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U.S. Geological Survey Appalachian Region Integrated Science Workshop Proceedings, Gatlinburg, Tennessee, October 22-26, 2001

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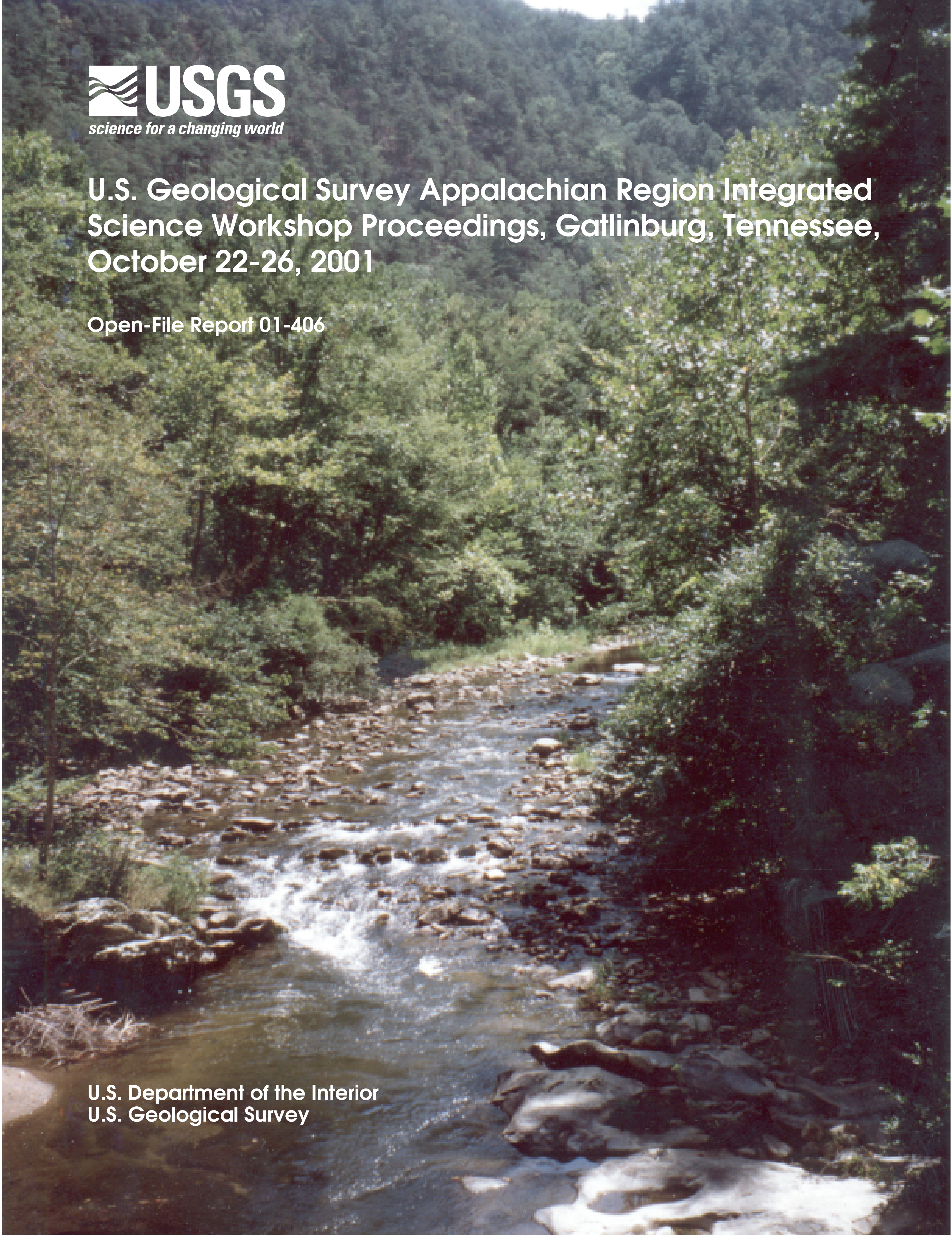

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U.S. Geological Survey Appalachian Region Integrated Science Workshop Proceedings, Gatlinburg, Tennessee, October 22-26, 2001

D. Briane Adams, Katrina Burke, Bruce Hemingway, Jeff Keay, and
Michael Yurewicz, compilers

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Charles G. Groat, Director

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For additional information write to:

D. Briane Adams
U.S. Geological Survey
3850 Holcomb Bridge Road
Suite 160
Norcross, Georgia 30092

Copies of this report may be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, Colorado 80225-0286

PREFACE

Why the Appalachians?
A U.S. Geological Survey Integrated Science Planning Effort

Some of nature's most magnificent creations on Earth are the picturesque landscape and the terrestrial and aquatic inhabitants of the Appalachian Mountains of the Eastern United States. Mother Nature has been kind to the region but man, often, has not. The Appalachian mountains and valleys have been home to a variety of human cultures, dating back approximately 12,000 years. A series of Native American peoples, including most recently the Cherokee Nation, inhabited the region prior to European settlement which began in the 1600's. All of these peoples have had the desire to reap the benefits of the land.

Current and historic use of the land ranges from mineral extraction to agricultural development to timber production to industrial and residential development, all of which have now threatened the landscape. Many individuals and organizations desire to save the awe and beauty of the Appalachians for the generations to come, in a way that is environmentally and economically sustainable. They have tried for years to raise alarms that this area is threatened and worth the attention of all who are interested in an effort of restitution and preservation. Residents, environmental groups, land managers, scientists, business groups, and the multitude of visitors who pass through the national parks and other public lands located within the Appalachians have raised these same alarms. There is a need to not only identify the issues resulting from anthropogenic pressures on the landscape, but also to collect the information and conduct the science that will allow land managers and policy makers to become better informed and better able to execute their responsibilities.

The issues are many—air quality, sustainable development, threatened and endangered species, invasive species, landscape fragmentation, watershed modification, ground-water contamination, mineral extraction, cultural and economic impacts—to list just a few. An important awareness has developed in the past decade …. individuals, businesses, government agencies, universities, and private groups are beginning to work together to preserve the landscape of the Appalachians for not only the economic future of human residents and the natural environment for endemic species, but also for the many millions of visitors who come to enjoy the majestic scenery. One such group is the Southern Appalachian Man and Biosphere (SAMAB) program, founded in 1988 as a cooperative of Federal agencies that collaborate to provide information necessary for solving issues related to their natural resource missions and responsibilities in the Southern Appalachians. This cooperation has resulted in numerous efforts to identify and correct longstanding problems and to improve management practices in the region. The most comprehensive of these efforts was the Southern Appalachian Assessment (SAA), which was completed in 1996. The assessment provided feedback on the current status of the resources of the area and identified many issues that needed to be addressed. To date, there has been no comprehensive effort to follow up and address the issues identified. About the same time that the SAA was being completed, the U.S. Geological Survey (USGS) initiated an effort to develop the Southern Appalachian Critical Ecosystem Program (SACEP), a solicited proposal for funding under the then National Ecosystem Program, which had initiated work in other parts of the United States, most significantly in southern Florida. The SACEP continues to remain unfunded. Since that time, the USGS has been reorganizing both administratively and programmatically. During this reorganization process, the USGS has concentrated on conducting science in an integrated and multidisciplinary manner. As a result, a number of national issues of concern have been identified, with several geographic areas and landscapes designated as specific focus areas for scientific study. Initially, the Appalachians were not considered as one of these specific areas of focus. USGS managers now have become convinced that the region should be reconsidered as a focus area for scientific study. Subsequently, USGS scientists and managers from all disciplines throughout the USGS gathered at a workshop in Gatlinburg, Tennessee, from October 22-26, 2001, to share data, scientific results, and ideas. An attempt was made to establish an understanding about the current status of science efforts, to develop new collaborative opportunities, and to further scientific understanding of the issues and the impacts on the earth resources of the Appalachians. As a result of this workshop, a draft "science opportunities" document is currently under development in an effort to help set USGS priorities for investment of resources for the foreseeable future. In developing this document, issues and gaps in scientific understanding are being identified. The plan will not be successful, however, if developed from within the USGS alone. It is critical that all USGS partners provide their voice in identifying issues and needs for science information in this region. A second workshop scheduled for early 2002 will invite the participation of USGS partners to not only critically review the draft integrated science opportunities document, but to come with their issues and needs as identified from their perspectives. The needs of USGS partners will be incorporated into a final document that will be used as a guide by the USGS to focus and seek additional resources for the future. The document on Appalachian area science opportunities will be made available to all who have an interest in the USGS efforts in the Appalachian region. A new USGS website is being developed for the Appalachian region — http://www.AppalachianRegionScience.usgs.gov. At this website, you can find data and information on current and past USGS research in the Appalachian region, and proceedings from the October 2001 USGS workshop. The website will also house the draft science opportunities document which will be available for review and input. You can also find links to other supporting websites with information on Appalachian region resources. We invite you to provide additional internet information links that can be added to the website.

In summary, the workshop was organized to bring together USGS scientists of all disciplines to not only identify their current areas of research in the Appalachian region but to allow them the opportunity to become familiar with whom they may collaborate in future work. We hope that the information presented at the workshop and in these proceedings will not only benefit USGS scientists, but will be of value to policy makers and resource managers in identifying additional needs for USGS participation in supplying science information for the Appalachian region in the future. Based upon this information and subsequent discussions in the development of the draft science opportunities document, we hope to provide some guidance for investment of USGS resources for the future. It is hoped that all who have an interest in USGS science will use these proceedings and the draft science opportunities document to help identify issues and gaps in information that they would like the USGS to provide. Input is not only solicited, but essential, along with participation at a second workshop planned for the spring of 2002. This workshop will invite existing and potential USGS partners to participate and provide input to the final science opportunities document that will be published and possibly used as a guide for future USGS research and data collection in the Appalachian region.

D. Briane Adams

CONTENTS

SESSION I

SESSION II

SESSION III

SESSION IV

DISCUSSION SESSION

POSTER PRESENTATIONS

ADDITIONAL ABSTRACTS

SESSION I

The Southern Appalachians: A Changing World
Sandra Clark, Judith Back, Anne Tubiolo, and Elizabeth Romanaux

A Framework for Integrated Science in the Appalachian Mountain Range
John D. Peine

Overview of Current and Future Fossil Energy Geoscience in the Eastern Region
Ione L. Taylor and Senior Scientists of the Eastern Energy Resources Team

Land Surface Change and Analysis
Dave Kirtland

The Collaborative Environmental Monitoring and Research Initiative in the Northern Appalachian Region
Peter Murdoch, Richard Birdsey, and Ken Stolte

The Southern Appalachians: A Changing World

Sandra Clark[1], Judith Back[1], Anne Tubiolo[2], and Elizabeth Romanaux[3]
[1]U.S. Geological Survey, 954 National Center, Reston, VA 20192
[2]National Park Service, Harpers Ferry Center/AV Arts, Fillmore Street, Harpers Ferry, WV 25425
[3]Liberty Science Center, Liberty State Park, Jersey City, NJ 08305

The Southern Appalachians is a region known for its beauty and rich biodiversity. Although it includes some of the most visited recreation areas in the country, few are aware of the geologic underpinnings that have contributed to the beauty, ecosystems, and quality of human life in the region.

The U.S. Geological Survey, in cooperation with the National Park Service, produced a 25-minute video to explain how geologic processes over the last billion years have interacted with other elements in the environment to result in the region we see today. The video includes several animated segments that show paleogeographic reconstructions of the Earth and movements of the North American continent over time; the formation of the Ocoee sedimentary basin beginning about 750 million years ago; the collision of the North American and African continents about 270 million years ago; the formation of granites and similar rocks, faults, and geologic windows; and the extent of glaciation in North America. The animated segments are tied to familiar public-access sites in the region. They illustrate geologic processes and time periods, making the geologic setting of the region more understandable to tourists and local students. The video reinforces the concept that understanding geologic processes, rates, and setting is an important component of informed land management to sustain the quality of life in a region.

