SESSION V

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Surficial Processes and Landslides in the Central Appalachians – Late Pleistocene and Holocene

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The Cenozoic and Quaternary history of the Appalachian highlands includes uplift of a passive plate margin and denudation of the landscape. The terrane is mantled by colluvial deposits that preserve much of that history, especially the late Pleistocene and Holocene. Study of these deposits, principally in the Blue Ridge Province of central Virginia, is providing new insight on the rate of development of soil, saprolite and colluvium during periods of extreme climatic variation, the role of periglacial processes during the late Pleistocene in shaping the landscape, the rates of landscape denudation and sediment transport resulting from mass failure of slopes, and the physical conditions required to trigger extreme ground failure events such as catastrophic debris flows. These insights are useful both for understanding the evolution of the Appalachian highlands as an ecosystem and for implications regarding natural hazards within the area.

Sedimentary analysis of small drainage basins in the Madison, Virginia area following an intense storm in 1995 suggests that nearly half of the mechanical, long term denudation within each basin is a result of debris flows. These failures are a major factor in regional denudation, even though ^{14}C data suggest that average recurrences of debris-flow activity within a given area may be as infrequent as 2000 years. Pollen analyses of dated colluvium and drill cores from bogs provide a record of strongly fluctuating climate during the last 35,000 years, a record of climate change that is similar to the pattern seen in ice-core records from Greenland. Rock streams, cambering, patterned ground, tors, slope wash deposits, and isolated, cold weather plant communities corroborate the presence of periodic scattered or pervasive permafrost conditions in the Appalachians during the late Pleistocene.

Catastrophic debris-flow events occur at about 3 to 5 year intervals within the Appalachian highlands. These events are triggered by heavy rain falling at rates of 1 to 4 inches per hour with a duration of several hours. Inventories of extensive debris flows produced by heavy rainfall in Nelson, Albemarle, and Madison Counties in central Virginia are being used to develop models that can predict the failure sites, timing of triggering, and downslope projections of debris flows. Analyses of debris flows and rates of rainfall have been used to develop an algorithm that defines conditions favorable for triggering flows. Analyses of debris-flow deposits containing charcoal fragments permits the calculation of an average recurrence interval for extreme hazardous events in the highlands area. These data – location, conditions, and frequency for debris-flow events – are critical for making recommendations to federal, state, and local officials on susceptibility to landslide hazards.

Integrating Hazards Information into a Web-Based, Near-Real Time, Geospatial Hazards Information System for the Appalachian Region

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The U.S. Geological Survey (USGS) Center for Integration of Natural Disaster Information (CINDI) is a geospatial research and operational facility that explores methods for collecting, integrating, and communicating information about the risks posed by natural hazards and the effects of natural disasters. The CINDI provides a focal point for the scientific programs of the Bureau and the Department to integrate information and produce derivative products, using geographic information system (GIS) technology to help communicate the potential impact of natural hazards, especially the impact on humans and their environment and infrastructure.

The CINDI is developing plans to provide a Web-based, near-real time geospatial Hazards Information System for the Appalachian region. A prototype GIS database for the Appalachian Region Focus Area has been produced by the CINDI, as described by Herr and others in the workshop poster session. This system will incorporate the base map data layers of the Appalachian GIS; data layers associated with flood and landslide hazards, such as real-time streamgaging stations, land cover, and slopes; and near-real time data on weather conditions (rain, wind), antecedent conditions (recent precipitation), and forecast conditions (predicted rainfall amounts). This Web-based Hazards Information System will be available to the USGS and others who are in an official capacity for planning and preparing for severe weather events, monitoring ongoing events, and providing follow-up evaluation and analysis of past events. Public access to this system will also be incorporated.

In the Appalachian region, natural hazards are defined by the geographic characteristics of the region. The location and extent of the region on the North American continent control the types of hazard events that the region is most likely to experience. For example, disasters from volcanoes and earthquakes have a very low probability, although a devastating earthquake in the region is still a possibility. The principal hazard is severe weather, primarily heavy precipitation and, to a lesser degree, high winds. Proximity to the Atlantic coast exposes the region to tropical storms, such as hurricanes, in the summer and fall, and to extratropical storms, such as northeasters, in the winter and spring. The occurrence, magnitude, and extent of disastrous or damaging effects from severe weather are controlled by the characteristics of the storm system and the geographic characteristics of the region.

The relief, geology, soils, and land cover influence the response of the land surface to heavy precipitation. High relief and narrow valleys, where the urban infrastructure is located, characterize the Appalachian region. Isolated communities and limited transportation routes are prevalent in the region. Flooding and landslides have caused major loss of life and property repeatedly throughout the history of this region.

The Status of Species and Recovery Programs for Endangered Freshwater Mussels in the Southern Appalachians

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ABSTRACT

Freshwater mussels are the most endangered faunal group in the Southern Appalachians, with 45 species on the Endangered Species List from this region. The Tennessee River is the dominant drainage system [in this region], receiving tributaries from seven states and encompassing a watershed of 105,000 km^2. Within this basin are 102 mussel species, including fifteen endemic taxa, thirty endangered or threatened, and nine presumed extinct species. Trends in abundance and distribution of federally listed species continue downward for most species in this and adjacent river systems, with numerous extirpations from major tributaries in the last half century. To implement objectives in recovery plans, Cooperative Research Units in Virginia and Tennessee and the Southeast Aquatic Research Institute, working with the Upper Tennessee River National Water Quality Assessment (NAWQA) Office-Knoxville, have successfully implemented production and culture methods for a suite of species. The Virginia Unit has released nearly 260,000 endangered juveniles since 1998, and the Tennessee Unit continues to perfect hatchery raceway cultures working with surrogate species. Riverine populations are being augmented with juveniles to increase recruitment and expand ranges in rivers critical to the survival of these species. A collaborative effort by federal and state natural resource agencies, universities, and non-governmental organizations is now focused on restoration of keystone rivers and the mussel species sustained therein.

INTRODUCTION

The freshwater mussel fauna (superfamily Unionoidea) of the United States is of world class diversity. Roughly 300 species and subspecies reside principally in streams and rivers from the Mississippi River system to most major river systems in the eastern United States. Regional and historic traits in geology, water chemistry, drainage patterns, and a suite of other factors have resulted in various degrees of endemism within river systems and faunal assemblages. Of the nearly 300 taxa of mussels, 269 species had historic ranges that included rivers in one or more states of the Southeast. Although a plethora of nominal species were described by early naturalists in the 19th and early 20th centuries using limited taxonomic traits, molecular genetics work in the last 20 years has largely confirmed the prodigious diversity of freshwater mussels in this geographic region. The decline in the mussel fauna began essentially in the early twentieth century with the construction of dams, timber harvest, urbanization, and a host of other anthropogenic impacts to the presumed river systems. In addition to extinct species (Table 1) and the 69 species presently listed as endangered or threatened in the United States, a recent status review has identified many more species as imperiled and in need of protection (Williams et al. 1993).

Freshwater mussels are the most endangered faunal group in the southern Appalachians, with 39 extant species listed as endangered or threatened in this region (Table 2) and 6 extinct species, mostly within the upper Tennessee River basin. This basin includes tributaries in seven states and encompasses a watershed of 105,000 km^2. Within this basin are 102 mussel species, including 15 endemic taxa, 30 endangered or threatened, and up to 9 presumed extinct species (Parmalee and Bogan, 1998). Several of the extinct species occurred in the upper Tennessee River and its major tributaries in Alabama and Tennessee (Table 1). As a taxonomic group, the riffleshells (genus

Epioblasma) and the pigtoes (genus *Pleurobema*) have experienced the greatest rate of extinction, presumably because of their occurrence and distribution in shoals of medium to large rivers that were inundated by reservoirs or destroyed by dredging to promote commercial navigation. These taxa seem particularly sensitive to habitat and water quality degradation, and these species are readily extirpated after anthropogenic disturbance.

