Fifth Annual

CLEMSON UNIVERSITY

Hydrogeology Symposium

April 11, 1997

Madren Center, Walker Golf Course
Clemson University

This symposium is supported by funds from the South Carolina Universities Research and Education Fund in cooperation with the US Department of Energy. Special thanks to Tom Temples who is our DOE Technical Representative.

Speaker Schedule

Moderators: Dave Snipes and Ron Falta

8:05 **"Welcome to the 1997 Clemson University Hydrogeology Symposium"**
Ed Page, *Clemson University*

8:20 **"Mud in the Courtroom: The Timberlake, VA, Sediment Injury Case"**
Robert C. Whisonant, *Radford University*

8:50 **"An Evaluation of the Miocene Aquifers in the Coastal Area of Georgia"**
William M. Steele, *Georgia Geologic Survey*

9:05 **"Lithostratigraphic Revisions of the Uppermost Cretaceous and Lower Tertiary of Eastern Burke County, Georgia."**
Joseph H. Summerour, *Georgia Geologic Survey* and Paul F. Huddlestun, *Georgia Dept. of Natural Resources*

9:20 **"Comparison of Geoprobe® Prepacked Monitoring Wells and Water Quality Samples to Paired Two-inch PVC Monitoring Wells Installed with Conventional HSA Techniques."**
Wesley McCall and Volker Wittig, *Geoprobe Systems, Salina, Kansas*

9:35 **"Vertical Sequence Interpretation of Piezocone Penetrometer Measurements in Eocene Coastal Plain Sediments."**
Frank H. Syms, *Bechtel Savannah River, Inc., Savannah River Site*

9:50 **"Groundwater Characteristics of the Medina System, Northeastern United States"**
James Castle, *Clemson University* and William Goodman, *The Sear-Brown Group*

10:05 -10:20 **BREAK**

10:20 **"Delineation of the Gordon Confining Unit in the Vicinity of the APT Site at the Savannah River Site"**
William Sharp, *Clemson University*

10:35 **"Numerical Model of the McQueen Branch-Mill Creek Divide, Savannah River Site, South Carolina: Characterization of Groundwater Flow in Tertiary Sand Aquifers"**
Jeffrey Thibault, *Clemson University*

10:50 **"The Appleton Confining System: A Unique Aquitard in the Central Savannah River Area, South Carolina"**
Samuel P. Watson, *Clemson University*

11:05 **"Palynofacies Analysis: Application To Paleoenvironmental Interpretations At The Savannah River Site, South Carolina"**
Donald W. Engelhardt, *Earth Science and Resources Institute, University of South Carolina* and Robert S. Van Pelt, *Westinghouse Savannah River Company*

11:20 **"Questions regarding the stratigraphic relationship between the Cape Fear and Middendorf Formations"**
Raymond Christopher, *Clemson University*

11:35 **"Mysteries solved in the stratigraphy of the updip Coastal Plain of Georgia"**
Lucy Edwards, Norman O. Frederickson, Laurel M. Bybell, Thomas G. Gibson and David Bukry, *US Geological Survey, Reston, Virginia*

11:50 - 1:15 **LUNCH (Ballroom B)**

1:15 **"The Direct Detection of Dense Non Aqueous Phase Liquids (DNAPL) using Amplitude Variation with Offset (AVO) Techniques"**
Tom J. Temples, *Department of Energy, Savannah River Site;* Michael G. Waddell and William Domoracki, *Earth Sciences and Resources Institute, University of South Carolina*

1:30 **"The Effects of Fingered Flow on Relative Permeabilities During Air Sparging"**
Wilson S. Clayton, *Fluor Daniel GTI, Inc., Golden, Colorado*

1:45 **"A Field Test of LNAPL Remediation By Tert-Butanol Injection"**
Ron Falta, Clemson University

2:00 **"The Effect of Heterogeneities on the Remediation of LNAPLS Using Cosolvent Flooding"**
Scott Brame, *Clemson University*

2:15 **"Potential Applications for Hydraulic Fractures in Residual Soils"**
Larry Murdoch, *Clemson University*

2:30 **"Vadose zone pumping tests using two innovative, depth-discrete sampling technologies and GASSOLVE*."**
Joe Rossabi, B.D. Riha, and B.E. Pemberton, *Westinghouse Savannah River Company*

2:45-3:00 **BREAK**

3:00 **"Pending"**
Brian Looney, *Westinghouse Savannah River Company*

3:15 **"Hydrogeological characterization and analysis — General Separations Area (GSA) Savannah River Site, SC"**
Mary K. Harris, *Westinghouse Savannah River Company;* Paul A. Thayer, *Univ. of North Carolina-Wilmington;* Andrew D. Smits, *Science Applications International Corp.;* Gregory P. Flach, *Westinghouse Savannah River Company;* and Kelley L. Hawkins, *Science Applications International Corp.*

3:30 **"Groundwater flow modeling using comprehensive hydrogeological characterization data — General Separations Area (GSA) Savannah River Site, SC"**
Gregory P. Flach, L. Larry Hamm, Mary K. Harris, and Sebastian E. Aleman, *Westinghouse Savannah River Company*

3:45 **"Simulation of DNAPL Emplacement and Redistribution Using Geostatistically Generated Heterogeneous Permeability Distributions"**
Rex Hodges, *Clemson University*

4:00 *Closing Comments and Discussion*

4:30 **Beverages and Heavy Hors d'ouerves (Ballroom B)**

Abstracts

MUD IN THE COURTROOM: THE TIMBERLAKE, VA, SEDIMENT INJURY CASE

WHISONANT, Robert C., Department of Geology, Radford University, Radford, VA 24142

Knowledge of the legal and applied aspects of sedimentology and surface water runoff is becoming increasingly important to the practice of hydrogeology in today's work environment. Many states now have laws regarding erosion and sediment control and promulgate guidelines (handbooks) to ensure that the laws are followed. A relatively new concept in legal circles is the notion of "sediment injury." The basic questions that usually arise in sediment injury cases revolve around how much sediment was produced by a land-disturbing activity and (especially crucial) how much of this sediment came to rest at a given site. Unfortunately, in most instances, measuring the sediment produced, transported, and deposited must be done "after the fact." At this point, technical experts, typically engineers and/or geologists, may become involved and find themselves in conflict over the actual amount of sediment produced and deposited. Especially popular with engineers are techniques of estimating erosion and runoff that use empirical equations, such as the USLE (Universal Soil Loss Equation) and the Rational Method of runoff calculation. These must be used in sediment injury cases with great care by professionals who understand the basic principles of sedimentation. Once in the courtroom, the ability of the technical expert to communicate the results of his or her analyses is of prime importance.