The U.S. Geological Survey sought feedback for the concept of the video from the Southern Appalachian Man and Biosphere (SAMAB) Program and its member agencies before starting work on the video. Suggestions by SAMAB's Environmental Education Committee significantly strengthened the resulting product. U.S. Geological Survey will continue to work with SAMAB to distribute the video to middle and high schools and Visitors Centers in the region.

A Framework for Integrated Science in the Appalachian Mountain Range

John D. Peine
USGS-Leetown Science Center
Southern Appalachian Field Laboratory
University of Tennessee at Knoxville

ABSTRACT

There is considerable scientific advantage to examining the Appalachian mountain range from a holistic perspective. First and foremost is that the mountains represent a continuous transect roughly following the configuration of the east coast of the U.S. This paper provides a synopsis of the distinctions of the region, over arching stressors and key responses within an environmental and socio-economic context, and opportunities for integrated science. The opportunity to structure a USGS science program at this geographic scale will allow for collaboration among scientists focusing on similar issues at various locations up and down the mountain range. There will also be a greater opportunity to engage in interdisciplinary science targeted to multidimensional issues. Climate sensitivity and change is a key overarching issue as is air and water pollution and changing land use, all of which is connected to the ever growing list of pests, pathogens and invasive species. Urbanization, mining and forest practices, and recreation are inextricably linked to sustainability in a social, cultural, economic and environmental context. Through the proposed initiative, the USGS can demonstrate its leadership and relevance to the conduct and management of integrated science. Also, as goals of the emerging USGS Science Impact and INCLUDE programs, the initiative provides an opportunity to demonstrate how to most effectively distribute scientific information in a useful form and context into the hands of decision-makers working toward improving and sustaining quality of life throughout the Appalachian Mountain region.

DISTINCTIONS OF THE BIOGEOGRAPHIC REGION

Geographic and Institutional Context

The Appalachian region includes the entire state of West Virginia and parts of 12 other states. For the purposes of this paper, comments will be directed to the highlands portion of the region. The Appalachian Mountains were formed when “continental drift” caused western Africa to collide with North America during the end of the Paleozoic era, about 230 million years ago. At that time, all the Earth’s major continents had merged to form the single super continent called “Pangaea”. Much of the genera of vascular plants prevalent then remain in the Appalachians and in the mountains of eastern China.

The Appalachian Mountains are rich in institutions dedicated to resources management, economic development and social services. The Southern Appalachian Man And Biosphere Cooperative (SAMAB) is an example of a consortium of public agencies working together for ecosystem management and sustainable development. Members include the Appalachian Regional Commission, Tennessee Valley Authority, Economic Development Administration and various federal agencies associated with science and/or management of natural resources (Hinote, 1999). The most notable accomplishment of SAMAB was to conduct a regional assessment of environmental, economic and social conditions, the results of which were published in 1996 (Berish and others, 1999). From that effort, the Southern Appalachian Regional Information System has evolved and is now incorporated in the Southern Appalachian Node of the National Biological Information Infrastructure (SARIS, 2001; SAIN, 2001).

Key factors contributing to the strength of the region being a focus for USGS integrated science include the following (Randolph and others, 1999):

- Diversity and abundance of natural and cultural resources residing within the complex topography;
- The degree to which the native environment is intact and/or in recovery;
- The size and configuration of protected lands being managed within the principles of sustainability;
- The presence of regional interagency organizations dedicated to integrated ecosystem management, information management and environmental education;
- The presence of robust programs to inventory, monitor, assess and research the natural resources and human dimensions of the region;
- The variety and severity of threats to natural resources occurring at the species, community and ecosystem levels; and
- The abundance of creative management and education actions being pursued to mitigate perturbations.

Continental Transect

The 2,168 mile-long Appalachian Trail from Maine to Georgia provides a reference for the linear transect afforded by the Appalachian Mountain range. This transect provides a geographic reference point to compare similar scientific investigation conducted at various latitudes and/or topographic positions along the mountain range. Examples include studies of black bear populations, brook trout, migratory birds, salamanders, spruce-fir forests and air pollution. This linear transect is in some instances a time capsule as well, particularly in the context of evaluating the environmental effects of various stressors. For example, many invasive pests and pathogens, such as dogwood anthracnose, gypsy moth and Hemlock adelgid, first invaded the northeast and in some cases have yet to reach the southeastern terminus of the mountain range (Schlarbaum and others, 1999). SAMAB is sponsoring a citizen-science program for resource monitoring along the Appalachian Trail.

Biological Diversity

The Appalachian Mountain range provided a geographic refuge for biodiversity and species richness during a series of ice ages. The spruce-fir forest in the southern Appalachians is a highly threatened remnant ecosystem of the last ice age. At the turn of the 20th century, mixed mesophytic and oak-chestnut forests once dominated throughout most of the region. Hemlock-white pine-northern hardwoods dominate in the north, and oak-pine in the south (Brawn, 1950). As an international biosphere reserve, the southern Appalachians are globally renowned for the biodiversity of their temperate forests and freshwater mountain rivers and streams. The Southern Appalachian Assessment (SAA, 1996) identified 16 broad vegetation classes and 31 rare community types such as the high elevation balds. The Nature Conservancy recognizes 200 community types in the region (P. White, pers. commun.). In the southern Appalachians alone, there are 2,250 species of vascular plants, 80 species of amphibians and reptiles, 175 species of birds and 65 species of mammals (Randolph and others, 1999). A larger percentage of species of nesting song birds are neotropical migrants (75 species) than anywhere else in the nation. The largest and most striking group includes 50 species of wood warblers (Simons and others, 1999). A comprehensive biological inventory is currently underway in Great Smoky Mountains National Park (ATBI, 2001). A Southern Appalachian Node has been recently established for the USGS National Biological Information Infrastructure program which among other things, will feature innovative means to access scientific information from many disciplines (SAIN, 2001). The Center for Virtual Appalachian (CVA, 2001) has identified 113 web sites on natural resources in the region. Commonly used keystone indicator species of ecological health include fresh water muscles and brook trout for the rivers and streams respectively, black bears and wood thrush for temperate forests, red spruce trees for high elevation forests and tulip popular and varieties of milkweed for ozone pollution.

Cultural Distinctions

The Native American population in the southern Appalachians was about one million when the first Europeans arrived. By the time large numbers of white settlers appeared in the southern Appalachians in the mid-18th century, the Mississippian Indian culture had been replaced by the Cherokee. Early European settlers in the southern Appalachian region were generally of three ethnic origins: Scotch-Irish, English and German. The early settlers shared many common characteristics, which are important in understanding their way of life. Many of these traits still endure in modern day residents of the region who trace their ancestry back to the early settlers. These people are proud of their cultural heritage and how they have overcome the many obstacles to their survival. Religion is an integral part of their lives and most are strongly individualistic and self-reliant. Being conservative, they tend to move cautiously toward change and are sensitive to "outsiders". Well into the 20th century, life for residents was largely tied to the land and natural resources. Perhaps more than other rural areas, physiography shaped social and culture patterns in the mountains. Each community occupies a distinct cove, hollow or valley separated from its neighbors. Land ownership patterns usually terminate at ridgetops, reinforcing the community's identity and independence (Randolph and others, 1999). These cultural dynamics are of critical importance when conveying scientific information in a community context. Today, the region, as defined by the Appalachian Regional Commission, includes 406 counties in which 20 million people reside, 42% of which live in rural areas compared to 20% nationally.

Social-Economic Challenges

The family farm was the preindustrial Appalachian regional economy. Each mountain homestead functioned as a nearly self-contained economic unit. After 1900, extractive industries such as logging and coal mining competed with mountain farmers for the use of the woodland. During the first three decades of the 20th century, private companies acquired large tracts of mountain land. Entire valleys were given over to railroads, coal mines and coal towns, while forest slopes were denuded to provide timber for underground mines and coal towns. By 1930, only 60% of the land in Appalachia was still owned by farm families (Eller, 1978). As mountain families abandoned the farms during the depression and after World War II, coal companies expanded their land ownership and introduced strip mining. Companies found that bulldozers and power shovels could remove overburden covering coal seams at a fraction of the cost of underground mining. The process stripped away soils and vegetation leaving barren slopes (Caudill, 1963). The process has been revived today to retrieve smaller coal veins by what is called mountain top removal, shoving the overburden down into ravines and covering first and second order streams.

Some of the abandoned farmland was converted into federal forests. The Clarke-McNary Act of 1924 permitted the federal government to acquire "cut over" lands for timber management purposes. The concept of creating national forests in the southern Appalachians was first documented in a report to President Theodore Roosevelt by the Department of Agriculture in 1901 (Message, 1902).

The central and southern Appalachian Mountains have long been recognized as pockets of entrenched poverty with substandard public services and devoid of viable economic opportunities. The central Appalachian region of eastern Kentucky and western West Virginia has historically been the nation's largest geographic area of poverty. There continues to be numerous Appalachian counties where the majority of the population achieves no more than an 8th grade education (US Census, 2001).

More recently, tourism has become one of the largest growth industries throughout the Appalachian region, but it does have significant limitations in that most jobs are seasonal and low paying without benefits such as health care (Tooman, 1997).

Public Land Holdings

There is a sizable public-lands estate in the Appalachian Mountains. There is a greater assemblage of federal lands here than anywhere west of the Rocky Mountains. The USFS is by far the largest federal landholder with 13 national forests totaling over 6,636,000 acres. The 25 NPS units total over 1,000,000 acres.

The primary units include Great Smoky Mountains, Shenandoah and Big South Fork. The 469 mile-long Blue Ridge Parkway links the Smokies and Shenandoah units. There are 3 national battlefields and 5 national historic areas as well.

STRESSORS AND RESPONSES

Climate Change

Climate is the most important factor influencing the relationship between soil, vegetation and site properties such as primary productivity. Climate, as a source of energy and moisture, acts as the primary control of ecosystems (Bailey, 1990). Variability in climate regimen and more extreme weather events are predictions of climate change (IPCC, 1992). Regional changes in temperature will effect local rainfall, snowfall and soil moisture conditions (Mitchel, 1990). As a result, there is also predicted to be change in the range of annual and seasonal temperatures, variability in frost free days, alterations in the quantity and timing of precipitation, and temporal distribution of moisture accumulation seasonally which in turn would vary traditional patterns in soil moisture (IPCC, 1992). Abrupt change of established climate conditions often creates stress on ecosystems (Overpeck and others, 1990). The implications of these predicted trends are exacerbated in a mountain environment.

Superimposed on the potential effects of climate change are a series of events which could be triggered by climate change such as increased incidents of pests and pathogens, fire frequency and intensity, and expanded periods of stagnant air resulting in the build up of pollution. The biological response to this litany of stressors could include decline in forest productivity; shifts in the structure and/or function of plant and animal communities; changes in population distribution; and an overall reduction in biodiversity and nutrient availability (Peine and Berish, 1999).

Examples of climate sensitivity include high elevation endemic species, organisms living in springs and first order streams, and species requiring moisture dependent habitats such as amphibians. The high-elevation spruce-fir forest ecosystem in the southern Appalachians is anticipated to be lost due to predicted climate change (Delcourt and Delcourt, 2000).

