Kentucky Geological Survey

2020-2021 Annual Report

University of Kentucky

Introduction

A Message from the State Geologist:

It was difficult to imagine at the beginning of the last fiscal year in July 2020 that we would just now, in July 2021, be coming back to our offices and labs in full force. The entire KGS staff was outstanding during an uncertain, confusing, and stressful year. Those whose work required them to be in our buildings or in the field followed carefully prepared resumption-of-research plans and safety protocols. Those who could work remotely did so to keep our building occupancy low. Although we suspended a few services such as on-demand printing

of publications, KGS functioned at almost 100 percent capacity during 16 months of largely remote work. I am proud of the things we accomplished under difficult circumstances.

In just a few weeks, I will finish my fifth year as Kentucky's state geologist and KGS director. Our world, our country, and our state have changed during those years and KGS has changed with them. Five years ago, the Cambrian Rogersville Shale in eastern Kentucky and West Virginia seemed like it might be the country's next big unconventional gas play. Depending on your perspective, that could be either very good or very bad for Kentucky. Five years later, that early enthusiasm has evaporated, KGS recently terminated a multimillion-dollar Rogersville research project funded by the U.S. Department of Energy because of insufficient industry interest, and large-scale fracking and shale-gas development won't be coming to Kentucky anytime soon (although, as some will correctly point out, fracking has been occurring here on one scale or another for decades). Regardless of industry trends, KGS will continue as the state's publicly accessible repository for invaluable oil, gas, and water well information useful for a range of research topics related to the rocks beneath our feet. We are adopting archival and data management best practices, constantly refining our interactive web mapping and data services, and striving to make as much information as easily available—at no charge—to as many people as possible.

Although night may have come to the Rogersville, KGS remains busy continuing or initiating research on topics such as rare earth elements in coal, strategic minerals in the Western Kentucky Fluorspar District, compressed-air energy storage, CO2 sequestration, coal-mine methane emissions, geologic controls on indoor radon, Appalachian landslide risk assessment, low-temperature geothermal resources, surficial geologic mapping, and developing a 3-D computer model of Kentucky's geology. We are continuing to create and strengthen innovative research collaborations with colleagues working in fields as diverse as

public health, nursing, rhetoric and science communication, education, engineering, hydrology, ecology, and agriculture. We will also play an important role in the newly established UK Center for the Environment and continue our affiliations with the UK Center for Appalachian Research on Environmental Sciences (funded by the National Institute of Environmental Health Sciences) and the Kentucky Climate Consortium.

Beyond Kentucky, several of our scientists are contributing to U.S. Geological Survey advisory committees related to 3-D geologic mapping, data preservation, and implementation of the recently passed National Landslide Preparedness Act; chairing technical sessions at major conferences; and serving on peer-reviewed journal editorial boards. I am in my second year of an appointment to the National Geospatial Advisory Committee, one of several members appointed to represent the interests of states.

In early July 2020, we mourned the passing of our colleague, Dr. Paul Potter, emeritus professor of geology at the University of Cincinnati. Although Paul was known internationally, his work was rooted in the North American Midcontinent, and he was a great friend of the Indiana, Illinois, Kentucky, and Ohio state geological surveys throughout his career. In 2007, former Director Jim Cobb presented Paul with a “Best Unpaid KGS Employee” award in honor of his many contributions to Kentucky geology. Paul returned the honor many times over through his scientific contributions and, more recently, he left a major financial gift that will allow KGS to offer paid summer internships for geology students to work with us on projects beneficial to Kentucky. We will do our best to honor his generosity and intentions as we implement the program.

In addition to the progress made during the past fiscal year, there have been some setbacks. Cuts to our recurring budget – which supports our mission as a state-mandated program at the University of Kentucky and goes overwhelmingly toward salaries and benefits – during the last fiscal year left no viable option other

than to reduce the size of our permanent staff. We accommodated nearly half of the cuts by not filling two vacancies after retirements and remain in discussions with the University of Kentucky administration about long-term solutions. Regardless of the outcome, we will continue to find ways to work more efficiently, minimize the services we must cut and the research we must curtail, and offer the best value we can to Kentucky.

William C. Haneberg, Ph.D., P.G.

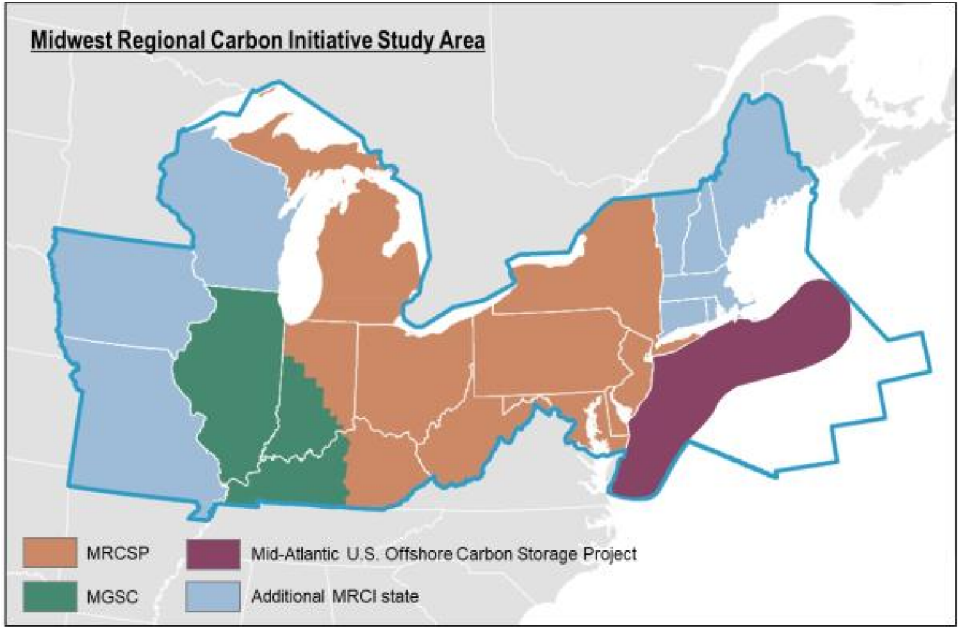
State Geologist and Director

July 2021

Energy and Minerals

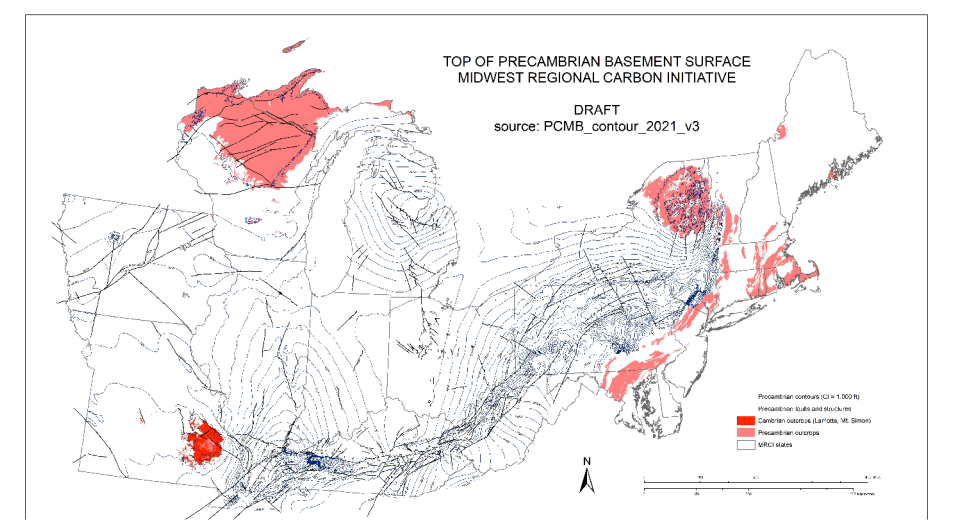
Carbon Storage Research

The Kentucky Geological Survey began work on the Midwest Regional Carbon Initiative this year. The initiative is a U.S. Department of Energy–funded project led by Battelle Memorial Institute and the Illinois State Geological Survey. The goal is to enable the deployment of carbon capture, utilization, and storage in a 20-state region of the Midwest and northeastern United States. The project combines and expands upon two previous regional partnerships in which KGS participated: the Midwest Regional Carbon Sequestration Partnership, which focused on the Appalachian and Michigan Basins, and the Midwest Geologic Sequestration Consortium, which focused on the Illinois Basin. In the new initiative, KGS is working with other state geological surveys, universities, nongovernmental organizations, and industrial partners.



Midwest Regional Carbon Initiative study area covers the areas of the previous Midwest Regional Carbon Sequestration Partnership (brown/orange), Midwest Geological Sequestration Consortium (green), and MidAtlantic U.S. Offshore Carbon Storage Project (purple), as well as new states added to the effort (blue). Used with Permission from Battelle.

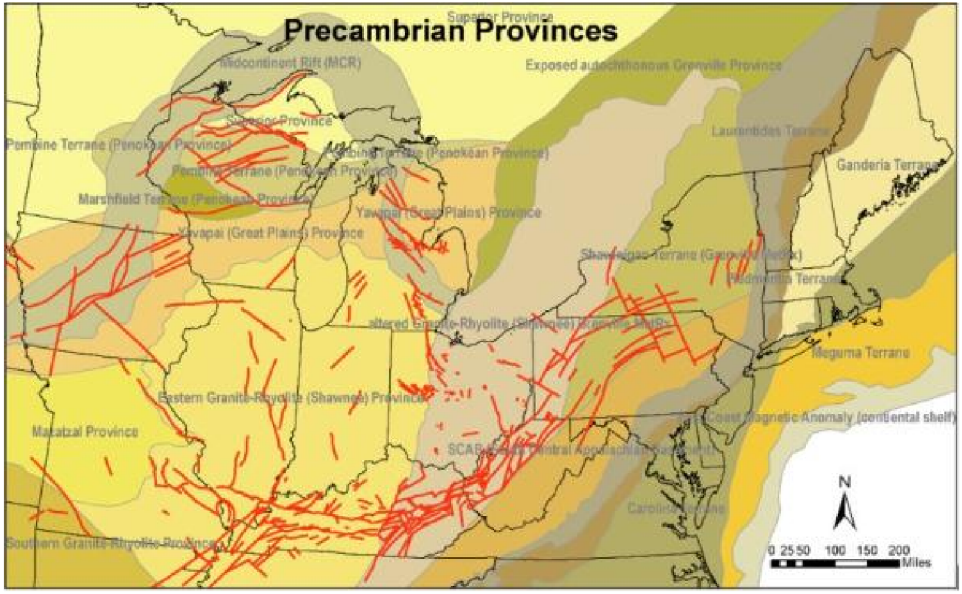
The initiative will consist of multiple tasks covering a wide range of carbon-storage topics. KGS geologist **Steve Greb** is the co-manager of one of the geologic tasks managed by the Kentucky Geological Survey; it focuses on the carbon-storage geology of the region. The region has been divided into several subregions based on regional structure (arches, basins), and the stratigraphy in those subregions is being summarized relative to carbon storage, based on a series of correlation charts and cross sections produced by the previous partnership programs. Digital data and the results from the previous partnerships are also being compiled by the regional team. KGS's **Tom Sparks** merged state and subregional maps of the Precambrian surface, the Cambrian Mount Simon Sandstone and its equivalents, the top of the Cambrian Eau Claire Formation and Conasauga Group, and the top of the Ordovician into regional maps to facilitate the task.



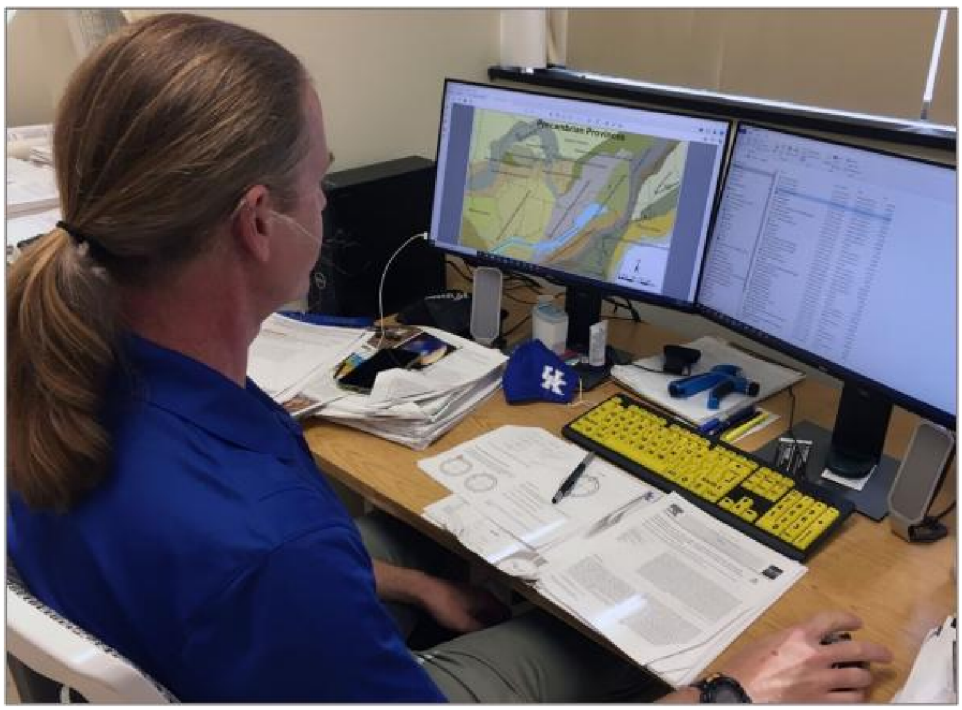
New regional draft Precambrian structure map compiled for the project from the latest Precambrian maps from the previous project areas and a variety of state maps. Click here for references.

Tom Sparks works at his computer on the new Precambrian structure map.

The second part of this task will develop a better understanding of the potential risks of induced seismicity from large-volume carbon storage using data from Precambrian basement, faults, and modern-day stress fields. KGS geologist **John Hickman** created a regional map of Precambrian provinces using GIS techniques and is working with the regional team to collect information about basement rocks and faulting in each state.



