High-Resolution Characterization of Comingled Contaminants in the Deep Vadose Zone, Hanford Site, Washington -17387

Sarah Springer*, Bruce Williams *, Farah Elloy *, James P. Hanson **

*CH2M Plateau Remediation Company, Richland, WA
** Department of Energy, Richland Operations Office

Abstract

The contaminated deep vadose zone in the Central Plateau of the Hanford Site in Washington state presents a unique challenge to remediation. The Comprehensive Environmental Response, Compensation, and Liability Act, commonly known as the CERCLA project responsible for addressing these deep contaminants is designated as the 200-Deep Vadose Zone Operable Unit (DV-1 project). The vadose zone is 55-82 meters (180-270 feet) thick and is contaminated with both radiological and chemical contaminants from multiple historical waste streams. The mobile contaminants from this waste are still present in the deep vadose zone and pose a potential threat to the groundwater. Characterizing the nature and extent of the comingled mobile contaminants is an important step before assessing possible remedial alternatives.

One factor controlling the migration and distribution of subsurface contaminants is the lithologic heterogeneity of the vadose zone sediments. A sampling plan for the DV-1 project includes continuous sediment core collection and analysis to identify key lithologic factors (i.e., small-scale bedding and structural features) that act as barriers, preferential pathways or conduits for mobile contaminants migrating through the vadose zone.

Over six hundred meters (2,000 feet) of intact sediment core from 26 boreholes were collected in 1.5 meters (5 feet) long, 10 centimeter (4-inch) diameter segments. These intact sediment samples provide significant improvement in the level of detail and understanding of mechanisms and features controlling contaminant distribution that is not possible with traditional homogenized drill cuttings or conventional split-spoon samples. Detailed geological descriptions and photographs of the intact core are correlated to high-resolution geophysical logs which aid in the development of a comprehensive contaminant distribution profile of the borehole. These lithologic interpretations are used to define specific depth intervals for sampling based on changes in moisture, lithology, and elevated gamma radiation. The selected samples are analyzed for contaminants of concern, geochemical parameters, and hydraulic properties.

Significant lithologic features observed in the intact cores include sharp contact boundaries to graded bedding, iron-oxide and carbonate cementation, silty laminations, clastic dike intrusions, and soft sediment deformation. Preliminary geologic logs integrated with the sample analysis indicate features that correlate to

the variable distribution of contaminants both laterally and vertically. Integration of measured hydraulic parameters to lithologic units in individual borehole profiles provide key inputs for more precise geoframework and vadose zone flux models supporting the DV-1 project.

Introduction

The U.S. Department of Energy and contractor CH2M HILL Plateau Remediation Company are addressing contamination deep beneath the central plateau of the Hanford Site in southeast Washington state. The 200-DV-1 Operable Unit (OU) is composed of 43 historical waste sites that are located in three distinct geographical areas within the Hanford Site Central Plateau, including: the B Complex Area, the T Complex Area and the S Complex Area. The 200-DV-1 OU was created in 2010 to support remedy selection for waste sites with deep vadose contamination. The deep vadose zone begins at a depth of approximately 50 feet below ground surface (bgs) and extends to the water table at depths ranging from approximately 55-82 meters (180 to 270 feet) below ground surface (bgs). The disposal of hazardous liquid waste associated with the plutonium separation process and the subsequent contamination of the deep vadose zone is a significant issue because it represents a potential source for continued release of mobile contamination to the groundwater. The deep vadose zone is being characterized by drilling boreholes and collecting soil samples at selected depths. The primary contaminants in the deep vadose zone driving a long-term risk are uranium and technetium-99 because of their abundance, high concentration, mobility, difficulty in predicting subsurface behavior, and long half-lives. Additional mobile contaminants of long-term concern are iodine-129, chromium, cyanide and nitrate (SGW-60265).

