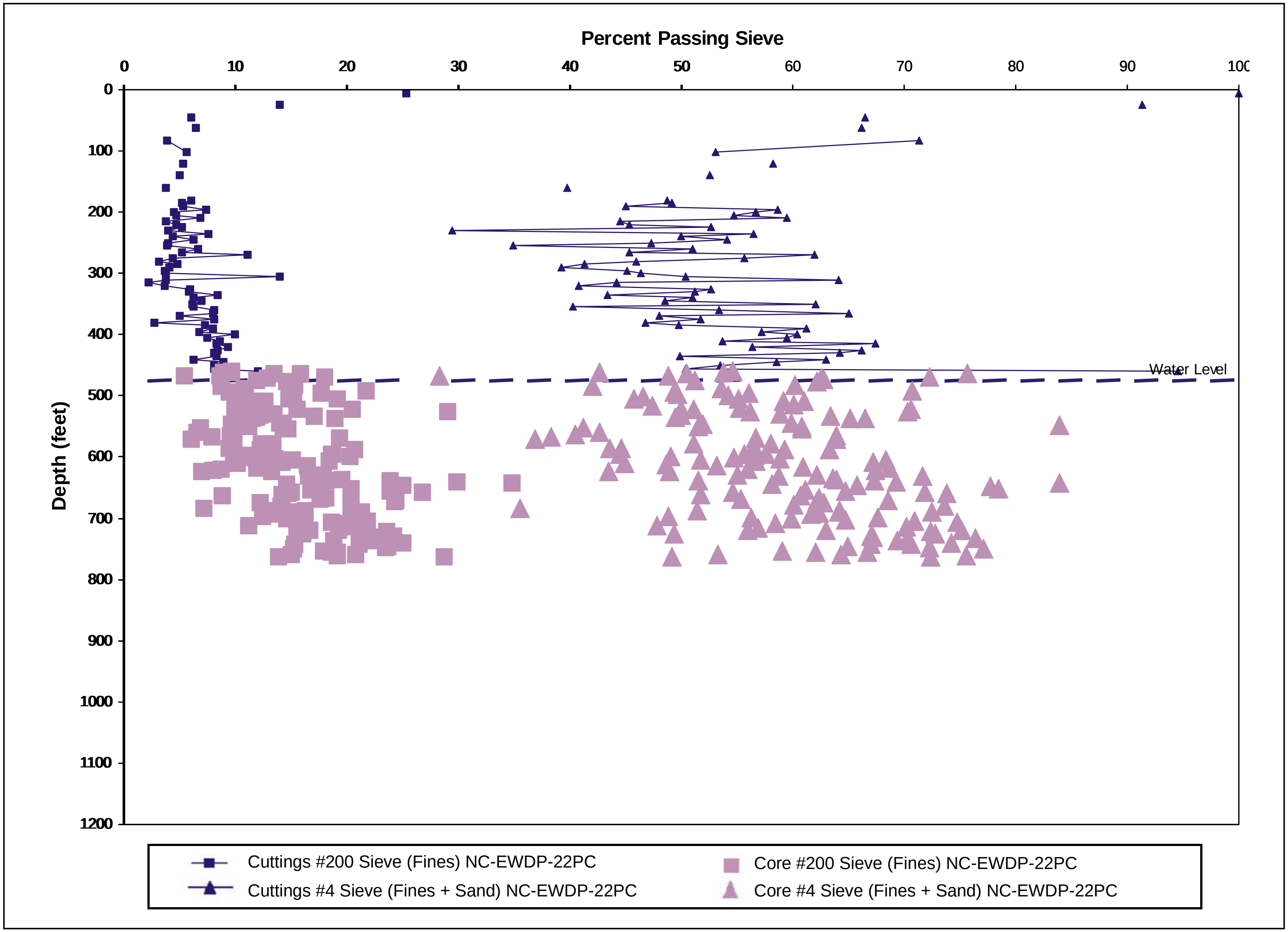


Figure 5.2-8
Laboratory Particle Size Distributions of Drill Cuttings and Core versus Depth in Alluvium for 22PC

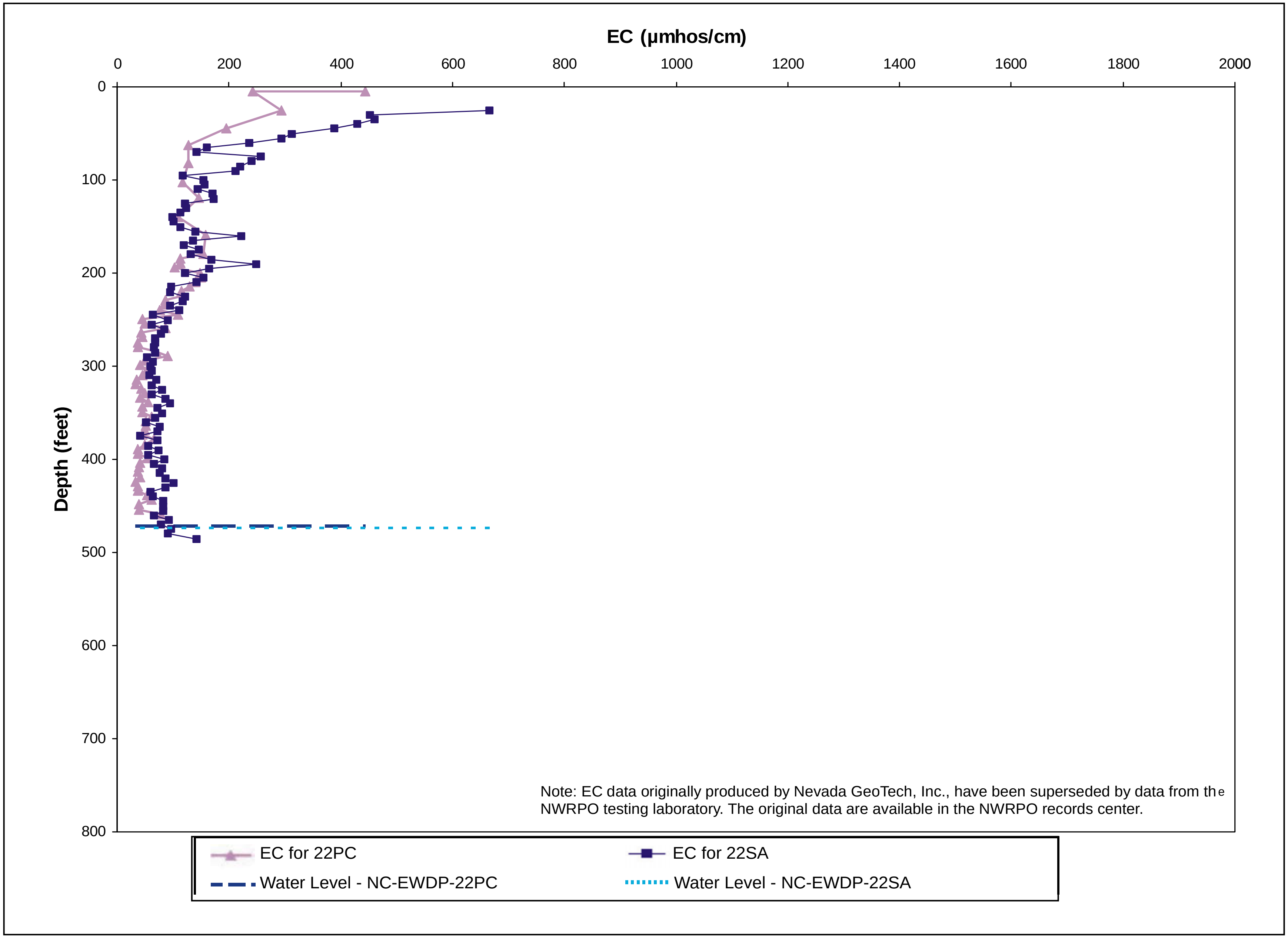


Figure 5.2-9
Electrical Conductivity versus Depth in Alluvium for 22PC and 22SA (0 to 460 Feet)

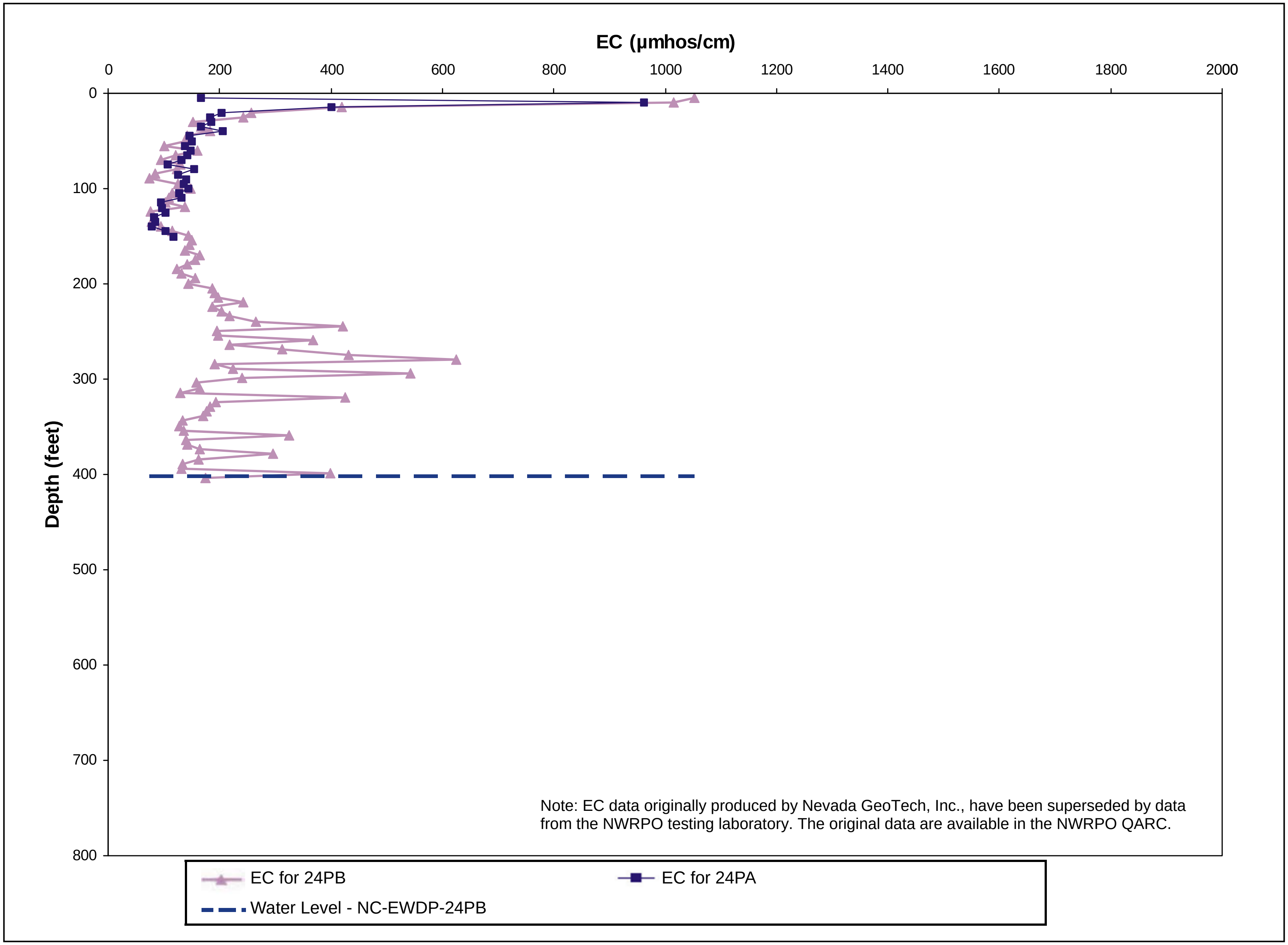


Figure 5.2-10
Electrical Conductivity versus Depth in Alluvium for 24PB and 24PA (0 to 405 Feet)

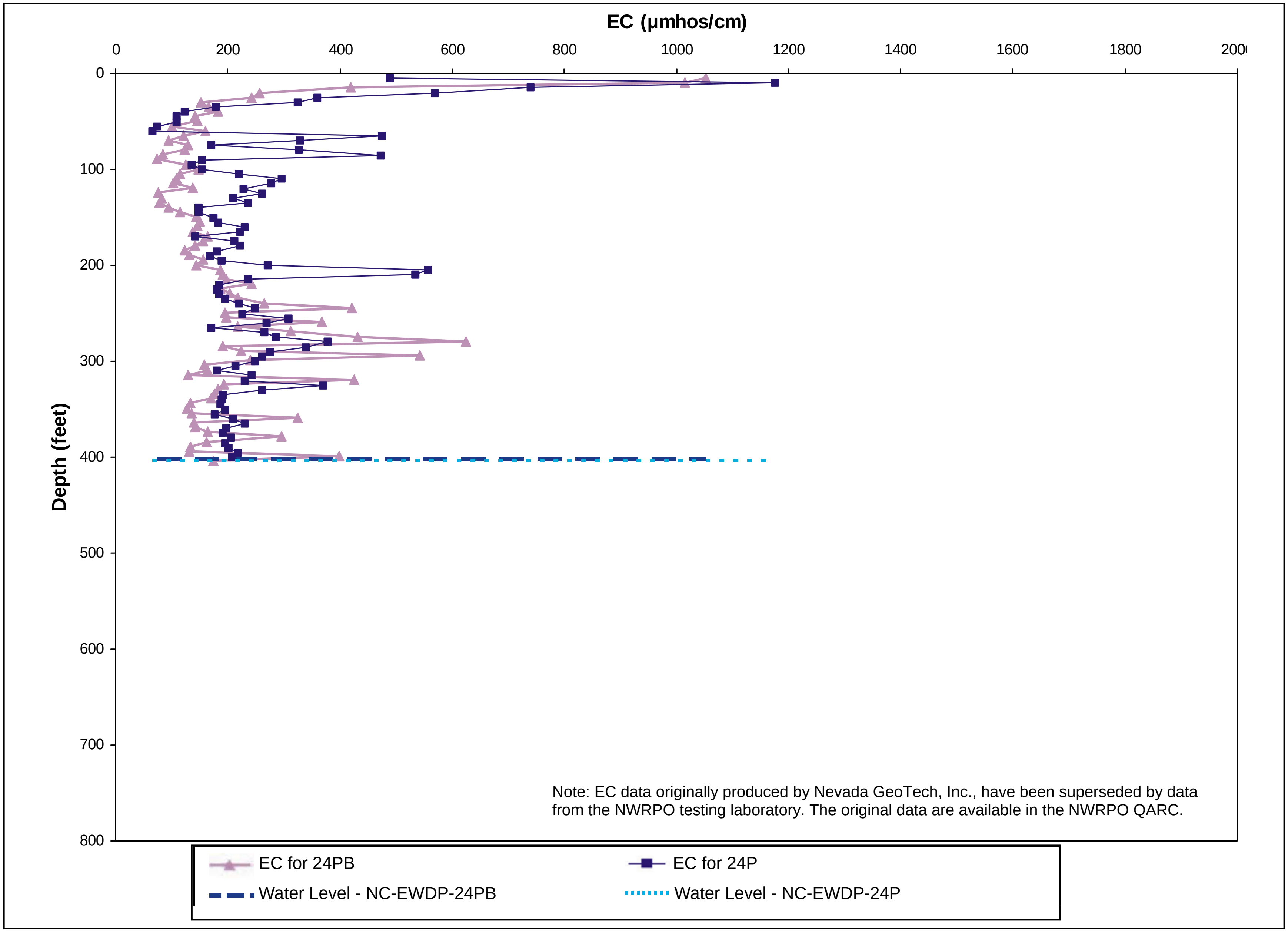


Figure 5.2-11
Electrical Conductivity versus Depth in Alluvium for 24PB and 24P (0 to 405 Feet)