Table 1. Species of freshwater mussels presumed extinct in the United States

Scientific Name	Common Name	State(s) of Occurrence
Alasmidonta maccordi Athearn, 1964	Coosa elktoe	AL
A. robusta Clarke, 1981	Carolina elktoe	NC, SC
A. wrightiana (Walker, 1901)	Ochlocknee arc-mussel	FL
Elliptio nigella (Lea, 1852)	winged spike	AL,GA
Epioblasma arcaeformis (Lea, 1831)	sugar spoon	AL, KY, TN
E. biemarginata (Lea, 1857)	angled riffleshell	AL, KY, TN
E. flexuosa (Lea, 1820)	leafshell	AL, KY, TN
E. florentina (Lea, 1857)*	yellow blossom	AL, KY, TN
E. haysiana (Lea, 1833)	acornshell	AL, KY, TN, VA
E. lenior (Lea, 1843)	narrow catspaw	AL, TN
E. lewisii (Walker, 1910)	forkshell	AL, KY, TN
E. metastriata (Conrad, 1838)*	upland combshell	AL, GA, TN
E. othcaloogensis (I. Lea, 1857)*	southern acornshell	AL, GA, TN
E. obliquata obliquata (Rafinesque, 1820)	catspaw	AL, KY, TN
E. personata (Say, 1829)	round combshell	KY
E. propinqua (Lea, 1857)	Tennessee riffleshell	AL, KY, TN
E. sampsonii (Lea, 1861)	wabash riffleshell	KY
E. stewardsoni (Lea, 1852)	Cumberland leafshell	AL, KY, TN
E. torulosa gubernaculum (Reeve, 1865)*	green blossom	TN, VA
E. t. torulosa (Rafinesque, 1820)*	tubercled blossom	AL, KY, TN
E. turgidula (Lea, 1858)*	turgid blossom	AL, AR, TN
Lampsilis binominata Simpson, 1900	lined pocketbook	AL, GA
Medionidus macglameriae van der Schalie, 1939	Tombigbee moccasinshell	AL
Pleurobema aldrichianum (Goodrich, 1831)	plain pigtoe	AL, GA
P. altum (Conrad, 1854)	highnut	AL
P. avellanum Simpson, 1900	hazel pigtoe	AL
P. flavidulum (Lea, 1831)	yellow pigtoe	AL
P. hagleri Frierson, 1906	brown pigtoe	AL
P. hartmanianum (Lea, 1860)	tawny pigtoe	AL,GA
P. johannis (Lea, 1859)	Alabama pigtoe	AL
P. murrayense (Lea, 1868)	Coosa pigtoe	AL, GA, TN
P. nucleopsis (Conrad, 1849)	longnut	AL, GA
P. rubellum (Conrad, 1834)	Warrior pigtoe	AL
P. verum (Lea, 1860)	true pigtoe	AL
Quadrula tuberosa (Lea, 1840)	rough rockshell	TN, VA

Revised from Turgeon and others. (1998)

*Southern Appalachians

Table 2. Occurrence of endangered mussel species in the Southern Appalachians

Species	Stream (State)
Alasmidonta atropurpurea	Big South Fork Cumberland system (TN, KY), Laurel Fork (KY), Marsh Creek (KY), Sinking Creek (KY)
Alasmidonta raveneliana	Little Tennessee (NC), upper Pigeon system (NC), Little River (NC), Tuckasegee (NC), Cheoah (NC), Toe (NC), Cane (NC), Nolichucky (NC,TN)
Cyprogenia stegaria	Clinch (TN, VA), Licking (KY)
Dromus dromas	Clinch (TN, VA), Powell (TN, VA)
Epioblasma brevidens	Clinch (TN, VA), Powell (TN, VA), Big South Fork Cumberland (TN, KY), Buck Creek (KY)
Epioblasma capsaeformis	Clinch (TN, VA), Nolichucky (TN)
Epioblasma obliquata obliquata	Extirpated
Epioblasma penita	Extirpated
Epioblasma florentina walkeri	Big South Fork Cumberland (TN, KY), Hiwassee (TN), Indian Creek (VA), Middle Fork Holston (VA)
Fusconaia cor	Clinch (TN, VA), Powell (TN, VA), Copper Creek (VA), North Fork Holston (TN, VA), Paint Rock (AL)
Fusconaia cuneolus	Clinch (TN, VA), Powell (TN, VA), Copper Creek (VA), North Fork Holston (TN, VA), Possum Creek (VA)
Hemistena lata	Clinch (TN, VA)
Lampsilis abrupta	Clinch (TN), Holston (TN), French Broad (TN), Tennessee (TN)
Lampsilis altilis	Conasauga (TN, GA), Holly Creek (GA), Duck Creek (GA)
Lampsilis perovalis	Black Warrior system (AL)
Lampsilis virescens	Paint Rock (AL), Estill Fork (AL)
Lemiox rimosus	Clinch (TN, VA), Powell (TN, VA)
Leptodea leptodon	Extirpated
Medionidus acutissimus	Conasauga (TN, GA), Holly Creek (GA), Black Warrior system (AL)
Medionidus parvulus	Conasauga (TN, GA), Holly Creek (GA)
Obovaria retusa	Extirpated
Pegias fabula	Clinch (VA), North Fork Holston (VA), Big South Fork Cumberland (TN, KY), Horse Lick Creek (KY), Cane Creek (TN)
Plethobasus cicatricosus	Extirpated
Plethobasus cooperianus	Extirpated
Pleurobema clava	Extirpated
Pleurobema collina	James (WV, VA)
Pleurobema decisum	Conasauga (TN, GA), Coosa (AL)
Pleurobema furvum	Black Warrior system (AL)
Pleurobema georgianum	Conasauga system (TN, GA), Shoal Creek (AL)
Pleurobema gibberum	Collins (TN), Big Hickory Creek (TN), Barren Fork (TN), Cane Creek (TN)
Pleurobema perovatum	Black Warrior system (AL)
Pleurobema plenum	Clinch (TN), Tennessee (TN)
Ptychobranchus greenii	Conasauga (TN, GA), Holly Creek (GA), Black Warrior system (AL)
Quadrula cylindrica strigillata	Clinch (TN, VA), Powell (TN, VA), Indian Creek (VA)
Quadrula intermedia	Powell (TN, VA)
Quadrula sparsa	Powell (TN, VA)
Toxolasma cylindrellus	Paint Rock (AL), Estill Fork (AL), Hurricane Creek (AL), Lick Fork (AL)
Villosa perpurpurea	Clinch (VA), Indian Creek (VA), Copper Creek (VA), Beech Creek (TN), Obed (TN)
Villosa trabalis	Hiwassee (TN), Big South Fork Cumberland (TN, KY), Buck Creek (KY), Laurel Fork Rockcastle (KY), Horse Lick Creek (KY), Sinking Creek (KY)

Most current efforts to propagate and recover endangered mussels are focused on Tennessee River system tributaries in Virginia and Tennessee. In spite of Tennessee Valley Authority dams and water quality degradation in the 20th century, tributaries have been able to sustain a species richness in reaches unaffected by these habitat alterations. The breadth of this recovery goal is huge; of the 102 species recorded historically from the Tennessee River basin, about 50 species occupy the work area in southwest Virginia and eastern Tennessee where most recovery efforts are focused. To complicate recovery of some species, several taxonomic questions await genetic analyses such as species complexes, cryptic species, and the level of intra-specific variation in shell characters. The list of current described and recognized species in Turgeon (1998) will likely change with further evaluation of the genetics and biology of these animals.

The restoration of this fauna is specified in the various recovery plans for the endangered species, and a national strategy for the conservation of native freshwater mussels (NNMCC 1998). The latter document was prepared by a committee established in 1997, consisting of federal, state, and shell industry biologists with responsibilities to manage the mussel resources in key states with commercial or rare species. The goal of this strategy is to conserve our nation's mussel fauna and ensure that the ecological and economic values to society are maintained at a sustainable level, and to prevent the extinction of federally protected species. To implement these documents, research has been ongoing since the late 1970's to study the life history, reproduction, and ecology of those species listed as endangered since 1975. The 23 species on the Endangered Species List in 1975 has now grown to 69 species, with many additional species of concern in need of status evaluation. Research in the 1980's and 1990's provided a wealth of information on population levels, reproductive biology, and some of the factors responsible for population declines. With these studies as a background, new research was initiated in the 1990's to develop techniques and technology to produce, culture, and release juvenile mussels back to source populations.

The methods for production and propagation of juvenile mussels are sufficiently developed now, such that interested biologists at fish hatcheries, research laboratories, academic institutions, or commercial facilities can pursue the culture of resident species. The culture technology and protocols for propagation have been described (O'Beirn and others, 1998, Milam and others, 2000). The methods accommodate juveniles during the initial pedal-feeding stage (Yeager and others, 1994) and their later filter-feeding mode for suspended algae. As with most bivalves, food quantity and quality are critical for good survival and growth of the juveniles. Empirical experiments have determined the cell density and suitable species to include in the algal diet. Geographic location, water resources, and available facilities need to be considered in any propagation plan to achieve success.