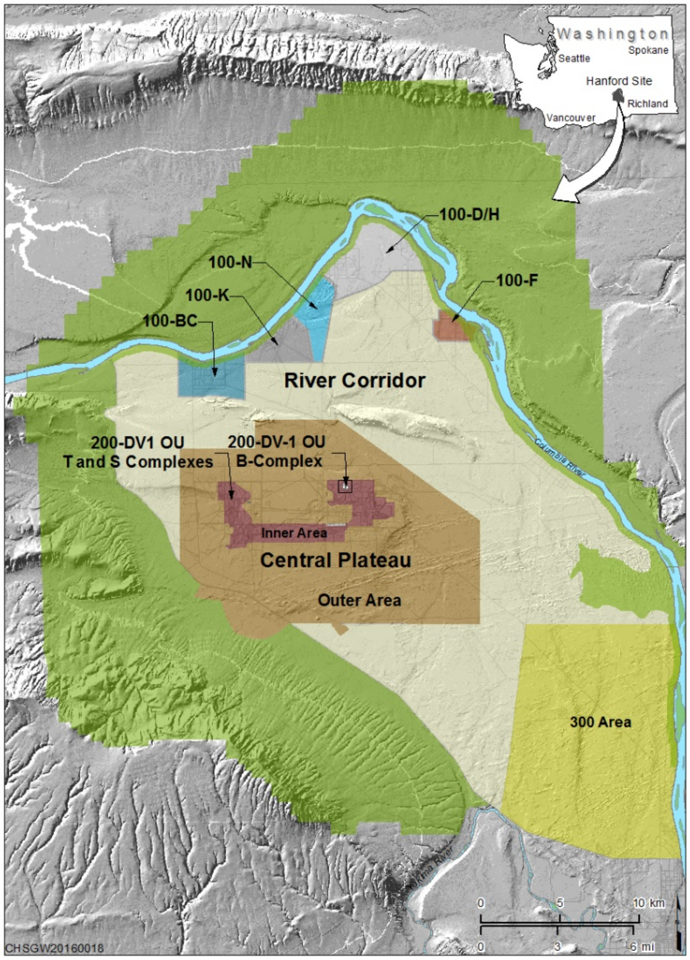

Figure 1: 200 DV-1 location within Hanford Site, Washington State

In 2015-2016, 26 boreholes were drilled for the DV-1 project in order to characterize the extent and distribution of the mobile contamination. An important component of this characterization effort is the detailed examination of subsurface strata through a variety of direct and indirect measurements. Studies of the lithologies withinthe deep vadose zone and comparison to depth specific analytical results extracted from soil sampling will help understand how lithologic heterogeneities may be controlling contaminant migration through the vadose zone.

The DV-1 project is located in the Central Plateau of the Hanford Site, which is defined by the topographically elevated region formed during the Pleistocene Missoula paleo-floods (Bjornstad, 2002). These ancestral floods deposited thick sequences of unconsolidated silt, sand and gravel known as the Hanford formation onto older Plio-Pleistocene sediments defined as the Cold Creek unit and Ringold Formation creating a giant mega flood bar. The unique glacial-fluvial depositional setting of these sediments created a series of erosional unconformities that can be very challenging to model or predict in the subsurface. All of the DV-1 waste sites are located within the Central Plateau on this ancestral flood bar.

The 55-82 meter (180-270 feet) thick vadose zone extends through the entire Hanford formation and the upper portion of the Cold Creek and Ringold Formation. The Hanford formation is the thickest vadose zone interval on the Central Plateau and comprises broadly mappable facies consisting of silt-, sand- and gravel-dominated sediment layers. The Hanford sediments typically have the highest permeability and hydraulic conductivity compared to the older more consolidated Cold Creek unit and Ringold Formation. The vadose zone overlies an unconfined aquifer system that is primarily contained within older Cold Creek and Ringold Formation sediments composed of semi- to- unconsolidated silt, sand, and gravel. Basalt bedrock or Ringold Formation mud (clay) units form the base of the unconfined aquifer system at the Hanford Site (PNNL-13858). Many groundwater contaminant plumes originated from past liquid waste disposal to cribs, ponds and ditches in the Central Plateau waste complex. Some plumes continue to receive residual contamination migrating through the overlying vadose zone.

Methods and Results

In order to achieve a high resolution view of the deep vadose zone lithology, standard borehole logging methods could not be applied. In general, boreholes at the Hanford Site are logged by onsite geologists describing texture and composition of soils via grab samples from drill cuttings every 1.5-3 meters (5-10 feet). Different drilling methods yield varying degrees of representative grab samples. The sonic drilling method employed for the DV-1 project permitted collection of continuous intact core samples through the majority of each borehole. The intact cores were opened and analyzed in a geotechnical laboratory where geologists could observe and record sedimentary structures and features on the millimeter scale.