To illustrate these points, I will discuss the Timberlake, VA, sediment injury litigation, a lawsuit wherein a private homeowners' association sued the Virginia Department of Transportation (VDOT) for allegedly causing massive amounts of sediment to enter a lake. A technical expert for the plaintiffs used the Rational Method to show that increased discharge had entered the lake from the watershed containing the VDOT project. He also employed the USLE to estimate how much sediment had come into the lake because of VDOT's construction activity. Technical experts for VDOT also used the rational method to estimate runoff but applied it to all watersheds discharging into the lake. This analysis showed that extensive urbanization had significantly changed the coefficient of runoff in each watershed and, in fact, the highway project was a relatively small contributor to the overall increase in discharge and sediment load. The VDOT experts also demonstrated that the USLE had been used incorrectly to estimate sediment deposition in the lake from the project. This case showed clearly that geologists and engineers must be familiar with not only the basic techniques of measuring sediment loss and stormwater runoff, but also with the proper application of these techniques.

AN EVALUATION OF THE MIOCENE AQUIFERS IN THE COASTAL AREA OF GEORGIA

STEELE, William M., Georgia Geologic Survey, 19 Martin Luther King, Jr. Dr., SW Room 400, Atlanta, GA 30334

Rapid growth in the coastal region of Georgia has created increased demand on ground-water resources and has placed hydrologic stress on the Eocene to Oligocene age Upper Floridan aquifer. The Upper Floridan is the principal source of water in coastal Georgia, and pumpage from it has caused encroachment of saltwater into wells in the Brunswick, Georgia, Hilton Head, South Carolina, and Jacksonville, Florida areas. If growth is to continue in coastal Georgia, alternative sources of water must be identified and utilized. An alternative source of ground water may be the Miocene (Upper and Lower Brunswick) aquifers. The purpose of this study is to conduct aquifer tests at selected sites to measure the properties (transmissivity and storativity) of the Miocene (Brunswick) aquifers in the coastal Georgia area to determine if they are viable alternatives to the Upper Floridan aquifer for smaller-demand needs such as golf courses, agricultural (lower demand or supplemental), small industries, and non-contact cooling water.

To effectively measure the properties of these aquifers, seven sites have been selected for evaluation. Four of these sites will be located in coastal counties, and three sites will be in counties where agricultural water use is prevalent. The Clemson University Department of Geological Sciences has been contracted to perform aquifer tests and to complete data analysis at these sites.

To date (February 1997), drilling has been completed, by the Georgia Geologic Survey, on Tybee Island, in Chatham County, Georgia. Aquifer testing on Tybee is scheduled for the week of March 17. Drilling is currently in progress at a site in St. Marys in Camden County, Georgia.The next scheduled drill site, Toombs County, Georgia, is in the agricultural region.

Results of aquifer tests will be published by the Georgia Geologic Survey as a series of Information Circulars.

LITHOSTRATIGRAPHIC REVISIONS OF THE UPPERMOST CRETACEOUS AND LOWER TERTIARY OF EASTERN BURKE COUNTY, GEORGIA

SUMMEROUR, Joseph H., Georgia Geologic Survey, 19 Martin Luther King, Jr. Dr., SW, Room 400, Atlanta, GA 30334 and HUDDLESTUN, Paul F., Georgia Dept. of Natural Resources, 4244 International Parkway, Suite 104, Atlanta, GA 30354

Since July, 1991, the United States Geological Survey (USGS) has been conducting the DOE-funded Trans River Flow Project, to investigate the conditions under which ground water from the Savannah River Site (SRS) could migrate beneath the Savannah River into Georgia aquifers. Since December, 1991 the Georgia Geologic Survey (GGS) has been conducting the DOE-funded Tritium Project, to investigate the presence of above background levels of tritium in surface waters and the unconfined Upper Three Runs aquifer of eastern Burke County, Georgia. Prior to these two projects, the subsurface geology (lithostratigraphy and hydrogeology) of eastern Burke County was poorly understood. As part of the USGS Trans-River Flow Project, approximately 9244 feet of core samples were examined and described by Paul Huddlestun. These core samples were from six GGS Tritium Project well sites, two USGS Trans-River Flow sites and 12 sites related to Ga. Power Co. Plant Vogtle construction and a previous GGS project.

The report on the revised lithostratigraphic framework (GGS Bulletin 127) formally introduced one new formation, two new members, and a redefinition of an established lithostratigraphic unit. The Still Branch Sand is the new formation and the two new members are the Bennock Millpond Sand Member of the Still Branch Sand and the Blue Bluff Member of the Lisbon Formation. The McBean Limestone was redefined from a formation to a member of the Lisbon Formation. The Oconee Group (of central Georgia) and four South Carolina formations, Steel Creek, Snapp, Black Mingo (undifferentiated), and Congaree are formally recognized in the Central Savannah River Area (CSRA) of Georgia, for the first time. The report also provides formal recognition of the presence of the Congaree Formation across Georgia to the Chattahoochee River area and perhaps into Alabama, as a stratigraphic equivalent of the Tallahatta Formation.

Also discussed in the report are the nomenclatural history, age, and correlation of all of the lithostratigraphic units, evidence of the extension of the Pen Branch fault zone into Georgia, and the hydrostratigraphic framework used in the GGS Tritium Project.

