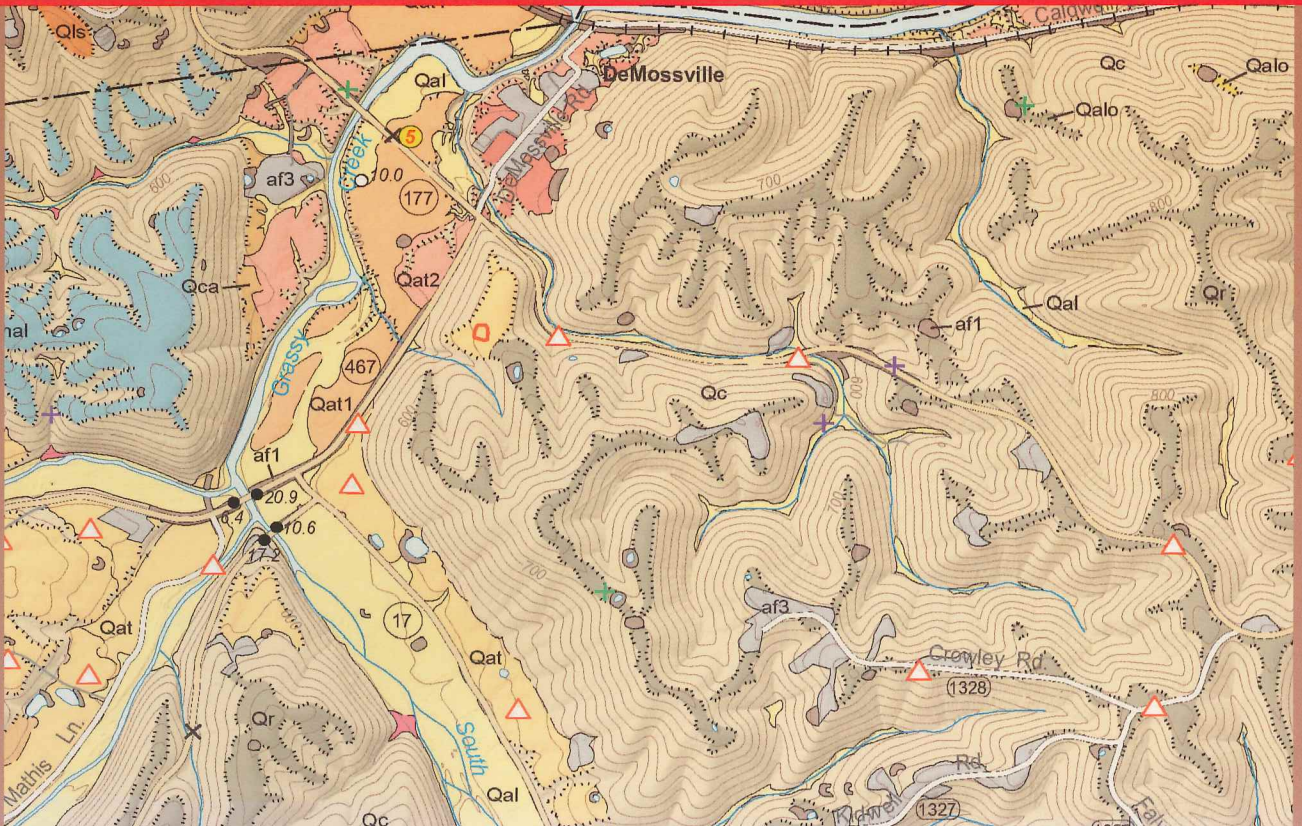


2016-2017

KENTUCKY GEOLOGICAL SURVEY ANNUAL REPORT



EARTH RESOURCES—OUR COMMON WEALTH

MISSION

The Kentucky Geological Survey is a state-supported research center and public resource within the University of Kentucky. Our mission is to support sustainable prosperity of the commonwealth, the vitality of its flagship university, and the welfare of its people. We do this by conducting research and providing unbiased information about geologic resources, environmental issues, and natural hazards affecting Kentucky.

VISION

To be the primary source of geologic information about and for Kentucky.

ON THE COVER

A detailed section of the "Surficial Geologic Map of the De Mossville 7.5-Minute Quadrangle, North-Central Kentucky," by Matt Massey and KGS cartographer Terry Hounshell. Hounshell designed the cartographic compilation from Massey's data to create the final version of the map. During his nearly 28 years at KGS, Hounshell created numerous geologic maps and illustrations. He retired in 2017.

CONTENTS



FROM THE DIRECTOR 2-3



WATER RESOURCES 4-11



ENERGY AND MINERALS 12-17



GEOLOGIC MAPPING 18-19



OUTREACH AND PROFESSIONAL ENGAGEMENT 20-21



GEOHEALTH 22-23



GEOLOGIC HAZARDS 24-27



GEOLOGIC INFORMATION MANAGEMENT 28-31



WELL SAMPLE AND CORE LIBRARY 32



WESTERN KENTUCKY OFFICE 33

KENTUCKY GEOLOGICAL SURVEY STAFF 34

STAFF ORGANIZATION CHART 35

RESEARCH PROJECTS 36-37

PUBLICATIONS 38



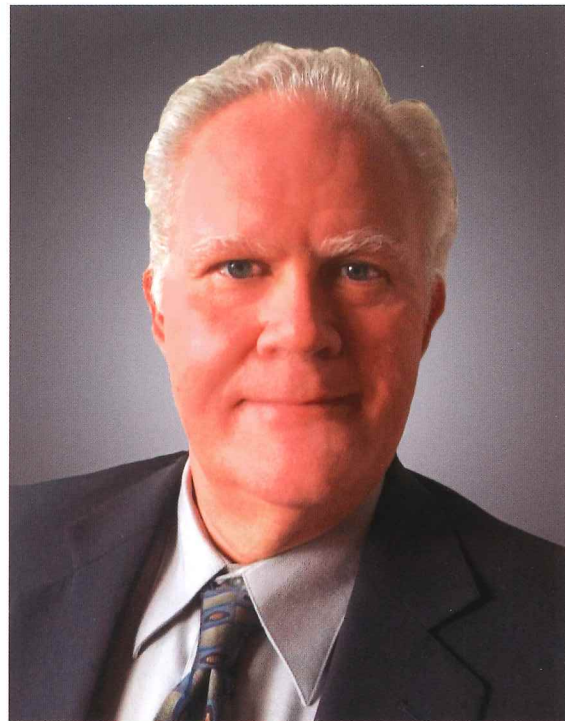
FROM THE DIRECTOR

The 2016-17 fiscal year was an active one at KGS. On Sept 1, 2016, I began my appointment as KGS director and the 13th state geologist of Kentucky. I am grateful to Jerry Weisenfluh, who served as the interim director for two years, for his leadership during the director search and invaluable assistance in the months after my arrival. Former Director Jim Cobb has also been a great source of information and inspiration.

One of my top priorities during my first year was developing a strategic plan for KGS, which is now available under the “About” tab on our website (www.uky.edu/kgs). The plan articulates a vision

of KGS as the primary source of geologic information for and about Kentucky, emphasizing the importance of research relevant to the economic prosperity, environmental quality, and practical well-being of the commonwealth and its people: in other words, the things that can make Kentucky a compelling place in which to live, work, and do business. The strategic plan also includes a set of 16 ambitious yet achievable strategic actions that KGS has already started to implement as we move into the future.

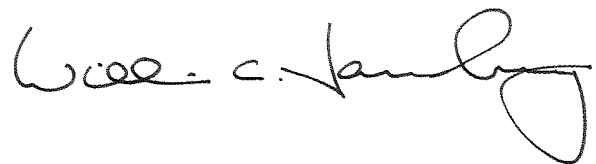
KGS has long been a national leader in geologic mapping and, in more recent years, developing new ways to disseminate via the web our maps and data to stakeholders that range from the energy and mineral industries to environmental consultants to regulators to individual taxpayers and public-interest groups. Toward the end of 2017, Kentucky will have available



complete airborne LiDAR coverage that will enable us to map and plan at an unprecedented level of detail. The statewide coverage will provide—literally—tens of billions of laser-accurate topographic measurements of Kentucky's 40,409 square miles and afford KGS scientists a more complete understanding of sinkhole and landslide occurrence, earthquake hazards posed by the New Madrid Seismic Zone, rock fracture systems that control groundwater flow and pollution potential, the locations of critical areas such as wetlands and archeological sites, and microtopographic variability useful for optimizing agricultural practices. KGS has established a Digital Earth Analysis Lab with high-performance workstations, a large touchscreen display for group meetings, specialty software, and an upgraded internet connection to help us make the best use of this incredible statewide data. We are also hiring a post-doctoral researcher who will spend two years working with KGS scientists to develop innovative ways to use the LiDAR data to solve practical problems in Kentucky.

As part of our emphasis on practical contributions to Kentucky, we continue to leverage our annual appropriation with research funds from federal agencies such as the U.S. Geological Survey, U.S. Department of Energy, U.S. Department of Agriculture, and state agencies such as the Kentucky Department for Public Health, Kentucky Water Resources Research Institute, Kentucky Energy and Environment Cabinet, and Kentucky Department of Military Affairs. We also collaborate with colleagues in the UK Colleges of Engineering; Agriculture, Food and Environment; Nursing; and Public Health on innovative externally funded research about geologic controls on indoor radon (a significant contributor to lung cancer), agricultural practices designed to improve water quality, and methods to extract strategically important rare earth elements from coal.

An integral part of the University of Kentucky, we pride ourselves on being the primary source of geologic information for and about the commonwealth. Please visit us in person or over the web and let us know how we're doing.

A handwritten signature in black ink, appearing to read "William C. Haneberg". The signature is fluid and cursive, with a large loop at the end.

William C. Haneberg



WATER RESOURCES

The Water Resources Section conducts research vital to the development, management, and protection of the commonwealth's groundwater and surface-water resources. Hydrogeologic information and other water-related data compiled by the section help meet the needs of state and federal public-health and environmental-protection agencies, public water suppliers, agriculture and industry, consulting geologists and engineers, and the general public. The section is charged by legislative mandate with managing the state's official repository for groundwater information (KRS 151.035) and overseeing establishment of a long-term groundwater monitoring network (KRS 151.625). Section staff also actively contribute to the educational mission of the University by interacting and collaborating with UK faculty and students.

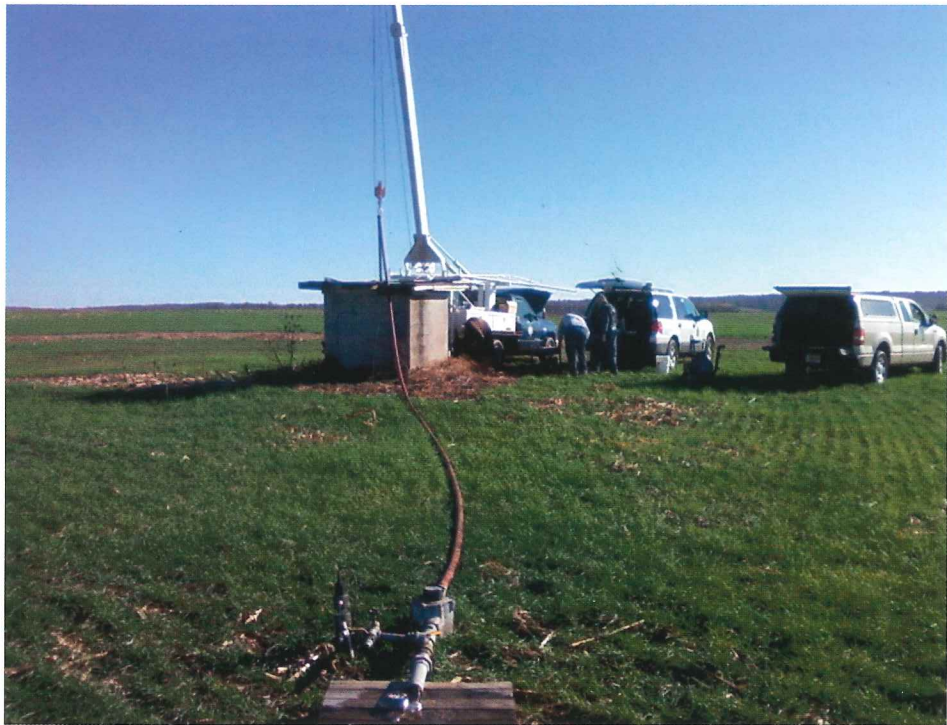
During fiscal year 2016-17, the section investigated groundwater availability, characterized aquifers, monitored groundwater levels, assessed groundwater and surface-water quality, used high-resolution LiDAR data to enhance sinkhole mapping, and monitored discharges from karst springs.

Hydrostratigraphy of the Claiborne Aquifer System

Hydrogeologist **Glynn Beck** is working to improve the delineation of aquifers and confining zones in the Claiborne aquifer system in the Jackson Purchase Region. Detailed cross sections have been constructed of these hydrostratigraphic units in Fulton; Hickman, Graves, Carlisle, and Ballard Counties using geophysical logs from lignite boreholes collected by the Phillips Coal Co. in the mid-1970s and recent gamma-ray logs collected by Beck from selected water wells in the area. Graduate student **Jason Merrick** of the UK

Department of Earth and Environmental Sciences is working with his thesis advisor, **Alan Fryar**, to use hydrostratigraphic tops and bottoms—the upper and lower elevations of aquifers and confining zones—to create a groundwater flow model for the Obion Creek and Bayou de Chien watersheds in Hickman and Fulton Counties. Beck and Merrick have worked together for more than a year to collect water-level measurements and other hydrologic data needed to calibrate the flow model.

In February 2017, KGS began investigating groundwater availability at the University of Kentucky Research and Education Center in Princeton. The study's objectives are to identify the best potential locations for drilling one or more irrigation wells and to determine whether groundwater withdrawn from the local limestone aquifer will be capable of meeting the water needs for planned agricultural research at the UK Grain and Forage Center of Excellence. Various investigative methods are being employed at the farm's 255-acre row-crop field. To this end, **Glynn Beck, Steve Webb, and Bart Davidson** performed aquifer tests on an unused domestic well and three irrigation wells. In addition, Beck, **Junfeng Zhu, David Williams, and Richard Smath** conducted electrical-resistivity surveys along five transects to attempt to identify high-permeability or water-bearing zones in the bedrock. Williams, **Jim Currens, Amy Bleichroth-King, and Jesse Boling** also conducted three dye-trace tests from sink-holes on the farm to determine local groundwater flow directions. Additional investigations, such as drilling a new test well, are planned and are likely to be conducted during the fall of 2017.