Precambrian basement provinces and faulting (in red). Precambrian sedimentary rocks are not shown. Click here for references.



John Hickman works on a map of Precambrian basement provinces and faulting.

KGS seismologist **Seth Carpenter** is working with the regional team on this project. He is compiling data to assess the crustal stability in regions where carbon dioxide sequestration may occur through subsurface injections. Carpenter compiled 160 stress measurements across the central and eastern United States from recently published datasets and datasets contributed by other

project participants. **Carpenter**, **Zhenming Wang**, **John Hickman**, and **Ed Woolery** contributed stress measurements to this compilation using recordings from the temporary Eastern Kentucky Seismic Network operated as part of another Department of Energy project focused on the Rogersville Shale.

More information about the initiative can be found on the website. Click here for references.

Earth MRI: Western Kentucky Fluorspar District

Earth MRI is a U.S. Geological Survey–funded initiative to improve knowledge about the geologic framework in the United States and identify areas that may have potential critical mineral resources. According to the USGS, "Enhancement of our domestic mineral supply will decrease the nation's reliance on foreign sources of minerals that are fundamental to our security and economy (usgs.gov/special-topic/earthmri). KGS is in the second year of a project funded by Earth MRI on the Western Kentucky Fluorspar District, specifically on Hicks Dome, to provide foundational data and information to assess critical minerals in the district. Critical minerals contain elements considered essential to the nation for manufacturing and commerce. Demand for such minerals has been escalating because of their increased use in advanced technology.

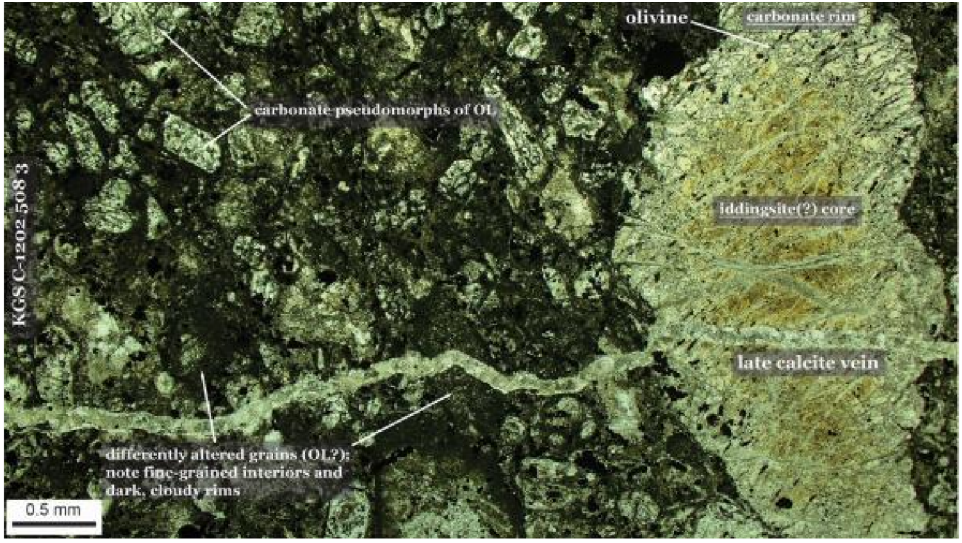
During the 2020-21 fiscal year, several KGS geologists worked on this project. Principal investigator **Gina Lukoczki,** working with **Craig Dietsch** of the University of Cincinnati, selected samples for geochemical analysis and provided petrographic descriptions and petrologic classification of igneous dikes in thin-section photomicrographs. **John Hickman** interpreted recently published geophysical data to locate and identify previously unknown igneous and structural features as shown in the map below **William Andrews** coordinated the preparation and updating of a geologic map of the fluorspar district. **Zachary Walton,** a student employee, organized and cataloged legacy mineral and rock

collections. Another student employee, **Stephanie Vicroy,** is working with the KGS Geoscience Information Management Section to update the Kentucky Minerals Information Map Service.

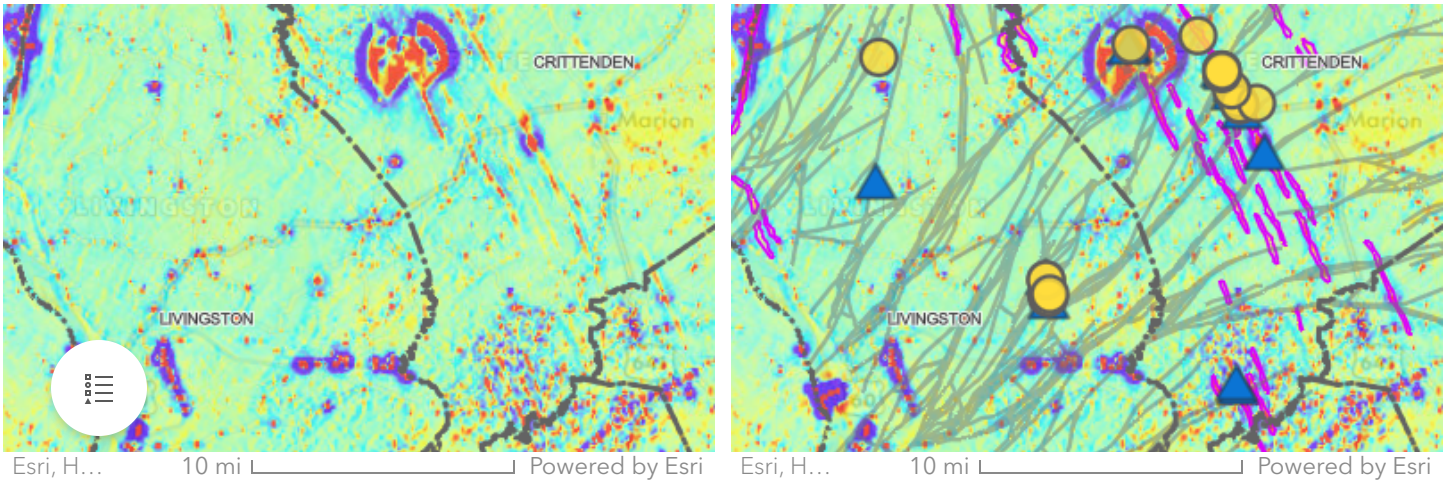
The rare earth element content of the igneous dikes in the district is of particular interest, so current research is focused on providing a better understanding of the occurrence and distribution of REE-bearing minerals in the fluorspar district. The igneous rocks in the district display varying degrees of alteration, and whole-rock geochemical analysis of dike samples indicates the total REE content (including scandium and yttrium) ranges from 37 parts per million up to 605 parts per million. Preliminary interpretation of the geochemical data did not reveal obvious spatial trends in the distribution of the rare earth elements, with regard to distance from assumed igneous centers, such as Hicks Dome in southern Illinois and the Coefield Anomaly in western Kentucky. High-resolution aeromagnetic maps indicate that movement along the pervasive northeast–southwest-trending faults in western Kentucky postdate the emplacement of northwest–southeast-striking igneous dikes. The fluorspar in the district is deposited along these faults, implying that the interaction of later hydrothermal (basin brine) mineralizing fluids with the REE-bearing dikes may have been crucial in remobilizing rare earth elements and allowed further migration of REE-bearing fluids between the fluorspar deposits.

Work in the fluorspar district will continue thanks to a new Earth MRI grant awarded in July 2021. From August 2021–July 2023, we will compile and synthesize geological, geochemical, and mining data into a three-dimensional geologic model and accompanying datasets, which will advance our understanding of the critical mineral potential in this area.

Core BH-2 from Hutson Mine, Livingston County, Kentucky (KGS call no. 1199). Red arrow points to the contact between Mississippian limestone (light gray) and the light brownish green igneous dike. The dike displays complex alteration, including cross-cutting calcite veins.



This thin-section photomicrograph of a light gray igneous dike from the Hutson BH-7 core (Hutson Mine, Livingston County, Kentucky, KGS call no. 1202) shows extensive alteration of the original igneous mineralogy composed of olivine phenocrysts set in a fine-grained matrix. The alteration has at least two phases: hydration of olivine to iddingsite, followed by pervasive alteration of olivine rims and the rock groundmass by carbonate. Late calcite-healed veins crosscut both alteration phases.

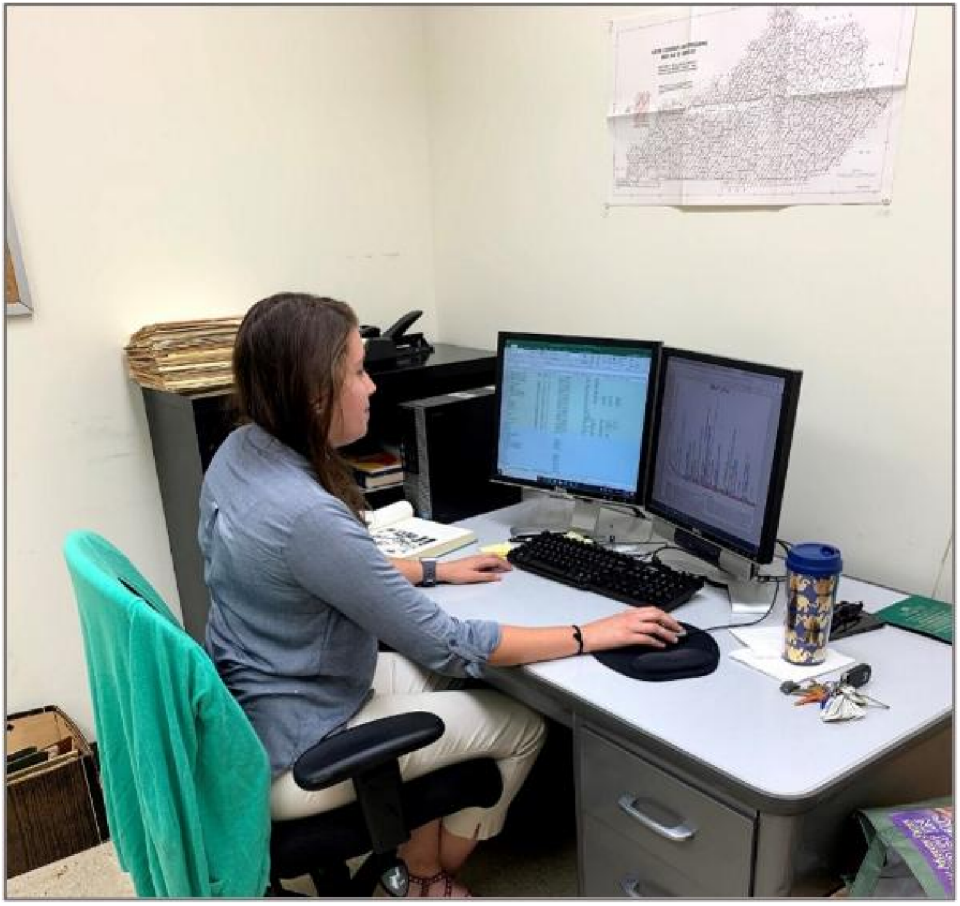


Filtered aeromagnetic data for the Western Kentucky Fluorspar District and surrounding area, from a new USGS survey acquired for the Earth MRI project (McCafferty and Brown, 2020). Use the slider to compare the magnetic data (left-side) with the magnetic data overlain by surface-fault traces (gray lines) and labels for sample locations used in the project (right-side). The Coefield Anomaly is the horseshoe crab–shaped, interpreted igneous feature near the center of the map. A series of north-northwest/south-southeast–striking igneous dikes are evident in Crittenden County (linear features highlighted in purple). (Note that the high-amplitude features along the Mississippi River and what appears as an alternating blue-red line extending to the northeast are from artificial structures and not the local geology.) View a full version of this map.

Reference:

McCafferty, A.E., and Brown, P.J., 2020, Airborne magnetic and radiometric survey, southeastern Illinois, western Kentucky, and southern Indiana, 2019: U.S. Geological Survey data release, https://doi.org/10.5066/P9R05B0M.

KGS student employee **Zachary Walton** organizes and catalogs legacy specimens at the Earth Analysis Research Library.



Stephanie Vicroy, a KGS student employee, organizes archived mining records and related documents.