COMPARISON OF GEOPROBE PREPACKED MONITORING WELLS AND WATER QUALITY SAMPLES TO PAIRED TWO-INCH PVC MONITORING WELLS INSTALLED WITH CONVENTIONAL HSA TECHNIQUES

MCCALL, Wesley, M.S., Environmental Geologist, Applications Research and WITTIG, Volker, M.S., Engineer, Research and Development, Geoprobe Systems, Salina, Kansas

Geoprobe Systems has designed a system to install permanent monitoring wells using percussion probing type equipment. These monitoring wells are constructed with prepacked screens that have an outside diameter of 1.5 inches and an inside diameter of 0.5 inches. The three foot long screens are prepacked with 20-40 grade silica sand. They can be assembled together to achieve a screened interval of the desired length. The prepacked screens and casing are installed through 2.125 inch outside diameter by 1.5 inch inside diameter probe rods after the rods are driven to the target depth. No drill cuttings are generated during well emplacement. Geoprobe System's high pressure grout pump allows for 'bottom-up' emplacement of bentonite seals and acceptable grout slurries by the tremie method as the probe rods are retracted. Geoprobe's Prepacked Monitoring Well meets the basic construction and operation requirements for a RCRA monitoring well with the only difference being the smaller well diameter.

Over a period of months samples were collected from several paired Geoprobe prepacked monitoring wells and conventional hollow stem auger (HSA) installed 2-inch PVC monitoring wells. The samples were analyzed for gasoline range organics (GRO), benzene, toluene, ethylbenzene, and total xylenes (BTEX), and several chlorinated volatile organic compounds (X-VOCs). Comparing the sample results of the Geoprobe prepacked wells and conventional monitoring wells shows a good correlation of the data sets. Standard field parameters (pH, conductivity, temperature), turbidity, and water levels were also measured in the paired wells. The results indicate that the cost effective Geoprobe prepacked monitoring wells can be used to conduct long term ground water monitoring that meets regulatory requirements.

VERTICAL SEQUENCE INTERPRETATION OF PIEZOCONE PENETROMETER MEASUREMENTS IN EOCENE COASTAL PLAIN SEDIMENTS

SYMS,Frank H., Bechtel Savannah River, Inc., Savannah River Site, Aiken, S.C. 29808, frank.syms@SRS.gov.

Measurements obtained from piezocone penetrometer soundings at the MWD Test Area, Savannah River Site, have been correlated with lithologic and geophysical data to delineate vertical depositional sequences. Traditional techniques for mapping subsurface sediment packages include drilled borings with core analyses and/or indirect geophysical techniques . Recent advances in direct push technology have allowed for deeper soundings with the piezocone penetrometer making it a viable alternative for geologic mapping of depths of up to two hundred feet in unconsolidated sediments. The piezocone measurements of tip resistance, sleeve friction and pore pressure have been correlated with adjacent core samples such that vertical changes in sorting, quantified from grain size analyses and visual descriptions, can be directly related to variances in the piezocone measurements i.e., fining or coarsing upwards sequences are readily identifiable from corresponding changes in tip resistance and sleeve friction values. Further, geophysical measurements obtained from adjacent boreholes provide compensurate data for correlating vertical changes in depositional sequences with piezocone measurements. Calibration of the piezocone with the site specific geology provides a means of mapping depositional packages via a quick and efficient alternative to conventional drilling.

GROUNDWATER CHARACTERISTICS OF THE MEDINA SYSTEM, NORTHEASTERN UNITED STATES

CASTLE, James W., Geological Sciences, Clemson University ,Clemson, SC 29634-1908 and GOODMAN, William, The Sear-Brown Group, 85 Metro Park, Rochester, NY 14623-2674

Regionally extensive sandsheets occur in the Lower Silurian Medina Group and correlative strata of the Appalachian Basin, northeastern United States. The Medina Group is exposed at the ground surface along the industrial belt of upstate New York, and directly underlies several landfills and industrial sites. The system contains various fluid and gaseous phases, and includes a major trend of unconventional natural gas extending from southwestern New York to Ohio. In the deeper parts of the system, primarily in central Pennsylvania and West Virginia, phases present include supersaturated brine, natural gas, carbon dioxide, and nitrogen.

Flow of fluid and gaseous phases, including both water and hydrocarbons, in the Medina system is controlled by a combination of structural, stratigraphic, and diagenetic factors. Flow occurs along open fractures in both shallow and deeply buried portions of the Medina. In many areas, flow follows the distribution of stratal patterns controlled by depositional facies, which represent various shoreline and shelf environments. Petrographic study indicates that matrix permeability in the sandstones is controlled by a combination of primary and secondary porosity.

A characteristic of Medina sandstones on the Lake Ontario Plain in western New York is the occurrence of saline groundwater, even at depths less than 100 feet. Groundwater geochemical data, including cation ratios and isotopic composition, indicate mixing of deep brines and meteoric water. A compartmentalized groundwater system is suggested by geochemical differences among water samples from discrete stratigraphic intervals within the Medina. Variability in petrophysical properties, including capillary pressure, is important in controlling fluid content and probably fluid composition in Medina sandstones. In some contaminated parts of the Medina, high capillary pressure is suspected in causing difficulty in removing the contaminants, increasing the cost of remediation.

DELINEATION OF THE GORDON CONFINING UNIT IN THE VICINITY OF THE APT SITE AT THE SAVANNAH RIVER SITE

SHARP, William R., Geological Sciences Dept., Clemson University, 340 Brackett Hall, Clemson SC 29634-1908, wrsharp@clemson.edu; BLANCHARD, John S., 23 Congress St., #10, Nashua NH, 03062; WATSON, Samuel P., and SNIPES, David S., Clemson University, 340 Brackett Hall, Clemson SC 29634-1908, spwatso@clemson.edu; snipes@geology.clemson.edu

The Gordon Confining Unit (GCU) is a critical aquitard at the Savannah River Site because it protects the underlying Gordon Aquifer from potential contamination. It is made up of the glauconitic sandy clays of the Warley Hill Formation and the clayey, silty sands of the Tinker/Santee Formation. The GCU is also significant because of its use as a regional mapping horizon due to its characteristic geophysical well log signature and its lateral extent.