An aquifer test is conducted by KGS Water Resources Section scientists on an unused water well (located inside the concrete blockhouse) at the University of Kentucky Education and Research Center in Princeton.

Collaboration With UK College of Agriculture, Food and Environment—Edge-of-Field Water-Quality Monitoring and Monitoring Soil Moisture and Groundwater Conditions in Western Kentucky

Glynn Beck began a multiyear collaboration with **Brad Lee** of the University of Kentucky Cooperative Extension Service and other researchers from the UK College of Agriculture, Food and Environment to study water quality at the edge of a field as well as soil moisture in irrigated fields.

The edge-of-field project, anticipated to run through 2029, has received partial funding from the Kentucky Soybean Board, and additional funding from the U.S. Department of Agriculture–Natural

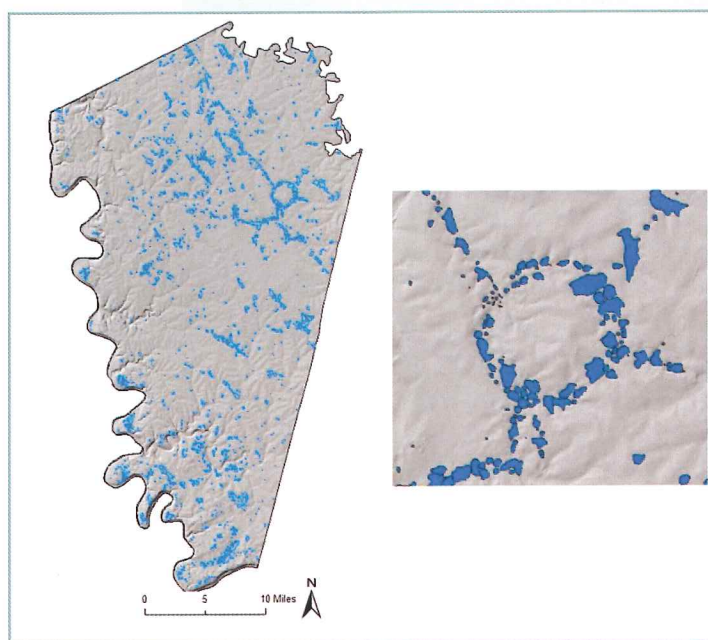
Resources Conservation Service is anticipated in the fall of 2017. Field instruments should be installed and surface-runoff sampling should begin once that funding is received. The project goal is to determine the nutrient and sediment loss from active row-crop fields under different nitrogen application methods and cover crops. **Mark Akland**, a recent hire in the UK Department of Plant and Soil Sciences who is stationed at the KGS Western Regional Office in Henderson, will assist Beck on the project.

In a separate project, soil-moisture and groundwater-level measurements are being collected at an agricultural site in Hickman County to investigate the potential influence that withdrawals from an irrigation well has on local groundwater conditions during a typical agricultural season. Groundwater-level measurements began in January 2017, before planting, and should continue through the end of the year. Groundwater-withdrawal measurements began in May 2017 and

should continue through the growing season. Soil-moisture sensors will be installed in the row-crop field, and data collection will begin in July and continue through the growing season. The data will be used to evaluate the soil-moisture conditions of a fragipan soil—a hardened soil that acts as an impermeable barrier—under different slope positions and to develop recommendations for sensor placement.

Enhanced Sinkhole Mapping Using LiDAR Data

Junfeng Zhu is using newly available LiDAR data to improve digital maps of sinkhole occurrence in parts of Kentucky. During the summer of 2017, Zhu and two UK student workers, **Adam Nolte** and **Kalli Beasley**, extended mapping to Woodford, Boyle, and Jessamine Counties. Approximately 6,200 possible sinkholes have been identified so far in these three counties, and the team is reviewing the data and verifying sinkhole locations in the field. In addition, Zhu is collaborating with **Ming Ye** from Florida State University and **Nathan Jacobs** from UK's Department of Computer Science to develop and test a variety of machine-learning methods to improve computer-automated methods of sinkhole identification and mapping.



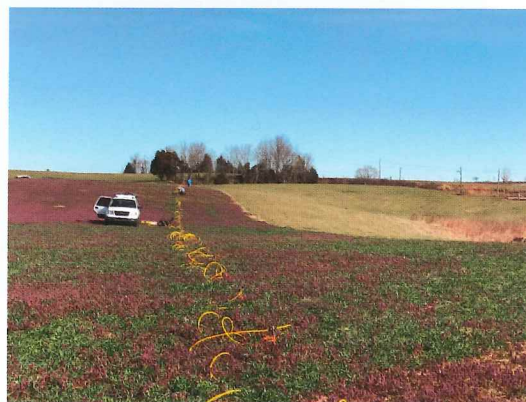
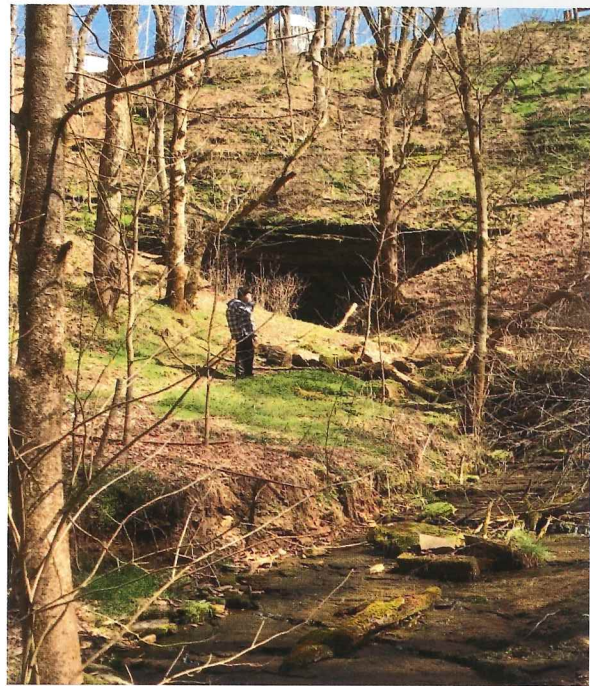
Probable sinkholes digitally mapped in Woodford County by KGS Water Resources Section staff using high-resolution LiDAR data. Inset shows how sinkholes delineate the shape and geographic extent of the Versailles cryptoexplosive structure, commonly interpreted to be the site of a meteorite impact.

Corrosiveness of Drinking Water Study

Working in collaboration with **Dr. Alan Fryar** and graduate students **Amanda Sherman** and **Jason Merrick** from the UK Department of Earth and Environmental Sciences, **Junfeng Zhu** is studying the quality of the Lexington-Fayette County public water supply to assess potential corrosion. This study is in response to the highly publicized water crisis in Flint, Mich., and is supported by the U.S. Geological Survey through the Kentucky Water Resources Research Institute at UK. In March 2017, the project team collected and analyzed 12 tap-water and source-water samples from throughout Lexington. A second round of sampling is scheduled for September 2017. The objectives of the project are to collect baseline information about tap-water quality in Lexington and to assess the water's potential for corrosion and its relation to concentrations of metals. The study should also provide insight into whether the concentration of dissolved metals such as iron and copper increases in tap water as pipe distance increases.

During the fall of 2016, Water Resources staff began investigating the hydrogeology of a karst spring at The Homeplace on Green River, near Campbellsville. This is the first phase of a larger planned effort, "Adapting Edge-of-Field Monitoring for Water-Quality and Soil-Health Assessments in Sinkhole-Dominated Crop Fields." This phase is funded by a Conservation Innovation Grant from the U.S. Department of Agriculture's Natural Resources Conservation Service. Water from the spring discharges from a cave at the head of a steep ravine. To begin continuous monitoring of the discharge from the spring, a flume and stilling well were installed in June 2017 by **Chuck Taylor, Steve Webb, and Jason Backus**. A data sonde capable of recording many water-quality parameters will be installed in the fall of 2017. It will continuously monitor changes in pH, specific conductance, temperature, and turbidity. A tipping-bucket rain gage was also installed at the farm. Sinkholes' surface-runoff routes and catchment boundaries are being mapped at the approximately 22-square-mile study area, using high-resolution LiDAR data and electrical-resistivity surveys in order to identify subsurface conduits beneath the farm's primary crop field. Dye-trace tests will be conducted late in 2017 and in 2018 to delineate karst flow paths and to determine the approximate boundaries of the spring's recharge area. All of these methods will contribute information needed to understand the spring's surface and subsurface hydrology and enable better planning and execution of anticipated water-quality sampling.

This karst spring located at The Homeplace on Green River, near Campbellsville, is the focus of a comprehensive investigation being conducted by staff of the Water Resources Section.



Hydrogeologists from KGS lay out electrodes and cables needed to conduct an electrical-resistivity survey at the farm at The Homeplace on Green River, near Campbellsville, to search for underground conduits containing groundwater.

Collaboration With Kentucky Division of Water Groundwater Sampling Program

The Kentucky Division of Water is responsible for sampling about 60 sites (both wells and springs) across Kentucky that comprise the Interagency Groundwater Monitoring Network (www.uky.edu/KGS/water/gnet). Most samples are collected quarterly or twice a year by Division of Water personnel on 12 different sampling runs across the state. **Bart Davidson** assists the Division of Water in sampling three sites: McConnell Spring and Russell Cave Spring in Fayette County, and Royal Spring in Scott County. The Environmental Services Branch Laboratory in Frankfort analyzes the samples, and the resulting groundwater-quality data are uploaded into the Kentucky Groundwater Data Repository.

Assessing Methane in Shallow Groundwater for the Berea Sandstone and Rogersville Shale Play Area, Eastern Kentucky

In early 2016, the Water Resources Section worked on a project funded by the U.S. Department of Energy, and in collaboration with GSI Environmental of Austin, Texas, to collect and analyze water samples from 51 domestic water wells in Greenup, Carter, Boyd, Lawrence, Johnson, and Elliott Counties. The samples were analyzed for major cations and anions, metals, and dissolved light hydrocarbon gases including methane. A detailed analysis during the fiscal year revealed that groundwater from about half of the wells contained methane in concentrations greater than 1 milligram per liter. These samples were analyzed further for carbon and hydrogen isotopes to identify the potential sources of the methane. The isotope data indicate that the methane in almost all of the wells is derived from microbial activity in the shallow groundwater and not from upward migration of oil or natural gas from deeper source rocks. A peer-reviewed paper that summarizes this research has been prepared and accepted for publication in the journal *Groundwater* in late 2017.

KGS Laboratory Activities

The KGS laboratory supports geologic and scientific research for KGS and University of Kentucky researchers. Water, coal, and mineral samples are analyzed and characterized, and analysis techniques and instrumentation are taught to students and faculty from many UK departments. The KGS laboratory also houses and maintains a University-shared X-ray diffraction instrument.

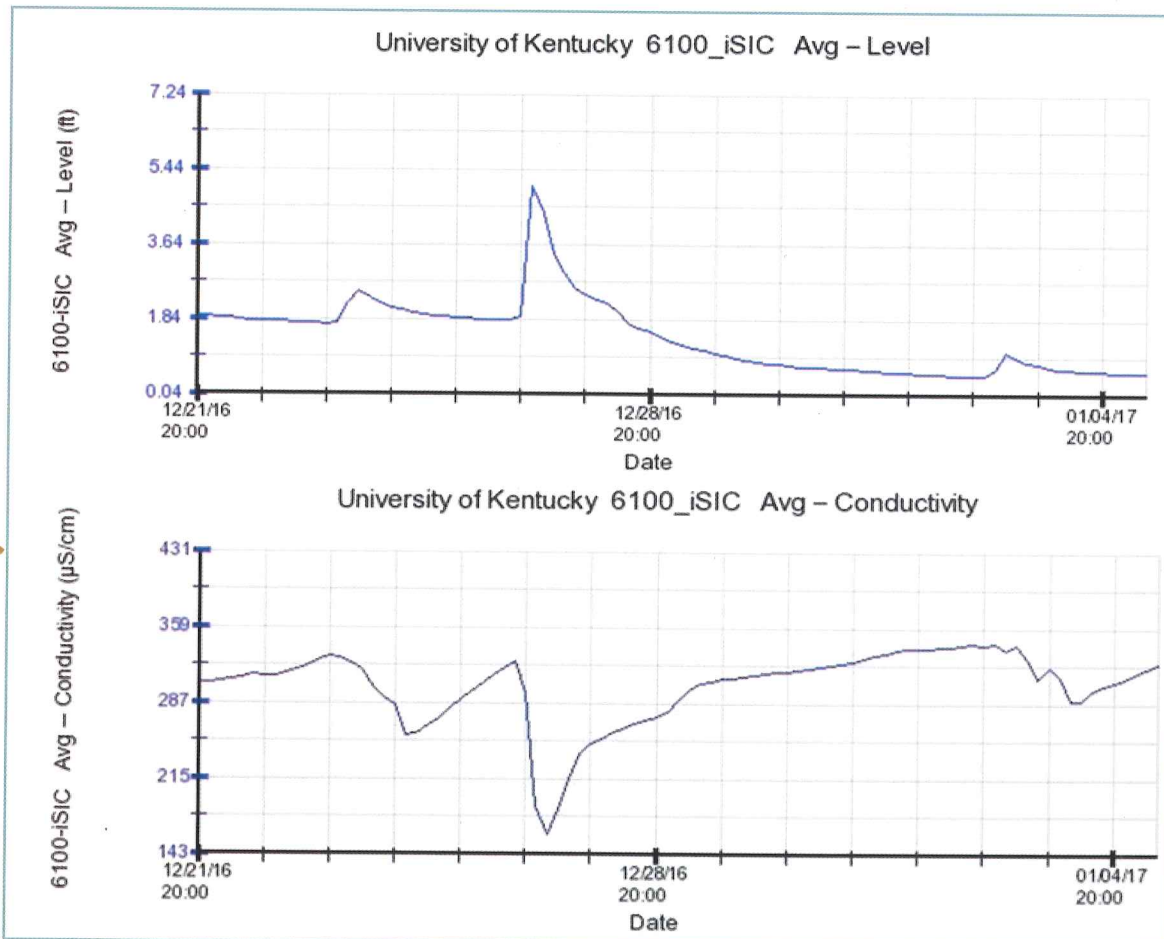
Among the recent and ongoing projects utilizing the laboratory to analyze water samples are the Head of Rough and The Homeplace karst-spring monitoring projects, the study of corrosion in Lexington drinking water, several hydrogeology thesis projects by students from the UK Department of Earth and Environmental Sciences, and a study of nutrients and carbon loads in the Cane Run basin by a doctoral student from the UK Department of Civil Engineering. The laboratory analyzes samples collected from the Kentucky River as part of the Kentucky River Watershed Watch program, as well as samples for student research projects sponsored by the Tracy Farmer Institute for Sustainability and the Kentucky Water Resources Research Institute. Coal and mineral samples are also routinely analyzed by the KGS laboratory, particularly samples from a large collaborative project funded by the UK Department of Mining Engineering and the Center for Applied Energy Research. This project assesses concentrations of rare earth elements in coal ash and coal refuse. Coal researchers use the laboratory's X-ray fluorescence instrument as well as other instruments in the laboratory. More than 3,100 samples were analyzed this year for the rare earth element project alone. The KGS laboratory trains students from the UK departments of Earth and Environmental Sciences, Mining Engineering, Civil Engineering, Chemistry, Materials Science, and Physics, as well as others, and works with them in the laboratory. More than 20 University of Kentucky graduate students have used the laboratory's resources and instrumentation.



