The 9th Annual David S. Snipes/Clemson Hydrogeology Symposium
April 12-13, 2001

7:30 AM Registration: Lobby

Session One: BellSouth Auditorium

9 AM Watershed Risk Analysis and Data Needs Evaluations Using GIS Applications, Gerald A. Mclane
9:30 Fecal Coliform TMDL Development for Three UBAN Watersheds in Mecklenburg County, North Carolina, David E. Kroening and Rusty S. Rozzelle

10:00-10:15 BREAK

10:15 Introduction to Thermal Remediation Methods for Organic Contaminant Remediation, Ron Falta
11:00 Steam Flood at Solvent Storage Tanks, SRS, Dave Noffsinger
11:30 Numerical Modeling of Steam Flood Designs for the M-Area Settling Basin, Savannah River Site, Rex A. Hodges and Ronald W. Falta

Session Two: Ballroom A

9:00 The Transmissive Confining Unit, A New Type of Conceptual Model for an Aquifer System, Larry Murdoch and Bill Harbor
9:30 Well Test to Characterize Idealized Lateral Heterogeneiteis, Vasi Passinos and Larry Murdoch

10:00-10:15 BREAK

10:15 Groundwater Characterization of a Site in the Milton Belt, North Carolina, Malcolm F. Schaeffer
11:00 Structural Control of Groundwater at Glassy Mountain, South Carolina Peidmont, C.M. Warlick, J.W. Castle and C.W. Clendenin
11:30 Applications of Surface Geophysics Measurements in Hydrogeology with Emphasis on Ground Penetrating Radar, Phillip Reppert

12:00-1:30 LUNCH

Session Three: BellSouth Auditorium

1:30 Fracture Closure in Extension and Stress Dependent Permeability of Jointed Rock, L.N. Germanovich, D.K. Astakhov and P.E. Dijk

2:00 Enhansed Estimation of Average Groundwater Elevation Using Curve Matching Techniques, Joseph A. Harrigan

2:30 Interpretation of Well Water Levels in the Presence of Steep Vertical Head Gradients, Gregory P. Flach

3:00-3:15 BREAK

3:15 Integration of Geological and Multiphase-Flow Medeling at the Savannah River Site, E. Roeder, J.W. Castle, R.W. Falta and C.L. Hann

3:45 An IN-SITU Measurement of Thermal Conductivity, Kirsten E. Melsheimer and Ronald W. Falta, Jr.

Session Four: Ballroom A

1:30 Speciation and Fractionation of Cadmium and Zinc in Stream Water and Bed Sediments in an Alkaline River (Nahr Ibrahim, Lebanon) Brian E. Davies, Samira I. Korfali and Laura Jacobs

2:00 Trace Elements in South Carolina Backround Soils, Judy L. Canova

2:30 Facies Control of Permeability Variation in a Sandstone Outcrop Near Escalante, Utah, C. Lorinovich, J. Castle, R. Bridges, C. Dinwiddie, F. Molz and S. Lu

3:00-3:15 BREAK

3:15 New Field-Scale Applications for Hydraulic Fracturing, Bill Slack and Joey Koon

3:45 An Analytical Study of the On-Site Waste Disposal Systems Operation in the Lake Keowee Watershed, Earl W. Meyer and Stewart Christner

Poster Session: Lobby

Transport of Microbial Pathogens in Saprolite Soils, M. Rietti-Shati, L.D. McKay, A.C. Layton and K. Smith

The Distribution of Maastrichtian (Upper Cretaceous) Depositional Environments in the Coastal Plain of Georgia and South Carolina, R.A. Bridges, H.L. Desteano, C.J. Lorinovich, K.L. Mize and Q. Tan

4:30-7:00 Social Hour Geology Museum

Abstracts

WATERSHED RISK ANALYSIS AND DATA NEEDS EVALUATIONS USING GIS APPLICATIONS

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A GIS project was developed to display and evaluate the vast amount of environmental, geographic, and hydrogeologic data available for the Savannah River Site's (SRS) Integrator Operable Unit (IOU) program. The IOU program is performing RI/FS/BRAs on potentially contaminated surface water bodies within the site's six watersheds. These surface water bodies are referred to as IOUs because they ultimately integrate all site-related contaminants to points of potential human and ecological receptor exposure. The project assembles the graphic and tabular data in a user-friendly format whichformat that enables analysis of every aspect of the conceptual site model. Existing data needs are easily identified, and the rationale supporting the identification of these data needs is unambiguously communicated. The most significant feature of the IOU GIS project is a customized utility application which allows users to perform real-time human healthapplication, which allows users to perform real-time human health, and ecological risk evaluations, obtain statistical summaries, and create scatter time series plots of the environmental data of interest. Unlike previous hard copy deliverables, a fully-automatedfully automated compact disc effectively communicates the maps, tables and hundreds of thousands of analytical records from a relational database. This enables reviewers to select and manipulate the graphic and/or tabular data of interest and customize it to their specific evaluation needs.

FECAL COLIFORM TMDL DEVELOPMENT FOR THREE UBAN WATERSHEDS IN MECKLENBURG COUNTY, NORTH CAROLINA.

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Sugar Creek, Little Sugar Creek and McAlpine Creek drain the most urbanized area of Mecklenburg County, North Carolina to the Catawba River System in South Carolina. These creeks have been identified on North Carolina's Draft 2000 303(d) list as water bodies that do not meet the minimum water quality standard for fecal coliform, due to point sources, urban runoff and storm sewers. For these creeks, the fecal coliform 30-day geometric mean standard of 200 c.f.u. /100 ml was applicable. Additionally, the standard states that exceedances are expected during storm flow conditions, therefore fecal coliform loading from storm water runoff were not included in the allocations. Because of this, fecal coliform Total Maximum Daily Loads (TMDLs) were developed for these creeks.

The TMDL process establishes the allowable loadings of pollutants and other quantifi-

able parameters for a water body based on the relationship between pollution sources and in-stream water quality conditions. Once the relationship has been established, various management and pollution reduction strategies can be implemented to restore water quality of the water body. Typically, TMDLs are comprised of a source assessment, water quality model, source allocation and implementation strategy.