A study involving the GCU was recently completed by John Blanchard (1996). He made a structure contour map on the top of the Warley Hill Formation in order to determine the relationship between the Copperhead Creek Anticline and the Tinker Creek Fault of Domoracki (1996). Control data was provided by surface exposures, geophysical well logs, and core descriptions. In addition, hand auger core samples collected by Sharp were used to delineate the GCU along some of the tributaries of Upper Three Runs Creek.

Included in Blanchard's study area is the northern part of the proposed APT site. APT stands for Accelerator for Production of Tritium. Construction of this facility requires knowledge of the aquifers and confining layers beneath the APT site. A limitation of Blanchard's (1996) thesis in this area is the lack of adequate well control on the GCU. One of the goals of the current study is to fill in the gaps in Blanchard's (1996) structure contour map.

Future research will focus on expanding Blanchard's (1996) study area. This may provide evidence for the northern extension of the Tinker Creek Fault and the associated Copperhead Creek Anticline.

THE APPLETON CONFINING SYSTEM: A UNIQUE AQUITARD IN THE CENTRAL SAVANNAH RIVER AREA, SOUTH CAROLINA

WATSON,Samuel P., Geological Sciences Dept., Clemson University, SHARP, Bill, and SNIPES, David S., Clemson University, 340 Brackett Hall, Clemson SC 29634-1908, wrsharp@clemson.edu and snipes@geology.clemson.edu; Aadland, Rolf, Westinghouse Savannah River Company, Aiken SC 29808.

The Appleton Confining System consists of clays and poorly sorted clayey sands of the Late Cretaceous Cape Fear Formation. This formation is the basal Coastal Plain unit of the Central Savannah River Area (CSRA). The thickness of this unit varies from about 30 feet near the northern boundary of the Savannah River Site (SRS) to about 250 feet in well C-10 which is situated approximately 12 miles south of the southern boundary of SRS. The extremely low porosity and permeability together with the firmness of the Appleton, as compared to the overlying units, make this aquitard unique within the CSRA. The dissolved solid content of the groundwater in the underlying Triassic sediments is 11,000 mg/L (Marine and Siple, 1974); whereas, the dissolved solid content of the Midville aquifer is 69 mg/L (Aadland and others, 1995). This finding documents the effectiveness of the Appleton as a confining unit. The unit is characterized by a distinctively low resistivity geophysical well log signature compared with the high resistivity of the overlying Midville sands. The distinctive log signature together with the unusual firmness of the Appleton sediments make this unit distinctly different from the overlying Midville, that is characterized by high resistvity and loose sands. These characteristics make the Appleton an easily identifiable marker horizon for correlation and sub-surface mapping.

Aquitard, Cretaceous, Correlation, Appleton

PALYNOFACIES ANALYSIS: APPLICATION TO PALEOENVIRONMENTAL INTERPRETATIONS AT THE SAVANNAH RIVER SITE, SOUTH CAROLINA.

ENGELHARDT, Donald W., Earth Science and Resources Institute, University of South Carolina, Columbia, SC and VAN PELT, Robert S., Westinghouse Savannah River Corp., Aiken, SC

Palynological analysis of the hydrostratigraphic units at the Savannah River Site can demonstrate the utility of palynology for age determinations, correlations, paleoenvironmental interpretations and sequence stratigraphy. Palynofacies is a description of the characteristics of the organic fraction of the sediments (kerogen). The organic constituents can be used to describe associations of palynofacies types which can be diagnostic for a specific depositional environment or for ranges of environments.

Palynofacies offers paleoenvironmental interpretation essential to understanding the complex depositional systems of the Savannah River Site area. By combining the kerogen analysis and the fossil occurrences, it is possible to distinguish various environments ranging from nonmarine fluvial and deltaic sequences to shelfal marine with several intermediate or restricted environments. The combination of utilizing the fossils and organic material can be used to distinguish highstand transgressive units that can be traced across the Savannah River Site using the core hole data. Examples of palynofacies analysis demonstrate the effectiveness of using all available data for interpretation of the paleoenvironments in the area.

QUESTIONS REGARDING THE STRATIGRAPHIC RELATIONSHIP BETWEEN THE CAPE FEAR AND MIDDENDORF FORMATIONS

CHRISTOPHER, RAYMOND A., Department of Geological Sciences, Clemson University, Clemson, SC 29634-1908, PROWELL, DAVID C., U.S. Geological Survey, Peachtree Business Center, 3039 Amwiler Road, Atlanta, GA 30360-2824, and GOHN, GREGORY S., U.S. Geological Survey, 926A National Center, Reston, VA 20192.

The Cape Fear and Middendorf Formations comprise the basal units of the updip portion of the Carolina Coastal Plain. Both units have been interpreted as occurring throughout the South Carolina Coastal Plain, with the unconsolidated sands of the Middendorf overlying the indurated clayey sands of the Cape Fear. However, physical and paleontologic data indicate that the relationship between these units is not so straight-forward, nor is the Middendorf Formation as geographically widespread as has been suggested traditionally. Paleontologic investigations at or near the type localities of these formations reveal that both units can be assigned to the same biostratigraphic zone (pollen zone V of late Coniacian to Santonian age). Although samples examined from the Cape Fear Formation throughout South Carolina confirm a zone V age for this formation, units mapped as the Middendorf Formation are of different ages in different places. In addition, units mapped as Middendorf are present in the Carolinas only on interfluves; outcrops along all of the major rivers between the Neuse in North Carolina and the Pee Dee in South Carolina consist of laminated, fossiliferous, organic-rich clays of the basal Black Creek Group overlying the indurated clayey sands of the Cape Fear Formation. These observations are supported by data obtained from several subsurface sections, and in the vicinity of the Savannah River Site, the unit mapped as the Middendorf Formation is biostratigraphically equivalent to these basal Black Creek clays. These observations suggest that considerable stratigraphic, paleontologic, and sedimentologic work is required before a compete understanding of the true relationship between the Cape Fear and Middendorf Formations can be attained.