Additionally, a full suite of spectral gamma ray and neutron moisture borehole logs were obtained for each borehole. The spectral gamma ray logs detect natural radioactivity from potassium, thorium and uranium as well as a variety of manmade gamma-emitting radionuclides (McCain et al., 2014). Variations in natural gamma radioactivity can indicate subtle changes in lithology. Smaller grain sizes or a higher clay mineral fraction often correspond with higher gamma counts, while an increase in grain size may correspond to a decrease in total gamma counts. Mineral composition changes can often be seen in the spectral logs as a change in proportion of the natural potassium, thorium and uranium activity. At the Hanford Site the Cold Creek Caliche, a calcic paleosol subunit of the larger Pliocene Cold Creek unit (Bjornstad, 2002), is identifiable in the spectral logs as a marked increase in natural uranium and a decrease in natural potassium and thorium. Neutron moisture logging records the hydrogen ion concentration in the surrounding borehole and is an indicator of moisture. Increased readings can be correlated to increased moisture zones. Integration of the moisture and gamma logs with the sediment data allow detailed delineation of lithology and elevated moisture intervals. Under high enough concentrations, the spectral gamma logs are good indicators for manmade cesium-137, cobalt-60 and uranium contamination.

Borehole sample depth criteria were established based on the conceptual model of the waste site being investigated. The contaminated vadose zone is defined by historical waste site information (e.g., subsurface waste site dimensions and waste volume disposed), available depth discrete contaminant distribution data, borehole geophysical logs, surface geophysical investigations (e.g., resistivity surveys), and extent of known groundwater contaminant plumes. Most of the conceptual models developed for the DV-1 project indicate that residual contamination lies deeper in the vadose zone, below sorbed immobile contaminants directly beneath the waste sites. The purpose of this characterization effort was to determine the nature and extent of the deeper, mobile contamination. The conceptual modeling indicates contamination is most likely to be found in areas of high moisture and/or high gamma activity. Collection of geophysical logs and continuous cores allowed refinements to the sample depth selection process. This is not possible using conventional drilling and sampling techniques because sample depths would have to be preselected prior to drilling and sampling. The geophysical borehole logs were integrated with high-resolution core analysis to select depths for analytical sub-sampling. Sample depths were selected based on gamma and moisture peaks in the geophysical logs that corresponded to noticeable lithologic changes or bed boundaries, and within thick sediment sequences in order to capture and delineate variations in contaminant distributions throughout the borehole profile. The sub-samples were sent to offsite laboratories to analyze for contaminants of concern, geochemical parameters, radiological constituents, and hydraulic parameters. Figure 2 shows an example of an integrated geologic and geophysical dataset for a DV-1 well and the locations where sub-samples were collected.