Propagation Programs in Appalachia

The Virginia Cooperative Fish and Wildlife Research Unit at Virginia Tech has developed recirculating aquaculture techniques for the propagation of endangered mussels (O'Beirn and others, 1998, Henley and others, 2001). The first release of endangered juvenile mussels (*Epioblasma f. walkeri*) occurred in the Hiwassee River, Tennessee during fall 1997. Indoor recirculating trough systems began to be used in 1998, and a total of 260,000 endangered juvenile mussels of 8 species were produced, cultured, and released into 4 rivers of the Southern Appalachians, Virginia and Tennessee. These juveniles were released principally at sites upstream of extant populations to expand species ranges or at sites to augment reproduction of resident populations. A gathering of mussel biologists from U.S. Fish and Wildlife Service, Tennessee Valley Authority, U.S. Geological Survey, National Park Service, state natural resource agencies, and non-governmental organizations selected release sites based on best available data on water quality, habitat suitability, historic occurrences, species richness of fish assemblages, and health of extant populations (Saylor and others, 1999). An evaluation of survival success for initial releases is planned for summer 2002, based on anticipated growth rates of juveniles, vulnerability to quadrat sampling, and projected dispersal at sites of release. Controlled experiments on survival and growth rates to be anticipated in the rivers were completed in 2000 (Hanlon 2000), using juvenile releases in a hatchery raceway supplied with ambient river water. These releases indicated that a survival rate of 20-40% can be expected after one year.

In addition to the research and propagation work at the Virginia Unit, the State of Virginia is developing mussel propagation capabilities at the Buller Fish Hatchery in Marion, Virginia. Water from the South Fork Holston River is diverted to several concrete raceways with river substratum. Specimens of several endangered species are being held in the raceway to allow spawning and maturation of glochidia, for induced infestation on host fishes at the hatchery and at Virginia Tech. This portion of the hatchery is to be renovated in 2005, to allow greater capabilities for mussel propagation.

The Tennessee Cooperative Fishery Research Unit at Tennessee Tech has been conducting research on the identification of host fishes for a suite of endangered mussel species in eastern Tennessee and, more recently, the suitability of hatchery raceways for grow-out of juvenile mussels. Graduate student projects have been conducted at both state and federal hatcheries for the last three years, to determine survival, growth rate, and substrate effects on production of juveniles. Six common mussel species were reared in the raceways with excellent growth rates. Juveniles, 2-4 years of age, have been released into various rivers to augment natural reproduction. Although no endangered species have yet been reared for release, additional propagation projects with rare species are planned for the next few years.

The field station of the Southeast Aquatic Research Institute, located in Cohutta, Georgia, has ongoing projects with rare mussels and snails in Georgia and Tennessee. In 2000, the facility released nearly 900 juveniles of two endangered species into the Conasauga River, Georgia and Tennessee. Fifty juveniles of a third endangered species were released into Holly Creek, Georgia, in 2001. This field station is only recently established, and is expanding its tank culture systems for greater production of rare mussels and snails in the lower Southern Appalachians.

The federal fish hatchery at White Sulphur Springs, West Virginia, is also involved in mussel culture activities. In the mid-1990's, the hatchery became a temporary refugium for mussel species, salvaged from the Ohio River system, that were infested with zebra mussels (*Dreissena polymorpha*). Beginning in 1998, a cooperative research project with Virginia Tech has been evaluating the suitability of an outdoor California raceway for grow-out of juvenile mussels. A second project began in 2001 to design and test a double pond system at the hatchery for holding adult and juvenile mussels. Water in one filled pond is fertilized to produce planktonic algae, and the water is pumped to an adjacent pond with chambers (6x2x0.2m) constructed of cinderblocks to contain mussels. Water flows over these chambers and is then pumped back to the algae-producing pond. A building for the production of endangered juvenile mussels is scheduled to be built in 2002, of similar design to the one at the Virginia Tech Aquaculture Center. This hatchery will focus on endangered mussel species in the mid-Appalachian region of the Ohio River system.

Other states (North Carolina, Alabama, Ohio) and federal field stations (Warm Springs National Fish Hatchery, Georgia) have expressed interest in developing capabilities for mussel culture or providing funds or in-kind services to promote species recovery within their respective states. In the last two years, a cadre of state and federal biologists have visited the mussel propagation facility at Virginia Tech, to evaluate whether such technology or techniques could be applied to their specific situation. Propagation is now viewed as a reasonable and prudent activity to prevent further extirpations and extinctions, and to expedite the recovery of listed species through establishment of self-sustaining populations. Water quality has improved substantially in many rivers, such that suitable habitat is no longer the limiting factor for recovery.

We are approaching a new era in federal conservation programs, where sportfish hatcheries will diversify their activities to become national conservation centers for a suite of rare freshwater taxa in their geographic area. Remediation of habitat and recovery of fauna will become the battle cry of the new generation of federal fish and wildlife biologists, becoming proactive rather than reactive to the needs of the species. This approaching wave of recovery programs will provide more opportunities for the Biological Resources Division of U.S.G.S. to participate as a partner with the U.S. Fish and Wildlife Service and other agencies in reversing the downward trend in mussel population losses at all spatial scales.

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The Life Cycle of Potentially Toxic Trace Elements in Appalachian Basin Coal

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The lifecycle of trace elements in coal consists of processes that lead to enrichment of these elements together with natural and anthropogenic pyrite occurred after considerable burial and coalification. We believe that some Paleozoic strata of the Appalachian Basin were aquifers for westward migrating fluids during a late phase of the Alleghanian orogeny. Coal beds were particularly favorable sites for deposition of arsenic-rich pyrite. Studies of geologic dispersal mechanisms. Our study concerns the distribution and dispersal of potentially toxic trace elements including As, Hg, Se, Mo, Tl, Sb, and Cu in Appalachian and Black Warrior Basin coal.

Although most Appalachian Basin coal is low in potentially toxic elements, a small but significant proportion of coal analyses are elevated in this suite. Whole coal arsenic contents range above 100 ppm in some samples. The host of the toxic elements is the mineral pyrite. Petrographic and geochemical studies indicate that formation of the trace-element rich controls on potentially toxic trace element distribution are ongoing in Alabama, Kentucky, Virginia, and West Virginia.

The presence of elevated contents of potentially toxic elements in coal raises the potential for natural weathering and coal mining to disperse these elements into the environment. We have conducted geochemical study of nearly 3000 stream sediment samples from northern Alabama and about 1000 steam sediments from Kentucky. Stream sediments from the coal mining area of Alabama are elevated in arsenic (generally >12 ppm) compared to adjacent areas (<12 ppm). Trace element enrichment in eastern Kentucky stream sediments is less apparent. Because the host of arsenic in coal is pyrite, pyrite oxidation, producing acid mine drainage (AMD) is the mechanism of arsenic dispersal to the environment. We conducted field studies at six sites in Alabama. The results show that both the coal mine refuse piles that are a major source of the AMD, and adjacent stream sediments are highly enriched in As with up to 500 and 200 ppm As respectively.

Coal utilization may also effect the environment. Atmospheric deposition of sulfuric and nitric acids from fossil fuel combustion has had a demonstrable impact on the geochemistry of land and water in the northeastern United States. However, atmospheric deposition patterns of particulates from coal-fired power plants are less well known. A recent evaluation of stream sediment data indicates that arsenic is enriched in stream sediment in a part of West Virginia with no major natural geologic source of As. This area is adjacent to (east) of the Ohio River, where numerous coal-fired power plants are located. The stream sediment arsenic could have come from coal fly ash. To evaluate this hypothesis, we studied lake-sediment chemistry in radiometrically dated West Virginia cores. A concentration maximum in As, Hg, Zn, and Pb occurs in sediment deposited in 1969, just prior to the clear air act of 1970. Magnetite derived from fly ash (with characteristic morphology and internal textures) shows a striking positive correlation with the trace elements. Studies are ongoing to understand the extent of the coal fly ash distribution in the northern Appalachian Basin.

