Kentucky Geological Survey

2021 - 2022 Annual Report

Kentucky Geological Survey, University of Kentucky

Letter From the Director

William C. Haneberg, Ph.D., P.G.
State Geologist and Director

Fiscal year 2021-2022 marked an almost complete return to campus and normal operations for KGS after nearly 18 months of remote work for most of our staff. Whether working in the office or remotely, however, one thing that never changed: our commitment to Kentucky and its people.

Our primary focus at KGS is on providing useful and unbiased geoscience information to benefit the Commonwealth. We are still releasing traditional products like PDFs of geologic quadrangle maps through our long-running collaboration with the U.S. Geological Survey STATEMAP

Program. At the same time, we are continuing to increase our capabilities by investigating applications of artificial intelligence and machine learning to make better maps, working with the Kentucky Energy and Environment Cabinet to monitor methane emissions from coal mines and orphan oil and gas wells, providing national level leadership in areas like 3D geologic mapping and geologic hazard assessment, using a drone to map soil radionuclides, and helping to assess the carbon storage potential of Kentucky's bedrock. We are even investigating novel approaches that might allow our Kentucky Seismic and Strong Motion Network to help determine when and where tornadoes touch down.

We are devoting additional resources to our publications and communications efforts by continuing to publish interactive story maps on topics of broad interest, engaging in user-centered research to better understand how non-traditional stakeholders use our information, adding new layers to our interactive web-based Kentucky Geologic Map Service, and cultivating social media audiences that differ for each platform. Behind the scenes, we are working on ways to more efficiently organize the many series of maps, reports, and other documents that KGS has published during its 184-year history. Our new podcast series, the Big Blue Rock Pod, debuted in April 2022 and features informal discussions about Kentucky geology and related topics with guest scientists. You can find it wherever your favorite podcasts are served.

The transdisciplinary challenges of climate change and its effects on Kentucky took center stage at UK and KGS during spring 2022. Dr. Erin Haynes, chair of the UK Department of Epidemiology and Environmental Health and director of the newly created UK Center for the Environment, and I co-chaired the 17th Annual UK Center for Clinical and Translational Science spring conference on the topic of climate and health. Our keynote speaker was Dr. Robert Bullard, widely recognized as the father of environmental justice, with a follow-up panel discussion about climate change and environmental justice in Kentucky. Several weeks later, I

served as a breakout session discussion leader at the 2022 John P. Wyatt, M.D. Environment and Health Symposium in April 2022. Our Wyatt Symposium keynote speaker, Dr. Aubrey Miller, discussed the role of applied science to address the health impacts of natural disasters and climate change. Other experts spoke about Kentucky's changing climate as well as emergency responses to the March 2021 Beattyville flood and December 2021 western Kentucky tornadoes. We culminated the spring 2022 UK triple crown of climate change events with our 61st KGS annual seminar devoted to the theme of geologic perspectives on climate change in Kentucky. The seminar presentations addressed climate driven geologic hazards, methane emission monitoring, satellite technology to document environmental change, geologic aspects of underground carbon storage, minerals for the energy transition, and climate communication. I was also honored to participate in a May 2022 panel discussion about climate change in Kentucky held as part of the Crucial Terrain event series organized by Dr. Zoé Strecker at our cross-town neighbor, Transylvania University.

This summer, our first group of six Paul Potter Summer Interns spent 10 weeks as temporary KGS employees, supported by a generous $1.1 million gift from the late Professor Paul Potter. The inaugural cohort of interns worked on KGS research projects supplemented by weekly enrichment activities ranging from short field experiences to workshops on technical writing, resume preparation, and the geology of Kentucky. The program culminated with a research showcase comprising lightning talks and posters summarizing each project. We will shortly announce 2023 internship program, which will be open to non-UK students, through our website and social media accounts.

As we move into 2023, we look forward to serving the Commonwealth as we mark 185 years since the legislature appropriated $1000 in 1838 for "some competent person" to reconnoiter the mineral resources of Kentucky.

Digital Earth Analysis Lab

Introduction

We established the KGS Digital Earth Analysis Lab (DEAL) in 2017 to leverage the value of Kentucky's statewide airborne lidar coverage that was then being completed. Five years later, Kentucky is well into its second round of statewide lidar data acquisition, the DEAL has become a nexus for remote sensing and terrain modeling research at KGS, and we are actively pursuing new research opportunities to benefit the commonwealth.

During the past year, the DEAL has supported KGS applied research on topics including mathematical rectification of legacy geologic quadrangle maps to improve their fidelity with modern airborne lidar data, development of machine learning workflows to classify surficial deposits on the basis of topographic attributes, landform-based geomorphological mapping, failure of supposedly stable engineered slopes associated with mountaintop removal coal mining, application of map-based risk assessment techniques to mitigate landslide hazards in eastern Kentucky, and drone-based gamma spectrometry to help delineate soil radon hazards.

Our previous DEAL post-doctoral scholar, Yichuan Zhu, left KGS in August 2021 to begin a new position as a tenure track assistant professor of civil engineering at Temple University in Philadelphia and is continuing to collaborate on DEAL research. The post-doctoral position was filled in January 2022 by Sourav Saha, who received his Ph.D. in geology from the University of Cincinnati and successfully completed a post-doctoral appointment at UCLA. Saha is contributing to several geomorphology and surficial geology research projects at KGS, including using the Google Earth Engine API to create interactive web mapping interfaces for statewide remote sensing data.

Machine Learning for More Efficient Surficial Geologic Mapping

KGS geologic mappers working on our U.S. Geological Survey (USGS) cooperative STATEMAP projects have historically spent months each year tediously digitizing surficial map unit contacts across several 7.5-minute quadrangles. Former KGS geologist Max Hammond III began investigating ways to efficiently digitize the contacts of colluvium map units, which had traditionally been delineated using slope angle thresholds supplemented by field checks. He teamed up with Jason Dortch and Bill Haneberg to expand his initial threshold-based models to include machine learning approaches based upon topographic attributes such as slope steepness, roughness, curvature, and topographic position information derived from lidar-based digital elevation models to identify colluvium with greater than 90% accuracy and produce maps arguably more robust than those made using traditional approaches. The significant speed increases realized from machine learning applications will allow KGS mappers to work more economically, efficiently, and safely by allowing them to prioritize fieldwork in rough terrain and reduce the chance of repetitive motion injuries in the office.
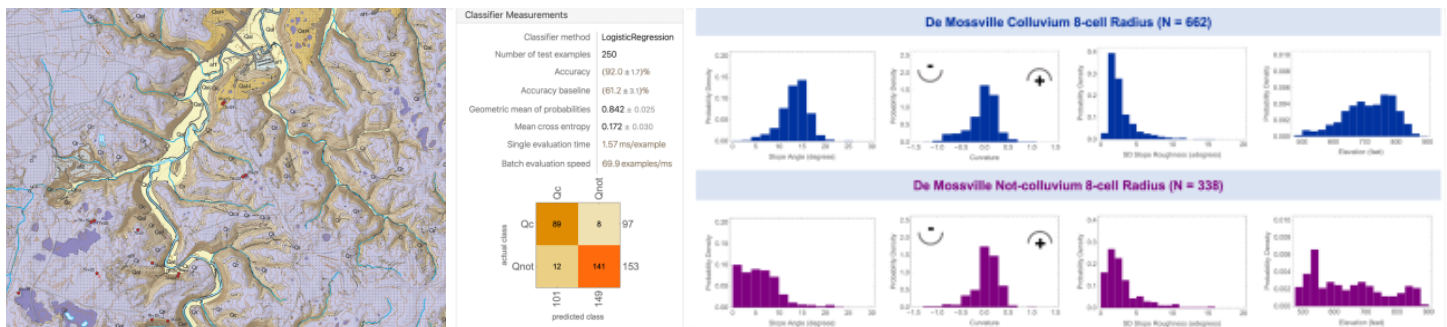
Left: Portion of a KGS surficial geologic map showing distribution of alluvium (Qal), colluvium (Qc), residuum (Qr), and other surficial map units.

Center: Output of a logistic regression machine learning algorithm to identify areas of colluvium based on lidar-derived topographic attributes, in this case with 92% accuracy.

Right: Histograms showing differences in statistical distribution of attributes for colluvium and non-colluvium map units, De Mossvile 7.5-minute quadrangle.

Drone-based Spectrometry to Characterize Radon Hazards

Ongoing KGS geohealth collaborations have led KGS scientists to think about new and more efficient ways to map soil radon concentrations that could ultimately lead to radon hazard microzonation maps and reduce lung cancer occurrences in Kentucky. KGS geologists Drew Andrews, Matt Crawford, and Bill Haneberg spent much of the year working with UK Earth and Environmental Sciences graduate student, UK Lyman T. Johnson Diversity Fellow, and KGS Potter Intern Alex Thomas to evaluate the suitability of a drone-compatible gamma spectrometer purchased with a University of Kentucky Center for Appalachian Research in Environmental Sciences (UK-CARES) high impact pilot grant for mapping soil radionuclides and radon potential. College of Nursing professor Stacy Stanifer was a co-principal investigator on the project. The team's work included extensive field testing to better understand the sensitivity and resolution of the instrument, which will ultimately have a bearing on the ability to detect radon signatures associated with subsurface geologic features such as faults and sinkholes. Work going forward will include test flights over known faults and sinkholes coupled with soil radon testing.

Interactive 3-D scene above depicts multi-altitude sUAV flight results showing variability of spectrometer total counts above an area with contrasting surface materials analogous to a fault. These and similar results will help to establish limits of detection and optimize flight altitudes and spatial density. Click into the map to interact with the scene and view the spectrometer points in 3-D (right-click to "grab" the scene and rotate).

Using Technology to Leverage the Value of Legacy Geologic Maps

Kentucky's statewide 1:24,000 bedrock geologic map coverage, which is completely digitized and freely available to the public, is a priceless resource. KGS geologists comparing details of the bedrock geology maps made during the 1960s and 1970s to modern airborne lidar topographic maps found that, although the geology was faithful to the best available topographic maps of the day, there could be noticeable discrepancies between the legacy maps and the lidar topography. Map units showing cliff-forming sandstones, for example, were in some cases not accurately aligned with cliffs in the lidar data. Valley bottom alluvium in other areas appeared on hillsides when draped over lidar coverage. DEAL researchers Yichuan Zhu, Jason Dortch, and Bill Haneberg obtained USGS funding to adapt computationally efficient image processing techniques that bring scanned copies of the legacy maps into better conformance with modern lidar topography, which can be important in site selection, transportation corridor

routing, and geologic hazards investigations. Because the amounts of adjustment vary across the map areas, Zhu, Dortch, and Haneberg developed their approach using spatially variable non-affine mathematical transformations between legacy and lidar digital elevation models, then applied the same transformations to scanned versions of geologic quadrangle maps. Their work will help to make the legacy geological maps valuable public resources in a time of rapidly evolving geospatial technology.
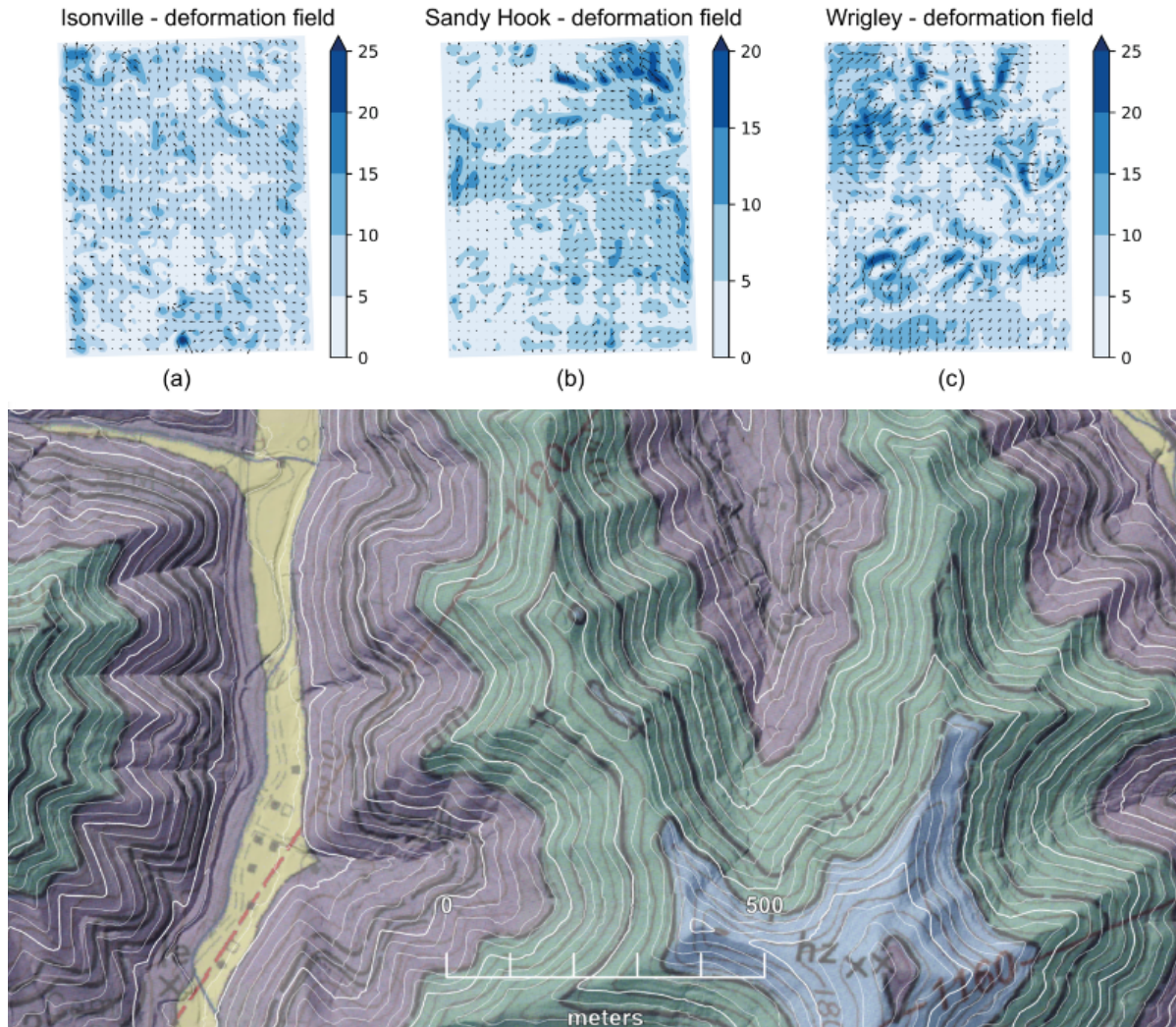
Left: Maps showing the amount of spatially variable adjustment — the deformation field — required to bring legacy digital elevation models into better agreement with modern lidar digital elevation models for the (a) Isonville, (b) Sandy Hook, and (c) Wrigley 7.5-minute quadrangles.

