Kentucky Geological Survey

2018 - 2019 Annual Report



















Kentucky Geological Survey 2018-2019 Annual Report

On the cover

This digitally enhanced photograph shows part of a slabbed core from the KGS No.1 Hanson Aggregates research well in Carter County. The cored interval, from 4,715–4,725 feet below the surface, contains a major erosional unconformity between red Precambrian Grenville Province granite gneiss (on the right) and overlying Middle Cambrian granite wash and basal sandstone on the left. Working with KGS scientists Rick Bowersox and John Hickman, Professor David Moecher of the UK Department of Earth and Environmental Sciences has isotopically dated metamorphic zircon rims from the Grenville gneiss at 1.018 billion years old, and zircon cores from the igneous parent rock at 1.45 billion years old. These metamorphic rocks formed in a Proterozoic mountain-building event known as the Grenville Orogeny. The overlying Precambrian unconformity, also known as the Great Unconformity, is present across the entire North American continent. At this location in eastern Kentucky, the unconformity represents a gap of at least 500 million years prior to deposition of Cambrian sedimentary rocks. The thin layer of eroded clasts of red gneiss and coarse sandstone that overlies the unconformity surface provides the only evidence for the millions of years of surficial exposure and erosion captured in the core.

Photograph by Natalie Fields.

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.



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In thinking about changes that have occurred at KGS during the past year, and which will continue in coming years, I'm reminded of the material time derivative. It's a variable used in continuum mechanics-especially fluid mechanics-to quantify rates

of change of properties of a small portion of material as it moves through a variable velocity field. The material time derivative is also an apt metaphor for the evolution of an organization such as KGS as it evolves over time. Our acceleration at this moment is a function not just of existing conditions, but also the velocity fields that existed along our way to this point.

During the last fiscal year, four KGS senior geologists-Dave Williams, Bart Davidson, Brandon Nuttall, and Warren Anderson-and communications specialist Mike Lynch took retirement after long careers in service to the commonwealth. Together, their experience amounted to about 175 person-years of knowledge about Kentucky's geology and natural resources. We will miss that. At the same time, KGS continued moving forward and reinventing itself as a modern geological survey for the 21st century. Continuous reinvention is an important endeavor because the Kentucky of 2019 is as different from the Kentucky of 1979 as it will be from the Kentucky of 2059. Our organizational path is being continually defined as we implement our strategic plan and increase the diversity of people, collaborations, and capabilities at KGS in order to best serve a changing commonwealth.

Although we lost valuable experience through retirements in 2018-19, we also added exciting new expertise and capabilities to our permanent staff during the past year or so. Dr. **Jason Dortch**, an ac-

From the Director

complished geomorphologist formerly on the faculty at Manchester University in the United Kingdom, brings insights and experience that will help us better understand the Kentucky landscape and our interaction with it. Dortch oversees the day-to-day operation of the KGS Digital Earth Analysis Library. Dr. Amy Wolfe, who joined KGS on July 1 and will be leading our geohealth initiatives, is an environmental geochemist with experience as an EPA scientist investigating the effects of hydraulic fracturing and coalbed methane production on groundwater quality. Her doctoral research on iron geochemistry and pyrite dissolution is relevant to problems with acid mine drainage. Careful readers of last year's annual report might notice that Dr. Ben Tobin joined KGS during the final days of fiscal year 2017-18. He is a karst hydrogeologist with a doctorate in aquatic biology, and adds important new dimensions to our groundwater expertise in a field that is critical to Kentucky. Tobin worked for the National Park Service as a hydrologist at Grand Canyon National Park before joining us at KGS. Hydrogeologist Sarah Arpin joined KGS in February to manage our state-mandated groundwater data repository, bringing advanced GIS and database skills to the position, some of which she honed as the volunteer database coordinator for the Kentucky Speleological Survey.

We've also been expanding, upgrading, and reorganizing our physical facilities. The Digital Earth Analysis Lab—KGS DEAL—profiled in last year's annual report, is often at capacity as our scientists continually find new ways in which the statewide LiDAR coverage for Kentucky can improve our geologic maps, geologic hazard and risk assessments, and more. Airborne LiDAR has fundamentally changed for the better the approach we take to geologic mapping, especially of surficial deposits. To help satisfy demand for DEAL resources, we've added a new high-capacity server that will allow us to create virtual workstations and run more powerful computer models of geologic processes affecting Kentuckians.

Our well sample and core library on Research Park Drive, an archive of rock cores and drill cuttings that provides invaluable and essentially irreplaceable information about the rocks and natural resources beneath our feet, is now known as the Earth Analysis Research Library or, for those on a first name basis, EARL. We've spent the past year reorganizing and improving just about every aspect of EARL-from workplace safety to sample organization to improved physical spaces such as a conference room for small group training and a better sample examination area—with the objective of making it into a first-class research support facility. The changes have been dramatic. This past spring, I was pleased to present the first-ever KGS Director's Awards to EARL staff Drew Andrews, Liz Adams, Ray Daniel, and Ryan Pinkston in recognition of their yearlong effort to transform EARL from a cluttered and inefficient warehouse full of rocks to a first-class research support facility. At the same time, we've started working on a three-year, nearly half-million-dollar project to adopt modern archival standards and create an online digital core library by reboxing, relabeling, cataloging, and photographing 10,000 boxes of core. When complete, the online digital core library will allow users to view high-resolution photographs of important cores before, or instead of, traveling to Lexington. As with all of our data, this new type of online data will be free to users. The archival work and photography are being supported by a combination of KGS funds and a major grant from the Institute for Museum and Library Services. Additional archival and sample-organization work at EARL is being funded through the National Geological and Geophysical Data Preservation and Earth MRI programs at the U.S. Geological Survey.

One of the consequences of our EARL reorganization is that we're no longer using the building as an ad hoc meeting center (we will still use it for classes and workshops related to core and sample description). We moved the 2019 KGS annual stakeholder seminar—our 58th—from its traditional location in the EARL building to a wonderful and far more comfortable lecture hall in the Don and Cathy Jacobs Science Building just a few steps from our main offices on the University of Kentucky campus. The annual seminar is an important event because, even in this age of social media, it is our best opportunity to engage our stakeholders in person over a cup of coffee or lunch.

Finally, we have been strengthening existing relationships and building new bridges with collaborators at UK and other Kentucky universities in fields as diverse as earth and environmental sciences. civil engineering, agriculture, computer science, economics, nursing and public health, and even rhetoric. Working with experts in allied fields helps bring cutting-edge research capabilities to KGS and increases the value of our work on behalf of Kentucky. This past year we also developed an agreement with the UK Department of Earth and Environmental Sciences to create the KGS-EES Commonwealth Research Assistantship in Earth and Environmental Sciences. The assistantship, which will be awarded annually starting in fall 2019, will provide a full-year graduate stipend, tuition, fees, and research support to an Earth and Environmental Sciences graduate student working on a project of clear and compelling interest to Kentucky, with preference given to applied research. What better way to emphasize the value of practical geoscience for the benefit of Kentucky?

William C. Haneberg Director and State Geologist

Water Resources

KGS works on a diverse range of research and data-collection projects in karst hydrology and sinkhole hazard mapping, agricultural hydrology and water quality, groundwater-resources monitoring, and aquifer designation. Many of these projects are in collaboration with UK faculty and students, stakeholders in state or federal government agencies, and academic researchers at other institutions. This research improves our understanding about the groundwater quality of Kentucky aquifers, the analysis and management of karst spring data, and our understanding of the relationship between karst limestone aquifers and sensitive aquatic ecosystems—all fields of research having many potential benefits to Kentucky.

As our research topics have changed and diversified, so too has the staff. Two new hydrogeologists, **Ben Tobin** and **Sarah Arpin**, joined KGS during the fiscal year, bringing new capabilities, expertise, and perspectives in karst hydrogeology and groundwater and karst data management.

Kentucky Groundwater Data Repository

KGS works with colleagues at the Kentucky Division of Water to periodically update the data in the Kentucky Groundwater Data Repository. One of KGS's two water-related legislative mandates, the repository is a web-accessible digital database containing data for 106,078 sites across Kentucky, comprising 43,361 domestic wells, 1,468 public wells, 882 industrial wells, 4,453 agricultural wells, 36,307 monitoring wells, and 5,419 springs. Most data are derived from water-well construction records required under the Kentucky Water Well Drillers Certification Program and from water-quality analyses conducted by various departments of the Kentucky Energy and Environment Cabinet; data are also contributed from other sources, including KGS, researchers from UK and other universities, and environmental and geotechnical consultants. The Division of Water also



Sarah Arpin measures the water discharged by a spring in western Kentucky. Photo by Chris Groves, Western Kentucky University; used with permission.

routinely forwards scanned documents relating to public and private water wells or karst springs being used for drinking-water supplies, irrigation, or other purposes. Approximately 80,000 scanned records are stored and available from the repository (www.uky. edu/KGS/water/research/gwreposit.htm).

A grant from the U.S. Geological Survey's National Geological and Geophysical Data Preservation Program provides funding to add lithologic data from scanned water-well construction records to the repository. Such lithologic data from more than 33,000 wells was entered into the database prior to 2002, but data entry was discontinued then because of funding cuts. Student interns will be hired during the 2019-20 fiscal year to resume entering these data, under the supervision of the new manager of the repository, **Sarah Arpin**. (See page 9 for more on Arpin and the repository.)



Sarah Arpin takes notes on a karst spring in Bowling Green while property owner John Zippay and Lee Anne Bledsoe of the Crawford Hydrology Laboratory at Western Kentucky University look on. Zippay volunteers as the Watershed Watch coordinator for the Upper Green River Basin.

Groundwater monitoring activities

Hydrogeologists Chuck Taylor, Steve Webb, and Glynn Beck collect water-level data from 12 groundwater observation wells—collectively termed the Kentucky Groundwater Observation Network in parts of western and central Kentucky where groundwater is heavily used for public supplies and irrigation. Water level is measured at 30-minute intervals using vented pressure transducers, and these measurements are shared periodically or on request with interested state and federal environmental and water-resource management agencies and with the U.S. Geological Survey's Kentucky Water Science Center. A webpage is being developed to make these data accessible to the public; it should be online before the fall of 2019. A proposal has been submitted to the USGS Groundwater and Streamflow Information Program to add water-level data from selected network wells to the National Groundwater Monitoring Network, which helps track groundwater availability in the nation's major aquifers.

Steve Webb collaborates with the Hardin County Water District No. 1 to maintain a stage-discharge and water-quality monitoring station at Headof-Rough Spring near Cecilia. A similar monitoring station is planned for Pirtle Spring, also near Cecilia, in the summer of 2019.

KGS partners with the Kentucky Division of Water on a statewide groundwater-quality sampling program conducted at about 60 sites, including both wells and springs, as part of the Kentucky Interagency Groundwater Monitoring Network (www.uky. edu/KGS/water/gnet). Division of Water personnel sample 12 different sites on a quarterly basis, and Steve Webb, Bart Davidson, and Richard Smath sample three karst springs: 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 data are entered into the Kentucky Groundwater Data Repository.

Aquifer designation

A project to identify and characterize the aquifers used by permitted water-supply wells will conclude at the end of 2019. This cooperative project between KGS and the Division of Water is funded by the U.S. Geological Survey's Water-Use Data and Research Program. Included in this project are wells that withdraw some of the largest amounts of groundwater in the state. An online map will provide locations and construction details for permitted water-supply wells in Kentucky and information about their associated aquifers. A webpage will allow, for the first time, a seamless interactive format containing detailed data about aquifer and water-well characteristics in the Ohio River alluvium, one of the most productive and heavily used aquifers in Kentucky; these data were published previously in the U.S. Geological Survey's Hydrologic Atlas map series. Making these data more accessible and easily understood will help state and local water-resource managers better

develop and protect Kentucky's groundwater resources. Chuck Taylor, Bart Davidson, Glynn Beck, Sarah Arpin, and Tom Sparks are working on the project, which is funded through June of 2019.