Water Resources and Geohealth

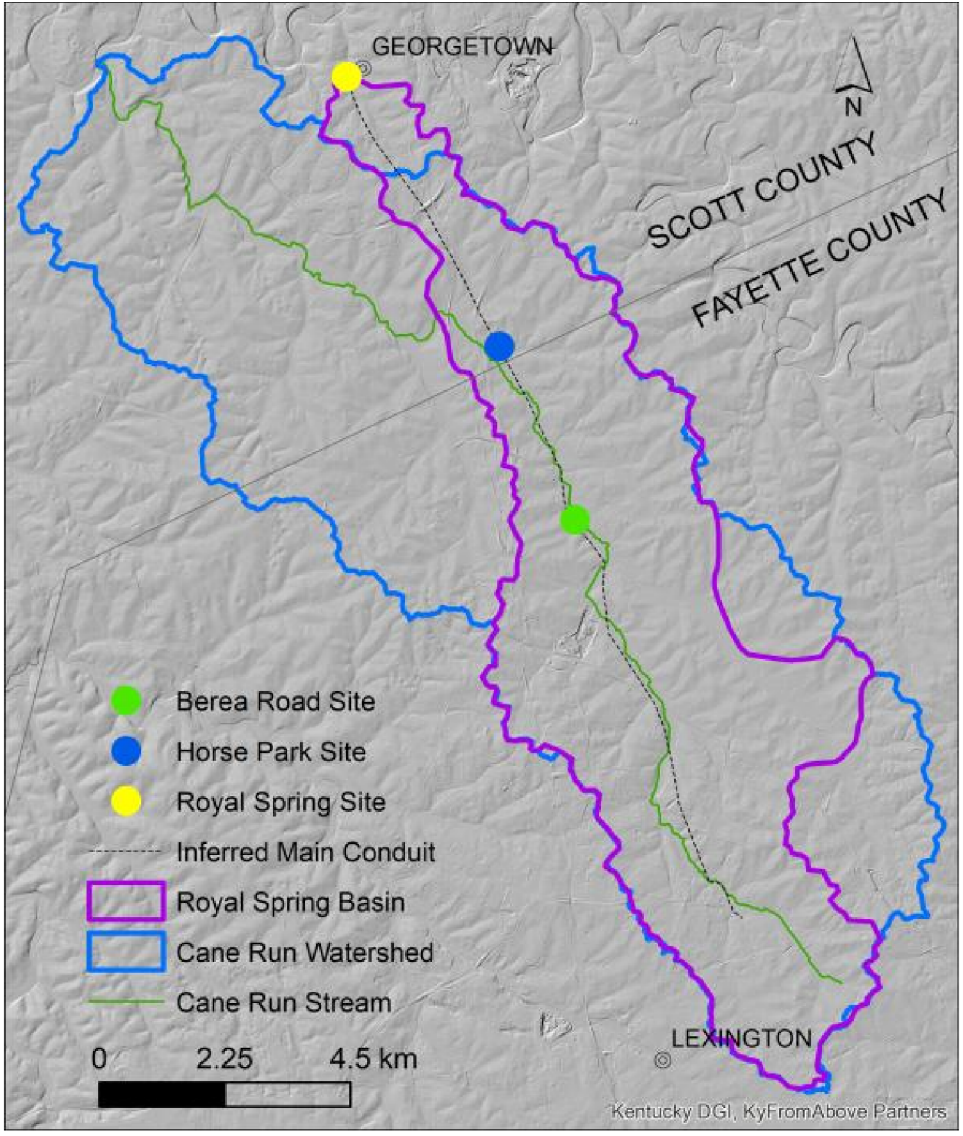
Integrating Traditional and Innovative Approaches to Improve Our Understanding of Karst Aquifers

Karst aquifers provide groundwater for drinking, irrigation, and many other uses to tens of thousands of Kentuckians. They're also important for the sustainability and health of Kentucky's natural surface waters, because karst aquifers and springs are headwaters or major tributaries to many of the commonwealth's streams, rivers, and lakes, and help sustain important aquatic ecosystems. Effective use and protection of karst aquifers is a challenge because of the complexity of the aquifers themselves. The infiltration of precipitation and movement of water through karst aquifers is dominated by subsurface networks of interconnected

fractures and solutional openings, called conduits, that are somewhat analogous to underground streams.

Because of these and other unique hydrogeologic features of karst, data needed for mapping and characterization of karst aquifers are difficult to obtain. Many investigative field methods have been developed and successfully applied to identify various properties of karst aquifers, but these methods generally must be applied in combination, are time intensive, and are often not cost-effective.

KGS hydrogeologist **Junfeng Zhu, Jimmy Fox** of the University of Kentucky Department of Civil Engineering, **Tian-Chyi J. Yeh** from the University of Arizona, and **Anton Kruger** from the University of Iowa have begun collaborating on a multiyear project funded by the National Science Foundation to develop and test a "data-fusion" approach to investigating the internal hydrogeologic structure of a karst aquifer in the Inner Bluegrass. The data-fusion approach combines innovative field techniques that use electrical and hydraulic tomography with more conventional karst investigation methods such as dye-tracing and inverse modeling to image the aquifer structure in three dimensions. The karst aquifer under investigation is the Cane Run–Royal Spring Basin — a 23-square-mile basin extending from north-central Lexington to Georgetown, Kentucky, that collects surface runoff from sinkholes and a sinking stream (referred to as Cane Run) and feeds an underlying karst aquifer that discharges to a municipal spring (Royal Spring). A geologic block diagram shows surface and subsurface karst features common to the Inner Bluegrass Region and the Cane Run–Royal Spring Basin.



The Cane Run–Royal Spring karst basin in the Inner Bluegrass Region of Kentucky.

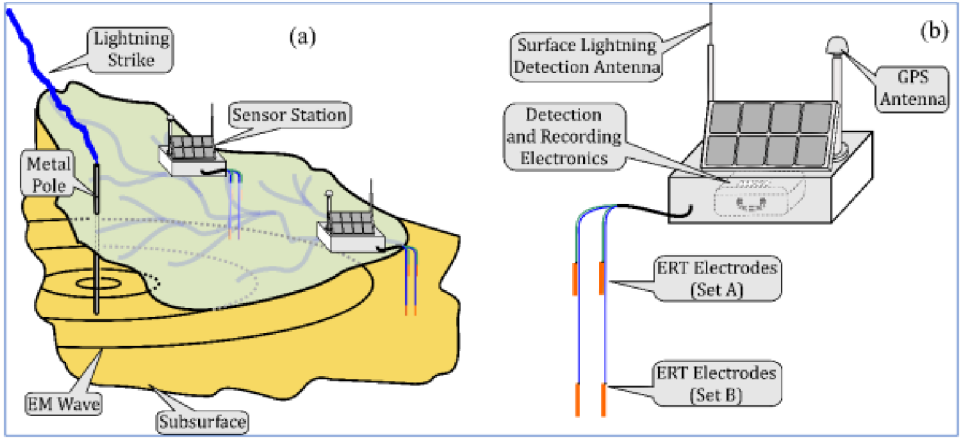
As part of the project funded by the National Science Foundation, KGS employees **Junfeng Zhu** and **Steve Webb** are leading instrumentation of river and conduit-stage tomography, in which 13 transducers and two rain gages will be installed across the basin. The transducers and rain gages will be used to monitor high-frequency, long-term precipitation responses in Cane Run, the basin's surface stream, in the subsurface Royal Spring conduit, and in other parts of the underlying karst aquifer.

A rain gage and pressure transducer monitoring station installed at Cane Run at Spindletop Research Farm. Photo by **Steve Webb.**

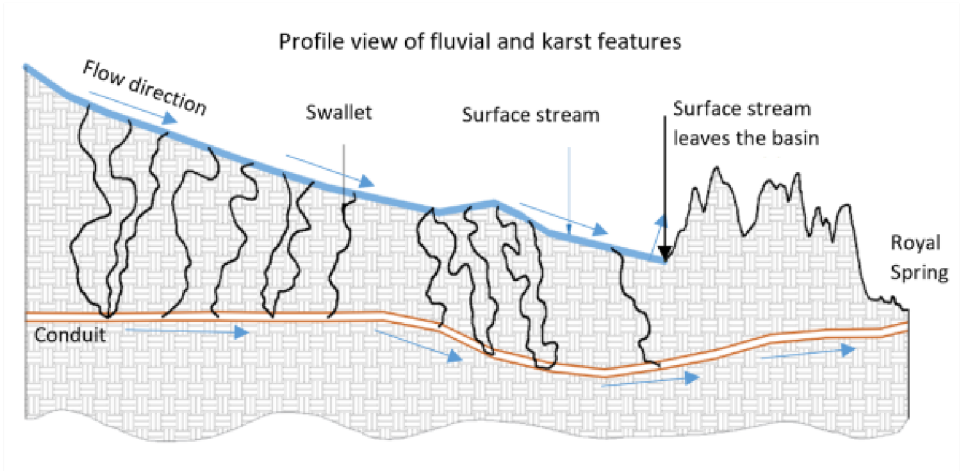
Junfeng Zhu is developing a new type of electrical-resistivity tomography to improve data accuracy and reduce fieldwork. Electrical resistivity of the subsurface is mainly controlled by water stored in soil and rocks, so measuring the electrical resistivity of the subsurface provides a snapshot that reflects the internal hydrogeologic structure of the subsurface. Typically, in an electrical-resistivity survey, electrodes are placed in the ground during the survey, and after the survey is completed, the electrodes are retrieved. **Zhu** has built electrodes that can be left in the ground for a long period and can be reused.

Fieldwork to install permanent electrodes in a sinkhole.

One unique aspect of the data-fusion approach is the implementation of a system of sensors that use ground-lightning strikes as a source of electrical impulses for large-scale electrical-resistivity imaging of the subsurface karst system. A lightning bolt generally contains a wide spectrum of electricity discharges at different frequencies. Electromagnetic waves of higher frequencies decay rapidly over a short distance, but the electromagnetic wave of the low frequencies (about 1 hertz) propagates over longer distances (several miles), with measurable voltages and currents. The project will attempt to use lightning directed into the subsurface to depths of 10 meters via a series of lightning towers and rods as a source of energy for electromagnetic-topographic imaging. The voltages and currents captured by the sensors will be distributed over the basin at different depths, which will provide data equivalent to a snapshot of the distribution of karst conduits within the aquifer. **Anton Kruger** of the University of Iowa is leading this part of the project and developing the sensors needed to monitor the karst aquifer's responses to lightning.



Schematic illustration of the lightning tomography concept and sensor station design.
Image courtesy of **Anton Kruger.** EM=electromagnetic. ERT=electrical resistivity tomography.



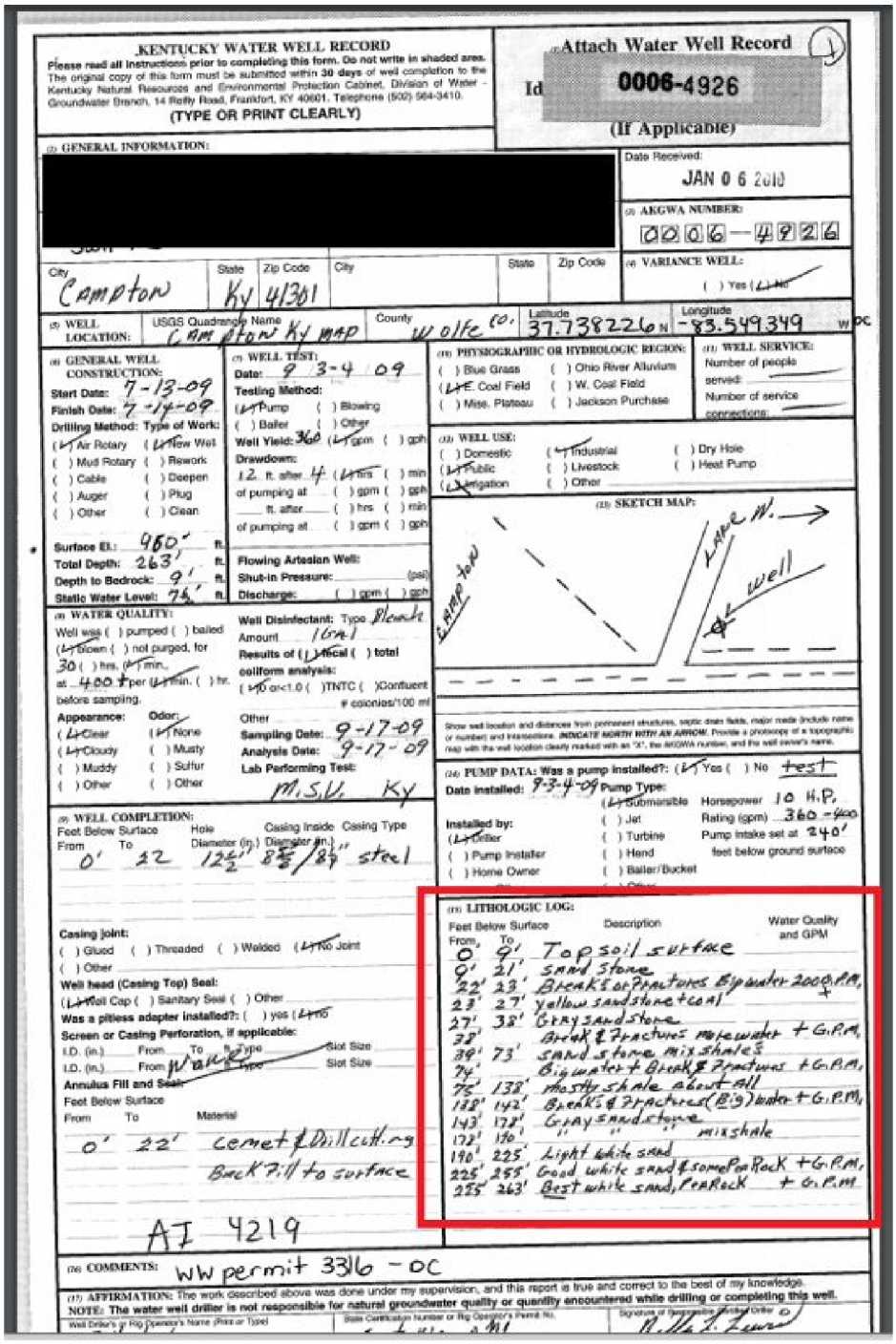
Profile view of major surface and subsurface hydrologic components of the Cane Run–Royal Spring karst basin, as represented in the numerical model Jimmy Fox's group is developing (Al Aamery and others, 2021, https://doi.org/10.1016/j.jhydrol.2020.125844). Used with permission from Elsevier.

Jimmy Fox and students from the UK Department of Civil Engineering are developing a separate model to evaluate the karst-aquifer structure characterized by the data-fusion approach. They're collecting an independent dataset of water flow, water chemistry, sediment, and isotopes for evaluation.

Groundwater-Data Preservation: Importance of Capturing Lithologic Data from Water-Well Construction Records

During the 2019-20 fiscal year, lithologic data in water-well records maintained in the Kentucky Groundwater Data Repository that had not been previously added to the repository were extracted and added to the repository. A grant from the U.S. Geological Survey's National Geological and Geophysical Data Preservation Program funded this project. The original source of these data is the notes made by drillers on official water-well construction forms submitted to the Kentucky Division of Water as required by law under the commonwealth's Water Well Drillers Certification Program. Information recorded in the "Lithologic Log" block on the form (below) includes descriptions of the sediments or rocks encountered during drilling, their top and bottom depths, comments about specific water-bearing zones, the amount of water flowing to the well, or water quality.

Since 1985, the Division of Water and KGS employees have worked together to extract the information on the water-well forms and compile it in electronic records stored and accessed via the Data Repository. Because of a series of state and federal budget reductions, however, cost-cutting measures enacted in 2002 resulted in the compilation of lithologic information being suspended, resulting in a backlog of lithologic data waiting to be extracted from 29,000 well records stored in the Repository.