In December 2016, KGS began a collaboration with the Hardin County Water District to construct and maintain a station to continuously monitor discharge and water quality at Head of Rough Spring near Cecilia. The project is funded by the Kentucky Division of Water through a Source Water Protection Assistance Program grant. Water-level measurements and water-quality data are being automatically collected at 30-minute intervals and uploaded to a cloud-based web server by satellite telemetry every 4 hours; this will provide daily tracking of the variability in spring-flow and water-quality parameters such as turbidity and specific conductance. Field data are also being collected so that a preliminary stage-discharge rating curve can be developed for the station, and to assess changes in total suspended solids concentrations.



KGS hydrogeologist **Steve Webb** installs water-quality and water-level monitoring equipment at the Head of Rough Spring monitoring station.



Example plots show variability in water level (top) and specific conductance (bottom) being monitored at Head of Rough Spring in Hardin County.

Chuck Taylor, Steve Webb, Glynn Beck, and **Bart Davidson** are establishing a network to monitor groundwater levels in the commonwealth's critical aquifers and help assess groundwater availability throughout the state. At present, 10 wells are equipped with automated equipment that measures water level at 15- to 30-minute intervals. Two of the wells are at the Kentucky Horse Park in Scott County, one is at Mammoth Cave National Park in Edmonson County, and one well each is in Calloway, Henderson, Hickman, and Marshall Counties. One new observation well, an unused domestic well on the University of Kentucky Research and Education Center property in Princeton, was added to the network in January 2017. A second observation well at Mammoth Cave National Park should be added in late 2017, and the suitability of additional wells in parts of south-central and eastern Kentucky is being evaluated. Water-level data collected continuously from these wells will help KGS assess seasonal changes in groundwater availability and identify the onset and severity of hydrologic droughts and their potential impacts to groundwater and surface-water resources. A webpage being designed to provide public access to network well hydrographs and other data should be accessible in the fall of 2017.



Hydrogeologist **Glynn Beck** uses downhole camera equipment to inspect the open borehole of an unused private water well in Oakville, as part of the evaluation for use in the Kentucky Groundwater Observation Network.

Kentucky Groundwater Data Repository

The repository contains well-construction and water-quality data for more than 103,000 sites across Kentucky. Included are data from more than 57,000 domestic, public, industrial, and agricultural wells; nearly 41,000 monitoring wells; and more than 5,300 springs. Hundreds to thousands of analytical sampling results are available for many of these wells and springs. Since the repository's inception in 1990, data have been compiled from more than 15 agencies, including KGS. The largest annual contributions come from the Kentucky Division of Water, and data compiled by the Division's Well Drillers Certification Program and the Interagency Groundwater Monitoring Network

are transferred to KGS for uploading to the repository approximately once every quarter. Scanned copies of drillers' logs are uploaded approximately every 6 months. All available data for wells and springs are publicly accessible from the repository website (www.uky.edu/KGS/water/research/gwreposit.htm) and can be searched, downloaded, and displayed online using various base maps. Users can generate comprehensive hydrologic site assessments for multiple applications, including groundwater resource exploration, environmental monitoring and remediation, land-use development, recreation, and agricultural planning, by pairing the repository data with digital geologic information.



KGS karst hydrogeologist **Jim Currens** (right) with his son, **Ben Currens**, a graduate student in the UK Department of Earth and Environmental Sciences, happily celebrate a successful caving trip.

After 37 years at KGS, **Jim Currens** retired from the Water Resources Section on June 1, 2017. During his long and productive career, Currens published more than 60 papers, reports, and maps. Jim's main research focus, and his passion, is caves and karst hydrogeology. As part of his professional work, and as a hobby, Jim explored and helped map and survey many Kentucky cave passages. He planned and conducted hundreds of dye traces to delineate karst underground flow paths and map the basin boundaries of a great number of Kentucky's many karst springs. It was this work, conducted mostly in collaboration with **Joe Ray** and **Rob Blair**, hydrogeologists at the Kentucky Division of Water, that led to the development of a unique and extremely valuable series of maps known informally as the Karst Atlas Series.

Jim also took a great interest in documenting the occurrences of karst-related sinkholes. Over the years, he responded to hundreds of reports of sinkholes around the state, and provided technical assistance and reassurance to concerned landowners. One of Currens's most recent KGS projects was compiling and analyzing data on the occurrence of more than 300 reported cover-collapse sinkholes. This research is the subject of a forthcoming KGS Report of Investigations to be published in late 2017 or early 2018.

Some of Currens's other accomplishments at KGS are a study of karst flooding in Jessamine County, a multiyear study of the relation between groundwater quality and agricultural practices in a large spring basin in southern Logan County, a model ordinance to help communities deal with sinkhole hazards and urban development on karst terrain, and establishing one of the first field monitoring stations for a karst aquifer system in the Cane Run–Royal Spring basin, which provides water for Georgetown. Karst-related hydrogeology and environmental issues will continue to be a significant focus of the Water Resources Section, and KGS anticipates hiring a new hydrogeologist during the next fiscal year who will continue the tradition of leading-edge karst research. Currens's enthusiasm, experience, and encyclopedic knowledge of the subject will be greatly missed, however.

Staff Awards and Recognitions

Chuck Taylor was an appointed member of the Kentucky Agriculture Water Quality Authority. He was also the lead author of a chapter on karst in a newly released update of a classic publication, "Handbook of Applied Hydrology." The book is considered an industry-standard resource on a wide range of hydrologic information, methods, and applications.

Bart Davidson was a member of the Kentucky Water Well Drillers Certification Board, which oversees issues such as examination requirements, applications, and disciplinary actions for drillers.

Glynn Beck is a member of the Kentucky Agriculture Science and Monitoring Committee and the Environmental and Natural Resources Issues Task Force.



ENERGY AND MINERALS

OIL AND NATURAL GAS RESOURCES

Unconventional Resource Potential of the Cambrian Rogersville Shale, Eastern Kentucky

Research to determine the unconventional oil and gas potential of the Cambrian Rogersville Shale in eastern Kentucky continued in 2016-17. Previous work by the Rome Trough Consortium at KGS in 2002 identified the Cambrian Rogersville Shale (Conasauga Group) as a mature hydrocarbon source rock, with total organic carbon content of up to 4 weight percent. Six wells have now been drilled to test the Rogersville Shale in Kentucky and West Virginia; log data from these new wells remains confidential. The most recent Rogersville Shale well was completed in Lawrence County in early 2017; the Bruin Exploration No. 1 Walbridge Heirs, a horizontal well, was completed with a 27-stage hydraulic fracture stimulation. This well remains under evaluation.

KGS is continuing research on the Rogersville Shale to support significant interest in the play. **John Hickman** and **Dave Harris** began writing a research proposal for a U.S. Department of Energy funding opportunity, to be submitted in August 2017. The proposed 5-year study will characterize and assess the emerging unconventional resource, collect baseline environmental data, and evaluate the social and economic impacts of resource development prior to significant drilling activity. In addition, an industry partner will be sought to collaborate on a Rogersville research well to acquire new core and log data. The project is in collaboration with researchers from the Kentucky Department of Forestry and Natural Resources and the Kentucky Transportation Center at UK.

Oil and Gas Workgroup

An oil and gas workgroup mandated by the Kentucky legislature (Kentucky House Bill 563, passed in the 2016 Regular Session) reviewed the regulations for management and disposal of technologically enhanced, naturally occurring radioactive waste materials (or TENORM) generated by the oil and gas industry. **Brandon Nuttall** was appointed to the group by Secretary Charles Snavelly of the Energy and Environment Cabinet. With help from the workgroup, the 2017 General Assembly passed Senate Bill 248, which corrected the definitions of NORM (naturally occurring radioactive materials) and TENORM. Draft regulations for disposal and management of TENORM waste in landfills, rock cuttings at drill sites, and oil-field pipe materials have been submitted to the Kentucky Legislative Research Commission for approval and adoption.

The study of the Berea petroleum system in eastern Kentucky concluded in May 2016, and a final report was made available to the public in May 2017. The project was headed by KGS and partners including the U.S. Geological Survey, Ohio Division of Natural Resources, and R.J. Lee Group, which made in-kind technical contributions. Industry partners were Fireborn Land and Energy, Nytis Exploration, EQT, Hay Exploration, Cimarex Energy, Vinland Energy, Abarta Oil and Gas, and Country Mark Energy Resources. A workshop organized by **Steve Greb** for the KGS annual seminar in May 2017 reviewed results of the Berea Sandstone core studies. Project results are being presented at the 2017 Eastern Section of the American Association of Petroleum Geologists annual meeting in Morgantown, W.Va.; abstracts have been submitted by **Steve Greb, Cortland Eble, Dave Harris**, and principal investigator **Marty Parris** (all from KGS) and **Paul Hackley** at the U.S. Geological Survey. Greb is leading another core workshop and field trip for the Geological Society of Kentucky annual meeting in October 2017. In addition, manuscripts are being written for peer-reviewed publications.



Steve Greb led a Berea Sandstone core workshop at the KGS annual seminar.

CARBON STORAGE

Carbon-Storage Demonstrations as Part of the Kentucky Energy Independence and Incentives Act

Steve Greb and **Dave Harris** continued to describe cores from the KGS No. 1 Hanson Aggregates well in Carter County.

Rick Bowersox and co-authors **Steve Greb** and **Dave Harris** have completed three reports on the KGS No. 1 Hanson Aggregates well: a KGS manuscript and two journal submissions on CO₂ storage capacity in the Maryville sand–Basal sand section, and in the Rose Run Sandstone. The final analytical report on the Carter County project, “CO₂ Storage Capacity of the Copper Ridge Dolomite in the No. 1 Hanson Aggregates Well,” is in progress and expected to be completed in early 2018. Bowersox and co-authors **Dave Williams** and **Dave Harris** also completed a journal article

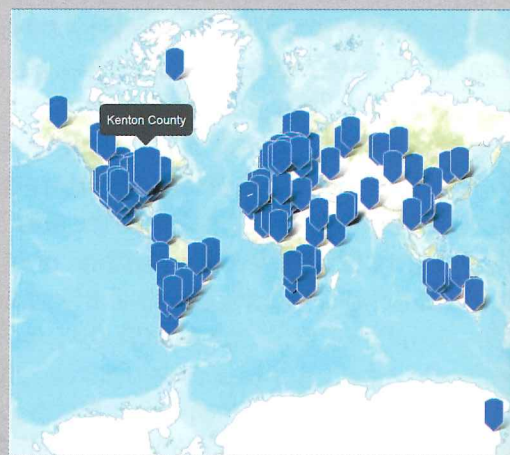
updating the CO₂ storage capacity of the Gunter Sandstone in the KGS No. 1 Marvin Blan well in Hancock County, using new analytical methodologies adapted from the Carter County project. Besides estimating CO₂ storage capacity in the reservoirs, these reports also review properties of caprock confining strata for each reservoir; confining strata must have a porosity and permeability low enough to prevent injected CO₂ from escaping from the proposed reservoir. The reports also identify geomechanical rock strength and natural fracture systems for these caprocks. Although there are no plans to store CO₂ in the deep subsurface anywhere in Kentucky, all of these reports indicate that CO₂ could be confined in the deep subsurface of Kentucky and remain confined indefinitely.

KGS participates in the Midwest Regional Carbon Sequestration Partnership, funded by the U.S. Department of Energy and managed by Battelle Memorial Institute. The partnership was established to assess the technical potential, economic viability, and public acceptability of carbon storage in the region. It is one of seven regional Department of Energy carbon storage partnerships in the United States.

Brandon Nuttall, Tom Sparks, and Steve Greb are working on phase III of the project, developing a regional assessment of the potential for carbon storage and enhanced gas recovery in organic-rich Devonian shales. Total organic carbon content, density, and maturity data are being compiled and analyzed for the Marcellus and Utica Shales. KGS also collaborates in research on regional subsurface geology of potential storage reservoirs and their confining intervals. Information about the regional partnership and a list of publications can be found at www.mrcsp.org.