In addition, the predicted increase in frequency and ferocity of weather events represents considerable risk to people and their infrastructure. For example, in Great Smoky Mountains National Park, the snow blizzard of the century in 1994 and flood of the century in 1995 resulted in over $10 million in damages to the park infrastructure (Peine and Berish, 1999). In late spring of 1997, there was a major landslide closing Interstate-40 for several months, the primary east-west transportation artery through the southern Appalachians. This landslide followed an extremely wet spring season in the southern Appalachians.

Land Use

Land use is a key issue concerning the integrity of critical habitats and ecosystem processes. Fragmentation of habitat, and sediment runoff from disturbed lands are dominant issues within watersheds throughout the Appalachian Mountains. Land use changed dramatically with the influx of European Americans on the Appalachian landscape. Deforestation and strip mining were at their peak in the first half of the 20th century. Since that time, there has been extensive reforestation of the landscape. In recent years, strip mining has converted to mountain top removal as a means to cost effectively mine smaller coal deposits. Overburden is pushed into gullies covering first and second order streams. Chip mills have moved in to harvest via clear-cut vast tracts of privately held forestlands. Since 1985, there are 156 chip mills in the southeastern U.S. consuming an estimated 1.2 million acres of forestlands per year. Seventy percent of the pulp production in the U.S. occurs in the southeast (Shaw, 2000). Severe flooding in southwestern West Virginia on August 4, 2001 has been blamed in part on forest harvest practices and mining by mountain top removal. In addition, the Appalachians have become a preferred landscape for residential development, particularly for tourists and retirees. The urbanization of the landscape is escalating dramatically, particularly in centers of tourism and along the fringes of metropolitan regions. Lands adjacent to protected areas are particularly popular for residential and commercial development. A variety of adverse impacts on protected areas can occur from adjacent lands such as attracting wildlife to human food sources, wildlife predation by domestic animals, and noise and light pollution. In addition, there is a greater likelihood of invasion by pests such as Gypsy Moth and alien plant species, and increased access for illegal activities such as poaching native plants and animals. These problems are of greatest concern in gateway communities to national parks. Another concern is the overuse of public lands for recreation. The Southern Appalachian Assessment identified numerous recreation sites where use was reaching or exceeding carrying capacity on peak-use weekend days. The highest density of these hot spots follow the outer edge of the southern portion of the Blue Ridge Province (SAA, 1996).

Air Quality

Deposition rates for air pollution in the high elevation forests are some of the highest in the nation. The deposition comes in the form of aerosols, gases, cloud moisture and rainfall. The Appalachians has for over three decades been a focus of monitoring of air quality and air pollution effects research. Landmark research in the 1980’s by scientists at Oak ridge National Laboratory documented that the highest rates of air pollution deposition in the nation occurs in the Appalachian Mountains (Johnson and Lindberg, 1992). Very high levels of ozone occur routinely in the Appalachian Mountains. In Great Smoky Mountains National Park, 90 plant species of plants have been reported to exhibit ozone foliar injury symptoms (Barish and others, 1999). The National Park Service routinely alerts park visitors of health warnings from excessive levels of ozone. This is of particular concern to through hikers on the Appalachian Trail. Also in the Smokies, extremely high correlation has been found between the level of sulfur dioxide gaseous emissions and an increase in haziness (Malm and Pitchford, 1994). Sulfur dioxide emissions have increased by a factor of five while the visual range has been reduced to one fourth of what was determined to be natural levels (Sisler and others, 1993). The Southern Appalachian Mountain Initiative program is just now completing a 7 year regional assessment of cause and effects of air pollution (SAMI, 2001). Throughout the Appalachian Mountains, the primary source of sulfate and nitrate pollution is fossil fuel power plants located in the Ohio and Tennessee River Valleys. Long range transport, deposition and effects models now available greatly enhance the potential to integrate air pollution effects into watershed assessments.

Pests and Pathogens

Exotic pests can be devastating as there is often no natural resistance present in the host species since the co-evolution of pests and their hosts have not occurred. Destruction of the American chestnut by the introduced chestnut blight fungus is the primary example in the Appalachian Mountains (Burnham and others, 1986). Transportation corridors and forest disturbance provides an opportunity for exotic pests and plants to become established, although many exotic plants do not require disturbance. These species are frequently more aggressive in occupying disturbed areas than native species (Shlarbaum and others, 1999). Examples of these plant pests include tree-of-heaven, privit, kudzu, musk thistle and Japanese grass. The end result of their invasion is the loss of some populations of native species. The exotic mammal of most concern is the European Wild Boar (Peine and Lancia, 1999). Particularly troublesome insect pests and pathogens include the Balsam and Hemlock Adelgids, Dogwood Anthracnose, Butternut Cancer, Gypsy Moth and Beech Bark disease complex. Once established, exotic pests and pathogens can be difficult, if not impossible to control or eradicate.

Community Sustainability

Cultural fabric in the Appalachian region is manifest largely in rural communities. People living in these small communities are less likely than their urban dwelling counterparts to have high quality social services such as schools and health care and fewer opportunities to find full time employment at a reasonable salary with benefits such as health care and retirement. One of the primary missions of the Appalachian Regional Commission is to aid these rural communities to achieve viable economies and public services. This has been a constant challenge over the 35-year history of the agency with mixed results. Poverty remains intransigent for countless numbers of these isolated communities. Jean Richardson, in her book *Partnerships in Communities: Reweaving the Fabric of Rural America* (2000), discusses integrating research into community action. She contends that there is no simple recipe for rural prosperity. "It is not a question of having inadequate data: as a nation we seem to flourish on data and the collection of data. The data used, whether national, regional or local, may be accurate, but what is typically missing is the integration of research with proposed actions, including actions proposed by the community itself." She mentions that applying GIS technology to convey information must be accomplished in such a way so as to foster non-technically oriented citizens to explore data fields to find information relevant to their issues of concern within an appropriate spatial and temporal context. She defines key principles of sustainable rural communities to include empowering community members, recruiting leaders particularly among women, engaging the young, encouraging innovation and fostering links to urban areas.

OPPORTUNITY FOR INTEGRATED SCIENCE

A compelling case for applying integrated science to address community sustainability issues can be made via Gatlinburg, Tennessee, the primary gateway community to the nation's most visited national park. The view of Mt LeConte is frequently obscured due to air pollution. Views of the mountains add over $30 per square foot to the value or residential real estate (Leedy, 2001). There is considerable controversy concerning road- building projects along the park boundary. One project in the community was recently stopped because of various concerns related to the park. The community, situated in a narrow valley at the foot of the steepest watershed in the Appalachian Mountain Range, is highly susceptible to flash flooding. During peak tourist seasons, there is a dense population of tourists and routine traffic congestion centered within the flash flood zone. The West Prong of the Little Pigeon River running through the heart of town has been frequently cited by the state for noncompliance of water quality standards due to fecal coliform contamination. Sport fishing in town is supported by a community operated fish hatchery where exotic rainbow trout are raised and released. There is considerable light pollution from the community intruding into the park's night sky. Black bears whose home range is centered in the national park have habitually ranged into town to partake of human-source food found in dumpsters and garbage cans. Tourists in condominiums and rental cabins routinely throw food to these bears. Local hunters come into town to hunt these easy to find bears during the height of the fall tourist season. In1997, after years of a build up of the bear population, there was a fall mast crop failure due to a late spring frost resulting in a large number of bears ranging outside the park foraging for food. Hunters were shooting bears in front of tourists, once while the bears were in a downtown dumpster. Local police were defending the rights of the hunters. National news media covered the story. Finally, under political pressure, the community recently adopted an ordinance requiring the use of bear-proof dumpsters and garbage cans, a policy state and federal wildlife officials had been advocating for 25 years previously to no avail (Newton, 1999; Peine, 2001).

Human Risks Due to Urbanization, Land Use and Climate Change

As the human population dramatically rises in the Appalachian Mountains, so do the hazards related to climate change. As noted previously, storm events are predicted to become more frequent, more extreme and less predictable as to the timing and location of their occurrence. This concern is particularly timely with the controversy in West Virginia concerning the increased potential for flooding due to mountain top removal and forest harvest practices.

In addition, the urbanization of the mountain landscape will result in more development occurring in areas of high risk from building more steeply inclined roads to building in areas susceptible to land slides and flash flooding. During periods of extended drought, urbanization encroaching on forested areas poses a danger from wild fires. An assessment of risks to people and their fiscal infrastructure would be invaluable for planning for future growth and related infrastructure development by federal, state and local government agencies. This project would provide an excellent opportunity to partner with FEMA and the ARC to demonstrate application of the emerging USGS Science Impact and INCLUDE programs.

Water Quantity, Quality and Distribution Implications from Stressors

The headwaters of countless rivers and streams are situated in the Appalachian Mountains. These water resources are vital to communities and economic interests within the related watersheds in the 12-state region. There are numerous stressors on these resources. For instance, some of the cleanest rivers in the state of Tennessee are located in Great Smoky Mountains National Park and have been designated "Outstanding Natural Resource Waters" by the state. For various reasons, the water quality standards for the designated use for three out of four of these rivers are violated within .1 to 10 miles outside the park boundary. Aquatic habitats associated with these rivers are highly impacted from runoff from impervious surfaces, sedimentation and loss of riparian habitat. Abrams Creek, the fourth designated waterway is in compliance with use standards in a rural area but only runs for 7 miles beyond the park boundary until it empties into a TVA reservoir.

As land use change in the Appalachians occurs due to mining, logging and development, and the demands for these water resources escalate by industry and urban sprawl, rivers quickly become degraded and/or over utilized. By primarily utilizing readily available data sources, there is an opportunity for USGS to partner with EPA, USFWS and state agencies to apply integrative science to selectively evaluate the long-term implications from these trends on the most critical of these water resources and related watersheds in the Appalachian region.

Threats to Ecological Integrity from Stressors

There is a need for the application of integrated science to evaluate the cumulative effect of various stressors on ecosystem viability for priority ecosystems and federal lands managed for natural resource sustainability. Examples of opportunities for integrated ecological science include the following:

- Risk assessment of the highly threatened spruce-fir ecosystem in the southern Appalachians is a concern of the NPS and USFS. This ecosystem includes a disproportionate number of endemic species. Threats from climate change, air pollution and numerous insect pests and pathogens are primary stressors (Nicholas and others, 1999).
- Fragmentation of forest landscapes reduces the potential to maintain corridors linking federal and state protected areas, a high priority issue of concern to EPA Region IV. They are developing a Web based data system called GeoBook whose primary goal is to facilitate identification of greenways to link key habitats and protected areas. Black bears and wood thrush are good indicator species for this type of analysis (Clark and Pelton, 1999; Simons and others, 1999).
- Adverse effects from changing land use on adjacent lands are particularly a concern to NPS officials in Shenandoah and Great Smoky Mountains National Parks, the Blue Ridge Parkway, the Appalachian Trail and selected national civil war battlefields. Along with threats to the integrity of the ecosystem, aesthetic values such as viewsheds are of concern as well.
- Mining has been a prominent activity for over 75 years, in central Appalachia. Acid mine drainage, loss of first and second order streams, unstable land fills and loss of native vegetation are all critical concerns.
- Threats to habitat of sensitive, threatened and endangered species are a concern of the USFS and USFWS throughout the region.

- Fire ecology is not well understood throughout the region and deserves more attention as NPS and USFS land managers increase their prescribed burn activities (Buckner, pers. commun. , Buckner and Turrill, 1999).