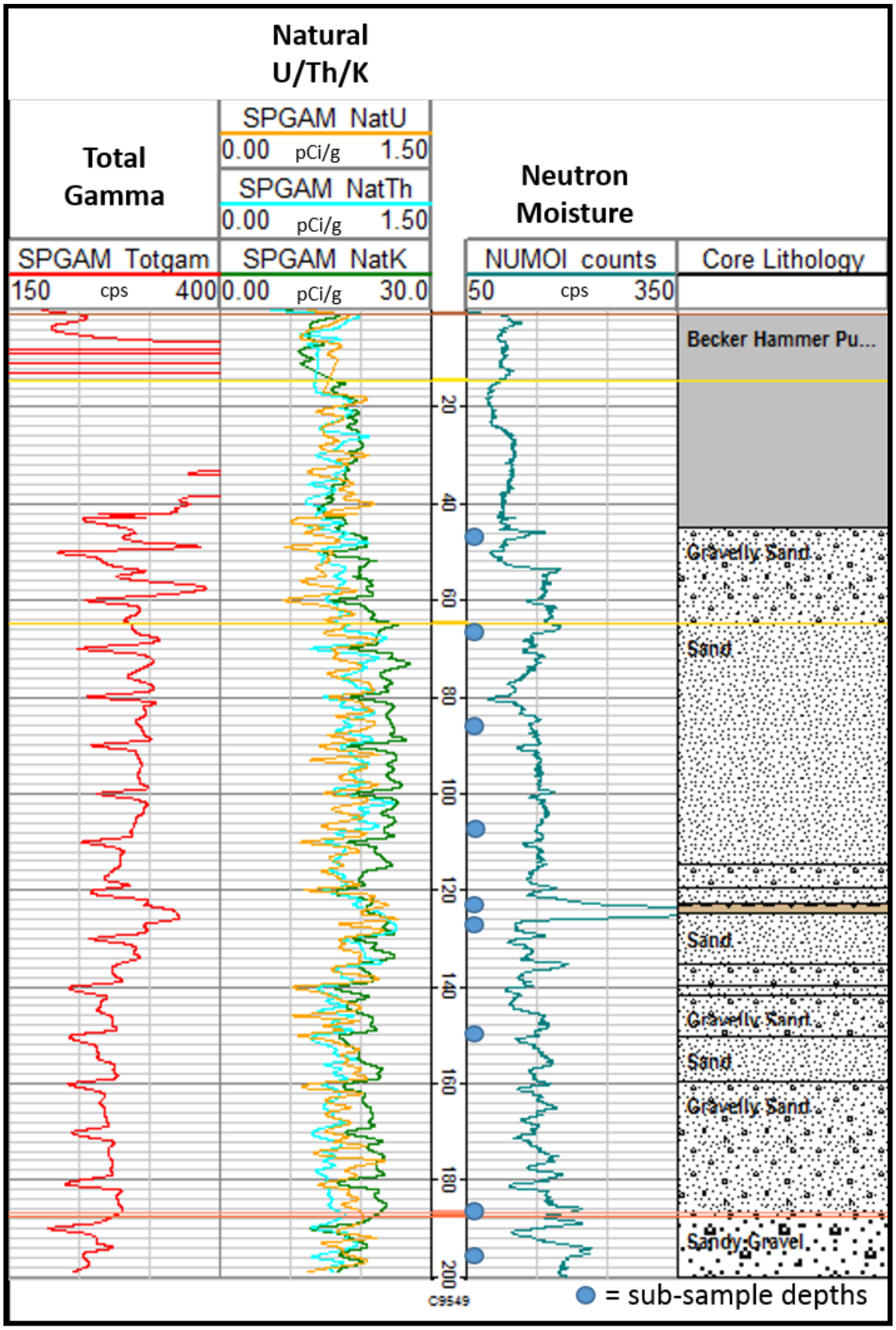

Figure 2: Borehole profile of C9549, a DV-1 borehole drilled in the 200-East B-Complex.

Results

Continuous intact coring provides opportunities for observing small-scale features and structures not visible in homogenized grab samples. Figures 3, 4, 5 and 6 show examples of sedimentary structures observed in DV-1 cores. Each of these structures have implications for contaminant migration as well as how the subsurface lithology is mapped and modeled in the future. These implications will be discussed in greater detail in the Discussion section below.

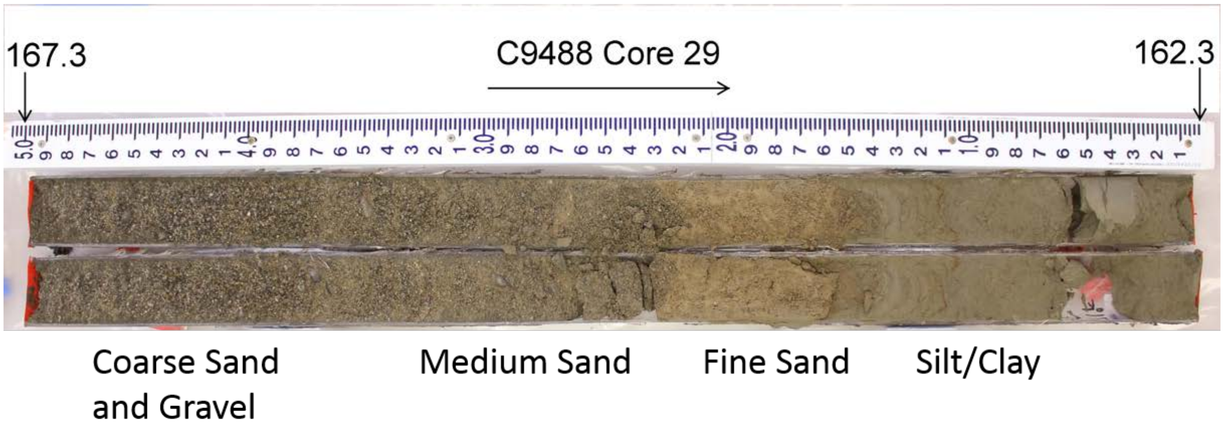

Figure 3: An example of graded bedding over a 1.5 m (5 ft) interval in Borehole C9488. This interval is a fining-upward sequence, grading from coarse sand and gravel to silt and clay.