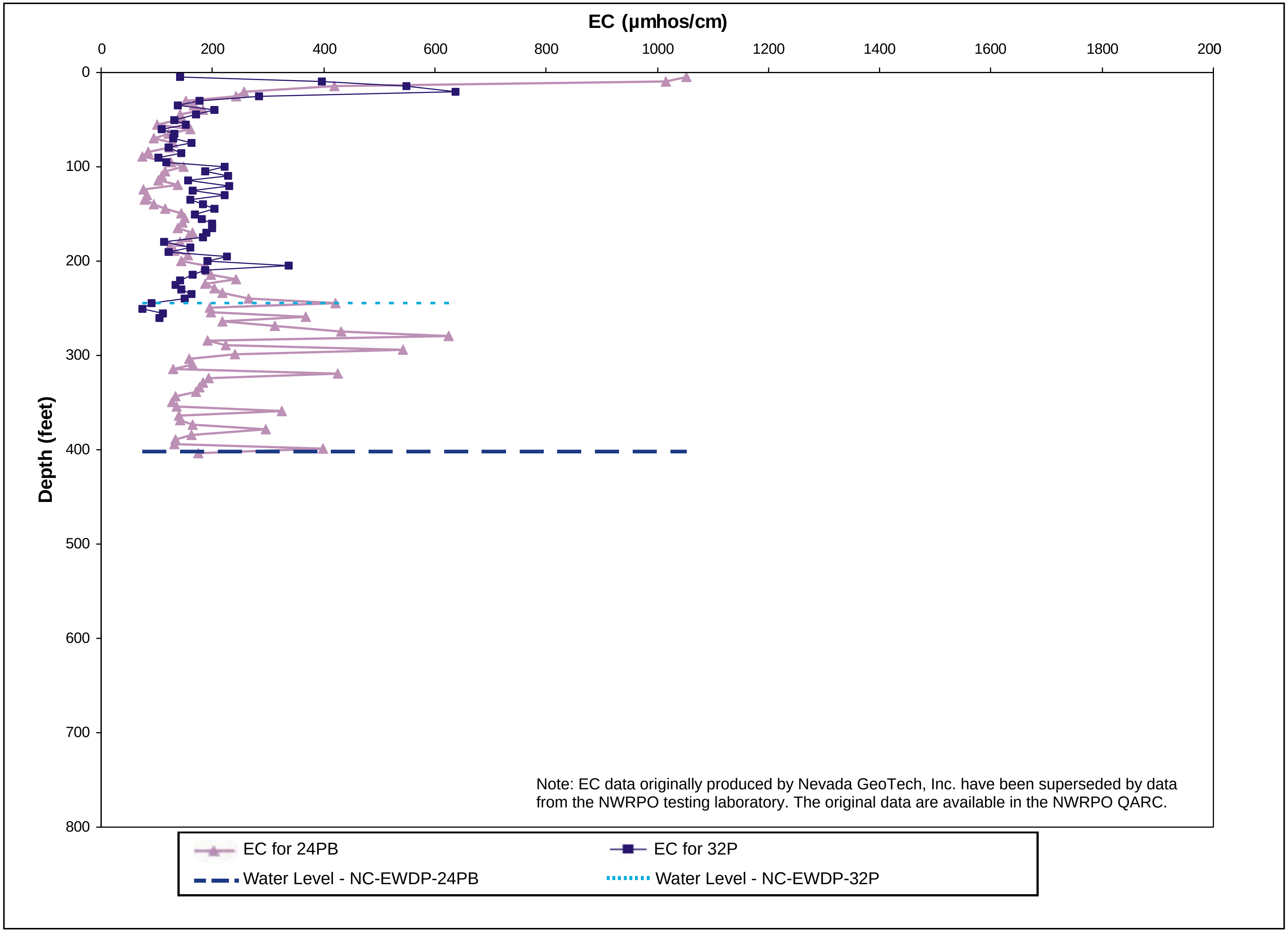


Figure 5.2-12
Electrical Conductivity versus Depth in Alluvium for 24PB and 32P (0 to 405 Feet)

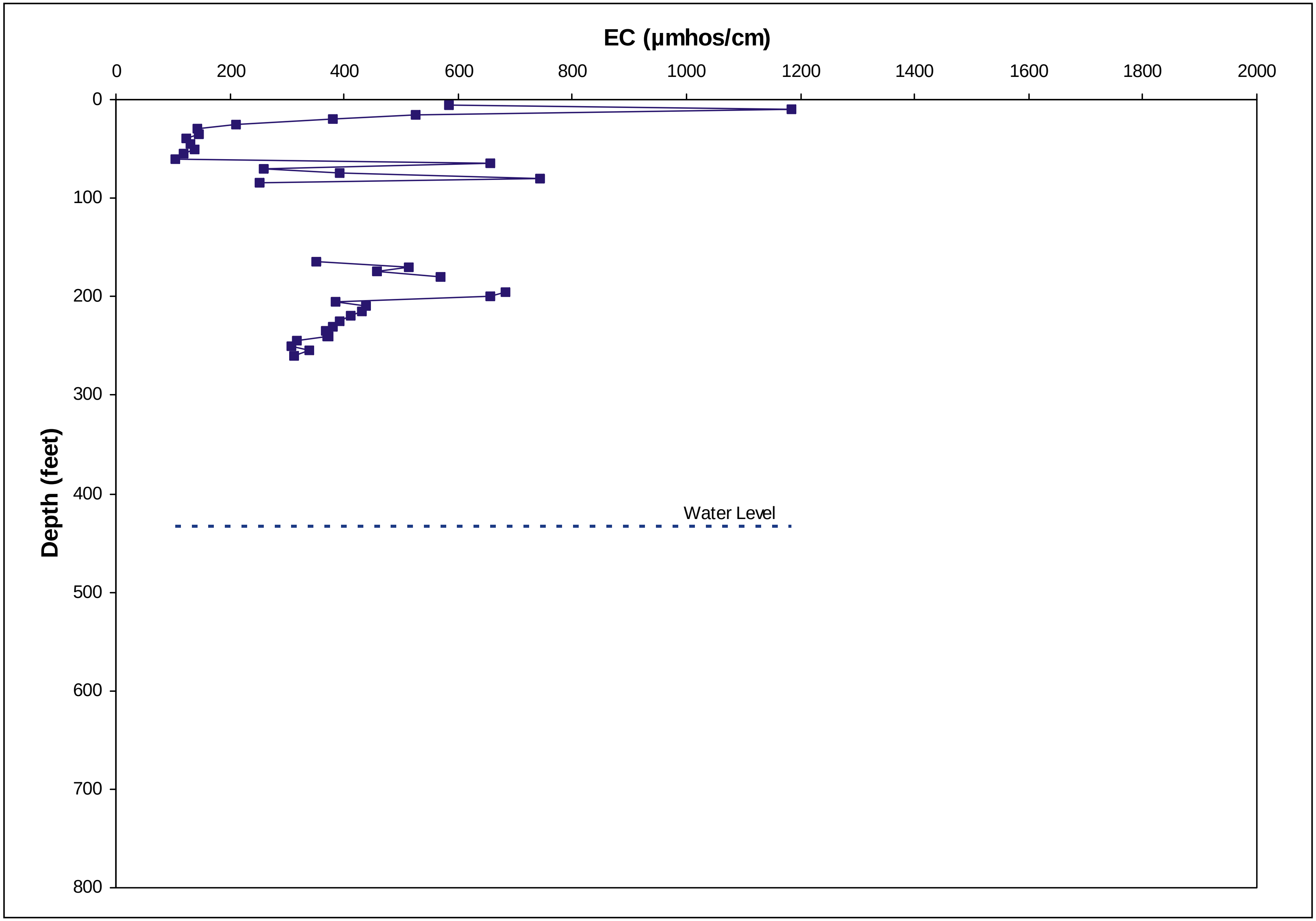


Figure 5.2-13
Electrical Conductivity versus Depth in Alluvium for 13P (0 to 260 Feet)

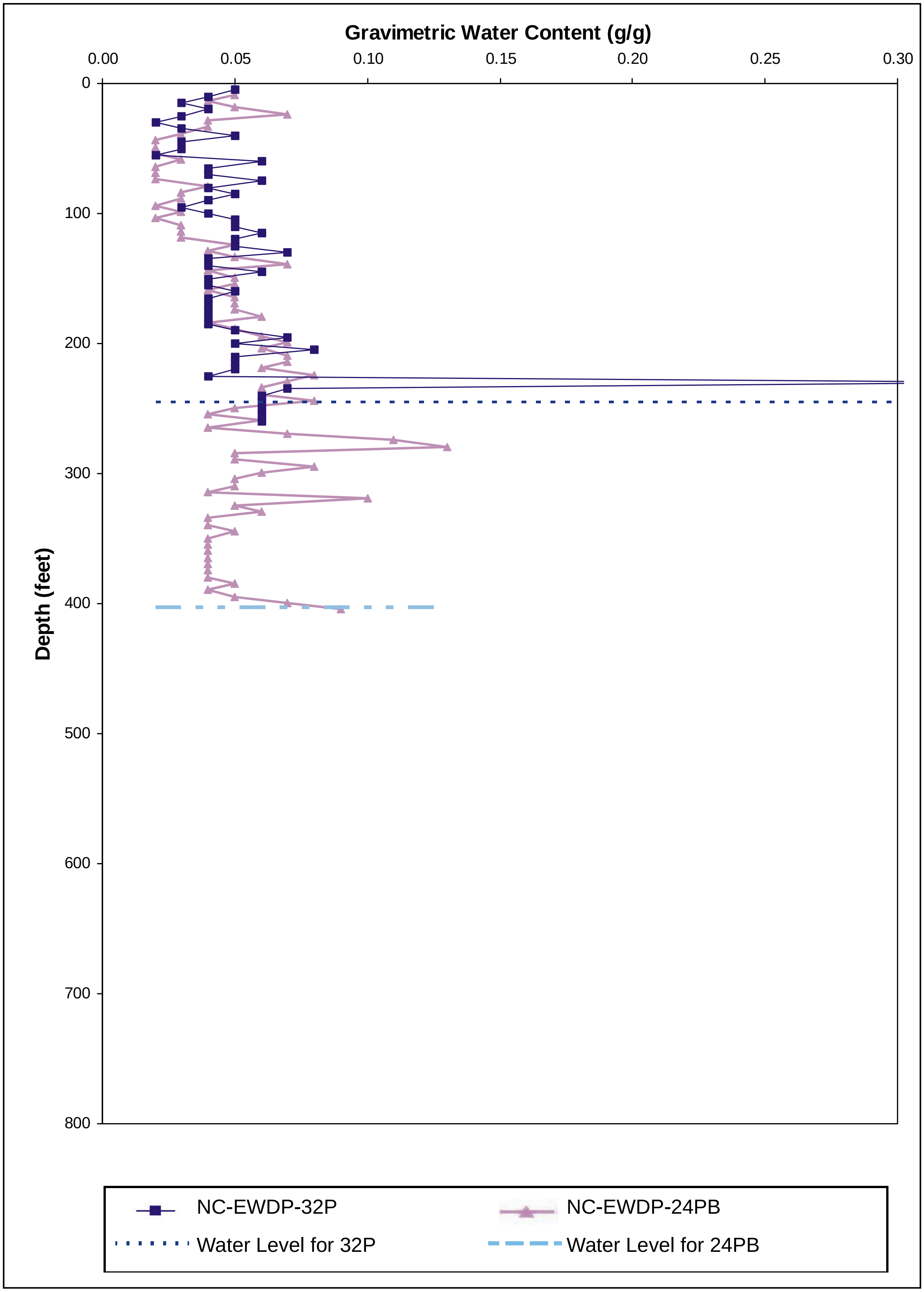


Figure 5.2-14
Gravimetric Water Content versus Depth in Alluvium and Non-Alluvium
for 32P and 24PB (0 to 405 Feet)

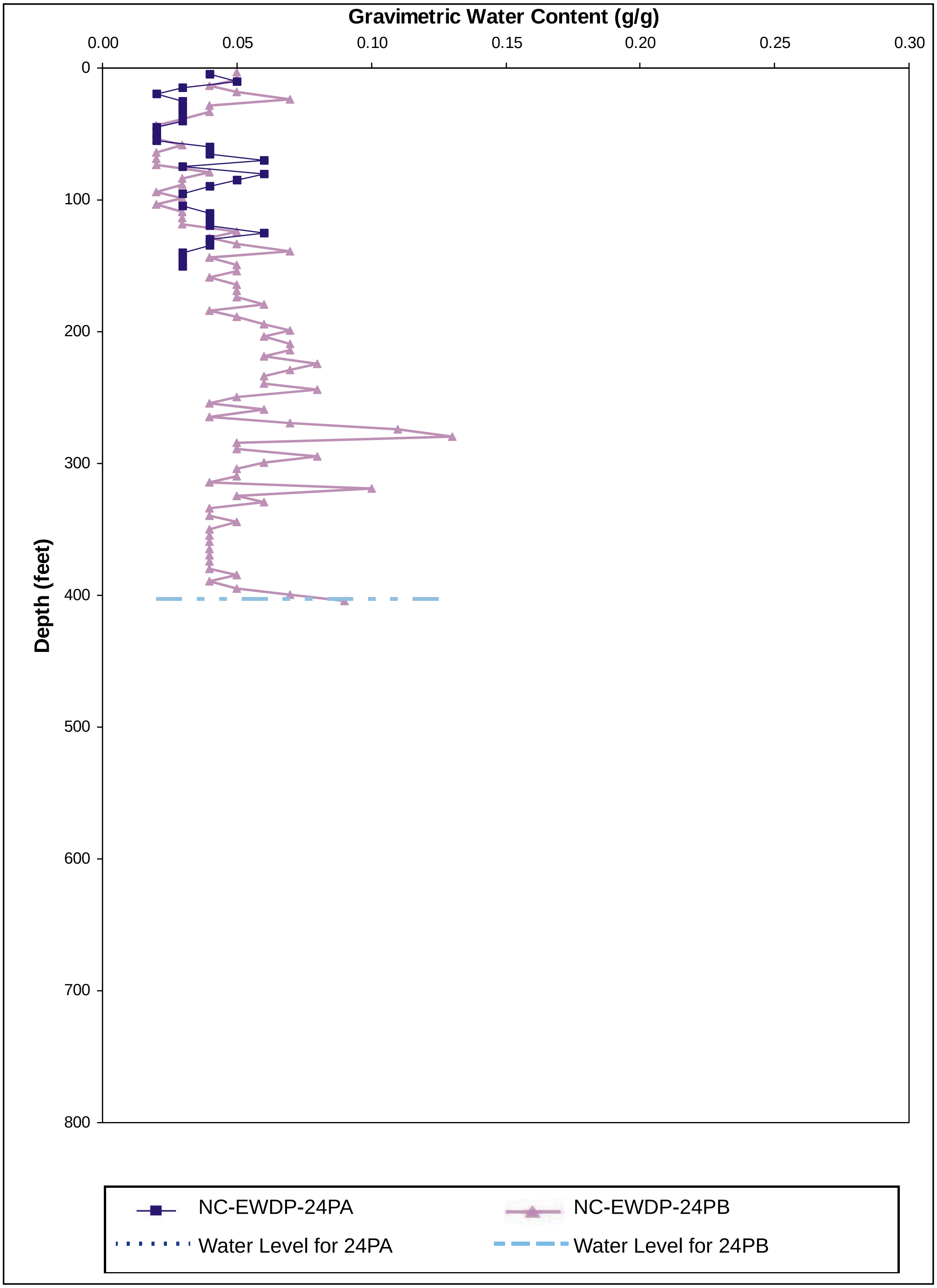


Figure 5.2-15
Gravimetric Water Content versus Depth in Alluvium and Non-Alluvium for 24PA and 24PB (0 to 405 Feet)