Appalachian Community Sustainability Assessments

As described previously in the Gatlinburg case example, there is considerable value in providing science-based information to communities in Appalachia applicable to problem solving and proactive planning for a sustainable future. Most federal agencies have numerous Web based national information centers including EPA, US Census, USGS, NRCS, USFWS, NPS, USFS, TVA and many others. Several organizations are dedicated to providing information on the people, economy and the environment in the Appalachian region. The primary agency covering the entire region is the ARC. The Center for Virtual Appalachia is another institution similarly dedicated (CVA, 2001). The Southern Appalachian Node of the USGS-NBII program is just beginning to establish a regional information system. The most advanced regional organization of its type is the Virginia based Canaan Valley Institute dedicated to providing technical information at a community level (CVI, 2001). This group has considerable experience in designing GIS based programs to access spatial databases on the Internet that are particularly user friendly. They also train individuals how to access and apply the information to community-based issues. Scientists engaged in integrated science in the Appalachian Mountains should be encouraged to focus their research on specific community-based client needs as well as involving, from the beginning of the project, organizations specializing in information transfer to the target clients. Project budgets should reflect this intent by allocating resources as needed to focus on client access to and utilization of the scientific information produced. Analysis of the utility of the scientific information produced for the client should be included as an objective in every project as well. This is what the new USGS Science Impact program is all about.

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Overview of Current and Future Fossil Energy Geoscience in the Eastern Region

Ione L. Taylor and Senior Scientists of Eastern Energy Resources Team
U.S. Geological Survey, MS-956, National Center, Reston, VA 20192

The Eastern Energy Resources Team conducts research within the context of the USGS Energy Resources Program. Scientists on the team have a long history of both fossil fuel resource assessment and coal, oil, and gas science in the Appalachian Basin. Areas of research range from resource analysis (genesis, distribution, quantity, and quality) to the environmental and health impacts of fossil fuel extraction and use. Work in the Appalachian Basin is currently focussed on four major projects: (1) oil and gas assessment (Milici et. al, this volume), (2) coal assessment (Ruppert et. al, this volume), (3) environmental impacts of coal extraction (Cecil et. al, this volume); and (4) geologic framework of energy resources (Ruppert et. al, this volume).

The first two projects will be completed in fiscal year 2002. The principal products will be GIS-based resource assessments of coal, oil, and gas – including both conventional gas, as well as unconventional gas, such as coal bed methane and basin-centered gas. The coal assessment will include, in addition to the geoscience-based assessment, the incorporation of modeled mining costs for an economic analysis of two top-producing Appalachian coal beds. The Coal Extraction Environmental Project is designed to examine the three major energy-related impacts of coal mining: mountain top mining and valley fill, mine pool coalescence and prediction, and mitigation and remediation of contaminated mine drainage. Research on mine drainage includes acidity of mine-related waters and potentially toxic metals (e.g. iron-bearing flocculates and manganese-bearing aqueous species). This project provides an excellent opportunity for collaboration with the water and biologic disciplines.

The forth project, Framework Geology and Energy Resources in the Central Appalachian Basin, is currently in an early stage. It is designed to utilize data, products and expertise coming out of the assessment projects. It represents a foray into a new type of product. In addition to the coal resources data, the project will also incorporate extensive USGS data on coal chemistry in the Appalachian Basin, including ash yield and moisture content, sulfur, and selected trace elements such as arsenic and mercury. The quantity, distribution and quality of all the fossil fuels in the Appalachian Basin will be consolidated within a GIS using the geologic and basin thermal history as the conceptual framework. This will be a first attempt to develop a true "energy mix" product. Our intention is for decision-makers at many levels to use this product to make informed choices about energy options within a region or within a given market. The goal is to help the Nation use non-renewable energy resources more wisely on the path to sustainability. Future incorporation of hydrologic and biologic data could enhance the usefulness and breadth of this product.

The Appalachian Basin is an excellent choice for USGS's pilot area for such an energy mix product for several reasons: (1) extensive data and expertise for all fossil energy product types (commodities) exist within the basin; (2) all of the commodities (conventional and unconventional gas, coal and oil) exist in proximity within the basin; (3) areas of resource occurrence (supply) are typically adjacent to areas of resource consumption (demand); (4) electric power generation is currently predominantly from coal, which is typical of the entire US; although proposed additions to generating capacity are anticipated to be fueled by natural gas; (5) the basin contains the entire history of land use for this country and thus encompasses most of the infrastructure issues associated with energy extraction and use. Infrastructure includes aging pipelines and other aspects of transportation, aging power plants, and abandoned mine lands, as well as competing land use issues of urban/suburban growth versus resource (minerals and energy) extraction and utilization.

Land Surface Change and Analysis

Dave Kirtland
U.S. Geological Survey, Eastern Region Geography, 521 National Center, Reston, VA 20192

The impact of land use and land cover change on the environment is substantial. Both represent a complex interaction of human and natural forces. The need to understand this interaction has been recognized as a critical challenge for environmental science and is a pillar of several scientific programs such as the U.S. Global Change Research Program. To help address this need, the National Mapping Discipline is investigating trends in contemporary U.S. land cover change during the late 20th century. A pilot phase of the project has been completed and work has begun on measuring the sectoral, spatial, and temporal variability of land use and land cover change for five time periods in 84 conterminous U.S. ecoregions. Documenting the rates and patterns of change across the nation and determining what sectors and time periods are most dynamic provides the context for investigating the driving forces and consequences of change. Preliminary work in the north central region of the Appalachians indicates that change from one land cover type to another during the period 1973 to 1992 has been minimal, but cyclical change such as forest to grassland to forest has occurred.

The Collaborative Environmental Monitoring and Research Initiative in the Northern Appalachian Region

Peter Murdoch[1], Richard Birdsey[2], and Ken Stolte[2]
1 U.S. Geological Survey, 425 Jordan Rd., Troy, NY, 12180
2 U.S. Forest Service, 11 Campus Blvd., Suite 200, Newtown Square, PA, 19073

The past 20 years of environmental research have shown that our world is not made up of discrete components acting independently, but rather of a mosaic of complex relationships among air, land, water, living resources, and human activities. Several resource management agencies have adopted a policy of "Ecosystem Management" for their lands and waters, but seldom have multi-component, ecosystem-level information to work with. Unfortunately, there is more to creating a scientifically-rigorous collaboration among programs than just deciding to work in the same region or make our data available to each other. Much of the information currently being collected is fragmentary and incompatible because it is collected through programs that are designed and conducted at different scales or for different objectives, and because protocols are inconsistent in sampling methodology and data management. The Delaware River Basin Collaborative Environmental Monitoring and Research Initiative (CEMRI) links existing intensive ecological research and monitoring stations, regional surveys, fixed-site monitoring networks and remote sensing programs, in order to track complex environmental issues at a range of spatial and temporal scales. The enhanced sampling is designed to allow integration of extensive monitoring with process-level studies, and facilitate scaling from intensive research sites to extended regions. At each sampling tier, measurement protocols have been enhanced to address several important regional issues: (1) causes, consequences, and regional extent of calcium depletion in the forests of the Appalachian Plateau, (2) forest biomass and productivity in the Delaware River Basin, (3) protocols for identification and monitoring of forests vulnerable to non-native invasive pests, (4) forest fragmentation and associated ecosystem changes, and (5) integration of forest and water monitoring to evaluate the effects of forest cover changes on water quality of the Delaware River. Programs participating to date include USFS Forest Health Monitoring, Forest Inventory and Analysis, and Global Change Research Programs; USGS National Water Quality Assessment Program, District COOP program, the National Mapping Division’s National Hydrologic Dataset program, and the National Atmospheric Deposition Program/National Trends Network; and National Park Service inventory and monitoring programs. The Initiative is serving as a model for regional collaborative research and monitoring networks that could be deployed throughout the United States.

SESSION II

Application of Coal Geology to Prediction, Prevention, Mitigation and Remediation of Contaminated Mine Drainage from Coal Mining in the Appalachian Basin

C. Blaine Cecil, Susan Tewalt, Frank Dulong, and Sandra Neuzil
U.S. Geological Survey, MS-956, National Center, Reston VA 20192

Coal from the Appalachian region has been a major source of energy to the nation for over two hundred years. Appalachian basin coal fueled America through a civil war and has helped win two world wars. In addition Appalachian coal has served as the basis for the steel, auto, organic chemicals, chlorine, and aluminum industries while keeping America warm in the winter and cool in the summer. Coal currently serves, and will continue to serve, as the primary fuel for the generation of the Nation's electricity. The benefits of coal utilization, however, have not come without costs. Coal extraction and utilization have had significant environmental impacts. Historically, coal extraction has lead to prodigious problems in contaminated mine drainage (CMD) subsequent to mine closure and abandonment. Contaminated drainage has been, and continues to be, particularly acute in streams in Pennsylvania, Ohio, West Virginia, and Maryland. Such drainage has had far ranging impacts on water quality as well as fish and wildlife. The impact of mine drainage from future mine closures is largely unknown, but such impact may cause extensive degradation of rivers in the region.

There are numerous other problems associated with coal mining and utilization. In recent years there have been major problems with failure of settling ponds associated with coal preparation operations. Coal-based synthetic fuels operations contaminate streams in the Appalachian region on occasion. Mine subsidence has damaged homes and other surface structures, and disrupted domestic water supplies. Many people are concerned about the impact of surface mining practices known as "mountain top mining" in the low-sulfur coal fields of southern West Virginia. Currently there is legislation pending in Congress for "clean coal technology". If successful, this legislation will likely lead to reactivation of mining in the high-sulfur coal regions in Pennsylvania, Ohio, West Virginia, and Maryland where CMD has been most acute in the past. The impact of future mining and waste disposal from clean coal technology processes on water quality in the Ohio River basin and drainage to the Chesapeake Bay is largely unknown. Power plants produce huge quantities of fly ash that are currently disposed of in slurry ponds. Little is known about the impact of slurry-pond drainage on surface water quality. Ideally, all of these issues, and perhaps others, need to be identified, clarified, and addressed through sound science in support of maximizing energy production while minimizing environmental impacts.

As coal continues to supply a significant part of the Nation's energy demands, USGS research can identify and clarify past, current, and future problems that may be associated with coal mining, cleaning, and utilization in the Appalachian region. The issues will require prioritization and recommendations to develop scientific research that will 1) predict and prevent future problems 2) mitigate problems that could arise from closure of active mines, and 3) remediate problems associated with abandoned mines. Coal geology has direct application to all aspects of coal mining issues. Comprehensive science planning can be accomplished through discussions with scientists from the USGS, other Federal, State, and local agencies, Universities, and the private sector.

Current Issues in Appalachian Coal Hydrology and Related Disciplines

Hugh E. Bevans
U.S. Geological Survey, Charleston, West Virginia

Modern high-extraction surface and underground coal-mining activities in Appalachia have the potential for causing regional-scale environmental disturbances. Mountaintop removal/valley fill surface coal mining typically involves blasting and excavating hundreds of feet of overburden from the tops of mountains to extract multiple coal seams. After the coal is extracted, some overburden is replaced on the former mountaintops, but large quantities of waste overburden are dumped into adjacent headwater valleys.

At long-wall coal-mining operations, continuous-mining machines enter coal seams at their outcrops and mine beneath mountainous areas. The machines support the overlying rock strata as the coal is extracted and allow the mine roof to collapse as the operation advances. The Pittsburgh Coal seam, which underlies most of the Monongahela River Basin in southwest Pennsylvania and north central West Virginia, currently is being mined by long-wall operations and historically has been mined by underground room-and-pillar operations. Active production of the seam is rapidly approaching completion. Active mines must continuously operate large pumps to dewater because production areas are far below the regional water table. As the mines close and dewatering operations cease, ground-water levels will rise and fill this extensive mined-out area with acidic water.