Naturally Occurring Radionuclides in Ground Water in the Appalachian Physiographic Province: Initial Results of Targeted Reconnaissance Surveys and Application to Regional Assessment

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Concentrations of uranium (U) and thorium (Th) generally are higher in the bedrock of the Appalachian Physiographic Province than in bedrock in most other parts of the United States. Because this area is not homogeneous geologically, hydrologically, or geochemically, radionuclide distributions in both bedrock and ground water vary widely. Concentrations of naturally occurring radionuclides in ground water have been detected in some parts of the region that are greater than the drinking-water standards (U, 30 µg/L (micrograms per liter); sum of radium-226 (Ra-226) and radium-228 (Ra-228), 5 pCi/L (picocuries per liter)) promulgated or proposed in 2000 by the U.S. Environmental Protection Agency. These concentrations have been documented as part of reconnaissance surveys conducted during 1990-2000 by the U.S. Geological Survey (USGS) in cooperation with State and local agencies. These surveys generally targeted areas in which the rock or water was known to contain high concentrations of these constituents. Concentrations tended to be highest in domestic wells that are not subject to Federal regulation and that consequently are not monitored.

Concentrations of U in ground water in many parts of the Appalachian Physiographic Province range as high as 100 µg/L. Concentrations typically are highest in oxic waters of neutral to alkaline pH. Dissolution of U is limited in most geochemical environments but typically exceeds that of Th, which is relatively insoluble. Some researchers have hypothesized that the observed concentrations of U may be controlled by adsorption and complexation reactions, because 100 µg/L is lower than the concentrations indicated by theoretical U-mineral solubility. In some parts of the Appalachian Province, such as northern South Carolina, concentrations of U on the order of 1,000 µg/L or more indicate little or no adsorption of U.

The isotopes of Ra form by decay of both U and Th. They are detected most frequently in elevated concentrations in reducing or acidic waters in quartzite, sandstone, shale, and glacial sediment; the greatest concentrations (Ra-226, 41 pCi/L; Ra-228, 180 pCi/L; and Ra-224, 265 pCi/L) were measured in water from an Early Cambrian quartzite in southeastern Pennsylvania. These three isotopes of Ra, as well as lead-210 (maximum concentration 4.14 pCi/L) were detected in 15 samples of water collected from six states in the Appalachian Physiographic Province during the 1998 USGS targeted national reconnaissance survey of selected radionuclides in public ground-water supplies. Concentrations of radon-222 (a progeny of Ra-226) in ground water in the Appalachian Province consistently have been among the highest in the United States.

Retrospective compilation of data from local ground-water-quality surveys in association with detailed mapping of the geochemical properties of the bedrock in the Appalachian Physiographic Province could be a first step in providing the information needed to formulate hypotheses regarding variations in the distribution of radionuclides in ground water and to design additional sampling surveys. Province-scale geochemical models of the controls on the occurrence and distribution of radionuclides developed from such data are needed to facilitate scientifically defensible decision-making with respect to water-resource management in the region.

Reconnaissance Investigation of the Uranium-Series Radionuclide Radon-222 in Drinking Water Wells in the South Carolina Piedmont

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A reconnaissance investigation of concentrations of the uranium-series radionuclide ^{222}Radon (radon) in water from 19 domestic wells in the Piedmont of South Carolina indicated concentrations above the proposed Maximum Contaminant Level (MCL) of 300 picocuries per liter (pCi/L) in all wells sampled; 5 wells had radon concentration that exceeded the 4,000 pCi/L Alternative MCL. These results for the Piedmont are high relative to radon concentrations measured in domestic wells in Coastal Plain aquifers where only 20 wells out of 61 sampled exceeded 300 pCi/L. In the Piedmont, the highest radon concentrations were observed in water from wells located at moderate (hillside) elevations characterized by a shallower depth to water relative to hilltop locations, and in water from wells having shallow producing zones, such as from near-surface fractures and/or residua. Higher radon concentrations also correlate with moderate (but still oxic) concentrations of dissolved oxygen, specific conductance greater than 100 µS/cm, sub-neutral pH, and low (less than 40 mg/L) bicarbonate concentration. These data may indicate that the domestic wells sampled with high radon concentrations are intercepting ground water in predominantly discharge areas that integrate both local and regional ground-water flowpaths. However, the correlation of high radon with increasing specific conductance suggests that longer flowpaths (greater residence time with host rocks for uranium leaching and subsequent radon production) may predominate. Chlorofluorocarbon (CFC)-based apparent recharge dates of the water sampled in these domestic wells indicate recharge occurring between 1960 and 1980, which is consistent with this hypothesis. These preliminary radon and geochemical data suggest the need to more accurately assess the areal and vertical distribution and processes controlling the fate of radon and other naturally occurring uranium-series radionuclides. This is timely in light of the need to understand the implications to human health in this area of South Carolina (and the Southeast) undergoing rapid development with dependence on these aquifers as a source of drinking water.

SESSION VI

Proxy Climate Evidence from Late Pleistocene Deposits in the Blue Ridge of Virginia
Ronald J. Litwin, Benjamin Morgan, Scott Eaton, Gerald Wieczorek, and Joseph P. Smoot

Use of Light Detection and Ranging (LIDAR) Technology for Mapping Hypsography and Hydrology
Vincent Caruso

Appalachian Basin Petroleum Systems
Robert C. Milici, Robert T. Ryder, and Christopher Swezey

Comparison of the Hydrology of Bent Creek and Cullasaja River Watersheds—An Evaluation of the Effects of Mountain Development
Melinda J. Chapman, Charles C. Daniel, III, and William C. Burton

Collaborative Hydrogeologic Studies in the Appalachian Region by the BRASS Project
William C. Burton, J. Wright Horton, Jr., Michael P. Ryan, Herbert A. Pierce, Lawrence J. Drew, David M. Sutphin, and Joseph P. Smoot

Base-Flow Characteristics of Streams in the Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces of Virginia and Other Mid-Atlantic States
Donald C. Hayes and David L. Nelms

DISCUSSION SESSION

Geologic Outreach in Public Lands: We Have the Gold, Let's Take it to the Bank
Jack B. Epstein

Proxy Climate Evidence from Late Pleistocene Deposits in the Blue Ridge of Virginia

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In 1995, a severe thunderstorm cell cluster initiated a series of approximately one thousand catastrophic slope failures (debris flows) along the east front of the Blue Ridge Mountains. These debris flows exposed a number of small depositional remnants (SDRs) of sub-formational rank, of alluvial-colluvial origin, and of unknown age. Most of these SDRs were found interbedded with deposits that we interpret as prehistoric debris flows. The abundance of the latter suggests that debris flows may have had a more substantial influence on the erosional history of the Appalachians throughout the Quaternary than commonly is thought.

Our ongoing study has revealed the following. The SDRs range in scale from one to ten meters in thickness and nearly all include a subinterval formed by sheetwash or ponded water. Some SDRs consist largely of angular, stratified colluvium, and show evidence of having been formed by cryogenic processes. Many SDRs include internally chaotic, poorly sorted deposits of matrix-supported, angular, cobble-to-boulder-sized clasts; these suggest a debris-flow origin. AMS ^{14}C analyses indicate that the SDRs range in age from the Late Pleistocene (>50 ka) to the Holocene (<2 ka). Pollen analyses were undertaken for a subset of these outcrops to test the feasibility of using pollen to determine the dominant vegetation, and thus the climate regime, at (or near) the time of deposition. We also used the pollen analyses to test: 1) the timing of climate change along the Blue Ridge, 2) the temporal responsiveness of the regional flora through the Late Pleistocene, 3) climatic preference in the occurrence of the prehistoric debris flows versus other processes, 4) the temperature variability along the Blue Ridge through the Late Pleistocene, and 5) similarity of Appalachian climate change patterns to patterns in other terrestrial long climate records.

The combined AMS ^{14}C, pollen, and sedimentologic evidence suggests the following:
1) Although these deposits most frequently are mapped as Quaternary alluvium or Quaternary colluvium, SDRs exhibit marked variability in age and depositional character;
2) Pollen analyses of SDRs frequently are successful, and permit characterization of regional flora, proxy temperature, and fire history where pollen productivity is sufficient;
3) Time-sequencing of the pollen results from geographically-clustered, but discrete, outcrops enables construction of a regional composite climate history record for the Late Pleistocene of the Appalachians, an area for which long climate records are sparse;
4) The construction of a composite climate history record enables robust testing against other terrestrial long climate records.

Use of Light Detection and Ranging (LIDAR) Technology for Mapping Hypsography and Hydrology

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In September 2000, the Department of the Interior and the USGS were among several other agency signatories to a historic agreement designating North Carolina as the first Cooperating Technical State (CTS) in the Nation. This agreement delegates the responsibility for developing digital flood insurance rate maps (DFIRM's) to the State. As a result, the USGS has been working with the State in technical review and coordination activities related to this effort. The State of North Carolina is collecting Light Detection and Ranging (LIDAR) data for use in developing DFIRM's for the entire State.