KENTUCKY WATER WELL RECORD

Please read all instructions prior to completing this form. Do not write in shaded areas. The original copy of this form must be submitted within 30 days of well completion to the Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water - Groundwater Branch, 14 Reilly Road, Frankfort, KY 40601. Telephone (502) 564-3410.

(TYPE OR PRINT CLEARLY)

Attach Water Well Record Id 0006-4926 (If Applicable)

(2) GENERAL INFORMATION: [redacted]

Date Received: JAN 06 2010

(3) AKGWA NUMBER: 0006-4926

City: Campton | State: Ky | Zip Code: 41301 | City | State | Zip Code

(4) VARIANCE WELL: ( ) Yes (Lno)

(5) WELL LOCATION: USGS Quadrangle Name: Campton Ky map | County: Wolfe Co. | Latitude: 37.738226 N | Longitude: -83.549349 W DC

(6) GENERAL WELL CONSTRUCTION: Start Date: 7-13-09 | Finish Date: 7-14-09 | Drilling Method: (Lx) Air Rotary ( ) Mud Rotary ( ) Cable ( ) Auger ( ) Other | Type of Work: (Lx) New Well ( ) Rework ( ) Deepen ( ) Plug ( ) Clean | Surface El.: 960' ft. | Total Depth: 263' ft. | Depth to Bedrock: 9' ft. | Static Water Level: 75' ft.

(7) WELL TEST: Date: 9-3-09 | Testing Method: (Lx) Pump ( ) Bailer ( ) Blowing ( ) Other | Well Yield: 360 (Lx) gpm ( ) gph | Drawdown: 12 ft. after 4 (Lx) hrs ( ) min of pumping at ( ) gpm ( ) gph; ft. after ( ) hrs ( ) min of pumping at ( ) gpm ( ) gph | Flowing Artesian Well: Shut-in Pressure: (psi) Discharge: ( ) gpm ( ) gph

(10) PHYSIOGRAPHIC OR HYDROLOGIC REGION: ( ) Blue Grass ( ) Ohio River Alluvium (Lx) E. Coal Field ( ) W. Coal Field ( ) Miss. Plateau ( ) Jackson Purchase

(11) WELL SERVICE: Number of people served: Number of service connections:

(12) WELL USE: ( ) Domestic (Lx) Industrial ( ) Dry Hole (Lx) Public ( ) Livestock ( ) Heat Pump (Lx) Irrigation ( ) Other

(13) SKETCH MAP: Lake W. well ramp to

(8) WATER QUALITY: Well was ( ) pumped ( ) bailed (Lx) blown ( ) not purged, for 30 ( ) hrs. (Lx) min., at 400 ± per (Lx) min. ( ) hr. before sampling. Appearance: (Lx) Clear (Lx) Cloudy ( ) Muddy ( ) Other | Odor: (Lx) None ( ) Musty ( ) Sulfur ( ) Other | Well Disinfectant: Type Bleach Amount 10 ml | Results of (Lx) local ( ) total coliform analysis: (Lx) 0 or <1.0 ( ) TNTC ( ) Confluent # colonies/100 ml | Other | Sampling Date: 9-17-09 | Analysis Date: 9-17-09 | Lab Performing Test: M.S.U. Ky

Show well location and distances from permanent structures, septic drain fields, major roads (include name or number) and intersections. INDICATE NORTH WITH AN ARROW. Provide a photocopy of a topographic map with the well location clearly marked with an "X", the AKGWA number, and the well owner's name.

(14) PUMP DATA: Was a pump installed?: (Lx) Yes ( ) No test | Date installed: 9-3-09 | Pump Type: (Lx) Submersible ( ) Jet ( ) Turbine ( ) Hand ( ) Bailer/Bucket | Horsepower 10 H.P. | Rating (gpm) 360 - 400 | Pump intake set at 240' feet below ground surface | Installed by: (Lx) Driller ( ) Pump Installer ( ) Home Owner

(9) WELL COMPLETION: Feet Below Surface From 0' To 12' | Hole Diameter (in.) 12½" | Casing Inside Diameter (in.) 8⅝/8" | Casing Type steel

Casing Joint: ( ) Glued ( ) Threaded ( ) Welded (Lx) No Joint ( ) Other

Well head (Casing Top) Seal: (Lx) Well Cap ( ) Sanitary Seal ( ) Other

Was a pitless adapter installed?: ( ) yes (Lx) no

Screen or Casing Perforation, if applicable: I.D. (in.) From To Type Slot Size | I.D. (in.) From To Type Slot Size

Annulus Fill and Seal: Feet Below Surface From 0' To 22' Material: cement & Drill cuttings | Back Fill to surface

AI 4219

(15) LITHOLOGIC LOG:

Feet Below Surface From	To	Description	Water Quality and GPM
0'	9'	Top soil surface	
9'	21'	sand stone	
22'	23'	Break's & Fractures Big water 200 G.P.M. ±	
23'	27'	yellow sandstone + coal	
27'	38'	Gray sandstone	
38'		Break & Fractures more water + G.P.M.	
39'	73'	sand stone mix shales	
74'		Big water + Break & Fractures + G.P.M.	
75'	138'	mostly shale about all	
138'	142'	Break's & Fractures (Big) water + G.P.M.	
143'	172'	Gray sand stone	
172'	190'	" " mix shale	
190'	225'	Light white sand	
225'	255'	Good white sand & some Pea Rock + G.P.M.	
255'	263'	Best white sand, Pea Rock + G.P.M.	

(16) COMMENTS: WW permit 3316 - DC

(17) AFFIRMATION: The work described above was done under my supervision, and this report is true and correct to the best of my knowledge. NOTE: The water well driller is not responsible for natural groundwater quality or quantity encountered while drilling or completing this well.

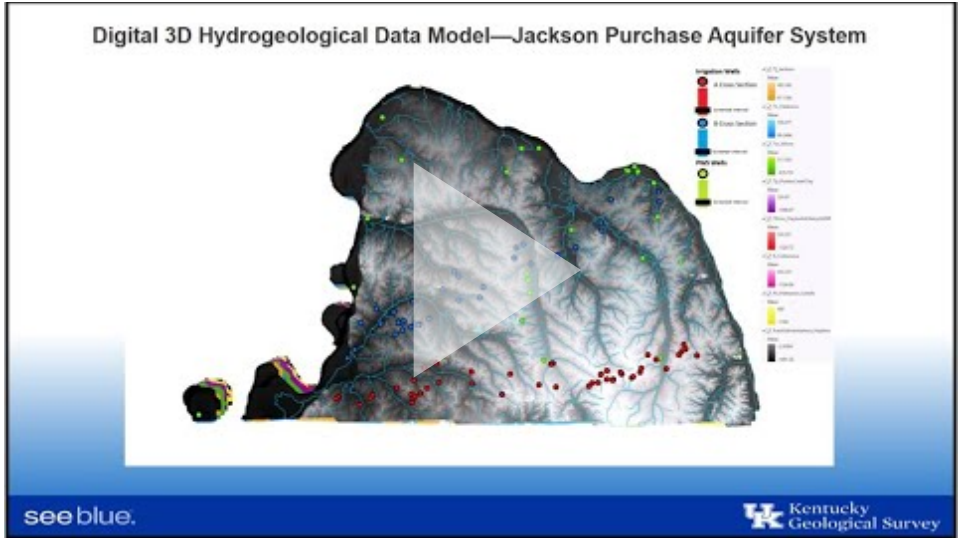
Well Driller's or Rig Operator's Name (Print or Type) | State Certification Number or Rig Operator's Permit No. | Signature of Responsible Driller or Rig Operator

A Kentucky water-well record.

From September 2019–August 2020, student employee **Scott Anderson,** working under the supervision of KGS hydrogeologist and Groundwater Data Repository Manager **Sarah Arpin,** helped to address the backlog, starting with a set of records from 17,000 high-priority well locations. A database was created in which to store the retrieved data. A review of 7,602 well records indicated that lithologic data could not be captured from all of them. Handwriting on many forms was difficult to decipher, which

slowed progress, and 1,860 records were rejected because they did not contain any written lithologic data at all. In spite of these challenges, useful lithologic data was compiled for 5,742 wells; these data are undergoing final checks for quality assurance before being uploaded to the Repository. KGS received additional grant funding through the National Geological and Geophysical Data Preservation Program to extend the project to fiscal year 2021-22 and continue this critical data compilation effort.

Capturing this information from the water-well construction forms and enhancing the digital data stored in and accessed through the Groundwater Data Repository are critical to the success of present and future efforts by KGS to characterize groundwater availability and sustainability. Water-well data obtained by projects such as this one help KGS apply 3-D mapping technology to identify and map local and regional aquifers and vital groundwater resources. For example, well-construction and lithologic data can be used to create visual 3-D hydrogeologic models; as shown by the accompanying video animation, this preliminary model is of the multilevel aquifer system in the Jackson Purchase Region. The rotating block model shows the stratigraphic configuration of aquifer zones and confining units, the locations of selected water wells used for public water supplies and irrigation, and the relative depths and screened intervals of these wells.



Click on this video to learn more about the preliminary model of the multilevel aquifer system in the Jackson Purchase Region.

Geohealth

KGS continued to foster innovative transdisciplinary collaborations in the emerging field of geohealth during the fiscal year, including active participation in the five-year citizen-science research project, Radon on the RADAR (*R*esidents *A*cting to *D*etect and *A*lleviate *R*adon), funded by the National Institute for Environmental Health Sciences (NIEHS). **Ellen Hahn,** a professor in the University of Kentucky Colleges of Nursing and Public Health, is the principal investigator and KGS Director **Bill Haneberg** is one of the project co-investigators. As part of the study, a team of KGS geologists collected soil-radon measurements at 60 homes in Rowan, Pulaski, Logan, and Christian Counties for comparison with parallel indoor-radon measurements obtained by citizen-scientist residents. KGS employees **Sarah Arpin, Jason Backus, Andrea Connor, Matt Crawford, Sydney Gutierrez-Gomez, Steve Webb,** and **Amy Wolfe** helped measure soil radon for the project.

Several years of collaborative research with UK College of Nursing's BREATHE program (Bridging Research Efforts and Advocacy Toward Healthy Environments) culminated in the publication of a paper, "A Geologically Based Indoor-Radon Potential Map of Kentucky," in the journal GeoHealth. The open-

access research article discusses the creation of a geologically based indoor-radon potential map for Kentucky and includes a detailed statistical analysis of lithologic controls on observed radon values. **Bill Haneberg** was the lead author of the paper, and KGS geologists **William Andrews**, **Doug Curl**, and **Steve Greb** were among the paper's co-authors. This publication, and ongoing research, were also recently featured in an article in the American Geophysical Union's *Eos* news magazine, "Detailed Geologic Mapping Helps Identify Health Hazards."

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The work described in the *GeoHealth* paper prompted additional questions about intraformational radon variability. **Bill Haneberg** was recently awarded a 2021 UK Center for Appalachian Research in Environmental Sciences Innovation and High Impact award to use drone-compatible gamma spectrometer to investigate the effect of geologic features such as faults and sinkholes on the spatial variability of radon levels in soil. He is working with KGS geologists **William Andrews** and **Matt Crawford**; **Alex Thomas**, a graduate student in the UK Department of Earth and Environmental Sciences; and UK College of Nursing assistant professor **Stacy Stanifer** on the project.

Could anything be better than using a drone to map radon potential? How about designing a comic book? Working with the BREATHE team, **Bill Haneberg** and **Amy Wolfe** helped to create and develop a comic book to communicate radon risks to a wide audience. The creative process and impacts of the comic book will be presented during the upcoming 2021 American Public Health Association annual meeting and expo (Oct. 24–27, 2021). The comic book, titled "Invisible Enemy: The Rise of Radon," is a KGS first and available online through the KGS website; printed copies are also available upon request.

KGS geologist **Amy Wolfe** is continuing to develop a geohealth-focused geospatial database on geohealth, building on pilot funding awarded by the UK Center for Appalachian Research in Environmental Sciences in 2020. The database will support future research efforts to understand exposure pathways and clarify relationships between contaminant exposure, risk factors, and health outcomes. Wolfe served as a panel member and presented preliminary findings at the 2021 John P. Wyatt, M.D. Environment & Health Symposium, sponsored by the University of Kentucky. She also presented her work at the 2021 KGS annual seminar.

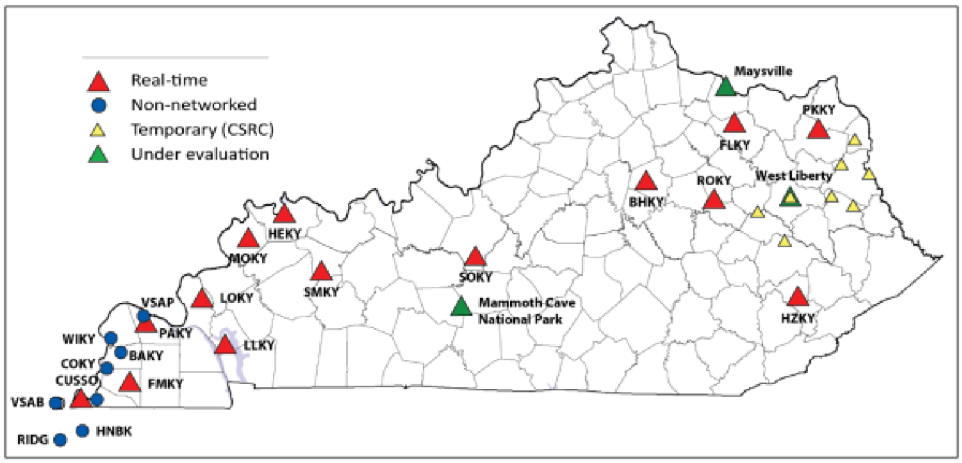
Geologic Hazards

Kentucky Seismic and Strong-Motion Network

The Geologic Hazards Section operates and maintains the Kentucky Seismic and Strong-Motion Network, which comprises 22 permanent seismic and strong-motion stations and monitors earthquakes in and around the commonwealth. During the 2020-21 fiscal year, 19 earthquakes, with magnitudes ranging from 0.4 to 2.4, were located within the state, eight of which occurred in the New Madrid Seismic Zone in western Kentucky and five of which occurred in the Eastern Tennessee Seismic Zone in eastern Kentucky. Temporary seismic stations operated by KGS as part of research by the Conasauga Shale Research Consortium facilitated

detecting four events beneath or near the Rome Trough that were not detected by other agencies.