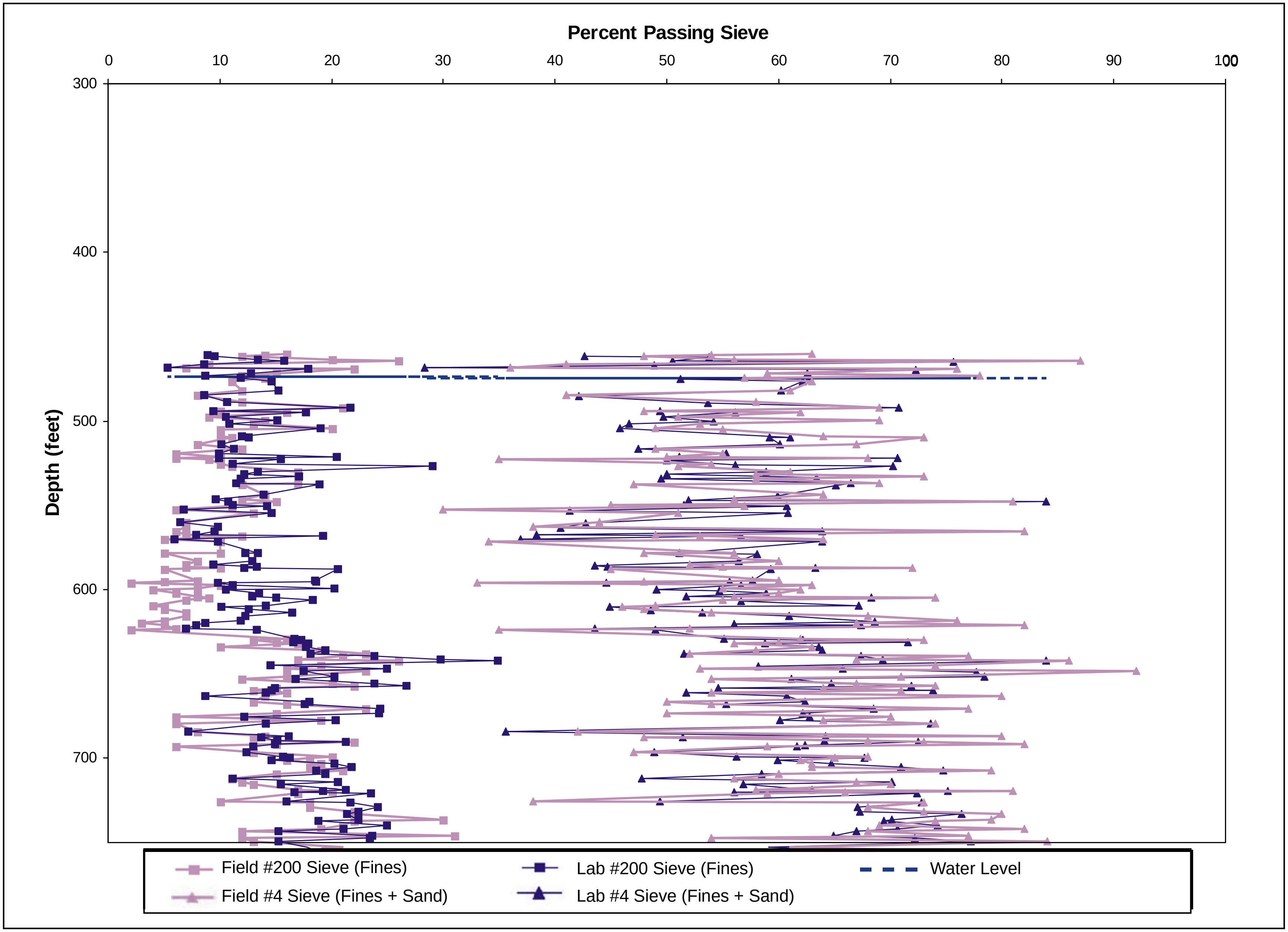


Figure 5.3-1
Field and Laboratory Particle Size Distributions of Sonic Core versus Depth in Alluvium for 22PC (460 to 763 Feet)

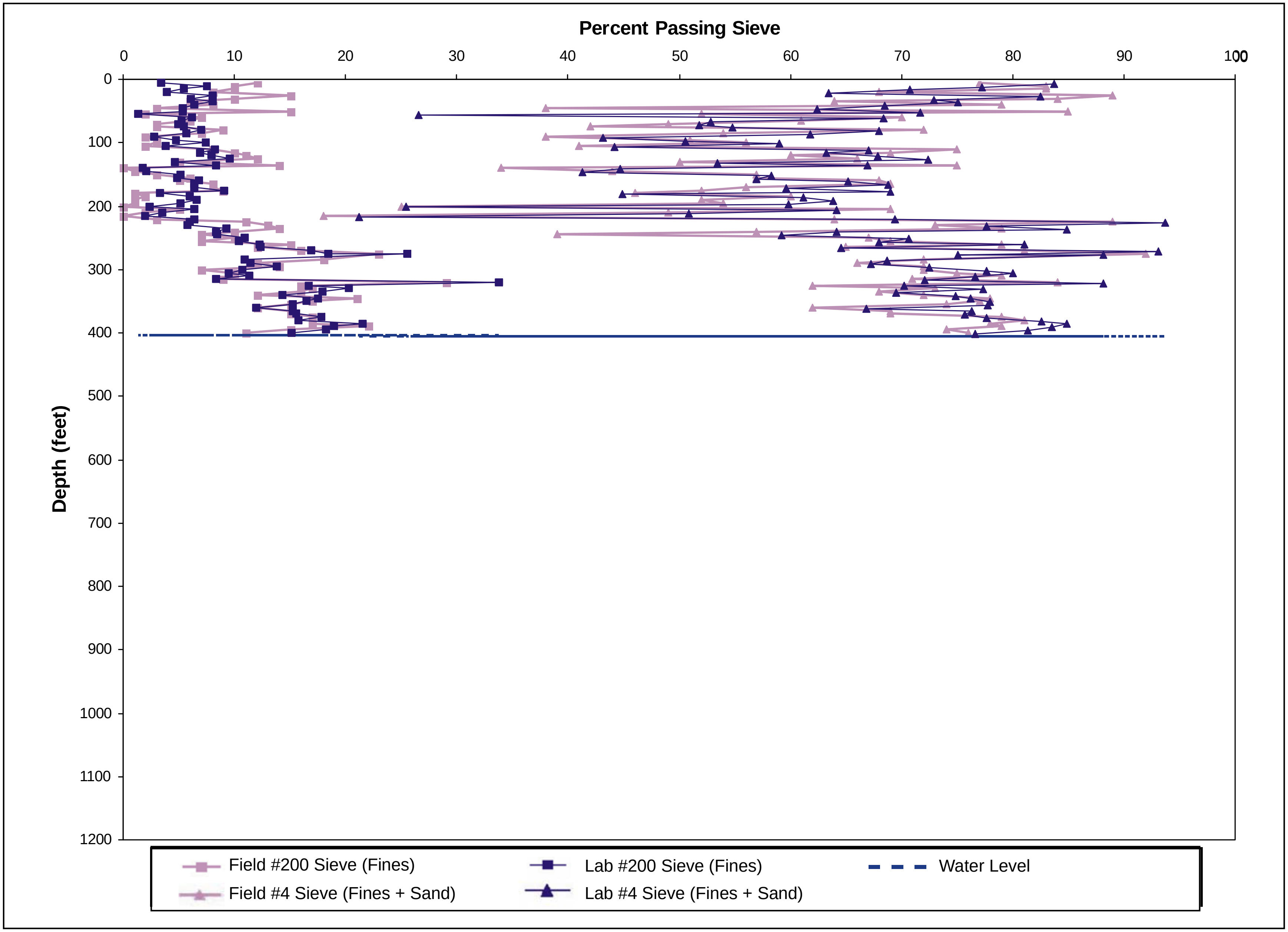


Figure 5.3-2
Field and Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for 24PB (0 to 405 Feet)

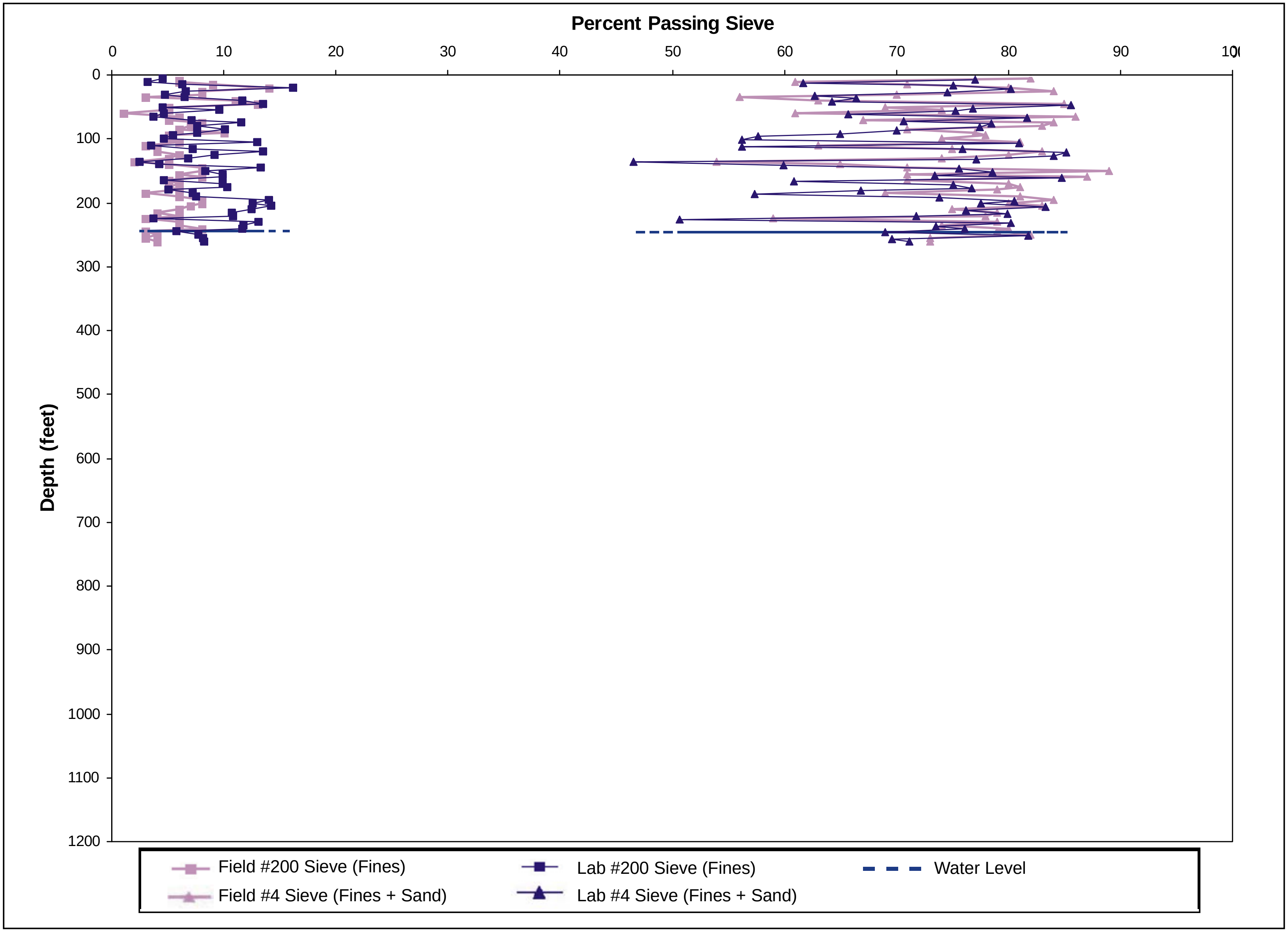


Figure 5.3-3
Field and Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for 32P (0 to 260 Feet)

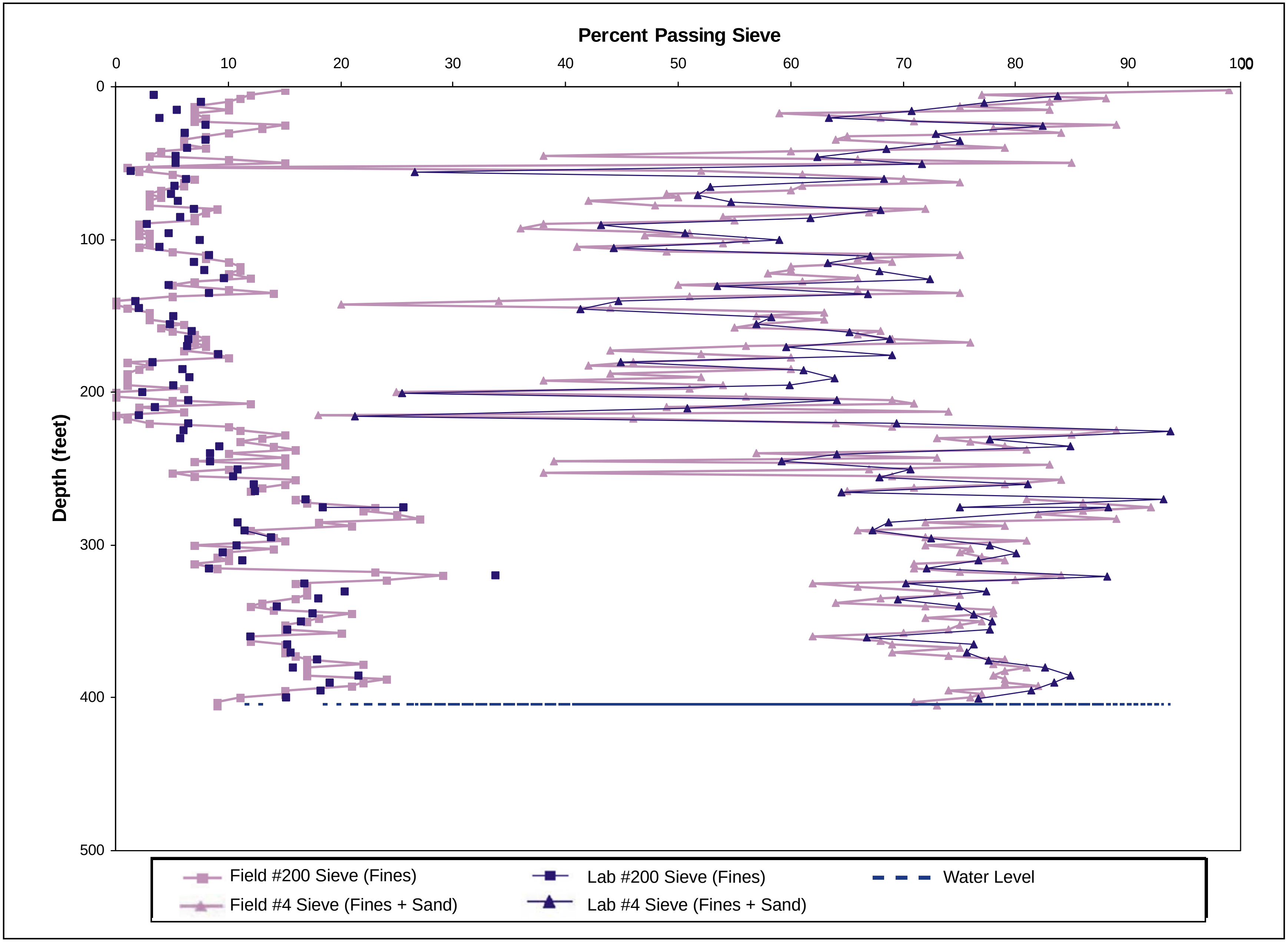


Figure 5.3-4
Field and Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for 24PB, Showing all Field Data (0 to 405 Feet)