Right: Modern airborne lidar based topographic contours (white) in part of the McDowell, Kentucky, 7.5' quadrangle draped over 1954-vintage geologic quadrangle topography (brown contours) and outcrop patterns. Geology and original topography from existing KGS bedrock geologic map coverage. Lidar topography (white contours) from the "Kentucky From Above" statewide DEM.

Earth Analysis Research Library (EARL)

Introduction

The Earth Analysis Research Library (EARL) is the survey's repository for geologic samples and associated documents and maps. EARL currently houses 36,214 geologic samples, including rock cores, soil cores, sets of oil and gas well cuttings, augers, and coal samples dating back to the late 1800s. The facility also houses nearly one million associated data objects in paper, mylar, microfilm, and microfiche form. Samples and data under the care of EARL staff are largely irreplaceable and crucial for research, industry, and education communities.

EARL staff filled requests for a total of 1,101 sub-samples from 20 researchers representing academia, government, and industry. These samples covered more than 36,983 feet of core for thin section and geochemical analysis. EARL collections contributed to significant research topics including critical minerals, biostratigraphy, and paleoceanography. Twenty patrons from the general public and academia were taken on in-person tours of the collection, including a Northern Kentucky University class.

Four projects funded by the Institute of Museum and Library Services (IMLS) and the U.S. Geological Survey (USGS) were completed in Oct 2021 and June 2022. These projects focused on increasing public access and discoverability of our rock core and thin section collections through scanning, photography, and sample description. Seventeen rock cores were added to the KGS collection due to their potential significance to the research community. The facility also received a much-needed new roof, and we upgraded public workspaces for our non-destructive analytical equipment.

Tim Paton came to KGS from the doctoral program in Geology at the University of Tennessee to work on federally funded mineral rock core projects significant to current and future critical

minerals research. He also holds a master's degree in Geology from the University of Cincinnati. Isaac Gavin was hired as a temporary archive technician to assist with several internal and federally funded projects focused on collection care. Isaac has a master's degree in Archeology from the University of Louisville and a bachelor's degree from Berea College.

Data Rescue and Increased Physical Specimens Online

During the 2022 fiscal year, EARL staff completed a three-year project funded by IMLS to preserve and photograph 10,000 boxes of rock core, along with three data rescue and dissemination projects funded by the USGS. These federal funds supported three temporary positions to establish a KGS thin section collection, rescue and describe 59 rock cores from the Tabb Fault System and focus core photography efforts on mineral cores from the three Kentucky mineral districts. These products will help reveal mineralization characteristics and improve researchers' understanding of critical minerals and other economically important distributions.

The thin section project alone resulted in nearly 2,000 thin sections cataloged, scanned, rehoused, and made publicly available online. Fin O'Flaherty, the KGS web and development specialist, created a new online search query tool to display thin section metadata and scans. Registration of the International Generic Sample Numbers (IGSNs) increases discoverability provides users access to KGS project data for future research without creating new thin sections.

Thin Section Details (open this page in new window)

Thin Section 6-AFBC13 Information:
IGSN Number: IEKGS00HV
Site Name: Albany Quarry
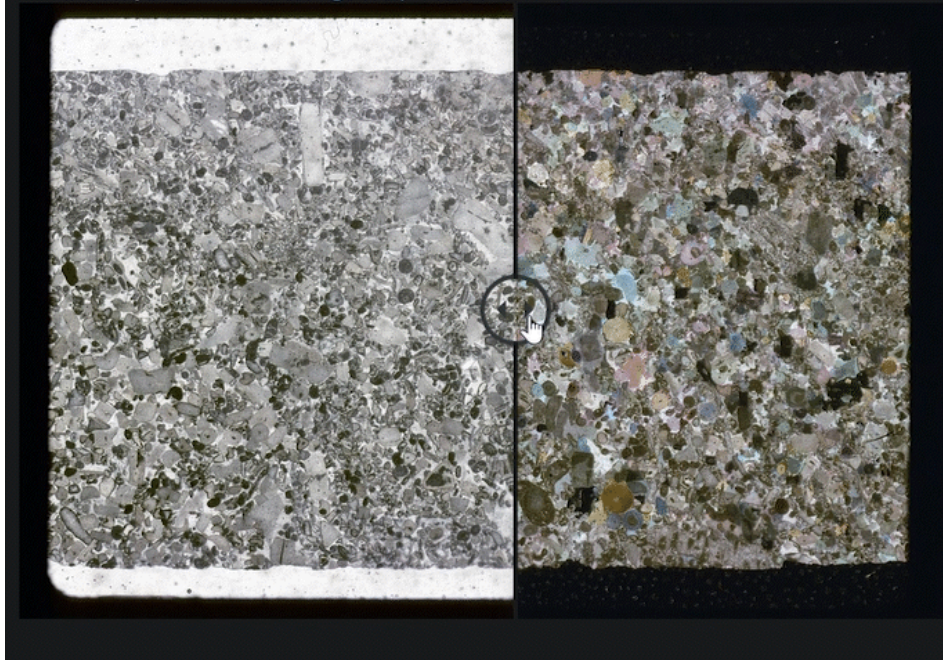Project Name: Garland Dever Legacy Collection
Thin Section Size: 46x26mm
Storage Location: KGS - Earth Analysis Research Library
Quadrangle: Albany
Quadrangle: Albany
County: Clinton
Map View: KGS Geologic Map Service

An example of thin section image scans with plane-polarized light (left) and cross-polarized light (right) in the online thin section viewer slider.

Lithologic information was recorded for 7,500 boxes of mineral cores during two USGS funded projects. The focus on mineral cores from the Tabb Fault System and Kentucky mineral districts illuminated the need to record secondary features, including mineral veins, fault systems, and vuges. Unlike other rock cores, these features are commonly found in mineral cores and provide vital insights into mineral distribution necessary for exploratory research. Similar processes are in place for documenting lithography information. Our data entry form and online core reports were updated to record and disseminate this important level of detail for public use. The combined information recorded independently of each other provides an improved digital account of the cores in our collection.

An example of lithology and secondary feature data displayed together with a core box photo from online core search service.

Other projects have been proposed for grant funding to further address our mineral cores and associated document collections vital to explaining critical mineral distributions in Kentucky. If funded, these projects will increase the critical mineral data available to our stakeholders and provide fundamental world skills to early career geologists working with our cores.

Exploring the Digital Image Archive of Geologic Cores at KGS Story Map

With the help of an EKU intern, KGS staff developed a story map about the core photography process. The Institute of Museum and Library Services (IMLS) funded the story map and core photography project. The publication (embedded and linked below) walks users through explanations of the coring process,

research uses, and preservation methods. Interactive features include several KGS-produced videos, a live map of photographed cores, and a 3D representation of the state-funded Hanson Aggregates well bore in Carter County, Kentucky.

Exploring the Digital Image Archive of Geologic Core at KGS

Collection Assessment for Preservation

KGS participated in a Collections Assessment for Preservation (CAP) project funded by the Foundation of the American Institute for Conservation of Historic and Artistic Works, in partnership with IMLS. Participation focused on gaining a holistic review of collections care practices at KGS including documentation, related policies and procedures, and housing environments. The recommendations will influence the development of a prioritization plan for future projects and improvements. EARL staff selected Building Assessor, Jeremy Linden of Linden Preservation Services LLC (Brockport NY) and Collections Assessor, Beth Heller, MA MSIS, PA of Beth Heller Conservation LLC (Asheville, NC) as key project partners. Linden has focused the last ten years of his career on enhancing preservation environments

and sustainability and has been a pioneering researcher on energy consumption in preservation settings. He earned an MLS in Information Studies and an MA in History from the University of Maryland and is an active participant on national and international standards committees. Heller is head of a private practice serving private and corporate collectors and cultural heritage institutions by preventing and mitigating damage to historic collections through preservation consulting and conservation treatment in accordance with standards and best practices, Linden and Heller spent two days touring EARL and the KGS campus building and meeting with KGS staff in September 2021. Their visit resulted in a 109-page report on our collections and their housing environment. In the report, we received helpful resources and suggestions for improving our preservation methods and related policies. In addition, EARL staff used the report to guide updated operating procedures and prioritize projects for grant proposals.

CAP assessors tour the EARL warehouse with KGS staff members Ryan Pinkston and Liz Adams

Energy & Mineral Resources

Introduction

Researchers in the section had a productive year as we fully returned to campus from over a year of remote work. The U.S. Department of Energy (DOE) funded study of the Cambrian Rogersville Shale (Appalachian Basin) was restructured when our industry partner was unable to drill the required research well. Principal investigator John Hickman, along with Dave Harris and Rick Bowersox revised the research tasks to use recently contributed data and completed the project final report in early 2022. The hydrocarbon potential of the Rogersville has not met expectations and the play is currently inactive. The section also explored a new research area for KGS, geologic energy storage; Rick Bowersox completed a pilot study on the potential for compressed air energy storage (CAES) in Kentucky. Grid-scale energy storage will be required to fully utilize renewable energy, whose availability does not always match demand. CAES involves using porous rock formations to store injected air during periods of excess electrical generation and releasing the air to generate power during high demand periods. The study developed a novel storage design which simplifies operation and increases energy efficiency.

The section continued research related to greenhouse gas emissions. Marty Parris, Cortland Eble, and Steve Greb completed a Kentucky Energy and Environment Cabinet (KEEC) funded project to identify methane emissions from underground coal mines in eastern and western Kentucky. This research utilized airborne and ground-based measurements to assess the amount of methane escaping from selected mines (more details can be found below). Steve Greb and Tom Sparks continued their research with the Midwest Regional Carbon Initiative (MRCI), generating new regional map compilations and stratigraphic correlations to support implementation of geologic carbon storage in the Midwest and eastern states.

Strong interest in locating new critical mineral resources for

technology development, renewable energy production, and electric vehicle manufacturing continued in 2021-22. Additional funding for characterization of these resources is included in the 2021 Infrastructure Investment and Jobs Act, also referred to as the Bipartisan Infrastructure Law. The USGS Earth Mapping Resources Initiative (Earth MRI) sponsored several KGS projects. Phase 1 of the Hicks Dome/Western Kentucky Fluorspar District project was completed in 2021 under the direction of Gina Lukoczki and Drew Andrews. John Hickman interpreted new airborne magnetic data which greatly improves definition of igneous rocks. Phase 2 of this project is now in progress and includes analysis of cored igneous dikes by Tom Uhl. KGS contributed to projects led by other state surveys, focused on rare earth elements in Pennsylvanian coal-associated underclays and Devonian phosphates. Funding for an Earth MRI South-Central Kentucky and North-Central Tennessee Mineral District project led by Gina Lukoczki is pending with a start date anticipated in early 2023.

Two new coal-focused rare earth element projects began in late 2021 with funding from the U.S. Department of Energy. KGS is participating in both the Illinois Basin and Central Appalachian Basin Carbon Ore Rare Earth and Critical Minerals (CORE-CM) projects, working with UK Mining Engineering and the UK Center for Applied Energy Research (CAER). KGS principal investigator for the Illinois Basin CORE-CM project is Steve Greb, and Cortland Eble is managing the Appalachian Basin project. The Illinois State Geological Survey and West Virginia University are the overall project leads, respectively.

Characterizing Methane Emissions from Coal Mines

With funding from the Kentucky Energy and Environment Cabinet, KGS geologists Mary Parris (principal investigator), Steve Greb, and Cortland Eble, along with collaborators Marcelo Guzman from the UK Department of Chemistry and Sean Bailey from the Department of Mechanical and Aerospace Engineering, are completing an 11-month study of methane emissions from

underground coal mines in Kentucky. Along with being the main component of natural gas, methane is a potent greenhouse gas 80-times stronger than CO_2 (over a 20-year period) when released to the atmosphere. These factors provide strong motivation for abating methane emissions. To that end, this study investigates different methods for characterizing methane emissions from underground coal mines. The results will help to assess the economic potential of methane emissions as a local power source or as offsets in the carbon market.

Using emissions and coal production data from the U.S. Environmental Protection Agency (EPA), the U.S. Energy Information Administration (EIA), and the Mine Safety and Health Administration (MSHA), 14 active, 4 non-productive active, and 4 abandoned mines were selected for study in eastern and western Kentucky (see figure below). The mines represent a range of coal production and methane emissions values. Over a nine-month period, methane emissions were measured using near-infrared spectrometers deployed from vehicles, a drone, and an aircraft. GHGSat, a Canadian based company, conducted the latter measurements November 15-19, 2021.

Coal mine methane study sites in eastern Kentucky (n= 15) and western Kentucky (n= 7). More numerous and smaller producing mines tend to occur in eastern Kentucky, whereas larger mines are in western Kentucky. View individual mine sites by clicking on bookmarks to each on the left or directly interacting with the map. Click on each site to view data. Sites where a methane anomaly was detected by land vehicle or airplane are labeled with a "V" (vehicle) and/or an "A" (airplane) or "V,A" for detected by both. Mine locations are referenced to the exhaust fan locations, but methane anomalies in the vehicle surveys are often nearby when they occur. Default basemap imagery is from KYFromAbove.

For each of the 22 mines, KGS supplied the GHGSat with location data for ventilation fans, belt portals, and coal piles. Flying at 10,000 ft , the GHGSat airplane measured methane concentrations at 21 mines visiting each mine at least twice on separate days. The airplane survey detected methane anomalies associated with ventilation fans at the Cardinal (Hopkins County), Pride (Muhlenberg County), and E4 Jarisa (Perry County) mines. The anomalies, 200 to 400 ppb above background (~2,000 ppb), are spatially linked to the fans (see figure below).
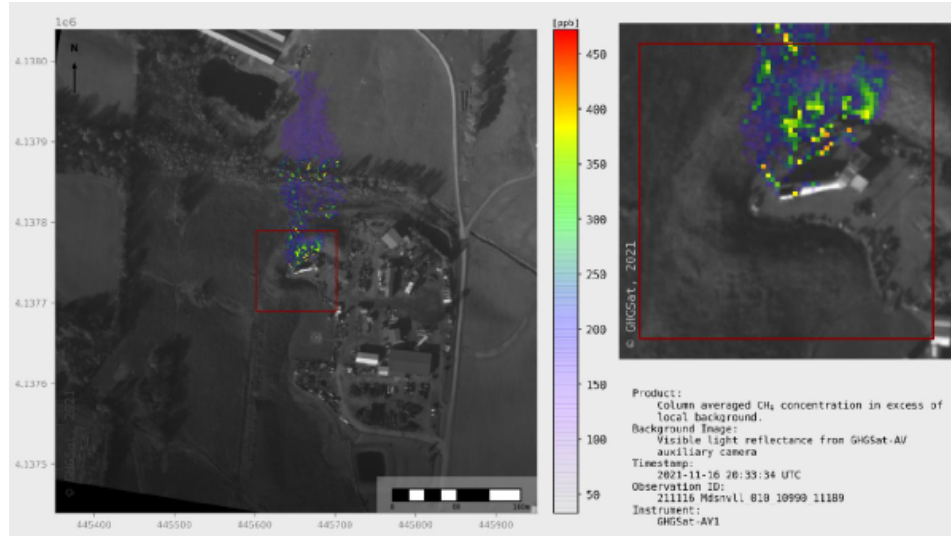
Airplane-based methane survey at the Nebo fan for the Cardinal mine in Hopkins County. Measured methane concentrations exceeding background level (~2,000 ppb) are shown with colored pixels (pixel area is 0.75 m2). Most of the plume is 200 to 350 ppb above background. Fan ventilation is directed to the west, but the north south plume orientation indicates wind from the south.