Meteorite Database

The KGS meteorite collection is an excellent representative sampling of meteorites derived from our solar system. Over the past 2 years, **Warren Anderson, Ethan Davis, and Richard Smath** photographed and inventoried more than 230 specimens from every continent all over the world, including many meteorites found in Kentucky. Many of the pieces of this collection are on display at KGS and at other major museums around the world, and the KGS collection is captured in an Interactive Tour on the KGS website, "KGS Meteorite Collection Database" (kgs.uky.edu/storymap/meteorites). The Interactive Tour gives location, weight, classification, year found, and a brief annotation of each meteorite in the KGS database. All of the Kentucky meteorites are discussed in "Space Visitors in Kentucky" by William Ehmann and Warren Anderson, published as KGS Special Publication 1 (series 12) in 2000.



COAL RESOURCES

National Coal and Energy Minerals Resource Data System

This national cooperative program between the U.S. Geological Survey and state geological surveys provides funding to collect and assimilate data on coal and organic shales; examples of the data are coal-quality analyses (proximate, ultimate), stratigraphic records (borehole descriptions, correlations), and resource estimates. The state-level data are included in a series of national databases. **Steve Greb and Cortland Eble** manage the Kentucky portion of the partnership. The funding was used in 2017 to support **Ethan Davis**, who analyzed coal and carbonaceous shale samples in the KGS laboratory; Davis performed proximate (moisture, volatile matter, ash, and fixed carbon), total carbon/sulfur, inorganic carbon, and X-ray fluorescence analyses on approximately 350 coal and shale samples.

KGS and researchers from the UK Department of Mining Engineering and the Center for Applied Energy Research are testing for economic concentrations of rare earth elements in Kentucky coal, coal-preparation refuse, and coal-fired power-plant byproducts. Rare earth elements are the lanthanide series elements (lanthanum through lutetium on the periodic table) plus scandium and yttrium—collectively known as REE+Sc+Y. Phase II funding for this research was secured from the U.S. Department of Energy in March 2017; the goal is to set up and operate a mobile unit to extract rare earth elements at an active coal mine and preparation plant in Kentucky. Approximately 350 samples from coal preparation plants have been evaluated thus far. Research is targeted primarily at identifying specific grades of material in preparation plants that contain the highest amounts of REE+Sc+Y. After this task is completed, experiments will determine the most cost-effective way to separate and concentrate REE+Sc+Y.

Funding for a second project was also secured from the Department of Energy to evaluate the REE+Sc+Y potential of western Kentucky coal beds. More than 400 samples from the KGS Well Sample and Core Library, exploration drill cores, and active coal mines have been collected and

tested for REE+Sc+Y. The primary goal of this project is to identify coal beds that contain more than 300 parts per million of REE+Sc+Y. Results thus far indicate that one coal in particular, the Baker, consistently meets or exceeds this threshold. Other coals are also being evaluated.

The role of KGS in both of the projects is to identify and collect samples, crush the samples, convert the coal to ash in a muffle furnace, and then dissolve the ash using strong mineral acids (hydrofluoric, nitric, and hydrochloric). The dissolved ash is then tested for REE+Sc+Y using inductively coupled argon plasma optical emission spectroscopy.

Funding for a third project has recently been secured from the Department of Energy to compare methods of testing for rare earth elements used by different laboratories across the United States. KGS will collect and test Kentucky coal samples, then distribute duplicate samples of the collected materials to other participating laboratories.

Since the late 1980s, nearly all of the rare earth elements used in the United States have been imported from China. The current projects at UK are part of an aggressive effort to boost domestic production. **Cortland Eble, Ethan Davis, and Jason Backus** are the principal investigators from KGS.

Pennsylvanian Geology of the Eastern and Western Kentucky Coal Fields

Steve Greb and **Cortland Eble** continued research on coal-bearing strata in both the Eastern and Western Kentucky Coal Fields. Although our state's coal production has declined in recent years, the national and international geologic community remains interested in data from past mining, the general geology, and outstanding outcrops. Many researchers from countries around the globe, including China, Great Britain, the Netherlands, and Switzerland, have come to Kentucky to see our extraordinary roadcuts and highwalls, and to collect data for their research. Depositional facies between coals are of particular interest to oil and gas researchers, because they can provide two- and three-dimensional exposures of a variety of coastal-deltaic reservoirs for comparison with downhole data from other areas.

Coal Information

Steve Greb, Jerry Weisenfluh, Meg Smath, and Rebecca Wang finished a coal education project funded by the Kentucky Department for Energy Development and Independence. The project resulted in new webpages on coal exploration cores and on the core-coding system in Kentucky, and geologic

obstacles and roof conditions in coal mines. Little information on these subjects had been available on the internet or in easy-to-access educational resources, so the new webpages should be useful for training miners, as well as groups that use core data, including the mining industry, permitting

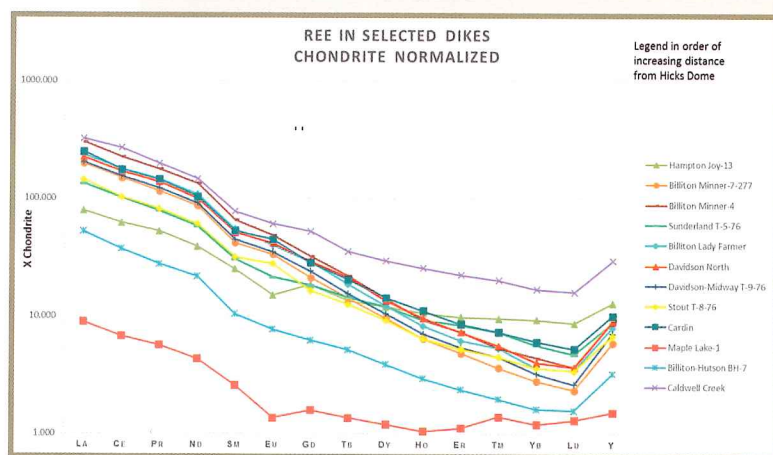
offices, reclamation and environmental groups, and land planners and developers. The section on coal core consists of 34 webpages of information with 119 photographs and diagrams explaining coring, rock properties, the history of the popular Fern coding system, and a step-by-step explanation of the coding system and core description. Quick guides, glossaries, numerical-to-English conversions, and downloadable core books are also included. These pages can be seen at www.uky.edu/KGS/coal/coal-core.php.

The section on mining geology contains information about 17 different types of geologic obstacles, discontinuities, and roof-fall conditions that have been encountered in Kentucky coal mines. Definitions, explanations, known trends, common geologic facies associations, known Kentucky occurrences, and information on planning for and mitigating these obstacles are available for each of these geologic features. The new pages, at www.uky.edu/KGS/coal/coal-mining-geology-intro.php, contain more than 100 representative photographs and diagrams.

MINERAL RESOURCES

Rare Earth Element Research in the Western Kentucky Fluorspar District

Warren Anderson and **Jason Backus** are investigating the occurrence of rare earth elements in alkaline ultramafic igneous rocks in the Western Kentucky Fluorspar District, and analysis indicates that the unique mineralogy of these igneous rocks suggests a mantle intrusion complex in parts of the district. Igneous dikes resulting from this intrusion contain astrophyllite, schorlomite, wustite, and fluorotetraferriphlogopite. The dikes are also slightly enriched in rare earth elements. Although the occurrence of rare earth elements has been confirmed, only slight enrichment has been found. A report documenting the mineralogy, petrology, and analytics of these igneous rocks, containing abundant photographs, diffraction images, and analytical results, has been written and is in review.



Scatter diagram of chondrite-normalized elemental analysis of igneous dikes in the Western Kentucky Fluorspar District, showing some dikes enriched and some depleted in rare earth elements.

Several presentations about this research were made this year.

BRINES AND UNDERGROUND WASTE DISPOSAL

Mapping Underground Brine-Disposal and Enhanced-Recovery Wells

Environmental concerns about wastewater disposal wells have received much attention recently from the news media and the public. In wastewater disposal, brines brought to the surface with oil and gas production are reinjected into the same or porous underground formations similar to the ones in which they were initially produced. This practice helps protect underground drinking-water sources. The U.S. Environmental Protection

Agency previously controlled permitting and regulation of all Class II underground injection wells in Kentucky under its Underground Injection Control Program, but the Commonwealth of Kentucky took over on Jan. 27, 2017. The Kentucky Department of Natural Resources—Division of Oil and Gas is now responsible for all activities associated with the regulation of Class II injection wells in Kentucky. All owners and operators of Class II injection wells in

Kentucky will be required to comply with the provisions of Kentucky's newly approved Class II UIC Program.

After a database of all Class II wells in Kentucky was compiled by **Tom Sparks**, a new internet map service was linked to the KGS petroleum map service on the KGS Oil and Gas Data webpage. The database was developed following the release of multiple Freedom of Information Act documents by the EPA and includes data from all of the original 100 brine-disposal wells whose locations are shown on "Class I Waste-Disposal Wells and Class II Brine-Injection Wells in Kentucky" (KGS Map and Chart 204, series 12, published in 2013), as well as an additional 2,900 enhanced oil-recovery injection wells. As new brine-injection disposal wells are permitted, the map service is updated.

KGS requested brine-injection volumes of all currently active disposal wells in Kentucky, and the data were received from the EPA in 2015. The annual volumes were integrated into the current database of operational data

(injection volumes and pressures) created during a previous project to build a framework for brine disposal. In addition, a legacy data set of historic injection volumes for Class II waste-disposal and enhanced-recovery wells covering a 25-year period and 30-year period, respectively, was secured from the EPA. From this extensive database of injection volumes, a series of charts and spatial maps were presented in "Class II Injection Wells in Kentucky—An Update of the Map Service of Wastewater, Brine-Disposal, and Enhanced-Recovery Wells in Kentucky" (AAPG Data-pages Search and Discovery Article 80585) at the 45th annual meeting of the Eastern Section of the American Association of Petroleum Geologists, in Lexington in September 2016.

These new data will help with the Geologic Hazard Section's microseismicity monitoring. Eventually, the data will be made publicly available. The Survey will update this database annually.

Reassessing the Fresh-Saline Water Interface in Eastern Kentucky

Ethan Davis, Marty Parris, and Jerrad Grider have completed an analysis of the maximum freshwater depth in eastern Kentucky. The 14-county study area includes the Berea unconventional oil and gas play area of Devonian age and the nascent Rogersville play of Cambrian age, in which there is no current production in Kentucky. The Berea play is being developed using horizontal drilling and hydraulic fracturing (fracking) at depths of less than 2,000 feet from the surface, whereas the Rogersville play will likely be developed using high-volume hydraulic fracturing at depths greater than 6,000 feet. The potential impact of these plays on groundwater quality prompted concern. Information about the distribution of potable

groundwater is largely based on the "Fresh-Saline Water Interface Map of Kentucky" by H.T. Hopkins (published by the U.S. Geological Survey in 1966). Examination of Hopkins's methods shows that the map likely underestimates the maximum depth of fresh water in most places, however. In comparison, this new analysis increases the average maximum depth of fresh water by 147 feet. Davis presented the work in a poster at the 2016 annual meeting of the Eastern Section of the American Association of Petroleum Geologists; the poster received the best presentation award by the Division of Environmental Geosciences. Results from this work will be submitted as a KGS Report of Investigations in the fall of 2017.

Staff Awards and Recognitions

John Hickman served as the 2016-17 president of the Eastern Section of the American Association of Professional Geologists. He also received a Certificate of Merit from the national AAPG in 2017.

Ethan Davis received the American Association of Professional Geologists—Eastern Section's Division of Environmental Geosciences Best Poster Award for "Revising the Fresh-Saline Water Interface in Eastern Kentucky," displayed at the Section's 2016 annual meeting, held in Lexington.



GEOLOGIC MAPPING

During fiscal year 2016-17, Geologic Mapping staff completed surficial mapping of four more 7.5-minute quadrangles—Verona (**Steve Martin**), Walton (**Antonia Bottoms**), DeMossville (**Matt Massey**), and Butler (**Max Hammond**)—with funding from the USGS STATEMAP program. This mapping and related projects provide useful surficial maps for communities as well as learning opportunities about surficial geology and mapping processes for the section's staff. For example, Massey and Hammond began collecting geochronology samples that will advance our understanding of the surficial deposits and landscape evolution of northern Kentucky.

Massey worked with **Doug Curl**, head of the Geologic Information Management Section, to expand the section's use of digital data-entry tools, especially Esri's Collector app. Collector allows mappers to record locations, photographs, and observations during field work and upload them to the section's databases any time a wireless data connection is available.

The mappers also expanded their use of LiDAR (light detection and ranging) data, which reveals detailed topographic information. The section is using the elevation data, contours, shaded relief, slope angles, and derivative maps resulting from LiDAR to highlight fluvial terraces along river valleys.



Geologic mapping staff, UK students, and staff with the Geological Survey participate in a field review of the De Mossville and Butler quadrangles, which were mapped for the 2016 STATEMAP program.

Staff Awards and Recognitions

William Andrews participated in the planning workshop for the USGS National Cooperative Geologic Mapping Program Decadal Strategic Plan. He continued to teach a review course for the professional geologist registration examination.

Bethany Overfield is active with the Kentucky River Watershed Watch and serves as a science advisor for the nonprofit organization, which promotes Kentucky River monitoring and public awareness.



Mike Angle, assistant state geologist of Ohio, examines a soil-probe core of high-level fluvial deposits in the Butler quadrangle during a field trip in northern Kentucky.

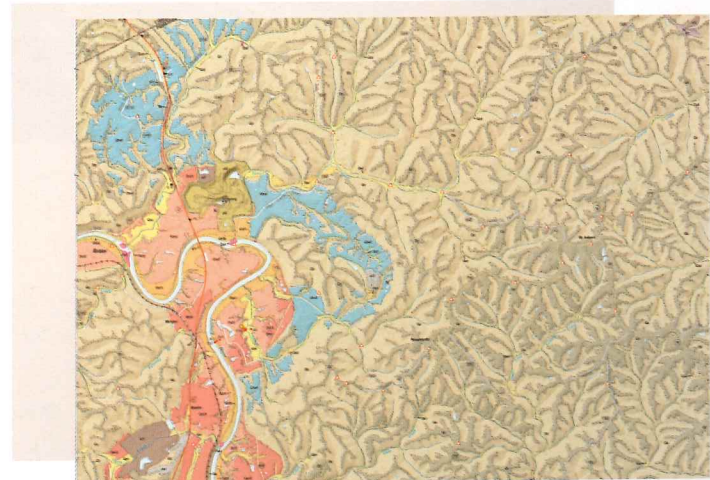
Section head **William Andrews** and **Matt Massey** attended the annual Geological Society of America meeting in Denver in September 2016 to present research results. Massey and **Max Hammond** attended the North-Central Section of the Geological Society of America's annual meeting in Pittsburgh in March 2017, also making presentations on their research.