Inventory of karst features and hydrogeologic investigation at The Homeplace on Green River, Campbellsville

By the end of 2019, an investigation of sinkhole drainage characteristics and the karst hydrogeology at The Homeplace on Green River farm near Campbellsville will be completed. The project was funded by a Natural Resource Conservation Service Conservation Innovation Grant. Ben Tobin, Chuck Taylor, Steve Webb, and Adam Nolte collected spring discharge data and conducted hydrogeologic mapping using dye-tracer tests to delineate groundwater flow paths and basin boundaries for karst springs on The Homeplace property. Leanne Bledsoe and others at the Crawford Hydrology Laboratory of Western Kentucky University analyzed the dye-tracer tests. A detailed statistical analysis of the spring's discharge characteristics, including variability in flow, water temperature, specific conductance, and other parameters, and their relation to precipitation, is being conducted and will be the subject of further investigation. The data collected during this project will help with planning for possible future water-quality

sampling to evaluate the effects of agricultural best management practices at the farm. The results of this project should also help inform agricultural resource managers, scientists, and others how edge-of-field monitoring techniques for assessing water quality and soil health at Kentucky farms must be modified where karst is present or surface runoff from cropped fields is controlled by sinkholes.

Incorporating machine learning in LiDAR-based sinkhole mapping

Junfeng Zhu and Adam Nolte are using high-resolution LiDAR topographic data to improve sinkhole mapping. To learn how to process LiDAR data more efficiently, Zhu collaborated with Nathan Jacobs, an associate professor of computer science at UK. They explored different machine-learning methods and developed a neural network model to automatically identify sinkholes. The model expedited the LiDAR data processing, and they were able to map approximately 15,000 sinkholes in 2018-19 in Anderson, Clark, Franklin, Garrard, Harrison, Mercer, Montgomery, Owen, Scott, Shelby, and Trimble Counties; most of these counties are in the Bluegrass Region. The collaboration with Jacobs also benefited his fall 2018 machine-learning class: Zhu provided LiDAR data from four central Kentucky counties to the class, and the students were challenged to use any machine-learning tools to identify sinkholes.



Steve Webb, Ben Tobin, and Adam Nolte prepare to inject fluorescent dye tracers into a sinkhole at The Homeplace on Green River near Campbellsville.

Water Resources

Understanding spatial variability of methane in groundwater in eastern Kentucky

Steve Webb and Marty Parris are collaborating with Dr. Andrea Erhardt and graduate student Cristopher Alvarez of the UK Department of Earth and Environmental Sciences on an investigation to improve characterization and understanding of the spatial variability of methane in groundwater in eastern Kentucky. The Cambrian Rogersville Shale in eastern Kentucky has the potential to become a major shale gas play, and a better understanding of the occurrence of methane in groundwater is critical to evaluating potential impacts of shale-gas development on the shallow groundwater in the region. Funded by the U.S. Geological Survey through the Kentucky Water Resources Research Institute, this study is part of a continuing effort by KGS to characterize and understand baseline groundwater conditions in an area of increasing unconventional oil and gas development. During April and May 2019, Alvarez and Webb, assisted by Adam Nolte, sampled 18 wells in Floyd, Knott, and Magoffin Counties. The samples were analyzed at the KGS analytical laboratory and Earth and Environmental Sciences' Stable Isotope Geochemistry Laboratory for major and minor ions, dissolved gases, and isotopic composition. The team plans to sample eight more wells during the summer of 2019.



Graduate student Cristopher Alvarez of the UK Department of Earth and Environmental Sciences collects water samples in eastern Kentucky.

Groundwater modeling for the Paducah Gaseous Diffusion Plant

Hydrogeologist **Junfeng Zhu** is providing scientific technical assistance on a project funded by the U.S. Department of Energy through the Kentucky Research Consortium for Energy and Environment to assess groundwater remediation plans at the Paducah Gaseous Diffusion Plant. Zhu is providing an independent review of computer-simulated groundwater models created by private contractors to assist in removal and treatment of groundwater contaminated by radionuclides and chlorinated solvents. The most recent version of the model incorporates new field data, but only simulates groundwater flow. Zhu will evaluate the model's capability of replicating the migration history of groundwater contaminant plumes at the site.

Edge-of-field monitoring in the lower Green River watershed

Glynn Beck is collaborating with other UK researchers on edge-of-field monitoring of nutrient and sediment loss from active row-crop fields in the lower Green River watershed. The multiyear collaboration is with Brad Lee and Dwayne Edwards of the UK College of Agriculture, Food and Environment. Phase 1 began in early 2018 and should run through 2028; during this phase, six suitable watersheds, ranging in size from 3.5 to 11.5 acres, were identified, and a flume, automated sampler, and ultrasonic flow meter were installed in each watershed outlet. Phase 1 nutrient and sediment sampling began in July 2018. Phase 2 began in 2019 when a flume, automated sampler, and ultrasonic flow meter were installed in four watersheds ranging in size from 3 to 7 acres. Nutrient and sediment sampling for Phase 2 is scheduled to begin in July 2019 and should run through 2029. The project will determine the nutrient and sediment loss from active row-crop fields under different nitrogen-application methods and cover crops. Results of this project will have local and national implications. Locally, results should help agricultural producers better manage their nutrient applications and soil loss, which are both directly related to a farm's economy and sustainability. Nationally, nutrient loss from



Glynn Beck switches out sample bottles at an edge-of-field station in the lower Green River watershed.

row-crop fields is directly linked to hypoxia in the Gulf of Mexico. Mark Akland of the UK Department of Plant and Soil Sciences, who is stationed in the KGS Western Kentucky Office, is conducting field work for the project. The project is funded in part by the Kentucky Soybean Board through an Environmental Quality Incentives Program contract from the Natural Resource Conservation Service.

Monitoring wetlands in western Kentucky

Glynn Beck is working with Brad Lee and Dwayne Edwards of the UK College of Agriculture, Food and Environment on a multiyear project to monitor nutrient and sediment runoff from retired row-crop fields that have been converted or are being converted to wetlands. This project, which should run through 2023, is funded through the now-repealed Wetland Reserve Program and the new Agricultural Conservation Easement Program administered by the Natural Resource Conservation Service. Six western Kentucky wetland watersheds, ranging in size from 1.5 to 13 acres, were instrumented with a flume, automated sampler, and ultrasonic flow meter in August 2018. Nutrient and sediment sampling began in February 2019. The project will assess the runoff from wetlands that are in various stages of agricultural or land-use management (for example, soybean field converted to trees, tree and dense vegetation, or mature forest). Leighia Eggett, a scientist in the UK Department of Plant and Soil Sciences stationed at the Natural Resource Conservation Service office in Mayfield, will perform the field work for this project.

Grand Canyon spring monitoring and management of cave-resource data

In October 2018, hydrogeologist **Ben Tobin** finalized a Cooperative Ecosystem Studies Unit task agreement with Grand Canyon National Park to develop (1) a scientifically defensible and economically feasible spring-monitoring program for the park and (2) a data management system for cave-resource data. The ultimate goal is for the monitoring and manage-



Vanessa Fichtner, a postdoctoral scholar in the University of Kentucky Department of Earth and Environmental Sciences, and Adam Nolte process water samples collected from a basalt spring near the rim of the Grand Canyon.

ment programs to be easily adapted to similar issues here in Kentucky. The agreement will fund a graduate student to work on the project. Data gaps have already been identified. In collaboration with the Stable Isotope Geochemistry Laboratory in the UK Department of Earth and Environmental Sciences and staff from Northern Arizona University and Grand Canyon National Park, Tobin collected 19 samples from May 7–19, 2019, at remote springs in the western Grand Canyon to begin filling some of the data gaps. These samples were analyzed for major-ion chemistry, isotope chemistry, and environmental DNA. The project is tied to three ongoing master's theses: two at Northern Arizona University and one at the University of Kentucky. Two of the graduate students will present results at the 2019 Geological Society of America annual meeting.

In addition, Tobin has been working with Esri and Grand Canyon National Park to develop a new model for managing cave-resource data. A presentation on their progress on this part of the project was made to the National Speleological Society in June 2019 and another will be made at the Geological Society of America annual meeting in September 2019.

Invertebrates and cave systems

Ben Tobin, working with two undergraduate students who received credit for independent study, began quantifying relationships between karst groundwater resources and cave-adapted ecosystems. One student assessed the relationship between land-use patterns and diversity of cave-adapted invertebrates throughout Kentucky. Although no statistically significant impact was found, the analysis will provide the foundation for future work in the state. The other student assessed spatial patterns in cave-adapted inver-

tebrates from Sequoia and Kings Canyon National Parks to quantify patterns in diversity and potential causal mechanisms for those patterns. The work has promise to provide a broader understanding of the interconnections between karst groundwater basins. The mobility of species in the subsurface allows us to begin quantifying connections between groundwater basins that are not as easy to track using traditional methods such as dye tracing. We hope this correlation of ecosystem structure and species mobility will improve our understanding of the potential for groundwater contamination under varying precipitation regimes and patterns. A proposal to continue this work has been submitted to the U.S. Fish and Wildlife Service via the U.S. Geological Survey and the University of Alabama-Huntsville. Presentations on the project will be made to meetings of the Ecological Society of America in August 2019 and the Geological Society of America in September 2019.

KGS analytical chemistry laboratory

The KGS analytical chemistry laboratory supports water, rock, and coal research by KGS and University of Kentucky researchers by providing geochemical analysis in both the laboratory and the field.

Lab personnel assisted 31 users of the University of Kentucky's shared-use X-ray diffractometer, and trained a postdoctoral scholar and several students and provided instrument time on our carbon analyzer and inorganic coulometer. Two graduate students in the UK Department of Earth and Environmental Sciences used our wavelength X-ray fluorimeter this year for their research projects.

The lab added a portable gas chromatograph this year, and two methods for its use have been developed: a low-level soil-gas method that allows us to measure low-molecular-weight hydrocarbons (measured in parts per million) and a higher-concentration gas method that will be used to determine natural-gas levels for the Abandoned Well Impacts and Analysis project (more information on this project can be found on page 14). A student in the Department of Earth and Environmental Sciences used both methods this spring to quantify methane, ethane, and propane concentrations for his thesis project.

The lab provides analysis for several KGS water-monitoring projects, three projects by UK Civil Engineering researchers that focus on water chemistry from Cane Run, and water monitoring and testing for Kentucky River Watershed Watch. We also analyze coal and coal-ash samples for rare earth elements; we analyzed more than 1,500 digested and leached samples for that project in the last 12 months.

Lab personnel measured radon levels at many sites in eastern Kentucky (more information about the radon project is on page 23).

Ten unique groups and individuals toured the labs this year, and we mentored a student from Lexington Catholic High School, which allowed her to gain lab experience for her senior project.

Change in Kentucky Groundwater Data Repository's management

In December 2018, **Bart Davidson** retired from KGS after 32 years; much of that time was spent in the Water Resources Section. As the longtime manager of the Kentucky Groundwater Data Repository, Davidson worked diligently with colleagues at KGS, the Kentucky Division of Water, and other state agencies to improve access to groundwater data by helping to make thousands of records on water wells and springs available online. He also helped users with searches for groundwater data, and developed material to educate the public about the state's groundwater resources. (More information about Davidson can be found on page 42.)

Following Davidson's retirement, Sarah Arpin, an alumna of Western Kentucky University with a master's degree in hydrogeology, joined the Water Resources Section in February 2019 as the new manager of the repository. Arpin's experience includes working for the National Park Service at Mammoth Cave in Kentucky, Mesa Verde in Colorado, and Carlsbad Caverns in New Mexico, and being an active member of the Kentucky Speleological Survey, in which she serves as a board member and the chair of its Data Access Committee.

Since joining the KGS team, Arpin has worked hard to familiarize herself with the repository's database and begin developing new ideas on how to enhance the current data search and user interface. She



Sarah Arpin

is developing plans to enhance the searchability and accessibility of the database and the Water section of the KGS website in general. Ongoing quality assurance and quality control have corrected a number of small errors in the database, such as miskeyed values.

To make the downloaded data ready for use, units of water-quality results were standardized, and a note was added to the comments field to document the conversion. Though all data are publicly available, Arpin often works with users to fill specific needs and large requests. She also works with landowners to inventory springs and collect water-quality data for entry in the repository. We encourage feedback from repository users and suggestions on how to improve the database. To report a new spring or provide feedback, please contact Arpin at sarah.arpin@uky. edu.