KGS maintained a data share of real-time Network recordings from 14 of its seismic stations with the neighboring seismic network operated by the University of Memphis and with the Data Management Center at Incorporated Research Institutions for Seismology for archiving and global usage. More than 1.3 terabytes of Kentucky Seismic and Strong-Motion Network data were downloaded from IRIS this fiscal year for use around the globe.



Locations of stations in the Kentucky Seismic and Strong-Motion Network. Yellow triangles represent the temporary stations operating as part of the Conasauga Shale Research Consortium. KGS established and started evaluating three new, permanent stations this fiscal year, shown as green triangles.

This year, KGS began evaluating the viability of three sites in the state for new, permanent seismic stations: Maysville, West Liberty, and Mammoth Cave National Park. The Maysville site, previously operated by St. Louis University but decommissioned in recent years, will provide important data to help characterize the changes seismic waves undergo in near-surface, soft deposits such as those found in this river-valley setting. The site in West Liberty previously hosted station EK22, which KGS operated as part of the Eastern Kentucky Microseismic Monitoring Project and the Conasauga Shale Research Consortium. This station will help to fill in a gap in earthquake-monitoring coverage in eastern Kentucky. In collaboration with Mammoth Cave National Park,

IRIS's PASSCAL (Portable Array Seismic Studies of the Continental Lithosphere), and Nanometrics Inc. In Mammoth Cave, KGS began work to identify a quiet location to install extremely sensitive seismic instruments. The park station fills in another monitoring gap in Kentucky and, as KGS seismologists **Seth Carpenter, Jon Schmidt,** and **Zhenming Wang** observed through noise tests conducted at four sites in the cave system, it provides a seismically quiet setting: The noise levels are low enough to operate some of the most sensitive seismic instruments. **Hunter Abshire,** a Paul Laurence Dunbar High School student from Lexington, helped KGS identify the quietest of the four sites by comparing regional and global earthquake recordings made at each site for his senior research Math, Science, and Technology Center project.

Seth Carpenter (right) and **Jon Schmidt** install a temporary seismic station in Miller Avenue of Mammoth Cave National Park. Photo by **Zhenming Wang.**

This year, **Ron Street, Zhenming Wang, Seth Carpenter,** and **Ed Woolery** authored a KGS Special Publication, "The Kentucky Seismic and Strong-Motion Network: History, Service, and Research," which summarizes the development of the network and its service to the commonwealth of Kentucky and the students at the University of Kentucky.

U.S. Geological Survey NEHRP Research Grant—Site Response in the Central United States

KGS employees **Seth Carpenter** and **Zhenming Wang,** along with **Ed Woolery** of the UK Department of Earth and Environmental Sciences, continued to study ground-motion site response in the New Madrid and Wabash Valley Seismic Zones; the research is funded by the USGS through the National Earthquake Hazards Reduction Program. They collected seismic soundings at 11 seismic stations that have previously recorded earthquake ground motions, and developed subsurface velocity structures for each site, which are needed to model the effects of the near-surface geologic layers on seismic waves (i.e., site response).

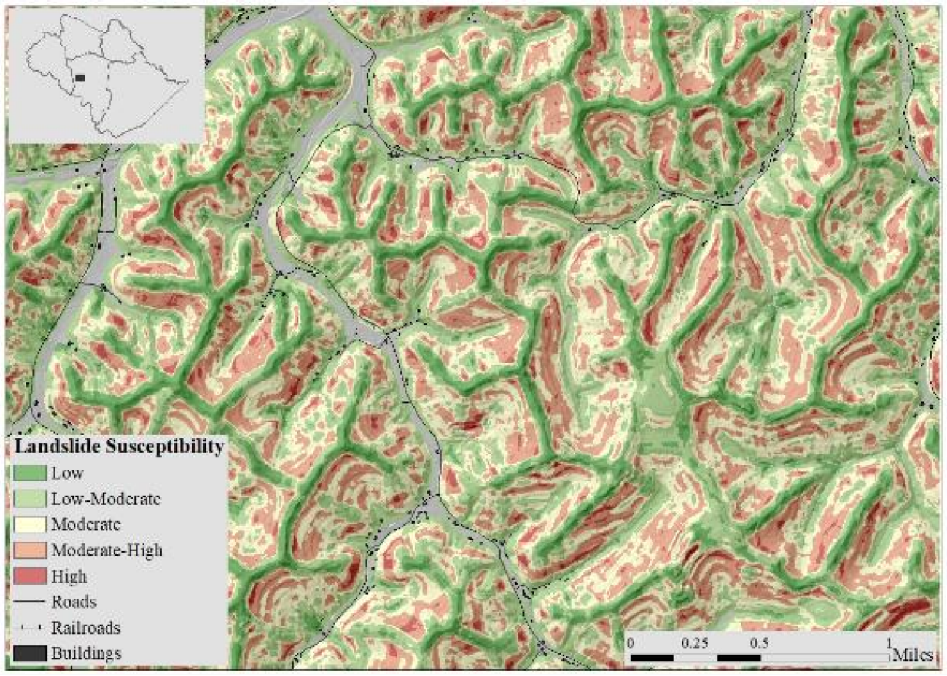
Using the velocity structures in western Kentucky developed as part of this NEHRP project and others available in KGS reports and publications, **Yichuan Zhu,** Wang, Carpenter, Woolery, and **Bill Haneberg** published an article in the *Bulletin of the Seismological Society of America*, "Mapping Fundamental-Mode Site Periods and Amplifications From Thick Sediments: An Example From the Jackson Purchase Region of Western Kentucky," in May 2021. The authors developed site-resonance maps, which they demonstrated are more reliable to estimate site response than the proxy currently used for engineering purposes.

Ed Woolery (left) and **Zhenming Wang** collect seismic-sounding data at Station T45B near Paducah. Photo by **Seth Carpenter.**

Pre-Disaster Mitigation Grant for Landslide Hazard and Mitigation in the Big Sandy Area Development District

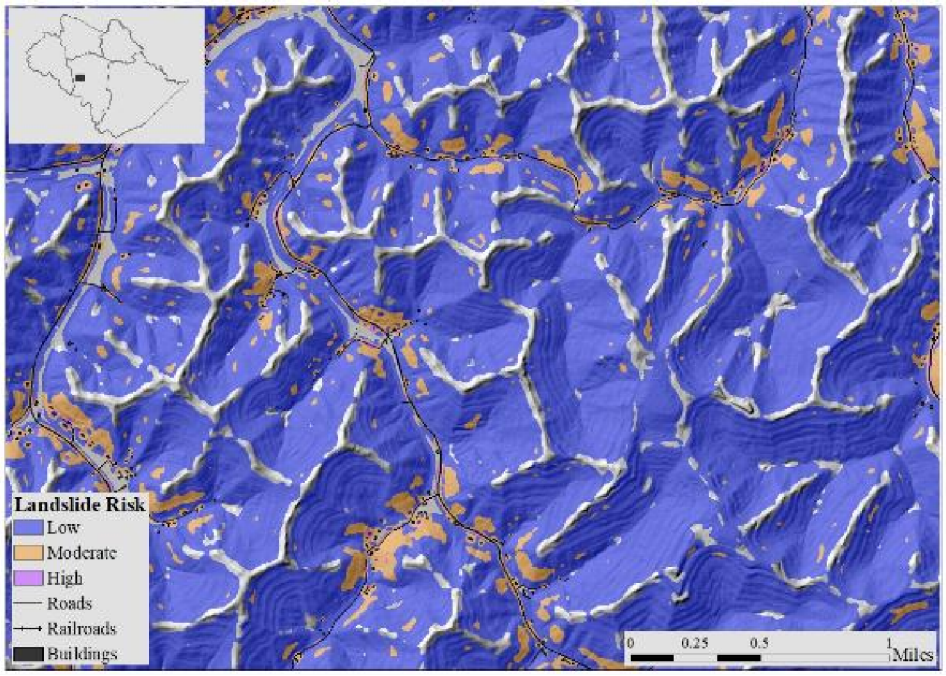
Matt Crawford, Hudson Koch, Jason Dortch, and **Yichuan Zhu** continue to work on a project to assesses landslide hazard and risk to identify vulnerable areas and determine the potential impact of landslides on the built environment in the Big Sandy Area Development District; the project is funded by a pre-disaster mitigation grant from the Federal Emergency Management Agency. The most important part of the project is to communicate the resulting information and share maps with stakeholders. A hybrid machine-learning approach was developed and applied to produce geomorphic-based landslide-susceptibility maps. Crawford and his research partners divided the landslide-susceptibility maps into five classes to increase their usefulness: low (which constituted 15.0 percent of the maps), low–moderate (70.7 percent), moderate (23.4 percent), moderate–high (13.9 percent), and high (3.7 percent).

Crawford, Dortch, Koch, **Ashton Killen**, **Junfeng Zhu, Yichuan Zhu,** Lindsey Bryson of the UK Department of Civil Engineering**,** and **Bill Haneberg** co-authored a paper, "Using Landslide Inventory Mapping for a Combined Bagged Trees and Logistic Regression Approach to Determine Landslide Susceptibility in Eastern Kentucky," published in the *Quarterly Journal of Engineering Geology and Hydrogeology.*



A geomorphic-based landslide-susceptibility map for part of Floyd County, Kentucky, produced using the technique from **Crawford** and others' paper published in the *Quarterly Journal of Engineering Geology and Hydrogeology*.

The project team performed a static and socioeconomic risk assessment to estimate potential landslide effects on population, roads, railroads, buildings, and land. The team combined vulnerability and consequence data with landslide-susceptibility data to calculate a risk factor. The resulting risk factors are classified as low (70.7 percent), moderate (11.1 percent), or high (1.5 percent). These percentages are based on the total area. The maps and data will be incorporated into hazard-mitigation plans that implement measures to improve spatial assessment of landslide hazards, land use and development, transportation, critical facilities, and safety.



Part of a landslide risk map for Floyd County, Kentucky.

The project ended in March 2021, but a no-cost extension through April 2022 has been granted to cover a few final tasks and ensure we provide project deliverables to stakeholders. Deliverables include landslide-susceptibility and risk maps, GIS files, and the final report, "Multi-Jurisdictional Hazard Mitigation Plan for Landslides for the Big Sandy Area Development District, Kentucky," which will be part of the district's hazard-mitigation plan.

Other work related to landslide hazards includes development and submission of a hazard-mitigation plan to the Federal Emergency Management Agency for the Kentucky River Area Development District; continued collection and compilation of data for the landslide inventory database for Kentucky; collaboration with U.S. Geological Survey staff and other researchers on the national landslide inventory; and collaboration with USGS staff and other researchers on the development of a uniform approach for mapping landslide susceptibility that can be implemented across the United States.

Crawford obtained a remote pilot certification from the Federal Aviation Administration to take part in a wide range of KGS

projects that will use the KGS unmanned aerial vehicle. He has been working with **Sarah Johnson,** a faculty member at Northern Kentucky University and current doctoral student in the University of Kentucky Department of Earth and Environmental Sciences, to characterize landslides in northern Kentucky using LiDAR-based terrain models and to detect changes in the landscape over time with repeated UAV flights.

Matt Crawford acquires LiDAR-based terrain data with a UAV in northern Kentucky. Photo by **Sarah Johnson.**

A landslide/river band collapse in Pike County, Kentucky, in April 2021. Photo by **Matt Crawford.**

Collaborations within and outside of the University of Kentucky

The Geologic Hazards Section collaborates in two U.S. Department of Energy projects with colleagues in the KGS Energy and Minerals Section as well as outside agencies. Click here to learn how KGS seismologists contributed to the Conasauga Shale Research Consortium project. The Geologic Hazards Section hosts a meeting every other week of a working group studying landslides and collaborates with the University of Kentucky's Department of Earth and Environmental Sciences, Department of Civil Engineering, and Center for Applied Energy Research. The Hazards section is also working on projects with the U.S. Geological Survey, the University of Missouri, and the University of Laussane. KGS is collaborating with UK's Department of Civil Engineering on a project funded by the Kentucky Space Grant. Read more about this project.

Geologic Mapping

STATEMAP Surficial Geologic Mapping

The field mapping team in the KGS Geologic Mapping Section completed four new 7.5-minute surficial geologic maps for quadrangles in central Kentucky during the 2020-21 fiscal year as part of the U.S. Geological Survey's STATEMAP program. KGS geologists continue to provide this detailed surficial information for the rapidly developing Interstate 65 corridor and Hardin County area. KGS geologists **Antonia Bottoms**, **Max Hammond**, and **Matt Massey** completed the project on time despite a delayed start date because of the COVID-19 pandemic. The new maps, as well as the digital dataset that contains all geologic data collected and used for the project, are currently being reviewed for publication.

Geologists in the Geologic Mapping Section recently began another mapping project that will complete surficial geologic mapping in Hardin County and provide reconnaissance mapping of Warren County. STATEMAP also funded this project, marking

the third consecutive year of increased financial support, and the largest award amount KGS has received through the STATEMAP program. The mapping project will include a field-mapping component led by Massey in cooperation with **Ann Hislop,** Bottoms, and Hammond. **Jason Dortch** will lead landscape modeling efforts, and **Matt Crawford** will assist with this part of the project. The landscape modeling will use LiDAR-derived digital-elevation datasets with new geochronology to automate the identification of surface features, create a surficial model of Warren County, improve our understanding of the rate of block-fall and landslide hazards in Hardin County, and increase the efficiency of future field mapping projects. Field mapping for Hardin County will be completed in the summer of 2022 and will continue to expand lithologic characterization, digital data standardization, and interoperability.