The USGS has been involved for the past few years in evaluating LIDAR technology and has developed new techniques for using LIDAR data to depict subtle changes in extremely flat coastal terrain as well as more extreme changes in upland areas that are steeper with more varied topographic relief. Because LIDAR data can depict highly detailed features of the Earth's surface, the potential exists to portray hydrography in unique ways. The LIDAR was used to capture very small features, such as narrow ditches and potential areas where ponding of water might take place, and thus depict the Earth's surface more as an image than as an elevation model. Therefore, LIDAR data was used to interpret drainage patterns, in addition to serving as the more traditional elevation reference model. As a result, a very detailed drainage network, highly representative of all actual water features, was produced.

This research was successful in deriving more comprehensive drainage networks from the new LIDAR data and able to combine the new networks with existing sources of hydrography and imagery. Innovative types of graphics and digital files were generated to detect and describe the terrain and drainage. It was observed that the LIDAR has very distinct signatures for both coastal and upland watersheds. For example, in low-relief coastal areas the topographic gradients can be very gentle. Using image-enhancement extraction techniques to isolate signatures and subtle variations in the grain of the topographic surface portrayed the associated landforms. ESRI spatial analyst was also key in extracting intermittent, perennial and flood plain drainage characteristics. The combination of LIDAR derived contours and including the use of the USGS DOQ as a visual base layer proved to be invaluable. These processes required high-resolution, centimeter-level measurements of topography that only LIDAR can supply. From these LIDAR data a comprehensive set of derivative graphics and digital files were extracted.

This technology is not restricted to just terrain common to North Carolina. It can be used whenever LIDAR data is acquired, in virtually any region. These techniques are particularly useful, in combination with limited ground truth. Typically, intermittent and perennial drainage can be inventoried and classified. Inaccurate topographic data that exist from older source maps may be updated with the new LIDAR data. Linkage can be made to national hydro database data sets by developing hyper links to the raster and vector data overlays developed with this technique. Invariably, previously undiscovered geologic features and structures are identified and studied. Effects of human induced changes on the topography can also be inventoried and updated. More accurate land use and zoning maps can be generated from the LIDAR using these techniques. For example, a comprehensive flood plan analysis is one product, which is typically produced.

Appalachian Basin Petroleum Systems

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INTRODUCTION

The Eastern Region oil and gas assessment team is currently assessing the technically recoverable undiscovered oil and gas resources of the northern and central parts of the Paleozoic Appalachian basin under the National Oil and Gas Assessment Project. In general, the hydrocarbon-bearing part of the basin extends from the Champlain Valley along the eastern side of the Adirondack Mountains in New York and Vermont to the Gulf Coastal Plain in Alabama. The assessment areas of the Appalachian basin include the Dunkard basin in Pennsylvania, Maryland, Ohio, and northern West Virginia, the Pocahontas basin in southern West Virginia, eastern Kentucky, Virginia, and northeastern Tennessee, and the Warrior basin in Alabama and Mississippi. Central Region personnel are assessing the hydrocarbon resources of the Warrior basin.

Although we are assessing selected conventional and continuous (unconventional) accumulations within the entire Paleozoic section in the central and northern part of the Appalachian basin, our assessment of is focused on the accumulations that have the greatest potential, mainly the continuous accumulations in the basin. The assessment is based upon geologically defined Petroleum Systems and their components, source beds, reservoirs, and traps. An understanding of the formation, quality, and thermal maturation of source rocks, the generation and migration of hydrocarbons, the formation of reservoirs, traps, and seals, and their interrelationships in space and time is essential to the assessment effort and must be developed in the context of the tectonic, climatic, and eustatic history of the region. We have defined four major petroleum systems in the Appalachian basin, (1) those related to deep Cambrian source beds in the Rome trough, (2) to the early Taconic Utica/Antes shales of Middle Ordovician age (Ryder and others, 1998), (3) to the Devonian black shales of the Catskill delta, and (4) to the Pennsylvanian coal beds of the Appalachian basin. Much of the continuous gas accumulations in basin-center Silurian sandstones have been derived from Utica/Antes source rocks. Black Devonian shales serve as source rocks and seals for conventional and basin-center accumulations in Devonian and Mississippian sandstones. Autogenic Devonian shales serve both as sources and reservoirs for the continuous accumulations of hydrocarbons they contain. Similarly, coalbed methane is generated and produced from its source rock, coal.

The products generated in the assessment process are digital maps of assessment units (GIS) for each of the petroleum systems, which include regional geologic structural elements, organic geochemistry and thermal maturation data, and illustrate pods of mature source rock, the minimum and maximum extent of the petroleum systems, and the location and distribution of reservoirs, pools, wells, and fields.

GEOLOGY

Appalachian petroleum systems developed under tectonic conditions that began in the Late Proterozoic with regional extension and thinning of continental crust during the opening of the Iapetus Ocean and ended 320 million years later with continental collision and crustal thickening during the Alleghanian orogeny. Much of the Paleozoic sedimentary fill of the Appalachian basin was deposited in this area underlain by thinned, transitional crust. The sedimentary deposits and petroleum geology of the basin reflect the interplay between the eustatic, climatic, and tectonic processes that controlled the development of source rocks, reservoirs, traps, and seals as well as thermal maturation, hydrocarbon generation, and migration pathways. Superimposed upon these rock-forming processes are the effects of organic evolution on the types and abundance of organic material available to Paleozoic depositional systems.

The number and quality of petroleum systems is determined primarily by the thickness and organic richness of thermally mature source rocks. Major Appalachian systems are sourced from Devonian shale that was deposited in foreland and intrashelf basins. Regionally interbedded Devonian shale and siltstone formations may reflect climate and/or eustatic sea level changes. Ordovician shale that occurs widespread within an intrashelf basin is the primary source rock for hydrocarbons in Cambrian sandstones and Ordovician limestones, and in the large continuous gas accumulations in Lower Silurian sandstones. Thick Ordovician shale deposited in rapidly subsiding foreland basins probably had good source-rock quality and apparently released hydrocarbons during the Devonian. Marginal conditions for source rocks occurred within Cambrian rift basins, such as the Rome trough (Milici and Ryder, 2000).

RESOURCES

The largest technically recoverable resources of gas remaining in the Appalachian basin are in continuous accumulations within Silurian and Devonian sandstones, Devonian shales, and Pennsylvanian coal beds. In addition, recent discoveries of natural gas in fractured, dolomitized Ordovician limestones in New York and West Virginia, as well as discovery of the Swan Creek field in the fold-and-thrust belt of eastern Tennessee, have demonstrated the potential of large, relatively untested plays in the Appalachian basin.

BASIN-CENTER GAS

Natural gas trapped in low-permeability sandstone reservoirs in the Appalachian basin is an important source of future energy. Most of this energy resource is located in basin-center gas accumulations and adjoining hybrid-conventional oil and gas accumulations. A basin-center gas accumulation (a variety of continuous gas) is a regionally extensive and commonly very thick zone of gas saturation that occurs in low-permeability rocks in the central, deeper part of a sedimentary basin. In comparison, a hybrid-conventional accumulation, which commonly is both oil-and gas-bearing, is located updip from the basin-center gas accumulation and has characteristics of both conventional and continuous accumulations. Typically, gas saturation is so pervasive in the basin-center accumulation that most wells drilled into it are productive. However, the yields are highly variable and range from high-volume wells (production “sweet spots”) to very-low-volume, noncommercial wells.