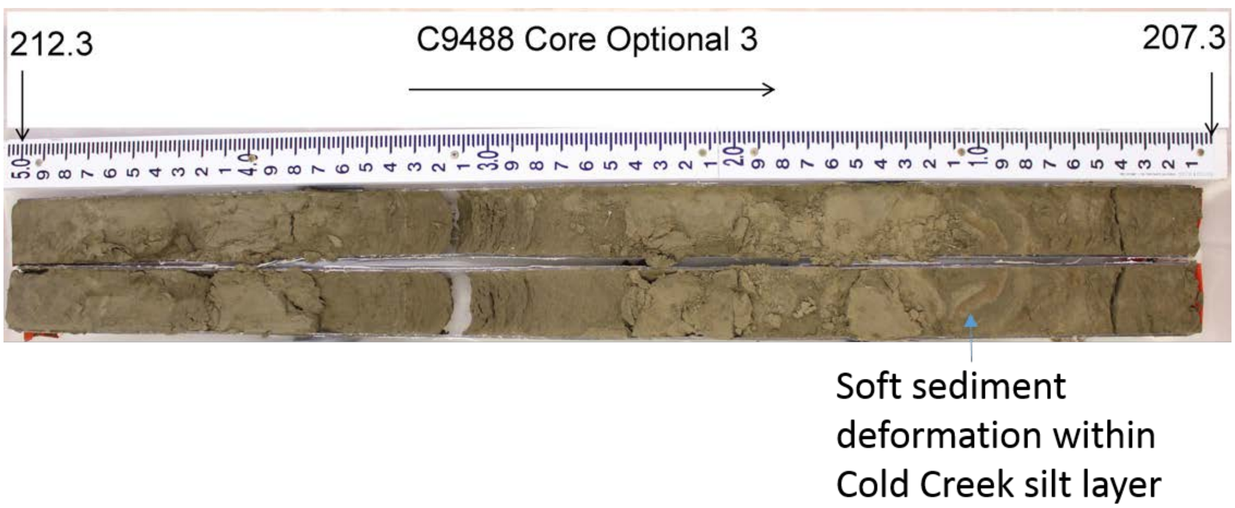

Figure 4: An example of soft sediment deformation in borehole C9488. Soft sediment deformation occurs during depositional loading of wet sediments, in this case the silts of the Cold Creek Silt unit were deformed during deposition of more silt above.

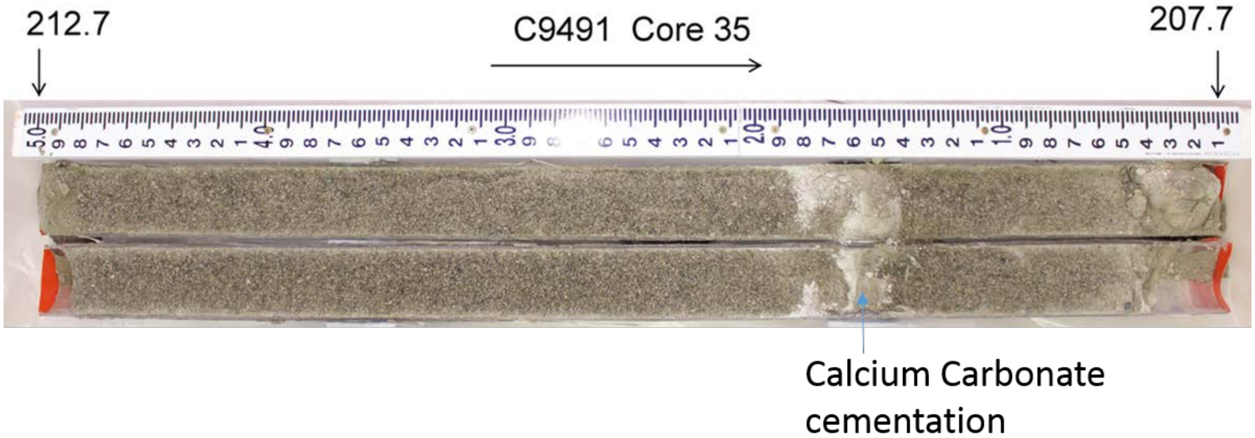

Figure 5: A small zone of calcium carbonate cementation is seen in borehole C9491. This is in a geographic area where carbonate cements are not typically observed at this depth.