The onsite processing of coal is common to coal-mining operations throughout Appalachia. Process wastewater with fine coal and waste rock refuse material and associated trace elements, known as coal slurry, is stored in impoundments. Catastrophic failures of impoundments have occurred due to dam failures and collapses into underground mines.

Hydrologic and related issues from Appalachian coal-mining activities include impacts on water budgets; streamflow characteristics; surface- and ground-water quality: flood, debris-flow, and landslide hazards; subsidence and collapses; stream morphology; and aquatic habitat and ecology. Many of these coal-mining issues are cumulative and could be subjects of regional interdisciplinary studies. For instance, relations among streamflow characteristics, stream morphology, and aquatic habitat in mountaintop removal areas could be investigated. Other examples include investigations of floods, landslides, and debris flows; or relations of geochemistry, water quality, and aquatic ecology. The U.S. Geological Survey has the expertise and logistical capability to conduct these regional interdisciplinary investigations.

Water-Quality Trends for a Stream Draining the Southern Anthracite Field, Pennsylvania

C.A. Cravotta, III and M.D. Bilger
U.S. Geological Survey, 215 Limekiln Road, New Cumberland, PA 17070

EXTENDED ABSTRACT

Streamflow, chemical, and biological data for the northern part of Swatara Creek, which drains a 112-km^2 area in the Southern Anthracite Field of eastern Pennsylvania, indicate progressive improvement in water quality since 1959, after which most mines in the watershed had been flooded. Drainage from the flooded mines contributes substantially to baseflow in Swatara Creek. Beginning in 1995, a variety of treatment systems and surface reclamation were implemented at some of the abandoned mines. At Ravine, Pa., immediately downstream of the mined area, median SO_4 concentration declined from about 150 mg/L in 1959 to 75 mg/L in 1999 while pH increased from acidic to near-neutral values (medians: pH~4 before 1975; pH~6 after 1975). Fish populations rebounded from nonexistent during 1959-90 to 21 species identified in 1999. Nevertheless, recent monitoring indicates (1) episodic acidification and elevated concentrations and transport of Fe, Al, Mn, and trace metals during stormflow; (2) elevated concentrations of Fe, Mn, Co, Cu, Pb, Ni, and Zn in streambed sediments relative to unmined areas and to toxicity guidelines for aquatic invertebrates and fish; and (3) elevated concentrations of metals in fish tissue, notably Zn. The metals are ubiquitous in the fine fraction (<0.063 mm) of bed sediment in mining-affected tributaries and the main stem of Swatara Creek. Because of scour and transport of streambed deposits, concentrations of suspended solids and total metals in the water column are correlated, and those for stormflow typically exceed baseflow. Nevertheless, the metals concentrations are poorly correlated with streamflow because concentrations of suspended solids and total metals typically peak before peak stream stage. In contrast, SO_4, specific conductance, and pH are inversely correlated with streamflow because of dilution of poorly buffered stream water with weakly acidic storm runoff derived mainly from low-pH rainfall. Declines in pH to values approaching 5.0 during stormflow events or declines in redox potential during burial of sediment could result in the remobilization of metals associated with suspended solids and streambed deposits.

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Effects of Acidic Runoff Episodes on Fish Communities in Appalachian Streams of Pennsylvania

Robert F. Carline[1], William E. Sharpe[2], and David R. DeWalle[2]
[1]Pennsylvania Cooperative Fish and Wildlife Research Unit, Biological Resources Division, U.S. Geological Survey, Merkle Laboratory, University Park, PA 16802
[2]School of Forest Resources and Environmental Resources Research Institute, Pennsylvania State University, Land and Water Building, University Park, PA 16802

During the past 20 years, government and university scientists at Penn State have been conducting studies on the effects of acidic runoff episodes on fish communities in headwater streams on the Allegheny Plateau. Acidic episodes can cause pH values to decline by more than one unit, with minimum values approaching 4.5. Simultaneously, concentrations of total dissolved aluminum may exceed 400 µg/L. Streams subjected to such episodes are characterized by simple fish communities. Where episodes are severe, the brook trout (*Salvelinus fontinalis*) is the only species present.

Acidic episodes can affect all life stages of fish. Brook trout embryos incubate in stream gravel over winter and are vulnerable to acidic episodes. Slimy sculpins (*Cottus cognatus*) spawn in spring when females attach eggs to the undersides of rocks. Mature slimy sculpins fail to spawn when subjected to acidic episodes. *In situ* bioassays have been used to demonstrate that acidic episodes can cause more than 80 percent mortality of brook trout and slimy sculpins. Brook trout are displaced downstream in response to acidic episodes. Displaced trout frequently congregate in areas where alkaline groundwater seeps or tributaries enter main channels. These chemical refugia mitigate lethal effects of episodes. Population density of brook trout is strongly related to episode severity, and many populations seem to be transient because of periodic lethal conditions caused by episodes. In 1994 and 1995, 75 streams subjected to acidic episodes had lower pH, lower total alkalinity, and supported fewer fish species than they did 25 to 30 years prior. Thus, acidic episodes affect both fish productivity and fish diversity.

Since passage of the Clean Air Act Amendments in 1990, there has been an improvement in air quality with notable decreases in concentrations of sulfate and hydrogen ions in precipitation. The consequences of these air quality improvements on stream chemistry and associated biological responses need to be documented to determine if historical trends of declining water quality have been reversed or if additional emission controls are warranted.

Metal Contamination and Acid Drainage Associated with Abandoned Metal and Sulfur Mines in the Appalachian Region

Robert R. Seal, II and Jane M. Hammarstrom
U.S. Geological Survey, 954 National Center, Reston, VA 20192

ABSTRACT

Massive sulfide and gold deposits are the two most problematic metallic mineral-deposit types in the Appalachian region from an environmental perspective. The environmental impacts of abandoned mines developed from massive sulfide deposits result from the formation of metal-laden acid drainage and from the presence of fine-grained, metal-rich mine wastes. Suites of problematic metals associated with these deposits differ with the type of massive sulfide deposit; in the Appalachian region, these are generally of either Kuroko or Besshi type. Mine drainage is mostly a threat to aquatic ecosystems, but metals also can contaminate local drinking water supplies. Abandoned gold mines are of environmental concern because of the mercury used in the gold-extraction process, which poses a threat to human health due to its ability to bioaccumulate in the foodweb, especially in aquatic systems.

INTRODUCTION

The environmental geochemistry and impact of abandoned metal and sulfur mines in the Appalachian region arise from a combination of factors that include the geology of the deposits, the geology of the surrounding watersheds, and the mining and ore-processing methods used. In addition to elevated concentrations of acidity, iron, aluminum, and manganese in drainage typically associated with coal mines in the eastern United States, which are dominantly aquatic ecosystem threats, the heavy metal suite associated with abandoned metal and sulfur mines poses a variety of other threats to both aquatic ecosystems and human health. Human-health effects from abandoned metal mines typically follow inhalation or ingestion pathways. Examples of potential threats include airborne, lead-rich dusts derived from mine wastes, elevated concentrations of arsenic in ground waters around abandoned mines and unmined deposits, and bioaccumulation of mercury in fish downstream from mine sites.

Environmental issues related to abandoned metal and sulfur mines are of interest to a variety of organizations, because of their environmental impact both to ecosystems and humans, their historical significance, and current regulatory requirements. The list is headed by numerous government organizations at federal, state, and local levels. The U.S. Environmental Protection Agency (EPA) recently placed the Elizabeth copper mine in Vermont on its National Priorities (Superfund) List, and the nearby Ely copper mine has been proposed for listing. The EPA is also involved in activities in the Copper Basin, Tennessee, and is exploring possibilities in Virginia, North Carolina, and Maine. The U.S. Army Corps of Engineers has authority to address abandoned mine issues. The Corps of Engineers has been assessing the extent of metal-mine issues in the Appalachians. State agencies concerned with abandoned mine issues include departments of environmental protection, environmental conservation, and transportation, among others. Local governments are concerned about the effects of the abandoned mines on environmental quality and property values, and the effects of remediation on property values, government spending, and quality of life.

This paper focuses on the environmental effects of abandoned mines of two types of metal and (or) sulfur deposits: massive sulfide deposits, principally exploited for their base- and precious-metal, and (or) sulfur contents, and gold deposits, the latter type commonly having imported mercury to the site for ore beneficiation purposes. Massive sulfide deposits have long been recognized for their environmental impacts in the Appalachians, whereas the potential environmental impact of the gold deposits has been under-appreciated.

ECONOMIC GEOLOGY AND MINING PRACTICES

The Appalachian region has had a long history of metal and sulfur mining dating back to Pre-Revolutionary times (Feiss and Slack, 1989). Of the numerous mineral deposit types that have been mined over this period, massive sulfide deposits, historically valued for their base- and precious-metal, and sulfur contents, and gold deposits hold the greatest potential for adverse environmental impacts.

Massive sulfide deposits formed on the ancient seafloor through submarine-hydrothermal processes and can be classified into several categories on the basis of host-rock compositions and metal contents (Franklin and others, 1998; Seal and others, 2000). In the Appalachian region, Kuroko-, Besshi-, and Noranda-type massive sulfide deposits are the most common. Kuroko- and Noranda-type deposits are characterized by host-rock packages dominated by bimodal submarine volcanic rocks with subordinate amounts of marine sedimentary rocks; they form in island-arc settings. The volcanic rocks associated with Kuroko-type deposits are dominantly felsic, whereas those associated with Noranda-type deposits are dominantly basaltic. Besshi-type deposits are characterized by host-rock packages dominated by siliciclastic marine sedimentary rocks and volumetrically minor to subequal basaltic volcanic rocks and subvolcanic intrusions. They form in rifted basins along continental margins.

Massive sulfide deposits are found throughout the Appalachian orogen in Proterozoic and Paleozoic rocks from Alabama to Maine, and northeast into Maritime Canada (Fig. 1). Notable deposits in New England include the Besshi-type deposits of the Vermont copper belt, Elizabeth, Ely, and Pike Hill (Hammarstrom and others, 2001a, b; Seal and others, 2001a, b; Slack and others, 2001), the Kuroko-type deposits in coastal Maine (Feiss and Slack, 1989), and the unmined Noranda-type deposit at Bald Mountain, Maine (Seal and others, 1998a). The USGS Mineral Resources Data System lists 71 Kuroko-type mines or prospects and 73 Besshi-type mines or prospects in the Appalachian states (McFaul and others, 2000). Within the central and southern Appalachians, significant Kuroko-type deposits or mining districts include the Pyriton deposit in Alabama, the Chestatee, Jenny Stone, and Swift deposits in Georgia, and the Mineral district and Cabin Branch deposit in Virginia (Stephens and others, 1984; Neathery and Hollister, 1984; Feiss and Slack, 1989). Significant Besshi-type deposits or districts include the Stone Hill deposit in Alabama, the Villa Rica deposit in Georgia, the Copper Basin district in Tennessee, the Fontana, Hazel Creek, and Ore Knob deposits in North Carolina, and the Gossan Lead district in Virginia (Neathery and Hollister, 1984; Stephens and others, 1984).

The ore mineralogy of the Kuroko-type deposits is dominated by pyrite, chalcopyrite, and sphalerite, with lesser pyrrhotite, galena, arsenopyrite, and tetrahedrite (Franklin and others, 1981; Seal and others, 2000). Gangue minerals typically comprise quartz, feldspar, muscovite, biotite, and amphibole. Ore mineralogy of Besshi-type deposits is dominated by pyrrhotite ± pyrite, chalcopyrite, and sphalerite, with minor galena (Slack, 1993; Seal and others, 2000). The gangue mineralogy is dominated by quartz, muscovite, biotite, plagioclase, and hornblende, with minor dolomite and ankerite. However, the stratigraphic package surrounding Besshi-type deposits can contain significant amounts of calcite and dolomite (Slack, 1993; Slack and others 2001; Seal and others, 2001b). The mineralogy of Noranda-type deposits is similar to that of Kuroko-type deposits, but can have higher proportions of chalcopyrite, and pyrrhotite may constitute a major phase (Seal and others, 2000). Collectively, the ore mineralogy of these deposits represents important sources of acidity and metals to impact surrounding ground and surface waters; the gangue mineralogy also provides a source of aluminum and manganese.