Lower Silurian (Taconic molasse) and Upper Devonian (Acadian flysch) sandstones constitute the more important basin-center gas accumulations in the basin. The Lower Silurian sandstone gas accumulation is charged by an Ordovician black shale source rock (Utica/Antes petroleum system), whereas the Upper Devonian accumulation is charged by several Upper Devonian black shale source rocks (Devonian Shale petroleum system). The potential for basin-center gas in the Appalachian basin, generally having drilling depths from 5,000 to 8,000+ ft, has been recognized since the early 1980s when exploration was expanded from largely depleted hybrid-conventional accumulations into deeper parts of the basin. Recent studies indicate that the Lower Silurian basin-center gas accumulation is characterized by: a) 5-10% reservoir porosity, b) ≤ 0.1 md reservoir permeability, c) low water saturation, d) a broadly defined updip “water block” trap in the adjoining hybrid-conventional accumulation, and e) abnormally pressured reservoirs (mostly underpressured). Estimates of recoverable undiscovered gas in the Lower Silurian accumulation (“Clinton”/Medina sandstones), at a mean value, range from about 8 to 30 trillion cubic feet of gas (Gautier and others, 1996; McCormac and others, 1996). The Upper Devonian accumulation (Elk, Bradford, Venango sandstones) has an estimated 10 to 14.5 trillion ft^3 of recoverable, undiscovered gas (Gautier and others, 1996; Boswell and others, 1996a,b; Donaldson and others, 1996). Additional gas-bearing low-permeability sandstone reservoirs in the Appalachian basin that may qualify as basin-center accumulations—and thus contain probable undiscovered gas resources—are the Upper Devonian-Lower Mississippian Berea Sandstone and the Lower Mississippian Price (Weir sandstone) and Pocono (Big Injun sandstone) Formations.

DEVONIAN GAS SHALES

In general, the Devonian gas-bearing shales constitute the distal part of the Catskill delta. During the deposition of this delta, which resulted from the Acadian orogeny in the northeastern part of the Appalachian region, thick accumulations of siliciclastic sediment spread westward and southward across the basin. Prodelta black shales, rich in organic material, accumulated under anoxic conditions on the periphery of the delta. This organic material consists of plant-derived kerogen, which is a source of natural gas in the east where the source beds are mature, and oil-prone algal-derived kerogen, which is the source of oil and natural gas in the western part of the basin, where the source rocks are marginally mature to immature and much of the produced gas may be biogenic or has migrated up from deeper, more mature parts of the basin (see Boswell, 1996, deWitt, 1986 and Milici, 1993, 1996 for summaries).

The first well drilled for Devonian shale gas was in Chautauqua County, New York, and since then more than 3 trillion cubic feet of gas have been produced from the shale, primarily from the Big Sandy field in eastern Kentucky. A very large resource remains in an area that extends from western New York to northeastern Tennessee, and gas-in-place estimates range from about 200 to 1860 trillion cubic feet. Cumulative production from individual shale gas wells ranges from about 50 to 900 million cubic feet of gas, commonly over a 20 to 30 year period, and the wells are most productive in eastern Kentucky where the black shale is thickest and thermally mature. For the producing areas that were assessed in the 1995 national oil and gas assessment, USGS estimated that the mean technically recoverable gas resource from Appalachian Devonian shales is about 17.3 trillion cubic feet (Gautier and others, 1996).

COALBED METHANE

Since 1980, coalbed methane (CBM) has been developed as a major gas resource in the Appalachian basin, first in the Warrior basin of Alabama, then in the Pocahontas basin of Virginia, eastern Kentucky, and southern West Virginia, and more recently in the Dunkard basin region of Pennsylvania, northern West Virginia, and Ohio. Alabama is by far the greatest producer, where over 5300 wells have been drilled and have produced 1.2 trillion cubic feet of methane. Virginia has produced about 226 billion cubic feet of methane from over 1500 wells, West Virginia 10.2 billion cubic feet from 149 wells, and Pennsylvania 1.8 billion cubic feet from 61 wells.

In the Appalachian basin, coalbed methane is produced from Pennsylvanian strata in advance of mining as a safety measure, may be produced from fractured rock wastes (gob) after underground mining, and may be produced from unmined or unmineable coal beds. The CBM industry began with the realization that methane vented to the atmosphere in advance of mining gassy coal beds was in reality an economic resource. Once ownership problems were resolved (surface owner vs. mineral owner vs. oil and gas lease holder), thousands of wells were drilled for CBM in Alabama and Virginia. Although gas flow rates and rock pressures are generally low compared to those of conventional wells, CBM drilling costs are relatively low and the wells are relatively long lived. Co-produced waters may be an environmental problem, especially if they are saline, and they are commonly injected into deeper depleted gas reservoirs. In addition, the environmental impact of well completion practices in coal beds that contain potable water is under investigation.

Coalbed methane (CBM) occurs within its own source rock (coal) or may migrate and may be trapped in nearby porous reservoirs. When produced, CBM desorbs from coal macerals into fractures and from there into the wells that were completed in the coalbed. Almost all wells drilled into coal beds produce some gas regardless of geologic structure and the reservoirs are regarded as continuous (unconventional) accumulations. Where water occurs within the coal beds, the gas exhibits little tendency to segregate from formation waters and formation waters must be removed to allow methane to escape from the coal macerals through fractures to the well bore. Coalbed methane fields tend to “grow together” as development progresses, so that fields commonly merge and form continuous accumulations that may persist laterally over several counties.

USGS coal assessment maps serve as excellent exploration guides for coalbed methane. These maps illustrate the outcrop and mined out areas of the coal bed, its thickness (isopach), geologic structure, and depth of the overburden above the coal bed. All of these parameters are essential guides for CBM exploration and may be utilized to develop drilling strategies for future development In addition, these assessment maps serve as a basis for ongoing environmental studies, such as acid mine drainage and deep underground mine pools.

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Comparison of the Hydrology of Bent Creek and Cullasaja River Watersheds – An Evaluation of the Effects of Mountain Development

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The effects of development in a mountainous hydrologic setting are being studied as part of the U.S. Geological Survey's (USGS) ongoing, multiyear Piedmont and Blue Ridge Ground-Water Project in North Carolina. Two watersheds of similar size and bedrock geology are being compared: Bent Creek in Buncombe County and Cullasaja River in Macon County. The effects of human impact on water budgets and water quality are being studied. Because of the growth of recreation, retirement, and second homes in mountain communities in the southeastern United States, this information will be useful in regional management and improving the scientific understanding of environmental changes related to development. USGS scientists in water resources (Raleigh, N.C.) and geologic (Reston, Va.) disciplines, are working with hydrogeologists from the North Carolina Department of Environment and Natural Resources, Division of Water Quality, Groundwater Section, in an effort to study the complex fractured-rock hydrologic system in the two watersheds.

The Bent Creek Research and Demonstration Forest near Asheville, which is managed by the U.S. Forest Service, was selected to represent a relatively undisturbed hydrologic setting. The demonstration forest covers approximately 9.4 square miles (mi^2) and lies almost entirely within the drainage basin of Bent Creek, a tributary to the French Broad River. Except for a paved access road that parallels Bent Creek, a small arboretum, and a few walking trails and isolated buildings, the watershed is almost entirely forested and nearly pristine. A detailed geologic map of the forest and watershed has been made by the North Carolina Geological Survey, and core drilling has begun at three areas along a down-slope transect in the forest in an effort to characterize the local subsurface geology. The installation of six clusters, each having three wells that tap the regolith, transition zone, and bedrock, is planned during the first phase of work. Construction of a real-time gage to measure runoff from the watershed is planned.

The upper Cullasaja River watershed, located in Macon County, North Carolina, represents a rapidly developing watershed, and was selected for comparison to the undeveloped Bent Creek watershed. The study area covers approximately 14.9 mi^2. The southern part of the watershed is occupied by the town of Highlands, currently experiencing rapid growth. Homebuilding has spread from Highlands throughout the watershed, and the number of golf courses and residential developments is increasing. Detailed geologic mapping of this watershed is being conducted by scientists from the Bedrock Regional Aquifer Systematics Study (BRASS) project of the USGS geologic discipline. Mapping the distribution of rock types and fractures characteristics will provide an improved understanding of the ground-water system. The collection of real-time ground-water level data from a well located near Highlands is planned, along with a network of observation wells.