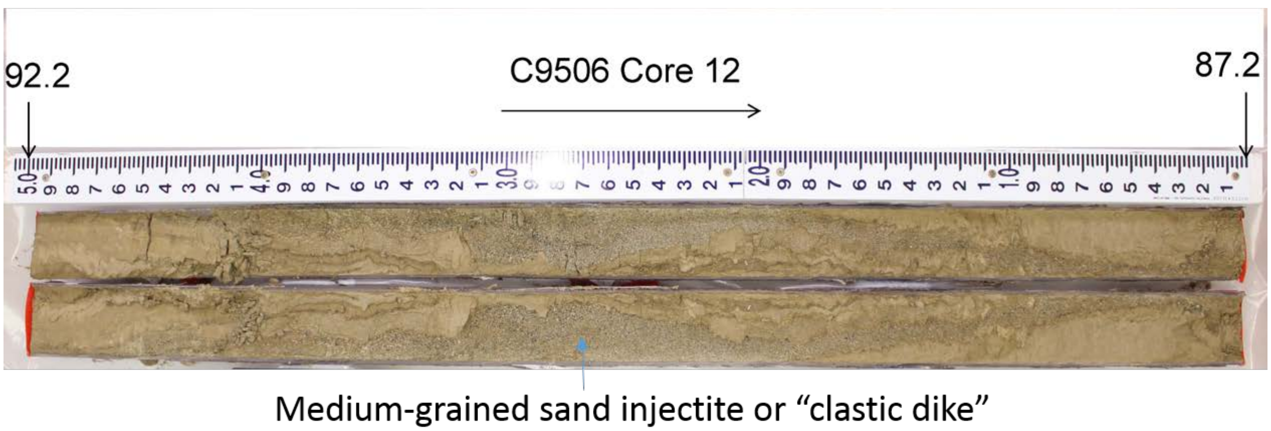

Figure 6: Clastic dikes are a phenomenon often suspected in the Hanford area subsurface but rarely directly observed. Borehole C9506 encountered a medium-grained clastic dike injected into the Cold Creek Silt unit.

Analysis of some of the collected sub-samples is still in progress, but preliminary results indicate that contamination within the deep vadose zone is highly variable both vertically as well as laterally (Figure 7). A cross section through the BY Cribs waste site illustrates variations in distribution and concentration and identifies elevated nitrate, technetium-99, cyanide, uranium and total chromium. For the boreholes northeast of the waste site, these contaminants are primarily located at discrete depths closely associated with silt beds and sediment boundaries and are most likely residual contamination that migrated through the area and eventually became trapped on or within the finer silt beds that dip in this direction, while the borehole drilled through the middle of the cribs revealed a more uniformly distributed contaminant extent throughout the lower portion of the vadose zone indicating a significant mass of contamination may still be moving through the deep vadose zone at this location.