Beginning in 1999, a combination of field investigation of surface and ground water, GIS analysis and evaluation of existing water quality data were utilized to assess the sources of fecal coliform in Mecklenburg County. The assessment included analysis of the contributions from waste water treatment plants (WWTPs), sanitary sewer overflows, stormwater runoff, failing septic systems, dry weather flow from the storm drain system, wildlife and exfiltration from sanitary sewer pipes.

Subsequent to completion of source assessment, continuous simulation water quality models (HSPF) were prepared for each of three TMDL watersheds. A combination of local and regional data was used to populate the models, which were initially calibrated to current conditions for 1999. The model results indicated that the greatest exceedance of the fecal coliform standard occurred during periods of low flow in the creek coinciding with high fecal coliform loads from WWTPs and sanitary sewer overflows.

The water quality models were then used to support the development of a fecal coliform source reduction strategy. The source reduction strategy adopted a significant reduction in sanitary sewer overflows, exfiltration from sanitary sewer lines, dry weather flow from the storm drain system and failing septic systems. Furthermore, a maximum daily fecal coliform concentration was adopted for the municipal WWTPs. The source reduction strategy resulted in a 34.5%, 70.4% and a 34.5% reduction in the 30 day geometric mean fecal coliform concentration in Sugar Creek, McAlpine Creek and Little Sugar Creek respectively.

INTRODUCTION TO THERMAL REMEDIATION METHODS FOR ORGANIC CONTAMINANT REMEDIATION

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Thermal methods are emerging as a viable source zone treatment option for many sites contaminated with organic compounds. Thermal methods generally work by increasing the vapor pressure and Henry's constant of organic contaminants to allow more favorable partitioning into the gas phase. Because the gas phase tends to be much more mobile than liquid phases, high contaminant removal rates can often be achieved. Although thermal methods are most commonly applied above the water table, they can also be used below the water table provided that the gas flow can be controlled. The coupled thermodynamic and multiphase flow phenomena that occur during application of thermal methods are often somewhat unusual and counterintuitive, but many of these phenomena can be exploited for improved contaminant recovery.

The various thermal methods are distinguished by the method used for heat energy delivery. Steam flooding (also called "dynamic underground stripping") is probably the fastest, and most widely applicable technique. Although steam zone temperatures are limited to about 100-120^{o}C, steam treatment may be effective on contaminants with somewhat higher boiling points. Recovery of contaminant vapors, control of mobilized NAPL, and the behavior of semi-volatile and nonvolatile components are special issues of concern.

NUMERICAL MODELING OF STEAM FLOOD DESIGNS FOR THE M-AREA SETTLING BASIN, SAVANNAH RIVER SITE

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The Savannah River Site (SRS) is located in west central South Carolina where the geology is dominated by sediments of the Coastal Plain province. The disposal of solvents (non-aqueous phase liquids, NAPLs, primarily PCE and TCE), used in manufacturing operations at M-Area to an unlined settling basin and to a nearby tributary, the A14 outfall, has created a significant subsurface contamination problem. An estimated 2 million pounds of solvents were discharged through an open sewer line to the M-Area settling basin and an additional 1.5 million pounds were discharged to the A14-outfall. Remediation efforts began in the early 1980's and have grown to include two full-scale pump and treat systems and six vacuum extraction remediation systems. Combined, more than 1.5 million pounds of solvents have been removed from the subsurface. Despite the success of conventional remediation methods, the time frame for cleaning up M-Area is measured in decades. The use of a more aggressive method, such as steam flooding, can remove the majority of contaminant from the source zone, decreasing remediation time and lowering overall costs. In a steam flood, steam is injected in wells surrounding the targeted source, spreading outward as a front, heating the surrounding formation. As the front expands, contaminants are mobilized toward centrally located extraction wells (combined SVE and water).

Several designs have been modeled, using the numerical simulator T2VOC, to predict heating patterns for a proposed M-Area settling basin steam flood. A "focused" design targets a source zone in the northern part of the basin where the process sewer line discharges. A total of 25,000 lbs/hr of steam is injected for a year in 3 levels (2 in the vadose zone and 1 in the saturated zone) at 8 sites surrounding the target. Contaminant is removed through 7 extraction wells. A "strategic" design strives to steam flood the entire basin by injecting 29,000 lbs/hr of steam for a year in 5 levels (3 in the vadose zone and 2 in the saturated zone) at 16 sites surrounding the entire settling basin. To coordinate arrival of the fronts in the northern part of the basin near the sewer line discharge point, steam is injected at a higher rate in the wells south of the basin. Extraction is from a 6 well pattern centered in the northern part of the basin. Five of the six extraction wells are angled (from 25 to 45º) to access the target zone beneath the basin cap without puncturing the cap, an advantage of the strategic design. A configuration that enhances the strategic design by injecting air to control the spread of the steam front is also simulated. This is a technology recently developed and tested by Bo Stewart of Praxis Environmental Technologies. Air injection wells placed opposite the target from the steam injectors limit the outward radial spread of the steam front, directing the steam towards the target and extraction well system.

THE TRANSMISSIVE CONFINING UNIT, A NEW TYPE OF CONCEPTUAL MODEL FOR AN AQUIFER SYSTEM

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A 16-day-long well test was conducted near Flakkebjerg, Denmark in a sand aquifer overlain by a 10-m-thick silty clay till. The aquifer and overlying till resemble a classic confined aquifer system, but drawdowns measured in four piezometers in the sand vary markedly from the behavior predicted by the Theis solution; they increase at several times during the test. A new conceptual model of a *transmissive confining unit* that releases little water from storage, but that can readily transmit recharge flux is introduced to characterize this site. This conceptual model differs from standard of models of aquifers that assume the overlying unit is either impermeable (Theis model), or leaky and defined by a type 3 boundary (Hantush model), or characterized by release of water stored in pores (unconfined). A theoretical analysis based on this conceptual model is used to estimate *T* and *S* of the aquifer, and to predict the recharge history during the well test. Recharge rates predicted by the analysis range up to 1.6 mm/day, and the history of recharge closely resembles the history of rainfall during the test. Four rainfall events occurred during the test, and the analysis predicts that recharge occurs as 4 pulses that start during the rainfall and last for a few days. The average recharge rate predicted during the test is remarkably similar to the recharge rate determined independently during the calibration of a regional model. The results of this investigation indicate that it seems to be feasible to determine the transient recharge flux during well tests. Moreover, an extension of the conceptual model will predict the onset of steady state conditions by capture of distributed recharge, which appears to be an important process controlling the performance of many shallow wells.

