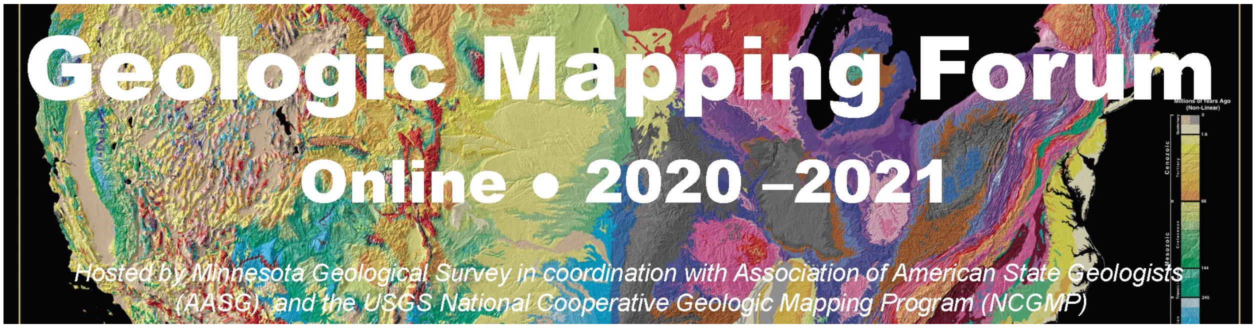
MINNESOTA GEOLOGICAL SURVEY
Harvey Thorleifson, Director



Geologic Mapping Forum 20/21 Abstracts

Edited by: Harvey Thorleifson, Minnesota Geological Survey

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MINNESOTA GEOLOGICAL SURVEY

COLLEGE OF Science & Engineering
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INTRODUCTION

The Geologic Mapping Forum in Minneapolis in 2018 and 2019 was attended by ~100 geological map authors, program managers and allied professionals from geological surveys and associated agencies, who met to discuss the status and future of geological mapping in the USA.

Due to the coronavirus pandemic, the 2020 Geologic Mapping Forum planned for April 7th to 9th was not held.

It therefore was decided that GMF Online would be held as meetings of about two hours duration on Thursdays at Noon Central, on October 8, November 5, & December 3, 2020, and January 28, February 11 & 25, March 25, & April 22, 2021.

The intended GMF audience is geological map authors and program managers, and the focus again was on geology rather than funding or GIS.

GMF20 invited speakers were re-invited, GMF20 submitted abstracts carried over, and State, Fedmap leaders, and additional colleagues were invited.

Optional abstracts for the 20-minute invited talks were requested, and are presented here.

John Brock, US Geological Survey

Harvey Thorleifson, Minnesota Geological Survey

HYDROGEOLOGIC PRODUCTS GENERATED FROM WATER-WELL LOGS FOR AREAS WITHIN THE GLACIATED STATES

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A computerized database of water-well logs was constructed for the glacial region of the United States as part of the National Water Availability and Use Program of the U.S. Geological Survey (Bayless, Arihood, and others, 2017). The database consisted of about 3 million well logs containing about 14 million lithologic records from State-managed collections of water-well drillers' logs. The water-well drillers' lithologic descriptions were converted to standardized U.S. Geological Survey lithologic terms and assigned hydraulic conductivity values so that hydrogeologic grids could be constructed from the well-log lithologies. Other information was obtained from the well logs, such as static water levels, pump-test data and bedrock-surface altitude and lithology. That information was used to calculate aquifer hydraulic conductivity and transmissivity, and to generate a grid of bedrock-surface altitude, and map of bedrock-surface lithology. In all, 19 hydrogeologic products are generated from well-log data using several ARC Macro Language programs. The individual programs used in the previous study were combined into a single program that can generate the hydrogeologic products anywhere within the glaciated states within hours to days, depending on the size of the study area. The only input that the single program requires to obtain the hydrogeologic products is a polygon defining the area of interest and a file defining the desired local projection system. The following list describes the hydrogeologic products:

Wells from individual state datasets combined into one dataset that uses a local coordinate system
A grid of land surface based on land-surface altitude values from the well logs
A polygon of surface geology clipped from a national surface-geology polygon
A polygon of bedrock-surface lithology based on the lithology record at the bedrock surface
A polygon of bedrock-surface lithology where lithologies of similar hydraulic characteristics are grouped together
A map of well locations used to define the bedrock surface
Grids showing two interpretations of the bedrock-surface altitude
A grid of unconsolidated thickness (land-surface grid – bedrock-surface grid)
Grids of texture-based horizontal and vertical hydraulic conductivity and transmissivity for individual layers subdividing the unconsolidated deposits
Altitude grids for the bottoms of the layers subdividing the unconsolidated deposits
A grid of total sand and gravel thickness within the unconsolidated deposits
A grid of hydraulic conductivity based on values calculated from the pump-test data recorded on the well logs
A grid of sand and gravel transmissivity based on the grids of hydraulic conductivity and total sand and gravel thickness
A grid of bedrock transmissivity based on the pump-test data recorded on the well logs
Tables of statistics for the hydraulic conductivities and transmissivities of unconsolidated and consolidated deposits grouped by depositional environment

Bayless, E.R., Arihood, L.D., Reeves, H.W., Sperl, B.J.S., Qi, S.L., Stipe, V.E., and Bunch, A.R., 2017, Maps and grids of hydrogeologic information created from standardized water-well drillers records of the glaciated United States: U.S. Geological Survey Scientific Investigations Report 2015–5105, 34 p., https://doi.org/10.3133/sir20155105

THE USGS NATIONAL CRUSTAL MODEL FOR SEISMIC HAZARD STUDIES; 2020 UPDATE

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The U.S. Geological Survey (USGS) National Crustal Model (NCM) is being developed to assist in the modeling of seismic hazards across the conterminous United States, specifically by improving estimates of site response. The NCM is composed of geophysical profiles, extending from the Earth's surface into the upper mantle, constructed from five primary elements: (1) depth to bedrock and basement; (2) 3D geologic framework; (3) petrologic and mineral physics database; (4) 3D temperature model; and (5) calibration of a rock type- and age-dependent porosity model. Parameters needed to estimate site response for existing ground motion models (GMMs), including the time-averaged velocity in the upper 30 meters (V_{S30}) and the depths to 1.0 and 2.5 km/s shear-wave velocity ($Z_{1.0}$ and $Z_{2.5}$), can be extracted from the NCM. As GMMs develop, other metrics could also be extracted or derived from the NCM such as fundamental frequency, a fully frequency-dependent site response function, or 3D geophysical volumes for wavefield simulations. Application of the NCM may also benefit other aspects of seismic hazard analysis including better accounting for path-dependent attenuation and geometric spreading and more accurate estimation of earthquake source properties such as hypocentral location and stress drop.

Introduction

Seismic hazards and associated risks are present in many regions across the United States. The USGS is tasked with producing the National Seismic Hazard Model (NSHM), which has been developed and used to inform public policy, building codes, and emergency response protocols since the 1970s. The NSHM is based on source models and GMMs, which are continuously updated and refined and fed into new hazard models.

GMMs within the current NSHM incorporate one or more model parameters that account for site response—V_{S30}, $Z_{1.0}$, and $Z_{2.5}$. For building codes and consistency with previous practice, the original version of the 2014 NSHM applied a uniform V_{S30} of 760 m/s to the entire country with default values of $Z_{1.0}$ and $Z_{2.5}$ leaving refinement for specific site conditions to end users such as engineers. Due to spatial variability in subsurface physical properties and the application of relatively simple site response metrics, the implementation of a V_{S30} map with default values of $Z_{1.0}$ and $Z_{2.5}$ and National Earthquake Hazards Reduction Program (NEHRP) site amplification factors can lead to substantial differences between predicted and observed ground motions. To reduce these differences, the USGS is moving towards: (1) implementing different values of V_{S30} directly in the GMMs, rather than using NEHRP amplification factors; (2) accounting for spatially variable $Z_{1.0}$ and $Z_{2.5}$ as can be obtained from local seismic velocity models and as was implemented in the 2018 NSHM for select areas; and (3) including knowledge about ground motions gained from urban hazard modeling efforts.

A USGS NCM (https://doi.org/10.5066/P9T96Q67) supports these efforts and will help to better predict site response in a uniform way and on a national scale by providing site response metrics for current and future GMMs. Development of an NCM will also provide consistency between models used to develop GMMs and models applied when calculating hazard. The effort to produce the NCM is divided into two phases: Phase 1 for the western United Sates (WUS); and Phase 2 for the central and eastern United States (CEUS).

Elements of the NCM

Depth to Bedrock and Basement (Shah and Boyd, 2018; Shah, Langenheim, and Boyd, 2018)

The depth to strong impedance contrasts such as bedrock and basement is one of the most critical parameters for estimating earthquake ground motions. In the NCM, numeric grids containing estimates of the thickness of unconsolidated sediments and depth to the pre-Cenozoic basement for the western United States were combined and integrated from previous studies or derived directly from gravity analyses. The grids are provided with 1-km grid-node spacing in ScienceBase, the USGS data release web portal.

Geologic Framework (Boyd, 2019a)

Once knowledge of the depth to bedrock and basement is established, knowledge of the material on either side of the contact is needed to better model how the seismic waves will propagate. A 3D geologic framework is developed based on a 1:250,000 to 1:1,000,000 State Geologic Map Compilation, the Geologic Map of North America, maps of basement geology, and the depths to multiple subsurface geologic contacts. Figure 1 shows the merged geologic map with some effort to resolve discontinuities across state and country borders.