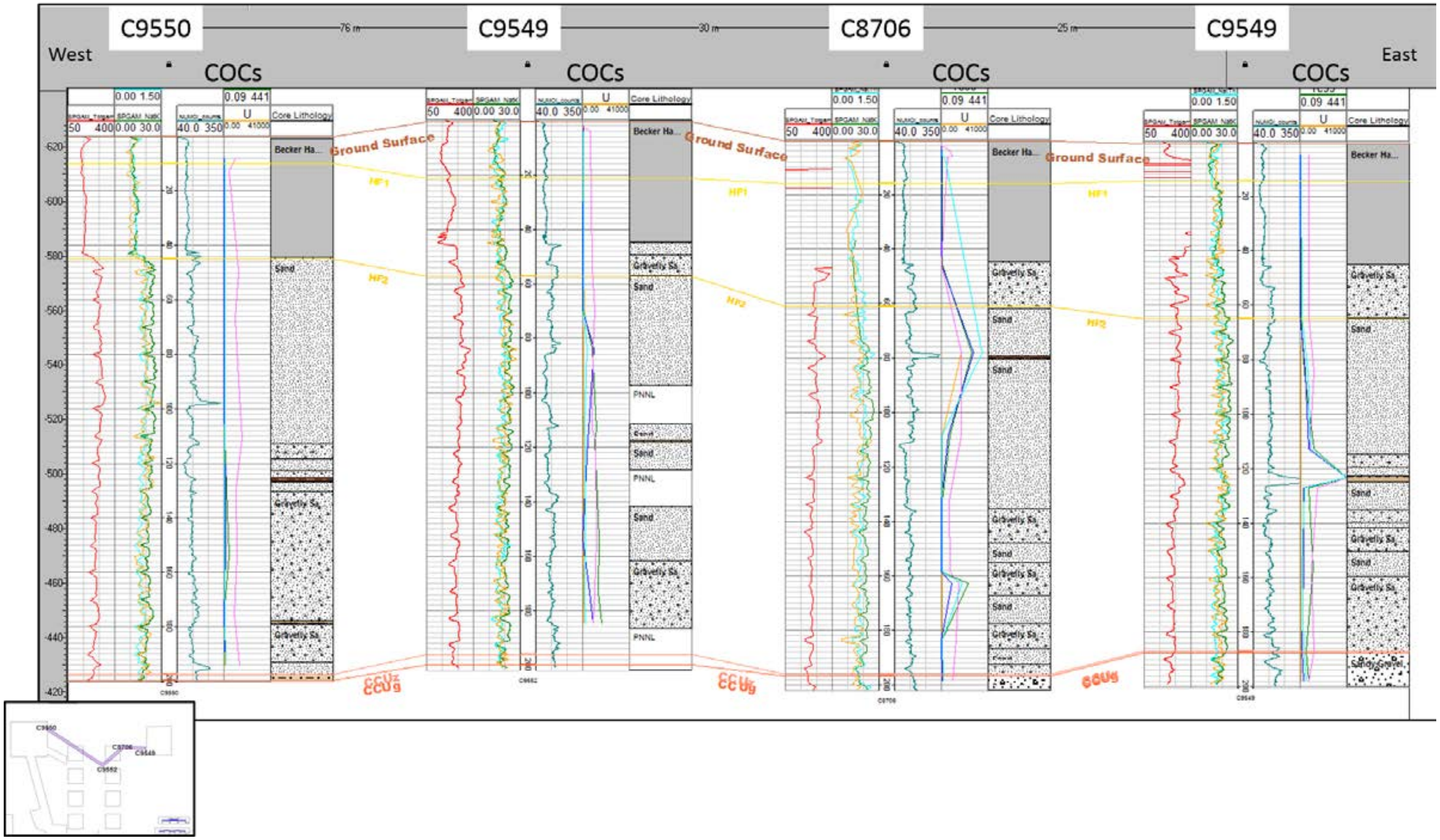

Figure 7: West to East cross section through BY Cribs, displaying the four new wells drilled for the DV-1 project. Contaminants of concern are plotted alongside geophysical and geological logs. Stratigraphic surfaces are interpreted through the cross section showing where the tops of the Hanford formation unit 1, Hanford formation unit 2, Cold Creek Silt unit and Cold Creek gravel unit.

Discussion

One of the key unknowns for completing the contaminant conceptual models in the Hanford Site Central Plateau is to what extent small-scale sedimentary structures occur and how they control contaminant distribution in the subsurface. Subsequently, we also want to know how predictable these small-scale structures are and how likely are we to detect them using traditional methods of subsurface characterization (i.e. grab sampling and borehole geophysical logs).

The continuous intact coring for DV-1 has revealed how important some of the small-scale structures are to the migration of mobile contaminants. Consider the one-foot thick silt layer observed in well C9549. Sub-sampling just above and below this silt layer shows high concentrations of the contaminants of concern above the silt and almost undetectable concentrations below the silt (Figure 8). These results indicate that this thin silt layer is acting as a barrier to vertical contaminant migration and may create a surface that causes liquid effluents to spread laterally much further than expected based on the hydraulic properties of the thicker and more permeable sediment. Sharp peaks in the Neutron Moisture and Total Gamma logs at the same depth of the silt indicate that the silt would have been detected in the geophysical logs if an intact core sample were not available. This validation method or ‘ground-truthing’, using the geophysical logs is helpful for boreholes without intact core samples collected. High contaminant concentrations correlated with fine-grained zones has been observed in several other DV-1 boreholes, although not all are as easily identified in geophysical logs. Calcium carbonate cementation is another phenomenon that may create barriers to vertical migration of effluents. However, only one DV-1 well with $CaCO_3$ cementation (C9491, figure 5) has completed contamination analyses and the results did not indicate any contamination concentrations above background associated with that cemented layer.

The clastic dike structure observed in well C9506 (figure 6) is predicted to be a potential conduit for contaminant migration. The injection of coarser grained sand through the Cold Creek silt during deposition may provide a higher permeability pathway through which contaminants could be transported. Samples were collected above and below the clastic dike feature but the chemical analyses have not yet been completed.

Other sedimentary structures observed such as soft sediment deformation and graded bedding are useful for broader lithologic correlation and framework modeling efforts. Both structures indicate the depositional setting of the sediments, which therefore provide better context for stratigraphic correlation. Tying the observed structures to the geophysical log signatures will make it easier to identify similar trends in offset wells.