Appointments

Chuck Taylor is an appointed member of the Kentucky Agriculture Water Quality Authority.

Taylor and **Glynn Beck** are members of the Kentucky Agricultural Science and Monitoring Committee.

Junfeng Zhu is an associate editor of *Groundwater*, the journal of the National Ground Water Association.

Ben Tobin is treasurer of the Karst Division of the Geological Society of America and is a member at large of the Kentucky Speleological Survey board.

Sarah Arpin is also a member at large of the Kentucky Speleological Survey board and is chair of the Speleological Survey's Data Access Committee.

Energy and Minerals

Fossil fuels research

Conasauga Shale Research Consortium

The Cambrian Conasauga Group has emerged as an unconventional hydrocarbon play in recent years; its Rogersville Shale is the most organic-rich research target. The newly formed Conasauga Shale Research Consortium, in which KGS is collaborating with five energy companies and geologists and petroleum engineers from West Virginia University and the West Virginia Geological and Economic Survey, secured funding this year from the U.S. Department of Energy to gather data and test well-completion designs in

order to accelerate the development of the Rogersville and other Conasauga shales. John Hickman will serve as principal investigator and Dave Harris as co-principal investigator.

The consortium will compile all available preexisting data on the Conasauga and combine them with new data collected from a horizontal well to be drilled into the Rogersville in Lawrence County. Numerous analyses will evaluate:

- thermal maturity
- organic content
- lithologic content
- provenance of clays
- major- and trace-element content
- pore types

- traditional and noble-gas geochemistry of produced oil or gas
- isotopic chemistry of natural gases.

Programmed pyrolysis will be done on sourcerock samples, and lithologic and geomechanical analysis will help develop effective completion strategies. Subsurface production will be monitored for a year through fiber-optic sensors, using temperature and acoustic methods. The subsurface of the Conasauga Group will be mapped in detail, using well data, reflection-seismic profiles, and remote-sensing (potential fields) data.

These data will be combined with extensive proprietary datasets acquired by West Virginia University for three similar shale plays. Data analytics and machine-learning techniques will be used to design innovative completion designs and a best-practices protocol that will result in maximum efficiency and recovery from future Rogersville wells.

The data and results will be released to the public in a final report at the end of the five-year project.



Berea petroleum system publications

The Berea Consortium, an industry-funded consortium led by KGS, investigated the petroleum geology of the Berea Sandstone shallow unconventional play and its likely source rocks: the Upper Devonian Ohio Shale and possibly the Lower Mississippian Sunbury Shale. Initial findings were presented in 2017, and five technical papers derived from the final report of the project and one overview paper were completed during the fiscal year and will be published in a special issue on the Berea Sandstone petroleum system by the *AAPG Bulletin*. KGS authors are **Cortland Eble**, **Steve Greb**, **Dave Harris**, **Brandon Nuttall**, **Rick Bowersox**, and **Marty Parris**, and Parris will be editorial manager for the special issue.

Enhanced oil recovery in the Berea Sandstone using ethane-rich gas

Marty Parris, along with partners from Advanced Resources International, Fireborn Energy, and Nytis Exploration, submitted a concept paper, "Using Ethane-Rich Gas for EOR in the Berea Sandstone (Lawrence County, Ky.) and Applications to Other Shallow Oil Reservoirs," to the U.S. Department of Energy as the first step of a research proposal on novel techniques in enhanced oil recovery. The concept paper was approved for full submission but ultimately withheld because of the prohibitive cost of ethane and lack of sufficient industry support.

Geology of the Eastern and Western Kentucky Coal Fields

Steve Greb and Cortland Eble are researching coal-bearing Pennsylvanian 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 geological community remains interested in data about past and present mining, coal-field geology, and Kentucky's outstanding surface exposures of Pennsylvanian strata. Researchers from around the world routinely come to Kentucky to study our extraordinary roadcuts and highwalls, and to collect data for their research.

Depositional facies between coals are of particular interest as analogs for hydrocarbon reservoirs in other basins. They provide three-dimensional exposures of a variety of coastal-deltaic reservoirs for comparison with downhole data from other areas. This year, Greb and Eble measured several outcrops from new roadcuts, sampled coal and carbonaceous shales for analysis, and updated the Kentucky Coal Information page on the KGS website. Their work on roadcuts in western Kentucky and southern Indiana culminated in a field trip for the Energy Geology Division of the Geological Society of America in November 2018. The trip will be run again for the fall 2019 Society for Organic Petrology meeting in Indiana.

Visiting scholar in organic petrology

Since November 2018, visiting geoscientist Xin Guo has been studying at the Kentucky Geological Survey under the supervision of Cortland Eble. Guo is a Ph.D. candidate at the China University of Mining and Technology in Beijing; in China, she analyzes feed coal and refuse material from coal gasification plants. At KGS, Guo has been able to gain experience in performing proximate analysis, total carbon/sulfur analysis, and X-ray fluorescence, and determining rare earth elements. Guo has also performed density separation analysis of her samples at different specific gravities. Although this is very labor-intensive work,



Xin Guo

she has completed the density fractionations on all of her samples and is in the process of completing reflected-light microscopic analysis.

While at KGS, Guo has collected reference material for her research using the University of Kentucky libraries system, resulting in two manuscripts, and is working on other manuscripts. She will be presenting her research at the Society for Organic Petrology meeting being held in Bloomington, Ind., in September 2019.

Energy and the environment

Energy Independence and Incentives Act

KGS was funded by the state of Kentucky and a consortium of industry partners from 2007 to 2016 to investigate carbon dioxide storage and enhanced oil and gas possibilities in the state. As a result, two deep test wells—one in eastern Kentucky and one in west-ern Kentucky—were drilled to test the use of CO_2 for enhanced recovery in several oil and gas wells. Information on these projects can be found on the KGS website at www.uky.edu/KGS/kyccs.

Although funding for the project has ended, reports, journal papers, and technical presentations from the research continue. In November 2018, "Overview of the Kentucky Geological Survey No.1 Hanson Aggregates Well, Carter County, Kentucky," by Rick Bowersox, was published as a KGS Information Circular; the publication summarizes the planning, drilling, and testing of the Hanson Aggregates stratigraphic research well. In March 2019, "Porosity and CO₂ Storage Capacity of the Maryville–Basal Sandstone Section (Middle Cambrian), Southern Appalachian Basin, Kentucky," by Bowersox, Steve Greb, and Dave Harris, was published in Environmental Geosciences, an American Association of Petroleum Geologists journal. In addition, Bowersox, Greb, and Harris made presentations at the AAPG Eastern Section meeting in Pittsburgh and at the Geological Society of America 2018 annual meeting in Indianapolis.

Midwest regional carbon storage assessment

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 is one of seven regional groups established in 2003 to assess the technical potential, economic viability, and public acceptance of carbon storage in the United States. This is the final year of the project, and completes Phase 3 of the partnership's research. For this last phase of the project, Brandon Nuttall, Tom Sparks, and Steve Greb completed a report on the potential for carbon storage and enhanced gas recovery in organic-rich Middle Devonian and Upper Ordovician shales in the region, and Greb, Sparks, and geologists from other states completed several cross sections for the partnership region. An Appalachian Basin topical report is being compiled that will contain contributions by several KGS geologists; Battelle will complete the consortium's Phase 3 capstone report and deliver it to the U.S. Department of Energy in the fall of 2019. The reports will be made public after approval from DOE. Reports from Phases 1 and 2 of the project are available at the consortium website, www.mrcsp.org.



Tom Sparks edits a map showing CO₂ storage potential of the Utica and Point Pleasant Shales in the northern Appalachian Basin as part of the Midwest Regional Carbon Sequestration Partnership project to assess the potential of organic-rich shales for carbon storage.

Total organic carbon content, density, and maturity data for the Middle Devonian Marcellus Shale and Upper Ordovician Utica-Point Pleasant interval were compiled and compared with subsurface geophysical log data from across the Appalachian Basin to determine if the units' total organic carbon could be estimated from log responses. This research builds on previous investigations of the Upper Devonian Ohio Shale in which KGS researchers proposed new models for estimating total organic carbon content using wireline-log data for the Ordovician Utica Shale and Point Pleasant Formation. Their models were used to generate a new series of regional maps showing total organic carbon content of the study units. The maps, in turn, were used to estimate the potential for CO₂ storage in these units, since storage in organic-rich shales is partly reliant on their organic content. Although no CO₂ is currently stored in these units, it might be used in the future for enhanced oil and gas recovery.

KGS staff, along with researchers from other states, compiled five regional cross sections to display the subsurface geology, from Precambrian basement to the surface, of the Cincinnati Arch, Michigan Basin, and Appalachian Basin; the cross sections will be useful for determining potential reservoirs and confining intervals that would be required for carbon storage. Each cross section contains general information about structure, oil and gas fields, and carbon-storage research in the area of the section. The cross sections should provide a quick, easy-to-understand visualization of the subsurface for nongeologists, as well as serve as a guide for researching stratigraphic units and structures of potential interest in different parts of the study area.

Results from the project were presented in fall 2018 at the Geological Society of America annual meeting in Indianapolis; at the Midwest Regional Carbon Sequestration Partnership annual meeting in Annapolis, Md., and at the Eastern Section of the American Association of Petroleum Geologists annual meeting in Pittsburgh; and in spring 2019 at the AAPG annual meeting in San Antonio, Texas.

Regional distribution of storage in the Utica Shale–Point Pleasant play was estimated at an ef-

ficiency factor of 10 percent: 6.9 billion short tons within the mapped area. These organic-rich calcareous shales have potential for storing injected CO_2 .

Abandoned well impacts and analysis

In partnership with the U.S. Forest Service, Jason Dortch, Tom Sparks, and Marty Parris have compiled preliminary data on abandoned oil and gas wells in the Daniel Boone National Forest. These wells are possible environmental hazards to natural resources and to users, such as hikers and ATV operators.

The research is being conducted along several complementary tracks. With a conservative estimate of 585 abandoned wells in the forest, accurately locating them in an efficient manner is a challenge. And because many of the wells were drilled in the early 1900s, locating them in a heavily forested and dissected terrain is especially challenging. Part of the challenge is being overcome by using LiDAR imagery and derivative maps that digitally remove the vegetative cover and allow observers to see features on the bare ground.

With a large number of potential wells to plug and a finite budget, a second component of the project will be to perform a risk analysis to help the Forest Service set priorities for plugging the wells. Input factors might include, for example, age and depth of wellbore casing and distance from critical wildlife habitat and hiking and ATV trails.

A final component of the project will be to measure methane fluxes from abandoned wells. Because methane is a potent greenhouse gas, and the impact of abandoned wells on the global methane budget remains largely unknown, KGS will work with scientists from the U.S. Department of Energy's National Energy Technology Laboratory in fall 2019 to make some of the first measurements on abandoned wells in the forest. KGS has submitted a proposal to the Forest Service for conducting this work (total project: \$165,594); if the initial project is successful, it could be extended to other forests.



LiDAR image of abandoned oil and gas wells in the Daniel Boone National Forest in Wolfe County. Green dots represent production wells and blue dots represent injection wells. Wells are typically found on or near roads and may have tank batteries with retention basins associated with them—indicated by the dimpled features. This area is heavily forested.

Oil and gas workgroup proposes new legislation

An oil and gas workgroup mandated by the Kentucky legislature in 2016 continued its work this year, focusing on the large inventory of orphan oil and gas wells in Kentucky. **Brandon Nuttall** represented KGS on this panel composed of industry, regulatory, and environmental stakeholders. This year the workgroup helped write House Bill 199, which addresses the problem of orphan wells, and permiting and bonding of new wells in the commonwealth. HB 199 was passed unanimously by the Kentucky House and Senate in the 2019 regular session, and signed by Gov. Bevin.

The bill expands the scope of the existing abandoned storage tank reclamation program to include setting priorities and remediating unplugged orphan wells. This bill is the first step in dealing with more than 10,000 unplugged orphan wells in the state. Although it does not provide funding to plug wells, it creates the regulatory framework required to address the problem. The bill also strengthens eligibility requirements for receiving a drilling permit and bonding requirements for new wells.