By comparison, of 11 mines surveyed with vehicle-based measurements, 9 showed anomalous methane at concentrations of 300 to 90,000 ppb above background. This includes the Cardinal and E4 Jarisa mines — Pride was not accessible (see figure below). The fewer number of anomalies observed with the airplane-based measurements versus those from the vehicle is unexpected as the former measured directly over the mine infrastructure and hence the potential sources of methane. In contrast, vehicle measurements along public roads were laterally offset from sources often by hundreds of meters. Some anomalous methane measured in the vehicle surveys likely represents local pooling of methane after being emitted from ventilation fans and other mine sources. This reason alone seems insufficient, however, to account for the performance differences. Moreover, vented mine methane concentrations reported to EPA often equal tenths and hundredths of a percent, values that should be readily detected with sensors having hundreds of ppb level sensitivity. As we complete our analysis, it's important to understand the factors influencing measurement performance especially since aircraft and satellites are touted as critical tools for remote detection and measurement of methane emissions.

West-looking view of vehicle-based methane survey conducted on April 1, 2022 at the Nebo fan at the Cardinal mine. Posted values represent concentrations (ppm) of methane above background (~2.089 ppm) along two survey traverses (orange and blue pins). The road bordering the east side of the mine shows two methane anomalies likely derived from the ventilation fan to the west. The shift in anomalies between traverses maybe the result of slight changes in wind direction from the northwest at 4 to 8 mph. In the anomalies, methane concentrations exceed background by 0.5 to 0.6 ppm (500- 600 ppb). To the upper left of the image an even larger methane anomaly (18 ppm above background) is associated with a gas compression facility.

Geologic Energy Storage Options

KGS researchers Rick Bowersox and John Hickman, with student aide Kyle Skeese, recently completed their project and report titled "Assessing the Potential for Compressed Air Energy Storage (CAES) in Kentucky to Augment Energy Production by Renewable Resources." Project funding was awarded from the University of Kentucky Energy Research Prioritization Partnership Seed Grant program. Bowersox presented this research at the Geological Society of America 2022 North-Central/Southeastern Joint Section Meeting in Cincinnati on April 7, 2022.

The project focuses on a potential tool for reducing greenhouse

gas emissions from Kentucky power plants using renewable photovoltaic (PV-Solar) power generation and Compressed Air Energy Storage (CAES). Most of Kentucky is suitable for co-installed PV-Solar power generation if there is a connection to the grid available. If both a PV-Solar power generation facility and the CAES power plant are part of the electrical power grid, they can be located remotely. This is critical in cases where there is not enough land available for both power generating facilities on the same site.

The utility-scale CAES process operates by storing high-pressure compressed air in a subsurface geologic storage reservoir or in cased wellbores which is then discharged during periods of high demand to drive electricity-generating turbines. CAES is an efficient method of generating electricity during periods of peak power demand to augment PV-Solar power generation and contribute to electrical charging of batteries or capacitors for nighttime use. At the end of the cycle, the stored compressed air supply is replenished by injecting air back into the storage reservoir or cased wellbores using surplus electricity to power compressors (see figure below).
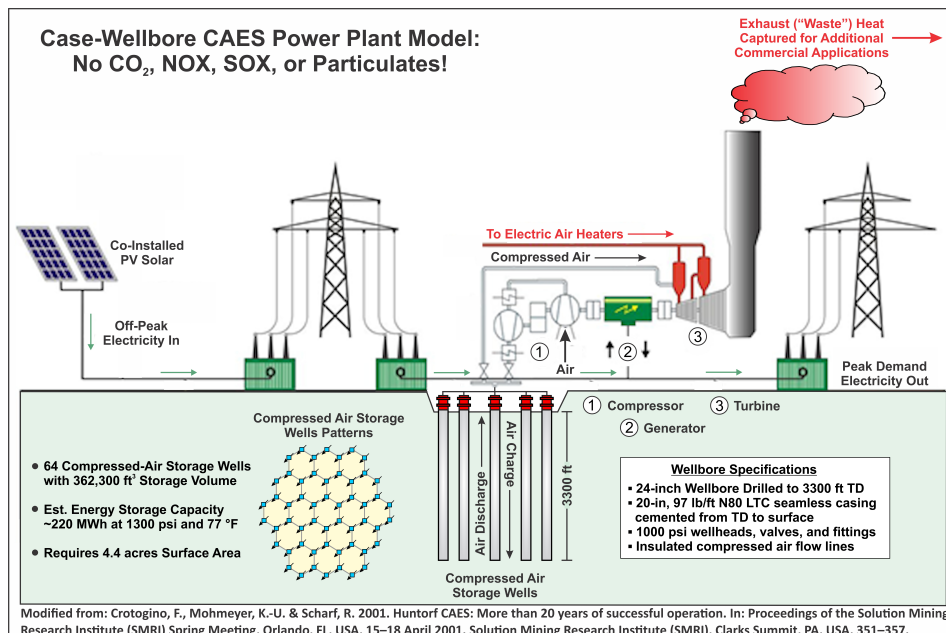
A diagram of the Case-Wellbore CAES power plant model.

There are only two utility-scale CAES plants in operation worldwide, although at least three more are presently under construction or in the process of obtaining government construction permits. Both existing power plants, located in Germany and Alabama, store compressed air in solution-mined caverns in salt domes to drive power-generation turbines. Both power plants require burning natural gas for heat to prepare air for compression in their electricity generating turbines. Co-installed PV-Solar-sourced electricity can provide the heat required by the CAES power plant and offset burning fossil fuels and discharging greenhouse gases. Thick salt deposits, however, are not part of Kentucky's geology.

Kentucky is fortunate to have six other options for compressed air storage: repurposing inactive or abandoned limestone mines; depleted oil and gas fields; saline aquifers; advanced compressed air storage in mined caverns; and in deep, non-geologic cased wellbores (see figure below). Ten inactive or abandoned limestone mines have been identified as potential candidates for conversion to compressed air storage after evaluation of their geotechnical integrity and sealing the interiors. Western Kentucky has abandoned oil and gas fields and confined saline aquifers lying at moderate subsurface depths that may be suitable for compressed air storage.
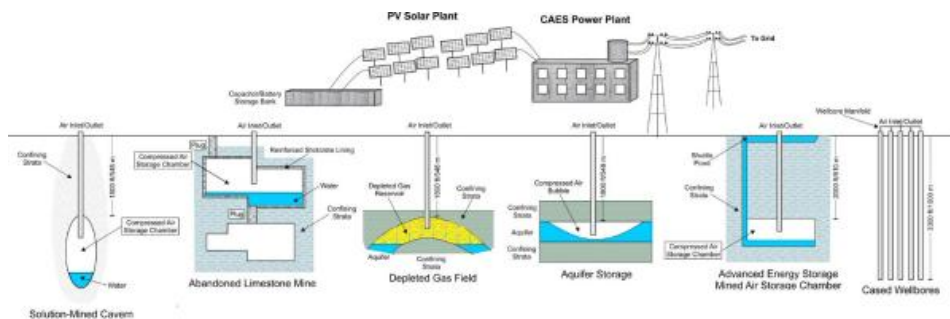
A diagram showing the six options for compressed air storage in Kentucky.

There are four areas in Kentucky where abandoned oil and gas fields in the Knox Group may be suitable for recompletion as compressed air storage reservoirs (see figure below). In central and

northern Kentucky acid-solution caverns as well-advanced energy storage mines could be constructed in Knox Group dolomites. Cased-wellbore compressed air storage, where a CAES project would have compressed air stored in up to 64 wells used as vertical air-storage tanks, is particularly suited to mined-out coal lands in eastern Kentucky. These options highlight the feasibility of further research on the development of CAES electrical power generation plants with co-installed PV-Solar power generation in the state.

A map of Kentucky illustrating potential sites for compressed air storage reservoirs.

Core-CM Projects

KGS is currently involved in two DOE funded grants to look for carbon ores, rare earth elements, and critical minerals (CORE-CM). One of the projects is in the Illinois Basin, in cooperation with the Illinois and Indiana geological surveys. The other is in the central Appalachian Basin in cooperation with the West Virginia, Tennessee, and Virginia geological surveys. In the current research phase, both projects are examining the potential for extracting Rare Earth Elements (REEs) from coals and coal refuse products (slurry ponds, ash ponds, acid mine drainage, etc). Rare Earth Elements (REE) are critical elements for much of our modern technology, and currently the United States is reliant on foreign countries (largely China) for REEs. These projects build on KGS experience in sampling and analyzing REEs from coal and coal

refuse. Nationally, the CORE-CM projects are evaluating a range of possible domestic sources for REEs and other CORE-CMs.
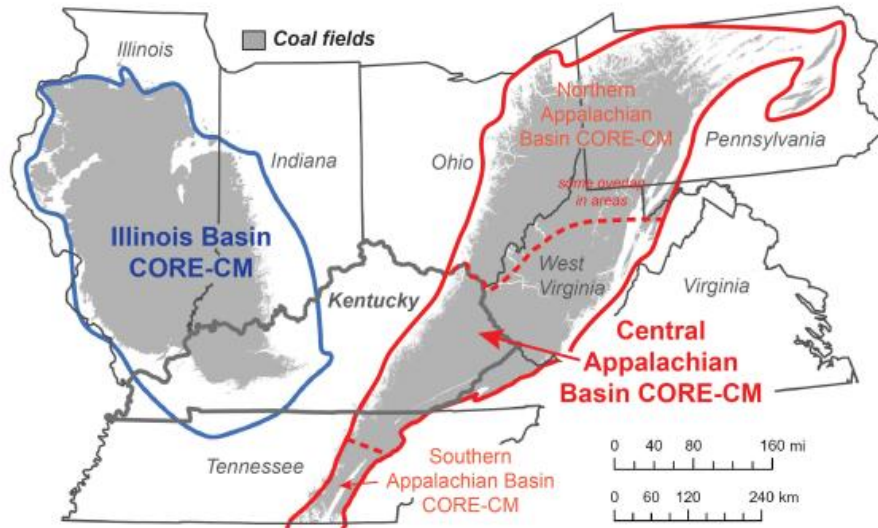
Map of US CORE CM projects and the two KY project areas. For more information about the national project see the US DOE website.

What are REEs?

REEs are elements in the lanthanide series of metallic elements on the periodic table. Although not technically a lanthanide element, yttrium (Y) is included with REEs because it has similar properties and commonly occurs with REEs. REES are usually found as trace elements, which are elements found in concentrations of less than 100 parts per million.
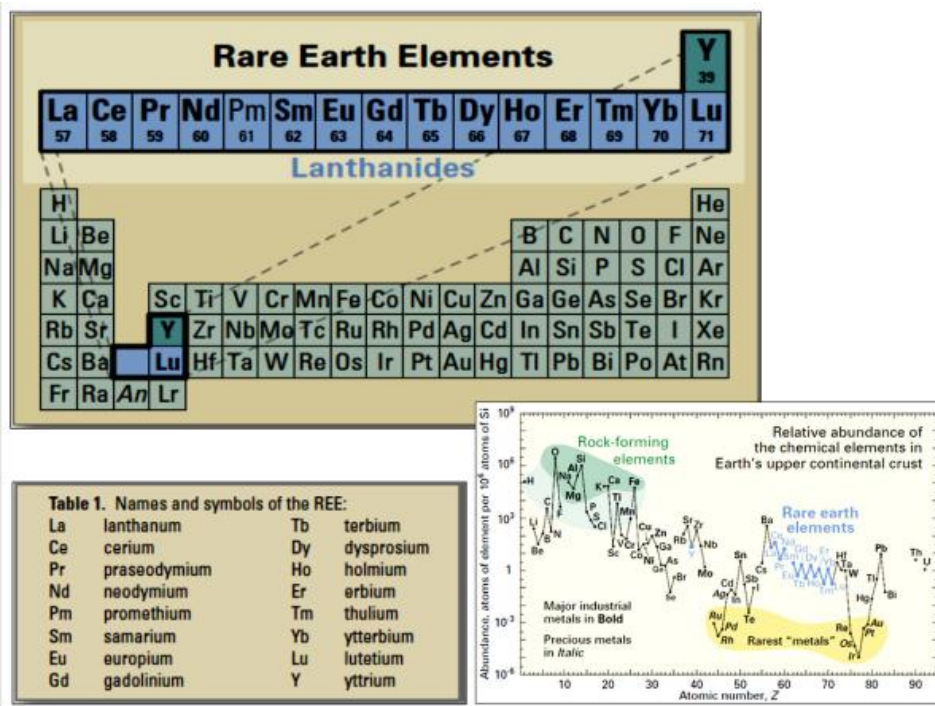
Periodic table of elements found in coals highlighting REEs and Yitrium. From USGS Fact sheet 087-02, Rare Earth Elements-Critical Resources for High Technology, 2002, By Gordon B. Haxel, James B. Hedrick, and Greta J. Orris, https://pubs.usgs.gov/fs/2002/fs087-02/

The unique properties of REEs make them critical for the production of magnets, electronics, and optical glasses used in cell phones, digital cameras, electronic displays (including computer monitors and television screens), rechargeable batteries, superconductors. These products are also used wide range of advanced technologies in the automobile (including electric vehicles), glass, wind energy technology, and national defense industries.

Types of REEs

REEs are commonly divided into light and heavy REEs (although sometimes they are classified as light, medium, and heavy REEs). Light REEs (sometimes abbreviated as LREE) are the elements with atomic numbers (weights) 57 through 64. Heavy REEs (sometimes abbreviated as HREE) have atomic numbers (weights) of 65 through 71. Yttrium has a low atomic number (39) but is classified as a heavy REE because it tends to occur with these elements.