WELL TESTS TO CHARACTERIZE IDEALIZED LATERAL HETEROGENEITIES

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The hydraulic properties of vertical layers and contacts between different aquifer materials are important to applications ranging from the compartmentalization of reservoirs to the remediation of aquifers. Despite their importance, there are few options for determining the hydraulic characteristics of lateral heterogeneities using field techniques. To address this issue, we have conducted numerical experiments designed to evaluate the possibility of using data from constant-rate pumping tests in the vicinity of idealized lateral heterogeneities. One type of heterogeneity consists of a long vertical strip whose hydraulic conductivity contrasts with the surrounding aquifer. The thickness and hydraulic conductivity of the vertical strip were varied to examine how they affect the drawdown in the area of the layer. The effects of the strip can be recognized on a semi-log plot by two straight-lines with the same slope connected by a sigmoidal curve. A derivative plot shows this behavior particularly well. The preliminary results of numerical experiments indicate that the drawdown response depends on the layer conductance, specifically the ratio of hydraulic conductivity to layer width, but it is relatively insensitive to the conductivity or the width individually. Type curves have been generated for this problem and used to analyze field data from a well test conducted in the vicinity of a suspected fault in the Piedmont region of

South Carolina. We have also evaluated the possibility of characterizing aquifers that consists of two regions with slightly different properties that are bounded by a vertical contact. This problem can be solved using an analysis that reduces to the Theis solution for the homogenous case. Preliminary results using this analysis suggest that it is possible to estimate the position of a vertical contact by graphically interpreting well test data. Inverse methods using the analytical solution allow both the location of the contact and aquifer properties of both regions to be determined.

GROUNDWATER CHARACTERIZATION OF A SITE IN THE MILTON BELT, NORTH CAROLINA

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The geology/groundwater conditions at a site in Stokes County, North Carolina have been studied utilizing field and laboratory methods and the conditions have been found to be consistent with the characteristics of the conceptual groundwater model developed by LeGrand (1988, 1989) for the Piedmont region. As such, there is nothing geologically or hydrologically unusual about the site that would preclude its use as an ash landfill. The subsurface geologic/hydrologic conditions at the site are described and hydraulic conductivity values have been calculated for the subsurface material. These form the basis for the hydrologic evaluation of landfill performance and the groundwater transport model of the site.

The site is in the Milton belt, one of several northeast-trending geologic belts of the southern crystalline Appalachians. The Milton belt is characterized by strongly foliated gneiss and schist, commonly with distinct compositional layering and having felsic composition; quartzite, calc-silicate gneiss, and marble are minor units (Carpenter, 1982). The available evidence suggest that the rocks of the Milton belt are mainly Precambrian in age and were metamorphosed and deformed during the early to late Paleozoic (Butler and Secor, 1991). The majority of the rocks in the belt are metamorphosed to the sillimanite and kyanite grade of amphibolite metamorphism. A steep metamorphic gradient occurs along the southeastern boundary where the grade decreases to the chlorite zone of greenschist metamorphism in the adjacent Carolina slate belt (Butler and Secor, 1991). This boundary with the Carolina slate belt is also a lithologic discontinuity and is marked locally with sheared rocks (Carpenter, 1982). The southwestern boundary of the belt is placed where the gneiss and schist units give way to the dominant non-layered mafic and felsic intrusive rocks of the Charlotte belt (Butler, 1980). The Sauratown Mountains Anitclinorium and the Dan River Triassic Basin lie to the northwest of the Milton belt.

Rock units mapped in the vicinity of the site include alluvium, terrace deposits, sedimentary rocks of the Triassic Dan River Basin, diabase dikes, and felsic gneisses and schists of the Milton belt (Figure 1). The alluvium consists of unconsolidated sand, silt, and clay with occasional subhedral to well-rounded pebbles and cobbles. The terrace deposits consist of unconsolidated sand, silt, and clay, with pebbles and cobbles of quartz. In places, the terrace deposits are comprised of large angular quartz fragments in a red matrix of sand, silt, and clay. The diabase occurs in long, relatively thin dikes of fine- to medium-grained diabase. The metamorphic rocks of the Milton belt include interlayered augen gneiss, quartzo-feldspathic gneiss, flaser gneiss, “button” mica schist, and mica schist with minor, thin interlayers of hornblende gneiss and schist.

The hydrogeology of the Piedmont region is different from and has to be considered in a different way from conventional sedimentary aquifer systems (LeGrand, 1988). LeGrand (1988, 1989) has developed a conceptual groundwater model for the Piedmont Province. In the Piedmont region, a thoroughly weathered and structureless material termed residuum occurs near the ground surface with the degree of weathering decreasing with depth. The residuum grades into a coarser-grained material that retains the structure of the parent bedrock and is termed saprolite. Beneath the saprolite,

partially weathered bedrock occurs with depth until sound bedrock is encountered. This mantle of residual soil, saprolite, and weathered rock (regolith) is a special hydrogeologic unit that covers and crosses various types of rock. (LeGrand, 1988). It provides an intergranular medium through which the recharge and discharge of water from fractured rock commonly occurs. A transition zone at the base of the regolith is present in many areas of the Piedmont (Harned and Daniel, 1989). In this zone the unconsolidated material grades into the bedrock. It consists of partially weathered bedrock and lesser amounts of saprolite. This zone may serve as a channel for rapid movement of groundwater toward the discharge points. The fractured nonporous bedrock is the most abundant lithologic unit underlying the Piedmont region (LeGrand, 1988). It includes many different types of igneous and metamorphic rocks. The fractures control both the hydraulic conductivity and the storage capacity of the rock mass (Trainer, 1988). LeGrand's (1988,1989) conceptual model incorporates the above two medium system into an entity that is useful for the description of groundwater conditions. That entity is the surface drainage basin that contains a perennial stream (LeGrand, 1988; see Figure 1). Each basin is similar to adjacent basins and the conditions are generally repetitive from basin to basin. Within a basin, movement of groundwater is generally restricted to the area extending from the drainage divides to a perennial stream (Slope-Aquifer System; LeGrand, 1988, 1989). Rarely does groundwater move beneath a perennial stream to another more distant stream (LeGrand, 1989). Based on the field studies the groundwater system at the Stokes County Site is basically a two medium system restricted to the local drainage basin, consistent with the LeGrand model (1988,1989).