Underground brine-disposal and enhanced-recovery wells

Environmental concerns about wastewater disposal wells have received attention from the media and the public in the past decade or so. In wastewater disposal, brines brought to the surface during oil and gas production are reinjected into the same or other porous underground formations. This helps protect underground drinking-water sources. The U.S. Environmental Protection Agency previously regulated all Class II underground injection wells in Kentucky under its Underground Injection Control Program, but the Commonwealth of Kentucky assumed primacy on Jan. 27, 2017. The Kentucky Department of Natural Resources–Division of Oil and Gas is now responsible for the regulation of Class II injection wells in Kentucky.

After Tom Sparks compiled a database of all Class II wells in Kentucky, a new KGS internet map service was developed to display the data and linked to the petroleum map service on the KGS website. The map service was based on the original 100 brine-disposal wells whose locations are shown on "Class I Waste-Disposal Wells and Class II Brine-Injection Wells in Kentucky," by Sparks, Dave Harris, and Rick Bowersox (KGS Map and Chart 204, series 12, published in 2013), as well as an additional 2,900 enhanced oil-recovery injection wells. Since 2014, the map service has been continually updated as brine-injection disposal wells are permitted or new EPA documents have been obtained. In the past 18 months of monitoring (January 2018–June 2019), seven more enhanced-injection wells and one wastewater (salt water) disposal well have been permitted by the Division of Oil and Gas.

In 2017, the Division of Oil and Gas received more than 100 boxes of legacy data related to the Kentucky underground injection control well inventory (annual reports of injection, mechanical-integrity tests, etc.) from the EPA. Division personnel have nearly finished scanning and tagging those records. The records will be indexed by Kentucky permit and UIC permit numbers and should eventually be matched to the KGS Oil and Gas Records Database. In the future, these data will be made publicly available through the KGS petroleum map service. These new data will help with microseismicity monitoring, as monthly injection volumes and pressures will be available to compare with seismic records.

New analytical methods: portable gas chromatograph

Jason Backus, working with Marty Parris, developed methodologies for measuring methane, ethane, and propane at various concentrations, using the flame ionization detector in our recently acquired portable gas chromatograph. UK Department of Earth and Environmental Sciences graduate student **Cristopher Alvarez** used the calibrations to measure these components in groundwater as part of a study of methane distribution and provenance.

Basin analysis

Regional stress map of Kentucky

John Hickman is collecting data related to regional stresses, including earthquake first-motion data (provided by Seth Carpenter), field measurements of fracture joint sets (provided by Steve Martin), field measurements of coal-cleat orientations (provided by Cortland Eble), and oriented image-log data from oil and gas wells (assisted by Rick Bowersox). Once enough data are available from all parts of the state, a statewide map of regional stress will be produced.

Precambrian geology of southeastern Laurentia

Rick Bowersox and John Hickman are studying the Precambrian geology and tectonic history of Kentucky and surrounding states. Hickman and Seth Carpenter attended a workshop in Evansville, Ind., July 25–28, 2018, that focused on possible interactions between the Grenville Orogeny and the Midcontinent Rift. The workshop was attended by 18 accomplished geoscience researchers from universities across the United States.

As a result of discussions at this meeting, Hickman and Bowersox organized an oral theme session, "Different Roads to Rodinia: Re-analysis of the Geochronology and Tectonic Evolution of Precambrian Sedimentary and Crystalline Basement Terranes in Southeastern Laurentia," at the 2018 Geological Society of America annual meeting in Indianapolis. During the session, Hickman and Bowersox presented their updated interpretations of the location and tectonic origin of the Grenville Front in Ohio, Kentucky, and Tennessee.

Bowersox has also been assisting UK Earth and Environmental Sciences Ph.D. student Mitchell Clay with sampling zircons from cores of Precambrian Middle Run Sandstone at KGS's Earth Analysis Research Library. Clay is using U-Pb geochronology in tandem with (U-Th)/He thermochronology to learn more about the crystallization and cooling temperatures of detrital zircons from Precambrian clastic basins in the Eastern Midcontinent underneath Kentucky and Ohio. Bowersox, who is also an adjunct professor in the Department of Earth and Environmental Sciences, is on Clay's dissertation committee.

Kentucky 3-D geologic database

KGS researchers who deal with subsurface stratigraphy or GIS analysis met on Sept. 26, 2018, to plan for a project to compile a 3-D geologic database for Kentucky and to solicit volunteers to compile datasets for inclusion in the database. They have made progress on a statewide 3-D fault zone GIS dataset and a statewide dip/azimuth map dataset of the geologic structures exposed at the surface.

John Hickman presented a poster on compiling the near-surface structure dataset at the 2018 Eastern Section of the American Association of Petroleum Geologists annual meeting in Pittsburgh.

The Alberta Energy Regulator office of the Alberta Geological Survey in Edmonton, Canada, has built one of the few regional 3-D geologic databases created using public data. Hickman and Drew Andrews held technical discussions with the Alberta Survey, both by email and conference call, during 2018-19. Dr. Kelsey MacCormack, the director of the Geology and Resources Modelling group at the Alberta Survey, visited KGS and was an invited speaker at the 2019 KGS annual stakeholders seminar. Although the Alberta database and the KGS database and resulting models will differ in scope and intent, these discussions should help us avoid the pitfalls the Alberta Survey encountered.

Paleotopographic map of the Cambrian-Ordovician Knox Group

Patrick Gooding began a new project to map structure and paleotopography at the top of the Knox Group in Kentucky during the fiscal year.

A regional unconformity at the top of the Cambrian-Ordovician Knox Group results in extensive karst topography, including residual hills and sinkholes. Gooding is analyzing a large collection of geophysical logs recently donated to KGS and reviewing geologic descriptions and drillers' logs to determine the subsurface depth of the post-Knox unconformity. The resulting data will be used to construct a paleotopographic map on the top of the Knox. More than 3,000 control points will be used to construct the map. This project will improve our understanding of the paleotopographic surface of the Knox in Kentucky, which will be useful in exploration for hydrocarbons associated with the unconformity, and improve our understanding of the structural history of the Knox and post-Knox interval.

Mineral resources

Findings of investigation on western Kentucky rare earth elements published

The results of Warren Anderson's research on rare earth elements in the Western Kentucky Fluorspar District were published as KGS Report of Investigations 8 ("Mineralogy and Chemistry of Rare Earth Elements in Alkaline Ultramafic Rocks and Fluorite in the Western Kentucky Fluorspar District"); the report is available for download on the KGS website. The study found some slight enrichment of rare earth elements in some minerals, but not reaching economic concentrations. (See page 38 for more information.)

Rare earth elements in coal and coal-combustion byproducts

Since the late 1980s, nearly all of the rare earth elements used in the United States have been imported from China. Several KGS projects are part of an aggressive effort to boost domestic production of these elements. 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.

Cortland Eble, Ethan Davis, and Jason Backus, along with 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-plant refuse, and byproducts from coal-fired power plants. The U.S. Department of Energy provided funding to UK for this research 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.

So far, approximately 1,000 samples from coal mines and preparation plants have been collected and evaluated. In 2018, samples were collected from mines in eastern and western Kentucky, Pennsylvania, and Alabama. Research will identify parts of coal beds, as well as specific grades of material in preparation plants, that contain the highest amounts of REE+Sc+Y. After that task is completed, the researchers will determine the most cost-effective way to separate and concentrate REE+Sc+Y.

The U.S. Department of Energy is also funding a second UK project to evaluate the REE+Sc+Y potential of western Kentucky coal beds. More than 600 samples from the KGS Earth Analysis Research Library, exploration drill cores, and active coal mines have been collected and tested for REE+Sc+Y. The goal 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. In 2018, a mobile laboratory was set up at the Dotiki Mine (Alliance Resource Partners LLC) in western Kentucky to begin testing separation procedures at an active underground coal mine. Additional sampling and testing was done at an eastern Kentucky coal mine (Blackhawk Mining LLC) in preparation for another mobile laboratory. Researchers continue to collect and evaluate other coals in eastern and western Kentucky.

The role of KGS in both 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 hydrofluoric, nitric, and hydrochloric acids. The dissolved ash is then tested for REE+Sc+Y using inductively coupled argon plasma optical emission spectroscopy.



Ethan Davis performs nitric, hydrochloric, and hydrofluoric acid digestion on a batch of coal-ash samples in the KGS laboratory, using the newly installed fume hood for a study of rare earth elements.

DOE has recently funded a third UK project to compare methods used by different laboratories across the United States to test for rare earth elements. In 2018-19, coal and rock samples from Pennsylvania, Kentucky, and Alabama were collected, crushed, and split into representative fractions. One split was analyzed by KGS, and others were distributed to other project participants. This project is a collaborative effort with the University of North Dakota.

Awards

Steve Greb received the Gilbert H. Cady Award from the Energy Geology Division of the Geological Society of America at the society's annual meeting in Indianapolis in November 2018. The award is presented to division members who make outstanding contributions to the field of coal geology. Greb was nominated for the award by **Leslie (Jingle) Ruppert** of the U.S. Geological Survey in Reston, Va.

Dave Harris received the John T. Galey Memorial Award from the Eastern Section of the American Association of Petroleum Geologists at its annual meeting in Pittsburgh in October 2018. The Galey Award, the highest honor given by the Eastern Section, recognizes distinguished geoscientists whose accomplishments and contributions have been directed toward improving society. Harris was nominated for the award by Hannes Leetaru of the Illinois State Geological Survey and fellow KGS researchers John Hickman and Marty Parris.

EARL Hosts Open House

After six months of reorganizing and improvements, KGS invited visitors to an open house at the renamed Earth Analysis and Research Library on Feb. 15, 2019. Dozens of interested people from industry, University of Kentucky academic and research departments, state agencies, and other universities attended. See pages 35–37 for more about the changes at EARL.



EARL co-manager William Andrews welcomes visitors to the open house and explains changes at the facility.



A visitor examines a rock sample under one of the new microscopes added to EARL.







Ryan Pinkston takes a group of visitors for a tour of the core and sample warehouse, which has undergone a major reorganization.





Natalie Fields explains her procedure for taking high-quality photos of cores to retired State Geologist Jim Cobb; the photos are then uploaded to the core database.





Visitors browsed dozens of cores in the viewing room, many of them newly boxed and labeled.



EARL co-manager Liz Adams talks to visitors about the improvements to the facility.



Eastern Kentucky University geology professor Walter Borowski uses the open house to give a geology lesson to his students.



Detailed section from the "Surficial Geologic Map of Part of the Covington 7.5-Minute Quadrangle, Northern Kentucky."



Amy Bleichroth-King performs grain-size analysis in the KGS Western Kentucky Office in Henderson on samples gathered by mappers.

Geologic Mapping

KGS mappers in 2018-19 completed five surficial geologic maps for 7.5-minute quadrangles in northern Kentucky as part of the U.S. Geological Survey's STATEMAP program. They also led a field trip to parts of the mapped area for the 2018 Geological Society of America annual meeting in Indianapolis.

The KGS mapping program received an 11 percent funding increase for 2019-20 from STATEMAP, and turned its focus to surficial mapping in the Fort Knox area of Bullitt and Hardin Counties. The Survey's Geologic Mapping Advisory Committee recommended new surficial mapping of this area and the entire Interstate 65 corridor because of increasing development along the route. The garrison command staff at the Fort Knox Military Reservation signed a memorandum of understanding with KGS to pave the way for the mapping and provide safe access to training ranges. The memorandum was also the foundation for another agreement for later cooperative projects between KGS and Fort Knox.

Mappers Antonia Bottoms, Max Hammond, Steve Martin, and Matt Massey have begun field work in the area, examining landforms and collecting samples. When the mapping team completes the field work and preliminary maps, Emily Morris will finish the cartography and create the final maps to be delivered to USGS and published by KGS. Morris also creates maps, graphics, and illustrations for other KGS staff needs.

The mapping staff worked with Mike McGlue of the UK Department of Earth and Environmental Sciences and the staff at the KGS Earth Analysis and Research Library to add the capability to make sediment smear slides that can be examined under microscopes at EARL. This will help the mappers more closely examine the constituents of the sediments and soils they are studying.