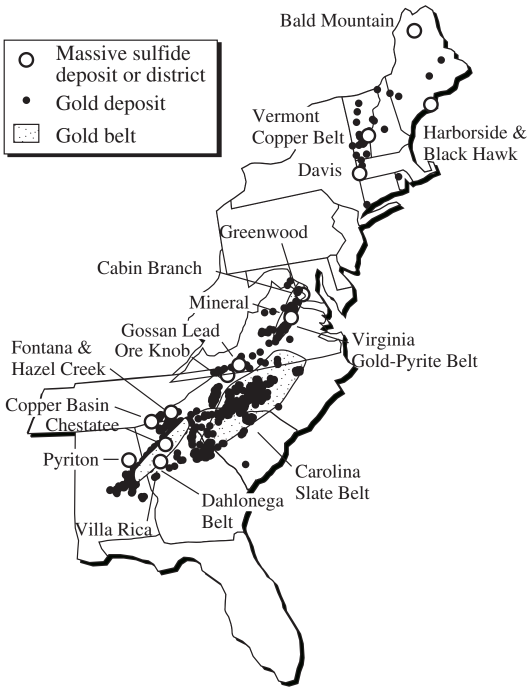

Figure 1. Map showing distribution of massive sulfide and gold deposits in the Appalachian region. Data from Feiss and Slack (19890 and McFaul and others (2000).

Massive sulfide deposits typically form lenticular or tabular bodies that range from several meters to tens of meters in thickness, and can extend laterally for hundreds to thousands of meters. They form on or beneath the sea floor. Thus, their modern geometry depends on the tectonic history of their host rocks. Because of varied geometries, massive ores are exploited by either open pit or underground methods. The ore-processing methods can vary greatly from site to site depending on the commodity or commodities sought, and the era of mining. Differences in mining and ore-processing methodologies can cause distinct differences in the character of the mine wastes, in addition to differences resulting from the natural variability of the ores (Hammarstrom and others, 2001a, b). Invariably, processing of the ores required the crushing of metalliferous rock to sizes ranging from cobbles to sand. Waste material contains high concentrations of pyrite and (or) pyrrhotite. Because of the small grain size and high sulfide content, mine wastes from massive sulfide deposits have the potential to release significant amounts of acid and metals to the surrounding environment. The wastes commonly contain limited amounts of carbonate minerals, and some lime may have been used in flotation circuits. Therefore, the mine wastes generally offer limited acid-neutralizing potential.

Gold mines in the Appalachian region exploited several types of gold deposits including low-sulfide gold-quartz vein (a.k.a. mesothermal, Mother Lode-type, shear-zone-hosted) deposits, gold-bearing massive sulfide deposits, their weathered equivalents, and placer deposits derived from these primary and secondary deposit types. Nearly 1,200 gold mines or prospects are known in the East, with the majority (96 %) occurring in Virginia, North and South Carolina, Georgia, and Alabama (Fig. 1; McFaul and others, 2000). The main historic gold districts or belts include, from north to south: (1) the Virginia gold-pyrite belt, including the Mineral district; (2) the Carolina slate belt, North and South Carolina; (3) the Dahlonega district, Georgia (and extensions into northeastern Alabama); and (4) the Hog Mountain district, Alabama (Feiss and Slack, 1989). The mineralogy of low-sulfide gold-quartz vein deposits is relatively simple; the deposits are dominated by quartz and carbonate minerals (siderite, ankerite, dolomite, magnesite, or calcite), with lesser sulfide minerals (pyrite, pyrrhotite, arsenopyrite), and gold (Ashley, in press). Other common gangue minerals, either within the veins or in adjacent wall rocks, include muscovite, chlorite, biotite, and fuchsite. Gold-bearing massive sulfide deposits share many characteristics with the massive sulfide deposits described above, the most significant examples being found in the Carolina slate belt.

Historic gold production in the central and southern Appalachians used three different methods of mining: (1) open-pit and underground mining of bed-rock ores; (2) hydraulic mining of saprolitic ores; and (3) placer mining of stream gravels. A typical progression of mining in the Dahlonega belt started with placer mining, followed by hydraulic mining of saprolitic ores (the so called "Dahlonega method"); when hydraulic mining reached bedrock, underground mining commenced (Yeates and others, 1896; Pardee and Park, 1948). Bedrock mining required the crushing of ores. Mine wastes from these operations typically contain minor amounts of pyrite, arsenopyrite, and other trace sulfide minerals. The limited acid-generating potential of these wastes is probably offset by the acid-neutralizing potential offered by carbonate minerals.

Of far greater environmental concern in these gold districts is the common usage of mercury amalgamation as a primary ore beneficiation technique (e.g., Ashley, in press). Mercury amalgamation has been used historically in all of the main districts and belts listed above. At present, documented use of mercury amalgamation has been identified at nearly 50 sites, which likely under represents the wide extent of its use, in light of the poor availability of historical records (Pardee and Park, 1948; Yeates and others, 1896; Sweet, 1980; Sweet and Trimble, 1983; Seal and others, 1998b, c). For example, historical and recent accounts of mining practices in the Dahlonega belt suggest the common usage of mercury amalgamation throughout the region, despite only 16 references of its use recorded in the literature (Yeates and others, 1896). For all three types of mining (placer, hydraulic, and bedrock), amalgamation was commonly used (Yeates and others, 1896).

PATHWAYS OF ECOSYSTEM AND HUMAN-HEALTH IMPACTS

Abandoned mines of massive sulfide and gold deposits cause detrimental environmental effects through a variety of pathways, which are best considered in terms of ecosystem or human-health impacts. For massive sulfide deposits, ecosystem threats are dominantly produced by acid-mine drainage. The oxidative weathering of pyrite (FeS_2) can generate acid-sulfate waters through the reaction:

$$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+ \quad (1),$$

and the oxidative weathering of pyrrhotite ($Fe_{1-x}S$) can generate acid-sulfate waters through the reaction:

$$Fe_{1-x}S + (2-x/2)\ O_2 + x\ H_2O \rightarrow (1-x)\ Fe^{2+} + SO_4^{2-} + 2x\ H^+ \quad (2),$$

where x ranges from 0.000 to 0.125. Similar reactions for pyrite and pyrrhotite using ferric iron as an oxidizing agent are also important. Continued oxidation and hydrolysis of dissolved ferrous iron enhances acid production as described by the reaction:

$$Fe^{2+} + 1/4\ O_2 + 5/2\ H_2O \rightarrow Fe(OH)_3 + 2\ H^+ \quad (3).$$

The lower pH values generated by the oxidation of pyrite and (or) pyrrhotite enhances the ability of the drainage to carry base metals such as Cu, Zn, Cd, Co, Ni, and Pb, and to attack silicate gangue minerals, thus liberating aluminum and manganese. Once liberated, the metals and acidity can impact downstream aquatic ecosystems. The toxicity of the divalent base-metal cations on aquatic ecosystems is strongly dependent on the hardness of the water; higher concentrations of metals are needed to exceed toxicity limits at higher hardness values (Smith and Huyck, 1999).

The impact and toxicity of metals extend beyond base-flow and peak-flow conditions. Secondary metal-sulfate salts commonly form on sulfide mine wastes during dry periods; such salts provide a means of storing acidity and metals (Hammarstrom and others, 2001b). These salts readily dissolve during rain events, releasing spikes of acidity and metals that can pass through watersheds in less than 24 hours, with extreme consequences. Another deleterious effect of acid-mine drainage is found in the abundant precipitation of secondary hydrated ferric oxides, such as ferrihydrite, which coat and fill interstices in stream gravels. The precipitates destroy habitat for aquatic invertebrates, thereby eliminating the lower levels of the food chain, regardless of overall water quality.

Human-health impacts of massive sulfide deposits are generally associated with either the contamination of drinking water or the ingestion of metals on dust and other particulates from mine wastes. For example, the concentration of dissolved arsenic in ground waters around the unmined Bald Mountain deposit in northern Maine reaches a maximum of 430 μg/L compared to the EPA maximum contaminant limit of 50 μg/L currently under revision (Seal and others, 1998a). Likewise, a shallow ground-water well near the abandoned Elizabeth copper mine in eastern Vermont has high concentrations of copper and cadmium (Hathaway and others, 2001). At the Valzinco mine in central Virginia, fine-grained flotation mill tailings exposed to wind and water contain 4,000 ppm lead, well in excess of EPA residential and industrial soil criteria (400 and 750 ppm lead, respectively).

Ecosystem impacts associated with gold deposits are less significant than those associated with massive sulfide deposits, with the exception of gold-bearing massive sulfide deposits. Dissolved metal concentrations, including iron, are generally low because the mined deposits contained only minor amounts of sulfide minerals (Ashley, in press). However, the mercury used to recover the gold poses a significant human-health threat. In aquatic settings, mercury occurs as a variety of species. Of these, methylmercury is of greatest concern, because it is a potent neurotoxin that bioaccumulates with increasing trophic level. Thus, the primary pathway for human-health impacts is through the consumption of fish and other higher organisms in mercury-contaminated environments. In aquatic settings, the primary mechanism for methylation of mercury is as a byproduct of the metabolism of sulfate-reducing bacteria (Compeau and Bartha, 1985). In addition to mercury, arsenic derived from the weathering of arsenopyrite or arsenian pyrite can pose human-health threats by contaminating ground-water wells.

MASSIVE SULFIDE DEPOSITS

Massive sulfide deposits exhibit a range of behaviors in surficial environments. Some of the characteristics are representative of massive sulfide deposits as a group, whereas others reflect the type of massive sulfide deposit, and yet others are unique to specific deposits, arising from specific details of the local geology or mining and ore-processing methods used.

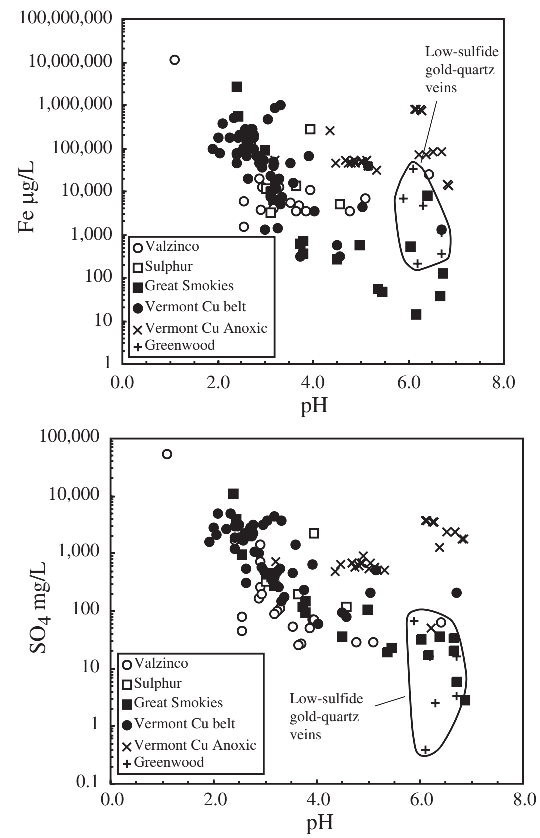

Figure 2. Plot of dissolved iron and sulfate versus pH for mine drainage from Kuroko- (open symbols) and Besshi-type (filled symbols) massive sulfide deposits and low-sulfide gold-quartz vein deposits.