Petrologic and Mineral Physics database (Sowers and Boyd, 2019)

A petrologic and mineral physics database is developed to be able to convert geology to geophysical parameters. Each of 209 lithologic units, 134 of which are currently part of the geologic framework within the NCM, is assigned a mineralogical composition according to generalized classifications with some refinement for specific geologic formations. The mineral physics database builds off previous work by adding the physical constants of 13 minerals relevant to more continental rock types.

Temperature Model (Boyd, 2019b)
The temperature model is most relevant to the impact of the *a–b* quartz phase transition in the mid crust and to the reduction of seismic velocities and amplitudes at greater temperatures where melt may be present and seismic attenuation can be high. Like the *a–b* phase transition, relatively high temperatures typically occur in the mid to lower crust but can occur near the surface in areas of recent volcanism or where geothermal resources are being developed. The thermal model assumes steady state conduction with heat production for the continent and cooling of a half space in the oceans. It is constrained by: (1) surface temperature from the Moderate Resolution Imaging Spectroradiometer; (2) near-surface temperature gradients, conductivity, and heat production using multiple databases; and (3) estimates of Moho temperature based on the velocity of P-waves that travel along the base of the crust.
Porosity Model and Calibration (Boyd, 2020)
Rock porosities have a significant effect on seismic velocities and ground motion amplitudes. As is observed for in situ rock specimens, porosity is assumed to be dependent on rock type and to decrease exponentially with depth. Calibration of the porosity model makes use of Biot-Gassmann theory and over 2000 compressional- and /or shear-wave velocity profiles (< 10 km deep) from across the conterminous United States and southwest Canada.
Validation
Validation of the NCM is specific to the application for which it is used. The first application of the NCM is to extract maps of V_{S30}, $Z_{1.0}$, and $Z_{2.5}$ in the WUS for use with the NSHM. Therefore, the first validation exercise is to see how well maps of V_{S30}, $Z_{1.0}$, and $Z_{2.5}$ extracted from the NCM reduce intra-event ground motion residuals from a WUS earthquake ground motion database. After the completion of Phase 2 in the CEUS, the next application could involve more sophisticated frequency-dependent 1D site amplification functions, and validation would likely involve reducing intra-event ground motion residuals from both WUS and CEUS ground motion databases. The NCM may also be used for 3D ground motion simulations. In this case, validation exercises involving the reproduction of earthquake time series would be required.

Availability
All of the elements of the NCM are published as Open-File reports and ScienceBase datasets though the geologic framework is presently restricted to the WUS. Software written in Python and Matlab is available for querying the datasets (code.usgs.gov/ghsc/nshmp/ncm) and a web service will also be available (earthquake.usgs.gov/nshmp/ncm).

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NATIONAL COOPERATIVE GEOLOGIC MAPPING PROGRAM

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The National Geologic Mapping Act (NGMA) of 1992 mandated the National Cooperative Geologic Mapping Program (NCGMP), consisting of geologic mapping and training by federal (Fedmap), state (Statemap), and university (Edmap) partners, made consistent and available as the National Geologic Map Database (NGMDB). The NCGMP Decadal Strategic Plan (Berry et al., 2017) outlines a renewal of the program as the nation's authoritative source for foundational geologic knowledge. Its vision for the year 2030 is to construct the national 3D geologic model that is needed by the Nation. The 1st goal is to achieve excellence and efficiency among Fedmap, Statemap and Edmap, through enhanced mechanisms for prioritization, allocation of funds, and accountability; through enhanced collaboration and innovation; and through compilation of required data. The 2nd goal is preeminence in field and airborne technologies, and infrastructure needed for efficient and effective construction of an interoperable national 3D geologic database. The 3rd goal is completion of a seamless 3D nationwide geologic map by 2030, based on renewed fieldwork, compilation, and enhanced 3D geologic map standards. Required actions related to the program include an implementation plan, an assessment of mapping needs and benefits, a database of completed and ongoing mapping, and longer-term planning of mapping, for example to influence collection of lidar, and increased use of database standards. Actions relevant to federal-state interaction include compilation of seamless mapping at multiple levels of resolution, and renewed expectations for Fedmap planning and productivity. Actions related to community building across the program include enhanced internal communication and outreach to academic and professional communities, annual Workshops, and adopting enterprise GIS. Actions relevant to Statemap include clarification of appropriate scales in varying geology, streamlined administration, as well as renewed prioritization and collaboration. Key action for the coming year include the Implementation Plan, the Assessment of Mapping Needs and Benefits, longer-term planning, and a national workshop.

CANADA3D: PROGRESS ON NATIONAL GEOLOGICAL MAPPING AND MODELLING

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A national geological framework is the cornerstone for a wide variety of applications in scientific research, health, safety, sustainability, and the economy. Key components are national 3D geological and geophysical models, 2D geological map compilations, and related databases. Development of such a framework is a key objective for many government agencies, as well as the focus of academic initiatives, however, significant challenges persist related to the scarcity of observations, complex geology, and huge data volumes.

The Canada3D project aims to overcome these challenges to create a national geological framework for Canada. The project is in relative early stages, being fully active since 2018, and is focussed on method development as well as on the compilation of existing 2D maps and 3D models. Early results include innovative modelling techniques, national 2D bedrock and surficial compilations for the Canadian North (north of 60□), improved 3D surfaces for depth-to-bedrock, the MOHO, and the Precambrian-Phanerozoic boundary, and an aggregation of several federal, provincial and crustal 3D models. While all these results are in various stages of progress, we expect the 2D compilations to be published on a new web portal in 2021. Presented will be an overview of Canada3D, including overall aims, emerging methods and early results, as well as a demonstration of the prototype web portal.

A REVISED 3-D GEOLOGIC MODEL OF THE BEDROCK OF SOUTHERN ONTARIO AND PROGRESS ON DEVELOPMENT OF A 3-D HYDROSTRATIGRAPHIC MODEL

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A regional three-dimensional (3-D) geologic model of the Paleozoic bedrock of southern Ontario (Carter et al 2019) has been revised to reflect data corrections and improved model layer rendering. The model encompasses the entire 1500 metres of Paleozoic bedrock of southern Ontario over an area of 110,000 km2. Fifty-three Paleozoic bedrock layers representing 70 formations, as well as the Precambrian basement and overlying unconsolidated sediment, were modelled at a spatial resolution of 400 m.

Revisions to model bedrock layers were largely controlled by corrections to formation top picks in the Ontario petroleum well database completed by QA/QC geologists at the Oil Gas and Salt Resources Library. Formation top data from a total of 20,836 Ontario petroleum wells, 199 OGS stratigraphic tests, 15 measured sections, 3 Michigan petroleum wells, and 30 control points were utilized, including seven new control points added to improve layer extrapolation beneath Lake Huron. Resolution of the subcrop surface is improved and there is a more accurate and realistic rendering and correlation of the topography and bedrock geology of the Niagara Escarpment. Many anomalous outliers and structural and thickness anomalies have been removed and gaps in model layers are greatly reduced. There was a focus on improving data quality and quantity for formations of the Lockport Group to improve model layers and support hydrostratigraphic modelling. Features added to the model include: 3-D extent of salt mining leases at Ontario's 2 underground salt mines, 3-D solution-mined caverns in salt units utilized for hydrocarbon and petrochemical storage and for mining of salt, two-dimensional representations of oil and natural gas reservoirs, regional faults, and lithotectonic boundaries in the Precambrian basement. An uncertainty analysis of individual model layers is underway. Public outreach and geological education initiatives include 3-D printed products and virtual reality (VR) realizations. The VR implementation is a fully interactive visualization of the model illustrating drill core cuttings samples. Release of the revised model will occur in early 2021.

Conversion of the geologic model to a 3-D hydrostratigraphic model is also underway. Thirteen bedrock hydrostratigraphic units are proposed, and one unit comprising all the surficial sediments. Assignment of lithostratigraphic units as hydrostratigraphic units is based principally on hydrogeologic characteristics in the intermediate to deep groundwater regimes, below the influence of modern meteoric water. Pending review of data support, the depiction of saturated zones of fresh, sulphurous and brine groundwater will be investigated. Related projects include a geospatial analysis of porosity and permeability variations in the Lockport Group, one of the principal bedrock aquifers, using petroleum industry drill core analyses from 11,513 depth intervals in 151 wells. Pore geometry and connectivity are also being investigated in paleokarst intervals from selected drill core from the Lockport and Salina groups using medical CT scan methodology.