Awards and appointments

Steve Martin served on the University of Tennessee Earth and Planetary Sciences Alumni Advisory Board in the 2018-19 fiscal year.

William Andrews was among several KGS staff to receive the first Director's Award for working to update the Earth Analysis and Research Library. He serves on the board of directors for the Kentucky Association of Mapping Professionals and on the Technical Advisory Committee for the National Geologic Map Database at the U.S. Geological Survey.

Radon collaboration

The Survey's collaboration with the UK College of Nursing on radon research and public education continued during the fiscal year, resulting in a page being added to the KGS website featuring links to radon potential maps for every Kentucky county. The maps were developed by **Bethany Overfield**, who worked with the College of Nursing for several years to add geologic context to their efforts to communicate the dangers of radon, an invisible, odorless gas emitted by rock and soil. Overfield, **William Andrews**, and staff of the College of Nursing



The RAD7 radon detector set up behind a house in Perry County during soil testing.

also developed a preliminary assessment of the economic benefits of the maps. See page 31 for more about the radon webpage.

As part of the radon work, **Andrea Connor** and **Emily Morris** tested soil for radon at homes in Perry County, using a DURRIDGE RAD7 radon detector. The portable instrument can take radon measurements from soil, air, and water.

KGS continues to develop its use of LiDAR in multiple research activities, including mapping. Jason Dortch has been using Kentucky's statewide LiDAR data for applications ranging from examination of land-forms and vegetation cover to estimating locations of geologic contacts to help with field checks of mapping work. He has also worked with KGS staff on identifying abandoned oil and gas wells, landslide modeling, and



other applications.

William Andrews worked with other KGS staff to develop a 3-D mapping database framework by studying the data other states have used for their 3-D mapping and determining the need for such mapping in Kentucky.

A thin loess deposit (yellowish brown soil) over residuum (reddish soil) that developed over bedrock in Hardin County, where surficial mapping funded by the STATEMAP program began in 2019.

Outreach, Communications, and Professional Engagement

Annual stakeholder seminar

The theme of the 58th annual seminar, held May 17, 2019, was "Dimensionality: Exploring, Integrating, and Visualizing Multidimensional Geoscience Data for Kentucky." More than 140 people attended the event at the Don and Cathy Jacobs Science Building on the University of Kentucky campus. They listened to speakers from KGS, several UK academic departments, and the Alberta Geological Survey. Dr. Kelsey MacCormack, the Alberta Survey's director of Modelling and Resources, gave the Donald Haney Lecture in Applied Geology. She spoke on the development of their 3-D mapping program.



Kelsey MacCormack

Special lectures with UK Department of Earth and Environmental Sciences

KGS and the UK Department of Earth and Environmental Sciences partnered to bring two special lectures to campus. On March 22, 2019, marine geochemist Evan Solomon of the University of Washington School of Oceanography spoke on "Revisiting the Role and Continental Margin Sediment Diagenesis in Marine Geochemical Cycles." A week later, Caroline L. Peacock of the School of Earth & Environment at the University of Leeds, England, presented, "Mud, Mud, Glorious Mud: How Marine Sediments Control the Earth System."



Evan Solomon (top) and Caroline L. Peacock deliver lectures in the Mining and Mineral Resources Building on the UK campus in March 2019.

Earth Science Week open house

Several organizations, including the Kentucky Science Center and the Nature Conservancy for the first time, brought displays and hands-on demonstrations to KGS's open house during Earth Science Week in October 2018. Central Kentucky students, families, and teachers visited displays on rocks and fossils, water resources, volcanoes, geologic hazards, weather and climate, and other earth science topics.



Kentucky Science Center staff brought weather demonstrations to the Earth Science Week open house, including this one on static electricity and lighting.

Media interviews on geologic hazards

Kentucky news media regularly contact KGS for expert information about geology-related issues, particularly when a geologic hazard event makes headlines.



Matt Crawford (above) points out landslide features in a LiDAR image during a TV news interview about landslides in Kentucky during the rainy winter of 2018-19. Seth Carpenter (top right) talks to a reporter after a 7.0-magnitude earthquake struck near Anchorage, Alaska, in November 2018. Zhenming Wang (bottom right) answers a reporter's questions about an earthquake in the Eastern Tennessee Seismic Zone in December 2018.





Geologic Hazards

The Kentucky Seismic and Strong-Motion Network

The Kentucky Seismic and Strong-Motion Network monitors seismic events across the state. KGS maintains a real-time data share of Network recordings with the seismic network operated by the University of Memphis and also with the Data Management Center at Incorporated Research Institutions for Seismology for archiving and global usage. More than 215 gigabytes of data from our network were downloaded from IRIS this fiscal year for use by seismologists around the globe.

Recordings from seismic stations in and around

Kentucky operated by other agencies were acquired simultaneously with real-time data from the Kentucky Seismic and Strong-Motion Network and used to detect mine blasts and earthquakes in and around Kentucky and larger events around the world. Sixteen earthquakes were recorded in the state during the fiscal year, ranging in magnitude from 1.3 to 2.6. Nine of these events happened in the Mississippi Embayment and six, including the largest, occurred in eastern Kentucky. Five of the earthquakes were reported as felt by local residents. The May 11, 2019, magnitude-2.6 earthquake southeast of Williamsburg was the largest earthquake

in the state this fiscal year, and was felt in Knox and Laurel Counties.

A temporary, sensitive seismic network detects small-magnitude earthquakes in eastern Kentucky. The network, which has operated in the Rome Trough of eastern Kentucky since June 2015, is the primary component of the Eastern Kentucky Microseismic Monitoring Project. By the end of the 2018-19 fiscal year, six of these temporary stations, whose instruments were loaned to KGS by project partner Cimarex Energy Inc., were removed. A summary report describing the monitoring and the first three years of seismicity recorded by the network, KGS Report of Investigations 5, "Seismic Monitoring and Baseline Microseismicity in the Rome Trough, Eastern Kentucky," by Seth Carpenter, Andrew Holcomb, Zhenming Wang, John Hickman, and Ed Woolery, was released during the fiscal year.

Andrew Holcomb left KGS in February 2019 to begin work at the Albuquerque Seismological



Seismic stations used for the Eastern Kentucky Microseismic Monitoring Project (triangles) and locations of earthquakes detected.



KGS visiting scholar Qian Wang and summer intern Russel Rogers remove station EK₃₃ near Salyersville.

Another master's thesis project, by **Brooks Rosandich**, evaluated Reelfoot Fault segmentation and strain accommodation along a corridor between the communities of Proctor City, Tenn., and Sassafras Ridge, Ky. Seismic-reflection imaging suggests a through-going transpressional shear zone pierces the Reelfoot Fault near Proctor City, extending at least 12 kilometers to Sassafras Ridge, and possibly an additional 22 kilometers to Wolf Island, Mo.

Seismic and strong-motion data recorded from the Kentucky Seismic and Strong-Motion Network, particularly from the bore-

hole strong-motion arrays, and our shear-wave veloci-

Laboratory, and **Russel Rogers**, a Morehead State University student majoring in geology, began an internship with **Seth Carpenter** in May 2019. Rogers is assisting with maintaining the seismic stations operated by KGS and analyzing their recordings.

Seismic hazards

KGS conducts research on seismic hazards, focusing on identifying active faults and ground-motion site effect. As part of a U.S. Department of Energy project at the Paducah Gaseous Diffusion Plant, we monitored seismicity in the surrounding area, and **Zhenming Wang, Ed Woolery,** and **Seth Carpenter** wrote KGS Report of Investigations 6, "An Update of Seismic Monitoring and Research in the Vicinity of the Paducah Gaseous Diffusion Plant: January 2013– December 2017."

The Charleston Uplift in Missouri and its connection with the New Madrid North Fault in particular, was investigated using microgravity and seismic-reflection techniques as part of a master's thesis by **Drew Burford**, supervised by **Ed Woolery**, our geophysics faculty associate with the UK Department of Earth and Environmental Sciences. The investigation revealed that the Charleston Uplift is bounded by faulting and structurally connected to the New Madrid North Fault.



UK Department of Earth and Environmental Sciences graduate student Drew Burford collects microgravity transects across the hypothesized southern boundary of the Charleston Uplift. Subsequent seismic-reflection profiling of the observed gravity anomaly determined the uplift is structurally controlled by a previously unknown extension of the New Madrid North Fault.



Brooks Rosandich, UK Department of Earth and Environmental Sciences graduate student, performs source-receiver field tests to optimize signal quality before acquiring data. His thesis research focuses on a potential through-going shear zone across the Reelfoot Fault.

ty database were used for research on ground-motion site effect. Zhenming Wang, Seth Carpenter, and Ed Woolery co-wrote "Horizontal-to-Vertical Spectral Ratio of S-Waves and SH-Wave Transfer Functions at the Vertical Seismic and Strong-Motion Arrays in the Central United States," which was published in the *Journal of Applied Geophysics*. Wang, Woolery, Ron Street, and Carpenter co-wrote "Shear-Wave Velocity Database for Communities Along the Ohio River Valley" and presented it at the 49th Annual Ohio River Valley Soils Seminar on Nov. 29, 2018, in Lexington. Two related presentations were made at the Seismological Society of America 2019 annual meeting, April 23–26, 2019, in Seattle.

Landslide hazards

The Federal Emergency Management Agency Pre-Disaster Mitigation grant program awarded KGS a three-year, \$400,408 grant through the Kentucky Division of Emergency Management to study landslide susceptibility and risk for the Big Sandy Area Development District. Matt Crawford is principal investigator for the project, which began in January 2019, and will focus on developing and implementing measures to reduce the risk to individuals and property from landslide hazards. Landslide-hazard susceptibility and risk maps will be developed, as well as products to communicate the results to stakeholders. A new geologist, Hudson Koch, was hired to work on the project. Koch earned a bachelor's degree from the University of Wisconsin, focusing on geophysics and hydrologic modeling.

Several new entries, including one on a debris flow in Powell County on June 17, 2019, that damaged a home, were added to the landslide inventory database, bringing the total number of entries to 2,713 by the end of the fiscal year. Crawford and Koch investigated the debris flow and provided assistance to Powell County Emergency Management. All landslide data can be viewed and queried in the KGS geologic map information service. The resulting map improves our understanding of landslide occurrence and provides information to land-use planners, transportation officials, emergency managers, and the public.

Matt Crawford is also co-principal investigator on a project, along with Lindsey Bryson of the UK



Matt Crawford, principal investigator for the Big Sandy Area Development District landslide project, leads a stakeholders meeting in Prestonsburg on March 18, 2019.



A debris flow (top) on June 17, 2019, damaged this home (bottom) in Powell County.

Department of Civil Engineering, that will develop change detection models by combining historical satellite precipitation data for known landslides with a rainfall threshold model for landslide initiation. The project is funded by a NASA-KY Space Grant. This work will contribute to the landslide susceptibility project in eastern Kentucky funded by FEMA. Monitoring at three sites in Kenton, Lewis, and Pulaski Counties was used to develop a framework for longterm monitoring to assess soil-moisture fluctuation and link hydrologic conditions to geotechnical properties that influence slope stability. Much of the monitoring was in collaboration with Bryson as part of the U.S. Geological Survey's Landslide Hazards Program and was the basis of Crawford's Ph.D. dissertation.

Crawford assisted the U.S. Geological Survey in developing a national landslide inventory. Along with a few other state surveys, KGS worked on data standardization, quality, and delivery. The resulting geodatabases of landslide occurrence across the country will be searchable in an online map. Crawford will make presentations on the project at the 2019 Geological Society of America and American Association of Environmental and Engineering Geologists annual meetings.

Crawford also worked with landslide researchers at NASA to get the KGS landslide inventory embedded into NASA's online Landslide Viewer (pmm. nasa.gov/landslides). The viewer is part of a larger global landslide catalog designed to show landslide hazard around the world. Having our inventory associated with the global inventory demonstrates the importance of regional and local government entities in hazard assessment.



Speakers and moderator for the Hazards Caucus Alliance in the U.S Capitol. Left to right: Matt Crawford, Brian Collins, Mark Jackson, and Laura Szymanski.