MYSTERIES SOLVED IN THE STRATIGRAPHY OF THE UPDIP COASTAL PLAIN OF GEORGIA

EDWARDS, L.E., FREDERIKSEN, N.O., BYBELL, L.M., GOHN, G.S., SELF-TRAIL,J.M., U.S. Geological Survey, Reston, VA 20192, GIBSON, T.G., Smithsonia Institution, Washington, DC 20560, BUKRY, David, Scripps Institution of Oceanography, UCSD, La Jolla, CA 92093-0231, and FLEMING, R.F., Littleton, CO.

Five cores in Burke and Screven Counties in Georgia form the basis for a multi-faceted paleontological study of Cretaceous and Tertiary Coastal Plain sediments. The recurrence of similar lithofacies and the highly selective removal of sediments by later erosion make the biostratigraphy of this area so intriguing.

The Cape Fear Formation, where studied, is of probable Coniacian age and is nonmarine. At least two different ages may be represented in the Middendorf Formation, one correlative to the type Middendorf and one correlative to the Shepherd Grove Formation of South Carolina. The Black Creek Group is nonmarine in its lower and upper parts, and in all but the most updip core, includes sediment in its middle part that represent a late Campanian transgression. In the Millhaven core, the upper part of the Black Creek is Maastrichtian. The Steel Creek Formation contains long-ranging Cretaceous pollen taxa. It overlies sediments dated as Maastrichtian in the Millhaven core and it therefore is of Maastrichtian age. The placement of the Cretaceous-Tertiary boundary in all cores is poorly constrained.

The Ellenton Formation contains sediments of three different ages: a thin early Paleocene (Danian) section, relatively thick early late Paleocene (Selandian) sediments, and a thin middle late Paleocene (Thanetian) section (in the Millhaven core only). The oldest material contains a significant component of planktonic foraminifers and thus represents deeper water deposition than the remainder of the Ellenton. The Paleocene Snapp Formation is present in varying thicknesses in four of the five cores. It is conspicuously absent in the Thompson Oak core, and its upper kaolinitic part is not present in the McBean core. The Congaree Formation as recognized here is of early and middle Eocene age. The oldest Congaree is present only in the Thompson Oak and possibly the Girard cores. The youngest Congaree is recognized only in the Millhaven core. The Santee Formation is of late middle Eocene age. It contains calcareous fossils even in the most updip cores. Paleo-water depths within the Santee, as inferred from foraminifers, deepen basinward. Sediments of the Barnwell Group are poorly fossiliferous and are late Eocene to questionably early Oligocene age.

THE DIRECT DETECTION OF DENSE NON AQUEOUS PHASE LIQUIDS (DNAPL) USING AMPLITUDE VARIATION WITH OFFSET (AVO)TECHNIQUES

TEMPLES, TOM J., Department of Energy, Savannah River Site, Aiken, SC; WADDELL, MICHAEL G. and DOMORACKI, WILLIAM, Earth Sciences and Resources Institute, USC, Columbia, SC

One of the most difficult problems in designing a remediation plan for cleaning up DNAPL contamination is locating the “pools” of free phase DNAPL. A mathematical model based on the Zoeppritz equation (Aki and Richards approximation) was constructed to test the feasibility of using Amplitude Variation with Offset techniques to detect the presence of free phase Trichloroethylene (TCE) and Tetrachloroethylene (PCE) in sediments. Simulations were run to determine the AVO effect on the DNAPL sand/water sand, water sand/clay interface, and DNAPL sand/clay aquitard. The results of the modeling indicate that the presence of DNAPL will cause a change in amplitude with offset when compared to a water sand with similar properties.

Three seismic lines were located to gather data over an area where a water sand transitions into a known pool of DNAPL and back into a water saturated sand. Using a weighted stacking processing technique (Smith and Gidlow, 1987)

known as a fluid factor stack, sections were generated from the data set. The results indicate an anomaly consistent with the model at the depth and location of the known DNAPL. Preliminary drilling results indicate that DNAPL is present in the areas shown by the seismic data, suggesting that under certain conditions, free phase DNAPL can be imaged using high resolution reflection seismic techniques.

TWO PHASE FLOW BEHAVIORS OF AIR SPARGING

CLAYTON, Wilson S., Ph.D., P.G., Fluor Daniel GTI, 1626 Cole Blvd., Golden, CO, 80228

Relative permeability-saturation-capillary head relationships (k_r-S-h_c) are the soil properties which control air and water flow during *in-situ* air sparging. These relationships can be effected by pore scale air fingering, which arises from interfacial instability as air displaces water during air sparging. Pore scale air fingering results in the development of dead-end air fingers which do not conduct air flow, yet reduce the water saturation. Only the portion of through going (backbone) pores conduct air flow. On this basis, we may expect reduced values of air relative permeability as a function of water saturation ($k_{ra}(S_w)$) for air sparging conditions.

Air injection displacement experiments were conducted to measure the effects of pore scale air fingering on k_r-S-h_c. These experiments were conducted using a novel displacement experiment apparatus which closely simulated the flow rates, pressures, and displacement rates typical of field air sparging. Air permeability breakthrough behavior was observed, where extremely low air relative permeability (k_{ra}) values would increase by up to an order of magnitude at quasi-steady saturation to approach $k_{ra}(S)$ functional relationships. Faster displacements resulted in lower k_{ra} and more extreme air permeability breakthrough. In many instances, k_{ra} followed $k_{ra}(h_c)$ functional relationships, while $k_{ra}(S)$ and $h_c(S)$ did not. A hypothetical backbone (conductive) air saturation was found to control both k_{ra} and h_c for many experiments where $k_{ra}(S)$ and $h_c(S)$ were very low. Thus, the unique air flow behaviors are inferred to reflect the development and subsequent breakthrough of pore scale dead-end air fingers, which initially do not conduct air flow.