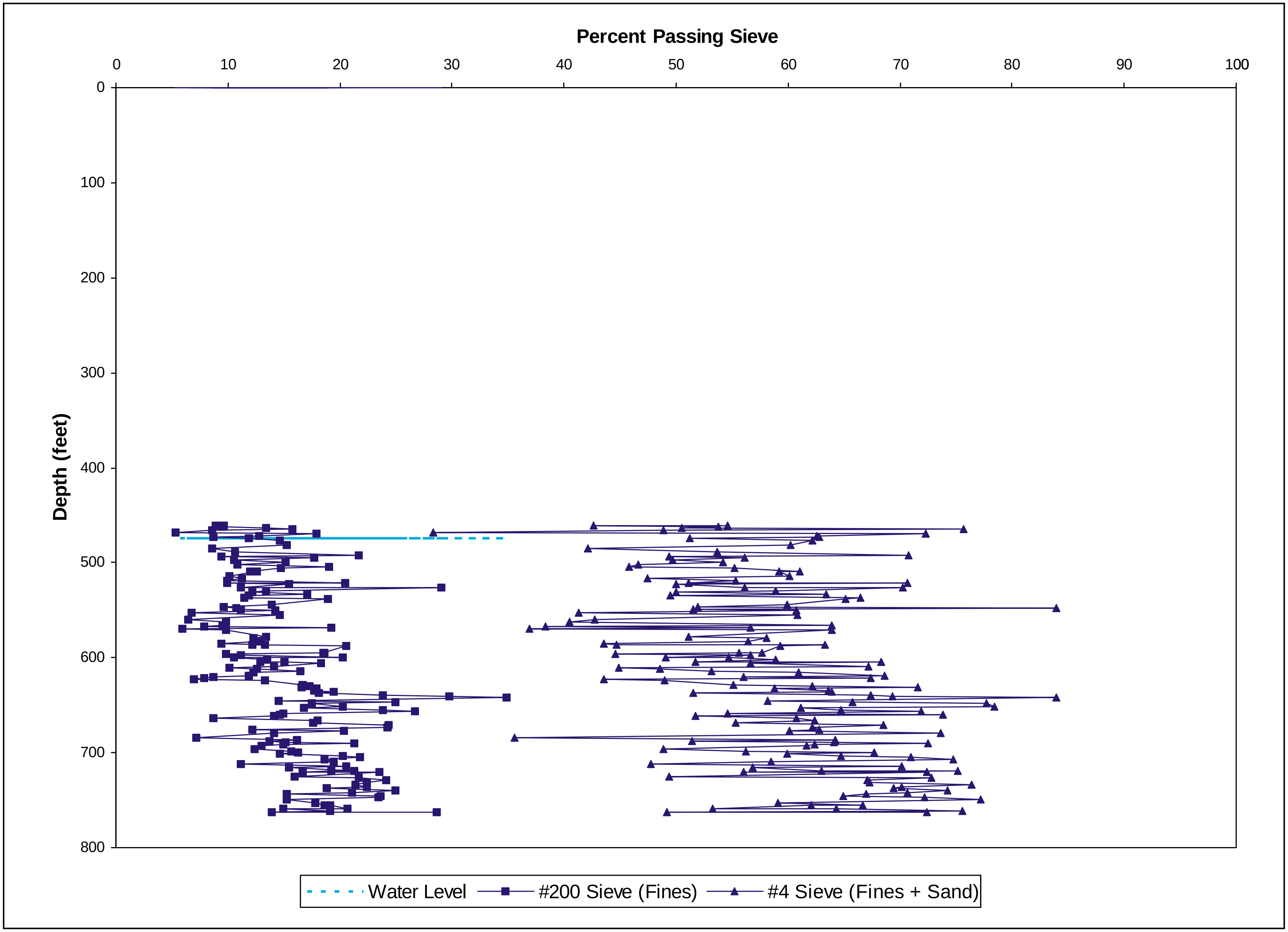


Figure 5.4-1
Laboratory Particle Size Distributions of Sonic Core versus Depth in Alluvium for 22PC (460 to 763 Feet)

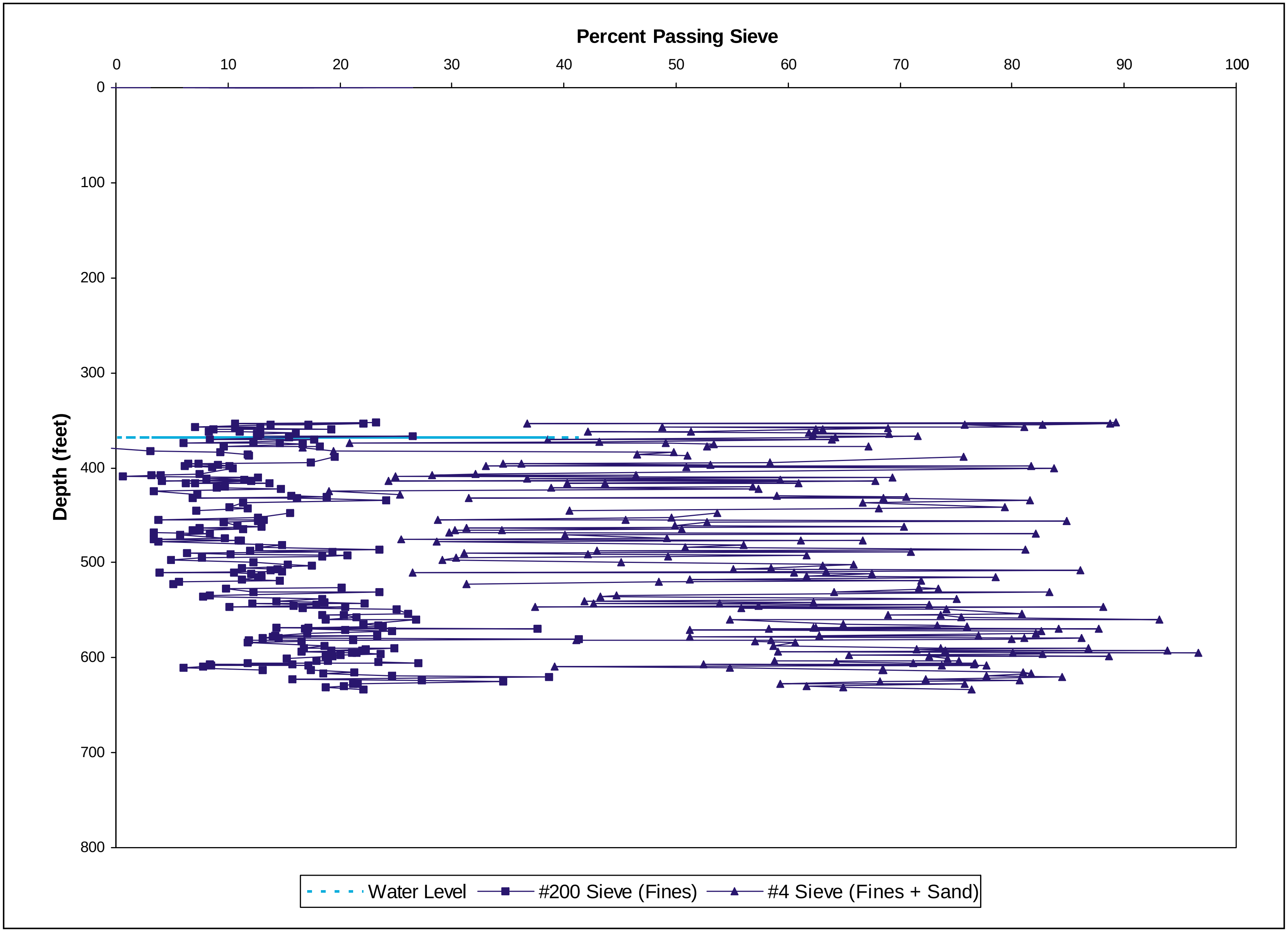


Figure 5.4-2
Laboratory Particle Size Distributions of Sonic Core versus Depth in Alluvium for 19PB (350 to 633 Feet)

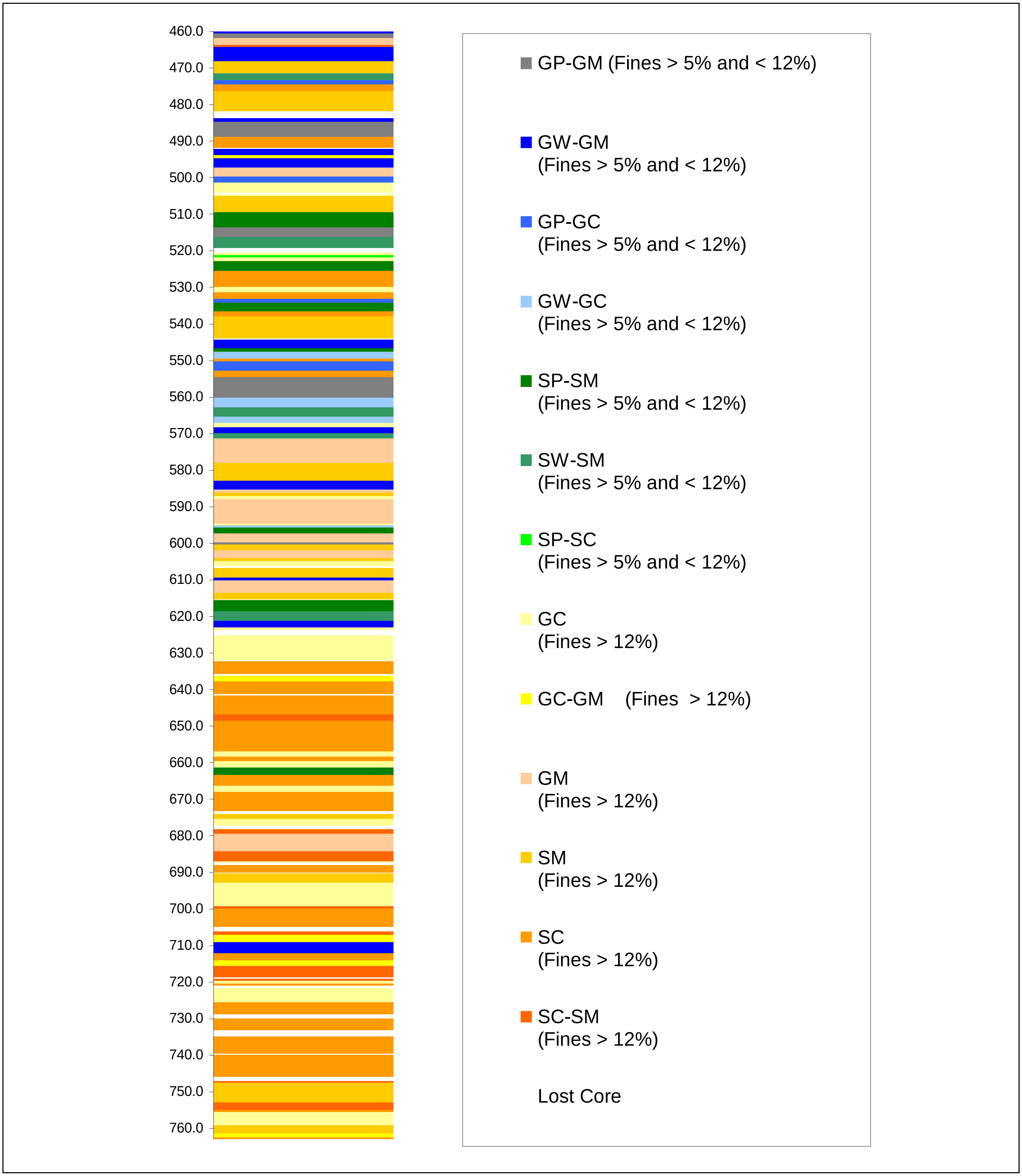


Figure 6.1-1
USCS Classifications (16 categories) by Depth for Sonic Core Recovered from 22PC

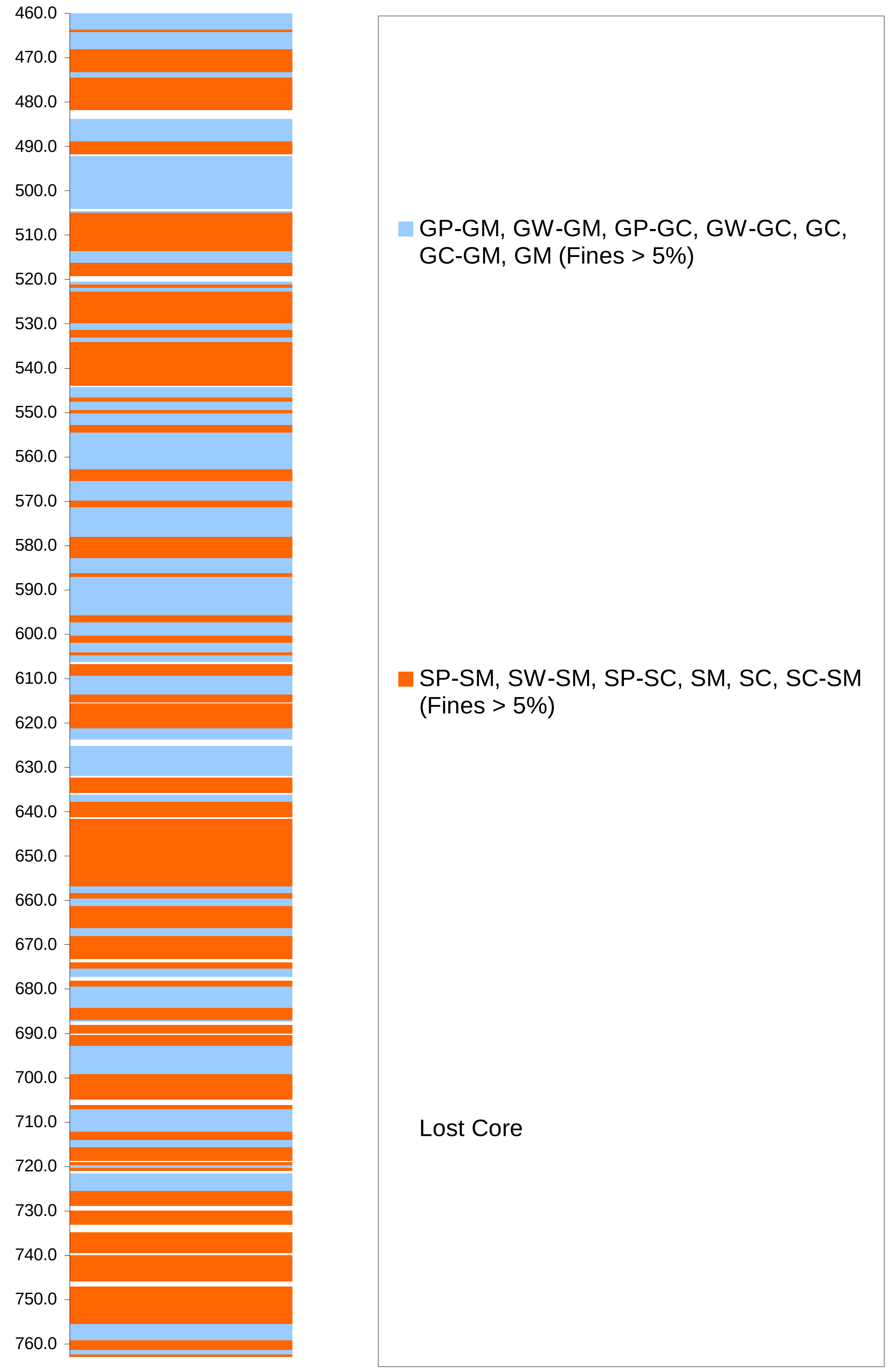


Figure 6.1-2
USCS Classifications (2 categories) by Depth for Sonic Core Recovered from 22PC