KGS received additional funding from STATEMAP to undertake several GIS standardization projects, coordinated by **William Andrews.** KGS geologist **Tom Sparks** and University of Kentucky student worker **Alex Thomas** used digital geologic map data on file at KGS to create a statewide bedrock map and converted the digital data into a U.S. Geological Survey standard format known as Geologic Map Schema, or GeMS. KGS geologist **Ann Hislop** compared geologic map units and contacts on the KGS 1:500,000-scale geologic map of Kentucky with state geologic maps in adjacent states.

Reference

Noger, M.C. (comp.), 1988, Geologic map of Kentucky--Sesquicentennial edition of the Kentucky Geological Survey: Miscellaneous Map, series 11, scale 1:500,000, 1 sheet, (Compiled from the "Geologic Map of Kentucky" (scale 1:500,000, 1981, U.S. Geological Survey) by Robert C. McDowell, George J. Grabowski Jr., and Samuel L. Moore).

Surficial Mapping Data

Surficial geologic mapping data are now available for Boone, Kenton, and Campbell Counties in northern Kentucky, as well as for Hardin County, our most recent mapping area, on the KGS Geologic Map Information Service. New mapping projects and previous mapping data will be added regularly to the service.

Fractures and Arches

KGS geologist **Steve Martin** is creating a database on joints and natural arches for the KGS Geologic Map Information Service that contains the location and orientations for joints. The information in the database is based on the data created when the geologic quadrangle maps for Kentucky were digitized from 1996 to 2004. The database also includes joint measurements from research projects and theses focused on Kentucky. Locations and measurements of natural rock openings, such as span, clearance, width, and related joint orientations, are in a related database on natural arches. Locations of natural arches that are on public property and are easily accessible by a trail or road can be displayed via the KGS website. Martin is also working with citizen scientists to compile natural-arch locations in the state and expand the information in that database.

In addition, Martin is working with Riverlands Alliance, a nonprofit organization promoting natural areas in western Tennessee and Kentucky, to create an Interactive Tour of Mantle Rock in Livingston County, Kentucky.

Geoscience Information Management

Updates to the KGS Website

Research data, maps and publications, databases, and other information is available on our website for researchers and the general public. The main KGS website (www.uky.edu/KGS) primarily hosts content with information about KGS research, education, and general geology. The website had more than

333,000 visits from 257,000 unique users originating from 201 countries during the past fiscal year. This was an increase of 13 percent in visits and close to a 10 percent increase in unique visitors over the 2019-20 fiscal year. Most visits were from the United States, and most users were from Kentucky (25 percent). Along with the main KGS webpage, pages with information about rocks and minerals, fossils, coal, the Kentucky Seismic and Strong-Motion Network, and maps and GIS were the most frequently visited.

KGS provides free online access to a vast array of Kentucky geologic data, including oil and gas records and data, water-well and springs data and documents, coal information, non-coal minerals data, geologic maps and associated data, publications, images, and other geologic data, now totaling more than 6.6 million records. KGS recently branded this part of the website "KYGeode" (kgs.uky.edu/kygeode), and along with webpages that allow users to find data through 17 data-search sites, KYGeode also includes 27 interactive map services, such as the redesigned Geologic Map Information Service (fiscal year 2019-20) and seven Interactive Tours.

During the past fiscal year, more than 131,000 visits originating from 143 countries were made to KYGeode, which was an increase of more than 60 percent over the 2019-20 fiscal year. Most visitors using KYGeode originated from the United States, and the top five states for KYGeode users were Kentucky, Georgia, Indiana, Ohio, and Texas. More than 84,000 users conducted approximately 110,000 database searches, which was an increase of 130 percent in users over last fiscal year, although the number of searches conducted was similar to last fiscal year.

KGS users downloaded more than 1.3 million files from our website, including data text files, well and elog documents, and KGS publications and presentations. Oil and gas records, water-well and springs data, online publications, coordinate conversion

services, and data from the geologic map server continue to be the most frequently downloaded data.

The online map services were accessed nearly 80,000 times, a slight decrease from the previous fiscal year. The most popular map service continues to be the Kentucky Geologic Map Information Service, accessed more than 41,000 times. The next-most-popular map services were for water wells and springs, Kentucky minerals information, Kentucky Watershed Watch, and KGS Interactive Tours.

Click here to view the fiscal year report for the KGS website.

Social-Media Metrics

The Kentucky Geological Survey uses five social-media platforms, primarily LinkedIn, Facebook, and Twitter. We use Instagram for particularly interesting photographs and YouTube for videos about KGS and our employees at work. Throughout the year, we've increased the number of posts and implemented new strategies such as posting frequently on Fridays about the work KGS employees are doing in the field.

KGS's presence on LinkedIn has grown over the past year and has reached a total of 669 followers. During the fiscal year, 229 new users started following our LinkedIn page. The majority of these followers are located in Lexington, Louisville, and Cincinnati. Other areas of the United States where we have a significant number of followers include Houston, Pittsburgh, and the Greater Denver area. Our overall engagement rate for the fiscal year is 6.58 percent, and we had a total of 170 posts or announcements. The engagement rate is calculated as clicks + likes + comments + shares + follows divided by impressions. (Impressions are views that occur when the update is at least 50 percent on screen, or when it is clicked.) The month with the most impressions was May 2021. Our engagement rates were highest during March, April, and June 2021. The majority of visitors to KGS social media are in the

fields of research (33.0 percent), media and communication (18.3 percent), and information technology (10 percent).

Our followers on Facebook are a combination of professionals in geology and related fields and interested community members. KGS's Facebook page gained 319 followers, and had a total of 1,994 followers at the end of the fiscal year. Over the course of the fiscal year, the KGS Facebook page reached 42,578 people, which was an increase of 26.8 percent. One post in June 2021 that focused on a KGS employee doing fieldwork reached 2,474 people, with 154 reactions, and 85 post clicks, or the number of times a post was opened.

Many of our 2,027 Twitter followers are scientists and scientific organizations such as other geological surveys. During the fiscal year, KGS tweets were viewed 159,600 times. One of our top tweets, with 3,892 impressions, was an announcement about an environmental health symposium held on Earth Day that had a geohealth breakout session organized by KGS.

KGS will continue to analyze its stakeholder reach via social-media platforms. We began a project in April to evaluate the style and content of our social-media posts and will complete it in October 2021. The information obtained will be used to develop best practices for engaging social-media posts and for reaching existing and potential stakeholders.

Analytical Laboratory

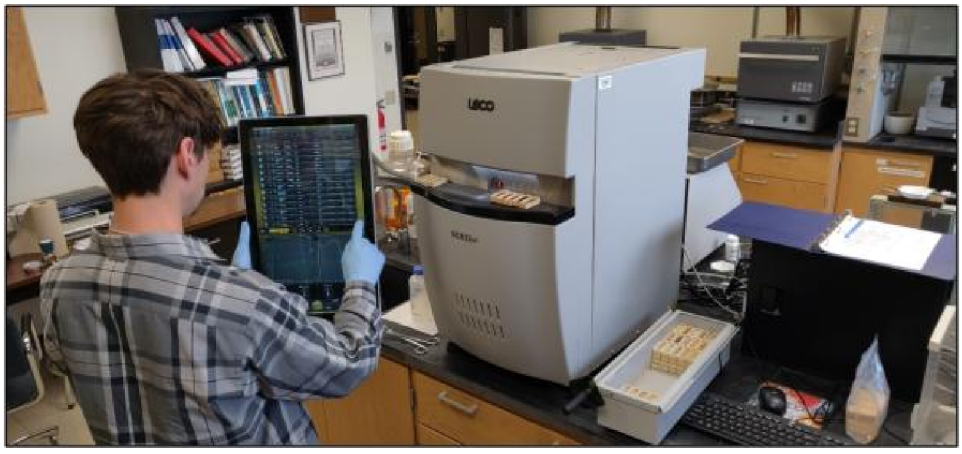
Jason Backus, Andrea Conner, and **Ethan Davis** analyzed samples for various KGS research projects. Laboratory staff analyzed and processed more than 750 samples for the University of Kentucky Department of Mining Engineering's rare earth element project. The lab analyzed water samples for nutrients for several of the UK Department of Civil Engineering's water-monitoring projects. Laboratory staff continue to analyze samples for the Kentucky River Watershed Watch program and performed

water-quality assays on the Kentucky River samples again this year.

The laboratory continues to analyze samples from **Ming Gong,** a researcher at the University of Kentucky Medical Center, for sodium and potassium, using the Inductively coupled argon plasma optical emission spectrometer. Gong is investigating the uptake and transport of these elements in certain organs in mice.

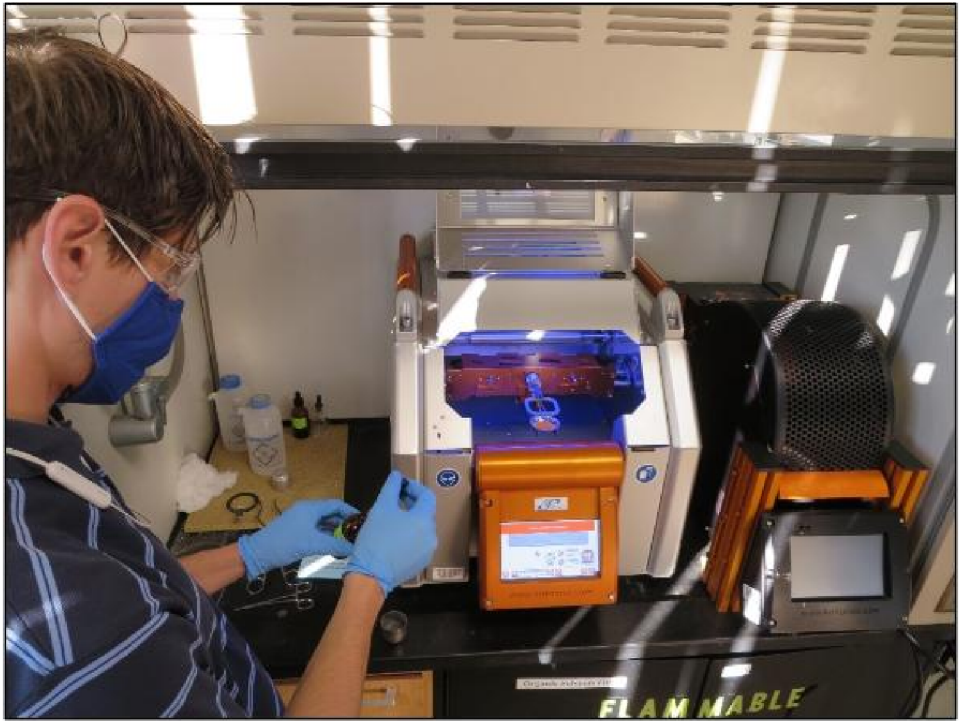
The X-ray laboratory supported research projects in several UK departments, in the form of training and instrument time. Twenty unique researchers and students used our X-ray diffraction equipment. The software and computer for this equipment were upgraded during the fiscal year for a better analysis interface.

KGS recently added several new pieces of equipment to the analytical chemistry laboratory. The laboratory now has a newer version of its carbon and sulfur analyzer, acquired via a University of Kentucky research grant awarded to KGS geologist **Cortland Eble.** The analyzer, used by KGS staff and UK Department of Earth and Environmental Sciences researchers and students, replaced an aging instrument.



KGS researcher **Ethan Davis** analyzes coal samples on the newly acquired carbon and sulfur analyzer.

The laboratory also added a new auto-fluxer, which prepares samples for analysis with our X-ray fluorescence spectrometer.



Ethan Davis prepares a fused disc for analysis on the X-ray Fluorescence Spectrometer using the new auto fluxer.

Digital Earth Analysis Laboratory

The highest-flying addition to the KGS Digital Earth Analysis Laboratory during the 2020-21 fiscal year was an unmanned aerial vehicle, better known as a drone, and an accompanying LiDAR scanner. Together the drone and scanner can produce exceptionally resolute and laser-accurate digital elevation models, even in forested areas. **Sarah Johnson**, a doctoral student in the UK Department of Earth and Environmental Sciences who is working with **Bill Haneberg**, used the drone as part of her ongoing doctoral research, which focuses on ways that regional LiDAR, site-specific drone-based structure from motion photogrammetry, and site-specific drone-based LiDAR can be combined to create geomorphic-change maps documenting the evolution of a northern Kentucky landslide over a 14-year period. The methods Johnson develops will be useful for studies to detect geomorphologic change as Kentucky continues to update its statewide airborne LiDAR coverage.

Sarah Johnson operates the KGS drone.

KGS geologist **Max Hammond** continued development of a digital terrain modeling workflow to delineate colluvium more efficiently for surficial geologic mapping as part of the STATEMAP project. Other members of the STATEMAP project team used DEAL computer resources and statewide LiDAR data extensively during their time working remotely because of the COVID-19 pandemic.

We are rightly proud of our statewide 1:24,000-scale bedrock geologic map coverage. Although the geologic maps are faithful to the topographic data available when the maps were made during the 1960s and 1970s, comparison of the geologic maps to modern LiDAR digital elevation models shows that older topographic maps have positional errors large enough that the geologic maps do not agree with the LiDAR topography in some places. DEAL post-doctoral scholar **Yichuan Zhu** and geologist **Jason Dortch**

worked with principal investigator **Bill Haneberg** on a project funded by the U.S. Geological Survey to evaluate methods of reprojecting geologic quadrangle maps to match modern LiDAR digital elevation models. Zhu, Dortch, and Haneberg presented a progress report at the U.S. Geological Survey Digital Mapping Technology conference in June 2021.

Yichuan Zhu led the development of an intelligent swath-extraction software package to characterize complicated topographic features, including stream-terrace sequences along the Licking River in northern Kentucky, that is much more flexible than previous swath-extraction approaches. He was the first author of a *Geomorphology* paper, along with co-authors **Jason Dortch**, **Matt Massey**, **Bill Haneberg**, and **Doug Curl**. The software, named PyOSP – Python Object-oriented Swath Profile – is open source and available for download. After two exceptionally productive years with KGS, Zhu moved to a faculty position as an assistant professor of civil engineering at Temple University at the beginning of the 2021-22 academic year.