There are 18 monitoring/observation wells (12 permanent, 6 temporary) as well as 6 additional borings at the site. Eleven falling head permeability tests were performed in five wells/borings. Slug tests were conducted in ten of the monitoring wells. The hydraulic conductivity (k) of the materials in both tests were calculated by the variable head method. Soil sampling and penetration testing (STP; ASTM D1586) were performed at regular intervals and the soil samples saved for later inspection and laboratory classification. Undisturbed samples from the wells and borings as well as bulk samples from auger cuttings were collected for laboratory testing. Laboratory testing included natural moisture content (ASTM D2216), soil plasticity (ASTM D4318), grain size distribution (ASTM D422), compaction (Standard Proctor compaction tests, ASTM D698), and permeability testing (USCOE EM110-2-1906) on undisturbed samples as well as on remolded soil collected at various depths from auger cuttings.

The soils encountered during the drilling of the wells and boreholes are the product of the in-place weathering of the underlying bedrock. In the areas not altered by excessive erosion or the activities of men, the typical residual profile consists of clayey soils near the surface overlying sandy silts to silty sands to sands). The residuum is very thin in the area and over much of the site has been removed. The residuum is underlain by saprolite followed by weathered/fractured rock overlying sound rock.

The weathering of the bedrock is facilitated by fractures, joints, and by the presence of less resistant rock types. Consequently, the profile of the partially weathered rock and sound rock can be quite irregular and erratic, even over short distances. It is possible to find lenses and/or boulders of hard rock and zones of partially weathered rock within the soil/saprolite mantel, well above the sound bedrock level. The main rock types underlying the site are mica schist, schistose mica gneiss, augen gneiss, flaser gneiss, quartz-feldspathic gneiss, biotite gneiss and minor hornblende schist/gneiss. Diabase dikes were not noted within the footprint of the landfill, however, some may be present. The mica schist is coarse-grained, well-foliated, “button” schist composed of muscovite and quartz with pinhead garnets. Interlayered with the “button” schist are thin layers of mica schist (non-“buttoned”) and fine- to medium-grained schistose mica gneiss. The augen gneiss is a fine- to medium-grained rock with a well-developed foliation wrapping around conspicuous pods or “eyes” of feldspar. They are comprised primarily of quartz, feldspar, and mica. The flaser gneiss consists of small lenses of granular materials (quartz-feldspar-mica) separated by wavy ribbons and streaks of finely crystalline, foliated materials (primarily mica). The quartzo-feldspathic gneiss is a medium- to coarse-grained, foliated, normally mica-poor rock, although some massive varieties have up to 15% muscovite. The hornblende schist/gneiss is a fine- to coarse-grained, dark colored rock composed of hornblende, biotite, and plagioclase. It is semi-massive to well foliated and occurs in thin layers. Based on the borehole data, the flaser gneiss is the most common rock type underlying the site followed by mica schist-schistose mica gneiss.

All the rock types are interlayered and the felsic rocks grade laterally into each other. The contacts of the hornblende schist/gneiss with the felsic rocks are generally sharp. The compositional layering is parallel to the strongly developed foliation. The orientation of the foliation is relatively consistent throughout the area (N72E; 67SE). The presence of “button” schist, augen gneiss, and flaser gneiss indicates that the rocks have been strongly deformed and sheared, probably during at least two episodes of isoclinal folding ("buttons" are formed by the intersection of two, nearly parallel, foliation planes). The deformation was ductile, although the presence of thin layers of flaser gneiss suggests that some of the deformation occurred under semi-brittle to brittle conditions.

Data on the orientation of fractures in the bedrock underlying the fill is sparse due to few and relatively poor bedrock exposures. Three joint sets have been observed in outcrops: 1) N20-40W with steep dips (>70^{o}), 2) NS to N20E with steep dips (>70^{o}), and 3) a set parallel to layering/foliation (about N60–70E with dips ranging from 30^{o} to vertical). In the mica schist, very few joints are present and are generally filled with clay. The gneissic rocks tend to have more fractures, but they are generally limited to the width of the gneissic layer. The are generally clay-filled in the saprolite/weathered rock zone. The hornblende-rich rocks have very few fractures associated with them. Steeply dipping joints and joints parallel to layering/foliation were encountered in all eight boreholes in which rock coring was performed. A zone of iron/manganese (Fe/Mn) stained joints is present in seven of the boreholes. The presence of Fe/Mn staining on joints indicates past percolation of groundwater through the rockmass. The data suggest that the fractured bedrock aquifer (as defined by LeGrand, 1988, 1989) is relatively thick (at least 20 feet).

Based on the boring data, the material in the subsurface at the site is divided into four layers:

1. Layer 1 – Residual soil and saprolite consisting primarily of sandy silts (ML) and silty sands (SM) with a Standard Penetration Resistance of N$\leq$30. It ranges in thickness from 10.6 to 43.3 feet with an average thickness of 25.2 feet.
2. Layer 2 – Saprolite and weathered rock consisting of sandy silts (ML) and silty sands (SM) with layers of moderately to very severely weathered rock. It has Standard Penetration Resistance of N>30. Its thickness ranges from 1.2 feet to 30.0 feet with an average thickness of 17.6 feet.
3. Weathered rock/fractured rock – consists of very severely weathered to slightly weathered rock and fractured rock. This layer is defined as the material below auger refusal with Recovery of less than 90% and Rock Quality Designation (RQD) of less than 50%. The weathered rock/fractured rock layer below auger refusal ranges from 0 (in one borehole MW2-3) up to 40 feet in thickness. The thickness of weathered rock above auger refusal (in Layer 2) is estimated at 5 to 11 feet based on site and local boring data.
4. Sound Rock – defined as rock with Recovery $\geq$ 90 and RQD $\geq$ 50.

Layers 1 and 2 correspond to the upper residuum/saprolite layer and Layers 3 and 4 correspond to the fractured bedrock layer of LeGrand's conceptual model. The transition zone occurs along the base of Layer 2 and top of Layer 3.