Steve Martin and Andrews made presentations at the Southeastern Section of the Geological Society of America annual meeting in Richmond, Va., early in 2017. Andrews spoke on the geology of the Camp Nelson Civil War site in Jessamine County, and Martin talked about his "Geologic Tour for Parklands of Floyds Fork" (Interactive Tour 2, series 13).

Andrews and **Matt Crawford** of the Geologic Hazards Section presented a series of workshops about KGS resources and programs related to geologic hazards (karst, landslides, earthquakes, radon) to the Kentucky Association of Mitigation Managers.

Twice during the year, Andrews taught a review course for professional geology exams through the Kentucky Section of the American Institute of Professional Geologists.

Matt Massey published an article in the *American Journal of Science* describing analysis of metamorphic rocks and tectonic evolution of an area in Massachusetts.



Detailed section of "Surficial Geologic Map of the Butler 7.5-Minute Quadrangle, North-Central Kentucky" (Contract Report 7, series 13), by **Max Hammond**.

Other Activities

Steve Martin produced a Story Map of the geology of Floyds Fork in eastern Jefferson County, based on new field mapping he completed for the Fisherville surficial geologic quadrangle map in 2015-16.

Amy Bleichroth-King operates the Beckman Coulter laser particle size analyzer in the KGS office in Henderson, and assists with compilation and management of legacy mapping data.



OUTREACH AND PROFESSIONAL ENGAGEMENT

As a state-mandated research and public-service organization, KGS offers seminars, workshops, lectures, and other outreach for academics, professionals, government agencies, and the general public.



With a theme of "Why KGS? Transformative Integration and Geoscience in the Public Interest," the KGS annual seminar drew a crowd of 160 people to our Well Sample and Core Library on May 19, 2017. Speakers included UK President Eli Capilouto, Kentucky Resources Council President Tom FitzGerald, and Merrill Stypula of EQT, a Pittsburgh exploration company. Researchers from KGS and other UK departments also spoke at the gathering.



The annual Earth Science Week open house draws students, teachers, and families to KGS to tour earth science displays and demonstrations by KGS researchers, students at the UK Department of Earth and Environmental Sciences, and other organizations. KGS also disseminates teaching resource packets provided by the American Geoscience Institute to schools in central Kentucky as part of Earth Science Week.



The Geological Society of Kentucky and KGS co-hosted the annual meeting of the Eastern Section of the American Association of Petroleum Geologists in September 2016. Three hundred twenty-four professionals and students came to the Lexington Convention Center and Hyatt Hotel for the meeting, whose theme was "Basins to Barrels." With technical sessions, field trips, exhibitors, poster displays, and social events, the event was a major undertaking. The technical program alone consisted of 70 oral presentations and 31 posters.

KGS scientists were invited to provide their expertise at events sponsored by outside organizations.

Well Sample and Core Library Manager Patrick Gooding and Core Library staff member Ryan Pinkston set up a temporary display of rocks, minerals, and fossils at the Jessamine County Public Library. The staff also participated in several school science nights and hosted a half-day geology program for elementary students at the Core Library.



Richard Smath and Bart Davidson judged submissions for the 4-H rock collection exhibits at the Kentucky State Fair.



Seismologist Seth Carpenter showed high school students in the Governor's Scholars Program geologic and landscape features in western Kentucky related to the 1811-12 New Madrid Seismic Zone earthquakes.

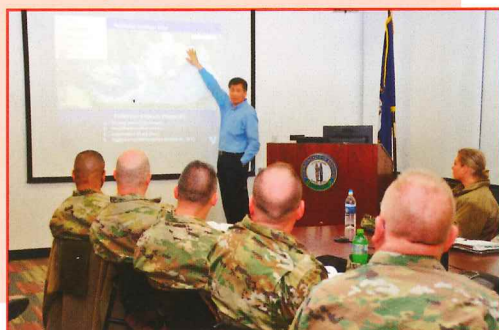


KGS sponsored a lecture by Fresno State University professor Jerome DeGraff on landslides and co-sponsored the annual Darwin Lecture, at which Utah State Paleontologist James Kirkland spoke.



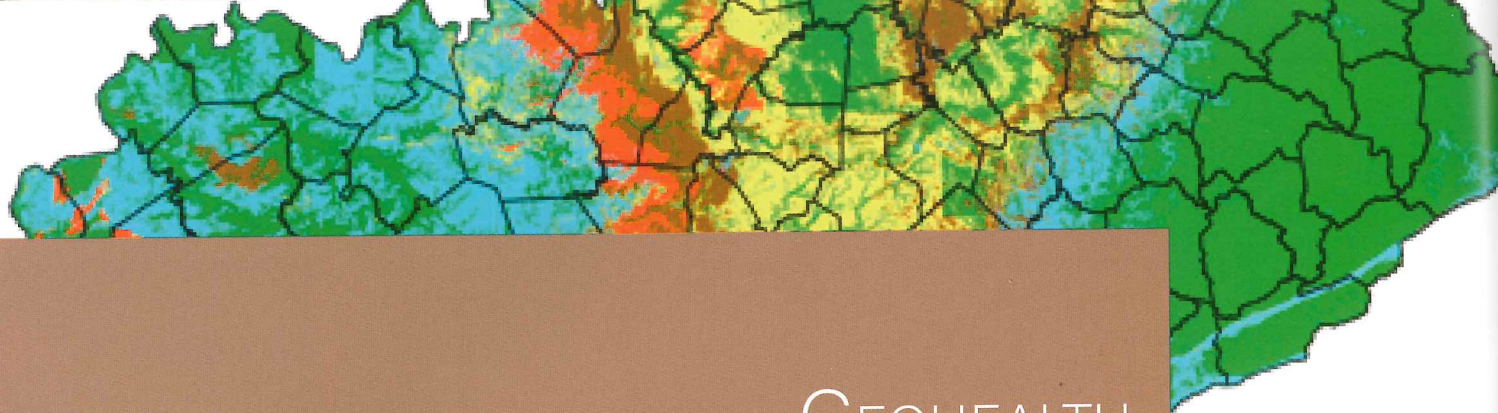
KGS staffed displays at several conferences to promote KGS services and data and provide educational outreach. Some of those meetings were the Kentucky Science Teachers Association annual meeting, the Kentucky Oil and Gas Association annual meeting, and the annual E-Day event at the UK College of Engineering, where Matt Crawford set up a landslide exhibit.

Geologic Hazards Section Head Zhenming Wang talked to the Kentucky National Guard about the earthquake threat in Kentucky.



KGS staff had a strong presence at the 2017 UK staff DanceBlue Mini Marathon, helping to raise more than \$8,000. DanceBlue is a completely student-led philanthropy at UK, supporting the Pediatric Hematology Oncology Clinic at the Kentucky Children's Hospital at UK.





GEOHEALTH

The emerging interdisciplinary field of geohealth explores connections between geology and human health sciences. **Bethany Overfield** of the Geologic Mapping Section is working on collaborative geohealth research projects with two colleges on the UK campus.

She completed maps for all 120 Kentucky counties showing radon-gas potential by rock type. This work was done for a continuing project with the UK College of Nursing and the college's Bridging Research Efforts and Advocacy Toward Healthy Environments initiative. Overfield's maps were used in a series of informational flyers, which were created to promote awareness about radon risk and to encourage home radon testing. The flyers are available on a BREATHE website, www.uky.edu/breathe/radon/radon-data-county, where users can click on the name of any county to see information about its radon levels, including the county's radon-potential map.

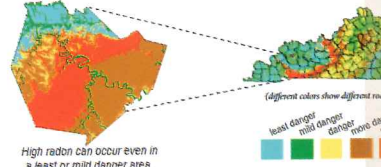
Are you in danger from RADON in Warren County?

Radon is a naturally occurring, radioactive gas.

- It cannot be seen, smelled or tasted.
- It may seep into your home from the rocks below.
- It is the second leading cause of lung cancer.


TEST YOUR HOME • KNOW YOUR LEVEL
For a radon test kit, contact the Kentucky Radon Program at (502) 564-4856

Certain types of rock have higher levels of radon
Radon is a problem in many areas in Kentucky, including Warren County.

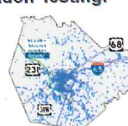


High radon can occur even in a least or mild danger area.


Smoking and radon:
Breathing radon is dangerous, but it is even **more** harmful when you also breathe tobacco smoke.



Radon Testing:



• Blue dots show homes already tested for radon.



More homes in Warren County need to be tested.

To Do List:


- ✓ **TEST** your home for radon.
- ✓ **TALK** with a health care provider about your results.
- ✓ **FIX** your home if the level is high. Call a certified radon professional.
- ✓ **ASK** people to smoke outside.
- ✓ **TELL** your loved ones about the dangers of radon and tobacco smoke.

TEST YOUR HOME • KNOW YOUR LEVEL

For a radon test kit, contact the Kentucky Radon Program at (502) 564-4856.
For more information about the maps, contact BREATHE at (859) 257-7028.

BREATHE
Bridging Research Efforts and Advocacy Toward Healthy Environments

Radon Policy Research Program



College of Nursing

Funding provided by the Kentucky State Radon Program © University of Kentucky BREATHE

Bethany Overfield developed maps for all 120 Kentucky counties showing radon-gas potential by rock type. The maps are being used in flyers to promote awareness about radon risk and to encourage home radon testing.

After finishing the county maps, Overfield began to focus on studying why some geologic formations and areas in Kentucky have higher radon levels than others. Devonian shale was expected to have the highest radon levels; data from more than 60,000 residential radon tests showed that the highest levels occurred over Mississippian and Ordovician limestones, however. Because radon gas is sourced from the radioactive decay of uranium, Overfield plans to start sampling rocks from different geologic formations to assess their uranium content.

Overfield continued her work with a team headed by **Nancy Johnson** of the UK College of Public Health, which is studying biological exposure to trace elements and their possible contribution to the rate of lung cancer in the Eastern Kentucky Coal Field. Smoking rates are the same in the Eastern and Western Kentucky Coal Fields, but lung cancer rates are higher in eastern Kentucky. Data for this research were collected by the Lung Cancer Research Initiative at UK's Markey Cancer Center, sponsored by the Department of Defense. Overfield focused on assessing geologic and geomorphologic controls using GIS. She calculated the distance of

potential environmental impact sources such as landfills, oil and gas wells, and coal preparation plants from the residential testing sites. She also calculated how many of those sources were within a 1-mile radius of the residential sites. In addition, heavy-metal levels in eastern Kentucky waters were examined, concentrating on valleys, since most homes in the region are situated in valleys.

As Overfield expands her work in the geohealth field, she and her collaborators have scheduled events to discuss the research. Working with **Ellen Hahn** at the College of Nursing and the U.S. Geological Survey, Overfield and KGS Director **Bill Haneberg** organized a technical session, "Origin, Transport, and Accumulation of Geogenic Carcinogens," for the December 2017 American Geophysical Union meeting in New Orleans.

Overfield and Haneberg also began planning for a short course, "Geospatial Approaches to Epidemiology," to be held in January 2018 on the UK campus in conjunction with other campus research offices and colleges.

Ellen Hahn of the UK College of Nursing and **Bethany Overfield** spoke at the KGS annual seminar about their collaborative work on radon.





GEOLOGIC HAZARDS

The Kentucky Seismic and Strong-Motion Network

The Kentucky Seismic and Strong-Motion Network monitors seismic events across Kentucky. KGS shared this year's network recordings in real time with the neighboring seismic network operated by the University of Memphis and also with the Data Management Center at Incorporated Research Institutions for Seismology for archiving and to make the data available globally. Almost 130 gigabytes of data from the Kentucky network was downloaded from Incorporated Research Institutions for Seismology this fiscal year.

Recordings from networks operating in Kentucky and surrounding states were acquired in tandem with the Kentucky Seismic and Strong-Motion Network data and used to detect mine blasts and earthquakes in Kentucky. Twenty earthquakes were recorded in the state during the fiscal year, ranging in magnitude from 1.0 to 3.3. Eleven of these events, including the largest, happened in the Mississippi Embayment and nine occurred in eastern Kentucky. Seven of the earthquakes were reported as felt by local residents. The May 16, 2017, magnitude 3.3 earthquake in westernmost Carlisle County was the largest earthquake in Kentucky this fiscal year, and was felt in three states and as far away as St. Louis.

Three of the eastern Kentucky earthquakes were not reported by other agencies. Detailed analysis of these earthquakes, including determination of faulting style for two events, was possible because of a temporary network that KGS established with state support and in partnership with the UK Department of Earth and Environmental Sciences and private companies; the



Lifang Zhang, Seth Carpenter, Junjie Sun, and Andrew Holcomb install seismic station EK-36 at Chapman in eastern Kentucky.

temporary network is the primary component of the Eastern Kentucky Microseismic Monitoring Project. By the end of the 2016-17 fiscal year, 15 of these temporary stations had been installed in the Rome Trough of eastern Kentucky. The data arrive at KGS in real time using wireless communication for processing and archiving.

Kyle Combs, a senior at Paul Lawrence Dunbar High School in Lexington, completed his Capstone research project, "Microseismicity in and Around Kentucky Using Permanent and Temporary Seismic Arrays," and presented the results at the Math, Science, and Technology Center Senior Symposium in April 2017. Combs also presented a poster at the KGS annual seminar on May 19, 2017. **Andrew Holcomb**, a master's student in the Department of Earth and

Environmental Sciences at UK, investigated microseismicity in eastern Kentucky using the data from the temporary network, and completed a thesis, "Initial Microseismic Recordings at the Onset of Unconventional Hydrocarbon Development in the Rome Trough, Eastern Kentucky." Holcomb also presented a poster, "Monitoring Microseismicity in the Rome Trough, Eastern Kentucky: Year One Observations and Network Performance," at the 2017 Seismological Society of America annual meeting April 18–20, 2017, in Denver.