Light and heavy REEs have different physical and chemical properties, so are used to make different products.
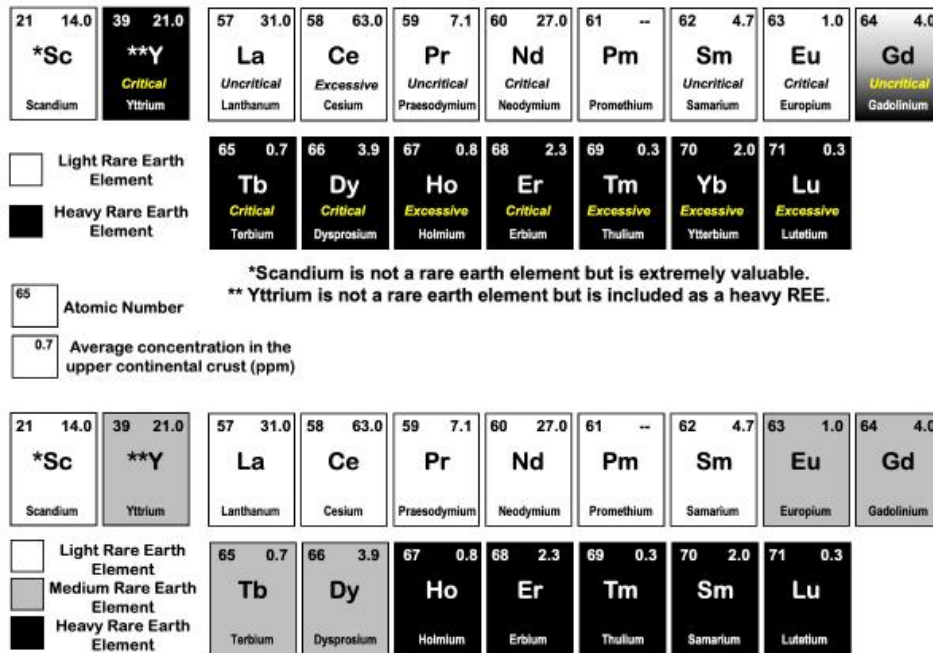
Two classifications for Rare Earth Elements. Top chart divides elements into Light and Heavy REEs. Bottom chart divides elements into Light, Medium, and Heavy REEs. Yellow text indicates the relative demand for some of the elements.

REES from coal and coal refuse

Coals and non-coal rock mined with coals in both the Illinois and Appalachian basins contain trace amounts of REEs. Most Kentucky coals in both basins are processed in coal preparation plants before being sent to power plants to make energy. In preparation plants, the mined coal and associated rock material are crushed to smaller sizes, and non-coal rock and minerals are separated from the coal. Receiving already crushed and separated material is advantageous in the REE process as this eliminates a typically costly and time-consuming preparation step. If concentrations of REEs could be economically removed from coal refuse, it would be an effective use of a material that is currently unused refuse.

As part of the CORE-CM projects, Stephen Greb, Cortland Eble, and Tom Sparks are compiling data on slurry pond locations and volumes in Kentucky. Eble and Ethan Davis are compiling coal

analyses data from past projects and preparing new samples of coal and coal refuse for analyses from both basins. Once prepared, new samples are brought to UK's CAER, where Inductively Coupled Argon Plasma-Optical Emission Spectrometry (ICAP-OS) is used to measure the amounts of REEs in the samples. KGS, CAER, and UK's Department of Mining Engineering have been working for several years on analyses of coal and coal refuse as a potential source for future REEs. The Department of Mining Engineering is also actively testing new technologies for extracting REEs from coal and coal refuse.

KGS staff and REE analyses. (A) Cortland Eble after grinding coal samples down to powder for analyses. (B) Ethan Davis treating samples with acids, (C) Jason Backus with prepared samples ready for analyses in the elemental spectrometer. See our REE analyses page for more information.

Geologic Hazards

Introduction

The hazards section made significant contributions to the KGS strategic goals in research, service, and professional development in FY 2021-22. The section conducted seven externally and internally funded projects including a U.S. Federal Emergency Management Agency (FEMA) funded landslide hazard and risk assessments for the Big Sandy and Kentucky River Area Development Districts; a Department of Energy (DOE) funded seismicity monitoring project in western Kentucky; a characterization of earthquake activity and tectonic stress at candidate sites for Carbon Capture, Usage, and Storage (CCUS) in

the north-central and northeastern regions of the US; a USGS funded installation and evaluation of Raspberry Shake seismographs; and national landslide susceptibility assessment. The section produced five manuscripts for peer-review journal publications, two reports, nine abstracts, and seven professional and public presentations. The section actively engaged in internal collaborations with the staff in other sections at KGS and external collaborations with researchers on the UK campus and beyond. Hazards researchers also actively engaged in public and student services, including supervising one MS student, two Paul Edwin Potter Interns, and one high school student. The section emphasized staff professional development, including the completion of MS degree by Jon Schmidt and the approval for promotion from Geologist I to II for Hudson Koch.

Seth Carpenter, Jon Schmidt, and Russel Rogers installing the strong-motion station, KBKY, in the Kentucky Bend of the most western part of Kentucky and the center of New Madrid Seismic Zone (photo by Zhenming Wang)

Kentucky Seismic and Strong Motion Network (KSSMN)

The hazards section operates and maintains the Kentucky Seismic and Strong-Motion Network (KSSMN), which consists of 22

permanent seismic and strong motion stations (see figure below), to monitor earthquakes and other activities in and around the commonwealth and to provide information in real-time to Kentuckians. The KSSMN provides essential data for research at UK, which are also shared with regional, national, and international institutions through KGS servers and through the Data Management Center at Incorporated Research Institutions for Seismology.

Kentucky Seismic and Strong-Motion Network (KSSMN). Click on the interactive map to view data from the stations.

KSSMN, especially the real-time online recordings, provide reliable information on earthquakes and other activities for media and stakeholders, including one interview with Stu Johnson of WEKU on earthquake activity in the New Madrid seismic zone. KSSMN also recorded the December 10-11, 2021, tornado-generating storms (see figures below), which was of particular interest to the public.
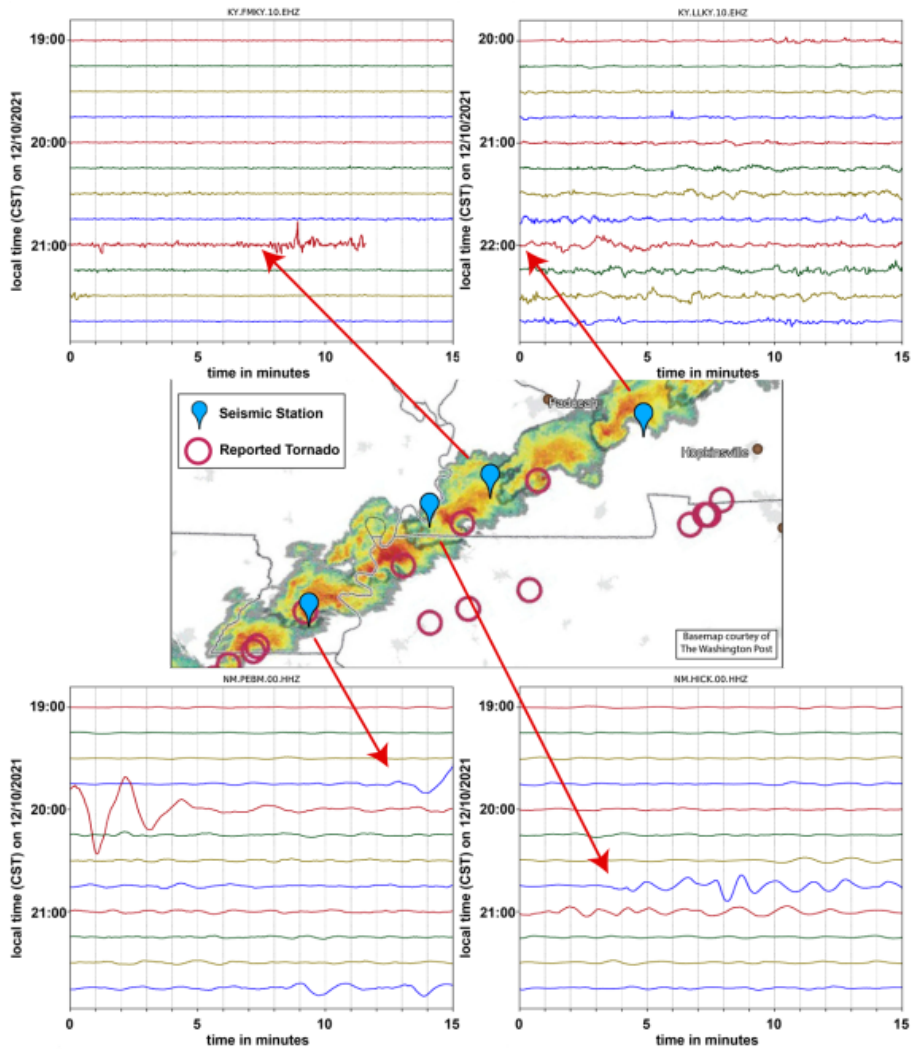
Recordings of the December 10-11, 2021, tornado-generating storms by seismic stations operated by KGS and by the University of Memphis.

The hazards section continued to renovate and upgrade KSSMN through internal and external support. Through the USGS National Earthquakes Hazard Reduction Program (NEHRP) external research program, six Raspberry Shake seismographs, including five RS3D and one RS4D, were purchased and installed at BAKY, CUSSO, HEKY, HZKY, and VSAP. The Raspberry Shake seismographs are newly developed and low-cost instruments for earthquake monitoring, which may be particularly useful for earthquake early warning systems (EEWS). The data collected from these instruments will be analyzed for amplitude, duration and spectral content and directly compared to data acquired by existing KSSMN instruments to assess whether the Shakes can produce reliable ground motion data. The data will also be used to evaluate the performance of the Raspberry Shake systems with

respect to latency to assess whether the signals can be uploaded quickly enough to allow the EEWS to generate and transmit a warning in a timely manner. Three stations, BAKY, KBKY, and VSAP, were upgraded to real-time data transmission through cellphone modem and with either new sensors or additional ones.

RS3D (top) and RS4D (bottom) are collocated with FBA-23 strong motion accelerometer and Guralp broadband seismometer in the instrument vault at CUSSO.

Russel Rogers, Paul Edwin Potter Intern and MS student in the Department of Earth and Environmental Sciences, began work

with Seth Carpenter to evaluate the performance of the newly acquired nodal geophones and to collect new datasets (see figure below). The nodal geophones respond to ground shaking in three dimensions and include an internal data logger and GPS receiver, all in a compact package that permits rapid and flexible deployments. For his internship, Russel used the nodes to evaluate the seismic velocity structure of sediments in the Jackson Purchase region.

Russel Rogers, Paul Edwin Potter Intern, installing a nodal geophone at station CUSSO (photo by Zhenming Wang).

Landslide Susceptibility and Risk in the Kentucky River Area Development District

This project, led by geologist Matt Crawford, is seeking to implement measures designed to evaluate landslide hazards and reduce risk to individuals and property in the Kentucky River Area Development District (KRADD). The results will contain useful information for each community to incorporate mitigation strategies that will support building and infrastructure needs, land-use planning, event awareness, response, and recovery actions for communities in the region.

Mitigation plans identify the landslide hazards that impact communities, identify actions to reduce losses from the hazards, and establish a coordinated process to implement the plan. Integration of landslide susceptibility data and risk information into a multi-jurisdictional plan revolves around goals of establishing resilience as a value of the community.

The landslide team, which consists of geologists Matt Crawford, Hudson Koch, Jason Dortch, established a reliable framework for assessing landslide susceptibility at a regional scale using a statistics and geomorphic-based approach. They incorporated landslide inventory data and with two traditionally distinct machine-learning methods that complement each other to produce a final susceptibility map. Hillslope factors such as slope, curvature, plan curvature, elevation, and aspect are used in a decision-tree and logistic regression analysis to determine significant factors for generating the map. Using the susceptibility map as a key input to a risk assessment, the team also produce a socio-economic risk map that includes landslide effects on assets such as population, roads, railroads, buildings, and land class.

A key component to achieving quality statistical models of landslide occurrence is landslide inventory mapping. The team started the process by mapping landslides in Knott and Owsley counties. Through the Paul E. Potter Summer Internship, Alex

Arimes mapped over 2,500 landslides in parts of the Knott County (see figure below).

Alex Arimes, Paul Edwin Potter Intern, conducting landslide inventory mapping for a part of Knott County, Kentucky (photo by Zhenming Wang).

For this project, Arimes primarily used the multi-directional, lidar-based hillshade to identify landslide geomorphic features and digitize the extent of each landslide deposits (see figure below). To support these interpretations, she used secondary, derivative maps including slope, curvature, plan curvature, aerial photography, traditional hillshade, and topographic contours.
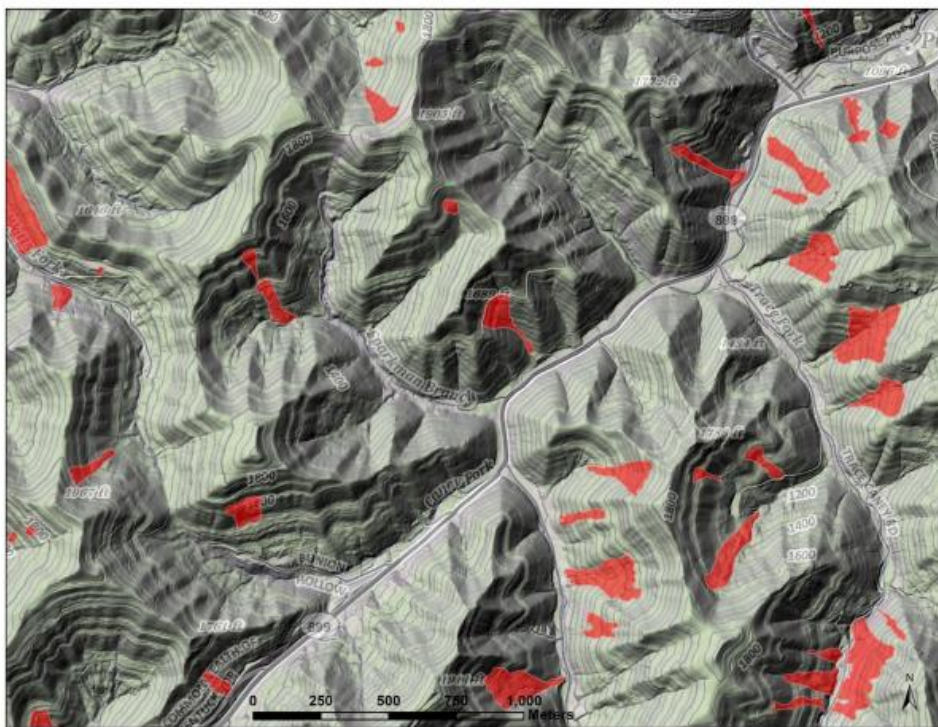
Existing landslides identified in part of the Hindman area 7.5-minute quadrangle, Knott County, Kentucky.