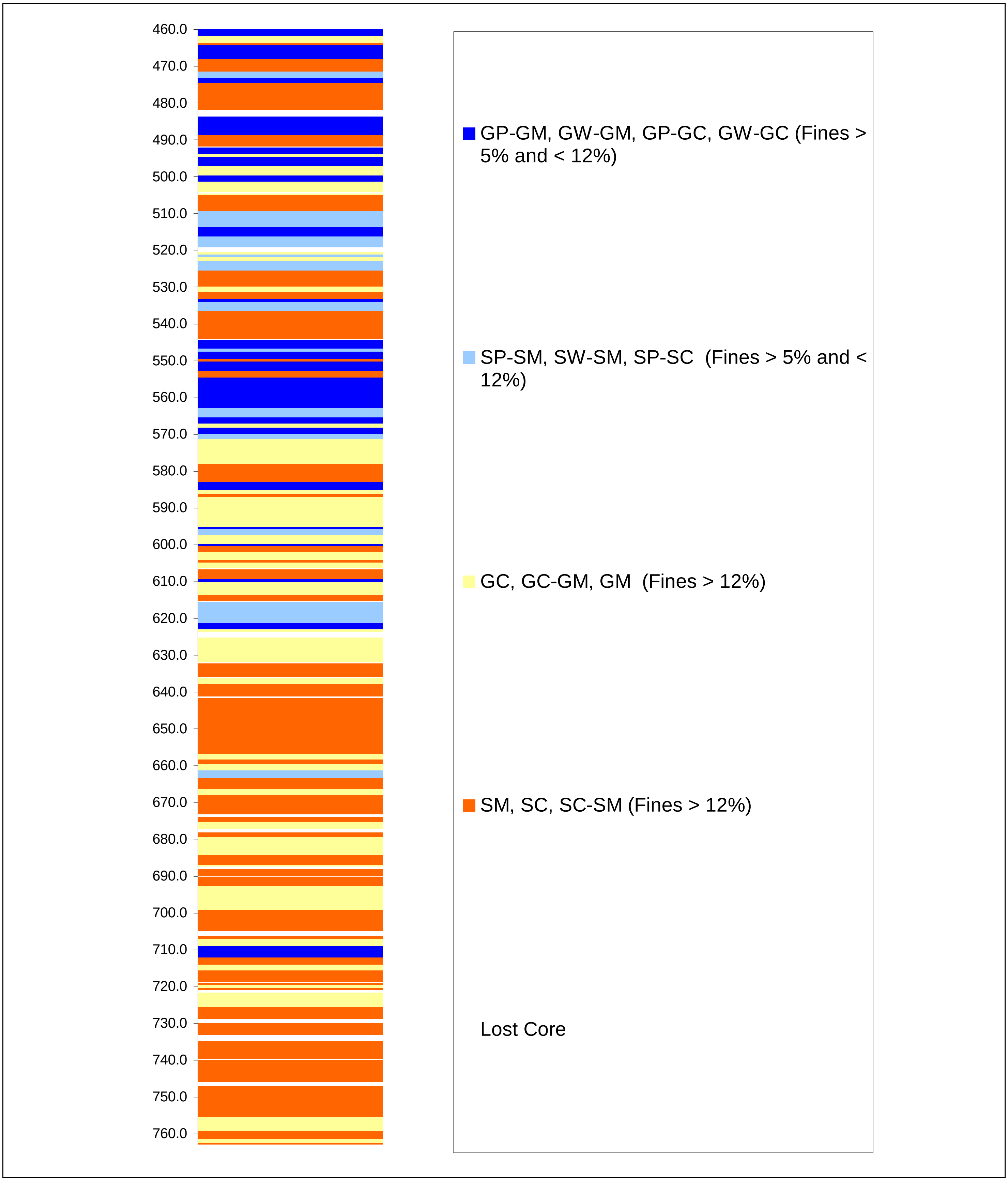


Figure 6.1-3
USCS Classifications (4 categories) by Depth for Sonic Core Recovered from 22PC

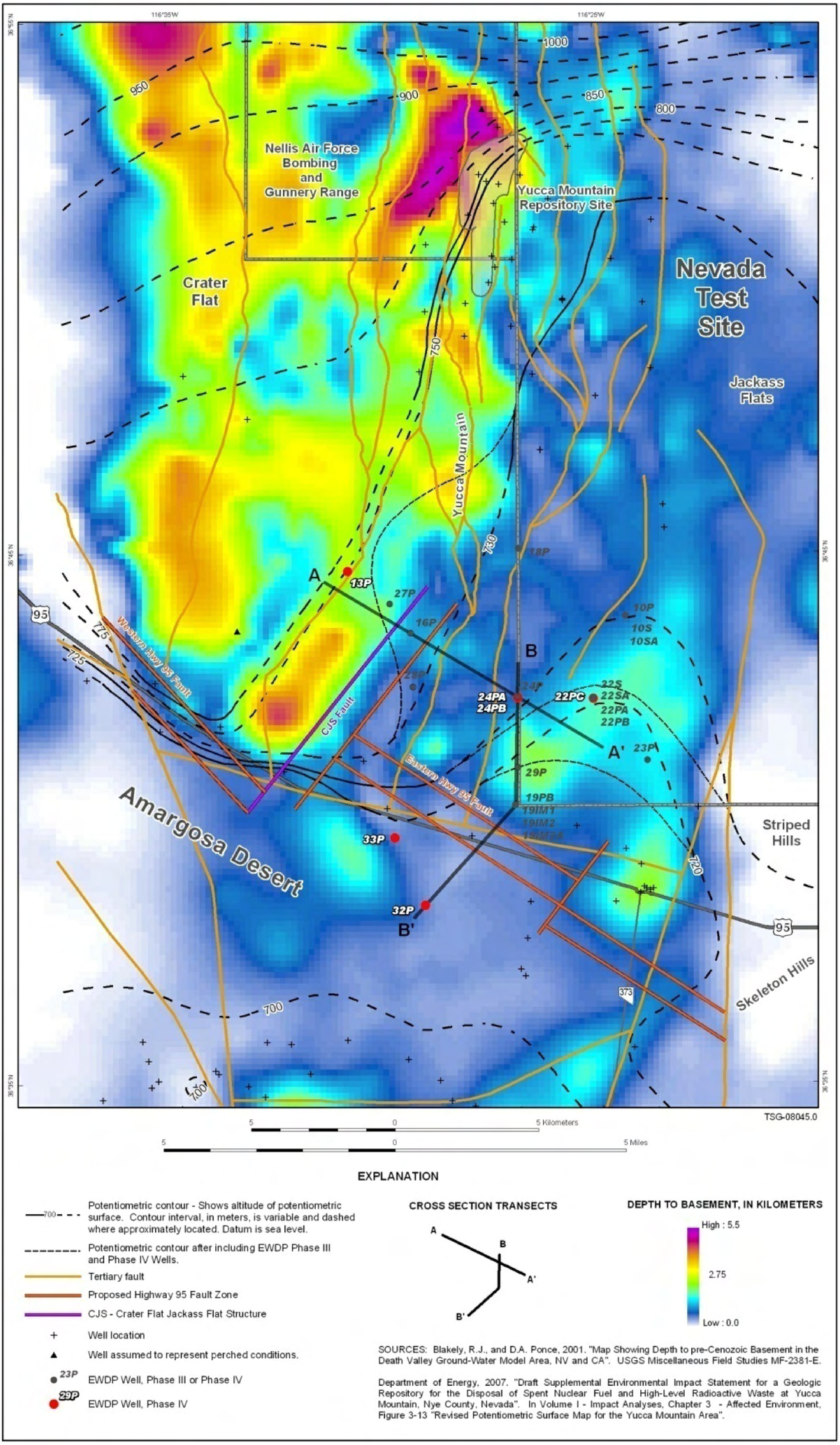


Figure 6.3-1
Depth to Pre-Cenozoic with Cross Section Locations and Proposed Location of the Highway 95 Fault System

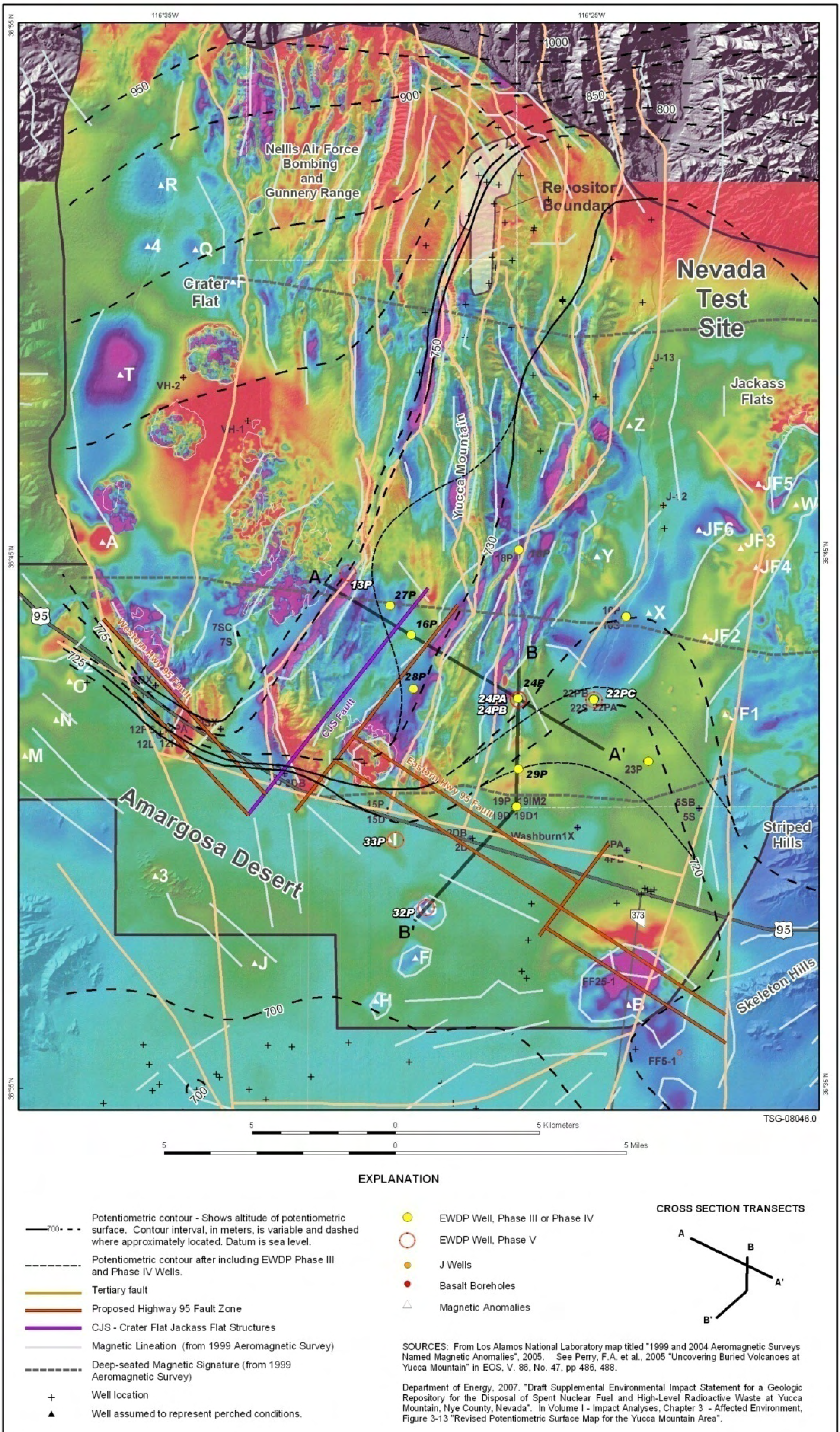


Figure 6.3-2
Aeromagnetic Survey Map with Proposed Location of the Highway 95 Fault System

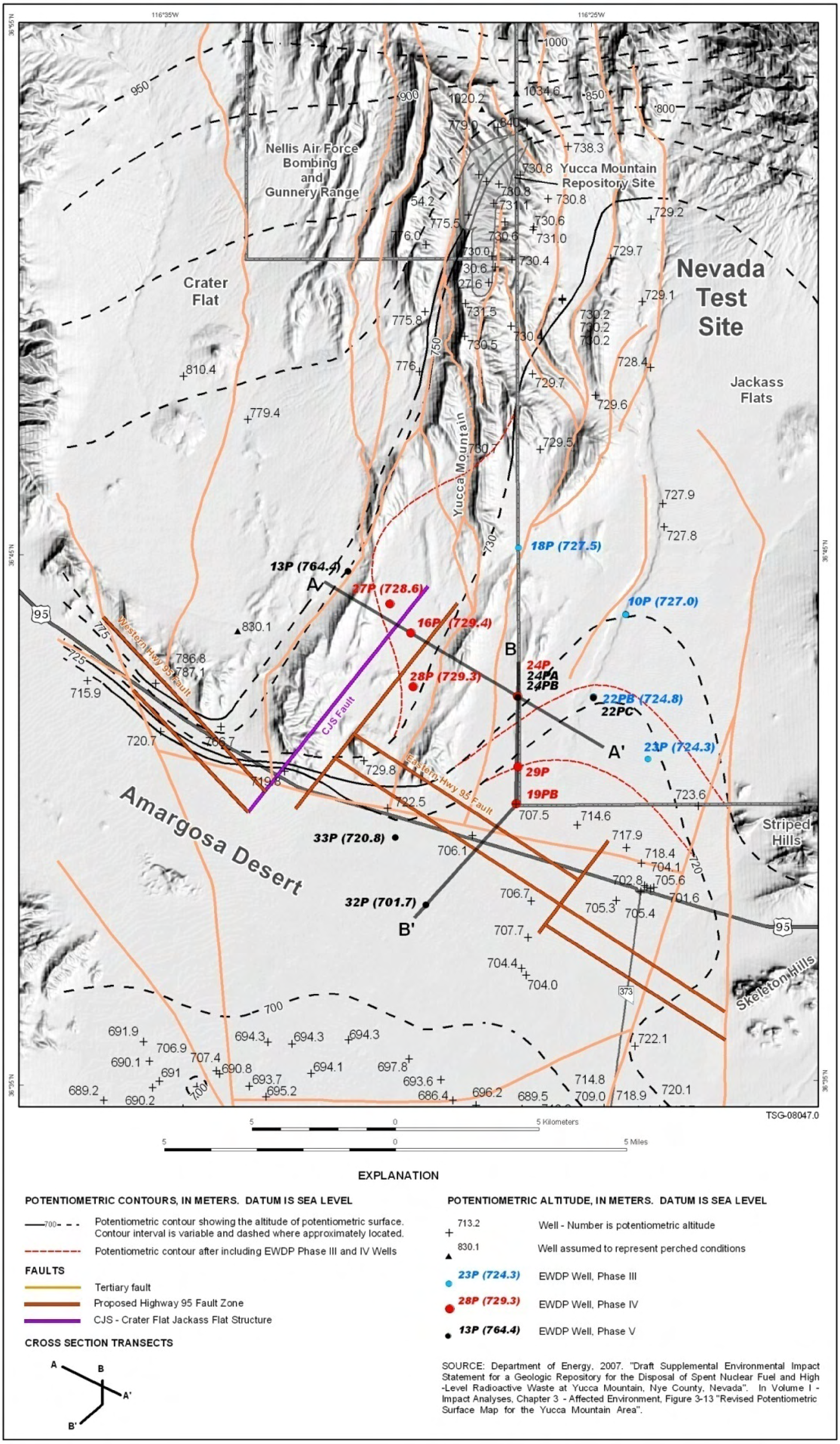


Figure 6.3-3
Potentiometric Surface Map with Proposed Location of the Highway 95 Fault System