Crawford, along with Brian Collins of the U.S. Geological Survey and Mark Jackson with the National Oceanic and Atmospheric Administration, was invited by the Hazards Caucus Alliance to provide a Congressional briefing, "Landslide Science: Nationwide Risk Reduction Applications," to inform Congress about landslide hazard and risk on June 7, 2019. The informational briefing was hosted by the Congressional Hazards Caucus co-chairs, Senators Lisa Murkowski (R-Alaska), Suzan DelBene (D-Wash.), and Maria Cantwell (D-Wash.). The briefing was sponsored by several earth science societies and emphasized how federal and state investments in research support landslide hazard assessment and preparedness, and ultimately save lives and money.

China scholarly exchange and cooperative research

The exchange program between KGS and the Lanzhou Institute of Seismology and other institutions under the China Earthquake Administration is in its 15th year. **Zhenming Wang** was invited to visit the Institute of Crustal Dynamics in Beijing Jan. 23– 26, 2019, and gave two lectures: "Geologic Hazards and Emergency Management in the United States" and "Landslide Hazard Mapping and Emergency Management in Kentucky." Wang also delivered a lecture to the Earthquake Administration of Jiangsu Province June 12, 2019, and the Lanzhou Institute of Seismology on June 14, 2019: "Strong Ground-Motion Site Effect."



Zhenming Wang lectures on ground-motion site effect at the Lanzhou Institute of Seismology in Lanzhou, China, on June 14, 2019.

Staff award

Temporary employee Andrew Holcomb received the award for the outstanding master's thesis submission in the Math, Physical Science, and Engineering category at the Conference of Southern Graduate Schools at its annual meeting in Knoxville, Tenn., Feb. 14–16, 2019.

Three visiting scholars—Fajun Miao of the Earthquake Administration of Jiangsu Province in Nanjing, Yanju Peng of the Institute of Crustal Dynamics, and Qian Wang of the Lanzhou Institute of Seismology—came to UK to conduct research on strong ground motion and site effect, seismic-network data processing and analysis, and near-surface geophysics. Miao presented "Earthquake and Blast Signal Discriminations Using Machine Learning" at the KGS internal seminar on Oct. 19, 2018, and a poster at the Commonwealth Computational Summit on Oct. 25, 2018. Peng presented "Site Effect in Beijing Metropolitan Area" at the KGS internal seminar on Nov. 16, 2018, and Wang presented "Characteristics and Mechanism of the Landslide in Yongguang Village, Minxian County, China" at the KGS internal seminar on May 3, 2019. Peng and Wang have submitted manuscripts for publication in the Journal of Engineering Geology and Seismological Research Letters, respectively. In addition to their research, the visiting scholars helped with seismic-network maintenance and operation, as well as geophysical investigations.

Zhenming Wang helped develop the UK Department of Earth and Environmental Sciences' matching curriculum for the 3+1+1 program between the University of Kentucky and Jilin University in Changchun, China. Wang traveled to Changchun with Alan Fryar, a professor in the Department of Earth and Environmental Sciences, June 3-8, 2019, to discuss the curriculum matching with deans and faculty in the colleges of Geo-exploration Sciences and Technology, New Energy and Environment, Earth Sciences, Construction Engineering, and Instrument and Electrical Engineering at Jilin University. Wang gave a lecture, "SH-Wave Reflection/Refraction and Their Applications in Central United States," to the College of Geo-exploration Sciences and Technology on June 5, 2019.

Geologic Information Management

KGS website updates

KGS makes research data, maps and publications, databases, and other information available on our website to researchers and the general public. More than 20,000 files are accessible from links on the homepage. **Rebecca Wang**, the lead developer of the website, is working with other KGS staff to update the content and design of various pages on the website. This fiscal year she has redesigned the Hazards section to improve how we deliver information about hazards, hazard monitoring, and hazard research at KGS. The Earthquakes page under the Hazards section has detailed information, including an interactive map of the loca-

tions of stations in the Kentucky Seismic and Strong-Motion Network, from which seismic recordings for each station can be accessed. Other new pages in the Hazards section are on landslides, karst, foundation engineering, and radon.

The radon page contains a link to a new internet map service, Kentucky Radon Potential, developed by **Bethany Over**field, **Rebecca Wang**, and **Doug Curl**. The map service displays the geology of Kentucky, derived from detailed 1:24,000-scale mapping, correlated with radon potential for each rock unit. This map is the result of a collaborative effort between the Kentucky Geological Survey and the UK College of Nursing's BREATHE (Bridging Research Efforts and Advocacy Toward Healthy Environments) team. KGS and BREATHE scientists combined the results from more than 70,000 home radon test kits with our digital geologic map coverage, and the result was the most detailed statewide indoor radon potential map in the country. (More information on the radon project is on page 23.)

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 83,000 visits originating from 152 countries were made during the past fiscal year to KY Geode, the Survey's new page from which to access data and information. The great majority of visitors were from the United States (90 percent), followed by India, Canada, France, the Netherlands, the United Kingdom, and Germany. Users from all 50 states and the District of Columbia visited the site; a little less than half were from Kentucky, followed by users from Ohio, Tennessee, Texas, Indiana, Illinois, and Georgia. More than 32,000 users conducted approximately 140,000 database searches.





The improvements to the Hazards section of the KGS website include embedded interactive maps showing locations of stations in the Kentucky Seismic and Strong-Motion Network along with links to seismic recordings from each station. Over a million files were downloaded from the website, including KGS publications and presentations, which was a slight increase from the previous year. Oil and gas records, water wells and springs data, online publications, coordinate conversion services, and data from the geologic map server continue to be the most frequently downloaded data.

KGS online map services were accessed close to 70,000 times, about the same amount from the 2017-18 fiscal year. The most popular map service continued to be the geologic map information service, accessed more than 42,000 times

(a decrease of just over 12 percent from the previous year). The next most popular map services were the new one on Kentucky radon potential, water wells and springs, KGS StoryMaps, and the Kentucky minerals information. There were nearly 10,000 tabular data downloads (primarily oil and gas records), which was an approximately 8 percent decrease from the 2016-17 fiscal year.

The most downloaded publications were:

- "Mineral and Fuel Resources Map of Kentucky," by Warren Anderson and Garland Dever Jr. (Map and Chart 26, series 12)
- "The Geologic Story of Kentucky," by Preston McGrain (Special Publication 8, series 11)
- 3. "Upper Cumberland River Basin in Kentucky," by Dan Carey (Map and Chart 190, series 12)
- 4. "Kentucky Landscapes Through Geologic Time," by **Dan Carey** (Map and Chart 200, series 12)
- "Geology of the Mammoth Cave National Park Area," by Ann Livesay and Preston McGrain (Special Publication 7, series 10)



The Kentucky Radon Map shows radon concentrations for each rock formation. The UK College of Nursing's BREATHE program also provides informational flyers showing radon potential in each county.

The most downloaded presentations were:

- "Kentucky Coal and Coal Combustion Byproducts as Potential Sources of Rare Earth Elements," 2016, by Cortland Eble
- "New Unconventional Oil and Gas Plays: The Berea Sandstone and Rogersville Shale," 2016, by Dave Harris
- 3. "Introduction to KGS Interactive Web-Based Services," 2012, by Brandon Nuttall and Doug Curl
- 4. "Regional Modeling of Class II Wastewater Injection Wells, Appalachian Basin," 2016, by **Tom Sparks**
- "Assessing Baseline Groundwater Chemistry for the Berea Sandstone and Rogersville Shale Play Area, Eastern Kentucky," 2016, by Junfeng Zhu

We continue to develop services for KY Geode; a new version of the Core Holdings search was recently released (kgs.uky.edu/kygeode/services/cslib): More search parameters were added, and the search functionality and search results were integrated on the same page, making it responsive to mobile devices. A map view of the core locations was also incorporated into the results. We also removed links to the core inventory from the Oil and Gas search function of KY Geode, which should make a search for rock core less confusing. The Oil and Gas Records search is now confined to oil and gas samples. Doug Curl, Carrie Pulliam, and Mike Ellis helped with upgrades to the KGS Earth Analysis and Research Library by updating databases describing well cores and cuttings and setting up new web services for the facility, and Ellis set up new computer workstations at the library.

Perhaps the most exciting addition to the Core Holdings search page is that high-resolution photographs of individual core boxes are now accessible in the detailed core reports that accompany each core. Rebecca Wang updated the EARL webpage to accommodate the thousands of photos and detailed information on the cores. This work is part of a project, funded by the Institute of Museum and Library Services, to improve the availability of the cores to industry and research institutions. The photos will reduce the need for people to travel to the library and the labor involved in retrieving core boxes from shelves, which in turn will reduce wear on the most frequently accessed boxes of core. The project is a multiyear effort, but links to the photos will be added to the web report for each core as the photos are



inventoried in the rock core database. More information about this project is on page 37.

The KGS homepage plays an important role in delivering information, and in fiscal year 2018-19 attracted nearly a million hits. Almost 250,000 users from 193 countries accessed information about KGS, Kentucky's resources, and geoscience education. Approximately 77 percent of the users were from the United States; others were from India, the Philippines, the United Kingdom, Canada, and Australia. About 33 percent of domestic users were from Kentucky; the next most common groups of users were from Tennessee, California, Ohio, Texas, Illinois, Georgia, and Michigan. Approximately 40 percent of visits to the KGS webpages were on mobile and tablet devices. More than 73 percent of users found pages on the KGS website through search engines such as Google or Bing. Approximately 27 percent of users used direct links, such as a bookmark or a referral from somewhere other than a search engine to reach our website; less than 2 percent of users linked to the KGS website through a social network such as Facebook or Twitter.

The most visited pages on our website were:

- 1. Coal
- 2. KGS main pages (homepage, staff, news, etc.)
- 3. Rocks and Minerals
- 4. Fossils
- 5. Seismic Recordings.

Dozens of people attended an open house at EARL on Feb. 15, 2019, to see the changes and improvements at the facility. (See page 35 for more information.)

Data preservation

Data from old projects, donated materials, and legacy datasets are preserved through high-resolution digital scanning, after which the data are entered into the KGS enterprise database; all data are backed up by robust data storage. Funds from the USGS National Geological and Geophysical Data Preservation Program help make this preservation possible. This funding supported student workers John Piening and **Trevor Bryant** from the UK Department of Earth and Environmental Sciences. Piening scanned donated documents from previously unknown oil and gas wells, and Bryant worked on a project to inventory abandoned collections of papers, datasets, publications, and photographs stored in KGS file cabinets. Having an inventory of these collections will facilitate future preservation projects to preserve valuable data.

A proposal by **Doug Curl** and **Drew Andrews** was funded by the National Geological and Geophysical Data Preservation Program for the 2019-20 fiscal year. The project will catalog samples from the Earth Analysis Research Laboratory, scan donated mineral and oil and gas maps, and enter lithologic information from water-well drilling documents into the KGS database. The Data Preservation Program is also providing funding for KGS to evaluate and salvage mineral cores stored at our Earth Analysis Research Library from the Western Kentucky Fluorspar and South-Central Kentucky Mineral Districts; this project is part of an effort by states to identify data in priority areas of the country that contain critical mineral resources.

Core and Sample Collection Facility Renamed and Services Upgraded

The previously named Well Sample and Core Library is now the Earth Analysis and Research Library, or EARL. With that christening, we began a major upgrade of the facilities and enhancement of services EARL provides to its multifaceted patrons.

Since William Andrews and Liz Adams were appointed co-managers in 2018, KGS has refocused the use of space in the facility. The large core-viewing room has been rededicated to that purpose, but core workshops and similar gatherings for up to 100 participants can still be held there. A smaller room



KGS staff pitch in to build additional shelving for core storage. During the reorganization, previously undocumented collections were rediscovered and will be added to our current collection. Ray Daniel is documenting more than 3,000 well cuttings in glass vials that predate most of the our collection. Jim Hower of the Center for Applied Energy Research reorganized more than 4,000 coal samples from him and KGS researcher Cortland Eble. All the library's holdings will be made available online, some for the first time, when cataloging is complete.