Groundwater data from October 2000 was used to prepare a contour map of the groundwater table. The water table contours were controlled by the groundwater elevation in the monitoring well and the assumption that the topography of the water table is a subdued replica of the land surface. The path of water movement is restricted to the zone underlying the gross topographic slope extending from the surface divides to the streams. The altered topography associated with the existing ash landfill has changed the drainage and groundwater conditions in the southwest corner of the drainage basin. The groundwater near the drainage divide spreads divergently according to the water table gradients

Hydraulic conductivity values, k, for the soils and rock at the site are summarized in Table 1. This data has been grouped according to its subsurface layer in which the tests were made, except for rock where Layers 3 (weathered rock/fractured rock) and 4 (sound rock) were combined, and the mean and median k values calculated. The highest

	Mean (cm/sec)	**Count-N**	**Maximum** (cm/sec)	**Minimum** (cm/sec)	**Median** (cm/sec)	**Std. Dev** (cm/sec)
Layer 1	9.1E-05	11	3.6E-04	2.5E-06	1.4E-05	1.2E-04
Layer 2	1.5E-04	11	5.0E-04	5.0E-06	9.7E-05	1.5E-04
Rock (Layers 3 and 4)	3.7E-04	5	9.9E-04	5.5E-06	7.8E-05	4.6E-04

Table 1: Hydraulic Conductivity Values 'k' for Defined Layers at the Site.

permeability values are found in Layer 2 - Saprolite and weathered rock within the transition zone between the regolith and the sound bedrock. This zone may serve as a conduit for more rapid movement of groundwater to discharge points in the drainage basin (as suggested by Harned and Daniel, 1989) with less infiltration of the bedrock. Three of the rock permeability measurements were made in the weathered rock/fractured rock layer and two of the rock permeability measurements were made in the sound rock layer (Table 1). The values for the sound rock are higher than for the weathered/fractured rock layer. Because of this, all five values were used to arrive at a value to use for both of the rock layers in a hydrologic model. All of the data has been combined to produce eight geologic cross-sections of the site. These form the basis for the geologic model of the site.

The geology/groundwater conditions at the site are consistent with the characteristics of the conceptual groundwater model developed by LeGrand (1988, 1989) for the Piedmont region. The subsurface conditions at the site have been described and hydraulic conductivity values have been calculated for the subsurface materials. Geologic cross-sections have been developed that form the basis for the hydrologic/groundwater models of the site. This modeling work is presently underway.

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STRUCTURAL CONTROL OF GROUNDWATER AT GLASSY MOUNTAIN, SOUTH CAROLINA PIEDMONT

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Lithologies and structures of Glassy Mountain, which is located north of Greenville, South Carolina, were mapped for the purpose of locating structural trends that control groundwater supply for a major, new residential development. Mapped features in the new development, which is known as the Cliffs at Glassy, show that lithostratigraphic and structural relations are more complex than previously recognized within this part of the Inner Piedmont. Three principal lithostratigraphic units are recognized within the study area: the Henderson gneiss, Upper Mill Spring unit, and Poor Mountain Formation. The contact between the Henderson gneiss and the overlying Upper Mill Spring-Poor Mountain sequence is mapped as the Sugarloaf Mountain Thrust. The contact between the Upper Mill Spring unit and the overlying Poor Mountain Formation is also recognized as a thrust contact. Structural relations, including contacts and fold vergence indicate that the Poor Mountain-Upper Mill Spring sequence is overturned and nonconformable.

Three periods of brittle faulting are exposed in the Cliffs at Glassy. The initial period is defined by pods of silicified cataclasite along the fault planes, while left- and right-lateral brittle faults of the subsequent periods are unsilicified. The identification of unsilicified down-to-the-south faulting along the south face of Glassy Mountain implies that an east-northeast trending branch of the Marietta-Tryon graben may be present between Glassy Mountain and Pax Mountain, immediately to the south.

The geologic relationships recognized in this study serve as a basis for understanding the groundwater supply for the Cliffs at Glassy. A pump test conducted in the community's main well field indicates a strong influence from surficial water, storage in saprolite, and silicified and unsilicified faults mapped proximal to the well field. The well test data is analyzed using the Theis solution with conceptual considerations given to the specific hydrologic conditions on Glassy Mountain.

APPLICATIONS OF SURFACE GEOPHYSICS MEASUREMENTS IN HYDROGEOLOGYWITH EMPHASIS ON GROUND PENETRATING RADAR

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In hydrogeology, monitoring of conditions is often conducted using boreholes and wells. While this can be and effective method, it has two major drawbacks: one is that these are point location measurements, and two, these measurements can be costly and time consuming. Surface geophysical measurements in many cases can provide a more complete picture of the subsurface, filling in the missing data between wells. Surface geophysical measurements can also be a cost effective method to monitor and characterize the subsurface. This talk will discuss several geophysical methods and potential uses in hydrogeology. These methods are resistivity, seismic, EM self-potentials, and ground penetrating radar. Special emphasis will be given to applications involving ground penetrating radar.

FRACTURE CLOSURE IN EXTENSION AND STRESS DEPENDENT PERMEABILITY OF JOINTED ROCK

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We have considered sets of parallel joints (open fractures) that represent one of the typical pathways for fluid flow in sedimentary rocks. It is well known that in many cases rock permeability depends upon the in-situ stress conditions and on the pressure of the flowing fluid. Frequently, joint sets are closely spaced and although joint mechanical interaction should significantly affect their aperture, the interaction is usually ignored in permeability evaluation. This approach corresponds to the upper limit for rock permeability. By accurately computing the interaction between the joints, we show that modeling a joint set by an infinite array provides the lower limit. Furthermore, based on the conducted computations and physical experiments, we suggest that the internal pressure can, in fact, close the pressurized joints. In general, there is a critical spacing between the joints below which their surfaces start contacting under the extensional load, dramatically reducing rock permeability. Furthermore, unless the number of joints in the set is very large (> 10^3), the fluid flow through the joint set becomes highly heterogeneous. We obtained asymptotically accurate, closed-form expressions for stress-dependent permeability. The expressions do account for joint interaction and show that the permeability dependence on the joint spacing is not monotonic and is always lower (often by orders of magnitude) than that based on the assumption of non-interacting joints. While the bulk of the model is devised based on the regular, symmetric segment arrangements, we have also started investigating the effects of non-ideality of joint set geometry that is typical for natural fracture systems.