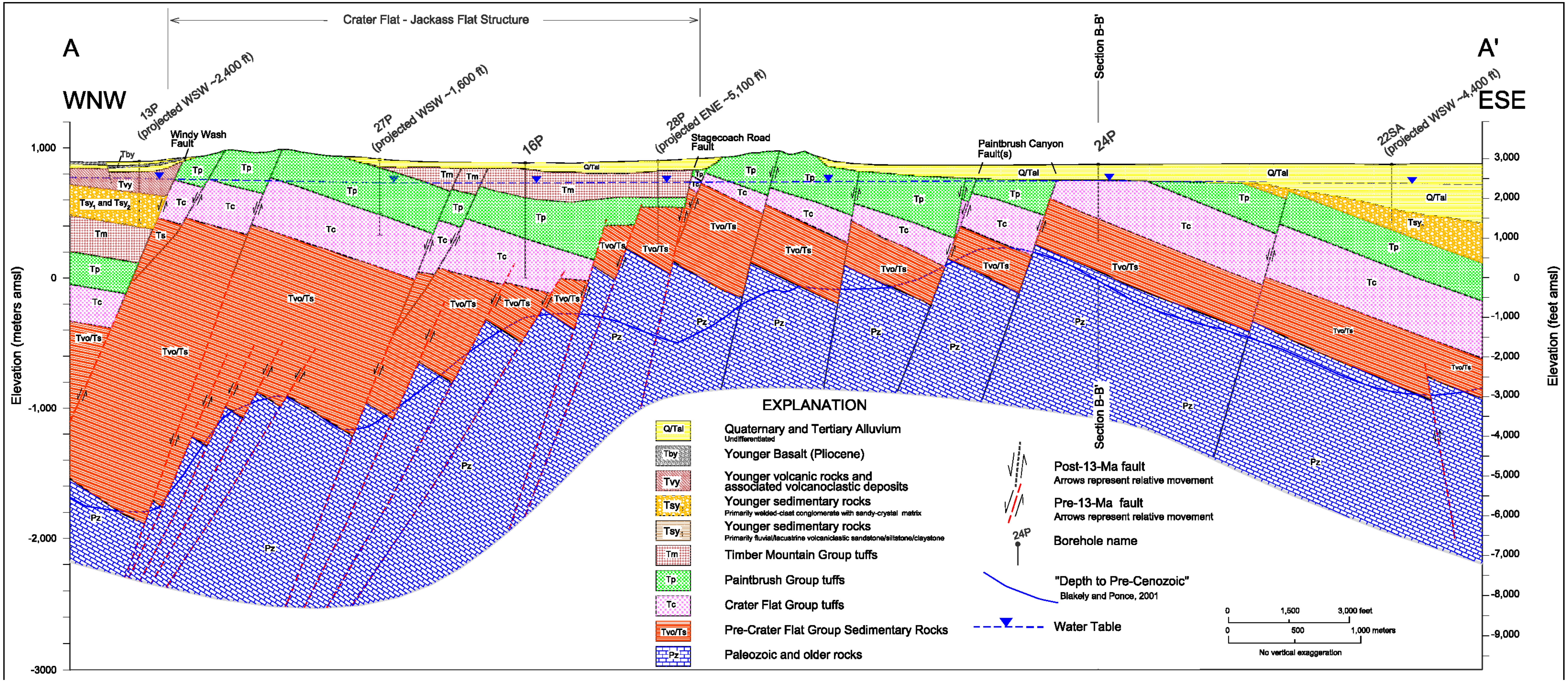


Figure 6.3-4
Geologic Cross Section A-A'

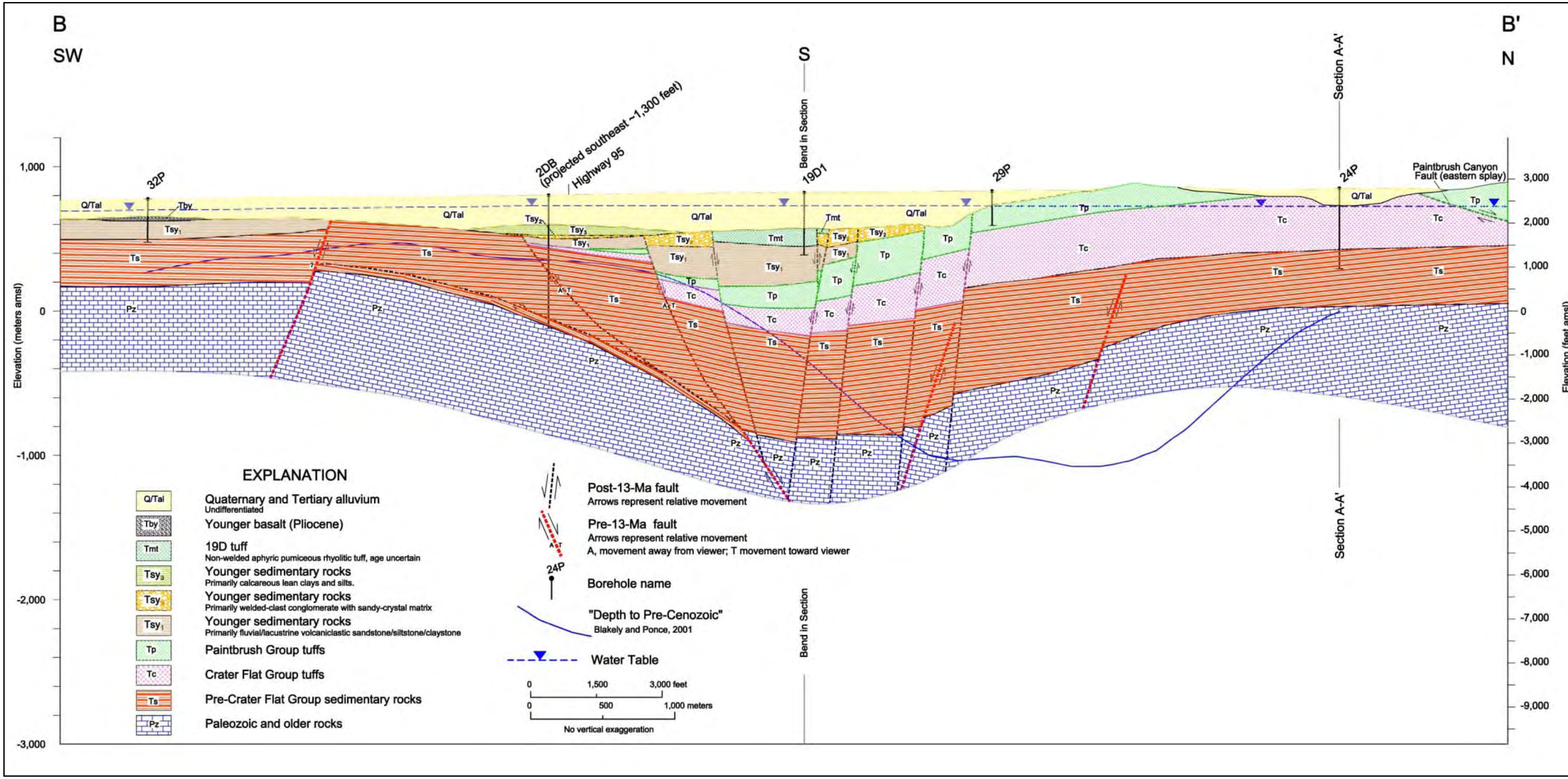


Figure 6.3-5
Geologic Cross Section B-B'

Table 1.3-1
Survey Coordinates and Well Completion Information

Well Name	Construction Duration		Total Depth (feet bgs[a])	Yucca Mountain Project Survey Coordinates		Ground Elevation (feet amsl[b])	Approximate Open Hole Water Level at End of Drilling (feet bgs)	Piezometer Screen and U-tube/ Injection Line Interval(s) (feet bgs)		Sand Pack Interval(s) (feet bgs)		Lithology at Sand Pack Interval(s)	Well Casing Type	Well Casing Total Depth (feet bgs)	Well Casing Outside Diameter (inches)
	Start	End		North Latitude	West Longitude			To	From	To	From				
22PC	10/14/04	11/11/04	763.0	36° 42' 15.090"	116° 25' 05.906"	2848.8	472	510.0	579.8	505.2	585.1	Alluvium	PVC	585.3	2 3/8
								665.4	755.0	659.2	763.0			760.5	
13P	6/16/05	7/28/05	1559.0	36° 44' 39.866"	116° 30' 50.235"	2937.5	433	426.0	466.0	419.0	471.0	Tertiary Tuff	PVC	476.1	2 3/8
24PA	1/25/06	1/28/06	152.0	36 42' 15.777"	116 26' 52.258"	2788.9	N/A[c]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
24PB	1/29/06	3/26/06	1394.1	36° 42' 15.777"	116° 26' 52.692"	2788.8	404	729.2	769.9	723.1	776.9	Tertiary Tuff	SS	1176.6[e]	2 3/8
								866.4[d]	870.5[d]	865.3	873.7				
								1145.2[e]	1149.4[e]	1143.8	1153.6				
33P	N/A	N/A	657.0	36° 39' 38.210"	116° 29' 45.814"	2570.1	204	210.8	249.9	205.0	254.0	Alluvium	PVC	260.1	1 2/3
								484.5	523.6	476.0	528.0	Alluvium		533.8	1 2/3
								600.9	640.0	591.0	657.0	Alluvium		650.2	1 2/3
32P	3/28/06	4/10/06	1000.0	36° 38' 21.544"	116° 29' 03.381"	2545.3	245	238.7	277.9	233.8	282.5	Alluvium	PVC	287.7	1 2/3
								463.7	483.3	458.4	489.4	Tertiary Basalt		493.0	1 2/3
								697.9	737.0	692.7	764.0	Tertiary Fluvial/ Alluvial Deposits		913.0	1 2/3

[a]Below ground surface.
[b]Feet above mean sea level.
[c]Not applicable.
[d]U-tube/injection line intervals from top of intake valve to the bottom of the U-tube.
[e]Casing below screen interval used as support casing for instrumentation.

NOTES:

24PA was abandoned due to drilling equipment lost in the borehole at approximately 152 feet.
Nye County completed 33P, which had been drilled previously by the U.S. Department of Energy.

Table 1.6-1
Phase V Quality Assurance Documents

Type	Number	Revision	Change	Title	Date
Work Plan	WP-5.0	4	N/A[a]	Phase V Drilling and Well Construction	5/31/05
	WP-5.0	5	N/A		12/15/05
	WP-5.0	6	N/A		3/6/06
	WP-6	1	N/A	Early Warning Drilling Program Geophysical Logging Work Plan	5/31/01
	WP-8.0	4	1	Sample Management	11/30/05
Technical Procedure	TP-7.0	3	N/A	Drill Site Management	9/30/02
	TP-8.0	5	N/A	Field Collection, Logging, and Processing of Borehole Geologic Samples	11/15/03
	TP-11.0	0	N/A	Borehole Geophysical Logging Data Identification and Acceptance	8/28/02
Test Plan	TPN-5.3	0	N/A	Construction of Sonic Corehole NC-EWDP-22PC	9/10/04
	TPN-5.3	1	N/A	Construction of Sonic Corehole NC-EWDP-22PC	10/13/04
	TPN-5.4	0	N/A	Data Collection at the U.S. Department of Energy Volcanic Hazard Boreholes in the Vicinity of Lower Fortymile Wash	11/7/05
Procedure	N/A	Version 1	N/A	Procedures for the Nye County NWRPO Rock Hydrologic Testing Laboratory	3/26/04
	N/A	Version 2	N/A	Procedures for the Nye County NWRPO Rock Hydrologic Testing Laboratory	6/11/04

[a]Not applicable.

Table 2.1-1
Summary of Drilling Equipment Used in Phase V Boreholes

Well Name	Drilling Method			Dual-Wall Pipe Specifications			Drill Bit Assembly			
	Type	Depth Interval (feet)		Diameter (inches)	Depth Interval (feet)		Type	Diameter (inches)	Depth Interval (feet)	
		From	To		From	To			From	To
13P	AR-RC[a]	0	1569	4.5	0	1569	Dual-wall casing; tricone bit; center return circulation.	6.5	0	1569
22PC	DR-CA[b]	0	460	7	0	460	Tricone bit; conventional return circulation.	14.75	0	61
								9.875	61	460
	Sonic[c]	460	763	3.5 (Single wall drill pipe)	460	763	Button bit; sonic core.	6.163	460	625
								4.716	625	763
24PA	AR-RC	0	58	5.5	0	152	Tricone bit; center return circulation.	6.75	0	58
	DR-CA	58	152				Hammer bit; reverse circulation (Symmetrix™ drilling system).	8.5	58	152
24PB	AR-RC	0	1395	5.5	0	1395	Tricone bit; center return circulation.	6.75	0	500
								6.5	500	1395
32P	AR-RC	0	1000	5.5	0	1000	Tricone bit; center return circulation.	6.5	0	1000
33P	N/A	No drilling - only cleanout and conditioning								

[a]Air-rotary reverse circulation.
[b]Dual rotary casing advance.
[c]Sonic coring and reaming.

Table 2.2-1
Summary of Drill Cuttings Sampling, Splitting, and Testing

Well Name	Geologic Material	Drilling Method	Drill Cuttings Sample Interval (feet)	Total Number of Drill Cuttings Samples	Number of Drill Cuttings Samples										
					Split (5-lb bag)				Nuclear Waste Repository Project Office (NWRPO) Laboratory Analysis						
					NWRPO Sample (Sent To YMP SMF[a])	DOE Sample (Sent To YMP SMF[a])	NWRPO Field Logging Sample	NWRPO Laboratory Sample	Gravimetric Water Content[b]	Soil Water Extract Electrical Conductivity[b]	Wet Sieve	Hydrometer	Specific Gravity	Atterberg Limits
13P	Alluvium[c]	AR-RC[d]	2.5	73	71	71	73	36	35	35	34	34	35	35
	Non-alluvium[e]		5	285	285	285	285	36	28	0	0	0	0	0
22PC	Alluvium	DR-CA[f]	2.5	184	184	184	184	93	93	66	66	15	16	16
24PA	Alluvium	AR-RC and DR-CA	2.5	61	61	61	61	30	30	30	30	30	30	30
24PB	Alluvium	AR-RC	2.5	161	161	161	161	81	81	81	81	80	81	81
	Non-alluvium		5	198	198	198	198	0	0	0	0	0	0	0
32P	Alluvium	AR-RC	2.5	132	132	132	132	52	52	52	52	52	52	52
	Non-alluvium		5	140	140	140	140	15	0	0	0	0	15	0
TOTAL				1234	1232	1232	1234	343	319	264	263	211	229	214

[a]U.S. Department of Energy Yucca Mountain Project Sample Management Facility.
[b]This test was not conducted on samples below the water table.
[c]Alluvium is defined herein as unconsolidated rock.
[d]Air-rotary reverse circulation.
[e]Non-alluvium is defined herein as consolidated rock.
[f]Dual rotary casing advance.

NOTES:
In 13P, 2.5-foot samples were collected in non-alluvium from 85 to 130 feet.
In 24PA, AR-RC methods were used from 0 to 57.5 feet; DR-CA methods were used from 57.5 to 151.8 feet.
In 32P, 5-foot samples were collected in alluvium from 260 to 400 feet and 2.5-foot samples were collected in non-alluvium from 400 to 500 feet.

Table 2.2-2
Summary of Sampling, Splitting, and Testing of Sonic Core from 22PC

Sample Type	Total Number of Samples	Density-Related Field Measure-ments	Number of Assigned Samples		Number of Nuclear Waste Repository Project Office (NWRPO) Laboratory Analysis					
			DOE YMP SMF[a]	NWRPO Laboratory	Gravimetric Water Content	Soil Water Extract EC[b]	Wet Sieve	Hydrometer	Atterberg Limits	Specific Gravity
Grab sample	151	NA[c]	0	151	151	10	151	151	151	151
Sonic core segment	204	204	204	NA	NA	NA	NA	NA	NA	NA
TOTAL	506	204	204	302	151	10	151	151	151	151

[a]U.S. Department of Energy Yucca Mountain Project Sample Management Facility.
[b]Electrical conductivity analyses not conducted on samples below the water table.
[c]Not applicable.