The seismic data recorded from the Kentucky Seismic and Strong-Motion Network, as well as from EarthScope USArray and stations in an Illinois Basin

network, were used for research on ground-motion site effect and deep-earth structure. **Seth Carpenter, Zhenming Wang, Ed Woolery,** and **Mianshui Rong** co-authored a paper, "Estimating Site-Effect in the Northern Mississippi Embayment With S-Wave HVSR and Recordings From Deep Vertical Strong-Motion Arrays," and submitted it for publication in *Bulletin of the Seismological Society of America*. Carpenter also co-authored a paper, "Detailed Crustal Thickness Variations Beneath the Illinois Basin Area: Implications for Crustal Evolution of the Midcontinent," with researchers at Purdue University, Indiana University, and the University of Illinois at Urbana-Champaign that will be published in the *Journal of Geophysical Research*.

Seismic Hazard and Mitigation Policy

UK Department of Earth and Environmental Sciences graduate student **Alice Orton** conducted a series of informal interviews with local businesspeople, public officials, and other professionals in occupations associated with seismic-hazard mitigation, with the goal of improving our understanding of the impacts of seismic-hazard assessments and resulting mitigation policies in Kentucky. The results were published as KGS Report of Investigations 32, "Earthquake Hazard Mitigation in the New Madrid Seismic Zone: Science and Public Policy," co-authored by Orton, **Zhenming Wang, Lanmin Wang,** and **Edward Woolery**. The report showed that ground-motion hazard assessments and resulting mitigation policies have a broad impact in Kentucky, western Kentucky in particular. The report also identified areas for further research about hazard assessments and resulting mitigation policies.

In order to improve understanding and communication about ground-motion hazards in the central United States, KGS and the U.S. Geological Survey held a meeting Jan. 27, 2017, in Lexington, attended by KGS and USGS staff, and representatives from Kentucky structural engineers and the state's Solid Waste Division. The participants concluded that the New Madrid Seismic Zone poses a significant hazard to western Kentucky. New scenario-based seismic-hazard analysis can help convey this message to the public.



Ed Woolery and **Seth Carpenter** collect shear-wave refraction data at an EarthScope station in southern Illinois.

The Geologic Hazards Section is working with the U.S. Geological Survey to develop ground-motion hazard maps based on scenario seismic-hazard analysis for the New Madrid Seismic Zone as well as other source areas in and around Kentucky. This type of hazard analysis has also been used to estimate ground-motion

hazards from potential induced earthquakes in eastern Kentucky. **Zhenming Wang, Seth Carpenter, Lifan Zhang,** and **Edward Woolery** co-authored a paper, "Assessing Potential Ground-Motion Hazards from Induced Earthquakes," which was accepted for publication in the journal *Natural Hazards Review*.

Landslide Hazards

Matt Crawford added several new entries to the landslide inventory database, bringing the total number to 2,559 by the end of the fiscal year. These entries come from state agencies, field investigations, published maps, LiDAR mapping, and reports from the public. Landslides are subdivided as translational slides, slumps, debris flows, earth flows, and rockfalls. All landslide data can be viewed and queried in the KGS online Geologic Map Information Service. The landslide inventory and maps are a foundation for improving our understanding of landslide occurrence and provide information for mitigation efforts by land-use planners, transportation officials, emergency managers, and property owners.

Crawford monitors three shallow colluvial landslides in Kenton, Lewis, and Pulaski Counties. Slope hydrogeology, precipitation, soil properties, landslide movement, and surface electrical-resistivity data were collected and analyzed. Electrical-resistivity measurements have been used to study lithologic differences, failure-zone depth, shape of the landslide body, and groundwater conditions. A framework will be developed based on field and laboratory techniques to correlate in situ hydrologic data and surface electrical-resistivity data to predict shear strength.

Much of the monitoring is in collaboration with **Lindsey S. Bryson** of the University of Kentucky Department of Civil Engineering to establish relationships between parameters that control slope stability. This collaboration is a good example of two UK departments working together, and emphasizes

the importance of applied engineering geology. Crawford and Bryson presented the results of their research at the International Conference on Natural Hazards and Infrastructure in Chania, Greece, on June 30, 2016, and at the 2017 North American Symposium on Landslides in Roanoke, Va., on June 7, 2017. A report by Crawford and Bryson was also published as KGS Report of Investigations 1 (series 13), "Field Investigation of an Active Landslide in Kentucky: A Framework to Correlate Electrical Data and Shear Strength" ([kgsweb/olops/pub/kgs/RI1_13.pdf](https://kgsweb.uky.edu/olops/pub/kgs/RI1_13.pdf)).

Crawford organized a collaboration between the University of Kentucky Department of Earth and Environmental Sciences and the U.S. Geological Survey to measure electrical resistivity at a large rockslide near Pittsburgh, Pa. **Clara Rucker** (Department of Earth and Environmental Sciences), **Francis Ashland** (USGS), and **Alex Fiore** (USGS) also participated in the project.

Matt Crawford hosted a field trip and discussion on landslide research in Pulaski County.



This research tested using electrical-resistivity methods to investigate aspects of subsurface geology, including depth to failure surface, displaced landslide material, and subsurface openings and fissures. The research found that integrating multiple array configurations and electrode spacings in conjunction with high-resolution mapping of surficial features is an effective way to characterize slope failure. This approach provides a comprehensive view of the slope and further supports interpretations of the modeled data, so that effective geotechnical investigations can be conducted.

To support landslide research and encourage future collaboration, **Matt Crawford**, **Bill Haneberg**, and **Mike Lynch** hosted a meeting in Burnside, Ky. Other attendees included a U.S. Geological Survey research

partner, researchers from universities, and landslide consultants from the Appalachian region. Participants observed current KGS landslide monitoring, discussed potential collaboration, and examined the status of landslide hazards research and funding at the state and federal levels.

Hannah Chapella, a graduate student at Kent State University, was hired as a summer intern to take on a project using LiDAR to map landslides in the Prestonsburg 7.5-minute quadrangle. Chapella developed a mapping protocol to create a landslide inventory, which will be used to model the study area's landslide susceptibility. The goal is to use the methodology at a county and statewide scale.

China Scholarly Exchange and Cooperative Research

This was the 13th year for an exchange program between KGS and the Lanzhou Institute of Seismology and other organizations in the China Earthquake Administration. **Bill Haneberg** and **Zhenming Wang** were invited to visit the Lanzhou Institute and conduct research and field investigations on earthquake-induced landslides in loess areas in Gansu Province from Oct. 25–Nov. 4, 2016. Haneberg and Wang also visited and gave lectures at the China Strong Motion Networks Center of the Institute of Engineering Mechanics in Beijing. During the trip, new memoranda of understanding between KGS, the Lanzhou Institute, and the Institute of Engineering Mechanics were signed to continue the exchange of researchers, joint research on slope stability in locations where earthquakes can cause landslides, develop hazard maps for regions in China, and develop research papers for publication.



KGS Director **Bill Haneberg** delivers a lecture on spatially distributed probabilistic slope stability assessment at the China Strong Motion Networks Center of the Institute of Engineering Mechanics in Beijing.

Two visiting scholars, one from the Lanzhou Institute and one from the Institute of Crustal Dynamics, came to UK to participate in research projects and exchanges. **Lifang Zhang** of the Institute of Crustal Dynamics was supported by the China Scholarship Council to conduct scenario ground-motion simulation using the finite-fault model and performed scenario seismic-hazard analysis. Zhang co-authored two papers, "Assessing Potential Ground-Motion Hazards From Induced Earthquakes" (accepted for publication in the journal *Natural Hazards Review*) and "Scenario-Based Seismic Hazard Analysis for the Xianshuihe Fault Zone, Southwest China" (submitted for publication in the *Journal of Pure and Applied Geophysics*). **Junjie Sun** of the Lanzhou Institute of Seismology conducted research on earthquake-induced landslides, liquefaction, and subsidence in loess. Sun also made a presentation, "Earthquake Hazards in Loess Plateau, China," at the KGS seminar series on May 5, 2017.



GEOLOGIC INFORMATION MANAGEMENT

The Geologic Information Management Section focuses on preserving and making research data, maps and publications, database updates, and other information available to both researchers and the general public.

With additional improvements, the KGS website (www.uky.edu/KGS) has a new look that improves performance on mobile devices. The responsive design was based on user behavior and environments, such as screen size, browser platform, and orientation. The new "mega menu" offers versatile format options and fewer clicks for navigation. By integrating social media platforms such as Facebook, YouTube, Twitter, and Instagram with our website, we can more easily share content in a timely manner and interact with audiences. More than 20,000 files are accessible from our website's homepage, and **Rebecca Wang**, the lead developer of the website, is working with KGS sections to further update the content and design of the webpages.

The KGS homepage continues to play an important role in delivering information, and in fiscal year 2016-17 attracted more than 1 million page views. More than 255,000 users from 215 countries accessed information from the website about KGS, Kentucky's resources, and geoscience education. Approximately 70 percent of the users were from the United States; others were from India, the United Kingdom, the Philippines, Canada, and Australia. About a quarter of domestic users are in Kentucky; the next most common groups of users were from Texas, California, Ohio, Georgia, and Illinois.

The new KGS homepage improves the responsiveness of the page on mobile devices and a variety of screen sizes and browsing platforms.



KENTUCKY | Academics | Athletics | Research | Site Index | UK HealthCare | Search UK

UK Kentucky Geological Survey
Earth Resources—Our Common Wealth

Search KGS...

About | Kentucky Geology | Energy | Water | Hazards | Data | Publications | Online Maps | Education | Contact

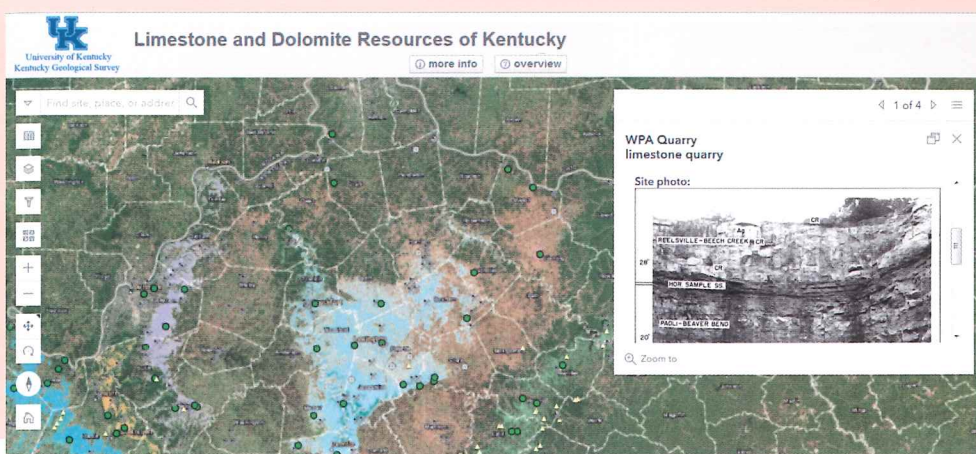
Kentucky has a strong legacy of geologic mapping

Launch Online Map Service

Research
Our research increases knowledge and understanding of Kentucky's geologic resources, hazards, and general geology.

Interesting Kentucky Geological Facts
Did you know that Kentucky's official state mineral is actually a rock that burns, and that our official state rock is agate?

Community Engagement
KGS makes a positive difference for Kentucky through research, service, online data, and outreach efforts.



The Limestone and Dolomite Resources of Kentucky webpage was launched this fiscal year, providing visitors with information gathered during the previous 65 years of research.

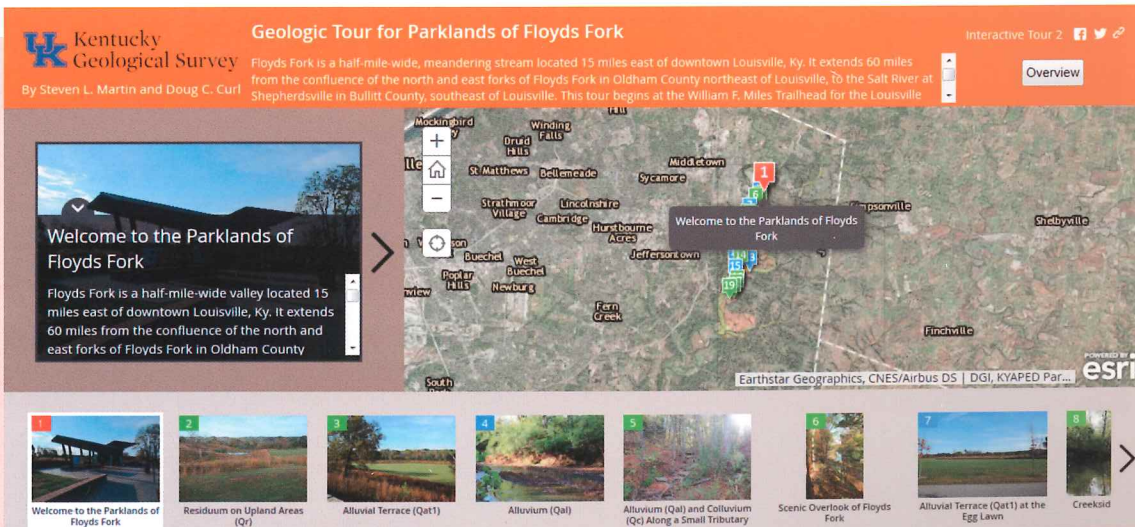
The Survey's online services had more than 1.2 million hits during the fiscal year. The most visited pages on the website, besides the homepage, were on fossil identification, followed by coal information, groundwater FAQs, rock and mineral identification, and mining methods.

searches were conducted by more than 83,000 users, of which almost 35,000 were unique users. There was a 29 percent decrease in database searches from last year, likely the result of a 33 percent decrease in searches for oil and gas data.