ENHANSED ESTIMATION OF AVERAGE GROUNDWATER ELEVATION USING CURVE MATCHING TECHNIQUES

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In preparation for a large-area multi-layer groundwater flow model for a large facility located in central Florida, monitoring well construction specifications and water-level data were compiled to evaluate their usefulness for the model construction and calibration. Numerous sites exist at this facility that were investigated at various times over the past 10 years. Consequently, water-level data are inconsistent and comprehensive water level data were not available. Due to the lack of uniformity of water-level data, the meaningfulness and compatibility of the "average" groundwater elevation calculated from the measured data was questionable. Results of the initial averaging of water level data at this facility, in some cases, produced significantly different "average" groundwater elevations in nearby wells and located at adjacent sites. The inclusion of the sites inside and outside the main study area was necessary to provide sufficient hydraulic control points within the study area to provide a model domain large enough to minimize impacts from boundary conditions on flow and transport dynamics.

A "curve-matching" procedure was developed and implemented to produce a uniform calibration data set using the varying groundwater elevation data within the model domain. Water-level measurements from nearby U.S. Geological Survey (USGS) groundwater wells were used as the basis for the curve matching procedure. Three USGS monitoring well data sets were used to verify groundwater trends. Local precipitation data, in the form of a cumulative-departure-from-normal plot, was compared with the USGS monitoring well data sets to qualitatively evaluate coincidence of trends. The groundwa-

ter elevation data correlated with the precipitation data showed increases in rainfall resulting in rising groundwater elevations, and conversely, decreases in rainfall resulting in falling groundwater elevations.

The curve matching consisted of the following plots: the benchmark hydrographs (USGS wells) and the comparison plot (site groundwater data). The time axis (x-axis) and the groundwater elevation axis (y-axis) of both plots (the benchmark hydrographs and the site well hydrograph) were set the same. Each site well hydrograph was overlaid on the benchmark hydrographs, one at a time, and a curve matching was attempted. After the curve match was centered, the average water level line from the benchmark hydrographs was traced to the site well hydrographs. This became the average ground water elevation for the particular site well, and resulted in lowering the average groundwater elevation for measurements collected during predominantly "high elevation" times, and raising the average for the converse situation. Average water-level data generated using this technique resulted in facility-wide average groundwater elevations that represent natural site conditions. This technique provided the data users with a "comprehensive" average water-level data set that could be applied across the model domain.

INTERPRETATION OF WELL WATER LEVELS IN THE PRESENCE OF STEEP VERTICAL HEAD GRADIENTS

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In the presence of steep vertical hydraulic head gradients, conventional interpretation of well water levels can be grossly inappropriate. For example, a well water level measured within the screen zone does not necessarily correspond to the water table elevation, when the vertical gradients are steep. More specifically, a well may be lie well below the formation water table, and yet exhibit a water level inside the casing that is below the top of the screen. This phenomenon was inferred at the Savannah River Site R-Reactor Seepage Basins from Cone Penetration Testing (CPT) with soil moisture and resistivity sensors, and concurrent "water table" well data. Subsequent analytical and numerical analyses demonstrate the phenomenon is physically possible, and define the necessary hydrogeologic conditions. The CPT and "water table" well data are then used to estimate vertical hydraulic conductivity at field-scale at the R-Reactor Seepage Basins. The resulting estimates confirm that the upper strata have very low hydraulic conductivity and behave more like a confining zone than an aquifer zone.

INTEGRATION OF GEOLOGICAL AND MULTIPHASE-FLOW MODELING AT THE SAVANNAH RIVER SITE

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The A/M area settling basin at the Savannah River Site, South Carolina, was used to dispose of liquid wastes. The resulting contamination of the vadose zone and groundwater, in particular by chlorinated solvents, has motivated studies to assess the geology, contaminant transport, and remedial options. Recently, three-dimensional geological models, defined here as quantitative, high-resolution representations of the subsurface, have been constructed of the area around the settling basin. The objective of the project is to demonstrate integration and utilization of such geological models with multiphase flow simulations, which can be used for predictions of contaminant fate and transport. The geological modeling software used in this study is IRAP-RMS, and the flow simulator is T2VOC v.2.

The geological modeling has involved using the available core and geophysical log information to create high-resolution interpolations of the measured properties. Interpolations of one parameter can be conditioned to the values of another parameter (e.g., percent clay to gamma ray). The final product of this step is a geological model with property values at every cell of the geological modeling grid. The two properties that we have focused on are permeability and grain-size class.

The resolution of the geological model is too high to use it directly as input for a flow and transport simulator. Therefore, the properties of several grid blocks of the geological model must be aggregated into properties of one grid block of the flow model. This upscaling can be done within the geological modeling software. Grid geometry and property data can then be exported from the geological model.

We implement a transfer program to create part of the input deck for T2VOC (ELEME and CONNE blocks) and MODFLOW (bas and bcf files). For multiphase flow simulations, capillary pressure and relative permeability parameters are needed. These can be related to permeability values or grain size, and facies information can be used. In the case of T2VOC, we have several options regarding the extent to which facies information is used. We are investigating the model response to different combinations of permeability and facies information. For comparison purposes, we use steady-state moisture distribution and responses to soil vapor extraction tests.

AN IN-SITU MEASUREMENT OF THERMAL CONDUCTIVITY

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Thermal conduction heating and subsequent vacuum extraction is a recent in-situ technology used for the removal of contaminants from the subsurface. Thermal remediation uses property changes that occur with a change in temperature to help remove contaminants. During thermally enhanced soil vapor extraction, a heat source is placed in the vadose zone near the contaminant plume and extraction well(s), aiding in the removal of the contaminants from the subsurface. An increase in temperature causes a increase in vapor pressure, aqueous solubility, Henry's constant, desorption and diffusion rates. A temperature increase also causes a decrease in liquid viscosity and interfacial surface tension. All of these changes can increase contaminant mobility and removal.

The thermal conductivity of a formation is an important factor to consider when using thermal conduction heating as a remediation technique. The conductivity of a region will help determine the number of heat sources, as well as how far apart the heat sources should be placed when designing a thermal remediation process at a contaminated site. This presentation shows an in-situ method to measure thermal conductivity of soil, using a conduction analytical solution. The solution utilized temperature measurements taken during the field experiment at Simpson Station, as well as an average power input during the experiment. The research also determined the isotropic nature of the Piedmont soils at Simpson Station, as well as the symmetry of the heating pattern in soils.