Collaborative Hydrogeologic Studies in the Appalachian Region by the BRASS Project

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The Bedrock Regional Aquifer Systematics Study (BRASS), based in the Eastern Earth Surface Processes Team, Geologic Discipline (GD), performs geologic investigations in the Appalachian Region (Pennsylvania to Alabama) to better understand the geologic controls on ground-water availability and quality in bedrock aquifers. These investigations include geologic mapping, structural analysis of rock fabrics and brittle fractures, statistical and geophysical analyses, and hydrogeologic experiments performed in collaboration with hydrologists in the Water Resources Discipline (WRD) and various state and federal agencies. The goal is to understand the bedrock and surficial geologic parameters that control ground water storage and transport, and to improve the ability of geologists, hydrologists, geophysicists, and geochemists to predict and model the physical and chemical processes affecting ground water. Research collaborators in the Appalachian Region include the WRD districts of Pennsylvania, Maryland, Virginia, North Carolina, and Georgia, the Virginia Division of Mineral Resources, the North Carolina Department of Environment and Natural Resources, and the USDA Agricultural Research Service. Current projects in the Appalachian Region include the following: 1) influence of fracture geometry on flow paths and chemical evolution of ground water in the Valley and Ridge province, Pennsylvania; 2) contaminant migration in tilted and faulted sedimentary rocks of the early Mesozoic Newark basin, New Jersey; 3) geologic influence on directional trends in well yields in the Blue Ridge province of northern Virginia; 4) lithologic and fracture control of ground water flow in the early Mesozoic Culpeper basin, Virginia; 5) relationship of ground water flow and geologic structure in the Piedmont of North Carolina; and 6) comparative hydrogeologic analysis of developed and undeveloped watersheds in the Blue Ridge of North Carolina.

Results to date indicate that detailed knowledge of the geologic framework is an essential first step toward understanding the hydrology of fractured bedrock. In central Pennsylvania, closely-spaced fractures parallel to inclined bedding planes in sedimentary rock exert a strong influence on ground-water flow paths and residence times, which in turn effect ground water chemistry. In northern Virginia, a north-south directional trend in well yields in Precambrian gneiss may reflect the influence of Paleozoic foliation and a swarm of diabase dikes. The regional ground-water flow pattern in the adjacent Culpeper basin is shaped by the complex geometry of diabase intrusions, which act as barriers to flow. In northern Georgia, high yields in municipal wells are controlled by the distribution of fault-bounded lithologic units, which are folded into a broad synform.

Because the integration of detailed geologic investigations into hydrogeologic studies is so fruitful scientifically, the BRASS project is seeking more opportunities for collaborative studies having high transfer value throughout the Appalachian Region.

Base-Flow Characteristics of Streams in the Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces of Virginia and Other Mid-Atlantic States

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Population growth within the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia has led to concerns about the allocation of surface-water flow and the increase in demands on the ground-water resources. Various hydrologic studies in Virginia have (1) described the base-flow characteristics of streams, (2) identified regional differences in these flow characteristics, and (3) described, where possible, the potential surface-water and ground-water yields of basins on the basis of the base-flow characteristics. Streamflow data were collected and low-flow characteristics computed (annual minimum average 7-consecutive-day flow for 2-year and 10-year recurrence intervals) for 254 continuous-record streamflow gaging stations and 461 partial-record streamflow gaging stations throughout Virginia. The continuous-record data were analyzed by means of historical mean daily discharge data, and the partial-record data were analyzed by means of correlation of discharge measurements to mean daily discharge data. The State was divided into eight regions on the basis of physiography and geographic grouping of residuals computed in regression analysis.

Additional base-flow characteristics were computed for streams in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia as part of the Appalachian Valley and Piedmont Regional Aquifer-System Analysis study. The provinces were separated into five regions: (1) Valley and Ridge, (2) Blue Ridge, (3) Piedmont/Blue Ridge transition, (4) Piedmont northern, and (5) Piedmont southern. Various flow statistics, which represent streamflows predominantly composed of base flow, were determined for 217 continuous-record streamflow-gaging stations and for 192 partial-record streamflow-gaging stations. Variability of base flow was represented by the logarithm of the ratio of the 50-percent exceedance discharge to the 90-percent exceedance discharge on the streamflow duration curve (base-flow variability index). Effective recharge rates also were calculated.

Median values for the various flow statistics range from 0.15 cubic foot per second per square mile for the 90-percent exceedance discharge on the streamflow-duration curve to 0.61 cubic foot per second per square mile for mean base flow. The 50-percent exceedance discharge on the streamflow-duration curve is an excellent estimator of mean base flow for the Piedmont/Blue Ridge transition region and Piedmont southern region, but this value tends to underestimate mean base flow for the remaining regions. The base-flow variability index ranges from 0.07 to 2.27, with a median value of 0.55. Effective recharge rates range from 0.07 to 33.07 inches per year, with a median value of 8.32 inches per year.

Differences in the base-flow characteristics exist between the five regions. The median discharges for the Valley and Ridge, the Blue Ridge, and the Piedmont/Blue Ridge transition regions are higher than those for the Piedmont regions. The flow statistics are consistently higher and the values for base-flow variability are lower for basins within the Piedmont/Blue Ridge transition region relative to those from the other regions, whereas the basins within the Piedmont northern region show the opposite pattern. Results from statistical analysis indicate that the regions can be ranked in terms of base-flow characteristics from highest to lowest as follows: (1) Piedmont/Blue Ridge transition, (2) Valley and Ridge and Blue Ridge, (3) Piedmont southern, and (4) Piedmont northern. The base-flow variability index shows an opposite relation and ranks the regions from lowest to highest in the same order.

Group rankings of the base-flow characteristics were used to designate the potential surface-water yield for the regions. An approach developed for this investigation assigns a rank for potential surface-water yield to a basin according to the quartiles in which the values for the base-flow characteristics are located. Both procedures indicate that the Valley and Ridge, the Blue Ridge, and the

Piedmont/Blue Ridge transition regions have moderate-to-high potential surface-water yield, and the Piedmont regions have low-to-moderate potential surface-water yield.

In order to indicate potential ground-water yield from base-flow characteristics, aquifer properties for 51 streamflow-gaging stations with continuous-record streamflow data were determined by methods that use streamflow records and basin characteristics. Areal diffusivity ranged from 17,100 to 88,400 feet squared per day, with a median value of 38,400 feet squared per day. Areal transmissivity ranged from 63 to 830 feet squared per day, with a median value of 270 feet squared per day. Storage coefficients, which were estimated by dividing areal transmissivity by areal diffusivity, ranged from approximately 0.001 to 0.019 (dimensionless), with a median value of 0.007.

The median value for areal diffusivity decreases as potential surface-water yield of the basins increases. Areal transmissivity generally increases as storage coefficient increases; however, basins with low potential surface-water yield generally have high values of areal transmissivity associated with low values of storage coefficient over a narrow range relative to those from basins designated as having moderate-to-high potential surface-water yield. Although the basins with high potential surface-water yield tend to have comparatively lower values for areal transmissivity, storage coefficients generally are large when compared to those from basins with similar values of areal transmissivity but different potential surface-water yield.

Aquifer properties were grouped by potential surface-water yield and were related to hydrogeologic units categorized by large, medium, and small well yields for the Valley and Ridge Physiographic Province and for the Blue Ridge and the Piedmont Physiographic Provinces. Generally, no trend is evident between areal diffusivity and the hydrogeologic units. Some of the high values of areal diffusivity are associated with basins predominantly underlain by hydrogeologic units with small well yields, especially basins with a low potential surface-water yield. Areal transmissivity and storage coefficient tend to decrease, as expected, as more of the basin is underlain by the hydrogeologic unit with small well yields in the Valley and Ridge Physiographic Province. A similar trend is indicated for the hydrogeologic unit with medium well yields in the Blue Ridge and the Piedmont Physiographic Provinces. Areal transmissivity and storage coefficient tend to increase, which is unexpected, as more of the basin is underlain by the hydrogeologic unit with small well yields in the Blue Ridge and the Piedmont Physiographic Provinces. The base-flow characteristics of a basin may provide a relative indication of the potential ground-water yield, but other factors need to be considered, such as geologic structure, lithology, precipitation, relief, and the degree of hydraulic interconnection between the regolith and bedrock.

Baseflow characteristics also were computed for 221 additional continuous-record streamflow gaging stations from North Carolina, Maryland, Delaware, Pennsylvania, and New York as part of the Mid-Atlantic Integrated Assessment study. Regional clusters of the group rankings of the base-flow variability index are evident spatially. Analysis of the data plots suggests that the Piedmont/Blue Ridge transition region extends into central and western North Carolina. Other regional clusters suggested by data analysis are within the Appalachian Plateaus in southwest Virgina and Pennsylvania and Fall Zone areas in eastern Virginia and possibly eastern North Carolina.

Geologic Outreach in Public Lands: We Have the Gold, Let's Take it to the Bank

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Communication of geologic information is crucial for informed decisions in making public policy. This is particularly true in managing public lands; in addressing environmental issues, coping with natural hazards, and recommending wise use of our natural and scientific resources. Research on state and federal lands should also be directed to enhance public understanding of our earth systems.