Carter, T.R., Brunton, F.R., Clark, J.K., Fortner, L., Freckelton, C., Logan, C.E., Russell, H.A.J., Somers, M., Sutherland, L., and Yeung, K.H., 2019. A three-dimensional geological model of the Paleozoic bedrock of southern Ontario; Geological Survey of Canada, Open File 8618; Ontario Geological Survey, Groundwater Resources Study 19, 1 .zip file. https://doi.org/10.4095/315045

COLGAN, Joe

No abstract

CONNORS, Tim

No abstract

COWMAN, Tim

No abstract

DIGITAL GEOLOGY TO ENABLE ANALYTICS

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Data science and geospatial technology are advancing the mineral potential modelling that supports mineral exploration and land use planning in the province of British Columbia. As part of our digital transformation efforts to deliver analytical ready geoscience, the British Columbia Geological Survey (BCGS) is developing a strategy to identify opportunities and prioritize solutions for our future digital capabilities. We define 'digital capability' as the ability to enable analytics by improving data, processes, skills, and infrastructure to optimize the acquisition, management, and delivery of geological data products and services. We use 'analytics' as a general term for computational analysis of machine-readable data to discover patterns. To guide our efforts, we follow the FAIR principles (Findable, Accessible, Interoperable, and Reusable; more details available at https://www.go-fair.org). The DataBC Data Catalogue provides ISO 19115 metadata standard-compliant web services to find and access our geoscience data and services. We continue to update the province-wide seamless digital geology database by compiling and integrating new geological maps with the Geospatial Frame Data (GFD) model. The GFD model stores primitive feature components decomposed from bedrock units and geological boundaries. The primitive feature components allow semi-automation in schema mapping and transforming our data to the GeoSciML Lite model and matching to the CGI vocabularies. This provides interoperable data access and sharing via OGC Web Map Service (WMS) and Web Feature Service (WFS), also available on One Geology. The current WMS and WFS have achieved syntactic interoperability and formed the foundation towards semantic interoperability. Geological feature components should be extended to include (or associate with) the source data, possible to examine the details and how the bedrock models are constructed. The BCGS has made progress digitizing the source data, such as field stations, observation methods, structural measurements, isotopic data, geochemical data, and drill-hole data, and is considering adding alteration, mineralization, and petrographic analysis. To make our digital geology reusable, we want to improve feature-level metadata, such as mapping scales and appropriate presentation scales, assist automating generalized bedrock units and geological boundaries, assemble small-scale geological maps, or balance data density in machine learning. The BCGS is building a geoscience Spatial Data Infrastructure as a common foundation to improve digital capabilities; a spatial database management system is indispensable to streamline digital transformation of our geological maps.

GEOLOGIC MAPPING IN THE NORTHERN MOJAVE DESERT

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The National Cooperative Geologic Mapping Program sponsors the Western Basin and Range – Eastern California Shear Zone project, affectionately known as the Mojave Geologic Mapping project. The project conducts bedrock, surficial and geophysical mapping in the western, central, and eastern parts of the Mojave Desert, California. Geologic mapping activities within the Mojave project are focused primarily on research questions related to tectonics and geomorphology, producing foundational geologic maps and accompanying Geologic Map Schema (GeMS) standard compliant databases, and associated data that provide the foundation for new knowledge central to addressing fundamental societal concerns: seismic hazards; energy, mineral, and water resources, and; land use-planning. Understanding the geology can significantly improve decisions relating to these areas of concern.

The tectonics of the Mojave Desert are driven primarily by the Eastern California shear zone (ECSZ), a broad zone of dominantly northwest-trending, right-lateral strike-slip faults and east-trending, left-lateral strike-slip faults. The ECSZ is part of the larger Pacific-North American plate boundary system and accommodates ~25% of total plate boundary slip to the east of the San Andreas fault system. Several faults in the ECSZ have generated strong earthquakes in the recent past, including the 1992 Mw 7.3 Landers and 1999 Mw 7.1 Hector Mine earthquakes in the south, and the 2019 Mw 6.4, 5.4, and 7.1 Ridgecrest earthquakes in the north. Determining whether such faults have had steady slip over their history, and how slip is distributed on different ESCZ faults in both space and time, remain fundamental applications of the hazard-focused portion of the project's mapping efforts. We address these, and other societally targeted research questions, through a combination of geologic map compilation accompanied by detailed bedrock and surficial geologic mapping that is focused on specific faults or fault systems. Examples of detailed mapping efforts, from the Lane Mountain area north of Barstow, CA, and the northeastern corner of Edwards Air Force Base, illustrate how project work is documenting new faults, significantly revising the ages of previously mapped faults, and providing new knowledge for both seismic hazard modeling and the monitoring and modeling of shallow groundwater flow.

THE USGS EARTH MRI EFFORT–NEW GEOLOGIC MAPPING, AIRBORNE GEOPHYSICS, AND LIDAR DATA IN SUPPORT OF CRITICAL MINERALS

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The Earth Mapping Resources Initiative (Earth MRI) is an effort by the US Geological Survey (USGS) to improve the understanding of the Nation's critical mineral resources as a response to Executive Order 13817. The USGS established Earth MRI with the fundamental goal of acquiring and making publicly available new framework geologic mapping, geophysical surveys data, and elevation (lidar) data for areas permissive for hosting critical mineral resources. The USGS is working with State geological surveys and the Association of American State Geologists (AASG) to generate the information needed to define areas in which to prioritize Earth MRI resources to acquire targeted earth science information. All of the Earth MRI-generated reports, data releases, and project descriptions can be found online at https://usgs.gov/earthmri.

Thirty-five critical mineral commodities underpin the nation's defense, manufacturing, and energy sectors (Fortier and others, 2018). The task of identifying where these commodities may occur is enormous, requiring a streamlined evaluation process using a mineral systems framework (Hofstra and Kreiner, 2020) and addressing the commodities in a phased approach. Phase 1 focused on regions permissive for hosting rare-earth element (REE)-bearing mineral deposits (Dicken and others, 2019; Hammarstrom and Dicken, 2019). Phase 2 expanded to include aluminum, cobalt, graphite, lithium, niobium, platinum group metals, tantalum, tin, titanium, and tungsten (Dicken and Hammarstrom, 2020; Hammarstrom and others, 2020; Kreiner and Jones, 2020). The current Phase 3 effort is currently outlining areas across the Nation permissive for hosting antimony, barite, beryllium, chromium, fluorspar, hafnium, helium, magnesium, manganese, potash, uranium, vanadium, and zirconium.

New geologic mapping is being conducted through cooperative agreements with State geological surveys administered by the USGS National Cooperative Geologic Mapping Program. These are two-year agreements with publication of data expected in the third year. In addition, the National Geologic and Geophysical Data Preservation Program Earth MRI is supporting State geological surveys to make archived critical mineral information publicly available. These types of data include mineral deposit databases, borehole information, and existing geochemistry; develop state-wide maps of critical mineral deposits and mineral belts, and maps depicting depth to basement. The goal is to serve this information to the public through state-based data portals. In the last two years, Earth MRI funded 11 new aeromagnetic surveys, and 26 geologic mapping projects and 4 reconnaissance geochemistry projects have been initiated. In addition, 5 new lidar projects are currently underway. A new effort is starting in Nevada through the USGS-DOE led GeoDAWN project. This effort will combine geologic mapping with a major lidar and airborne geophysical survey in the Walker Lane and adjoining areas. The goal is to provide framework data to highlight geothermal and critical mineral resources.

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DEASY, Ryan

No abstract

SURFICIAL GEOLOGIC MAP COMPILATION WITHIN THE DELAWARE RIVER BASIN IN SUPPORT OF THE USGS EARTHMAP/NGWOS INITIATIVE

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The Delaware River Basin (DRB) was chosen in 2019 as the first USGS pilot study area in the ongoing USGS Earth Monitoring, Analysis and Prediction (EarthMAP)/Next Generation Water Observing System (NGWOS) initiative. The purpose of this surficial geologic map compilation is to support efforts to predict baseflows in the Delaware River supplied by surficial and bedrock aquifers. The NGWOS strategy is to compile inventories of existing data and remote sensing information for support of surface water monitoring and modeling at various scales. The Delaware River Basin covers several geologic provinces and captures much of the complexity of geology in the Mid-Atlantic region. Groundwater storage is conceptualized to be greatest in the near-surface regolith and surficial aquifer reservoirs, and thus characterization of this critical zone is of primary importance for modeling baseflows to streams.

The first task of this effort is the compilation of existing lidar-derived elevation data to create high-resolution base map imagery of the terrain. The goal is to assemble seamless digital elevation models (DEMs) and derivative products at 3m resolution within the sixteen 1:100,000 scale quadrangles that cover the DRB. The second major task is compilation of existing surficial geologic map data. Data availability is patchy, and at different scales. Some areas have maps only as scanned rasters which need to be digitized. The surficial geologic map of the Allentown 1:100,000 scale quadrangle is an example of a map that has been converted to vector format according to the USGS Geologic Map Schema (GeMS) data model. The attribute table of the individual map unit polygons was expanded to include maximum, minimum, and median thickness of each unit in the map, taken from the description of map units. Where thickness information may be lacking or inaccurate, lidar-derived thicknesses of surficial units will be applied based on profile-derived heights of cut banks along streams, terrace levels or other vertical exposures, in addition to borehole information where available.

The geologic compilation work will also support intensive monitoring studies at the sub-basin scale. Three examples where the geologic compilation work will support intensive monitoring studies at the sub-basin scale are the White Clay Creek watershed, Little Lehigh Creek watershed and the upper Neversink watershed. The goal in each of these sub-basins is to use the existing geologic information to map a variety of regolith types as hydrogeomorphic units. The upper Neversink watershed supplies water to the Neversink Reservoir, which provides water supply to New York City. Groundwater/surface water interactions are investigated at testbed sites where monitoring instrumentation are focused on ‘preferential’ groundwater discharge zones using temperature as a tracer. Deployment of temperature sensors to date has focused on the major stream channels, but data are missing in the headwater areas where glacial sedimentary fill in valleys provides groundwater storage. Using the lidar data, stream vectors were extracted in channels to identify headwater streams as targets for future study of focused groundwater flow. Other surface features such as groundwater sapping landforms may be a guide to localized zones of perennial groundwater flow out of glacial sediments.

Lidar-derived elevation data is a critical tool for mapping surficial and shallow bedrock geology where detailed information is currently lacking. Prior work based on borehole logs and geologic cross section profiles has produced estimates of depth to bedrock in the lower Neversink and Roundout watersheds in New York state, but data are missing in upland areas where glacial sediments and bedrock have not been divided on surficial geologic maps. Profile analysis of channel bank heights along streams incised to bedrock can provide an estimate of the minimum thickness of surficial materials. Furthermore, a deep learning approach in ArcGIS Pro is being used to automate the mapping of shallow bedrock in a central region of the upper Neversink watershed. The input into the deep learning model is a 3-band, 8-bit raster of lidar-based elevation derivatives of slope, profile curvature, and plan curvature. With a trained model, large areas of shallow bedrock can be mapped automatically using the previously compiled lidar data. Preliminary results of this model illustrated that shallow bedrock, alluviated channels, and water surfaces were captured quite well and significantly increased the resolution of the mapping of shallow bedrock across the Pepacton Reservoir 1:100,000 scale quadrangle. Field work to ground-truth the results of the deep learning modeling approach will commence in spring of 2021.