The results of this research indicated that the horizontal and vertical thermal conductivity of the field test site is 1.9 W/mºC, suggesting that the soils may be isotropic. The analytical solution provided an excellent match with the data. The field experiment also demonstrated that the heating pattern in Piedmont soils is uniform. The results from this research showed that the analytical solution yields accurate temperature distributions in low-heat applications. The results also showed that the analytical solution yields accurate temperature distributions in low-heat applications, but that in high-heat applications where convective and evaporative effects become significant, the model will overestimate the temperature close to the heat source.

SPECIATION AND FRACTIONATION OF CADMIUM AND ZINC IN STREAM WATER AND BED SEDIMENTS IN AN ALKALINE RIVER (NAHR IBRAHIM, LEBANON).

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Most zinc and cadmium discharges arise from human activities. Zinc and cadmium entering waterways are captured by sediments but may subsequently be released. Self-cleansing in rivers is controlled by the ability of suspended sediments to retain metals. Zinc toxicity to aquatic organisms depends on physical and chemical forms of zinc and problems are least in alkaline rivers. The objectives of this research were to characterise and compare the aqueous speciation and sediment forms of selected metals (Ca, Mg, Zn, Cd) in a carbonate dominated river and hence obtain a fuller understanding of the fate of aqueous pollutants.

The river Nahr Ibrahim flows north of Beirut in Lebanon. Its catchment (330 km^2) is largely underlain by limestone. There were five sampling sites along a 13-km stretch from the confluence with the Mediterranean The annual average precipitation for Beirut is 930 mm and 86% of this falls in winter. Summer precipitation is negligible and the river is fed entirely by baseflow from aquifers. Results are reported for zinc and cadmium in summer in water and bed sediments.

Solute analysis was on filtered (0.45 µm membrane) water. Sediments (<75 µm) were subjected to sequential extraction to yield operationally defined fractions. Water solute speciation was modelled by MINEQL+. The sediment mineralogy was determined by x-ray diffraction..

Saturation indices with respect to Cd/otavite, Mg/dolomite and Ca/dolomite-calcite were zero and the aqueous metal species represented only a small proportion of the apparent total metal implying that colloid transport may be important. For Zn, water was undersaturated with respect to $ZnCO_3$ and all Zn was soluble. Rivers are open systems with respect to dissolved carbon dioxide and pCO2 is usually taken as $10^{-3.5}$ bar. However, there can be wide fluctuations. The effect of allowing pCO_2 to vary from $10^{-4.0}$ to $10^{-1.0}$ bar was investigated. Small increases from $10^{-3.5}$ bar resulted in the water being dominated by the anionic ion pair $Zn(CO_3)_2^{-2}$. Cadmium speciation was not pCO_2 sensitive. X-ray diffraction analyses of sediment showed peaks corresponding to quartz, calcite and dolomite. The highest percentage (55 – 60%) of sediment Cd was in the carbonate fraction followed by the moderately reducible fraction (16 – 24%). Zinc was approximately equally distributed among the same fraction.

Calcium and Mg may form colloidal carbonates on to which Zn sorbs whereas Cd diffuses into the colloids to form a Ca-Cd solid solution. These carbonate colloids deflocculate and contribute to the bed sediment. The hydrous oxide colloidal particles of Fe(III) also offer active surfaces for the sorption of Zn. The implications of changing pCO_2 are being further investigated as is the occurrence of sediment dolomite since dolomite does not usually precipitate in water.

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TRACE ELEMENTS IN SOUTH CAROLINA BACKGROUND SOILS

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From 1985 to 1995, 254 background soil samples were collected in South Carolina under the auspices of the Site Ranking Program. The samples were analyzed for various inorganic elements. Averages, ranges, correlations, and upper confidence limits for trace elements in South Carolina background soil were determined. Aluminum, arsenic, barium, calcium, chromium, copper, iron, lead, magnesium, manganese, nickel, potassium, vanadium, and zinc data groups were sufficient for division into Piedmont and Coastal Plain groups for further evaluation. Except for calcium, average and maximum concentrations and percentage of detections were significantly higher for the Piedmont group. Statewide correlations between aluminum and iron, aluminum and vanadium, and vanadium and iron were noted. Average concentrations are, as follows:

Element	Coastal Plain	Piedmont	Element	Statewide
Aluminum	5405	24,255	Antimony	ND
Arsenic	2	11	Beryllium	0.6
Barium	19	59	Cadmium	1
Chromium	7	29	Calcium	804
Copper	5	13	Cobalt	4
Iron	5271	28,467	Cyanide	1
Magnesium	260	1916	Lead	16
Manganese	22	235	Mercury	0.18
Nickel	4	9	Selenium	ND
Potassium	227	1588	Silver	4
Vanadium	11	67	Sodium	194
Zinc	14	34	Thallium	ND

The lower concentrations of most elements in the Coastal Plain samples appear to reflect the effects of weathering.

FACIES CONTROL OF PERMEABILITY VARIATION IN A SANDSTONE OUTCROP NEAR ESCALANTE, UTAH

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Field permeability measurements at approximately 500 points on a 6 x 21-m sandstone outcrop demonstrate facies-dependent variations in permeability values and scale. A newly designed drill-hole mini-permeameter was used to obtain data with a sample spacing of 15 cm along horizontal transects and vertical profiles in a portion of the shallow-marine Upper Cretaceous Straight Cliffs Formation near Escalante, Utah. Permeability ranges from 100-950 millidarcies in massive-bedded, poorly to well-sorted, very fine to fine-grained, bioturbated sandstone facies. Permeability in this facies shows relatively little variability (less than plus or minus 25%) over a scale of several meters, which is attributed to homogenization due to burrowing activity. In contrast, permeability ranges from 450 to over 6,000 millidarcies in poor to moderately sorted, fine- to coarse-grained, cross-bedded sandstone facies. Permeability variations and lithologic characteristics in the cross-bedded facies can be correlated between vertical profiles. Both planar-tabular and trough cross-beds, which range from 15-45 cm in thickness, are present in the cross-bedded facies. Permeability in this facies varies by more than an order of magnitude over a scale of only a few cm. This high degree of variability is caused by small-scale variations in grain size and structure related to the depositional processes. Thirty-two representative samples from both facies were examined in thin section. Petrographic analysis reveals that the permeability variation is caused by grain size and clay content.