Clayton Gullett and Laura Streib organize oil and gas well cuttings.

has been equipped with tables and audiovisual equipment to serve as a classroom or meeting space for about 20 people.

A central records room holds KGS and USGS reports, core description manuals, and other documentation about EARL's holdings. Because some of our archived material is on microfilm or microfiche, a reader for those media has been set up in the records room.

Upgrades include two microscopes provided by KGS petrologist **Dave Harris** and a photomicrograph camera provided by another KGS petrologist, **Cortland Eble. Mike McGlue** of the UK Department of Earth and Environmental Sciences helped set up equipment to make smear slides for use in studying fine-grained sediments.

Another addition to the library is new equipment to take core plugs, which means we no longer need to ship core to external labs for this purpose, eliminating shipping fees and possible loss of core. We've also added more workstations, a large-screen



Participants in an October 2018 core workshop sponsored by Exxon view 982 feet of core. Ryan Pinkston schedules workshops like this one and other research visits.

monitor, and scanners for visitors and KGS staff to use.

KGS scientists Warren Anderson and Steve Greb, along with Jim Hower of UK's Center for Applied Energy Research, provided specimens and documentation for new educational displays in the lobby and core viewing room.

New safety procedures and personal protective equipment have been added, and the facility has become a pilot program for UK's Occupational Health and Safety Office.

Ryan Pinkston and other EARL staff, with help from other KGS staff, are reorganizing the collection and the data about the cores and samples. A temporary employee was hired to help reorganize, rebox, and store backlogged well cuttings.

During the upgrades, the facility stayed open to serve the needs of industry, researchers, and academic



Darion Carden reorganizes oil and gas well cuttings and removes extraneous materials from the building.

groups from around the U.S. and half a dozen other countries. College students from institutions across the country visited EARL as part of their research; students came from UK's Department of Earth and Environmental Sciences, Eastern Kentucky University, Centre College, Oklahoma State University, the University of Cincinnati, and the University of Alabama.

Grants will improve core storage and web information

In October 2018, the Institute of Museum and Library Services awarded KGS a grant of more than \$243,000 for a three-year project to replace and relabel thousands of worn and damaged core storage boxes and photograph 10,000 cores. EARL co-manager Liz Adams is overseeing the project. As part of the process of examining the facility's cores for this project, EARL staff have found some previously unknown but important cores, which can now be made available for examination. See page 33 for more information about how this grant is helping KGS.

In the upcoming year, 2,870 rock cores will be reorganized, along with auger samples taken from 1,200 sites in Kentucky during the 1960–78 USGS-KGS geologic mapping program. The U.S. Geological Survey's Data Preservation and Earth MRI programs are providing some funding for the reorganization.



Natalie Fields photographs wet and dry cores as part of a project funded by the Institute of Museum and Library Services. She fills out a form with information for each core, and the photos and information are uploaded to the core database.



Gordon Dowell records the lithology of cores, then repairs damaged boxes or replaces and relabels the boxes that are damaged beyond repair.

Publications for 2018-19

Scientific information gathered through KGS research projects is disseminated through our own serial publications, peer-reviewed science journals, and in abstracts published for major scientific conferences. Eleven new KGS publications were released during the fiscal year. Among them was "Using Watershed Pour-Point Elevations to Evaluate the Base of Fresh Groundwater in the Cumberland Plateau of Eastern Kentucky" (Report of Investigations 7) by **Ethan Davis, Marty Parris,** and **Jarrad Grider**. They found that the 1966 publication, "Fresh-Saline Water Interface Map of Kentucky" by H.T. Hopkins, used by oil and gas drillers to determine how deep surface casing should be placed to protect groundwater, underestimates the maximum depth of fresh groundwater in eastern Kentucky. Their analysis showed that the deepest observed fresh groundwater is, on





average, 147 feet deeper than estimated by the Hopkins map, suggesting groundwater could be contaminated if the Hopkins map is used as a reference for deciding the depth of surface casing.

Warren Anderson, who retired from KGS near the end of the fiscal year, completed "Mineralogy and Chemistry of Rare Earth Elements in Alkaline Ultramafic Rocks and Fluorite in the Western Kentucky Fluorspar District" (Report of Investigations 8). Anderson examined the igneous rocks of the Western Kentucky Fluorspar District and found that they are slightly enriched with rare earth elements, which are used in many technology applications, from cellphones to advanced weapon systems.

Five surficial geologic maps covering parts of six 7.5-minute quadrangles in northern Kentucky were published. The maps were funded through the U.S. Geological Survey's STATEMAP program. (More information on these maps can be found on page 22.) KGS partnered with UK's W.T. Young Library to make the Survey's digitized publications easier to find online, by assigning digital object identifiers to them. A DOI is a unique string of numbers and letters that identifies a publication's content and provides a link to its location on the internet. Older KGS publications were assigned DOIs that link to a copy at the library's UKnowledge webpage. New publications are assigned DOIs as they are released.

2018-19 KGS publications

Contract Report 12: "Surficial Geologic Map of Part of the Covington 7.5-Minute Quadrangle, Northern Kentucky," by Matt Massey, Antonia Bottoms, and Max Hammond

Contract Report 13: "Surficial Geologic Map of Parts of the Lawrenceburg, Aurora, and Hooven 7.5-Minute Quadrangles, Northern Kentucky," by Antonia Bottoms, Max Hammond, and Steve Martin

Contract Report 14: "Surficial Geologic Map of Part of the Newport 7.5-Minute Quadrangle, Northern Kentucky," by Matt Massey, Antonia Bottoms, and Max Hammond

Contract Report 15: "Surficial Geologic Map of Part of the Patriot 7.5-Minute Quadrangle, Northern Kentucky," by Max Hammond, Antonia Bottoms, and Steve Martin

Contract Report 16: "Surficial Geologic Map of Part of the Rising Sun 7.5-Minute Quadrangle, Northern Kentucky," by Steve Martin, Antonia Bottoms, and Max Hammond

Information Circular I: "Overview of the Kentucky Geological Survey No. 1 Hanson Aggregates Well, Carter County, Kentucky," by Rick Bowersox, Steve Greb, and Dave Harris

Map and Chart 5: "Mississippian-Devonian Black Shales of Kentucky: East-West Transect in Five Cores from the Appalachian Basin to the Illinois Basin," by Patrick Gooding and Frank Ettensohn

Report of Investigations 5: "Seismic Monitoring and Baseline Microseismicity in the Rome Trough, Eastern Kentucky," by **Seth Carpenter, Andrew** Holcomb, Zhenming Wang, John Hickman, and Ed Woolery

Report of Investigations 6: "An Update of Seismic Monitoring and Research in the Vicinity of the Paducah Gaseous Diffusion Plant: January 2013–December 2017," by Zhenming Wang, Ed Woolery, and Seth Carpenter

Report of Investigations 7: "Using Watershed Pour-Point Elevations to Evaluate the Base of Fresh Groundwater in the Cumberland Plateau of Eastern Kentucky," by Ethan Davis, Marty Parris, and Jerrad Grider

Report of Investigations 8: "Mineralogy and Chemistry of Rare Earth Elements in Alkaline Ultramafic Rocks and Fluorite in the Western Kentucky Fluorspar District," by **Warren Anderson**

Peer-reviewed papers

- Bair, R.T., **Tobin, B.W.,** Healy, B.D., Spangenberg, C.E., Childres, H.K., and Schenk, E.R., 2019, Modeling temperature regime and physical habitat impacts from restored streamflow: Environmental Management, doi:10.1007/s00267-019-01157-8.
- Bandy, A.M., Cook, K., Fryar, A.E., and **Zhu, J.**, 2019, Differential transport of *Escherichia coli* isolates compared to abiotic tracers in a karst aquifer: Groundwater, doi: 10.1111/gwat.12889.
- Bowersox, J.R., Greb, S.F., and Harris, D.C., 2019, Porosity and CO₂ storage capacity of the Maryville–Basal sandstone section (Middle Cambrian), southern Appalachian Basin, Kentucky: Environmental Geosciences, v. 26, no. 1, p. 21–40, doi:10.1306/eg.06181818004.
- Crawford, M.M., Bryson, L.S., Woolery, E.W., and Wang, Z., 2019, Long-term landslide monitoring using soil-water relationships and electrical data to estimate suction stress: Engineering Geology, v. 251, p.146–157, doi.org/10.1016/j. enggeo.2019.02.015.
- Husic, A., Fox, J., Adams, E., Ford, W., Agouridis, C., **Currens, J.**, and **Backus, J.**, 2019, Nitrate pathways, processes, and timing in an agricul-

tural karst system: Development and application of a numerical model: Water Resources Research, v. 55, issue 3, p. 2079–2103, doi. org/10.1029/2018WR023703.

- Kougkoulos, I., Cook, S.J., Edwards, L.A., Clarke, L.J., Symeonakis, E., **Dortch, J.M.**, and Nesbitt, K., 2018, Modelling glacial lake outburst flood impacts in the Bolivian Andes: Natural Hazards, v. 94, issue 3, p. 1415–1438, doi.org/10.1007/ s11069-018-3486-6.
- Massey, M.A., Andrews, W., Martin, S.L., Hammond, W., III, and Bottoms, A.E., 2018, Significance of Pleistocene fluvial systems and glaciations on the landscape evolution of northern Kentucky, *in* Florea, L.J., ed., Ancient oceans, orogenic uplifts, and glacial ice: Geologic crossroads in America's heartland: Geological Society of America Field Guide 51, p. 165–180, doi. org/10.1130/fld051.
- Matthews. J.A., Winkler, S., Wilson, P., Tomkins, M.D., **Dortch, J.M.**, Mourne, R.W., Hill, J.L., Owen, G., and Vater, A.E., 2018, Small rock-slope failures conditioned by Holocene permafrost degradation: A new approach and conceptual model based on Schmidt-hammer exposure-age dating, Jotunheimen, southern Norway: Boreas, v. 47, no. 4, p. 1144–1169, doi:10.1111/bor.12336.
- Miller, A.E., Steele, N., and Tobin, B.W., 2018, Vulnerability and fragility risk indices for non-renewable resources: Environmental Monitoring and Assessment, doi:10.1007/s10661-018-6749-5.

- Reyes, J., Wendroth, O., Matocha, C., and Zhu, J., 2019, Delineating site-specific management zones and evaluating soil water temporal dynamics in a farmer's field in Kentucky: Vadose Zone Journal, v. 18, 180143, doi:10.2136/ vzj2018.07.0143.
- Tomkins, M.D., Dortch, J.M., Hughes, P.D., Huck, J.J., Stimson, A.G., Delmas, M., Calvet, M., and Pallàs, R., 2018, Rapid age assessment of glacial landforms in the Pyrenees using Schmidt hammer exposure dating (SHED): Quaternary Research, v. 90, no. 1, p. 26–37, doi:10.1017/ qua.2018.12.
- Tomkins, M.D., Dortch, J.M., Hughes, P.D., Huck, J.J., Tonkin, T.N., and Barr, I.D., 2018, Timing of glacial retreat in the Wicklow Mountains, Ireland, conditioned by glacier size and topography: Journal of Quaternary Science, v. 33, no. 6, p. 611–623, doi:10.1002/jqs.3040.
- Wang, Z., Carpenter, N.S., and Woolery, E.W., 2018, Horizontal-to-vertical spectral ratio of S-waves and SH-wave transfer functions at the vertical seismic and strong-motion arrays in the central United States: Journal of Applied Geophysics, v. 162, p. 64–71, doi.org/10.1016/j. jappgeo.2018.10.017.
- Zhang, X., **Zhu, J.**, Wendroth, O., Matocha, C., and Edwards, D., 2019, Effect of macroporosity on pedotransfer function estimates at the field scale: Vadose Zone Journal, v. 18, 180151, doi:10.2136/vzj2018.08.0151.

Five Longtime KGS Staff Members Retire

Dave Williams

Dave Williams, who came to the KGS Western Kentucky Office in July 1974, retired from the Survey in October 2018. While managing the office in Henderson, he conducted research on paleochannels in western Kentucky as they relate to the most important



coal-producing strata in the region. Williams served as a co-principal investigator for a project from 2008 to 2010 in which KGS and several partners drilled an 8,126-foot-deep well in Hancock County and injected more than 300 tons of CO_2 to investigate the carbon-storage capacity of deep formations in the Western Kentucky Coal Field.