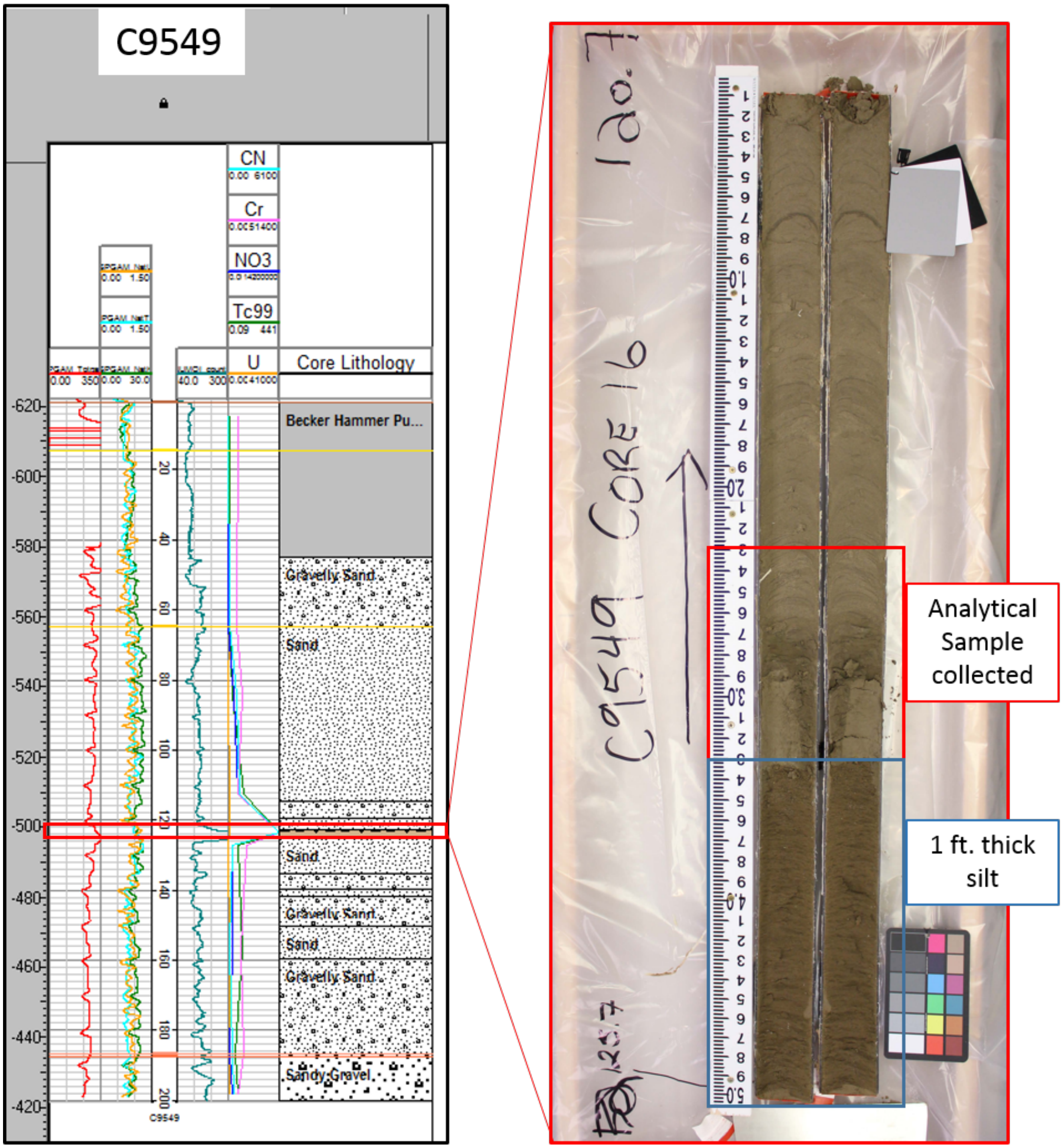

Figure 8: Borehole profile of C9549 with core photo from 120.7' to 125.7' depth below ground surface. The bottom of the core chows the moist silt layer reflected in the Neutron Moisture log. The analytical sub-sample collected just above the silt layer has high concentrations of nitrate, technetium-99, Total chromium and cyanide.

Conclusions

The purpose of the DV-1 characterization project is to determine the vertical and lateral extent of mobile contamination that may pose a current or future threat to the groundwater in the Central Plateau of the Hanford Site. Integration of high-resolution characterization datasets have resulted in a better understanding of the small-scale sedimentary structures within the vadose zone that influence contaminant distribution and mobility. This detailed sampling method led to a more precise sub-sampling strategy and will provide information to determine how the small-scale structures influence the migration of mobile contaminants. Ultimately this information will lead to a detailed conceptual site model that will help guide a future remedy selection for the DV-1 waste sites.

References

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