AMERICA'S AEROMAGNETIC DATA: ASSESSMENT OF QUALITY, IMPLICATIONS FOR EARTH MRI, AND FREQUENTLY ASKED QUESTIONS

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High-quality aeromagnetic data are profoundly useful for directly supporting surface and subsurface characterizations relevant to geologic mapping and structure, mineral resources, groundwater, earthquake hazards, volcanic hazards, and petroleum resources. Aeromagnetic surveys measure the intensity of the Earth's natural magnetic field. From these surveys, we construct maps representing variations of magnetic rock properties and two- and three-dimensional models of crustal geology. Moreover, aeromagnetic data are relatively inexpensive to acquire compared to other types of geoscientific data. Simply put, aeromagnetic data are foundational for constructing 3D geologic models that can be used to address society's geoscientific needs. It is thus no surprise that many countries in both the developed and the developing world have completed or are working to complete national-scale coverage of public ("precompetitive"), high-quality aeromagnetic data. Cost-benefit economic analyses of such national programs produce compelling estimates of the long-term return on investment (e.g., Indecon International Economic Consultants, 2017).

The U.S. Geological Survey (USGS) was an early pioneer in aeromagnetic surveys and has been acquiring aeromagnetic data since the 1940s. However, the USGS has been unable to replace older, inadequate data with modern surveys. Instead, legacy analog data have been digitized, surveys that have inadequate sampling have not been replaced, modern surveys have been acquired only over small postage-stamp-sized areas (generally <2000 km^2), and these disparate datasets have been merged without the ability to standardize the data to common parameters. As a result, high-quality public aeromagnetic data do not exist for most of the US, placing the country behind much of the rest of the developed world.

How do we properly evaluate the adequacy of aeromagnetic data coverage in the U.S.? An assessment, or ranking, methodology was developed that considers modern best practices for acquisition of aeromagnetic data, common practices in the past, and the suitability of the data to support geologic mapping and other research activities at various scales (Drenth and Grauch, 2019). The quality of existing aeromagnetic surveys, and the corresponding data, were ranked with respect to three categories: data type, survey specifications, and data issues. The three categories were ranked separately for each survey; then an overall rank was assigned based on the poorest category rank, with 1 being the best and 5 being the worst.

Data Type. The issue of data type focuses on two considerations. The first is real-time GPS navigation, a revolutionary development for aeromagnetic surveys in the mid-1990s. Surveys flown with GPS have superior data quality due to the accuracy of the positioning. GPS navigation is required for a Rank 1 survey. The second consideration is the presence or absence of digital flight-line data. Digital flight-line data allow for rigorous quantitative interpretation and are required for Rank 1.

Survey specifications. The proper specifications for an aeromagnetic survey consider two related principles. The first principle is that the lower the terrain clearance of the aircraft (specifically, the magnetometer), the greater the resolution of the data in the direction of flight, meaning that subtle anomalies related to finer details of the geology are more likely to be captured. Surveys with Rank 1 specifications are flown with terrain clearances of 500 feet (~153 meters) or less, as permitted by safety and legal airspace restrictions. The second principle is related to the spatial sampling required to produce adequate maps of the magnetic field. In a classic paper, Reid (1980) showed that the ratio of flight-line spacing to the shallowest magnetic anomaly source depth from the magnetometer should not exceed 2:1. Rank 1 survey specifications have a ratio that does not exceed 2:1.

Data issues. The final criterion consideration for the ranking scheme evaluates the presence and/or severity of problems that commonly plague legacy public data, such as data gaps, instrumentation errors, processing errors, and data accessibility problems. Rank 1 surveys have no significant data problems. Ranks 2 through 5 have increasing levels of problems.

Rank 1 aeromagnetic data are those acquired using modern best practices for survey design, meet all modern international standards for data type and quality, and support the widest variety of geologic studies. Rank 1 data are appropriate to directly support 1:24,000 scale geologic mapping. Rank 2 data can meet interpretation and mapping needs at less detailed scales, but quantitative interpretation is handicapped. Rank 3, Rank 4, and Rank 5 present increasingly difficult, even impossible, challenges to geologic interpretation.

A group of USGS experts applied the ranking scheme to every public aeromagnetic dataset in the US to assess the quality of aeromagnetic data coverage (Drenth and Grauch, 2019). The analysis reveals that most of the US requires updated, high-resolution aeromagnetic data. For example, only about 1% of the lower 48 states is covered by Rank 1 data that meet modern standards, and no Rank 1 surveys have been flown in Alaska or Hawaii. Areas covered by Ranks 3, 4, and 5 data represent over 95% of the country; geoscience studies in these areas are hampered by a lack of supporting information from aeromagnetic data.

These results and considerations have spurred the new USGS Earth Mapping Resources Initiative (Earth MRI) to adopt a nominal Rank 1 standard for aeromagnetic surveys. This requires the use of helicopter surveys, or surveys with specially modified airplanes, in topographically rugged areas. This standard will ensure that the Earth MRI-funded data will stand the test of time and provide the Nation with consistent and ideal data useful for quantitative modeling for numerous applications, both within and beyond the core mineral resource mission of the program. The only exception for Rank 2 specifications made to date has been for the Yukon Tanana Upland of eastern Alaska, where the unusually challenging combination of rugged terrain and remoteness would presumably result in Rank 1 specifications being cost-prohibitive, and the most detailed scale of mapping to be supported by the data is 1:63,360.

In the years since the ranking scheme was devised internally at the USGS, there have been certain questions that keep arising about the scheme and its implementation across the US. The most frequently asked questions and our corresponding answers are listed below.

FAQ #1: Are Rank 2 data really that bad? Why don't we just go with a Rank 2 standard to save money?

Rank 1 data stand the test of time, in the sense that the initial investment is optimized and ensures that no more detailed data will be required to meet foreseeable future needs. Rank 1 data support the broadest range of public geoscientific research needs, allow for rigorous quantitative interpretation, and fully meet modern international standards. The temptation will always be present to cut costs or to cover a larger area with Rank 2 specifications (i.e., wider line spacing), but the interpretive utility of the resulting data will be permanently handicapped. In the vast majority of foreseeable situations, Rank 1 data present the most cost-effective option in the long run.

FAQ #2: Can't we use drones to acquire aeromagnetic data more cheaply and/or easily?

Drones are not a viable option for geophysical surveys that extend beyond site investigation scales (i.e., areas beyond a few 10s of square kilometers), mainly due to regulatory hurdles. These hurdles are not anticipated to be overcome in the foreseeable future.

FAQ #3: How did the situation get this bad with aeromagnetic data quality in the US?

Simply put, the cost benefits of upgrading the data quality have been undervalued for several decades. Although efforts to improve the legacy aeromagnetic data have received some support in the past, proposals to systematically replace inadequate data with new, modern surveys have never received high enough priority for funding. Major deterrents have been the perception that the US is already covered by aeromagnetic data combined with a lack of appreciation of the utility of modern aeromagnetic data for a wide variety of applications.

FAQ #4: Are Rank 1 data "exploration" quality?

The answer depends on how one chooses to define "exploration" quality. Rank 1 specifications are generally appropriate for regional targeting activities by the private sector. However, most mineral exploration companies choose to fly significantly higher resolution surveys to aid detailed targeting (i.e., locating boreholes).

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NEVADA'S GEOLOGIC MAPPING PROGRAM: UNRAVELING THE GEOLOGIC FRAMEWORK, HAZARDS, AND NATURAL RESOURCES OF THE NATION'S FASTEST GROWING STATE

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The Nevada Bureau of Mines and Geology (NBMG) serves as the state geological survey for Nevada. NBMG is a public service unit of the University of Nevada, Reno (UNR), serving as both a statewide agency and a department in the College of Science at UNR. State statutes define the mission of NBMG as the Bureau of analysis, information, and exchange on Nevada geology, natural resources, and geologic hazards. Our mapping program reflects these responsibilities for a state that is the top producer of gold in the country, rich in geothermal and other mineral resources, third most seismically active, fastest growing (tectonically speaking), and most urban (in terms of proportion of citizens living in large cities).

To address this dynamic setting, NBMG has three priority regions for geologic mapping: 1) Clark County in southern Nevada, which is home to Las Vegas and nearly ¾ of Nevada's citizens; 2) the Reno-Carson City urban corridor in western Nevada and adjacent areas rich in geothermal and mineral resources; and 3) north-central to northeastern Nevada due to its wealth of mineral resources and classic setting for extensional tectonics. Northeastern Nevada contains the Carlin Trend, one of the richest regions on Earth for gold production. All areas contain geologic hazards (e.g., earthquakes, floods, and landslides) that must be reckoned with for infrastructure planning and development. To date, we estimate that ~30% of the state has been mapped in sufficient detail (typically 1:24,000) to adequately understand the geologic framework, hazards, and resources. Accordingly, significant work remains to produce high-quality, detailed geologic mapping for the state. The USGS STATEMAP program and other sources of funding generally permit publication of about five new quadrangles/areas per year. Although the arid climate greatly facilitates geologic mapping in Nevada, the complexity of the geology, with multiple overprinting tectonic episodes since the late Paleozoic, impedes more rapid progress. Due mainly to the large amount of public land (>85%), Nevada has lagged behind many states in the acquisition of high-resolution lidar and geophysical data that could expedite geologic mapping. However, this is changing, as evidenced by the ongoing GeoDAWN project (Geoscience data acquisition for western Nevada), which is a major collaborative effort between the USGS, Geothermal Technologies Office of DOE, and other federal agencies. GeoDAWN will provide high-resolution lidar for nearly 1/3 of Nevada.