The contrast in permeability variation between the bioturbated facies and cross-bedded facies has important implications for subsurface fluid-flow prediction. Fractal scaling properties of the data have been analyzed for application to predicting permeability distributions. We are now incorporating the results of this investigation into subsurface geological computer models and fluid-flow models.

NEW FIELD-SCALE APPLICATIONS FOR HYDRAULIC FRACTURING

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When the first commercial hydraulic fracture was created in 1994 at a gasoline station in northern Ohio, the site operators envisioned nothing more than an enhancement to an SVE project. Since then hydraulic fractures have been used to enable a variety of more complex fluid recovery processes, including dual phase extraction, free product recovery, and hydrological control of groundwater plumes. Despite the initial strong focus on fluid recovery, hydraulic fractures have always been recognized as effective means for placing reactive materials required by in situ remediation processes. Within the last year, we have created several fractures intended to either (1) enhance the delivery and in situ distribution of oxidative solutions or (2) form permeable reactive barriers of biologically or chemically reactive solids. Site operators have already recognized that the projects have accelerated closure of their sites.

AN ANALYTICAL STUDY OF THE ON-SITE WASTE DISPOSAL SYSTEMS' OPERATION IN THE LAKE KEOWEE WATERSHED

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On-site waste disposal systems (septic tank / drain field systems) are used in over 5800 homes in the watershed. All these systems are either on the waterfront or within a _ mile of a tributary of the lake. This study focused on evaluating the way these systems operate in the Lake Keowee Watershed.

Using the equation for diffusion it demonstrates that the soil under a drain field will saturate in 2 to 195 days depending on the soil and its topography after onset of operation. The maximum effluent that can go downward, through saturated soils, to the water table is between 17 and 43% depending on the soil and its slope. The remainder of the effluent must go sideways, through saturated soils, and down the hillside (everything is on a hillside in the Watershed) or through structural voids.

It describes the effect of bacteria on the process of 'neutralizing' effluent and the effect of soil saturation on the types of bacteria that can exist. It also calculates the density of the chemicals and nutrients deposited on each sub watershed through sideways flow.

Two empirical studies are reported, one by Clemson University in 1996 and one by S.C. Department of Health and Environmental Control (D.H.E.C.) in 1997, which show that significant fecal material is getting into the streams feeding Lake Keowee exactly as this analysis predicts.

The authors conclude that on-site waste disposal systems can and will contribute to pollution in Lake Keowee. The State projects that Oconee County may grow an additional 25% by 2015. Most is expected in the Watershed and around the shoreline. This would suggest a more serious pollution problem for Lake Keowee.

TRANSPORT OF MICROBIAL PATHOGENS IN SAPROLITE SOILS

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Recent field and laboratory tracer experiments in East Tennessee saprolite, the fine-grained residue from weathering of bedrock, indicate that colloids (microorganisms and other suspended particles) can travel very rapidly, 10's to 100's of meters per day, through these soils (Harton, 1996; Cumbie, 1997; Haun, 1998; Cumbie and McKay, 1999; McKay et al., 2000). This phenomenon has been attributed to flow through fractures and root-holes that act as fast-flow pathways in an otherwise low permeability material. The experiments suggest that microbial pathogens from sources such as septic fields and livestock manure may also be highly mobile in saprolite, possibly resulting in contamination of wells or springs used for water supply.

The first hypothesis to be tested in this study states that bacteria-sized pathogens are expected to have greater mobility in saprolite than larger (Protozoa), or smaller (Viruses) pathogens. This type of an "optimal-size" effect on transport was observed in tracer experiments with latex microspheres (Haun, 1998; Cumbie and McKay, 1999), where the larger particles experienced greater losses due to settling and the smaller particles experienced greater losses due to attachment to fracture walls. The second hypothesis is that the chemical composition of the soil water will have a major influence on pathogen attachment and retention. This influence is expected to increase in the vicinity of the contaminant source, where the ionic strength is typically higher than in the surrounding soil-water.

The above two hypotheses will be investigated under controlled laboratory conditions, using undisturbed samples of typical East Tennessee saprolite representative of the zone in which septic fields are usually located, and geochemical conditions that exist in the vicinity of a septic field. The saprolite columns were collected from an existing field research site in Eastern Tennessee (Smith et al., 2000). The transport experiments will utilize microorganisms that are representative of each of the three main types of pathogens: protozoa, bacteria and viruses. The composition of the inflow will simulate conditions in which equal amounts of septic tank effluent and rain were mixed, i.e., an intermediate composition between highly concentrated solutions (septic tank effluent) and highly diluted ones (rain).

This study will help assess the susceptibility of fractured saprolite to contamination by pathogens and will be of interest to a wide variety of researchers, consultants and regulators. It will also provide the scientific basis for larger-scale studies.

THE DISTRIBUTION OF MAASTRICHTIAN (UPPER CRETACEOUS) DEPOSITIONAL ENVIRONMENTS IN THE COASTAL PLAIN OF GEORGIA AND SOUTH CAROLINA

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The Maastrichtian Stage in the Georgia and South Carolina Coastal Plain consists of six depositional environments that can be recognized across four allostratigraphic units. These environments are dominated by a prograding deltaic complex with its axis of deposition located in the vicinity of the present-day Savannah River. The specific depositional environments recognized are: upper delta plain; lower delta plain; delta front; prodelta/shelfal; shoreface/beach; and restricted marine. These depositional environments occur within five lithostratigraphic units: the Sawdust Landing Member of the Rhems Formation, the Peedee Formation, the Steel Creek Formation, the Providence Sand, and the uppermost part of the Ripley Formation.

The depositional environments and their stratigraphic relationships were established in more than 60 outcrop and subsurface sections, and were interpreted on the basis of lithology, sedimentary structures, paleontologic characteristics, and wireline log signature. The criteria used to recognize the unconformities that bound the allostratigraphic units include lithologic, wireline log, and biostratigraphic data. Two regional cross sections and four maps were constructed that illustrate the distribution of the depositional environments throughout Georgia and South Carolina during the Maastrichtian.

Use of allostratigraphic units as the basis for subdividing the Maastrichtian resulted in consistent regional correlations, and helped clarify the complex relationships and stacking patterns among the various deltaic and nearshore environments. In addition, post-depositional tectonic and structural deformation is expressed on cross sections adjusted to