Matt Crawford led a research team using DEAL computer resources as they completed their FEMA-funded landslide hazard and risk assessment of the Big Sandy Area Development District in eastern Kentucky. The team used LiDAR-based landslide inventory maps and machine-learning methods to develop statistical models of landslide susceptibility and, with the addition of infrastructure and population density maps, landslide risk maps for the five-county area development district. They published a paper about the research behind the susceptibility modeling in the *Quarterly Journal of Engineering Geology and Hydrogeology.*

Cooper Cearley, a graduate student in the UK Department of Earth and Environmental Sciences, worked with **Ed Woolery**, **Zhenming Wang**, and **Jason Dortch** to create a series of roughness maps in order to visualize the geomorphology around Sassafras Ridge in western Kentucky and the New Madrid Seismic Zone. Delineating fluvial-terrace packages using LiDAR-based

surface-roughness maps showed that the Sassafras Ridge Fault developed in a pre-existing terrace package, which constrained both relative timing of the rupture and total displacement.

Earth Analysis Research Library

The University of Kentucky operated on a phased return-to-work plan during the fiscal year because of the COVID-19 pandemic. As a result, on-site work at EARL was limited to externally funded KGS projects. KGS employees were present and working there during much of the fiscal year and outside visitors started using the facility again in May 2021. The University of Kentucky operated on a phased return-to-work plan during the fiscal year because of the COVID-19 pandemic. As a result, on-site work at EARL was limited to externally funded KGS projects, through virtual presentations, fulfilling photography and data requests, and providing specimens for these projects. KGS employees were present and working in the library during much of the fiscal year, but outside visitors were not allowed access until May 2021.

KGS researchers were the predominant users of the collections at EARL. **William Andrews** and **Gina Lukoczki** examined geophysical samples for Earth MRI projects focused on the Western Kentucky Fluorspar District, Pennsylvanian underclays, and Devonian phosphates; **John Hickman** conducted research on the Rogersville Shale; and KGS purchased a portable permeameter using funds from the Energy Research Prioritization Partnership to measure the permeability of several cores from select western counties in the state. There were 221 visits for research purposes and 438 samples were provided from almost 11,000 feet of core and more than 53,000 feet of well cuttings. **Antonia Bottoms** used EARL's grain-size analyzer on soil samples collected for the U.S. Geological Survey's STATEMAP Program.

Virtual Presentations

EARL employees participated in Earth Science Week by contributing four videos to the KGS Virtual Open House. The videos focused on EARL and its collections, emphasizing how geologists use its resources for their research. Information about current projects and data-management best practices was given, as well as a virtual tour of EARL for students taking classes in the UK Department of Earth and Environmental Sciences and professionals attending industry meetings. These presentations and the virtual tour inform stakeholders about the work being done at EARL and contribute to the continuing education of undergraduate students unable to attend field camp because of the pandemic.

In April, KGS employees representing all sections took part in an unmanned aerial vehicle, or drone, demonstration by **Wesley Turner** from the Kentucky Division of Water. The demonstration outside of EARL provided KGS employees an opportunity to better understand the mapping capabilities of these devices.

Core Photography Project Funded by the Institute of Museum and Library Services

October 2020 marked the third year of this project to photograph cores at EARL. During the 2020-21 fiscal year, we processed 47 cores in roughly 3,800 boxes, exceeding our annual goal. Several KGS employees and outside researchers used photos from this project while they conducted their work remotely. As a result, the number of requests for core photography of select cores increased. Click here to learn more about the Institute of Museum and Library Services.

USGS National Geological and Geophysical Data Preservation Program

In December 2020, KGS staff and student workers completed the U.S. Geological Survey's National Geological and Geophysical Data Preservation Program project that began in fiscal year 2019-20. The work for this project was divided into multiple smaller tasks and involved staff and student workers from the Geologic Information Management Section, Earth Analysis Research Library, Geologic Mapping Section, and Water Resources Section.

For fiscal year 2020-21, the program awarded KGS $57,718 for digital archiving of KGS laboratory documents dating back to 1992 and assessing water-damaged and unwashed oil and gas well cuttings for deaccession or salvage, https://www.uky.edu/KGS/news/usgs-preservation-funding.php. We evaluated 5,000 water-damaged and unwashed well-cutting sets based on available geographic information, distance from existing undamaged washed sets, representative depth, and rock formation. This task was further divided into two phases for efficiency and safety. Phase 1 evaluated the water-damaged sets. To ensure we made all efforts to recover data prior to deaccessioning any well-cutting sets, we performed data forensic measures. A negative-pressure containment area was used during the physical deaccession process. Project staff wearing appropriate personal protective equipment – including Tyvek suits, hard hats, safety glasses, and N95 masks – identified 2,073 sets of well cuttings that fit the deaccession criteria. Click here to learn more about Phase 1.

In Phase 2, roughly 1,600 unwashed well-cutting sets were designated for deaccession; excess and unusable material was removed from the collection, making more storage space available for EARL collections.

The National Geological and Geophysical Data Preservation Program also funded a student position for eight months to digitize archived documents from the KGS laboratory. Standard

operating procedures were developed for archiving existing records and for future records.

Foundation for Advancement in Conservation's Collections Assessment for Preservation Program

In February 2020, the Foundation for Advancement in Conservation selected the Kentucky Geological Survey to participate in its Collections Assessment for Preservation program. Our participation was delayed because of the COVID-19 pandemic but resumed in spring 2021 with interviews of people to serve as assessors of KGS. In 2021, the selected assessors will meet with several KGS staff and visit both the Mining and Mineral Resources Building and the Earth Analysis Research Library to review the state of both buildings and collections housed in them before making recommendations for future renovations. Read more about the project.

Outreach and Communications

Earth Science Week Open House

Our Earth Science Week open house is traditionally held in person, but COVID-19 forced us to hold a virtual open house for an entire week, primarily accessible via a KGS-hosted webpage. The new format allowed us to reach more Kentuckians from outside the Lexington area. Short videos showed geologists at work and shared information about different areas of geology. UK's Departments of Earth and Environmental Sciences and Mining Engineering also contributed videos. Additional partner organizations included the Kentucky Water Resources Research Institute, The Nature Conservancy, Central Kentucky Gem and Mineral Club, Kentucky Science Center, Bluegrass GreenSource, Kentucky Speleological Survey, and Ben E. Clement Mineral Museum.

We also provided links to KGS's educational information and resources. KGS geologists **Steve Greb, Sarah Arpin,** and **Matt Crawford** answered questions about geology during a live Q&A hosted by **Sarah Mardon** and **Doug Curl.**

60th KGS Annual Seminar Held in May

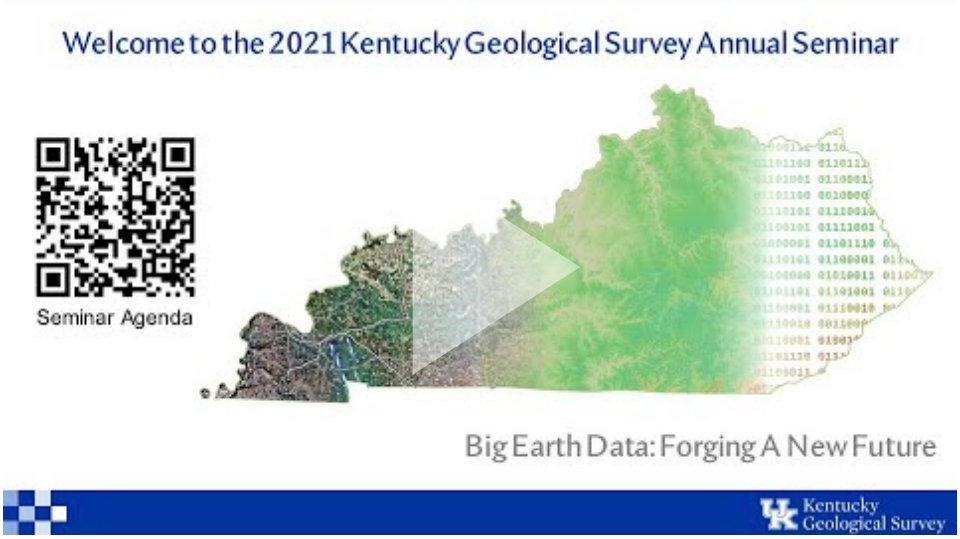
The theme of the 60th KGS annual seminar on May 20, 2021, was "Big Earth Data: Forging a New Future." As was true of last year's attendees, this year's participants represented a large number of geologists but also a notable number of professionals from other disciplines and from outside of Kentucky, likely because of the virtual format. A total of 169 people registered for the event.

The 2021 seminar had five oral presentations. **Sarah Battersby,** the 2021 Haney Distinguished Lecturer, presented "How People Think About Maps: Analytics and Building Trust." Battersby is the principal research scientist on the Tableau Research team at Salesforce. Her primary area of expertise is cartography, with an emphasis on cognition. Battersby's work emphasizes how to help people visualize and use spatial information more effectively.

Ken Casey, with NOAA/National Centers for Environmental Information, spoke on Earth Science Information Partners, a collaborative organization that shares data and information. **Bryan Bunch** of the Kentucky Infrastructure Authority and **Jeff Jalbrzikowski,** with the NOAA National Geodetic Survey, delivered "Kentucky's Contribution to the Modernized National Spatial Reference System (NSRS)." **Matt Crawford,** a KGS geologist, talked about mapping landslide susceptibility and risk. **Amy Wolfe,** a geologist at KGS, presented "Linking Environmental Exposure and Health Outcomes: The Importance of Data Coordination."

Lightning talks and poster sessions by KGS scientists **Doug Curl**, **Steve Martin**, **Matt Massey**, **Bill Haneberg**, and **Max Hammond** were part of this year's seminar. The posters can be viewed here https://www.uky.edu/KGS/news/kgs-annual-seminar-

2021.php#posters and the lightning talks can be viewed at the end of the KGS annual seminar video.



View recording of the 60th Kentucky Geological Survey annual seminar.

Professional Meetings and Outreach

KGS staff participated in and presented at several professional events during the fiscal year, including the ESRI User Conference, Geological Society of America annual meeting, and American Geophysical Union fall meeting. They practiced their talks for the GSA meeting during a KGS seminar, and recordings have been archived here. In honor of GIS Day, **Sarah Mardon** and **Emily Morris** made a poster to describe the different ways KGS researchers use GIS in their work.

On April 22, 2021, KGS Director **Bill Haneberg** moderated the "Communicating Geoenvironmental and Geohealth Hazards and Risks" session for the 2021 John P. Wyatt, M.D. Environment & Health Symposium. The symposium coincided with Earth Day and honored University of Kentucky pulmonologist John Wyatt and his pioneering environmental clinical research.

Funded Research Project List

Research Projects for Fiscal Year 2020-21

Listed below are all of KGS's funded research projects for the 2020-21 fiscal year. Some of the projects are described in detail in other sections of the annual report. Additional information is available for projects not discussed in this report (click on the "Read More" links).

Energy and Minerals

Conasauga Shale Research Consortium

- End Date: 7/31/21; Fiscal Year Funding: $176,449; Project Total: $964,378
- Funding Source: U.S. Department of Energy

Regional Initiative to Accelerate Carbon Capture, Utilization, and Storage Development

- End Date: 9/30/22; Fiscal Year Funding: $45,219; Three-Year Project Total: $150,000
- Funding Source: U.S. Department of Energy through Battelle Memorial Institute

Assessing the Potential for Compressed Air Energy Storage in Kentucky to Augment Energy Production by Renewable Resources

- End Date: 11/30/21; Fiscal Year Funding and Project Total: $50,131
- Funding Source: UK Energy Research Prioritization Program, UK Vice President for Research
- Read More

Geochemistry

Controls of Dolomitization on Matrix Porosity and its Effect on Cave Passage Formation as Inferred From Numerical

Simulations Based on Geochemical and Experimental Analyses

- End Date: 11/30/21; Fiscal Year Funding: $2,618; Project Total: $24,934

- Funding Source: National Cave and Karst Research Institute

Kentucky Geologic Data for the Hicks Dome Regional Earth MRI Priority Project

- End Date: 7/31/21; Fiscal Year Funding: $62,675; Two-Year Project Total: $75,000

- Funding Source: U.S. Geological Survey

Geochemistry of Pennsylvanian Underclays: Earth MRI

- End Date: 6/30/22; Fiscal Year Funding: $47,175; Two-Year Project Total: $75,000

- Funding Source: U.S. Geological Survey

Geologic Information

Engaging Nontraditional Geoscience Information Stakeholders in Appalachian Kentucky

- End Date: 6/1/21; Fiscal Year Funding: $22,737; Project Total: $83,357

- Funding Source: National Academy of Sciences

Kentucky Geologic Core Digital Image Archive

- End Date: 9/30/21; Fiscal Year Funding: $134,076; Three-Year Project Total: $487,396

- Funding Source: Institute of Museum and Library Services

National Geological and Geophysical Data Preservation Program FY20

- End Date: 12/31/20; Fiscal Year Funding and Project Total: $172,022

- Funding Source: U.S. Geological Survey

National Geological and Geophysical Data Preservation Program FY21

- End Date: 12/31/21; Fiscal Year Funding: $42,422; Project Total: $115,436

- Funding Source: U.S. Geological Survey

Geologic Mapping

Converting Kentucky Geological Survey 2D Geologic Map Data for Nationwide Compilations

- End Date: 7/15/21; Fiscal Year Funding: $177,658; Project Total: $355,316

- Funding Source: U.S. Geological Survey

New Surficial Geologic Mapping Along the I-65 Corridor in Hardin County, Kentucky

- End Date: 7/15/21; Fiscal Year Funding: $164,022; Project Total: $328,004

- Funding Source: U.S. Geological Survey

New Surficial Geologic Mapping Along the I-65 Corridor in Bullitt and Nelson Counties, Kentucky

- End Date: 10/9/20; Fiscal Year Funding and Project Total: $325,708

- Funding Source: U.S. Geological Survey

Soil Maps for Seismic Hazard Planning in the Green River Area Development District