Table 2.4-1
Laboratory Test Methods

Test	Method[a]
Specific Gravity (grain density)	ASTM D-854-02. Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. In: 2003 *Annual Book of ASTM Standards,* Vol. 04.08, American Society for Testing and Materials.
Atterberg Limits	ASTM D-4318-00. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. In: 2003 *Annual Book of ASTM Standards*, Vol. 04.08, American Society for Testing and Materials.
Soil-Water Extract Electrical Conductivity	Rhoades, J.D. 1982. Soluble Salts—Extracts at Soil/Water Ratios of 1:1 and 1:5, Electrical conductivity of saturation extract. In: Page, A.L. (ed), *Methods of Soil Analysis,* Part 2, Chemical and Microbiological Properties (2nd ed.), American Society of Agronomy, Chapter 10, pp. 169-170 and 172-173.
Gravimetric Water Content	ASTM D-2216-98. Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. In: 2003 *Annual Book of ASTM Standards,* Vol. 04.08, American Society for Testing and Materials.
Wet Sieve Analysis	ASTM D-1140-00. Standard Test Methods for Amount of Material in Soil Finer Than the No. 200 (75 µ) Sieve (Method B for wet sieve analysis). In: 2003 *Annual Book of ASTM Standards,* Vol. 04.08, American Society for Testing and Materials.
Hydrometer Analysis (silt/clay break)	ASTM D-422-63 (Re-approved 1998). Standard Test Method for Particle Size Analysis of Soils. In: 2003 *Annual Book of ASTM Standards,* Vol. 04.08, American Society for Testing and Materials.

[a]Method used by Nuclear Waste Repository Project Office Rock Hydrologic Testing Laboratory.

Table 2.5-1
Description of Types and Applications of Geophysical Logs

Log Name	Suite	Description	Application
Caliper	Open-hole	Borehole diameter	Provides borehole correction (e.g., wash-out zones) for other logs, borehole volume for well completions, and possible identification of fractures and contacts.
Density	Drill-string, open-hole, and well completion	Tool output altered by formation materials[a]	Yields density information on adjacent borehole wall formation material; identifies washout zones.
Deviation	Drill-string, open-hole, and well completion	Deviation of borehole from vertical	Permits calculation of true elevations for lithologic contacts, well screens, water levels, and other borehole depth measurements.
Fluid Electrical Conductivity	Open-hole	Borehole and injection fluid conductivities	Estimates relative amount of dissolved salts in borehole fluid and may provide an indication of inflow in open boreholes.
Fluid Resistivity	Open-hole	Borehole fluid resistivity and conductivity	Estimates relative amount of dissolved salts in borehole fluid and may provide an indication of inflow in open boreholes.
Fluid Temperature (Temperature)	Drill-string, open-hole, and well completion	Borehole fluid temperature	Helps identify locations of inflow/outflow in open boreholes, and geothermal gradient in cased boreholes.
Gamma (Natural Gamma)	Drill-string, open-hole, and well completion	Gamma radiation from natural sources in formation and in borehole drilling fluids	Helps identify lithology and stratigraphic unit correlation; may respond to differences in clay content.
Neutron (Moisture)	Drill-string, open-hole, and well completion	Tool output altered by water in formation and borehole[b]	Identifies moisture content changes in the unsaturated zone and/or indicates porosity changes in the saturated zone.
Optical Televiewer	Open-hole	360° image of reflection of borehole wall via prism mirror and camera	May help detect fractures, thin beds, and bedding dip; provides caliper and deviation data.
Resistivity (Formation) (R8, R16, R32, or R64)	Open-hole	Apparent formation resistivities at different distances from the borehole	Helps identify lithology and stratigraphic unit correlation; indicates relative changes in water quality.
Single-Point Resistivity (SPR)	Open-hole	Resistivity of borehole fluids and adjacent formation	Helps identify lithology and changes in borehole fluid composition.
Sonic	Open-hole	Compressional wave velocity through fluids and formations	Helps define changes in porosity and lithology; indicates of fractures.
Spectral Gamma	Drill-string, open-hole, and well completion	Radiation emitted by uranium, thorium and potassium	Can help identify minerals containing uranium, thorium and potassium.
Spontaneous Potential	Open-hole	Electrical potential between fluids in borehole and adjacent formation	Helps identify lithology, clay, and shale content and relative changes in formation water quality.

Source: Modified from Keys (1990) and Telford and others (1990).

[a]Geophysical Logging Services density tool contains no radioactive source; Century Geophysical tool uses a cesium-137 source.
[b]Geophysical Logging Services moisture tool contains no radioactive source; Century Geophysical tool uses a directed americium-beryllium source.

Table 2.5-2
Summary of Phase V Geophysical Logs

Well Name	Date	Suite	Interval Logged (feet)		Log Name													Record Index Designator (RID) Number	Company Name	Comments
					Gamma	Density	Spectral Gamma	Neutron (Moisture)	Fluid Temperature	Resistivity (SPR, R8-R64)	Fluid Resistivity	Fluid Electrical Conductivity	Spontaneous Potential	Caliper	Acoustic Velocity (Sonic)	Optical Televiewer	Deviation			
13P	7/24/05	Drill-string	0	1,558	X		X		X								X	6698	GLS	Run in 4.5-inch dual-wall drill pipe inside 6.5-inch borehole with 57.8 feet of 8.625-inch surface casing.
	7/24/05	Open-hole	140	709	X				X	X	X		X	X				6788	GLS	Run in open borehole below drill string set at 140 feet. Borehole conditions did not permit logging below 709 feet. Conductivity and induction resistivity logs run for evaluation purposes. Data are contained in RID6698.
	7/24/05	Open-hole	0	140												X		6790	GLS	Video run to observe bridging in borehole during geophysical logging.
	8/4/05	Drill-string	0	1,512.4	X	X		X										6773	Century	Run in 5.5-inch steel casing inside 6.5-inch borehole with 57.8 feet of 8.625-inch surface casing.
	9/21/05	Well-completion	0	477	X		X		X		X						X	6794	GLS	Run in 2-inch schedule 80 PVC well casing with 57.8 feet of 8.625-inch surface casing.
	9/21/05	Well-completion	0	464.7												X		6790	GLS	Video run in 2-inch schedule 80 PVC well casing during completion logging.
22PC	11/11/04	Drill-string	1.2	759	X	X		X										6783	Century	Run in 5.5-inch steel casing within multiple telescoping casings and 460 feet of 10.75-inch surface casing.
	11/12/04	Drill-string	0	762.5	X	X	X	X	X	X	X						X	6787	GLS	Run in sonic core casings within multiple telescoping casings and 460 feet of 10.75-inch surface casing.
	11/17/04	Well-completion	346	710										X				6573	GLS	Caliper run in 2-inch schedule 80 PVC casing to inspect it for cracks or separation of joints.

Well Name	Date	Suite	Interval Logged (feet)		Log Name													Record Index Designator (RID) Number	Company Name	Comments
					Gamma	Density	Spectral Gamma	Neutron (Moisture)	Fluid Temperature	Resistivity (SPR, R8-R64)	Fluid Resistivity	Fluid Electrical Conductivity	Spontaneous Potential	Caliper	Acoustic Velocity (Sonic)	Optical Televiewer	Deviation			
	11/17/04	Well-completion	0	698												X		6567	GLS	Video run in 2-inch schedule 80 PVC casing to inspect it for cracks or separation of joints.
24PB	2/14/06	Drill-string	0	773.4													X	6868	GLS	Run in 5.5-inch dual-wall drill pipe with 467.3 feet of 10-inch surface casing.
24PB	2/23/06	Open-hole	0	1,395	X					X	X		X	X				6865	GLS	Run in 6.5-inch open borehole with 467.3 feet of 10-inch surface casing.
24PB	3/8/06	Open-hole	0	480												X		6870	GLS	Video log run to observe obstruction in borehole at 480 feet.
24PB	3/8/06	Drill-string	0	1,375													X	6870	GLS	Run in 5.5-inch dual-wall drill pipe with 467.3 feet of 10-inch surface casing.
24PB	3/8/06	Open-hole	0	1,000												X		6870	GLS	Video log run in 6.5-inch open borehole with 467.3 feet of 10-inch surface casing.
24PB	3/8/06	Open-hole	387	1,392											X			6870	GLS	Run in 6.5-inch open borehole with 467.3 feet of 10-inch surface casing.
24PB	3/9/06	Open-hole	464.5	1,395												X	X	6871	GLS	Run in open borehole with 467.3 feet of 10-inch surface casing.
24PB	4/9/06	Well-completion	0	1,175	X		X		X		X						X	6904	GLS	Run inside 2-inch stainless steel casing with 467.3 feet of 10-inch surface casing.
24PB	2/24/06 - 2/28/06	Open-hole	480	1,385 (maximum)								X						6866	GLS	Run in 6.5-inch open borehole with 467.3 feet of 10-inch surface casing. Multiple logs were run as part of Fluid Electrical Conductivity (FEC) testing. Primary FEC data sets.
24PB	2/24/06 - 2/28/06	Open-hole	480	1,386 (maximum)	X				X	X	X		X					6867	GLS	Run in 6.5-inch open borehole with 467.3 feet of 10-inch surface casing. Conventional open-hole logging data collected in conjunction with FEC data.

Well Name	Date	Suite	Interval Logged (feet)		Log Name													Record Index Designator (RID) Number	Company Name	Comments
					Gamma	Density	Spectral Gamma	Neutron (Moisture)	Fluid Temperature	Resistivity (SPR, R8-R64)	Fluid Resistivity	Fluid Electrical Conductivity	Spontaneous Potential	Caliper	Acoustic Velocity (Sonic)	Optical Televiewer	Deviation			
32P	4/10/06	Open-hole	0	995	X				X	X	X		X	X				6901	GLS	Run in 6.5-inch open borehole with 53.5 feet of 8.625-inch surface casing.
	4/19/06	Open-hole	0	775												X		6903	GLS	Video run in open borehole with 53.5 feet of 8.625-inch surface casing.
	4/19/06	Open-hole	50	775												X		6903	GLS	Optical televiewer run in open borehole with 53.5 feet of 8.625-inch surface casing.
	4/11/06 - 4/12/06	Open-hole	320	960 (maximum)								X						6902	GLS	Run in open borehole with 297.3 feet of temporary steel casing and 53.5 feet of 8.625-inch surface casing. Multiple logging runs made as part of FEC testing. Primary FEC data sets.
33P	2/27/06	Drill-string	0.6	652.7	X	X		X										6862	Century	Run in 5.5-inch steel casing inside 6.25-inch borehole with 55 feet of 10.875-inch surface casing.
	2/28/06	Open-hole	0	637	X		X		X	X	X		X	X	X		X	6864	GLS	Run in 6.25-inch open borehole with 58.9 feet of 10-inch surface casing.

Table 3.1-1
Summary of Well Elevations and Water Levels

Well Name	Top of Casing Elevation[a] (feet amsl[b])	Original Ground Surface Elevation[c] (feet amsl)	Water Level Measurement Date	Groundwater Elevation[d] (feet amsl)	Depth to Water[d] (feet)
22PC Shallow	2850.6	2848.8	5/30/06	2378.3	472.3
22PC Deep	2850.6	2848.8	5/30/06	2378.3	472.3
13P	2940.5	2938.5	6/1/06	2507.8	432.6
24PB	2790.6	2788.7	10/30/06	2385.7	404.8
32P Shallow	2547.3	2545.3	6/2/06	2302.2	245.1[e]
32P Intermediate	2547.3	2545.3	6/2/06	2299.9	247.4
32P Deep	2547.3	2545.3	6/2/06	2300.2	247.1
33P Shallow	2572.2	2570.2	6/2/06	2365.1	207.1
33P Intermediate	2572.2	2570.2	6/2/06	2368.4	203.8
33P Deep	2572.2	2570.2	6/2/06	2368.2	204.0

[a]Elevations provided by the Yucca Mountain Project and based on a Global Positioning System.
[b]Above mean sea level.
[c]Based on GPS survey elevation at top of casing, minus casing stickup.
[d]Groundwater elevation and depth-to-water data have not been corrected for borehole deviation.
[e]32P Shallow screen became plugged with bentonite from uphole completion materials subsequent to this measurement.

Table 4.1-1
Summary of Censored Geologic, Drilling, and Laboratory Data

Well Name	Sample Type	Field Logging Data Depth Interval (feet below ground surface [bgs])				Laboratory Test Data Depth Interval in Alluvium (feet bgs)					Calculation of Dry Bulk Density Per Core Run in Table 4.2-1 (feet, bgs)[e]
		Particle Size Distribution Data[a]	Samples Not Recovered and Logged [b]	Sample Bulk-Density-Related Data[c]		Wet Sieve PSD	Hydrometer PSD	Atterberg Limits	Gravimetric Water Content	Electrical Conductivity	
		Alluvium	Alluvium	Alluvium	Non-Alluvium						
13P	Drill Cuttings		132.5 – 162.5	0-87	87 - 135						
				162.5 – 260	260 - 320						
					340 - 545						
22PC	Drill Cuttings			0 - 215							
				400 - 460							
	Sonic Core Grab Samples										460.0 – 463.7, 560.2 – 565.4, 565.4 – 568.1, 568.1 – 578.1, 625.2 – 632.1, 678.1 – 687.4, 688.1 – 690.1, 759.5 – 762.8
24PA	Drill Cuttings			0 – 151.8							
24PB	Drill Cuttings			0 - 405	405 - 420				412.5-415[d]		
32P	Drill Cuttings	247.5 – 260[d]		0 - 260		247.5 – 260[d]	247.5 – 260[d]	247.5 - 260[d]	247.5 - 260[d]	247.5 - 260[d]	
		670 – 675[d]				950 – 950.1[f]	950 – 950.1[f]				
		690 – 940[d]				970 – 970.1[f]	970 – 970.1[f]				
						990 – 990.1[f]	990 – 990.1[f]				

[a] Sample intervals are beneath the water table; particle size distribution data should not have been recorded.
[b] Samples not recovered over this depth interval. Logging data could not be recorded.
[c] A significant amount of sample was not collected and weighed over each drill run.
[d] Special precautions to collect fines were not taken during sampling; samples are not considered representative.
[e] Problems with fill material, recovery, and/or water content data.
[f] Indurated non-alluvium samples; tests should not have been performed.