Williams also investigated rockfalls, landslides, and soil-piping incidents during his career, and conducted outreach and led field trips in the western part of the state.

He was recognized in 2008 with the Gordon H. Wood Jr. Memorial Award from the American Association of Professional Geologists. The award noted his "dedicated service with the Kentucky Geological Survey and providing geologic service to private companies, state and federal agencies, and the public in western Kentucky."

Williams authored or co-authored numerous KGS publications, including reports on coal and tar sands, the Hancock County carbon-sequestration project report, and land-use maps for counties in western Kentucky.

Brandon Nuttall

In 1978, Brandon Nuttall joined what was then known as the KGS Oil and Gas Section. More than 40 years later, he retired from KGS on June 3, 2019. He spent a lot of time at his first job at the Survey on



a manual keypunch machine at the UK Computing Center, punching programs and data onto cards as part of reviewing drilling-permit applications from the state's Division of Oil and Gas. The information gathered from that work and other projects was used to start the KGS Oil and Gas Well Records Database.

He was principal investigator on a 2012 state-funded project to test enhanced gas recovery using carbon dioxide in the Devonian shale in Johnson County and wrote a publication on the project. He earned a bachelor's degree in geology from Eastern Kentucky University and took a job with a coal resource consulting firm before joining KGS. He served for several years as a liaison between KGS and the Kentucky Energy and Environment Cabinet.

Warren Anderson

Warren Anderson closed a 41-year career at KGS on May 31, 2019, after researching such diverse topics as minerals and metals, digital mapping, and black shales. He had explored for base and precious metals for Union Carbide in Wyoming and South Dakota after completing a bachelor's



degree in engineering from the South Dakota School of Mines and Technology. He came to KGS in January 1978.

Anderson gathered data from the state's mineral districts that eventually became available online from the Mineral Resources section of the KGS website. He also chaired the Digital Mapping Program Committee that planned the conversion of geologic quadrangle maps to digital format. He investigated ground-swelling issues caused by pyrite oxidation in black shales and wrote a KGS publication on the issue. KGS published his "Mineralogy and Chemistry of Rare Earth Elements in Alkaline Ultramafic Rocks and Fluorite in the Western Kentucky Fluorspar District" just before his retirement. Anderson also curated the large collection of meteorites at KGS, made up mostly of specimens donated by William Ehmann and William Russell, which is on display in the atrium of the Mining and Mineral Resources Building and discussed in a StoryMap on the KGS website.

Bart Davidson

While studying geology at Eastern Kentucky University in 1985, Bart Davidson took a class on coal geology taught by Jim Cobb, former KGS director and state geologist, who at the time headed the



former Coal Section at KGS. Cobb invited Davidson to apply for a job as a student worker in the section. When he was hired, Davidson worked on several projects evaluating eastern Kentucky coal resources and answered public requests on coal issues.

Davidson left KGS temporarily in 1991 to work in environmental consulting but returned the following year to resume his career in the Water Resources Section, and helped develop and manage the Kentucky Groundwater Data Repository. He created numerous statewide maps on water quality, and assisted in field work for many Water Resources Section projects, including groundwater-quality sampling and aquifer testing. He was the lead investigator for a project to compile bacteriological sampling data from county health departments across Kentucky, funded by the Centers for Disease Control and Prevention. He served for the last seven years on the Kentucky Water Well Certification Board, and compiled the annual report for the Kentucky Interagency Groundwater Monitoring Network for the past nine years. Davidson also managed the KGS Office of Geologic Information, now known as the Public Information Center, from 1996 until 2002.

Mike Lynch

Mike Lynch came to KGS in November 2004 to manage communications and outreach. He wrote and edited KGS news releases, newsletters, and annual reports; took photos of KGS activities; and man-



aged the Survey's social media. Lynch, who retired on June 7, 2019, earned a bachelor's degree in journalism from Eastern Kentucky University.

He oversaw a 2017-18 project to update the geologic hazards section of the state hazard mitigation plan, in which KGS researchers used new techniques and data to revise evaluations of the state's earthquake, landslide, sinkhole, and mine-subsidence risks. Funding for the project was provided by the Federal Emergency Management Agency. He co-authored two KGS publications: "Earthquakes in Kentucky: Hazards, Mitigation, and Emergency Preparedness" and "Ground Motions Induced by the March 11, 2018, Implosion of the Capital Plaza Tower, Frankfort, Kentucky."

Kentucky Geological Survey Staff Fiscal Year 2018-19

State Geologist's Office

Haneberg, William: State Geologist and 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

Banks, Roger: Stores Supervisor
Lynch, Mike: Technology Transfer Officer; retired June 7, 2019
Smath, Meg: Geologic Publications Manager

Digital Earth Analysis Lab

Dortch, Jason: Geologist IV Johnson, Sarah: Research Assistant

Energy and Minerals

Harris, Dave: Section Head Anderson, Warren: Geologist V; retired May 31, 2019 Bowersox, Rick: Geologist IV Eble, Cortland: Geologist V Gooding, Patrick: Geologist IV Guo, Xin (Erica): Visiting Scholar Greb, Steve: Geologist V Hickman, John: Geologist IV Nuttall, Brandon: Geologist V; retired June 3, 2019 Parris, Marty: Geologist V Sparks, Tom: Geologist III

Geologic Hazards

Wang, Zhenming: Section Head Ahmed, Faisal: Research Assistant Carpenter, Seth: Geologist IV Crawford, Matt: Geologist III Holcomb, Andrew: Geological Technician Senior Killen, Ashton: Landslide Hazards Intern Miao, Fajun: Visiting Scholar Peng, Yanju: Visiting Scholar Rogers, Russel: Seismic Network Intern Wang, Qian: Visiting Scholar Woolery, Ed: Geophysics Faculty Associate

Geoscience Information Management

Curl, Doug: Section Head Adams, Elizabeth: Research Administrative Coordinator Bryant, Trevor: Student Worker Ellis, Mike: Computer Support Specialist II Mullins, Seth: Student Worker Piening, John: Student Worker Pulliam, Carrie: Geologist II Smath, Richard: Geologist III Thompson, Mark: Information Technology Manager I Wang, Rebecca: Database Analyst

Geologic Mapping

Andrews, William: Section Head Bottoms, Antonia: Geologist I Dortch, Jason: Geologist IV Hammond, Max: Geologist I Martin, Steve: Geologist III Massey, Matt: Geologist IV Morris, Emily: Cartographic Data Manager Overfield, Bethany: Geologist III

Water Resources

Taylor, Chuck: Section Head Arpin, Sarah: Geologist II Davidson, Bart: Geologist IV; retired Jan. 1, 2019 Nolte, Adam: Geological Technician Senior Tobin, Ben: Geologist IV Webb, Steve: Geologist II Zhu, Junfeng: Geologist V

Laboratory

Backus, Jason: Geologist III/Laboratory Manager Conner, Andrea: Geologist II Davis, Ethan: Laboratory Technician

Earth Analysis Research Library

Andrews, William: Geologic Manager Adams, Elizabeth: Archive Manager Carden, Darion: Geologic Technician Daniel, Ray: Principal Research Analyst Dowell, Gordon: Geologic Technician Fields, Natalie: Photographic Technician Gullett, Clayton: Geologic Technician Pinkston, Ryan: Research Analyst Streib, Laura: Student Worker

Western Kentucky Office

Williams, Dave: Section Head; retired Oct. 1, 2018 Beck, Glynn: Geologist IV/Manager Bleichroth-King, Amy: Laboratory Technician

Research Projects Fiscal Year 2018-19

Energy and minerals

Midwest Regional Carbon Sequestration Partnership (Appalachian Basin) End date: 12/31/2019 FY funding: \$15,491 6-year project total: \$400,011 Funding source: U.S. Department of Energy through Battelle Memorial Institute

Geochemistry

Fundamental Studies on the Recovery of Rare Earth Elements from Coal and Coal Byproducts End date: 1/31/2019 KGS FY funding: \$3,505 UK 2-year project total: \$400,000 Funding source: Virginia Polytechnic Institute and State University through UK Department of Mining Engineering Production of Salable Rare Earths Products From Coal and Coal Byproducts End date: 5/31/2019 KGS FY funding: \$21,036 UK 2-year project total: \$346,600 Funding source: Marshall Miller and Associates Inc. through UK Department of Mining Engineering Rare-Earth Elements (REEs) in U.S. Coal-Based Resources: Sampling, Characterization, and Resource Assessment End date: 9/30/2019 KGS FY funding: \$9,370 UK 2-year project total: \$150,000 Funding source: University of North Dakota through UK Center for Applied Energy Research Low-Temperature Ashing for Enhanced Recovery of Rare Earth Elements End date: 8/31/2019 KGS FY funding: \$14,020 UK 2-year project total: \$322,352 Funding source: U.S. Department of Energy through UK Department of Mining Engineering Student Intern, Water Quality Assessment End date: 11/30/2018 FY funding: \$6,833 UK project total: \$76,046 Funding source: Beam Suntory Inc. through UK Kentucky Water Resources Research Institute Water Quality Analyses for the Kentucky River Watershed Watch Program

End date: 6/30/2019 KGS FY funding: \$5,213 UK project total: \$122,506 Funding source: Kentucky River Authority through UK Kentucky Water Resources Research Institute

Geologic information

Kentucky Geologic Core Digital Image Archive

End date: 9/30/2021 FY funding: \$42,673 Project total: \$243,472

Funding source: Institute of Museum and Library Services

Geologic information

National Geologic and Geophysical Data Preservation Program End date: 6/30/2019 FY funding and project total: \$30,482 Funding source: U.S. Geological Survey

Geologic mapping

Quaternary and Surficial Geological Mapping for Multiple Applications in Kentucky End date: 7/15/2019 FY funding and project total: \$146,639 Funding source: U.S. Geological Survey

Prescription for Radon: County Scale Maps of Geologic Radon PotentialEnd date: 6/30/2019 KGS FY funding: \$3,338 UK project total: \$75,000Funding source: Kentucky Department for Public Health through UK College of Nursing

Hazards

Multi-Jurisdictional Hazard Mitigation Plan for Landslides for the Big Sandy Area Development District End date: 3/22/2021 FY funding: \$28,495 Project total: \$300,212 Funding source: Federal Emergency Management Agency through Kentucky Department of Military Affairs

Seismic Monitoring and Research at the Paducah Gaseous Diffusion Facility End date: 12/31/2019 KGS FY funding: \$7,980 UK 4-year project total: \$1,095,000 Funding source: U.S. Department of Energy through UK Center for Applied Energy Research

Water resources

Aquifer Designation—Kentucky Department of Water: Water Use Program
 End date: 6/30/2019 FY funding: \$77,138 2-year project total: \$94,367
 Funding source: U.S. Geological Survey through Kentucky Energy and Environment Cabinet–Division of Water

Develop a Groundwater Management Tool for Grand Canyon National Park End date: 7/31/2021 FY funding: \$14,989 Project total: \$74,770 Funding source: National Park Service

Groundwater Modeling at the Paducah Gaseous Diffusion Plant

End date: 02/15/2020 FY funding: \$5,090 KGS project total: \$48,710 UK 4-year project total: \$1,095,000

Funding source: U.S. Department of Energy through UK Center for Applied Energy Research

Water resources

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

End date: 12/31/2018 FY funding: \$69,641 2-year project total: \$70,641

Funding source: U.S. Department of Agriculture through The Homeplace on Green River Inc.

Blue Water Farms: Edge-of-Field Water Monitoring in Kentucky Soils End date: 6/30/2019 KGS FY funding: \$27,410 UK 1-year project total: \$200,047

Funding source: Kentucky Soybean Promotion Board through UK College of Agriculture

Nutrient and Sediment Runoff Assessment in the Upper Mississippi River Embayment

End date: 9/15/2022 KGS FY funding: \$30,457 UK 5-year project total: \$2,074,131 Funding source: U.S. Department of Agriculture through Natural Resources Conservation Service through UK College of Agriculture

KGS Annual Report

KGS Director and State Geologist William Haneberg

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