Some of the notable recent mapping projects include: 1) quadrangle mapping and Quaternary fault studies in the Las Vegas metropolitan area, 2) a transect across highly extended, mineral-rich terrain in northeast Nevada, and 3) detailed mapping of geothermal systems in western to central Nevada. Most of these efforts have been funded by STATEMAP, but significant funding has also been obtained from Clark County, DOE, and the geothermal industry. Our mapping workflows utilize tablets for field data collection, lidar base data wherever available, various radiometric dating techniques, and ArcGIS map production in the GeMS schema. In some cases, we have also developed detailed 3D geologic maps of geothermal systems through integration of surface geologic maps with both geophysical and well data.

THE APPLICATION OF ANALYTICAL GEOCHEMISTRY DATA IN MAPPING; LESSONS LEARNED AT THE IDAHO GEOLOGICAL SURVEY

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For decades geochemical analytical data has been an essential tool for geologic mapping at the Idaho Geological Survey (IGS). From the Quaternary and Tertiary Snake River Plain-Yellowstone Volcanic Province, Miocene Columbia River Basalt Province, and the Eocene Challis Volcanic field geologists have used geochemical data along with field investigations, thin sections observations, and advanced analytical techniques such as paleomagnetic analyses to tease out the complexities within these fields. The geochemical toolbox is as deep as it is wide, and multiple factors go into choosing an analytical technique and a laboratory, including aim of the study, cost, and turn-around time. The IGS has primarily used whole-rock X-Ray Fluorescence (XRF) elemental analysis to classify, group, and subdivide volcanic rocks. Tools available to process and evaluate geochemical data can range from simple (Excel) to complex (R, petroplot, IgPet), and the resulting petrologic diagrams (total alkali vs silica, ternary, Fenner, Harker, Spider) is where we derive a meaningful interpretation. In our effort to provide more data and information to the reader, we are generally limited by the size of the map paper. In the end, IGS has chosen to display complete analytical records in table form on paper maps along with location data and geologic units as assigned by the geologists for each 7.5’ quadrangle. Once we have compiled and complete the 100k geologic sheets we publish all geochemical data as a Digital Analytical Database (DAD), currently in spreadsheet format. The DAD is merged into a statewide geochemical database currently containing 5,887 individual records, where it is served through our interactive map portal and queried by location, percent silica, unit name, age, lithology, or group and downloadable as a spreadsheet.

FERGUSON, Chad

No abstract

WE STILL HAVE WORK TO DO: ADDITIONAL TASKS TO SUPPORT THE DEVELOPMENT OF A NATIONAL GEOLOGIC MAP

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The stated vision of the National Geologic Mapping Program is to create an integrated, three-dimensional, digital geologic map of the United States and its territories to address the changing needs of the Nation by the year 2030. This is a challenging goal, and meeting it will require the full support and cooperation of federal and state geological surveys, the private sector, and academia.

We have already made considerable progress towards a foundation to support such a map. This includes establishing national standards for geologic map symbols and digital 2-D geologic maps, building a national database of existing geologic maps and a lexicon of geologic names, cataloging legacy geologic and geophysical data, and securing additional funding for continued geologic mapping, digital geologic map compilation, and data preservation at the federal, state, and academic levels. Even with all of this progress, we still have necessary work to accomplish:

1) Establish province-based best practices for geologic mapping to ensure good quality and consistency, and enhance our ability to create useful 3D maps in the future.
2) Establish standard criteria for the dimensions of geologic units and structures that are mappable at various scales.
3) Develop national databases for boring logs and geochemical, geochronological, geophysical, and paleontological data.
4) Link data sources within individual geodatabases to the National Geologic Map Database and other widely available geologic databases.
5) Establish a national glossary for geologic terms that is linkable to all geologic map products, possibly in cooperation with AGI.
6) Establish a mechanism to allow private-sector geologists to contribute useful information to the national geologic map.
7) Promote interstate geologic compilation projects through STATEMAP to address regional geologic issues, encourage resource sharing, and improve consistency.
8) Establish one or more USGS coordinators for each major geologic province. These coordinators will work closely with state geologic surveys and academia within the province to promote best practices in geologic mapping and map compilation, address regional correlation issues, and facilitate access to specialized resources that improve geologic maps such as geochemistry, geophysics, paleontology, and geochronology.
9) Provide a standard but flexible approach to allow for the construction of useful 3-D geologic maps in areas of differing geology.
10) Establish end-user goals and standard practices for building 3-D geologic models in each geologic province.

The Geologic Mapping Forum and Digital Mapping techniques meeting are ideal platforms to plan this work. Sessions at each meeting between now and 2030 could focus on developing a plan to address each priority and highlighting accomplishments from the previous year. STATEMAP, FEDMAP, and EDMAP funds could be used to allow a participant from each agency to attend these meetings, ensuring adequate representation.

HOUSE, Kyle

No abstract

THE USGS OZARK DOME-ARKOMA BASIN-OUACHITA BELT TRANSECT (ODABOUT) PROJECT: PLANS AND PROGRESS

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The USGS ODABOUT project has goals to compile geologic mapping at 1:100,000 scale, construct regional cross-sections, and conduct supporting topical studies to understand the geologic history for a transect in western Arkansas that extends from Ouachita orogenic belt northward through the Arkoma basin and into the southern flank of the Ozark dome. Scientific themes for the project include understanding the evolution of southern Laurentian margin in a late Paleozoic flexural basin system and investigating the role of pre-existing basement structures on foreland deformation patterns and paleofluid flow. In-progress research to be presented includes (1) a review of Late Mississippian to Permian timing constraints on flexural extension and subsequent shortening associated with accretion of the Ouachita belt, (2) a Desmoinesian shift in foreland sediment provenance determined from detrital zircon populations, and (3) evidence for the influence of basement weaknesses in southern Ozarks deformation as demonstrated by faulting characteristics and a new high-resolution aeromagnetic survey.

MAPPING MINNESOTA'S PRECAMBRIAN BEDROCK: WHAT'S NEW AND WHAT'S NEXT

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Minnesota's Precambrian bedrock ranges in age and rock type from ca 3.5 Ga (Paleoarchean) gneisses of the Minnesota River Valley subprovince of Superior Province, to ca 1.1 Ga (Mesoproterozoic) volcanic, intrusive, and sedimentary rocks of the Midcontinent Rift. This presentation explores the creation of Precambrian bedrock geologic maps. It provides a progress report on mapping in the state, describes new endeavors to better understand, portray, and convey the State's Precambrian geology, and speculates about what's next. Mapping relies on a variety of data sources, most of which are digital. The maps incorporate bedrock outcrops, drilling records, cuttings and core, aeromagnetic and gravity maps and models, lidar topographic imagery, minerals exploration records, structural data, and previously published and unpublished works. These data sets are interpreted in the context of contemporary orogenic, rift, and depositional models, and temporally pinned by high- resolution geochronologic data. The data, maps, rasters, and documentation are now available through the MGS Open Data Portal (https://cse.umn.edu/mgs). In addition to traditional mapping, we're currently using geophysical methods to model Precambrian surfaces beneath "removable layers" and infer map units in the underlying basement (Fig. 1). These "layers" are largely relict forelands, continental margins, and successor basins. Their floors are major unconformities representing temporal hiatuses that involved extensive chemical and physical weathering, In many cases, they are the result of continental peneplaination, followed by subsidence and deposition. The basin surfaces and fill convey significant shifts in crustal rheology and tectonomagmatic processes. Their geometry says something about the tectonic forces that formed and deformed them, and they may have potential for placer gold, uranium, and other mineral deposits.

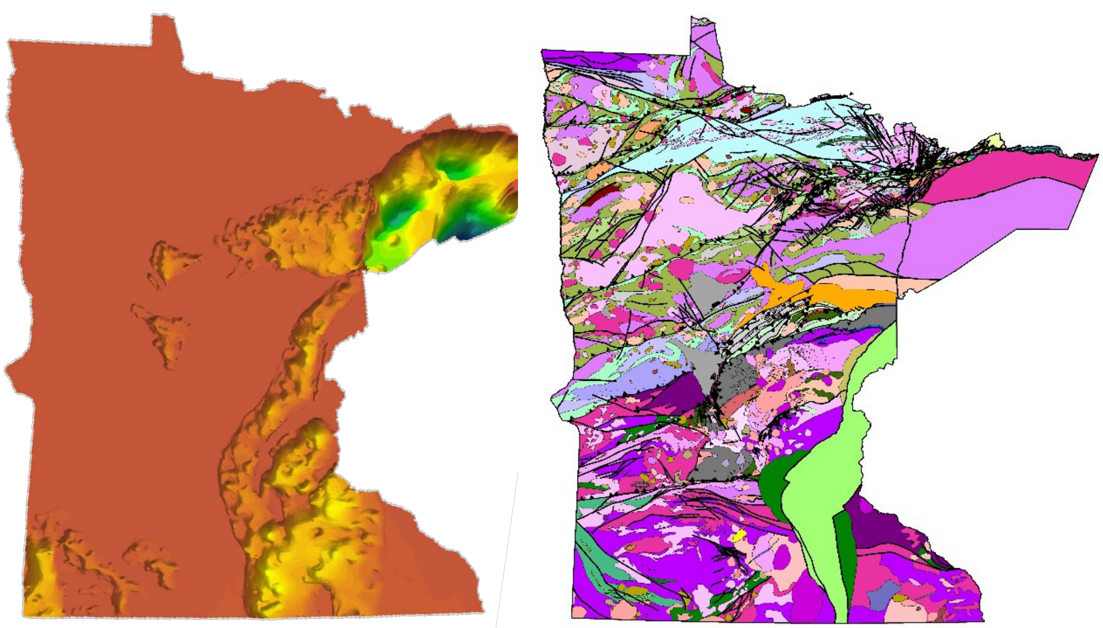

Figure 1. Precambrian bedrock geologic maps of Minnesota; left image depicts the geometry of basins composed of supracrustal rock (sedimentary, volcanic, and hypabyssal intrusive); right image portrays an interpretation of Precambrian "basement" on the floors of basins.