Soil pore size distributions are recognized to control fluid fingering in porous media, yet the low air relative permeability and air permeability breakthrough behaviors could not be predicted based on physical soil properties, including common pore size distribution indices. This is consistent with the fact that non-wetting fluid invasion is controlled by variations in the size distribution of the largest pores, which control $h_c(S_w)$ behavior near air entry values. This is further supported by the observation that h_c frequently remained near the air entry pressure when extreme air fingering was inferred by low $k_{ra}(S_w)$.

Field scale air sparging may involve processes not represented at the core scale, including macroscopic air fingering. However, the effects of pore scale fingering observed here at the core scale are likely to be relevant at a scale less than the capillary length, which was determined to be from 20 cm to 10 m. Therefore it is reasonable to expect that the relative permeability curves obtained may govern air flow during field scale sparging. Additional research is needed to determine the physical soil properties which control the air permeability breakthrough, to develop k_r-S-h_c functions which properly account for the time and displacement rate dependance of air permeability breakthrough, and to assess the field-scale expression of the air permeability breakthrough behaviors.

A FIELD TEST OF LNAPL REMEDIATION BY TERT-BUTANOL INJECTION

FALTA, R.W., LEE, C.M., BRAME, S.E., ROEDER, E., WRIGHT, C., PRICE, S., HASKELL, P., and COATES, J.T., Geological Sciences and Environmental Systems Engineering Departments, Clemson University, Clemson, SC 29634-1908

A pilot scale field test of NAPL removal using miscible cosolvents was conducted at Operable Unit 1, Hill Air Force Base, Utah. Large amounts of petroleum hydrocarbons and spent solvents were disposed of in chemical disposal pits from 1954 to 1973 at this site, and these materials are now present in the subsurface in the form of a NAPL. The field experiment was performed in a 3m by 5m confined test cell, located in the vicinity of a chemical disposal pit, and it involved the injection and subsequent extraction of seven thousand gallons of a mixture of tert-butanol and n-hexanol. The cosolvent flood mobilized large amounts of the NAPL, and the results of post flood soil coring and partitioning tracer tests indicate at least an order of magnitude reduction in the level of contamination in the test cell.

THE EFFECT OF HETEROGENEITIES ON THE REMEDIATION OF LNAPLS USING COSOLVENT FLOODING

BRAME, Scott E., FALTA, Ron W., and ROEDER, Eberhard, Geological Sciences, Brackett 340, Clemson, SC 29664, scott@geology.clemson.edu, eroeder@hupcap.clemson.edu, and faltar@clemson.edu.

A field demonstration of cosolvent flooding was conducted at Hill AFB in Utah. A 3m x 5m test cell was installed down to an impermeable clay layer using interlocking sheet walls. Injection and extraction wells along with several multilevel samplers were installed inside the test cell. Once the flow regime was established, a fluorescein tracer was injected to determine the breakthrough fronts at the multilevel samplers and the extraction wells.

The fluorescein tracer test revealed that a major short circuit was occurring in the flow through the cell. The fluorescein peaked in several of the lowermost multilevel samplers before ever showing up in some of the uppermost samplers. More significantly, the fluorescein showed up in the extraction wells at about 1/8 of a pore volume. The bulk of the injected fluids were flowing along the bottom of the cell, indicating a high permeable layer.

This situation raised concerns about the delivery of the cosolvent to the contaminated region. The contaminant is primarily an LNAPL with the main concentrations found near the top of the water table. Even though the cosolvent being used, tert-butanol, has a lower density than water, there is a concern that the higher permeable unit will divert the cosolvent away from the target area. Numerical simulations were run to determine the impact of the problem and to assess the effectiveness of such actions such as partially grouting the bottom of the screen zone and the use of packers. The results of the actions taken in the field will be presented.

POTENTIAL APPLICATIONS FOR HYDRAULIC FRACTURES IN RESIDUAL SOILS

MURDOCH, Larry, Geological Sciences, Clemson University, Clemson, SC 29634

A broad range of environmental applications for hydraulic fractures have been developed based on field studies in glacial tills of the Midwestern US. Preliminary field tests and geotechnical characteristics suggest that these applications could also be used to address environmental problems in residual soils of the southeastern US.

Hydraulic fractures are created by injecting fluid into a cased borehole that is open somewhere along its length. The pressure increases during injection and a fracture is nucleated when the pressure exceeds some critical value related to depth, borehole geometry, and material properties of the enveloping formation. A slurry composed of a viscous liquid and solid granules is injected, filling the fracture as it grows away from the borehole. The solid granules prop the fracture open after injection is terminated, and it is the properties of these granules that can be exploited for remediation.

The geometry of a hydraulic fracture depends on the state of stress and material properties of the enveloping formation. A typical fracture in glacial till is roughly flat-lying in the vicinity of the wellbore and curves upward at its outer edges forming a gently bowl-shaped feature. In most cases, the fracture develops a preferred direction of propagation so that it is slightly asymmetric in plan. Lengths of 8 to 12 m and thicknesses of 1 cm are typical of fractures in the upper few m (2 to 4m). Approximately 0.25 to 0.75 m^3 of solid material can be injected into fractures of those dimensions. In general, larger fractures containing even more solid compounds can be created at greater depths.

The most common application is to use guar-gum gel, a food additive that thickens water, to suspend sand grains during injection. This creates a sand-filled hydraulic fracture that can be 3 or more orders of magnitude more permeable than silty clay. Field tests involving a wide range of fluids, including NAPL recovery and either injection or recovery of water or air, show that hydraulic fractures can increase the specific discharge of wells in low permeability formations by 10 to 100 times compared to conventional wells. Moreover, wells intersecting sand-filled hydraulic fractures affect the pressure in the formation approximately 10 times further than conventional wells. The field observations are predicted by theoretical analyses where the fractures are treated as permeable layers of appropriate geometry and conductivity.