- End Date: 5/20/21; Fiscal Year Funding and Project Total: $29,139

- Funding Source: Webster County, Kentucky, through Federal Emergency Management Agency

Transforming Past Into Present: A Registration Approach to Using Old and New Topographic Information to Improve the Fidelity and Value of Legacy Geologic Maps

- End Date: 2/28/22; Fiscal Year Funding: $108,453; Project Total: $133,973

- Funding Source: U.S. Geological Survey

Geology and Human Health

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

- End Date: 6/30/21; KGS Fiscal Year Funding: $7,267; UK Project Total: $75,000

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

Radon on the Radar

- End Date: 11/30/24; KGS Fiscal Year Funding: $80,820; UK Four-Year Project Total: $585,908

- Funding Source: National Institute of Environmental Health Services through UK College of Nursing

UAV-Based Aeroradiometric Mapping to Understand Geologic Controls on Intraformational Radon Variability: Toward an Improved Rational Basis for Indoor Radon Potential Microzonation

- End Date: 3/31/22; Fiscal Year Funding and Project Total: $63,574

- Funding Source: UK Center for Appalachian Research in Environmental Sciences through National Institute of Environmental Health Sciences

Geologic Hazards

Multijurisdictional Hazard Mitigation Plan for Landslides for the Big Sandy Area Development District

- End Date: 3/22/22; Fiscal Year Funding: $153,412; Project Total: $400,292

- Funding Source: Federal Emergency Management Agency through Kentucky Department of Military Affairs

Improving Estimates of Ground-Motion Site Response in the New Madrid and Wabash Valley Seismic Zones

- End Date: 6/30/21; Fiscal Year Funding: $45,560; Project Total: $64,462

- Funding Source: U.S. Geological Survey

Seismic Monitoring and Site Response Study at the Paducah Gaseous Diffusion Plant: Kentucky Research Consortium for Energy and Environment

- End Date: 9/30/21; KGS Fiscal Year Funding: $5,200; UK Five-Year Project Total: $1,640,000

- Funding Source: U.S. Department of Energy through Center for Applied Energy Research

- Read More

Water Resources

Collaborative Research: Data Fusion for Characterizing and Understanding Water Flow Systems in Karst Aquifers

- End Date: 2/28/23; Fiscal Year Funding: $110,028; Three-Year Project Total: $421,448

- Funding Source: National Science Foundation

In-Situ 3D Electrical Resistivity Method for Understanding Water Dynamics in Shallow Karst Features

- End Date: 2/28/21; Fiscal Year Funding: $6,979; Project Total: $21,380

- Funding Source: U.S. Geological Survey through UK Kentucky Water Resources Research Institute

Multi-Jurisdictional Hazard Mitigation Plan for Karst/Sinkholes for the Lincoln Trail ADD

- End Date: 4/1/22; Fiscal Year Funding: $69,835; Project Total: $391,992

- Funding Source: Federal Emergency Management Agency through Kentucky Department of Military Affairs

Development of a Groundwater Management Tool for Grand Canyon National Park

- End Date: 12/31/21; Fiscal Year Funding: $42,129; Three-Year Project Total: $115,871

- Funding Source: National Park Service

Kentucky Geological Survey Groundwater Observation Wells – Support for Inclusion in the USGS National Groundwater Monitoring Network

- End Date: 11/30/21; Fiscal Year Funding: $18,739; Two-Year Project Total: $80,000

- Funding Source: U.S. Geological Survey

Examining Hydrologic Connections at Fern Cave, Alabama, and Implications of Stream Connectivity on Biological Diversity and Isolation

- End Date: 12/31/21; Fiscal Year Funding: $12,008; Project Total: $14,999

- Funding Source: U.S. Fish and Wildlife Service

Blue Water Farms: Edge-of-Field Water Monitoring in Kentucky Soils

- End Date: 6/30/21; KGS Fiscal Year Funding: $30,745; UK Project Total: $165,000

- Funding Source: Kentucky Soybean Promotion Board through UK College of Agriculture

- Read More

Nutrient and Sediment Runoff Assessment in the Upper Mississippi River Embayment

- End Date: 6/30/22; KGS Fiscal Year Funding: $104,472; UK Five-Year Project Total: $2,074,131

- Funding Source: U.S. Department of Agriculture through Natural Resources Conservation Service through UK College of Agriculture

Staff Retirements, Awards & Honors

Staff Retirements

Geologist **Richard Smath** retired Sept. 30, 2020, after a 37-year career at KGS. During his employment with the Survey, Smath answered public requests, organized and participated in outreach events, and authored or co-authored 35 KGS publications. He judged the rock and mineral exhibition at several Kentucky State Fairs. According to KGS geologist **Steve Greb,** "For decades, [Smath] volunteered with educational outreach to schools, Scout groups, 4-H, and a variety of other organizations, not because he had to, but because he wanted to help." Also, according to **Doug Curl,** KGS geologist and section head, Smath "has always been at the forefront of KGS's data preservation projects by leading efforts to scan and catalog many KGS documents, maps, and publications."

Smath is a member of several professional organizations. He's served in leadership roles with the Geological Society of Kentucky and the Kentucky Section of the American Institute of Professional Geologists, using his organizational skills to ensure field trips and other events operated efficiently. In 2016, he received an Outstanding Service Award from the Geological Society of Kentucky. In retirement, Smath is continuing to work on an Interactive Tour about the geology of Lower Howards Creek in Clark County, continuing his involvement with the Geological Society of Kentucky and the Kentucky Section of AIPG, and

volunteering with organizations that restore and improve natural areas in Kentucky. Read more.

Roger Banks retired from KGS in December 2020 after working in the KGS Publications Sales office for 37 years. Banks managed map and publication sales, working alongside now-retired KGS geologist **Richard Smath** for many years. Smath says, "[Banks] had a good understanding of the maps and publications; this was helpful in answering requests from the public and provided customers with the proper items they needed. His attitude with the public was one in which he became friends with many people, and they would always ask for him on future calls."

Banks shared that "everyone, past and present, has been so nice to work with [that] I simply stayed at KGS. I liked being in customer service, where I met many memorable characters and made some good friends and acquaintances." During his retirement, Banks plans to work on some home-improvement projects and visit family in Kentucky and overseas. Read more.

Staff Awards and Honors

William Andrews

- Kentucky Association of Mapping Professionals: president-elect (January 2021–present)
- National Geologic Map Database Technical Working Group
- Association of American State Geologists: associate member
- Geological Society of America: Florence Bascom Geologic Mapping Award Committee member
- National Cooperative Geologic Mapping Program: National GeoFramework Initiative Implementation Plan working group

- UK Strategic Materials and Recovery Technologies (SMaRT) Center: Management Committee member

Sarah Arpin

- Association for Women Geoscientists, Southeastern Bluegrass Chapter: treasurer, Steering Committee (October 2019–present)
- Kentucky Academy of Science: secretary of Geology Section (November 2019–present)
- Kentucky Speleological Survey: Board of Directors (March 2019–present); chair, Data Committee (April 2017–present)
- National Cave and Karst Research Institute: Board of Directors; chair, Research Committee (May 2020–present)

Glynn Beck

- Kentucky Agricultural Science and Monitoring Committee

Antonia Bottoms

- Association for Women Geoscientists, Southeastern Bluegrass Chapter: secretary, Steering Committee (October 2019–present)

Rick Bowersox

- Kentucky Board of Registration for Professional Geologists: vice president

Matt Crawford

- U.S. Geological Survey Mendenhall Research Fellowship Program: research advisor (January 2021–July 2022)

Doug Curl

- Kentucky River Watershed Watch: board member (2014–present)

- KYFromAbove Kentucky Aerial Photography & Elevation Data Program: Technical Advisory Committee

- National Geologic Map Database Working Group

Ray Daniel

- Geological Society of Kentucky: councilor at large

Bill Haneberg

- National Geospatial Advisory Committee (2020–present)

- International Advisory Panel for Geological Uncertainty and Societal Risk: The Perspectives of Engineering, Environment, and Geohazards at National Central University in Taoyuan City, Taiwan

Dave Harris

- Potential Gas Committee: Atlantic Work Group

Gina Lukoczki

- Association for Women Geoscientists, Southeastern Bluegrass Chapter: president, Steering Committee (October 2019–present)

- *Földtani Közlöny* (Bulletin of the Geological Society of Hungary): English language editor (March 2021–present)

Meg Smath

- Association of Earth Science Editors: secretary, co-editor of newsletter *(Blueline)*

Richard Smath

- American Institute of Professional Geologists, Kentucky Section: communication coordinator and website manager (2005–present)

- Geological Society of Kentucky: councilor at large

Charles Taylor

- Kentucky Agriculture Water Quality Authority

- Kentucky Agricultural Science and Monitoring Committee

Ben Tobin

- Geological Society of America Karst Division: treasurer (term ended October 2020)

- National Speleological Society: director (2020–2023)

- Kentucky Speleological Survey: member at large (term ended January 2021)

- International Association of Hydrogeologists, Karst Commission: co-chair (2021–2025)

Rebecca Wang

- Geological Society of Kentucky: webmaster

Amy Wolfe

- American Geophysical Union, Geohealth Section: co-chair, Communications and Outreach Sub-committee

Junfeng Zhu

- *Groundwater:* associate editor (December 2017–present)

Publications

Interactive Tour Blends Geology and History

Camp Nelson in Jessamine County, Kentucky, was a supply depot for the Union Army during the American Civil War and served as a training center for new Union troops, including thousands of U.S. Colored Troops. **William Andrews** and **Doug Curl** produced an Interactive Tour about Camp Nelson's geology, using the StoryMap platform, for a U.S. Geoheritage and Geoparks Advisory Group workshop. "Camp Nelson National Monument—A Geologic Story" explores the history of the site in relation to the geology and landscape features that helped provide natural defenses and an ideal location for a military camp.

The Interactive Tour was introduced by **Bill Haneberg** as part of the National Academies of Sciences, Engineering, and Medicine's geoheritage distinguished speaker series, https://www.nationalacademies.org/our-work/americas-geoheritage-ii-a-workshop. His presentation may be viewed here: https://www.nationalacademies.org/event/10-06-2020/geoheritage-and-state-geological-surveys-aasg.

KGS Publications

Interactive Tour 4. *Geologic Tour of Boone County, Kentucky, Public Parks*, by **Steve Martin** and **Emily Morris**. Released 9/18/20.

Interactive Tour 5. *Camp Nelson National Monument: A Geologic Story*, by **William Andrews** and **Doug Curl**. Released 11/06/20.

Special Publication 1. *The Kentucky Seismic and Strong-Motion Network: History, Service, and Research*, by **Ron Street**, **Zhenming Wang**, **Seth Carpenter**, and **Ed Woolery**. Released 06/24/2021.

Kentucky Geological Survey annual report 2019-20. Released 12/14/20.

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Andrews, W.M., Hickman, J.B., and **Curl, D.C.,** 2020, Statewide three-dimensional database and model at the Kentucky Geological Survey [abs.]: Geological Society of America, GSA 2020 Connects Online.

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Arpin, S.M., and Groves, C., 2021, Structural, geomorphic, and hydrochemical influences on the karst hydrogeology of the Haney Limestone in south-central Kentucky, USA: Hydrogeology Journal, v. 29, p. 443–459, https://doi.org/10.1007/s10040-020-02269-w.

Carpenter, N.S., Wang, Z., and **Woolery, E.W.,** 2020, Can proxies adequately approximate site resonance? [abs.]: Seismological Society of America, Eastern Section, 92nd annual meeting, https://www.seismosoc.org/wpcontent/uploads/2020/10/ESSSA_2020_abstract_final-1.pdf, 71 p.

Carpenter, N.S., Yassminh, R., **Hickman, J.B.,** and **Wang, Z.,** 2020, Site response from deep stratigraphic layers in the Illinois

Basin from S-wave H/V observations and spectral-element modeling [abs.]: American Geophysical Union 2020 fall meeting, https://agu.confex.com/agu/fm20/meetingapp.cgi/Paper/751658.

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Chabalala, V.P., Wagner, N., Malumbazo, N., and **Eble, C.F.,** 2020, Geochemistry and organic petrology of the Permian Whitehill Formation, Karoo Basin (RSA) and the Devonian/Carboniferous shale of the Appalachian Basin (USA): International Journal of Coal Geology, v. 232, 103612, https://doi.org/10.1016/j.coal.2020.103612.

Crawford, M.M., Koch, H.J., Dortch, J.M., Killen, A.A., and **Haneberg, W.C.,** 2020, Landslide susceptibility mapping and risk assessment, eastern Kentucky [abs.]: Geological Society of America GSA 2020 Connects Online, https://gsa.confex.com/gsa/2020AM/meetingapp.cgi/Paper/355833.

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- Haneberg, William. State Geologist and Director
- Cobb, Jim. State Geologist Emeritus

Administrative

- Ellis, Kati. Administrative Business Officer

- Long, Mandy. Administrative Support Associate I
- Phillips, Gwen. Staff Support Associate II

Communications and Outreach

- Mardon, Sarah. Geoscience Communications Professional
- Smath, Meg. Geologic Publication Manager

Digital Earth Analysis Laboratory

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- Johnson, Sarah. Research Assistant
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Energy and Minerals

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- Bowersox, Rick. Geologist IV
- Eble, Cortland. Geologist V
- Greb, Steve. Geologist V
- Hickman, John. Geologist IV
- Lukoczki, Gina. Geologist III
- Parris, Marty. Geologist V
- Skeese, Kyle. Student Worker
- Sparks, Tom. Geologist III

- Vicroy, Stephanie. Student Worker
- Walton, Zachary. Student Worker

Geologic Hazards

- Wang, Zhenming. Section Head
- Carpenter, Seth. Geologist V
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- Ellis, Mike. Computer Support Specialist II
- Mardon, Sarah. Geoscience Communications Professional
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- Smath, Richard. Geologist III
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- Wang, Rebecca. Database Analyst

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- Massey, Matt. Geologist IV
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- Shirkey, Felicity. Student Worker
- Thomas, Alex. Student Worker.

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