GEOLOGICAL MAPPING, GEOPHYSICS, AND INTEGRATED GEOSCIENCE DATABASES FOR EARTH SYSTEM VISUALIZATION, MODELING, AND ANALYSIS IN ALASKA

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Research by the U.S. Geological Survey Mineral Resources Program (USGS MRP) in Alaska integrates geologic, petrologic, geochemical, geo- and thermo-chronological, structural, and geophysical data to provide a comprehensive framework for understanding metallogeny in the context of Earth systems. Investigations are focused on mineralizing systems through regional, site-specific, and targeted topical research to evaluate mineral resource potential and the geologic controls on ore deposit formation, localization, and evolution. Geological mapping is an essential part of this work, and Alaska MRP scientists typically conduct mapping and geological sampling at the regional, reconnaissance scale of 1:250,000. Our mapping, sampling, and multi-component analytical efforts are integrated with available geophysical data to model crustal features in three dimensions. Maps and geophysical data provide a basis to project geological units and structures beneath areas with limited or no bedrock exposures and to better develop and refine testable hypotheses. We coordinate where possible with more detailed (1:100,000 to 1:63,360 scale) geological mapping and sampling conducted by the Alaska Division of Geological and Geophysical Surveys. Highly innovative, site-specific collaborations with university faculty and students further allows for state-of-the-art research advancements and mentorship of next generation geoscientists. Together our integrated and cooperative research approach provides the best available information required for understanding the geological evolution and metallogenic potential of broad regions of the state.

Our data and research findings are incorporated into multiple state-wide databases, including a digital geologic map database and supporting geo-thermo-chronologic, geochemical and mineral occurrence databases. These Alaska databases provide an essential and adaptable foundation for documenting the mineral endowment of Alaska and for guiding ongoing and future geologic mapping and other MRP research throughout the state. As an example, the USGS has produced numerous GIS-based assessments of critical mineral potential across Alaska by integrating and evaluating relevant minerals-related data. These assessments and the maps of mineral resource prospectivity that they produce are inherently adaptable and scalable, and they are useful to a wide range of stakeholders. More broadly, though, our seamless and integrated geoscience databases provide an opportunity to develop a comprehensive geospatial model to investigate natural resources in the context of broader Earth systems across large, complex, and dynamic regions. The Alaska Earth Model (Fig. 1) is a concept that allows us to integrate, visualize, and analyze relationships between a wide variety of geospatial data in a common framework. This concept can and should be developed for the conterminous United States through development, maintenance, and integration of similar seamless databases to address a wide variety of geoscience questions.

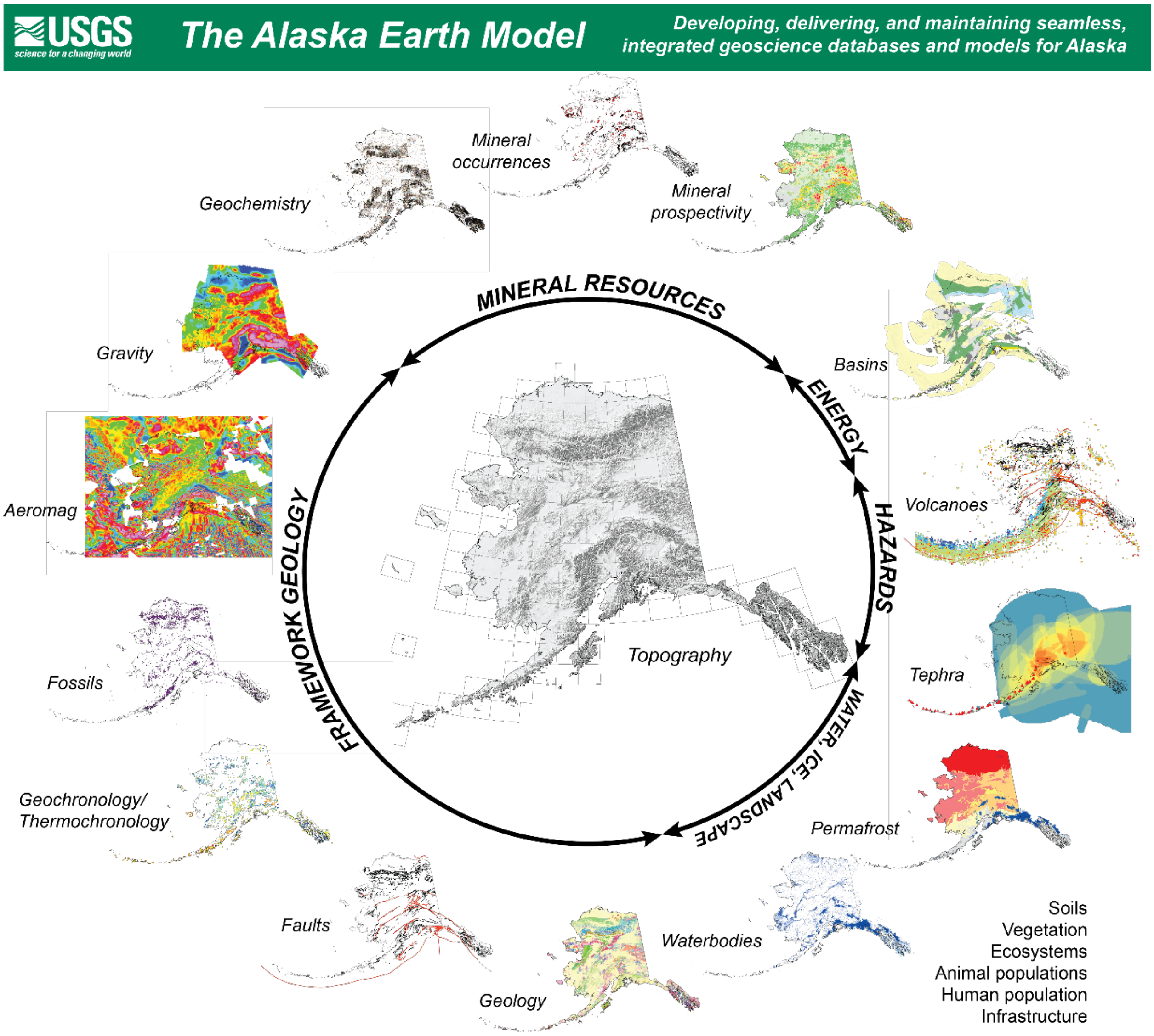

Figure 1 shows a representative selection of published geospatial datasets that cover Alaska and are incorporated into the Alaska Earth Model. The arrows represent overlaps and feedbacks between the datasets and their associated features in the context of various USGS mission areas.

MAPPING EVERYTHING TO UNDERSTAND THE 3D FATE AND TRANSPORT OF PFAS IN FRACTURED ROCK AQUIFERS IN VERMONT

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Statewide testing for per- (and poly-) fluoroalkyl substance (PFAS) contamination of groundwater was driven by the 2016 discovery of PFAS in the Town of Bennington by the Vermont DEC, an occurrence related to the use of PFAS (specifically PFOA) to manufacture Teflon-coated fiberglass fabrics. In 2018, numerous wells and springs near the Rutland-Southern Vermont Regional Airport (RSVRA) were found to be contaminated with PFAS, which was associated with the use of aqueous film-forming foam (AFFF) during fire suppression equipment tests over 3 decades and at 2 crash sites. The Vermont Geological Survey and academic partners are collaborating on multidisciplinary investigations at both sites.

PFAS compounds are composed of alkane-like carbon chains of varying lengths that are bonded to fluorine atoms and contain a functional tail (typically a carboxylic or sulfonate groups) giving them hydrophobic and hydrophilic ends. PFAS compounds have been called “forever” chemicals because of their resistance to degradation in the environment. The hydrophilic end allows PFAS to be sequestered in the vadose zone by organic carbon and Fe oxyhydroxides in soils. Since PFAS can enter the environment through air emissions or point sources, their fate and transport is complex and requires that multiple mapping techniques be employed at different scales.

Our research group utilizes physical and chemical mapping approaches to characterize PFAS-contaminated aquifers. The former consists of surficial and bedrock mapping (including unmanned aerial vehicle (UAV=drone) surveys and photogrammetry), spatial analysis of well reports in GIS to generate hydrogeologic maps (isopach, bedrock surface contour, and potentiometric surface), and geophysical logging; whereas the latter is comprised by chemical mapping of groundwater for different PFAS species, major and trace elements and anions, stable isotopes, and recharge-ages. This talk will focus on the different physical and chemical mapping techniques and how they are integrated to generate 3D conceptual site models, which are used to portray the “plumbing” of groundwater (and contaminants) in the bedrock aquifer. This general approach is also useful for investigating the fate and transport of other contaminants in groundwater such as phosphorous, nitrate, arsenic, and radionuclides.