Recent research has focused on applications that go beyond advective transport, and significant potential appears to exist for applications involving permeable barriers and electrokinetics. Reactive compounds have been injected into hydraulic fractures to create flat-lying permeable barriers. Slowly dissolving peroxides have been used with porous ceramics to create in situ bioreactors for aerobic degradation of petroleum hydrocarbons. This approach has resulted in a marked decrease in TPH at a site in Denver. Zero-valent iron has been injected into fractures to reductively dechlorinate, and solid crystals of potassium permanganate have been injected to oxidize chlorinated solvents in situ. In another application, graphite is injected into fractures to create pairs of flat-lying electrodes stacked one on top of the other. The electrode/fractures are energized with 40 to 80 amps DC to induce electroosmosis, a process that accelerates transport through fine-grained soils.

VADOSE ZONE PUMPING TESTS USING TWO INNOVATIVE, DEPTH-DISCRETE SAMPLING TECHNOLOGIES AND GASSOLVE*.

ROSSABI, J., RIHA, B.D., and PEMBERTON, B.E., Westinghouse Savannah River Company, Bldg. 773-42A, Aiken, SC 29808

Two cone penetrometer-deployable technologies, the Depth-Discrete Sampling Port (DDSP) developed at the Savannah River Site (SRS) and the FLUTe (a.k.a. SEAMIST) flexible membrane well, were used for monitoring pressure changes at several subsurface depths during vadose zone pumping tests. The pumping tests were performed to determine the zone of capture of a vacuum extraction/catalytic oxidation system operating in the M Area of SRS. The GASSOLVE analytical model was used to determine the permeability of the formation and the potential zone of capture of the extraction system. Vacuum extraction is part of an integrated remediation system in the A/M area that has removed nearly 400,000 pounds of volatile organic contaminants (VOCs) from the subsurface, both above and below the water table.

In the A/M area of SRS, several million pounds of solvent used in manufacturing operations (primarily tetrachloroethylene and trichloroethylene) were released to the subsurface as a result of early disposal practices, leaks and spills. To address the cleanup of the site, SRS personnel have installed and operated one of the most successful VOC remediation programs in the world. As part of this evolving remediation effort, SRS is striving to increase contaminant removal and optimize cost-effectiveness. One component of this strategy is to maximize the removal efficiencies of existing vadose zone extraction units by performing careful analyses of the zone of capture of these units. To determine the zones of capture, pumping tests were performed, using the FLUTe and DDSPs for pressure monitoring and the standard 4”-diameter extraction wells as sources.

The FLUTe (developed by C. Keller and available from FLUTe Ltd.) is an inverted fabric tube that is everted into a borehole using air pressure. Air pressure is maintained in the tube to press the tube fabric against the borehole and maintain a gas tight seal. The 2” diameter, 100 foot-long flexible membrane well used in these tests has nine gas sampling ports at different depths with tube connections to the surface and was installed with a cone penetrometer in less than 3 hours. All of the ports were monitored initially to determine the most permeable subsurface zones. These zones were then instrumented with a custom-designed, microprocessor controlled, pressure datalogging station. Other pressure data were taken with a series of previously installed DDSPs. Up to four of these 1”-diameter sampling ports can be installed as part of a single 1”-diameter PVC well using a cone penetrometer. The DDSP has been licensed by Timco Inc. and will be available later this spring. Both of these devices can be deployed rapidly in temporary or permanent installations and provide depth-discrete sampling capabilities at lower costs than standard well nests or clusters.

The GASSOLVE analytical model was used to analyze the pumping test data because of its simplicity, ease-of-use and accuracy in describing subsurface gas flow behavior. The proficiency of the elegant analytical methods in describing environmental scenarios is supported by the excellent results obtained in these pumping tests.

*Falta, R.W. 1996. A Program for Analyzing Transient and Steady-State Soil Gas Pump Tests, Ground Water. v.34, no. 4, pp. 750-755.

HYDROGEOLOGICAL CHARACTERIZATION AND ANALYSIS – GENERAL SEPARATIONS AREA (GSA), SAVANNAH RIVER SITE, SC[1]

HARRIS, Mary K., Westinghouse Savannah River Co., P.O. Box 616, Aiken, SC 29808, mary.harris@srs.gov; SMITS, Andrew D., Science Applications International Corp., 360 Bay Street, Suite 200, Augusta, GA 30901, a.smits@srs.gov; THAYER, Paul A., Department of Earth Sciences, University of North Carolina, Wilmington, NC 28403, thayer@uncwil.edu; FLACH, Gregory P., Westinghouse Savannah River Co., P.O. Box 616, Aiken, SC 29808, gregory.flach@srs.gov; HAWKINS, Kelley, L., Science Applications International Corp., 360 Bay Street, Suite 200, Augusta, GA 30901, k.hawkins@srs.gov.

The 15 mi^2 GSA contains more than 35 RCRA and CERCLA waste units. The extent and mobility of contaminants at these facilities require a means by which remedial alternatives can be quickly developed and evaluated. Data collected since the mid 1980's have been input into a Paradox® relational database. These include core descriptions, water elevation measurements, down-hole geophysical logs, porosity and permeability measurements; and pump and slug test data. These measurements have been combined with subjective data, such as hydrostratigraphic and lithostratigraphic picks, to develop a hydrogeologic model of the area.

The data have been synthesized for use in EarthVision® 3-D visualization software and geospatial analysis. A series of integrated maps have been produced (e.g., structure contour, isopach, percent mud, percent sand, leakance, conductivity) for input into a 3-D finite-element groundwater flow model. Using 3-D software allows almost instantaneous visualization of the data, facilitates spatial analysis, and provides feedback allowing continuous refinement of subjective data in the database (i.e., lithostratigraphic and hydrostratigraphic picks).