Assessing Induced Seismicity Potential with the Midwest Regional Carbon Initiative

Carbon Capture, Usage, and Storage (CCUS) can perturb pore fluid pressure on preexisting faults and lead them to premature failure, inducing an earthquake. The crust in the central and eastern U.S. is understood to be critically stressed and thus past earthquake activity indicates the presence of faults that may cause future earthquakes. Therefore, characterizing earthquake activity and tectonic stress at candidate CCUS sites is critical. Toward assessing the potential for induced seismicity from CCUS, Seth Carpenter and Jon Schmidt assembled a set of stress measurements and began compiling a catalog of earthquakes for the 20-state region comprising the Midwest Carbon Sequestration Initiative (MRCI) project area. The earthquake compilation, which consists of more than 42,000 events, is being developed from lists of earthquakes obtained from seismic networks, data centers, publications, and individual researchers (see figure below).
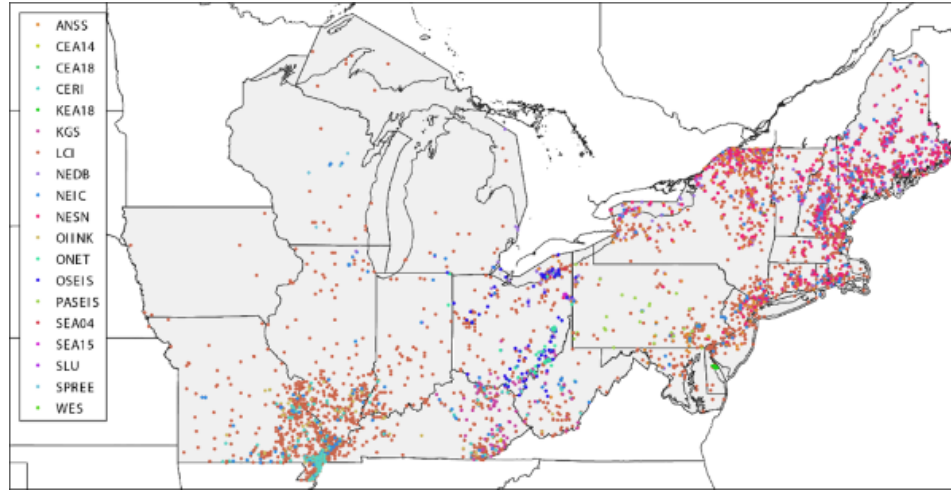
Earthquakes compiled for the MRCI seismicity catalog. Epicenters are colored by data source.

Earthquakes induced by CCUS activities could create seismic hazards – ground motion hazard in particular that could compromise reservoir integrity, and impact communities at CCUS sites. This work will provide important input needed to assess seismic hazards from CCUS development at candidate sites in the northeastern quadrant of the U.S. The next steps in this work involve merging all lists of earthquakes and to calculate a new magnitude for each event using a uniform magnitude scale.

The compilation is being enhanced by earthquakes located in the MRCI states by the Array Network Facility (ANF) during the EarthScope project. More than 6,000 seismic events – earthquakes and blasts – were located using EarthScope's uniformly spaced Transportable Array stations (see figure a below), which operated in phased deployments in the region from 2010 to 2015. The KGS team is applying an innovative approach to distinguish the rare earthquakes from the numerous blasts in this dataset, an otherwise labor-intensive task that requires manual analysis of waveform data. For each event in the ANF database, three-component recordings from each nearby Transportable Array station are analyzed by the machine-learning-based event classifier developed by Miao et al. (2020). The classifier was trained on a dataset of earthquake and blast recordings from Kentucky, Ohio, Tennessee, and West Virginia, and automatically

discriminates between these event types. The figure below shows example automatic classifications of an earthquake and of a nearby blast.
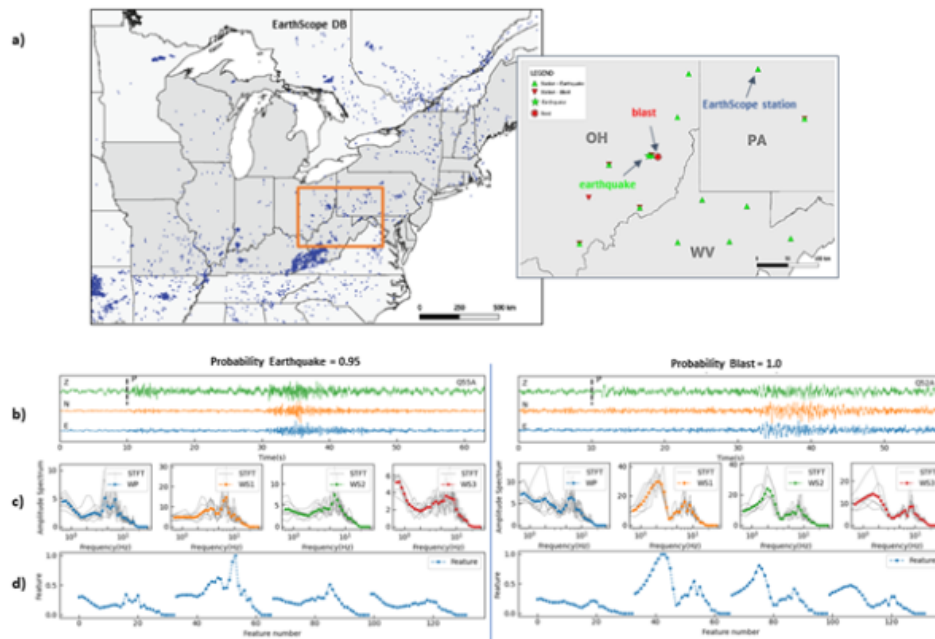
Machine-learning-based automatic classifications of an earthquake and of a nearby blast. a) EarthScope event database in and around the MRCI states (shaded) and zoomed view of a nearby earthquake and blast pair in eastern Ohio. b) Three-component waveforms recorded by one station of the earthquake (left column) and of the blast (right column). c) Spectra determined from four different parts of the waveforms. d) Features used for the discrimination algorithm, composed of the average spectra in c).

Geologic Mapping

Introduction

In 2021-22, the KGS geologic mapping section continued to generate new geologic maps, new geologic data sets, useful geochronologic tools, and geologic communication projects for the Commonwealth. The KGS Geoframework team made great strides to develop a robust database of 3D stratigraphic data in their first year of funded support from the USGS National Cooperative Geologic Mapping Program's National Geoframework Initiative (funded with STATEMAP support). The goals of the KGS effort are to rapidly develop 3D data elements from best available

2D resources while developing tools and resources for future 3D work following the best practices developed and demonstrated at organizations with established 3D programs.

New temporary employee Anna Pearson generated a database of roughly 200 3D stratigraphic surfaces from published sources and developed web-based visualizations and web tools to illustrate and explore the data.Rapid development of these 3D surface representations is critical to identify areas of uncertainty, errors in the previous work, and to enable development of 3D web tools to interrogate the data. Devan Robinson worked with John Hickman to develop a statewide fault model, as well as detailed 3D fault representations for the Earth MRI 3D model of the Western Kentucky Fluorspar District (Gina Lukoczki, PI). These fault models are the essential first step for future 3D stratigraphic interpolations and revisions. Dibya Koirala worked with Dave Harris to generate a statewide set of reference geophysical logs from oil and gas wells. These wells were selected as some of the deepest or most important wells in the state and will serve as the foundation for future correlations across the state.

In addition, William Andrews and Steve Martin were engaged in national conversations regarding geoheritage communications and development. Andrews helped convene a high-profile geoheritage session at the October 2021 GSA Connects meeting in Portland, Oregon.

Geologic Mapping

Geologists Matt Massey, Antonia Bottoms, Max Hammond, Ann Hislop, and Meredith Swallom continued surficial geologic mapping efforts in Hardin County as recommended by our State Mapping Advisory Committee. Mapping was funded by USGS STATEMAP awards and the KGS. STATEMAP award #G20AC00291 resulted in the publication of four new 1:24,000-scale quadrangle maps (Cecilia, Constantine, Howe Valley, and Sonora quadrangles) and one GIS dataset. Current mapping supported by U.S Geological

Survey STATEMAP award #G21AC10834 was completed in September 2022 with five new geologic quadrangle publications (Flaherty, Big Clifty, Summit, Millerstown, and Upton quadrangles) and one new GIS dataset publication (see map below for quadrangle locations). This will conclude a four-year effort to complete Hardin County and will provide a robust dataset for county land use planning and development, including lithologic characterization, surficial thickness (depth to bedrock) information, and geotechnical parameters. Recent surficial geologic mapping projects have been compiled into a KGS web map service and will be updated with the recent Hardin County mapping in the fall of this year. Older surficial mapping will be added on a rolling basis as they are updated to fit a national standardized GIS format.
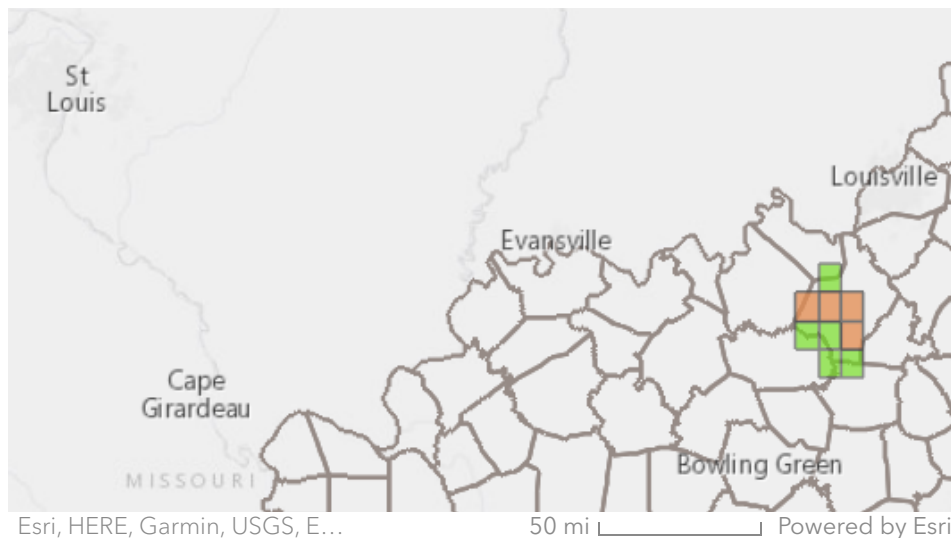
Interactive map showing locations of recently mapped 7.5-minute quadrangles from the surficial geologic mapping program. Click quadrangle for a link to the published quadrangles (orange quadrangles).

Age Analysis Tool

The Probabilistic Cosmogenic Age Analysis Tool (P-CAAT), developed by geologist Jason Dortch, enables researchers to more accurately determine the age of landforms that have been dated with techniques such as terrestrial cosmogenic nuclide or luminescence dating. Researchers examining landscape processes are now in a better position to determine if the events that lead to

the deposition of a landform are catastrophic or gradual. Also, multiple events can more accurately be compared to climatic records to determine if regional changes in temperature and precipitation have influences the development of the Kentucky landscape. This approach incorporates both laboratory and geologic uncertainties and enables researchers to utilize geologic context to inform post-analysis interpretations of chronology data. While the current statistical tool is in an easy-to-use GUI interface, some of the processes that require expert knowledge could potentially be automated. This would make our statistical approach more user friendly and also help standardize results. A standalone downloadable version of the P-CAAT statistical tool along with tutorial videos can be found here: kgs.uky.edu/anorthite/PCAAT/.
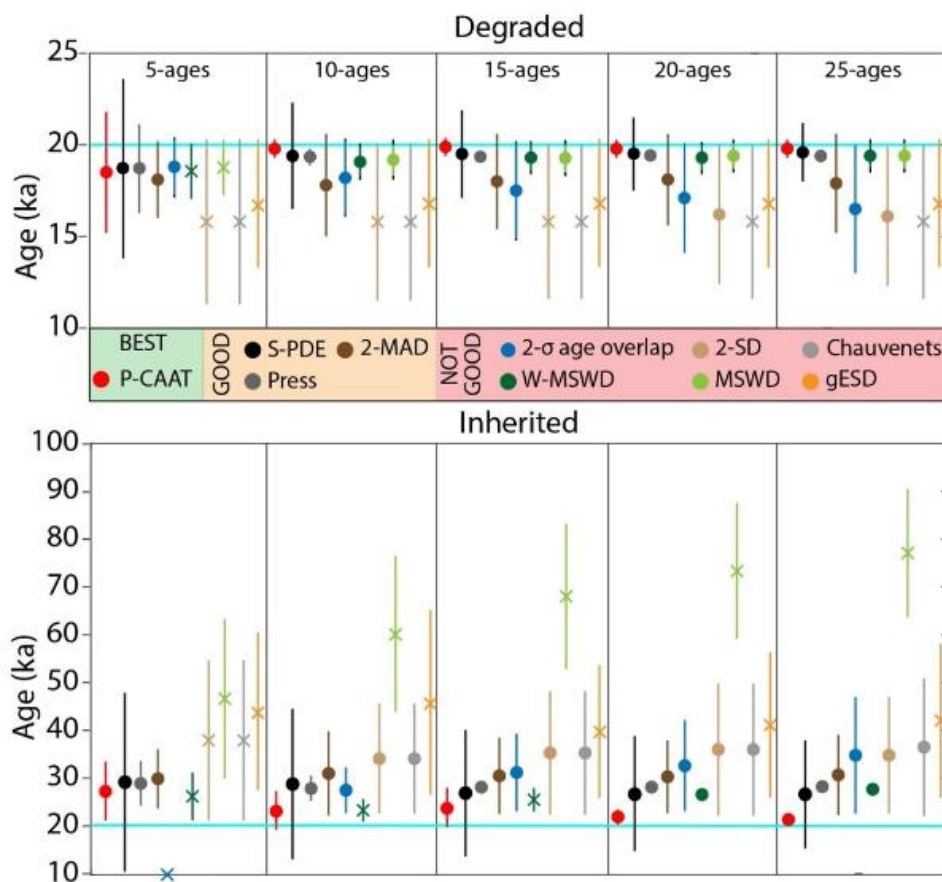
This comparison plot shows how previously used statistical approaches compare against skewed datasets from Applegate et al. (2012) represented by turquoise horizontal bars with true ages of 20 ka. Note that P-CAAT is consistently closer to the "true age" (more accurate), with smaller average uncertainties (more precise) than other methods. × = failed test and circles = successful test. All vertical uncertainty bars are 1σ. P-CAAT is represented by the left most points in each subplot. Other methods are Stübner probability density estimate (SPDE), Bayesian probability density (Press), Two Mean Absolute Deviations from the Median (2-MAD), 2σ Overlap of Age Uncertainty (2σ-overlap), Mean Squared Weighted Deviates (MSWD) and Weighted Mean Squared Weighted Deviates (W-MSWD), Chauvenet's Criterion (Chauvenets), Generalized Extreme Students Deviates (gESD), and Two Standard Deviations from the Mean (2-SD).