Since 2001, KGS has provided free online access to oil and gas records and data, water-well and springs data, coal data, publications, images, and other geologic data, now numbering more than 6.6 million records. More than 517,000 visits originating from 161 countries were made during the past fiscal year to the KGS database, maps, and publications search website (kgs.uky.edu/kgsweb). The great majority of visitors were from the United States (90 percent), followed by India, Canada, the United Kingdom, Venezuela, and Germany. Users from all 50 states and the District of Columbia visited the site; a little more than half were from Kentucky, followed by users from Indiana, Texas, Ohio, Tennessee, and Pennsylvania. Approximately 196,000 database

KGS online map services were accessed more than 66,000 times, about a 14 percent decrease from the previous fiscal year. Much of that reduction and the resulting 21 percent decrease in accessing oil and gas map data are likely related to the slump in oil and gas drilling. There were nearly 11,000 tabular data downloads, which was about a 22 percent decrease from the 2015-16 fiscal year, consistent with the decrease in oil and gas database searches. The total number of files downloaded from the website, including KGS publications and presentations, was nearly 944,000, which was an increase of nearly 13 percent from the previous year. Oil and gas records, online publications, coordinate conversion services, and data from the online geologic map server continue to be the most frequently downloaded data.

“Geologic Tour for Parklands of Floyds Fork” has sparked interest among other KHGS staff in presenting their research as part of the Survey’s new Interactive Tour series.



Several new web services were added to the site.

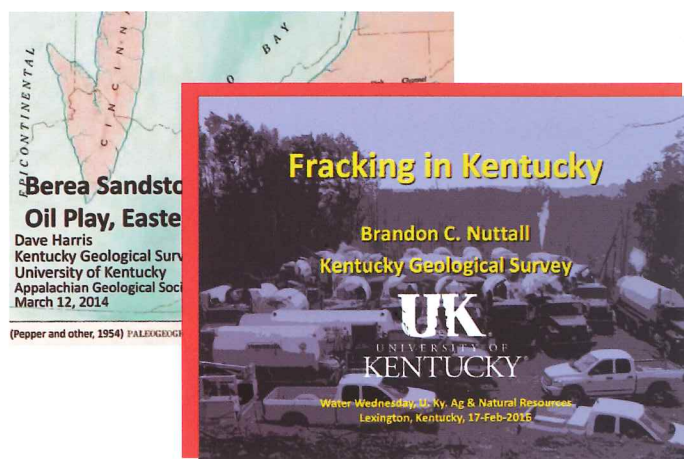
- As part of a new initiative to develop Story Maps, a technique developed by Esri that enables users to explore a particular topic or tour an area through an interactive map or series of maps, KGS instituted a new series, Interactive Tours. Two new Interactive Tours were published online (kgs.uky.edu/storymap). **Rebecca Wang** and **Doug Curl** helped KGS authors develop and launch them. (See page 38 for more information.)
- **Doug Curl** and **Jerry Weisenfluh** developed and launched the Limestone and Dolomite Resources of Kentucky website (kgs.uky.edu/kylimestone), a compilation of information about the occurrence and character of quarried carbonate stone and character of quarried carbonate stone resources in the state. It is the culmination of more than 65 years of field examination, sampling, and analysis by KGS geologists of rock units available for economic development. The sites shown on the interactive map represent quarries, mines, outcrops, and cores that expose carbonate units. Many of the sites were visited by geologists to characterize the stratigraphy of the rock and to take samples for analysis. Other sites show evidence of historical mining, but were not sampled or described. Part of the work to preserve and digitize the limestone and dolomite resource data, including scanning field notebooks and compiling a chemistry database, was supported by the USGS National Geological and Geophysical Data Preservation Program.

Other Activities

- The section received grant funding from the USGS National Geological and Geophysical Data Preservation Program to continue support for two University of Southern Indiana students, **Holly Keimig** and **Jessica Mayes**, to scan legacy oil- and gas-well documents from the KGS Western Kentucky Office for the 2016-17 USGS National Data Preservation project. Students in the Lexington office, **Meghan Hackett** and **John Piening** from the UK Department of Earth and Environmental Sciences, were also partially supported with this funding to add new data to our oil and gas databases, and scan and organize oil- and gas-well documents for archiving and web dissemination.
- **Elizabeth Adams** and **Doug Curl** applied for and received grant funding for the 2017-18 USGS National Data Preservation project to continue the western Kentucky oil and gas scanning project, and to develop a new database for storing legacy and newly derived oil and gas geochemistry data.
- With a grant from the Watershed Watch Kentucky organization, **Doug Curl** worked with the Kentucky Division of Water and the Kentucky River Watershed Watch to develop a pilot lake-sampling program in which volunteers use mobile devices with the Esri Survey123 app to collect and submit water-quality information.
- **Carrie Pulliam** supervised a student, **Holly Young**, from the UK Department of Earth and Environmental Sciences, who acquired and entered data from well records into the KGS oil and gas database and also entered data from projects of the Energy and Minerals and Geologic Mapping Sections.

Most Downloaded Presentations from the KGS Website

1. Fracking in Kentucky—**Brandon Nuttall**
2. Berea Sandstone Horizontal Oil Play, Eastern Kentucky—**Dave Harris**
3. A Review of Oil and Gas Resource Trends in Kentucky—**Brandon Nuttall**
4. Kentucky Seismic and Strong-Motion Network—**Seth Carpenter**
5. Kentucky Coal and Coal Combustion Byproducts as Potential Sources of Rare Earth Elements—**Cortland Eble**



Most Downloaded Publications from the KGS Website

1. Report of Investigations 32 (series 12), "Earthquake Hazard Mitigation in the New Madrid Seismic Zone: Science and Public Policy," **Alice Orton, Zhenming Wang, Lanming Wang, Ed Woolery**
2. Map and Chart 203 (series 12), "Limestone and Dolomite Resources of Kentucky," **Garland Dever, Jerry Weisenfluh**
3. Special Publication 3 (series 12), "Geologic Maps and Geologic Issues in Kentucky: A Citizen's Guide," **Carol Ruthven, John Kiefer, Steve Greb, William Andrews**
4. Map and Chart 190 (series 12), "Upper Cumberland River Basin in Kentucky," **Dan Carey**
5. Report of Investigations 36 (series 12), "Heavy-Oil and Bitumen Resources of the Western Kentucky Tar Sands," **Rick Bowersox**
6. Map and Chart 186 (series 12), "Geology of Mammoth Cave National Park," **Matt Crawford, Richard Olson, Richard Toomey, Lillian Scoggins**

Limestone and Dolomite Resources of Kentucky

Garland R. Dever Jr. and Gerald A. Weisenfluh

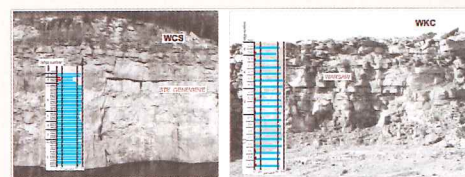


Figure 4. CaCO₃ (blue) and CaMg(CO₃)₂ (red) contents in feet by foot samples (based from stratigraphic units of limestone sources). Chemical analyses, lithology descriptions, and depth (depth) in feet are available for data files reported on the map or sample files.



Staff Awards and Recognitions

Doug Curl was vice chairman of the Kentucky River Watershed Watch, a nonprofit organization that supports citizen monitoring to protect the watershed and increase public awareness about it.



WELL SAMPLE AND CORE LIBRARY

The collections at the KGS Well Sample and Core Library were enhanced by the donation of 55,000 feet of core late in 2016. The cores had been drilled at 50 locations in southern Crittenden and western Caldwell Counties on property owned by **Bill Frazier**. An exploration company was searching for deposits of fluorite (also called fluorspar), galena (a lead ore), and sphalerite (a zinc ore). Frazier also donated the core descriptions, maps, and logs, which were added to the KGS minerals database.

KGS research staff use the 48,000-square-foot core library for their research, and the collection also serves as a resource for geology professors and students, 151 of whom visited during the year. Forty-three industry professionals with exploration companies examined cores and cuttings at the facility during the year. Core library staff also provided 235 requested samples for geochemical analysis for hydrocarbon research.

This year, the staff began developing a system to photograph geologically significant cores stored at the facility. A conveyor system and lights have been bought for the project. The core photos will eventually be added to the KGS database.

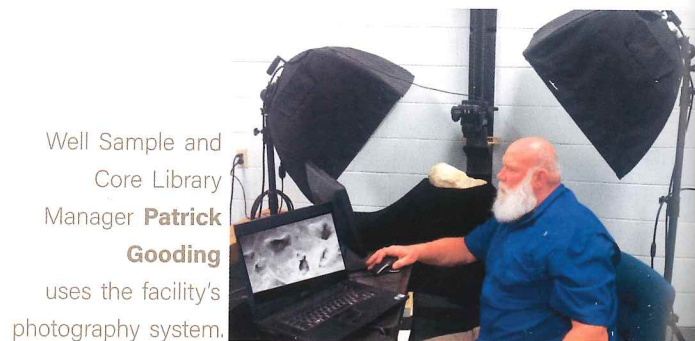
Well and borehole information, as well as data on samples and the call numbers for the samples, are available through a searchable online database. Information, including forms for donating cores and requesting samples for testing, are available on the core library's webpage, www.uky.edu/KGS/core_library.



Ray Daniel and **Ryan Pinkston** examine cores and record information.



Cores donated by **Bill Frazier** arrive at the core library.



Well Sample and Core Library Manager **Patrick Gooding** uses the facility's photography system.

Staff Awards and Recognitions

Patrick Gooding was vice president of the Eastern Section of the American Association of Petroleum Geologists. He also served as a member of the AAPG House of Delegates and the national organization's Honors and Awards Committee and as co-chair of its Preservation of Geoscience Data Committee. He was also the secretary/treasurer of the Geological Society of Kentucky.

Ray Daniel served as a councilor at large for the Geological Society of Kentucky.



WESTERN KENTUCKY OFFICE

During the 2016-17 fiscal year, the Western Kentucky Office at Henderson was managed by **Dave Williams**, who completed his 43rd year working for KGS. Williams supervised two employees, **Holly Keimig** and **Jessica Mayes**, who are scanning petroleum records as part of a geologic data preservation project funded by the U.S. Geological Survey. Scanned petroleum records will be added to the KGS oil and gas records database. This project is expected to continue through 2018.

Williams also answered numerous public-service requests related to geology and assisted with the development of a new coal mine in McLean County by providing detailed core descriptions to engineers developing the mine. He is in the final editing phase of a publication on tar sands, and continues to map paleochannels affecting the more mineable coals in the Western Kentucky Coal Field.

Amy Bleichroth-King completed water-well inspection forms for the Water Resources Section.

Groundwater and surface-water resources are important research areas in western Kentucky. **Glynn Beck**, with the Water Resources Section, is mapping the hydrostratigraphy of the Jackson Purchase Region



Dave Williams describes a rock core in McLean County.



Bert Combs of the Kentucky Division of Oil and Gas Conservation, **Jessie Boling**, **Holly Keimig**, and **Jessica Mayes** compare notes on the Powell No. 3A well in Webster County.

and working with **Jason Merrick**, a graduate student with the UK Department of Earth and Environmental Sciences, to create a groundwater model for the Bayou de Chien and Obion Creek watersheds in Hickman, Fulton, and Graves Counties. Beck has also worked on a groundwater availability assessment project with the University of Kentucky Education and Research Center at Princeton; **Dave Williams** and **Amy Bleichroth-King** assisted with electrical resistivity and groundwater dye-tracing.

Beck has also collaborated with researchers from the UK College of Agriculture, Food and Environment to monitor edge-of-field nutrient and sediment loss from row-crop fields in western Kentucky; funding is from the Kentucky Soybean Board, and additional funding from the U.S. Department of Agriculture–Natural Resources Conservation Service is expected in the fall of 2017. Instruments should be installed and surface water sampled beginning in fall 2017.

Jesse Boling, a geology major from Western Kentucky University, worked with Beck in May and June of 2017 to conduct quality-assurance checks of groundwater-elevation data collected from six Kentucky Groundwater Observation Network wells in western Kentucky.

Staff Awards and Recognitions

Dave Williams is a member of the Interagency Advisory Committee for the I-69 Ohio River Crossing and the Henderson City-County Planning Commission.