A MINERAL SYSTEMS FRAMEWORK FOR ALASKA GEOLOGIC MAPPING AND DATABASE DEVELOPMENT

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Critical minerals are a current research priority of the Mineral Resources Program of the U.S. Geological Survey (USGS). The USGS Earth Mapping Resources Initiative (Earth MRI) was developed in partnership with state geological surveys to better understand the distribution and potential for critical mineral resources across the nation. In Alaska, critical minerals are most commonly found as by-products within ore deposits being exploited principally for Pb, Zn, Au, Ag, and Cu. Critical minerals are enriched in many different types of mineral systems that occur in a variety of geologic and tectonic settings. A mineral system consists of five fundamental components that include 1) an energy drive (topography, geothermal gradient, magma), 2) a source of components (metals and ions), 3) transport media (melts, aqueous fluids, petroleum, ligands), 4) transport pathways (channels, permeable structures and lithologies), and 5) traps (physical or chemical). These five components occur across multiple scales ranging from the tectonic setting (1,000's of linear kms), geologic environment (100's-1,000's of linear kms), mineral system (10-100's, rarely 1,000's linear kms) down to the deposit (1-100's linear kms) scales. They may also be active for 10,000 to a few millions of years. Heterogeneities in these environments account for relative mineral enrichments and may ultimately control why some systems concentrate critical, precious, and base metals whereas others do not.

In Alaska, we are using a data-driven, analytical approach to map mineral systems, to evaluate critical mineral resource potential, and to prioritize areas in need of new geological and geophysical data across broad regions. We can map and evaluate many of the processes outlined above at the mineral system scale across the entire state using a rich array of geological, geochemical, and geophysical data that are curated in multiple modern databases that are regularly updated. We analyze the databases for specific criteria associated with mineral systems and critical elements to generate continuous, data-driven maps of mineral resource prospectivity across the entire state. Key databases involved in this effort are the Alaska State Geological Map database (Wilson and others, 2015), the Alaska Resource Data File (U.S. Geological Survey, 2011), the Alaska Geochemical Database (Grannito and others, 2019), and the state wide geochronology databases (Wilson and others, 2015). From the outset, these databases were designed to maximize end-user functionality, facilitating rapid and automated prospectivity analyses. Published prospectivity maps for mineral systems include data tables detailing the criteria on which the analyses were completed (Karl and others, 2016). Data-driven analyses are completed on a 100 km^2 basis, however the analysis can be scaled or modified in a GIS environment to suit other research or assessment needs. Furthermore, the maps can be utilized to highlight the potential prospectivity for critical minerals for which data are not available, based on the knowledge of possible by-product enrichments in similar geologic environments or tectonic settings. Regions with multiple overlapping mineral systems with the potential for critical mineral by-products have been prioritized as initial focus areas for new geological mapping and geophysical data collection through Earth MRI and other projects funded by the USGS Mineral Resources Program.

As an example of the application of mapping in a mineral systems framework, the following can be applied. A strong understanding of the tectonic setting is required (e.g. island arc versus continental arc) as heterogeneities in the composition of magmas generated and chemistry of the crustal column may influence available fluid and metal sources and compositions. Secondly, the composition of rocks in the local geologic environment that fluids may interact with play an important role in determining the metal budget in a system. Framework geologic mapping of lithologies, structures (as pathways), and surficial geochemical environments are required to understand the possible source(s) of components in the system and the potential fluid pathways and interactions along flow paths. Lastly, ore deposits form at some depth below the surface, in most cases. Post-ore processes, such as uplift and erosion are critical to exposing, and preserving the ore deposits. A strong understanding of surficial processes is thus required to predict the location, and hopeful preservation of deposits on the modern landscape. Mapping features at a multitude of scales is critical to the full integration of a mineral system framework, which will lead to better prediction and characterization of metal endowments.

Granitto, M., Wang, B., Shew, N.B., Karl, S.M., Labay, K.A., Werdon, M.B., Seitz, S.S., and Hoppe, J.E., 2019, Alaska Geochemical Database Version 3.0 (AGDB3)—Including "best value" data compilations for rock, sediment, soil, mineral, and concentrate sample media: U.S. Geological Survey Data Series 1117, 33 p., https://doi.org/10.3133/ds1117.

Karl, S.M., Jones, J.V., III, and Hayes, T.S., eds., 2016, GIS-based identification of areas that have resource potential for critical minerals in six selected groups of deposit types in Alaska: U.S. Geological Survey Open-File Report 2016–1191, 99 p., 5 appendixes, 12 plates, scale 1:10,500,000, http://dx.doi.org/10.3133/ofr20161191.

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Wilson, F.H., Hults, C.P., Mull, C.G, and Karl, S.M, compilers, 2015, Geologic map of Alaska: U.S. Geological Survey Scientific Investigations Map 3340, pamphlet 196 p., 2 sheets, scale 1:1,584,000, http://dx.doi.org/10.3133/sim3340.

MINNESOTA GEOLOGICAL SURVEY QUATERNARY GEOLOGIC MAPPING

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MGS Quaternary geologic mapping is used throughout the state for applications such as modeling groundwater, supporting assessment of aggregate resources, for engineering and infrastructure design such as planning of fiber optic cable installation, and also to directly support research on glacial geology and Quaternary history.

This Quaternary geologic mapping is based on fieldwork, shallow and deep drilling, textural, lithologic, and geochemical analyses, geophysical surveys that currently focus on passive seismic soundings, and reference to statewide lidar and soil mapping. The mapping at 1:500,000 (Fig. 1) and 1:100,000 levels of resolution is conducted similarly, although subsurface mapping of 3D Quaternary geology is based on cross sections at a 5-kilometer spacing (Fig. 2) for the 1:500,000-scale mapping, and at a 1-kilometer spacing for 1:100,000-scale mapping. The statewide subsurface legend currently includes about sixty layers. The subsurface mapping is guided by all available data, is anchored at thoroughly analyzed cores, and is guided by the 500,000-site water-well database. Ongoing research facilitated by the mapping is addressing topics such as glacial sedimentary processes, glacial history ranging from the character of pre-Wisconsinan events to the details of final deglaciation, along with topics such as quantitative hydrogeologic characterization of the Quaternary sediments.

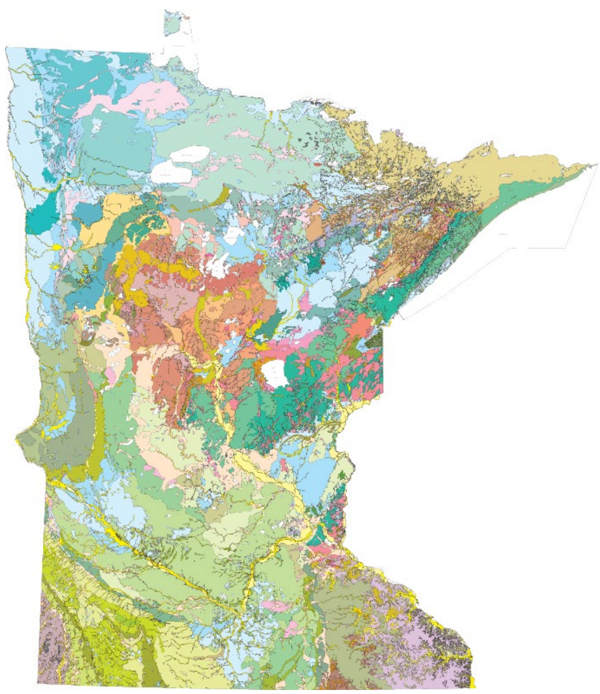

Figure 1. The 1:500,000 scale Quaternary Geology of Minnesota (Lusardi and others, 2019).

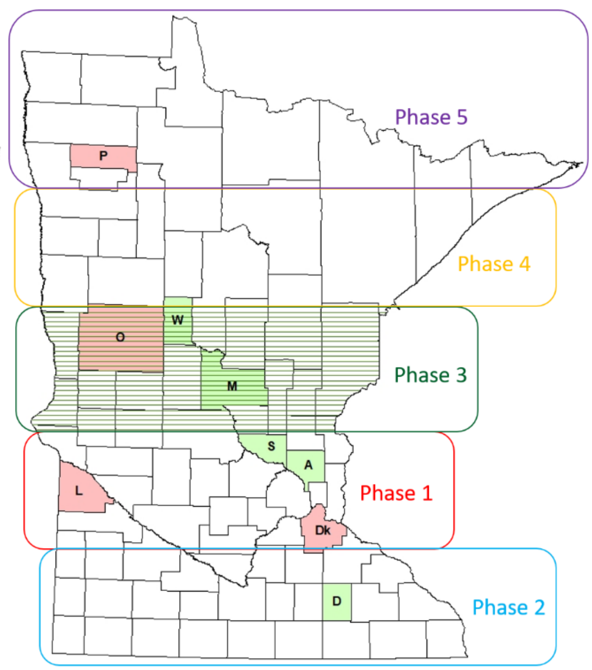

Figure 2. Five phases of 5-km spaced cross-sections for a total of 132 statewide cross sections.

We are currently building our 3D mapping of the Quaternary sediments, building on the current one-layer model provided by the depth to bedrock map. Full modeling of the strata based on the 5km-spaced cross sections will begin when all 132 sections are complete.