Wall rocks of abandoned mine workings and waste from massive sulfide deposits generate acid-sulfate drainage with high concentrations of iron (Fig. 2). Thus, the abundance of pyrite and pyrrhotite is distinctly reflected in the drainage chemistry of this group of mineral deposits. However, differences between typical pyrrhotite-rich Besshi-type deposits and pyrite-rich Kuroko-type deposits are most apparent in settings where the access of atmospheric or dissolved oxygen is limited, but are less obvious in oxygenated settings. The reason for this distinction can be seen by comparing reactions 1 and 2 above. The oxidative weathering of pyrrhotite only generates a limited amount of acid, proportional to the nonstoichiometry of the mineral relative to ideal FeS. Thus, pyrrhotite-rich mines or waste piles where the supply of oxygen is limited, such as in the mine pool or tailings piles at the Elizabeth mine, can produce waters with high concentrations of iron at near-neutral conditions where the iron is dominantly in the ferrous state.

Trace metal concentrations of drainage are best considered in terms of individual elements. Plots of pH versus dissolved total base metals (Cd + Co + Cu + Ni + Pb + Zn) have been shown to be useful in distinguishing between major mineral-deposit types such as massive sulfide deposits and low-sulfide gold-quartz vein deposits (Plumlee, 1999), but they have limited utility in distinguishing among the various classes of massive sulfide deposits (Fig. 3). Differences between Kuroko-type and Besshi-type deposits are readily apparent in the zinc and copper compositions of mine waters. Zn:Cu ratios in ore from Besshi-type deposits are uniformly lower than those from Kuroko-type deposits. The difference in Zn:Cu ratios between ores of Besshi- and Kuroko-type deposits are also reflected in the mine drainage from abandoned mines in the Appalachians (Fig. 4). The Zn:Cu ratios of waters from Besshi-type deposits range from approximately 1:20 to 35:1, whereas those from Kuroko-type deposits range from 1:1 to 4,000:1. Thus, the Zn:Cu ratio is a direct manifestation of the geology of the deposit.

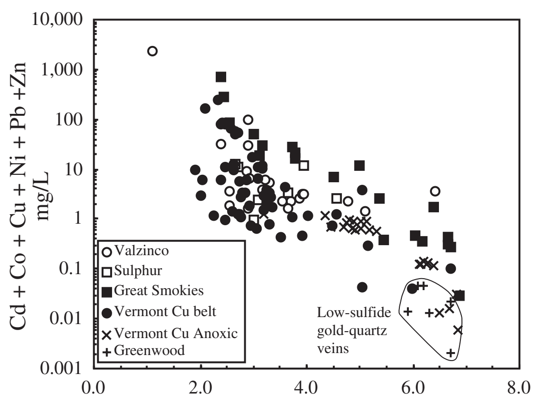

Figure 3. Plot of dissolved total base metals versus pH for mine drainage from Kuroko- (open symbols) and Besshi-type (filled symbols) massive sulfide deposits and low-sulfide gold-quartz vein deposits.

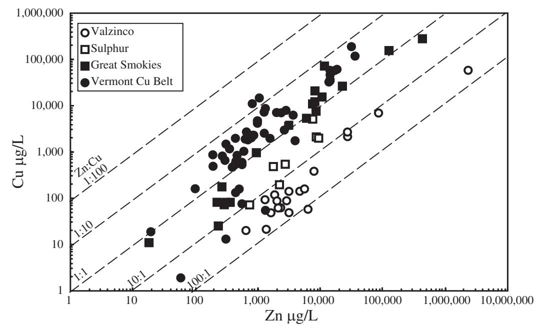

Figure 4. Dissolved copper and zinc concentrations for mine drainage associated with Kuroko- and Besshi-type massive sulfide deposits.

Compositions of other trace metals in mine drainage are influenced by the mineralogy and other characteristics of the mine waste. Mine wastes include mine dumps, flotation mill tailings piles, and smelter slags and calcine. Soluble efflorescent salts intermittently form on all of these materials, and temporarily sequester iron, aluminum, sulfur, and other metals and acidity between rainstorms. In Valzinco ores, sphalerite contains minor cadmium (0.2 wt. %) and pyrite contains minor cobalt (0.2 wt. %); these trace metals are released during weathering. Highly reactive, fine-grained pyrite (Kuroko-type) and pyrrhotite (Besshi-type) are the major sulfide minerals present in tailings. Zinc was present in many of the massive sulfide ores, but was not recovered in all cases and remains on-site in waste. Leachates from passive leach experiments (Hageman and Briggs, 2000) on slag and calcine exposed along Davis Mill Creek in the Copper Basin, Tennessee, exceed acute freshwater guidelines for copper. Pellet slag, which is used for roofing materials, released significantly higher concentrations of copper (860 µg/L vs. 26 µg/L) and zinc (400 µg/L vs. 86 µg/L) when leached with a synthetic acid rain solution instead of with deionized water.

The regional geologic setting of the deposit is also an important factor, particularly as it pertains to the alkalinity and hardness of receiving bodies of water, and how these parameters relate to vulnerability of the watershed. Host rocks of Kuroko-type deposits, such as those of the Mineral district, Virginia, are dominantly felsic and mafic submarine volcanic rocks, and siliciclastic sedimentary rocks. The hardness and alkalinity of watersheds underlain by these rocks, upstream from the impacts of mining, are low. Upstream of the Valzinco and Sulphur mines, the hardness ranges from 5.2 to 12.2 mg/L $CaCO_3$ and the alkalinity from 0 to 16.0 mg/L $CaCO_3$. In contrast, the alkalinity and hardness of watersheds hosting Besshi-type deposits is more variable. Upstream of the Elizabeth and Ely mines, Vermont, watersheds are underlain by carbonate rocks. The hardness and alkalinity upstream of mine effluents ranges from 55.3 to 128.0 mg/L $CaCO_3$, and 18.0 to 113.9 mg/L $CaCO_3$, respectively. However, in the Great Smoky Mountains National Park, watersheds have a limited amount of carbonate strata. In this area, away from the impacts of mining, the hardness (0.7 to 7.0 mg/L $CaCO_3$) and alkalinity (0 to 5.7 mg/L $CaCO_3$) are uniformly low.

GOLD DEPOSITS

Geochemical studies of the environmental impact of mercury related to historic mining in the Appalachian region are limited in both number and scope. Studies have been conducted in Alabama, Georgia, North Carolina, and Virginia. Studies of mercury speciation in surface waters in and around the abandoned Greenwood mine, a low-sulfide gold-quartz vein deposit in the Virginia gold-pyrite belt, illustrate the potential for extreme geochemical environments in Eastern settings (Fig. 1; Seal and others, 1998b, c). The mine site is at the headwaters of Quantico Creek, which empties into the Potomac River. Mercury concentrations in soils around the mine range from <0.02 ppm (background) to 692 ppm at the gold ore processing site. These mercury concentrations exceed residential (23 ppm) and industrial (610 ppm) soil screening guidelines (U.S. EPA, 2000).

Surface waters around the abandoned Greenwood mine were sampled and analyzed for their major and minor constituents (Figs. 2 and 3), including mercury speciation. The waters include samples within shaft depressions, and both upstream and downstream from the site. The waters from the shaft depressions display anomalously high dissolved concentrations of methylmercury. Ratios of methylmercury to total mercury in the dissolved fraction (up to 0.89) are also anomalous (Fig. 5). The geological and geochemical environment in shaft depressions at the Greenwood mine favors the methylation, but not the demethylation of mercury. Water in the shaft depressions is characterized by stagnant, near-neutral pH (6.3 to 6.7), low total dissolved solids (<160 mg/L), low redox potential (dissolved oxygen <1.3 mg/L), abundant organic matter, and moderate dissolved sulfate concentrations (2.5 to 16.0 mg/L). These conditions stimulate sulfate-reducing bacteria, which are the principal methylators of mercury under anoxic conditions (Compeau and Bartha, 1985). Demethylation is not favored because of anoxia and insufficient mercury and other heavy metals to induce gene transcription in microbes to detoxify methylmercury (Robinson and Tuovinen, 1984). Dissolved mercury levels are depressed because the shaft waters are saturated with respect to cinnabar (HgS); low levels of other heavy metals are characteristic of low-sulfide gold-quartz vein deposits (Ashley, in press). Within the watershed, the percentage of methylmercury rapidly decreases downstream of the shaft depressions. Dilution decreases the total concentration of total mercury and methylmercury at less than 10 km from the mine site.

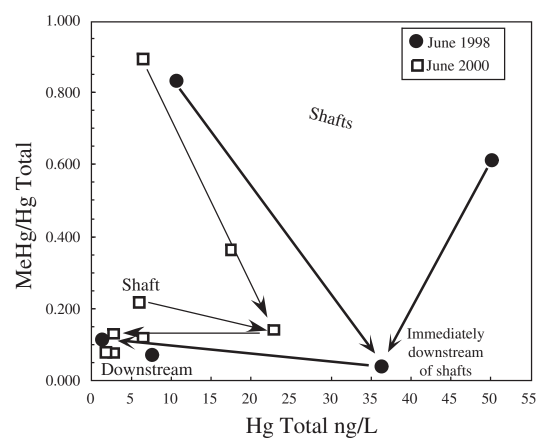

Figure 5. Plot of the proportion of methylmercury versus concentration of total mercury for the Quantico Creek watershed in the vicinity of the Greenwood mine.

Compared to mining districts in California (Ashley, in press), the waters in and around the Greenwood mine are characterized as having higher total mercury concentrations than waters of similar sulfate concentrations. The percentage of dissolved mercury to total mercury is similar to ranges reported for waters from gold districts in California. However, the percentage of methylmercury relative to total mercury in unfiltered waters near the Greenwood mine exceeds that observed in waters from mining districts in California by up to an order of magnitude (Fig. 6). The anomalous character of the mercury geochemistry of the Greenwood site can be attributed to the local environmental setting, particularly features such as deciduous vegetative cover, which provides abundant organic matter as leaf litter in the shaft depressions, and low topographic relief, which enhances stagnation of water.

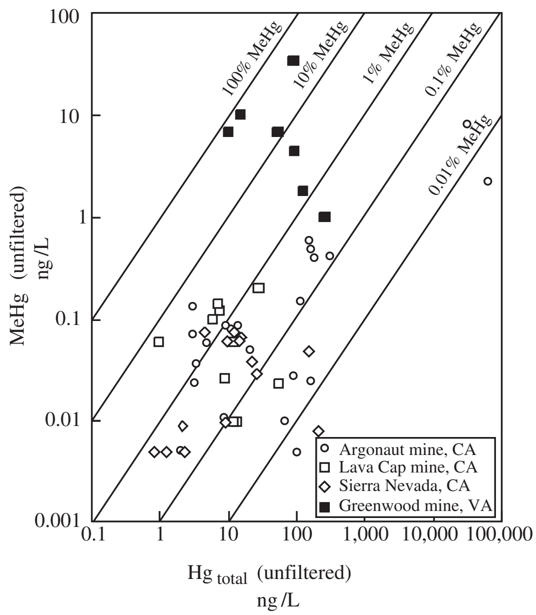

Figure 6. Comparison of methylmercury and total mercury concentrations of mine waters from the Greenwood mine with concentrations of mine waters from the Mother Lode belt, California.