Utilizing a database of this type coupled with 3-D visualization software allows rapid and cost-effective updates of the area hydrogeological model. Computer mapping yields accurate 3-D subsurface depictions of hydrogeologic systems that can be related to the flow and transport of contaminants in the subsurface. These types of models expedite design optimization for groundwater corrective action programs.

[1]Information developed under contract DE-AC09-89SR18035 with the U.S. Department of Energy.

GROUNDWATER FLOW MODELING USING COMPREHENSIVE HYDROGEOLOGIC CHARACTERIZATION DATA - GENERAL SEPARATIONS AREA (GSA), SAVANNAH RIVER SITE, SC[1]

FLACH, Gregory P., Westinghouse Savannah River Co., P. O. Box 616, Aiken, SC 29808, gregory.flach@srs.gov; HAMM, L. Larry, Westinghouse Savannah River Co., P. O. Box 616, Aiken, SC 29808, luther.hamm@srs.gov; HARRIS, Mary K., Westinghouse Savannah River Co., P. O. Box 616, Aiken, SC 29808, mary.harris@srs.gov; ALEMAN, Sebastian E., Westinghouse Savannah River Co., P. O. Box 616, Aiken, SC 29808, sebastian.aleman@srs.gov.

The 15 mi^2 General Separations Area (GSA) contains more than 35 RCRA and CERCLA waste units, and is the focus of numerous ongoing and anticipated contaminant migration and remedial alternatives studies. To meet the analysis needs of GSA remediation programs, a new groundwater flow model was developed. The model spans the entire GSA, uses several types of data to define conductivity in an automated fashion, includes the vadose zone, and contains relatively fine vertical mesh resolution. The focus of this presentation is on the process used for developing model hydraulic conductivity fields using several types of characterization data, including lithologic core descriptions, down-hole geophysical logs, permeability measurements, slug tests, pumping tests, hydrostratigraphic picks, and hydraulic head data. The model preprocessor accesses the comprehensive Paradox® relational database discussed in the accompanying presentation. For rapid and efficient model updates, preprocessing of the various characterization data is performed in an automated manner using the "make" language. "Make" automatically tracks data dependencies and executes only affected portions of the data flowchart. The resulting model conductivity fields are heterogeneous and directly reflect variations present in the various characterization data. Satisfactory model calibration was generally achieved through global adjustments to the conductivity field, rather than more arbitrary spatial adjustments. Sample model results are presented, followed by a discussion of the strengths and weaknesses of the modeling approach used.formation developed under contract DE-AC09-89SR18035 with the U. S. Department of Energy.

SIMULATION OF DNAPL EMPLACEMENT AND REDISTRIBUTION USING GEOSTATISTICALLY GENERATED HETEROGENEOUS PERMEABILITY DISTRIBUTIONS

HODGES, R.A., rhodges@clemson.edu, and FALTA, R.W., Geological Sciences Dept., Clemson Univ., 340 Brackett Hall, Clemson, SC 29634; FINSTERLE, S., Earth Sciences Division, Lawrence Berkeley Laboratories, Berkeley, CA, 94720.

The M Area of the Savannah River Site was used for processing materials for nuclear production reactors. These processes involved metallurgical and mechanical operations,

and as a part of these operations, solvent cleaning and acid/caustic etching were used to prepare materials. Over a 21 year period, process effluent which contained approximately 2.0 million pounds of chlorinated solvents, mainly tetrachloroethylene (PCE) was sent to the M Area Settling Basin where it was released to the subsurface. PCE is a non-aqueous phase liquid that is denser than water (DNAPL) and flows downward subject to gravity and capillary forces. The migration pathway is controlled by the permeability variations of the lithologic units. As a DNAPL release moves through the unsaturated zone, chemicals become trapped in the soil pores by capillary forces. Because the DNAPL acts as a wetting phase in the presence of soil gas, it enters fine-grained sediments above the water table. As a DNAPL invades the saturated zone, it tends to accumulate in coarser sediments overlying finer grained sediments such as clays. As DNAPL accumulates on top of clay layers below the water table, it can continue to flow down dip, towards local topographic lows in the clay surface.

In order to perform realistic three-dimensional numerical simulations of DNAPL emplacement and redistribution in the subsurface, the heterogeneity of the subsurface must be emulated. The geology and hydrogeology was used in conjunction with generated geostatistical parameters for three lithologic units at M Area to develop a realistic model of hydrogeologic parameter distribution. A fine mesh was generated to be vertically conformable to the lithologic units. The mesh was populated with a spatially correlated “random” permeability field for each lithologic unit that incorporates unit average parameters. This information, along with historical contaminant release profiles, was used as model input for the numerical simulator.

Corporate Sponsors

The following groups and individuals have provided funds for the mixer:

Kubal-Furr & Associates
James E. Furr, Vice-President
1120 West Butler Road, Suite Q
Greenville, South Carolina
864-277-0999

Godfrey and Associates, Inc.
Steve Godfrey
P.O. Box 863
Blythewood, South Carolina
803-337-3889

A.E. Drilling Services, Inc.
Mark Lassiter, President
Two United Way
Greenville, South Carolina
864-288-1986

Cummings/Riter Consultants, Inc.
Patrick F. O'Hara, P.E., President
339 Haymaker Road, Suite 210
Monroeville, Pennsylvania
412-373-5240

Haynsworth, Marion, McKay & Guérard, L.L.P.
John Adams Hodge, Esq.
Post Office Drawer 7157
Columbia, South Carolina 29202

Hydrologic, Inc.
Becky Wood, S.E. Regional Sales Manager
Carolina Business Center
!-85 South, Building 2848, Suite E
Charlotte, North Carolina
704-392-1164

Constangy, Brooks and Smith, LLC
Charles Ormond
P.O. Box 11297
Columbia, SC 29211
803-256-3200

V. O. C. Analytical Laboratories, Inc.
Carl Baker and Ashley Amick
7435 Broad River Road, Suite 105
Columbia, SC 29063
803-781-0006