Usable scientific data are required by the National Park Service to carry out its mission of management and interpretation of much of the nation's public lands. The USGS has had a long history of geologic research in the Nation's Parks. In 1994, based on the USGS concern with "total quality management" and recognizing the NPS as a prime customer of our geologic information, both agencies entered into a memorandum-of-understanding in which the USGS would supply earth-science information for selected park lands. The projects were funded through the National Cooperative Geologic Mapping Program in the Geologic Division, so bedrock and surficial geologic maps were to be the prime products to help optimize land-use decision making on NPS lands. NPS personnel ranked approximately 40 geologic project proposals submitted by the national parks. Fourteen projects, distributed nationally, were selected in 1995 that meet the immediate needs of both agencies. Issues related to land management and planning were of prime concern in prioritizing these projects. In 1996 the Geologic Division initiated a "Geologist-in-the-Park Program" which designated a USGS scientist for each park to interpret the geology, to prepare geological information packets, videos, or other outreach materials, and to assist in training park rangers.

Many of the unique attributes of the nation's National Parks are based on geology. Their scenery is the result of many natural processes acting upon the variety of rocks that were formed in diverse environments in the geologic past. Knowledge of the geologic origin of these attributes, training of NPS personnel in their proper interpretation, and communication of this information to the public is an important priority of NPS. A comprehensive geologic information data base of each park is necessary to carry out that park's mission of management and serving the public. The USGS along with the State Geological Surveys are uniquely qualified to contribute to that inventory of park resources. Geologic maps and scientific reports form the basis for a variety of interpretive publications. These include digital data as part of a GIS showing bedrock and surficial geology, resource and hazard potential, trail guides, interpretive leaflets and brochures, and exhibits. Issues addressed include water availability and quality, scientific and cultural resource management, trail and visitor center location, ecosystem characterization, and inventory of paleontologic, geologic, and archaeologic sites. Public educational outreach is a major aspect of this cooperative interagency effort. USGS geologists have developed innovative ways to communicate geologic information and its applicability to environmental issues to park staff through workshops, field trips, and seminars.

Each national park has developed a unique management system. Few parks have geologic expertise (biologists outnumber geologists by more than 20:1). Perception of the usefulness for geologic data is quite variable and park management may be unaware of the value of geologic data. Therefore, in order to propose meaningful tasks, there must be considerable preliminary interaction and evaluation between park officials and USGS scientists. While the perceived (and unperceived) needs for geologic information may be unique for each park, a national perspective within the USGS should be developed. A national project is needed to coordinate the efforts, and to work closely with NPS-Geologic Resources Division (GRD) to ensure coordination of funding, manpower, and data base standards.

National Parks within the Appalachian Highlands are close to large population centers and are heavily visited. The Eastern Earth Surfaces Processes Team has done geologic mapping and concomitant outreach in several parks, including Great Smoky Mountain National Park, Shenandoah National Park, C&O Canal National Historical Park, Great Falls Park, Harpers Ferry National Historical Park, and Delaware Water Gap National Recreation Area.

The Delaware Water Gap National Recreation Area (DEWA), which lies within the heart of the Boston-Washington urban corridor, is the largest National Park facility in the northeastern United States and the ninth most heavily visited NPS facility in the country, attracting about 5 million visitors a year (Great Smoky Mountains NP is third). The efforts to supply earth-science information to DEWA to carry out its management responsibilities include upgrading their inventory data bases, land-use management/planning, training of Park Rangers, aid in trail and exhibit design, involving the park in a GSA symposium and a major Field Conference, informal geologic fireside chats, and potential development of a curriculum-based education program that will meet State and National curriculum standards at the K-6 level. Resulting curricula materials will be included in the park's web site, making it readily accessible to many schools not involved in the project preparation. Based on an extensive mapping program and complete understanding of the geology of the park by the USGS, this task will allow the USGS to help in the primary mission of interpretation and education in the NPS. Geologic resources within the park allow for the following themes to be developed: glaciation, geomorphic development of the Appalachians, origin of waterfalls, rocks and minerals, structure and plate tectonics; fossils, relation of geology to anthropology and historic development of the region.

The results of efforts in DEWA have been only a partial success. Similarly, the total USGS-NPS project, which was divided among the three USGS administrative regions, could have been better. The successes and failures in the three regions were variable. Also, coordination with the Geologic Resources Division of the NPS, whose mission includes protection, preservation, and understanding the geologic resources of the National Park system, could have been better, especially if a more formal liaison had been established. Presently, NPS has liaison personnel in the three USGS regions, but the reverse is not true. This is especially significant because recently some funding has crossed the line from the NPS to the USGS. Finally, there are many ways in which a USGS-multi-disciplinary approach can be made with the National Park Service. For example, BRD’s Vegetation Mapping Program in the National Parks could be facilitated with geologic maps that will foster better understanding of the geologic framework of the park.

What might we do?

Geologic maps and research articles by themselves may have little meaning to non-geologists. It is crucial that we develop a methodology to interpret these products for the variety of land-use issues in the National Park service. Whereas the present efforts in the “National Parks Project” in the USGS is directed mainly to geologic mapping and related scientific research, we have come to realize that without taking the next step, much of the valuable information gleaned from this research will not be useful. The USGS has built a huge geologic data base, both published and in the corporate memory of its geologists. Much of that information is going unused. It is the gold needed by the Park Service. Let’s discuss how to take it to the bank.

A three-component approach is suggested: **research, interpretation, resource management**.

Research: Without the basic science, including mapping, the other two components would not have a supportive base. This includes completion of geologic mapping in individual parks where necessary and at the proper scale, and basic research in structure, stratigraphy, paleontology, surficial processes, material resources, and hazards. Scientific publications would be the result of this category. The knowledge gained by this research should be incorporated in park interpretation programs and decisions of resource management. Much of this effort is presently underway. Unfortunately, it is the main basis for promotion in our personnel evaluation system. Because of this, the two following components may be demeaned.

Interpretation: The data developed by the scientific research needs to be reformatted and made understandable to NPS personnel and the general public. The products may include interpretive maps, manuals, brochures, field guides, trail and roadside exhibits, visitor center displays, and others. Keith High, former computer specialist at DEWA once said, "now that I have geologic maps in my GIS data base, what can I do with them?" As scientists, we are steeped in jargon, an obscure geologic vocabulary. We try to cram as much information into the smallest space (abstracts), be as efficient with words and graphics as possible (reports, maps), or give the impression of great knowledge (oral presentation). Our colleagues may understand us (sometimes they don't), but this obscure vocabulary may exclude our non-scientist audience, the planners, managers, politicians, common folk, etc. This language barrier may effectively keep these people from understanding the value of our science. Again, we have the "gold"; let's make sure we convert it into currency that has not been devalued by our jargon.

Resource and Land Use Management: Geologic information, both scientific reports and interpretive products, needs to be useful to NPS in their resource Management Plans. This includes aid in inventories and monitoring of their geologic resources, including paleontologic sites, type or reference stratigraphic sections, and unique geologic features such as tectonic and sedimentary structures, glacial features, and sites uniquely displaying geologic processes. An understanding of potential hazards, especially landslides and karst subsidence in the Appalachian Highlands, as well as an understanding of the land-use characteristics of surficial materials, is critical for proper land use management in the parks. USGS geologists could coordinate with NPS personnel, as appropriate, to help update a park's resource management plan and help implement actions and studies that the plan advocates. This includes applying existing and updated theories of geologic principles to understand the park's geologic resources, incorporating this knowledge into understanding ecosystem attributes, and amelioration of human-caused disturbances, especially related to watershed contamination. Additionally, we can coordinate with NPS in their "Geologists in the Park Program" by aiding in selection of individuals and, where requested by the individual park, guide and mentor those individuals.

In conclusion, the NPS has indicated in their web site that their scientific needs include fundamental research, synthesis of geologic literature, mapping, inventory, site evaluation, developing brochures and informative media presentations, and educating staff. The purpose of the USGS program should be to help NPS management understand, manage, and interpret their geologic resources.

Some questions and thoughts for consideration:

1. Without going deeply into the debate concerning basic research vs. applied research, how much of our future research should be directed toward preparing information that is truly useful to our customers, the NPS being an example?

2. To what extend does the present funding criteria within GD encourage or discourage the application of our geologic research to the management needs in public lands?

3. Have we been seamless or *seamfull*? There are many examples of projects within a Discipline that is unknown to workers in other Disciplines. How can we improve this situation?

4. Can we better integrate our activities with other federal agencies, especially the Park Service?