DISCUSSION

For massive sulfide deposits, the associated acid-sulfate drainage with its high concentrations of dissolved iron and aluminum bears similarities to drainage associated with coal mines in the Appalachians. However, drainages associated with massive sulfide deposits have higher trace-metal concentrations than those from coal mines. Some base-metal concentrations, such as those for Cu, Zn, and Cd, vary in a predictable fashion between the two types of massive sulfide deposits found in the Appalachians on the basis of geologic and mineralogic features. Over the range of pH commonly encountered in mine drainage environments, the behavior of the individual metals can vary significantly in terms of solubility, sorption, and precipitation properties. Sorption of metals on hydrated ferric oxides (e.g., amorphous $Fe(OH)_3$, ferrihydrite, goethite) can remove significant amounts of divalent metals from solution. Lead will be sorbed almost completely on hydrated ferric oxides at pH values above 4.0, but cadmium, for example, will partition almost exclusively into solution at pH values below 5.5, and sorption will not be complete until pH exceeds 7.0 (Smith, 1999). Thus, a thorough understanding of the source, transport, and fixation processes and their variability is essential to finding remediation solutions to mine drainage problems.

Historic gold production from the Appalachian region is roughly three percent of the historic gold production from the Mother Lode belt in California (Craig and Rimstidt, 1998). Therefore, it can be expected that the total amount of mercury used in the Appalachians is also proportionally lower than that in California. Despite the much lower amount of mercury used in the Appalachians, results of our single study of mercury speciation in mine drainage in the region suggest that environments in the Appalachians that are highly conducive to mercury methylation can be established that produce proportions of methylmercury to total mercury that are one to four orders of magnitude higher than concentrations documented in California. Therefore, the total amount of methylmercury in drainages from gold mines may be higher in the Appalachians.

On a regional and global scale, there is a general correlation between the distribution of massive sulfide deposits, especially those of Kuroko type, and low-sulfide gold-quartz vein deposits, which raises possibility of adverse synergistic effects. For example, the Dahlonega and Carroll County gold belts of Georgia are generally known for their gold mines, but several massive sulfide deposits are also located in these districts; the Chestatee deposit is the largest massive sulfide in the Dahlonega belt, and the Villa Rica deposit is the largest in the Carroll County belt (German, 1989). Likewise, the Mineral district of Virginia contains both

Kuroko-type massive sulfide deposits and low-sulfide gold-quartz vein deposits and associated gold placers. Contrary Creek in the Mineral district receives acid drainage from three massive sulfide mines before emptying into Lake Anna, a manmade reservoir. Downstream of the last major sulfide mine, Contrary Creek commonly has a pH around 3.7 and dissolved sulfate concentrations of about 200 mg/L. The elevated sulfate concentrations of effluent from Contrary Creek have enhanced the rate of bacterial sulfate reduction in sediments in Lake Anna (Herlihy and others, 1987). Because sulfate-reducing bacteria are the primary methylators of mercury in aquatic settings, the enhanced rate of sulfate reduction in Lake Anna caused by the elevated sulfate concentrations in Contrary Creek may be exacerbating the methylation of dissolved mercury that was originally supplied to the watershed by historic mining activity. Therefore, it is important to consider the potential interrelationships of various ore-deposit types as they relate to ecosystem and human-health risks in specific watersheds. In Lake Anna, the most likely place to find the effects of enhanced methylation of mercury is in the concentration of mercury in the tissue of large game fish.

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Tracking the Effects of Acidic Deposition in Medium-Scale Forested Watersheds of the Eastern United States

Peter S. Murdoch, U.S. Geological Survey, Troy, New York
James B. Shanley, U.S. Geological Survey, Montpelier, Vermont
Thomas Huntington, U.S. Geological Survey, Augusta, Maine

The U.S. Geological Survey Hydrologic Benchmark Network (HBN) was established in the mid-1960's for continuously monitoring flow and seasonally monitoring water quality in medium-scale naturally vegetated watersheds (100-500 km^2) throughout the United States. Unlike small watershed research sites, the HBN sites are large enough to contain well-developed riparian zones, and as such are more representative of a natural reference landscape for assessing the relative effects of air pollution, development and agriculture on water quality in the U.S. During the past 3 years more frequent water-quality monitoring (biweekly and during stormflows) has been established at five of these stations in the Eastern United States. The stations are located in eastern Tennessee (Little River, 275 km^2), western North Carolina (Cataloochee Creek, 127 km^2), north-central Pennsylvania (Young Woman's Creek, 120 km^2), southeastern and northeastern New York (Neversink River, 168 km^2), and northwestern Maine (Wild River, 180km^2), and thus lie along southeastern and northeastern gradients of decreasing sulfate deposition from west to east across the region. Concentrations of nitrate and sulfate in streamwater decrease in the northeastern sites from the southwestern-most watershed to the northeastern-most watershed. Sulfate concentrations have decreased at the Little River, Neversink River and the Wild River during the period of record, but sulfate concentrations in Young Woman's Creek and Cataloochee Creek show no trend. No trend in sulfate concentrations is evident in any of the three northeastern streams since 1995, when the last significant reduction in emissions was enacted. Sulfate concentrations in Little River have continued to fall since 1995. No trends are observed in ANC in any of the streams, but calcium concentrations in streamwater have decreased in Little River, Neversink River, and Wild River since the 60's. Calcium concentrations in streamwater decrease from a range of 80-120 µmole per liter in the northeastern streams. The stream chemistry patterns observed are similar to those in small research watersheds nested within several of the basins, and indicate that medium-scale forested watersheds are useful indicators of landscape response to changing emission standards.

Patterns of Imperilment of Southern Appalachian Fishes

Noel M. Burkhead, Stephen J. Walsh, and Robert M. Dorazio
U.S. Geological Survey, Biological Resources Division, Florida Caribbean Science Center, Gainesville, FL

North America (north of Mexico) has the richest temperate riverine ecosystems in the world. Of the 800+ freshwater fishes in the United States and Canada–about 350 species or 44 percent–occurs in the southeastern United States in the un-glaciated highlands of southern Appalachia. This diversity is paralleled in other aquatic groups, notably snails, mussels, crayfishes, and microcrustaceans. Comprised of four physiographic provinces, topographically diverse southern Appalachia is a geologically and environmentally complex area that has been a major center of evolution in the North American fishes. Southern Appalachian river systems are characterized by high diversity and in some cases, extraordinary endemism. The composition of the southern Appalachian ichthyofauna was delineated based on zoogeographic patterns of faunal breaks and endemism. The fauna includes archaic species–sturgeon, paddlefish, and gars–traceable to Pangea, and modern species virtually at the forefront of evolution.

The broad impact of human population growth on aquatic biodiversity is the basis for the Southeast being recognized as a global freshwater conservation hot spot. Imperilment of southeastern freshwater fishes is increasing. Multiple investigators estimate that present levels of imperilment to be 20 to 25 percent of the fauna. Obviously a primary conservation concern is that many declining species may become extinct, a pattern that appears evident in the beleaguered mussel fauna. Imperilment in southern Appalachian fishes was examined by comparing the imperiled and non-imperiled subsets of the fauna across multiple biological attributes that reflect basic patterns of adaptive strategies. Attributes included range size, physiographic province, stream sizes, vertical orientation in water column, trophic guilds, spawning guilds, body size, longevity, and fecundity. The resultant matrix of ~ 350 species by 48 categorical variables was analyzed by running 10,000-iteration randomized sampling of the matrix to construct a statistical model unique to the data set.

Imperilment among southern Appalachian fishes was not random relative to the ecological and habitat attributes tested. In general, small-sized, short-lived, benthic fishes with low to moderate fecundity, and small- to moderate-sized ranges are disproportionally imperiled. Secondly, some large-river, vagile fishes exhibit higher imperilment levels. Although the dire negative effects of nonindigenous fishes has largely been in the West, recent spread of non-indigenous transplants threaten listed species, and logical, testable inferences regarding how human activities relate to the observed patterns. It is inferred that excessive sedimentation is a principal cause of degradation and destruction of benthic habitats. Research investigating the effects of suspended sediment on reproductive success showed significant negative effects in a native, benthic-spawning minnow, and provides insight into the long-term effects of chronic sedimentation on population persistence and stability of benthic fishes. Biological pollution by non-indigenous transplants, especially the red shiner, may prove serious, long lasting threats to endemic fishes.

Fortuitously, creeks and rivers can inherently rebound when sources of degradation are abated. Southern Appalachian streams are far from being thoroughly investigated; indeed, new species are still being discovered. Although the diverse cultures of the southern highlands have long been recognized, appreciation of regional biological diversity is still a work in progress. While some groups of southern Appalachian fishes appear on the verge of extinction, these river systems are remarkably resilient and can recover from egregious abuses. New alliances are being made at this very moment; hopefully, new ways of addressing these complex problems are at hand.

Framework Geology and Energy Resources in the Central Appalachian Basin

Leslie F. Ruppert, Robert T. Ryder, Robert C. Milici, John E. Repetski, Linda J. Bragg, Susan J. Tewalt, Michael H. Trippi, Elizabeth L. Rowan, and Robert E. Crangle
U.S. Geological Survey, Eastern Energy Resource Team, MS 956, Reston, VA 20192

The U.S. Geological Surveys USGS) Energy Resource Program (ERP) is in the second year of funding for a five-year project which will result in a GIS-based framework to relate coal, oil, and gas resource distribution, quality, and quantity with geologic processes in the Appalachian Basin. The primary objective of the project is to understand the genetic links between geology and processes that exert significant influences on the quantity and quality of economic fossil energy resources in the basin. These processes include, but are not limited to, coal-forming processes, timing of oil and gas generation, basinal fluid migration, thermal maturation, and burial history. Information developed in this project will allow us to better forecast the distribution of fossil fuels within geologic basins in order to improve our coal, oil, and gas assessments and to better predict the economic and environmental consequences of producing and using fossil fuel resources.

The Appalachian Basin is a mature, well-studied, foreland basin with an extensive infrastructure for supporting economic development of its fossil fuel resources. Significant central Appalachian geologic and energy resource databases exist within USGS, State surveys, universities, and industry. Coal bed and petroleum systems maps and databases produced during USGS ERP National Coal Resource Assessment (NCRA) and the National Oil and Gas Assessment (NOGA) will provide the energy resource GIS coverages that are basic to understanding fossil fuels within the basin.

Five of the top-producing coal beds within the Appalachian Basin—the Pennsylvanian Pittsburgh, Upper Freeport, Lower Kittanning, Fire Clay, Pond Creek, and Pocahontas No. 3 coal beds and coal zones—were fully assessed in the NCRA project. The areal extent, structure contour, overburden thickness, and isopach thickness maps that were created to calculate original and remaining coal resources for NCRA can be directly utilized in the GIS. We will build upon this work and focus on other top-producing coal beds and those with high potential for coalbed methane production. Oil and gas plays assessed by NOGA, including the Ordovician Trenton deep gas play and numerous unconventional plays from sandstone, shale and coal, will be augmented by studies of other potentially productive intervals. In addition to the ERP data, digital stratigraphic data are available from the Eastern Region Minerals Team, structural data are available from USGS and State survey databases, and seismic data are available from a variety of sources. We are augmenting available seismic stratigraphy, regional cross-sections, and thermal maturation data with new data generated within the project. These new data, produced in fiscal year 2001 include (1) new, detailed seismic interpretations of the Dunkard Basin and underlying Rome Trough, both sub-basins of the Appalachian Basin, (2) more than 3,000 thermal maturation data points (R_o and CAI) for the Ordovician, Devonian, and Pennsylvanian strata within the basin, (3) thermal maturation maps for Ordovician and Devonian strata in Pennsylvania, and (4) digitized published and non-published regional cross-sections throughout the basin.