Table 4.2-1
Saturated Formation Dry Bulk Densities Calculated by Core Run for NC-EWDP-22PC

Core Barrel Diameter (inches)	Core Run Number	Depth Interval (feet bgs)		Average Dry Bulk Density (g/cm^3)		Lost Core (feet)	Calculated Porosiity for Core Runs with less than 2 feet of lost core (cm^3/cm^3)	Comments
		From	To	All Core Runs	Core Runs with less than 0.2 feet of lost core			
6.16	1	460.0	463.7			0		Censored - due to problems coring, causing fill to be introduced into sample
	2	463.7	471.4	1.79	1.79	0	0.29	
	3	471.4	481.8	1.61	1.61	0	o.36	
	4	483.7	491.8	1.75		0.3		
	5	492.1	494.2	1.86	1.86	0	0.27	
	6	494.2	504.2	1.79	1.79	0	0.29	
	7	504.2	509.1	1.77	1.77	0	0.30	
	8	509.1	519.2	1.42	1.42	0.1	0.44	
	9	520.4	526.5	1.82		1.1		
	10	526.5	533.1	1.57	1.57	0	0.38	
	11	533.1	534.1	1.59	1.59	0	0.37	
	12	534.1	544.0	1.64	1.64	0.2	0.35	
	13	544.2	550.2	1.50	1.50	0	0.41	
	14	550.2	560.2	1.57	1.57	0	0.38	
	15	560.2	565.4			0		Censored - not enough water content data available
	16	565.4	568.1			0		Censored - recovered less material than expected
	17	568.1	578.1			0		Censored - recovered less material than expected
	18	578.1	585.3	1.66	1.66	0	0.34	
	19	585.3	595.0	1.67	1.67	0	0.34	
	20	595.0	599.6	1.77	1.77	0	0.30	
	21	599.6	606.3	1.52		0.3		
	22	606.6	615.4	1.71	1.71	0.1	0.32	
	23	615.5	625.2	1.48		1.5		
			Average	1.66	1.66		0.34	
4.5	24	625.2	632.1			0.2		Censored - due to error in water content measurement (0.7)
	25	632.1	635.8	1.54		0.3		
	26	636.1	641.3	1.84		0.3		
	27	641.6	648.4	1.74	1.74	0	0.31	
	28	648.4	656.8	1.74	1.74	0	0.31	
	29	656.8	661.2	1.65	1.65	0	0.35	
	30	661.2	668.0	1.67	1.67	0	0.34	
	31	668.0	673.2	1.49		0.7		
	32	673.9	677.3	1.73		0.8		
	33	678.1	687.4			0.7		Censored - not enough water content data available
	34	688.1	690.1			0.2		Censored - not enough water content data available
	35	690.3	699.2	1.67	1.67	0	0.34	
	36	699.2	704.9	1.58		1.2		
	37	706.1	709.0	1.71	1.71	0	0.32	
	38	709.0	718.7	1.60		0.3		
	39	719.0	720.9	2.04		0.6		
	40	721.5	728.8	1.96		1.1		
	41	729.9	733.2	1.74		1.6		
	42	734.8	739.6	1.93		0.3		
	43	739.9	745.9	1.72		1.1		
	44	747.0	754.9	1.62	1.62	0	0.36	
	45	754.9	759.5	1.56	1.56	0	0.38	
	46	759.5	762.8			0.2		Censored - due to problems coring, causing fill to be introduced into sample
			Average	1.71	1.67		0.34	

Table 4.2-2
Saturated Formation Dry Bulk Density Data for 19PB Sonic Core Runs

Core Barrel Diameter (inches)	Core Run Number	Depth Interval (feet below ground surface)		Average Dry Bulk Density (grams per cubic centimeter [g/cm^3])		Lost Core (feet)
		From	To	All Core Runs	Core Runs with Less than 0.2 Feet of Lost Core[a]	
6.16	7	371.0	375.4	1.78		0.3
	8	375.7	378.4	1.98		0.6
	10	381.3	386.1	1.85	1.85	0.0
	11	386.1	396.1	1.85	1.85	0.0
	12	396.3	406.1	1.74	1.74	0.2
	13	406.3	416.1	1.84	1.84	0.0
	14	416.2	424.4	1.80	1.80	0.1
	15	424.6	429.3	1.78	1.78	0.2
	16	429.3	434.1	1.81		1.1
	17	435.5	445.1	1.76		1.9
	18	445.3	447.9	1.77		0.5
	20	450.6	460.7	1.85	1.85	0.0
	21	460.7	466.3	1.66	1.66	0.2
	22	466.5	476.2	1.93	1.93	0.2
	23	476.4	478.0	2.11	2.11	0.2
	24	478.2	481.9	1.78		1.0
	25	481.9	489.4	1.57	1.57	0.2
	26	489.6	494.6	1.85		1.6
	27	495.2	499.0	1.72		0.7
	28	500.1	510.0	1.67		0.4
	29	510.0	519.4	1.57	1.57	0.0
	30	519.4	522.7	1.75		1.7
Average Dry Bulk Density				**1.79**	**1.80**	
4.5	31	524.4	527.1	1.75	1.75	0.0
	33	528.8	531.1	2.24		0.9
	34	533.0	534.1	2.34		1.3
	35	534.4	543.1	1.85	1.85	0.2
	36	543.3	545.7	2.23		1.0
	37	545.9	549.6	1.83		1.9
	38	550.7	553.3	1.79		1.0
	39	553.7	557.8	2.17		2.0
	40	559.6	560.4	2.95		0.5
	42	563.3	565.9	1.60	1.60	0.0
	43	565.9	567.1	2.04		1.3
	44	568.4	570.9	2.39		0.8
	45[b]	571.7	578.3	1.78	1.78	0.0
	46	578.3	581.8	2.15	2.15	0.1
	47	581.9	587.4	1.71		0.9
	48	588.3	591.7	1.86	1.86	0.2
	49	591.9	601.0	1.88		0.9
	50	601.9	605.2	1.86	1.86	0.0
	51	605.2	615.3	1.85	1.85	0.0
	52	615.3	619.9	1.64	1.64	0.0
	54	622.0	627.9	1.72		0.5
	55	628.4	633.8	1.81	1.81	0.2
Average Dry Bulk Density				**1.97**	**1.82**	

[a]Shading indicates excluded core run.
[b]Last core segment deleted from density calculation due to field error in mass.

Table 5.1-1
Alluvium Laboratory Core Summary Statistics for 22PC
(460 to 762.8 Feet)

Parameter	Depth Interval Containing Data (feet)		Number of Samples in Depth Interval	Minimum	Maximum	Average	Standard Deviation	Coefficient of Variation
	From	To						
Electrical Conductivity (µmhos/cm)	460	473.2	10	121	327	194	74	38
Wet Sieve Gravel (%)	460	762.8	151	16.0	71.7	40.4	10.3	25
Wet Sieve Sand (%)	460	762.8	151	23.0	73.3	44.0	8.2	19
Wet Sieve Fines (%)	460	762.8	151	5.4	34.8	15.6	5.4	34

Table 5.2-1
Laboratory Particle Size Distribution Data Summary Statistics
for Phase V Drill Cuttings Samples, except those from 22PC

Well Name	Depth Interval Containing Data (feet)		Number of Samples in Depth Interval	Wet Sieve Parameter	Summary Statistics				
	From	To			Minimum (%)	Maximum (%)	Average (%)	Standard Deviation (%)	Coefficient of Variation
13P	2.5	260	34	Gravel	0	54	21	12	60
				Sand	17	80	60	13	22
				Fines	2	84	19	19	95
24PA	2.5	150	30	Gravel	9	65	35	15	42
				Sand	33	82	59	13	22
				Fines	1	10	5	2	43
24PB	2.5	150	30	Gravel	16	73	39	13	34
				Sand	25	80	56	12	21
				Fines	1	10	6	2	37
24PB	2.5	405	81	Gravel	6	79	33	14	43
				Sand	19	88	58	11	19
				Fines	1	34	10	6	62
32P	2.5	990.1	67	Gravel	0	54	23	12	54
				Sand	13	92	63	12	19
				Fines	3	87	14	15	111

Table 5.2-2
Laboratory Particle Size Distribution Data
Summary Statistics for Selected Phase III, IV and V Drill Cuttings Samples

Well Name	Number of Samples in Depth Interval	Depth Interval Containing Data (feet)		Wet Sieve Parameter	Summary Statistics				
		From	To		Minimum (%)	Maximum (%)	Average (%)	Standard Deviation (%)	Coefficient of Variation
22SA	92	2.5	460	Gravel	6	53	29	10	34
				Sand	36	90	57	9	16
				Fines	4	24	14	5	32
22PC	66	2.5	460	Gravel	0	71	45	12	27
				Sand	26	82	48	10	21
				Fines	2	25	7	3	50
24P	79	2.5	400	Gravel	6	47	27	10	36
				Sand	43	78	59	6	11
				Fines	3	36	14	7	53
24PB	81	2.5	405	Gravel	6	79	33	14	43
				Sand	19	88	58	11	19
				Fines	1	34	10	6	62

Table 5.3-1
Summary Statistics for Core from 22PC

Parameter	Depth Interval Containing Data (feet)		Number of Samples in Depth Interval	Minimum (%)	Maximum (%)	Average (%)	Standard Deviation (%)	Coefficient of Variation
	From	To						
Unsaturated Alluvium Geologic Logging Parameters for Core (460 to 471.4 Feet)								
Drilling Rate (feet/minute)	460	471.4	2	0.8	1.7	1.3	0.6	51
% Gravel (estimated)	460	471.4	9	13	64	42	16	38
% Sand (estimated)	460	471.4	9	29	61	42	10	25
% Silt (estimated)	460	471.4	9	2	8	5	2	37
% Clay (estimated)	460	471.4	9	5	18	10	4	42
% Fines (estimated)	460	471.4	9	7	26	16	6	39
Saturated Alluvium Geologic Logging Parameters for Core (471.4 to 762.8 Feet)								
Drilling Rate (feet/minute)	471.4	759.5	43	0.2	3.2	1	0.7	67
% Gravel (estimated)	471.4	759.5	139	8	70	39	12	32
% Sand (estimated)	471.4	759.5	139	24	77	48	11	22
% Silt (estimated)	471.4	759.5	139	1	11	5	2	47
% Clay (estimated)	471.4	759.5	139	1	20	9	4	46
% Fines (estimated)	471.4	759.5	139	2	31	13	6	45
Unsaturated Alluvium Laboratory Parameters for Core (460 to 471.4 Feet)								
Gravimetric Water Content (g/g)	460	471.4	9	0.02	0.07	0.042	0.016	37
Electrical Conductivity (µmhos/cm)	460	471.4	9	121	327	192	78	41
Wet Sieve Gravel (%)	460	471.4	9	24.3	71.7	45.6	14.6	32
Wet Sieve Sand (%)	460	471.4	9	23	59.9	43	11.2	26
Wet Sieve Fines (%)	460	471.4	9	5.4	17.9	11.3	4	35
Saturated Alluvium Laboratory Parameters for Core (471.4 to 762.8 Feet)								
Wet Sieve Gravel (%)	471.4	762.8	142	16	64.4	40.1	9.9	25
Wet Sieve Sand (%)	471.4	762.8	142	26.7	73.3	44	8	18
Wet Sieve Fines (%)	471.4	762.8	142	6	34.8	15.9	5.3	34

Table 5.3-2
Summary Statistics for Drill Cuttings from 24PB

Parameter	Depth Interval Containing Data (feet)		Number of Samples in Depth Interval	Minimum (%)	Maximum (%)	Average (%)	Standard Deviation (%)	Coefficient of Variation
	To	From						
Unsaturated Alluvium Geologic Logging Parameters for Drill Cuttings (0 to 405 Feet)								
Drilling Rate (feet/minute)	0	405	162	0.6	1.8	1.1	0.3	28
% Gravel (estimated)	0	405	161	1	97	34	16	45
% Sand (estimated)	0	405	161	2	84	56	12	21
% Silt (estimated)	0	405	156	0	12	5	2	52
% Clay (estimated)	0	405	148	0	17	5	4	79
% Fines (estimated)	0	405	156	0	29	10	6	64
Unsaturated Alluvium Laboratory Parameters for Drill Cuttings (0 to 405 Feet)								
Gravimetric Water Content (g/g)	2.5	405	81	0.02	0.13	0.05	0.02	41
Electrical Conductivity (µmhos/cm)	2.5	405	81	74	1052	212	168	79
Wet Sieve Gravel (%)	2.5	405	81	6.3	78.8	32.6	14.3	44
Wet Sieve Sand (%)	2.5	405	81	19.2	87.7	57.7	11.2	19
Wet Sieve Fines (%)	2.5	405	81	1.3	33.8	9.6	6	62

Table 5.3-3
Summary Statistics for Drill Cuttings from 32P

Parameter	Depth Interval Containing Data (feet)		Number of Samples in Depth Interval	Minimum (%)	Maximum (%)	Average (%)	Standard Deviation (%)	Coefficient of Variation
	To	From						
Unsaturated Alluvium Geologic Logging Parameters for Drill Cuttings (0 to 260 Feet)								
Drilling Rate (feet/minute)	0	260	104	0.3	2.5	1.1	0.8	67
% Gravel (estimated)	0	260	103	11	60	26	10	36
% Sand (estimated)	0	260	103	38	82	68	9	13
% Silt (estimated)	0	260	101	0	7	2	1	53
% Clay (estimated)	0	260	103	1	9	4	2	46
% Fines (estimated)	0	260	103	1	16	6	3	46
Unsaturated Alluvium Laboratory Parameters for Drill Cuttings (0 to 260 Feet)								
Gravimetric Water Content (g/g)	2.5	260	52	0.02	0.35	0.053	0.044	84
Electrical Conductivity (µmhos/cm)	2.5	260	52	73	637	186	101	54
Wet Sieve Gravel (%)	2.5	260	52	14.4	53.5	27.8	9.3	33
Wet Sieve Sand (%)	2.5	260	52	44	78	63.7	7.4	12
Wet Sieve Fines (%)	2.5	260	52	2.5	16.2	8.5	3.5	41

Table 5.4-1
Alluvium Laboratory Core Summary Statistics for 22PC
(473.2 to 762.8 Feet)

Parameter	Depth Interval Containing Data (feet)		Number of Samples in Depth Interval	Minimum (%)	Maximum (%)	Average (%)	Standard Deviation (%)	Coefficient of Variation
	To	From						
Electrical Conductivity (µmhos/cm)			0					
Wet Sieve Gravel (%)	473.2	762.8	141	16	64.4	40.1	10	25
Wet Sieve Sand (%)	473.2	762.8	141	26.7	73.3	44	8	18
Wet Sieve Fines (%)	473.2	762.8	141	6	34.8	15.9	5.3	33

Table 5.4-2
Alluvium Laboratory Core Summary Statistics for 19PB
(368.5 to 633.1 Feet)

Parameter	Depth Interval Containing Data (feet)		Number of Samples in Depth Interval	Minimum (%)	Maximum (%)	Average (%)	Standard Deviation (%)	Coefficient of Variation
	To	From						
Electrical Conductivity (µmhos/cm)			0					
Wet Sieve Gravel (%)	368.5	631.1	201	3.4	83.4	40.7	17.9	44
Wet Sieve Sand (%)	368.5	631.1	201	14.8	75.6	45.1	14.0	31
Wet Sieve Fines (%)	368.5	631.1	201	.06	41.3	14.3	6.8	47

Table 5.4-3
Depth-Weighted Percent Fines in Saturated Completion Zones in Sonic Coreholes

Sonic Corehole	Completion Zone	Depth Interval of Completion Zone (ft, bgs)	Thickness of Completion Zone (ft)	Depth Weighed Average Fines Content in Completion Zone Interval (%)	Depth Weighted Average Fines Content over all Zones (%)
22PC	Upper Bentonite Seal	471.4 - 505.0	33.6	13.9	
	Upper Sandpack	505.0 - 585.3	80.3	11.8	
	Lower Bentonite Seal	585.3 - 659.5	74.2	16.8	
	Lower Sandpack	659.5 - 759.5	100	17.9	15.4
19PB	Upper Sandpack	368.5 - 401.1	32.6	12.2	
	Upper Bentonite Seal	401.1 - 506.0	104.9	10.8	
	Lower Sandpack	506.0 - 547.5	39.7	13.8	
	Lower Bentonite Seal	547.5 - 633.8	88.1	22.0	14.8

Table 6.2-1
Summary of Censored Geophysical Logs

Well Name	Record Index Designator (RID) Number	Log Type	Interval (feet)		Reason for Censoring
			From	To	
13P	6773	Compensated Neutron	0	430	Tool appears to not respond correctly in the unsaturated zone.
	6698	Fluid Temperature	0	446.5	Fluid temperature data only valid below the top of the water table.
	6788	Fluid Temperature	0	434	Fluid temperature data only valid below the top of the water table.
22PC	6783	Compensated Density	8.9	444	Tool appears to not respond correctly in the unsaturated zone.
		Compensated Neutron	8.9	475	Tool appears to not respond correctly in the unsaturated zone.
	6787	Moisture	0	463	Moisture data are only valid below the top of the water table.
		Fluid Resistivity	0	488	Fluid resistivity data only valid below the top of the water table.
		Fluid Temperature	0	474	Fluid temperature data only valid below the top of the water table.
24PB	6904	Fluid Resistivity	405	1175	Log run inside steel casing - resistivity data invalid.
		Fluid Temperature	0	405	Fluid temperature data only valid below the top of the water table.
32P	7188	Compensated Neutron	0.6	245	Tool appears to not respond correctly in the unsaturated zone.
	7194	Fluid Resistivity	0	975	Log run inside steel casing - resistivity data invalid.
	7199	Gamma	0	910	Tool not functioning correctly.
33P	7198	Gamma	0	653	Tool not functioning correctly.