Mantle Rock Story Map

Geologists Steve Martin and Steve Greb, along with cartographer Emily Morris, developed a KGS story map detailing the geology of Mantle Rock Nature Preserve in western Kentucky. The virtual tour is the result of a UK Cooperative Extension pilot project to connect KGS with the Riverlands Alliance, a non-profit organization promoting public lands in western Tennessee and Kentucky. The trail guide that explains geologic features along the

preserve's 2.8-mile trail.

Mantle Rock Nature Preserve is in Livingston County, Ky. near the Illinois-Kentucky border and approximately 45 minutes north of the Land Between the Lakes National Recreation Area. The land was acquired by The Nature Conservancy in order to protect the fragile sandstone glades, upland forests, and rare wildflowers such as June grass and Buckley's goldenrod. The preserve trails and the adjoining Livingston County Wildlife Management Area and State Natural Area lands are open to the public.

Geologic Tour of Mantle Rock Nature Preserve story map.

The central attraction, Mantle Rock natural arch, has the longest span of any natural rock opening in the state at 165 feet. This rock opening formed in the Pounds Sandstone Member of the Caseyville Formation because of weathering and erosion caused by the action of water, temperature variations (freeze-thaw), and tectonic stresses on the rock. The Mantle Rock trail is an ideal

setting to learn about depositional (crossbedding), tectonic (joints), and weathering (natural rock openings, honeycombs) features that can be observed in the sandstone. Additionally, hikers can see common landscape features such as loess and residual soils in upland areas, colluvium along hillsides, and alluvium along the streams along the trails. The Geologic Tour of Mantle Rock Nature Preserve story map includes photos and illustrations of the area and is accessible on the KGS website.

Geoscience Information

The GIMS section is responsible for maintaining and managing data, IT infrastructure, communications, and the physical collections at the KGS Earth Analysis Research Library (EARL). While much of our section work is ongoing and supports all research areas and sections at KGS, section staff completed several noteworthy, funded projects, primarily in the area of data preservation and data dissemination. Section accomplishments include completing a major phase of a funded rock core photography project, publishing an online story map about the process, preserving and making available photos of KGS thin sections via an online web service, rescuing mineral core for critical minerals research, and hosting an assessment of all our physical collections and facilities. Detailed project information is included in the EARL section of the annual report.

In February we welcomed two new members to the section, Rachel Noble-Varney as our geoscience publications manager and Fin O'Flaherty as our web and database specialist. Both Rachel and Fin hit the ground running by making an immediate impact on improving both our written and digital communications and our web services.

In May, after a two-year hiatus, the GIMS section (and others from KGS) were able to gather as a section for a yearly team building outing by taking a field trip to the Berea Forestry Center. They were graciously hosted by the staff at the Center and took a guided hike on one of the trails to Anglin Falls. Pictured on ledge next to Anglin Falls (left to right): Hudson Koch (Hazards Section), Doug Curl (GIMS), Elizabeth Adams (GIMS), Monte Rivers (GIMS), Rachel Noble-Varney (GIMS), Jason Dortch (Geologic Mapping Section), Sarah Arpin (Water Section), Carrie Pulliam (GIMS), Tim Paton (GIMS).

The section continued to support KGS's robust online data and information capacity and several new data services and story maps. We were also involved with the production and publication of our new podcast, the Big Blue Rock Pod, highlighted below. The publications sales office re-opened on Wednesdays to complete orders, after a COVID and staffing-related closure. Section staff are continuing to assess how to best service the public by both continuing to provide publications and data online and in physical form where needed and feasible.

Orphan Well Data

In 2021, the Federal Infrastructure Act Orphan Well Plugging Initiative awarded Kentucky over 45 million dollars for the plugging of orphaned oil and gas wells in the commonwealth. This sparked a renewed interest in historic and pre-law well data that KGS has collected since the mid-1800s. In response to call for

applications, the Kentucky Division of Oil and Gas reported/submitted approximately 14,000 orphaned wells acknowledged by the state. This quickly highlighted a data discrepancy, as the archive at the Kentucky Geological Survey has an additional 16,000 possible orphans that pre-date Kentucky's oil and gas drilling regulations. Geologist II Carrie Pulliam, who manages the state oil and gas well database and documents archive immediately began working to distinguish and reconcile these pre-law wells with the state historic wells, which are reported to DOG and inspected after drilling is completed. Using a process of spatial comparison, examination of pre-law documentation, and identifying plug descriptions, Pulliam continues to reconcile the KGS and state databases allowing DOG to evaluate and rank wells based on environmental risk. In April 2021, Pulliam presented her work on the identification and classification of well records to the KGS Advisory Board. Along with energy and minerals section head Dave Harris, Pulliam also presented to the state oil and gas working group, to ensure the DOG and other major stakeholders were aware of the discrepancies in public data. Citizens of the commonwealth who suspect they may have an orphan well on their property can report the location to DOG.

Big Blue Rock Podcast

In January, KGS debuted the Big Blue Rock Pod, a Kentucky-themed earth science podcast where hosts Matt Crawford, Sarah Arpin, and Doug Curl invite guests, typically geoscience researchers, to join in a relaxed, impromptu conversations about specific geologic topics. The aim of the podcast is to highlight how geology and earth processes impact daily life. Formatted around monthly themed episodes and guest experts, the show explores what host Matt Crawford describes as "the tentacles of geology that reach out to all the other sciences."

KGS employees (left to right) Sarah Arpin, Matt Crawford, Doug Curl host the Big Blue Rock Pod.

Seven episodes were released this year which range in topics including discussions about Red River Gorge, glaciers in Kentucky, the southern Appalachian Mountains, bourbon, geology of Mammoth Cave, and paleontology. Plans for future episodes include a discussion with the KGS Director, Bill Haneberg, an exploration of geologic time, and other topics which will investigate how geology shapes the culture, economy, and history of Kentucky.

Along with having fun talking shop, the hosts of the Big Blue Rock Pod are serious about improving science communication and spreading awareness of geology. As Crawford shares in the introductory episode, despite a growth in science podcasts, the number of earth science podcasts trail far behind similar fields like physics, biology, and ecology. That's surprising, according to co-host Sarah Arpin, because "understanding the environment you live in, the geological, biological, and ecological processes, makes the world that much more exciting to experience."

Big Blue Rock Pod Player.

Thanks to the support of the Office of Research Communications, specifically editor Ben Corwin and director Alicia Gregory, the first episode launched in January 2022. The Big Blue Rock Pod is hosted on PodBean and available on multiple applications, including Apple Podcasts, Amazon Music, Spotify, and Google Podcasts. The podcast series is also available for download from the KGS homepage.

KGS Annual Seminar

The Kentucky Geological Survey (KGS) hosted its 61st Annual Seminar on May 12th: the first to focus on the intersection between geoscience research and climate change in Kentucky. The goal of the event is to present truly collaborative and interdisciplinary work related to the KGS mission. However, the GIMS and administrative sections of KGS work diligently on the logistics and communications that support science communication and event management.

State Geologist and Survey Director Bill Haneberg set the direction for the day by emphasizing how interdisciplinary research is vital to shaping Kentucky's future, saying "climate change is here, and the impacts reach far beyond geology. It's an economic, human health, and policy issue. Our job at KGS is to provide unbiased data and information to help mitigate potential impacts to Kentucky and support science-based decision making."

Each of the seminar's six technical presentations explored climate-related research topics relevant to Kentucky: geologic hazards, remote sensing for environmental mapping, methane emissions from orphaned oil and gas wells, carbon storage, and critical minerals. KGS geologist Jason Dortch outlined how global phenomena like more frequent high-intensity precipitation events and forest dieback help researchers understand and predict landslides in Kentucky. Another member of the landslide research team, Sourav Saha, highlighted how geoscientists can use the Google Earth Engine scripting environment to create free, wide-scale maps for geohazard research. Discussing his collaboration with the Yale Carbon Containment Lab, Marty Parris presented an example from the Daniel Boone National Forest as a template for reducing methane emissions and plugging orphaned oil and gas wells in Kentucky. Reporting on a separate national initiative, Steve Greb discussed Kentucky's contributions to plans for potential storage of carbon dioxide in deep subsurface rocks. Gina Lukoczki, referencing upcoming plans to build three electric vehicle plants in Kentucky, explained the critical mineral needs of the energy transition and Kentucky's potential role in supplying these. Presenting on the Kentucky Climate Consortium, a statewide, interdisciplinary research and teaching collaboration for academics, Lauren Cagle of UK's Writing, Rhetoric, and Digital Studies department focused on the need for narratives of climate change that resonate with Kentuckians. She explained, "here, we don't have polar bears or beachfront property, but as today's talks have shown, climate change touches on every part of academia and research in the state."

Bill Haneberg also presented the 2022 KGS Director's Awards to a group of KGS scientists involved in the Radon on the RADAR research project, a NIEHS-funded citizen science project through the UK College of Nursing that involved 16 weeks of time-sensitive fieldwork to measure soil radon levels at more than 60 homes in four rural Kentucky counties. The radon data will inform public health efforts to decrease radon exposure, which is the second

leading cause of lung cancer and significantly increases the likelihood of lung cancer in those exposed to tobacco smoke. Other key events included research poster session lightning talks and an open discussion for public comment. The 12 talks and accompanying posters showcase KGS climate research on topics ranging from carbon storage to seismology. Haneberg ended the session with a reflection on the breadth of topics discussed and emphasized that truly transdisciplinary challenges must have transdisciplinary solutions.

Director's Award winners from left to right: Jason Backus, Matthew Crawford, Steven Webb, Andrea Conner and Sarah Arpin. Emily Morris not pictured.

Analytical Laboratory

Introduction

Jason Backus, Andrea Conner and Ethan Davis analyzed water, coal and mineral samples for a variety of KGS and UK research projects. Laboratory staff processed and analyzed 2,800 samples for the UK Department of Mining Engineering, investigating rare earth elements and a project looking at other critical elements from recycled electronics. Water samples were analyzed for the UK Department of Civil Engineering's and UK Department of Biosystems and Ag Engineering's water monitoring projects. Laboratory staff continue to analyze samples for the ongoing Kentucky River Watershed Watch program as well as a water monitoring project for the Clarks Run Environmental Education Corporation (CREEC).

The lab has processed and analyzed samples for a soil assessment project for the UK College of Public Health. The citizen science project is led by Dr. Erin Haynes. Soil samples collected by citizens are prepared in the lab and analyzed using our X-ray Fluorescence Spectrometer for elemental concentrations.

The laboratory houses an X-ray Diffractometer that was utilized by 14 different researchers from several UK departments. KGS supports those research efforts through instrument time and XRD training of graduate students.

A new coulometer was added to the lab this year. This instrument, a UIC CM5017, is utilized by KGS researchers as well as UK Department of Earth and Environmental Sciences graduate students. This analytical instrument allows researchers to determine inorganic carbon concentrations in water, soil, shale and other mineral samples.

Andrea Conner explains the newly acquired UIC CM5017 coulometer to Danielle Cottrell, a Natural Resources and Environmental Sciences student with the College of Agriculture, as she analyzes inorganic carbon on marine sediment samples for a project of Dr. Kevin Yeager of the UK Earth and Environmental Sciences Department.

Meteorite Identification

Kentucky Geological Survey scientists used an assortment of KGS laboratory's analytical instruments to confirm the identity of two meteorites recently discovered in Kentucky. The meteorites are the first to be found in the Commonwealth since 1990. Quade Mott discovered the newly named "Handys Bend" meteorite on a farm near Wilmore, Kentucky in July of 2021. The "Flax Creek" meteorite was unearthed by Johnathan Baldwin

nearly 8 months later near Crab Orchard, Kentucky. The confirmation of these meteorites brings the total number of Kentucky meteorites to 29.

Handys Bend meteorite, as found shortly after its discovery in the summer of 2021. Photo by Quade Mott.

A specimen from each meteorite was initially extracted by geologist Ryan Pinkston using a diamond-bladed oil bath saw at the Earth Analysis Research Library. Ethan Davis then determined the chemical composition of the extracted pieces using an energy dispersive X-Ray Fluorescence (edXRF) spectrometer. The physical structures, deformation histories, and mineralogical contents of each meteorite were analyzed by Davis via acid etching and scanning electron microscopy. Both meteorites are classified as iron octahedrites, but they did not originate in the same planetary body, and Handys Bend is believed to have fallen more recently than Flax Creek. KGS geologists plan on accessing analytical instruments outside of the survey to further classify these latest finds and determine their relationship to other meteorites in the region.

Sliced, polished, and etched section of the Handys Bend meteorite displaying Widmanstatten pattern. Photo by Ethan Davis.

Paul Edwin Potter Internship Program

Introduction

In the summer of 2022, KGS hosted the inaugural class of the Paul Edwin Potter Internship program funded by a gift from the late Dr. Paul Potter. The program focused recruitment at the University

of Kentucky for its inaugural class but plans to open applications to other Kentucky institutions in 2023. Focusing recruitment efforts on undergraduate and master's students from diverse backgrounds interested in geologic topics, the internship hosted six interns including four females, two from historically underrepresented populations.
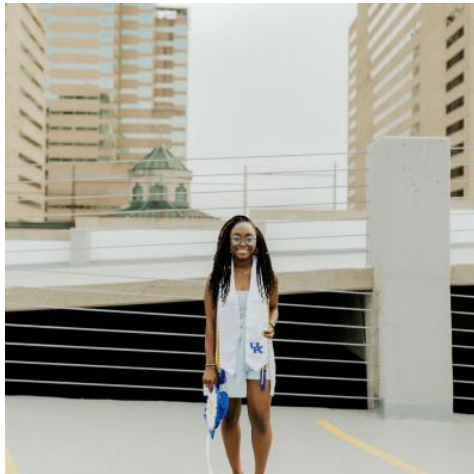
2022 Paul Edwin Potter interns (clockwise from top left) Dilni Abeyrathne, Alex Arimes, Russel Rogers, Ellie Stevens, Alex Thomas and Zachary Walton.

Projects

The program allowed our interns to develop new skills in machine learning, lab work, and drone use while working on 10-week projects with KGS researchers. Projects included studies of seismic waves, landslides, fluid inclusion in mineral veins, sinkholes, radon, and environmental justice in coal country.

- Alex Thomas worked with KGS Director Bill Haneberg and William Andrews to map perform field tests of a drone-based gamma spectrometer to evaluate its suitability for soil radon potential mapping.
- Russel Rogers worked with KGS seismologist Seth Carpenter using new seismic instrumentation to investigate the effects of near-surface sediments on seismic waves in the New Madrid seismic zone.
- Ellie Stevens worked with KGS geologist Junfeng Zhu to identify sinkholes from lidar-derived high-resolution elevation data with assistance from a machine learning model.