KENTUCKY GEOLOGICAL SURVEY STAFF

STATE GEOLOGIST'S OFFICE

Haneberg, William: State Geologist and Director
Weisenfluh, Jerry: Associate Director
Cobb, Jim: State Geologist Emeritus

ADMINISTRATIVE

Ellis, Kati: Administrative Staff Officer II
Long, Mandy: Administrative Support Associate I
Phillips, Gwen: Staff Support Associate II

COMMUNICATIONS AND OUTREACH

Weisenfluh, Jerry: Section Head
Banks, Roger: Stores Supervisor
Hounshell, Terry: Chief Cartographic Illustrator
Lynch, Mike: Technology Transfer Officer
Smath, Meg: Geologic Publication Manager

ENERGY AND MINERALS

Harris, Dave: Section Head
Anderson, Warren: Geologist V
Bowersox, Rick: Geologist IV
Davis, Ethan: Student Worker
Eble, Cortland: Geologist V
Floyd, Julie: Student Worker
Greb, Steve: Geologist V
Hickman, John: Geologist IV
Nuttall, Brandon: Geologist V
Parris, Marty: Geologist V
Sparks, Tom: Geologist III

KGS LABORATORY

Backus, Jason: Scientist II/Laboratory Manager
Conner, Andrea: Scientist I

GEOLOGIC MAPPING

Andrews, William: Section Head
Bottoms, Antonia: Geologist I
Hammond, Max: Geologist I
Jones, Daren: Student Worker
Martin, Steve: Geologist III
Massey, Matt: Geologist IV
Overfield, Bethany: Geologist III

WELL SAMPLE AND CORE LIBRARY

Gooding, Patrick: Geologist IV/Manager
Daniel, Ray: Principal Research Analyst
Pinkston, Ryan: Research Analyst

WESTERN KENTUCKY OFFICE

Williams, Dave: Section Head
Beck, Glynn: Geologist IV (Water Resources Section)
Bleichroth-King, Amy: Temporary Technician
Keimig, Holly: Temporary Technician
Mayes, Jessica: Temporary Technician

GEOLOGIC HAZARDS

Wang, Zhenming: Section Head
Carpenter, Seth: Geologist IV
Crawford, Matt: Geologist III
Holcomb, Andrew: Student Worker
Rodriguez Asihama, Paul: Student Worker
Sun, Junjie: Temporary Technician
Woolery, Ed: Geophysics Faculty Associate
Zhang, Lifang: Temporary Technician

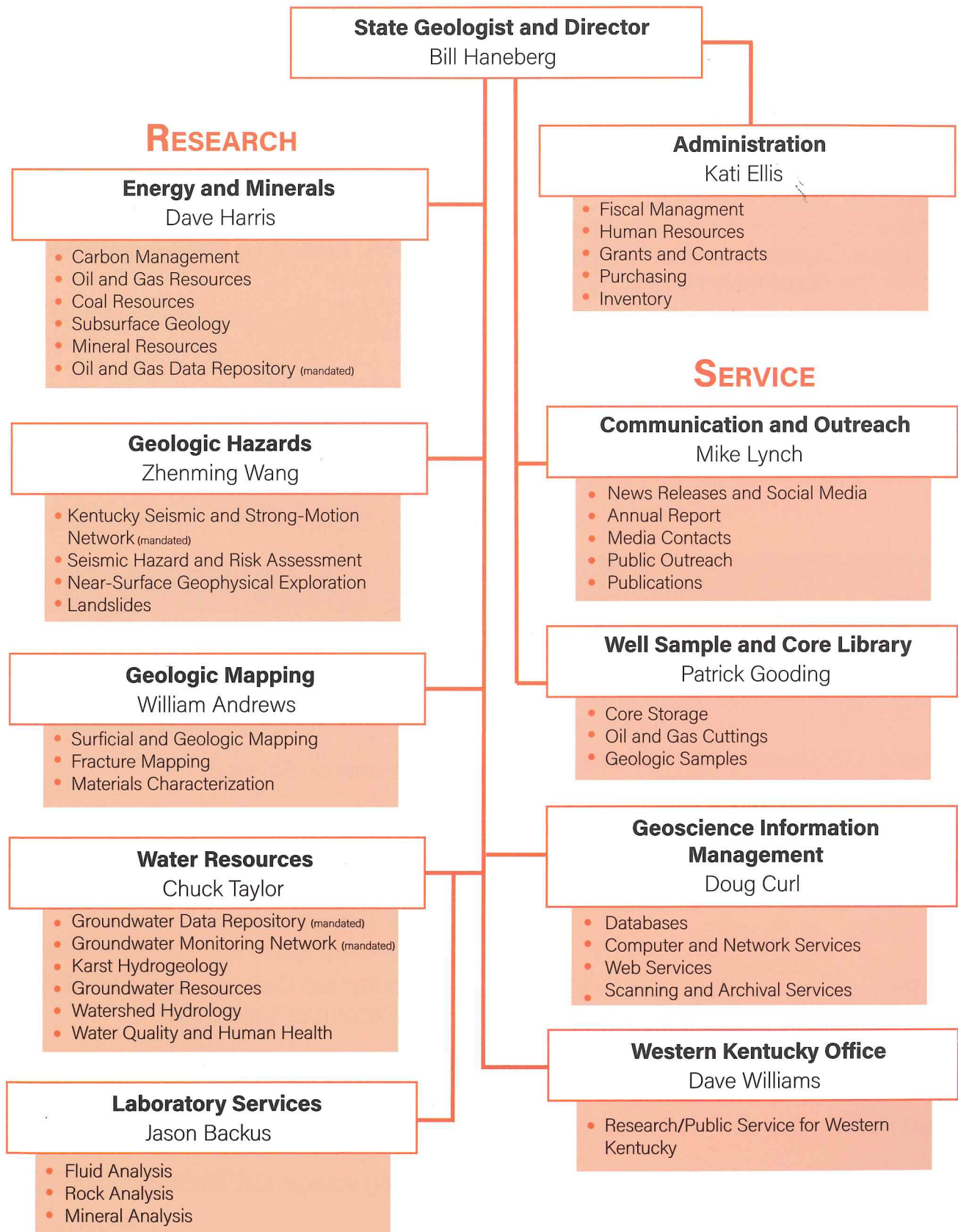
WATER RESOURCES

Taylor, Chuck: Section Head
Beasley, Kalli: Student Worker
Currens, Ben: Student Worker
Currens, Jim: Geologist V
Davidson, Bart: Geologist IV
Nolte, Adam: Student Worker
Webb, Steve: Geologist II
Zhu, Junfeng: Geologist V

GEOSCIENCE INFORMATION MANAGEMENT

Curl, Doug: Section Head
Adams, Elizabeth: Program Coordinator I
Ellis, Mike: Computer Support Specialist II
Hackett, Megan: Student Worker
Piening, John: Student Worker
Pulliam, Carrie: Geologist II
Smath, Richard: Geologist III
Thompson, Mark: Information Technology Manager I
Wang, Rebecca: Database Analyst
Young, Holly: Student Worker

KENTUCKY GEOLOGICAL SURVEY ORGANIZATIONAL CHART



RESEARCH PROJECTS

FISCAL YEAR 2016-17

ENERGY

Carbon Management

- Midwest Regional Carbon Sequestration Partnership (for the Appalachian Basin)

End date: 9/30/2018

FY funding: \$100,001

Funding source: U.S. Department of Energy through Battelle Memorial Institute

Coal Resources

- Identification and Characterization of Coal and Coal Byproducts Containing Rare Earth Elements

End date: 4/30/2018

FY funding: \$22,189

Funding source: U.S. Department of Energy

GEOCHEMISTRY (CONT.)

Geochemistry of Water

- Kentucky Watershed Management Services: WaterWatch

End date: 6/30/2017

FY funding: \$11,491

Funding source: Kentucky River Authority through Kentucky Water Resources Research Institute

- Aquifer Quality Study at the H.L. Disney Training Site

End date: 6/30/2017

FY funding: \$3,105

Funding source: Kentucky Department of Military Affairs through UK Department of Earth and Environmental Sciences

GEOCHEMISTRY

Geochemistry of Rock

- Pilot-Scale Testing of an Integrated Circuit for the Extraction of Rare Earth Minerals Characterization of Slurry Impoundments for Rare Earth Elements Extraction

End date: 8/31/2017

FY funding: \$18,413

Funding source: U.S. Department of Energy

GEOLOGIC INFORMATION

Coal Information

- Computerized Coal Resources for the National Coal Resources Data System

End date: 8/31/2017

FY funding: \$15,000

Funding source: U.S. Geological Survey

GEOLOGIC INFORMATION (CONT.)

- Kentucky Coal Education—Mining Geology

End date: 6/30/2017

FY funding: \$44,828

Funding source: Kentucky Energy and Environment Cabinet

Data Preservation

- National Geologic and Geophysical Data Preservation Program

End date: 6/30/2017

FY funding: \$79,472

Funding source: U.S. Geological Survey

WATER RESOURCES (CONT.)

FY funding: \$27,927

Funding source: U.S. Department of Agriculture–Natural Resources Conservation Service through The Homeplace on Green River

Surface-Water Resources

- Head-of-Rough Spring Discharge and Water-Quality Characterization Study in Hardin County Water District No. 1

End date: 6/30/2018

FY funding: \$44,331

Funding source: Kentucky Energy and Environment Cabinet–Division of Water through Hardin County Water District No. 1

WATER RESOURCES

Groundwater Resources

- Investigation of Groundwater Availability for Irrigation at the UK Research and Education Center at Princeton

End date: 6/30/2018

FY funding: \$11,429

Funding source: UK College of Agriculture, Food and Environment

Surface-Water Monitoring

- Adapting Edge-of-Field Monitoring for Water Quality and Soil Health Assessments in Sinkhole-Dominated Crop Fields

End date: 12/31/2018

GEOLOGY

Geologic Mapping

- Quaternary and Surficial Geologic Mapping for Multiple Applications in Kentucky

End date: 6/30/2017

FY funding: \$158,625

Funding source: U.S. Geological Survey

Geology and Human Health

- Prescription for Radon: County-Scale Maps of Geologic Radon Potential

End date: 6/30/2017

FY funding: \$6,326

Funding source: Kentucky Department for Public Health through UK College of Nursing

In addition to papers in external peer-reviewed journals and conference proceedings, KGS researchers make their work available to a broad audience in academia, government agencies, or the general public in KGS publications. The 10 new publications that KGS made available this fiscal year vary from technical research reports to posters and online interactive tours.

Among the technical publications was "Field Investigation of an Active Landslide in Kentucky: A Framework to Correlate Electrical Data and Shear Strength" (Report of Investigations 1, series 13). It was authored by Geologic Hazards Section landslide researcher **Matt Crawford** and UK College of Engineering Associate Professor **Sebastian Bryson**, and describes a study of a shallow, colluvial landslide at Doe Run Lake Park in Kenton County, northern Kentucky.

Two Interactive Tours, a new series for KGS, published this year allow visitors to our website to take virtual tours. "Geologic Tour for Parklands of Floyds Fork" (Interactive Tour 2, series 13), by **Steve Martin** and **Doug Curl**, describes the bedrock geology and overlying surficial deposits in the Floyds Fork area of eastern Jefferson County. "KGS Meteorite Collection Database" (Interactive Tour 3, series 13), by **Warren Anderson**, **Ethan Davis**, and **Doug Curl**, provides photographs, descriptions, and locations where specimens in the KGS meteorite collection were found.

Three educational posters were completed and made available: "Is There Space Inside Solid Rock?" (Map and Chart 207, series 12), by **Steve Greb**, **Dave Harris**, and **Rick Bowersox**; "Storing CO₂ Deep Underground" (Map and Chart 208, series 12), by **Steve Greb**; and "Injecting Liquids and Gases Deep Underground" (Map and Chart 209, series 12), also by **Steve Greb**

KENTUCKY GEOLOGICAL SURVEY
David A. Williams, Director
and Director
UNIVERSITY OF KENTUCKY, Lexington


Is There Space Inside Solid Rock?

Stephen F. Greb, David C. Harris, and J. Richard Bowersox

Porosity
Although rocks are solid, some contain microscopic holes called pores. Pores are tiny open spaces between the mineral grains and natural cements that make up a rock. As much as 30 percent of a rock's volume can be open pore space (even if it looks solid).

Permeability
If pores spaces in a rock are connected, then the rock is permeable. The degree to which gases and fluids can travel through a rock are a measure of its permeability.

Microscopic Views
This microscopic view of a sandstone shows the light colored mineral grains and the darker colored cementing spaces or pores between them.



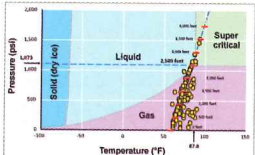
MAP AND CHART 207
Series 12, 2012

KENTUCKY GEOLOGICAL SURVEY
David A. Williams, Director
and Director
UNIVERSITY OF KENTUCKY, Lexington

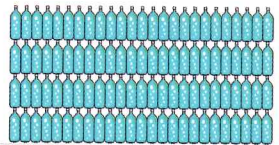
Storing CO₂ Deep Underground

Stephen F. Greb

What Is Supercritical CO₂?
In chemistry, the term "supercritical" does not imply danger. Rather, it defines a phase in which materials have properties of both gases and liquids.



Bubbles in Soft Drinks Are CO₂
If you had 250 bottles of CO₂ at the surface and you injected them more than 2,500 feet below the ground...



This graph shows the phases of carbon dioxide (CO₂) at different pressures and temperatures. The yellow dots represent pressures and temperatures recorded

MAP AND CHART 208
Series 12, 2012

KENTUCKY GEOLOGICAL SURVEY
David A. Williams, Director
and Director
UNIVERSITY OF KENTUCKY, Lexington

Injecting Liquids and Gases Deep Underground

Stephen F. Greb

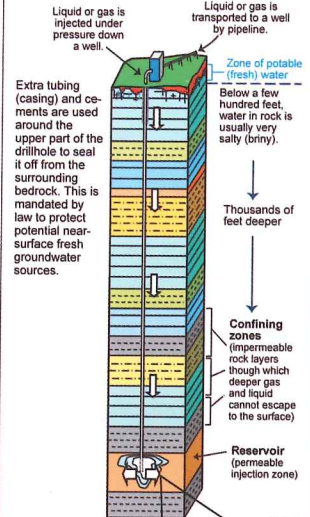
Every year, thousands of wells are drilled into underground reservoirs in search of water, oil, and natural gas. The gases and fluids are trapped inside tiny pores and cracks in underground reservoirs.

Underground Injection
Sometimes natural salt water (brine) is produced with petroleum and natural gas. The fuels are collected and used, but the brine needs to be disposed of. Likewise, some manufacturing processes produce waste fluids and gases that need to be disposed of. One method of disposal that helps ensure that the produced fluids and gases don't contaminate the air or groundwater is to inject the waste fluids and gases into deep, subsurface reservoirs.

Underground injection of fluids or gases is strictly regulated and monitored to ensure safety and protect the environment, especially near-surface, underground drinking-water supplies.

The U.S. Department of the Interior, state governments, and industries are currently testing small-scale carbon dioxide injections deep underground in different parts of the United States.

Injecting manmade carbon dioxide into deep, underground reservoirs with demonstrated seals or confining intervals may be one way to curb greenhouse gas emissions.



Liquid or gas is injected under pressure down a well.

Liquid or gas is transported to a well by pipeline.

Zone of potable (fresh) water

Below a few hundred feet, water in rock is usually very salty (briny).

Thousands of feet deeper

Confining zones (impermeable rock layers through which deeper gas and liquid cannot escape to the surface)

Reservoir (permeable injection zone)

Brine

Injected CO₂ displaces or dissolves in saline water (brine) in pore spaces in the underground rock reservoir.

mineral grains
mineral cement

Microscopic view of permeable rock (field of view: 0.5 to 1.0 millimeter)

For more information, visit the KGS website: www.uky.edu/KGS

MAP AND CHART 209
Series 12, 2012

KGS ANNUAL REPORT

KGS DIRECTOR AND STATE GEOLOGIST

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