Photo of Ellie Stevens working on the sinkhole identification project.

- Alex Arimes worked with KGS landslide geologist Matt Crawford using the KGS unmanned aerial vehicle (UAV) and GIS techniques with collected lidar data to evaluate past landslide activity near Hindman (Knott County) in eastern Kentucky
- Dilni Ameyrathne worked with KGS Director Bill Haneberg to make lidar-based maps and understand the potential environmental justice implications of landslides associated with mountaintop removal coal mining in Kentucky.
- In the KGS fluid inclusion lab, Zach Walton worked with KGS geologist Gina Lukoczki. He will help with the ongoing KGS critical mineral research project by collecting temperature data from fluids trapped in minerals within rock core samples taken from the Western Kentucky Fluorspar District.

Zach Walton at Hicks Dome in the Western Kentucky Fluorospar District.

Program Experience and Intern Showcase

Every week the interns participated in discussions and field experiences led by UK and KGS staff. These activities help provide a holistic program focused on hard and soft skills not typically presented during college courses. The program culminated in a half-day research showcase that included two-minute lightning

talks and posters generated by the interns. More than twenty invited KGS staff and UK faculty members attended the event and offered structured feedback to the presenters.

Photos from a program field experience at Camp Nelson Cemetery and National Monument focusing on geoheritage led by KGS geologist Drew Andrews.

Water Resources

Introduction

Over several decades, a hallmark of KGS research and public service has been our work in karst hydrogeology. In the past year we've continued to strengthen and diversify our efforts in karst research, resulting not only in an increased number and scope of projects, but also increased national and international recognition, and requests for collaboration and application of our karst expertise. Ben Tobin, and Sarah Arpin, have been elected to, and serve, as members of national and international karst and caving professional societies. Junfeng Zhu, working with KGS, UK, and outside collaborators, oversees an innovative "data fusion" karst research project that garnered interest and financial support from the National Science Foundation (NSF), our first NSF-funded research project. I was invited, and privileged, to co-author "Introduction to Karst Aquifers" a freely accessible digital textbook published by The Groundwater Project, a non-profit groundwater educational organization headquartered in Canadian, but international in scope and reach. Of course, karst is not the only

research we do. Another ongoing area of research of high priority to Kentucky, and also having potential national and international significance, is our work in agricultural edge-of-field water quality studies. We're pleased to be able to highlight a bit of this work here and welcome any questions from readers interested in learning more about our water resources research and data.

Karst Hydrogeology Research

One example of new and innovative karst research at KGS is our multi-collaborative research project to develop a "data fusion" method for better characterizing and understanding the groundwater hydrology and surface water-groundwater interaction in karst aquifer systems. KGS continues to collaborate on this project with researchers from the Civil Engineering Department at UK, at the University of Arizona, and University of Iowa. With funding support from the NSF, the "data fusion" method is being designed and tested as a means of collecting multiple types of karst characterization data and integrating these data using new and innovative numerical techniques to obtain a three-dimensional characterization of porosity and permeability, and groundwater flow, in karst aquifer systems. The study area includes the Royal Spring-Cane Run Creek basin in Fayette and Scott Counties. During 2021-2022, KGS researchers Benjamin Tobin, Steven Webb, and Junfeng Zhu conducted two quantitative dye traces in the Cane Run – Royal Spring basin in the Inner Bluegrass region of Kentucky with dye injections in February and June 2022. Each trace involved injecting dye into the same sinkhole and monitoring dye concentration, water level, temperature, and electrical conductivity in three wells. In the June trace, we also monitored the main spring. The wells provided a unique opportunity to monitor a transect across a phreatic karst conduit, with one well in the known conduit and two in the fractures and matrix adjacent to the conduit. Dye tracing data, along with complex responses of water level, temperature, and electrical conductivity data to the storm events during the two trace tests provided a multi-faced field dataset for future modeling

efforts to characterize karst aquifers. In addition, KGS researcher Steven Webb and Junfeng Zhu continued river and conduit stage tomography data collection efforts with 13 pressure transducers and 2 rain gages installed throughout the Cane Run – Royal Spring basin. Data collected have been shared with collaborators at the University of Arizona for inverse modeling efforts.

Activities for the project that are being undertaken by UK Civil Engineering Professor Jimmy Fox and his students involve assisting with field data collection and analyses, creating numerical models of the karst flow system, journal paper writing, mentoring graduate students, and facilitating an educational and outreach program to broaden diversity in a STEM undergraduate student cohort. Data collection efforts are focused on sensor and water-quality data, while modelling work focused on simulating the hydrology and sediment transport in the Cane Run Royal Spring Basin. Unsaturated zone (soil water) modelling is also under development. One paper was submitted to the Journal of Hydrology and is currently resubmitted for review of the revised version. Three other journal papers are currently under development. Eight undergraduate students, most of whom are underrepresented in STEM, were impacted by the project by participating in research activities this past fiscal year.

Students from UK civil engineering department, and participating in the KGS Paul Potter intern scholarship program, participated a field dye-tracing experiment to broaden their knowledge in karst hydrogeology. (Benjamin Tobin explains dye tracing to students from civil Engineering during the dye tracing in February 2022).

Karst Data Collection

KGS also continues efforts to improve collection, quality, management, and accessibility to karst data. Two project efforts presently underway demonstrate this:

1. *Dye-Tracer Test Data Preservation (USGS Data Preservation funded):* This project, being conducted under supervision of KGS Groundwater Database Manager Sarah Arpin, was initiated in June 2022 with the goal of improving the quality and quantity, as well as the interpretation and use, of water-tracing test data in the KGS groundwater database. Existing information about water-tracer tests that have been conducted over many decades by KGS and other karst researchers using fluorescent dyes, is being supplemented by compiling additional metadata and associated background information on each tracer test to make the database more robust and bring the database contents up to FAIR data standards. Project has begun to develop data

dictionaries (to define attribute fields and values) and metadata (to show more clearly the data source and methods).

2. *Multi-Jurisdictional Mitigation Plan for Karst for the Lincoln Trail Area Development District:*

   With funding support from the Federal Emergency Management Agency (FEMA), the water resources section worked to develop a karst hazard mitigation plan for the Lincoln Trail Area Development District (LTADD), which includes Breckinridge, Grayson, Hardin, LaRue, Marion, Meade, Nelson and Washington Counties. During 2021-2022, KGS researchers Hudson Koch and Junfeng Zhu mapped sinkholes for the LTADD using high resolution digital elevation data derived from lidar assisted by a machine learning neural network model. They mapped approximately 50,000 sinkholes for the area. In addition, KGS researchers Benjamin Tobin, Junfeng Zhu, and Charles Taylor developed a sinkhole reporting tool to allow Kentuckians to report sinkholes using a computer or a mobile device. The research team also started to develop sinkhole brochures to provide information to help local residents and emergency management agencies to mitigation sinkhole and other karst related hazards.

   KGS researcher Junfeng Zhu collaborated with Dr. Nathan Jacobs in the Computer Science Department at UK and they developed a deep learning convolutional neural network model to identify sinkholes from digital elevation data directly. The work has been published in Earth and Space Science (doi.org/10.1029/2021EA00219) and further research on using deep learning in analyzing geologic data offers additional tools for karst aquifer characterization.
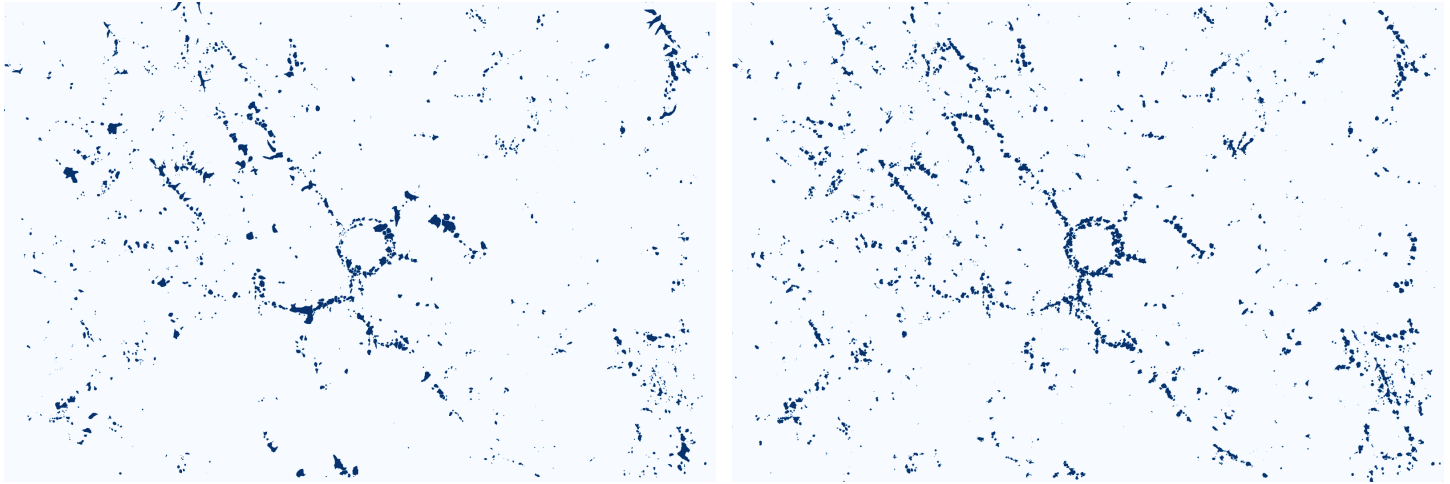
Comparison between mapped sinkholes (left) and deep learning model predicted sinkholes (right). Areas with dark color depict sinkholes. Pull the slider in the center to compare the left from right image.

Agricultural Edge-of-Field Water-Quality Studies

a. Edge-of-field monitoring of nutrient and sediment loss from no-till corn and soybean fields in western Kentucky

Nutrient (nitrogen and phosphorus) and sediment derived from urban construction as well as food production activities are leading contaminants resulting in stream and river impairment in Kentucky. While agricultural producers commonly employ best management practices (e.g., crop rotation, cover crops, no-till, etc.) to mitigate nutrient and sediment losses to retain nutrients in-field, studies evaluating the efficacy of best management practices on the reduction of nutrient and sediment in agricultural runoff are limited in western Kentucky. To further understand the relationships between agronomic practices and water quality, Glynn Beck is collaborating with researchers (Brad Lee, Zach Creech, Sarah Cain, Jason Unrine, Erin Haramoto and John Grove) from the University of Kentucky College of Agriculture, Food and Environment to conduct edge-of-field water quality monitoring in the lower Green River and lower Cumberland River watersheds. This project is part of a national effort to evaluate the efficacy of best management practices and assist the agricultural community in making informed nutrient management decisions. Funding is from the U.S. Department of Agriculture Natural Resources Conservation Service, Kentucky Soybean Promotion Board, and

Kentucky Agriculture Development Board.

During the 2021-22 fiscal year, year-round sampling of surface water runoff from 10 no-till corn/soybean fields watersheds (3 to 12 acres in size) in the lower Green River watershed continued. Also, in 2021-22, year-round sampling of surface water runoff from 12 no-till corn/soybean fields watersheds (3-11 acres in size) in the lower Cumberland River watershed continued. Monitoring of these row-crop watersheds will improve our understanding of nitrogen, phosphorus, and sediment loads from active row crop fields in western Kentucky. Edge-of-field monitoring in the lower Green River and lower Cumberland River watersheds is expected to continue through 2026 and 2028, respectively.

b. Edge-of-field monitoring of nutrient and sediment loss from wetland watersheds in the northern Mississippi Embayment
Wetland conservation easements are promoted by the U.S. Department of Agriculture Natural Resource Conservation Service to return floodplains and other flood-prone, row-crop agricultural fields to natural vegetation to filter nutrients and sediments in surface water runoff prior to reaching a stream or river. Glynn Beck is collaborating with researchers (Brad Lee, Leighia Eggett, and Jason Unrine) from the University of Kentucky College of Agriculture, Food and Environment to conduct edge-of-field water quality monitoring (nitrogen, phosphorous, and sediment) of six wetland watersheds in the northern Mississippi Embayment (Jackson Purchase) and one watershed in the lower Green River watershed (Henderson County). Surface water runoff sampling of the seven watersheds began in 2019 and continued during the 2022-22 fiscal year. A drone mounted multispectral camera was used to collect images of each watershed to document leaf on and leaf off, which will be used to correlate with surface-water quality. Surface water sampling is scheduled to continue through 2024. Funding is provided by the U.S. Department of Agriculture Natural Resource Conservation Service Wetland Protection Program.

KGS researcher Glynn Beck flying a UAV (top photo), setting up a GPS station (lower left), and taking a precipitation measurement (lower right) for edge-of-field monitoring research funded by the U.S. Department of Agriculture Natural Resource Conservation Service Wetland Protection Program.

Funded Research Projects

Energy and Minerals

Regional Initiative to Accelerate CCUS Development

- End date: 9/30/22
- FY funding: $99,017
- Project Total: $180,254
- Funding Source: Battelle Memorial Institute

Characterizing Mine Methane Emissions in Kentucky: Historic Trends and New Measurements

- End date: 6/30/22
- FY funding: $ 129,264
- Project Total: $179,795
- Funding Source: Kentucky Office of Energy Policy

Kentucky part of the Carbon Ore, Rare Earth and Critical Minerals (CORE-CM) Resource Assessment of the Appalachian Basin (MAPP-CORE)

- End date: 9/30/23
- FY funding: $30,419
- Project Total: $135,072
- Funding Source: U.S. Department of Energy through West Virginia University through UK Center for Applied Energy Research

Kentucky part of the Carbon Ore, Rare Earth and Critical Minerals (CORE-CM) Resource Assessment of the Illinois Basin

- End date: 9/20/23
- FY funding: $17,127
- Project Total: $124,995
- Funding Source: U.S. Department of Energy through Illinois State Geological Survey

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

- End date: 2/1/22
- Project Total: $50,131
- Funding Source: UK Energy Research Prioritization Program, UK Vice President for Research

Illinois Basin Geologic Data Compilation to Support Utilization and Storage of Carbon and Energy Gases

- End Date: 03/31/2023
- Project Total: $12,500
- Funding Source: U.S. Geological Survey

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
- FY funding: $22,316
- Project Total: $24,934
- Funding Source: National Cave and Karst Research Institute

Earth MRI Western Kentucky Fluorspar District 3D Geological Modeling

- End date: 7/31/23
- Project Total: $ 99,996
- Funding Source: U.S. Geological Survey

Geology

EarthMRI Geochemistry of Pennsylvanian Underclays

- End date: 6/30/22
- FY funding: $27,825
- 2 Year Project Total: $75,000
- Funding Source: U.S. Geological Survey

Quaternary and Surficial Geological Mapping for Multiple Applications in Kentucky

- End date: 9/16/22
- FY funding: $449,188
- Project Total: $898,380
- Funding Source: U.S. Geological Survey

Kentucky Geological Survey Categorizing and Documenting Geologic Map Discontinuities

- End date: 8/31/22
- FY funding: $37,457
- Total Project $60,000
- Funding Source: U.S. Geological Survey

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
- FY funding: $25,520
- Project Total: $133,973
- Funding Source: U.S. Geological Survey

Geologic Information

Kentucky Geologic Core Digital Image Archive

- End date: 9/30/21
- FY funding: $29,432
- 3 Year Project Total: $487,396
- Funding Source: Institute of Museum and Library Services

National Geologic and Geophysical Data Preservation Program FY21-22

- End date: 6/30/22
- FY funding: $95,472
- Project Total: $207,504
- Funding Source: U.S. Geological Survey

National Geologic and Geophysical Data Preservation Program FY20-21

- End date: 12/31/21
- FY funding: $15,296
- Project Total: $115,436

- Funding Source: U.S. Geological Survey

Geology and Human Health

Radon on the Radar

- End date: 11/30/22
- KGS FY funding: $27,506
- UK 2 Year Project Total: $1,655,990
- Funding Source: National Institute of Environmental Health Services through UK College of Nursing

Hazards

Multi-Jurisdictional Hazard Mitigation Plan for Landslides for the Big Sandy ADD

- End date: 3/22/22
- FY funding: $9,590
- Project Total: $400,292
- Funding Source: Federal Emergency Management Agency through Kentucky Department of Military Affairs

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

- End date: 9/30/22
- KGS FY funding: $15,997
- UK 5 Year Project Total: $1,944,987
- Funding Source: U.S. Department of Energy through Center for Applied Energy Research

Towards a National Landslide Susceptibility Map of the United States

- End date: 7/14/22
- FY funding and Project Total: $10,000

- Funding Source: U.S. Geological Survey

Multi-Jurisdictional Hazard Mitigation Planning-Related Activity for Landslides for the Kentucky River Area Development District

- End date: 4/24/24
- FY funding: $23,683
- Project Total: $421,312
- Funding Source: Federal Emergency Management Agency through Kentucky Department of Military Affairs

Acquisition of Strong Ground Motion Data in the New Madrid Seismic Zone using novel devices

- End date: 12/31/22
- FY funding and Project Total: $59,230
- Funding Source: U.S. Geological Survey

Water Resources

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

- End date: 2/28/23
- FY funding: $138,817
- 3 Year Project Total: $421,448
- Funding Source: National Science Foundation

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

- End date: 4/1/22
- FY funding: $67,772
- Project Total: $391,992
- Funding Source: Federal Emergency Management Agency through Kentucky Department of Military Affairs

Develop a Groundwater Management Tool for Grand Canyon National Park

- End date: 12/31/21
- FY funding: $35,866
- 3 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: 11/30/22
- FY funding: $21,261
- 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
- FY funding: $2,991
- Project Total: $14,999
- Funding Source: U.S. Fish and Wildlife Service

Nutrient and Sediment Runoff Assessment in the Upper Mississippi River Embayment

- End date: 9/15/23
- KGS FY funding: $30,465
- 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

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

- End date: 6/30/22
- KGS FY funding: $30,465
- UK Project Total: $194,715
- Funding Source: Kentucky Soybean Promotion Board through UK College of Agriculture

Comprehensive Biodiversity Inventory and Hydrological Analysis of the Key Cave System at Key Cave National Wildlife Refuge

- End date: 7/31/23
- FY funding: $ 1,641
- Project Total: $20,000
- Funding Source: U.S. Fish and Wildlife Service

No P on my lawn

- End date: 8/31/23
- KGS FY funding: $2,388
- UK Project Total: $49,967
- Funding Source: Lexington Fayette Urban County Government through UK College of Agriculture

Staff Retirements, Awards & Honors

Staff Retirements

Editor Meg Smath retired in September 2021 after a 43-year career at KGS. Smath began working at KGS in as the assistant editor and assumed the editor position in the mid-1980s. In that role, she shepherded all KGS publications through the editorial and approval process. Smath also contributed to the larger editorial

community through multiple leadership and service roles within the Association of Earth Science Editors.

Smath will be missed and remembered by her colleagues for her technical writing and editing skills, making them better writers, and shared enjoyment of sports. According to Steve Greb, "Meg has reviewed thousands of pages of my writing through the years. I used to joke that I would get an abstract through her review without any changes before she retired. That never happened, but it's a testament to the lessons she taught me that I came close a couple of times. She taught me to make my sentences shorter and get to the point, to limit jargon, and that hyphens are not all created equally! Her reviews made me a better writer, and a better technical reviewer."

Meg Smath

Dave Harris has worked with Smath since 1990 and says, "KGS will certainly not be the same without her. I always admired Meg's dedication to her profession, setting clear and consistent editorial standards for KGS publications. Even so, I never quite lost the trepidation I felt on opening a document she had edited to discover whether there was more red pencil than black ink (or tracked changes in the later years...). She made us all look good in print, patiently correcting the same errors year after year, while meeting the inevitable short deadlines." Read more.

KGS administrative support associate Mandy Long retired in January of 2022 after more than 36 years of service to the University of Kentucky. Former KGS Director and State Geologist Jim Cobb shared, "my very first responsibility after becoming director in 1999, was to hire a staff assistant for my office. I could not have made a better choice than to hire Mandy Long. She filled the job beautifully for the 15 years we worked together – she was

the best. At that time there was official correspondence to be prepared on letterhead, travel to be arranged, flights to be booked and meetings to be planned. Mandy was terrific at all of these. We made a good team only squabbling over how much food we should have for official functions—Mandy wanted us to be good hosts and feed all who came, and she did. She even prepared food at home to compliment what UK catered for us. She helped me arrange my office, hanging pictures and keepsakes. I consider her a vital part of the 12th Survey, a person who went above and beyond the call of duty." In 2003, Long was presented with the 'Heart of the Survey' award for her service to KGS. Read more.
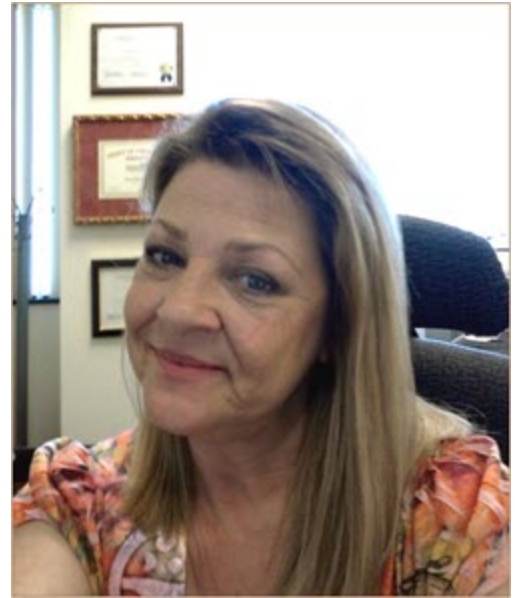
Mandy Long

Staff Honors and Service (2020-2021)

William Andrews

- Kentucky Association of Mapping Professionals: president (2022)
- 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
- UK Strategic Materials and Recovery Technologies (SMaRT) Center: Management Committee member
- U.S. Advisory Group on Geoheritage, interim 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

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

Stephen Greb

- Session Co-Chair: T42. Carbon Storage Research: Geological Society of America, Joint North-central-Southeastern Section Meeting
- Field Trip Co-chair: Geological Society of America, Joint North-central-Southeastern Section Meeting

Bill Haneberg

- National Geospatial Advisory Committee (2020–present)

- Quarterly Journal of Engineering Geology and Hydrogeology editorial board
- Kentucky Geographic Information Advisory Council
- Kentucky Board for Registration of Professional Geologists
- UK Center for Applied Energy Research (CAER) Advisory Board
- Kentucky Water Resources Research Institute (KWRRI)
- UK Center for Clinical and Translational Science (CCTS) Annual Conference Co-chair

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)
- Diversity, Equity and Inclusion Award, American Institute of Professional Geologists, Kentucky section

Charles Taylor

- Kentucky Agriculture Water Quality Authority
- Kentucky Agricultural Science and Monitoring Committee
- Kentucky Water Well Drillers Certification Board

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)
- 2021 U.S. Fish and Wildlife Service Recovery Champion Nominee/Challenge Coin Recipient

Junfeng Zhu

- Groundwater: associate editor (December 2017–present)

Publications

KGS Publications

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Bottoms, A.E., Hammond, M.L., III, Massey, M.A., Morris, E.R., and McHugh, M., 2021, Surficial geologic map of the Constantine 7.5-minute quadrangle, central Kentucky, Kentucky Geological Survey, ser. 13, Contract Report 42.

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KGS-Affiliated Journal Publications

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Evaporites, v. 37, no. 1, https://doi.org/10.1007/s13146-021-00752-3.

Bowersox, J.R., Greb, S.F., Zhu, J., Harris, D.C., 2021, Geomechanical properties will constrain CO2 injection into the lower Ordovician Rose Run sandstone deep saline reservoir, Appalachian Basin, Kentucky, USA: Journal of Rock Mechanics and Geotechnical Engineering, v. 13, no. 5, p. 947-960, https://doi.org/10.1016/j.jrmge.2021.04.010.

Clay, J.M., Moecher, D.P., Bowersox, J.R., 2021, Detrital zircon U-Pb geochronology of the Precambrian Middle Run Formation (Eastern North America Basement): Implications for Grenvillian foreland basin evolution and Midcontinent Rifting: Precambrian Research, vol. 364, https://doi.org/10.1016/j.precamres.2021.106332.

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Pentecost; Guillermo García Pérez; Bianca Perla; Abdullah A. Saber; Donald Sada; Stefano Segadelli; Kamilla Skaalsveen; Abraham E. Springer; Susan K. Swanson; Benjamin F. Schwartz; Peter Sprouse; Memory Tekere; **Benjamin W. Tobin**; Ernest Azwindini Tshibalo; Olivier Voldoire;. 2021. The Ecological Integrity of Spring Ecosystems: A Global Review.Reference Module in Earth Systems and Environmental Sciences,Elsevier; ISBN 9780124095489; https://doi.org/10.1016/B978-0-12-821139-7.00111-2.

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Fiscal Year 2021 - 2022 Staff List

State Geologist's Office

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

Administrative

- Ellis, Kati. Administrative Business Officer
- Armstrong, Ambre. Administrative Support Associate I
- Long, Mandy. Administrative Support Associate I, retired 1/7/22
- Phillips, Gwen. Staff Support Associate II

Communications and Outreach

- Noble-Varney, Rachel. Geoscience Publications Manager
- Smath, Meg. Geologic Publication Manager, retired 9/30/21
- Mardon, Sarah. Geoscience Communications Professional

Digital Earth Analysis Laboratory

- Dortch, Jason. Geologist IV
- Saha, Sourav. Post-Doctoral Scholar
- Thomas, Alex. Research Assistant
- Zhu, Yichuan. Post-Doctoral Scholar

Energy and Minerals

- Harris, Dave. Section Head
- Bowersox, Rick. Geologist IV

- Eble, Cortland. Geologist V
- Greb, Steve. Geologist V
- Hickman, John. Geologist IV
- Lukoczki, Gina. Geologist III
- Parris, Marty. Geologist V
- Puckett, Paul. Student Worker
- Skeese, Kyle. Student Worker
- Sparks, Tom. Geologist III
- Uhl, Tom. Geologic Technician
- Walton, Zachary. Student Worker

Geologic Hazards

- Wang, Zhenming. Section Head
- Carpenter, Seth. Geologist V
- Crawford, Matt. Geologist IV
- Koch, Hudson. Geologist II
- Schmidt, Jon. Geologist II
- Woolery, Ed. Geophysics Faculty Associate

Geoscience Information Management

- Curl, Doug. Section Head
- Adams, Elizabeth. Research Administrative Coordinator
- Ellis, Mike. IS Technical Support Specialist IV
- Noble-Varney, Rachel. Geoscience Communications Professional
- o'Flaherty, Fin. Web and Database Specialist
- Pulliam, Carrie. Geologist II
- Rivers, Monte. Geologist I
- Thompson, Mark. Information Technology Manager I
- Mardon, Sarah. Geoscience Communications Professional
- Wang, Rebecca. Database Analyst

Geologic Mapping

- Andrews, William. Section Head
- Bottoms, Antonia. Geologist II

- Dortch, Jason. Geologist IV
- Hammond, Max. Geologist II
- Hislop, Ann. Geologic Technician
- Koirala, Dibya. Geologic Technician
- Martin, Steve. Geologist III
- Massey, Matt. Geologist IV
- Morris, Emily. Cartographic Data Manager
- McHugh, Michele. Student Worker
- Pearson, Anna. GIS Geology Technician
- Robinson, Devan. GIS Geology Technician
- Swallom, Meredith. Geologist II
- Whitt, Nolan. GIS Technician

Water Resources

- Taylor, Chuck. Section Head
- Arpin, Sarah. Geologist II
- Blitch, William. Student Worker
- Campbell, Stewart. Student Worker
- Clark, Gillian. Student Worker
- Heimel, Sierra. Research Assistant
- Link, Adam. GIS Karst Technician
- McQueen, Bronson. Student Worker
- Preece, Madison. Student Worker
- Tobin, Benjamin. Geologist IV
- Webb, Steve. Geologist II
- Wolfe, Amy. Geologist IV
- Wong, Nicole. Student Worker
- Zhu, Junfeng. Geologist V

Analytical Laboratory

- Backus, Jason. Geologist III/Laboratory Manager
- Conner, Andrea. Geologist II
- Davis, Ethan. Laboratory Technician
- Gutierrez-Gomez, Sydney. Geologic Technician

Earth Analysis Research Library

- Pinkston, Ryan. Research Facility Manager
- Adams, Elizabeth. Archive Manager
- Daniel, Ray. Principal Research Analyst
- Dufour, Amber. Geologic Archive Technician
- Fields, Natalie. Photographic Technician
- Garvin, Isaac. Geologic Archive Technician
- Paton, Timothy. Geologic Research Technician
- Vicroy, Stephanie. Geologic Technician

Western Kentucky Office

- Beck, Glynn. Geologist IV/Manager

KGS Paul Edwin Potter Internship

- Adams, Elizabeth. Internship Coordinator
- Abeyrathne, Dilni. Potter Intern
- Arimes, Alex. Potter Intern
- Rogers, Russel. Potter Intern
- Stevens, Ellie. Potter Intern
- Thomas, Alex. Potter Intern
- Walton, Zachary. Potter Intern