The Great Lakes Geologic Mapping Coalition (GLGMC) has significantly advanced this Quaternary mapping by funding a stratigraphic naming guide (FY11), Atlas mapping (FY12-13 and 16), lithologic databases (FY14), pilot statewide cross sections (FY15) as well as 5-km cross sections starting in the southern part of the state (FY19, 20, and 21) (Fig. 3), and both pilot and mapping phases of 1:500,000-scale plan-view compilation mapping (FY16-19).

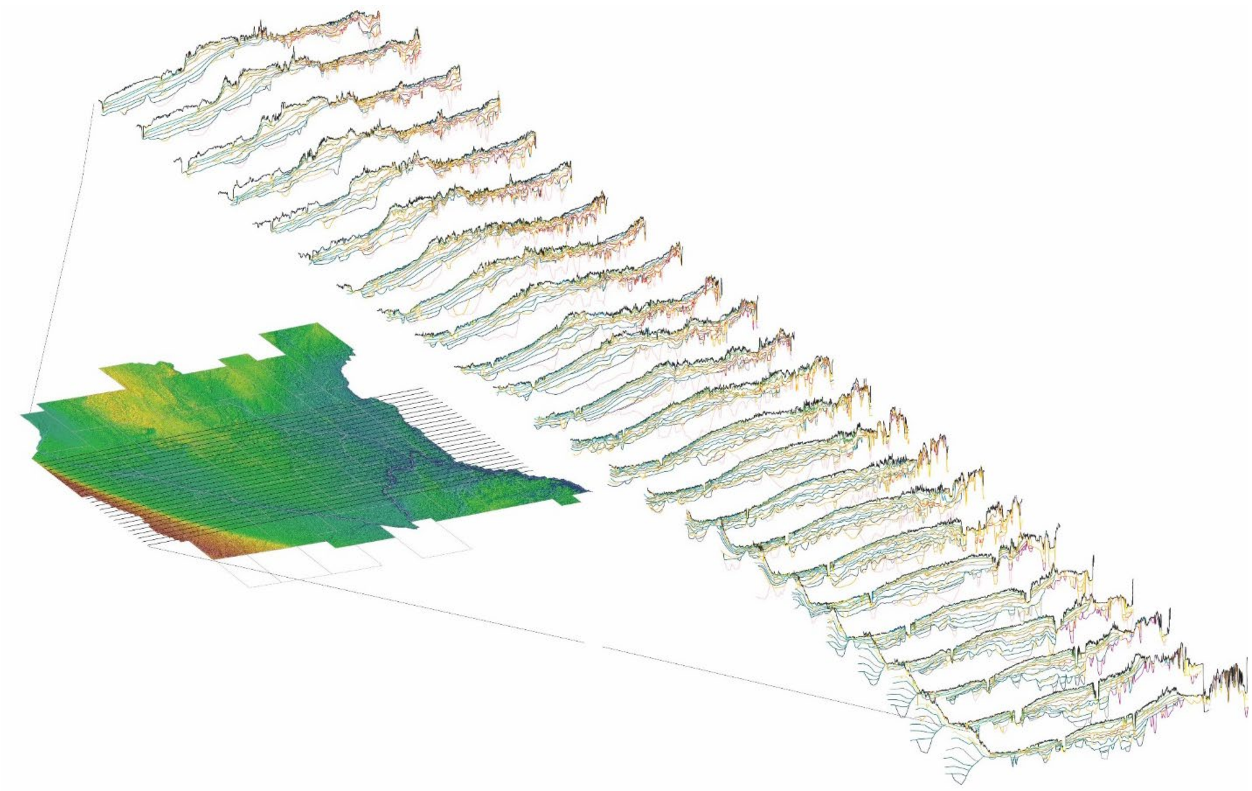

Figure 3. Schematic image of 24 statewide cross sections (Phase 1) (Staley and others, 2019).

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Lusardi, Barbara A; Gowan, Angela S; McDonald, Jennifer M; Marshall, Katherine J; Meyer, Gary N; Wagner, Kaleb G. (2019). S-23 Geologic Map of Minnesota - Quaternary Geology. Minnesota Geological Survey. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/208552.

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MACCORMACK, Kelsey

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MADIN, Ian

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WHAT LIES BENEATH THE HARNEY BASIN OF SOUTHEAST, OREGON?: INTEGRATED GEOLOGICAL DATA REVEALS THE HIDDEN LATE MIOCENE SILVIES RIVER CALDERA

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Geologic maps are essential to solve practical problems, including deciphering Earth history and processes, evaluating resources, and preparing for hazards. The complexity of modern geologic questions necessitates efficient and detailed field studies, integrated with all available data sets, including lidar, geochemistry, geochronology, petrography, structural measurements, well information, and geophysics. Such comprehensive studies markedly improve the accuracy and usability of geologic maps and further allow for the deduction of geological structures hidden at depth. The results of comprehensive studies range from the fine-tuning of map units, to improved subsurface resolution, to fundamental advances in the conceptual understanding of an area. Recent geologic mapping by the Oregon Department of Geology and Mineral Industries (DOGAMI) has focused upon the Harney Basin of SE Oregon, where the Oregon Water Resources Department (OWRD) has recognized significant groundwater development and long-term groundwater level declines (Figure 1). A key element of developing a conceptual model of the Harney basin is defining the 3D geologic framework and how it affects groundwater and surface water distribution and movement.

The Harney Basin encompasses approximately 13,566 km^2, lying at the east end of the late Cenozoic High Lava Plains (HLP) volcanic province (Figure 1). Volcanic rocks in the HLP, younger than 12 Ma, are strongly bimodal, including relatively equal volumes of primitive basalt flows and rhyolitic tuffs and domes. Rhyolitic rocks, in general, young to the NW., toward Newberry Volcano. Three voluminous, locally erupted late Miocene ash-flow tuffs are widely exposed across the Harney Basin. The 7.1 Ma Rattlesnake Tuff is the youngest and most extensive of the three, having an estimated eruptive volume >280 km^3 and outcrops covering >35,000 km^2 (Figure 1). The 9.7 Ma Devine Canyon Tuff is the oldest with an eruptive volume estimated at 250 to 300 km^3 and outcrops covering >30,800 km^2. The intermediate age 8.48/8.41 Ma Prater Creek Tuff is the smallest, having an eruptive volume of ~200 km^3 and outcrops covering ~9,615 km^2. Caldera sources for the Devine Canyon, Prater, and Rattlesnake tuffs have no surface expression and thus have been difficult to locate. While previous studies have inferred the likelihood of late Miocene source calderas beneath the Harney Basin, there have been no direct observations of such features (Figure 1). Widespread Rattlesnake Tuff, erupted from Capehart Lake, completely buried evidence of earlier tuff sources.

Several deep exploration wells have been drilled in the Harney Basin near the city of Burns, penetrating through the Rattlesnake Tuff. Cuttings retained for the Federal 1-10 (drilled 1979; total depth = 2,343 m) and CTI (drilled 1996; total depth = 596 m) wells by DOGAMI provide direct evidence revealing the presence of a concealed eruptive center underlying the Burns Butte area that McClaughry et. al (2019) referred to as the Silvies River caldera (Figures 1, 2). Careful geologic mapping, combined with lithologic and geochemical characterization of the Federal 1-10 and CTI wells has identified a previously unknown, >427-m-thick section of thickly ponded, geochemically monotonous caldera-filling rhyolitic tuff characterized by a pervasive granophyric texture (Figures 1, 2; McClaughry et. al, 2019). The buried rhyolitic tuff has a similar stratigraphic position, shares an indistinguishable isotopic age (8.52 ± 0.02 Ma), and is geochemically identical to surface outcrops of the Prater Creek Tuff, exposed N. and NE. of Burns Butte. This relationship provides a direct link that the source vent of the Prater Creek Tuff is the Silvies River caldera. Caldera-filling tuff is spatially associated with a bimodal suite of 8.52 to 8.46 Ma rhyolite tuffs (tuff of Wheeler Springs) and 8.46 to 7.68 Ma exogenous rhyolite domes and flows (rhyolite of Golden Ranch, rhyolite of Burns Butte), and 7.68 to 7.1 Ma basaltic trachyandesite and trachyandesite flows, dikes, and vent deposits. These rocks define a narrow volcanic field of silicic domes and mafic shield volcanoes lying above the caldera-filling tuff (Figure 2). A 622-m-thick cryptic volcanic sequence lying below the tuff of Wheeler Springs and above caldera-fill tuff in the Federal 1-10 well, appears to be a series of lava flows erupted from post-collapse caldera-related vents, that partially fill the structure. This mafic to intermediate, flow-on-flow unit has no surface expression and is absent in the CTI well (Figure 2). Distribution of the caldera-fill tuff below Burns Butte, also corresponds to an area of missing regional stratigraphic units. Mesozoic accreted terrane rocks, Oligocene volcanics, Columbia River Basalt, and Devine Canyon Tuff are all exposed at the surface in areas 10 to 20 km N. and NE. of Burns Butte, yet are conspicuously absent in the Federal 1-10 and CTI wells (Figure 2).

Recognition of the previously unknown Silvies River caldera, underlying the Burns Butte area, has profound implications for developing a conceptual volcano-tectonic model for the Harney Basin and evaluating regional aquifer conditions. The caldera discovery also highlights the significance of gathering, analyzing, and interpreting comprehensive geologic data sets when attempting to unravel complex geology and establish a detailed geological framework. Such advancements in conceptual understanding also emphasizes the value of commitments by organizations to collecting, archiving, and managing descriptions and physical samples (e.g., cuttings, cores, etc.) from earlier exploratory investigations that will be of long-term use and interest in future scientific research. Discovery of the Silvies River caldera would not have been possible without the availability of historic oil and gas and geothermal well cuttings archived by DOGAMI as part of agency statute (ORS 516.030 [11]).

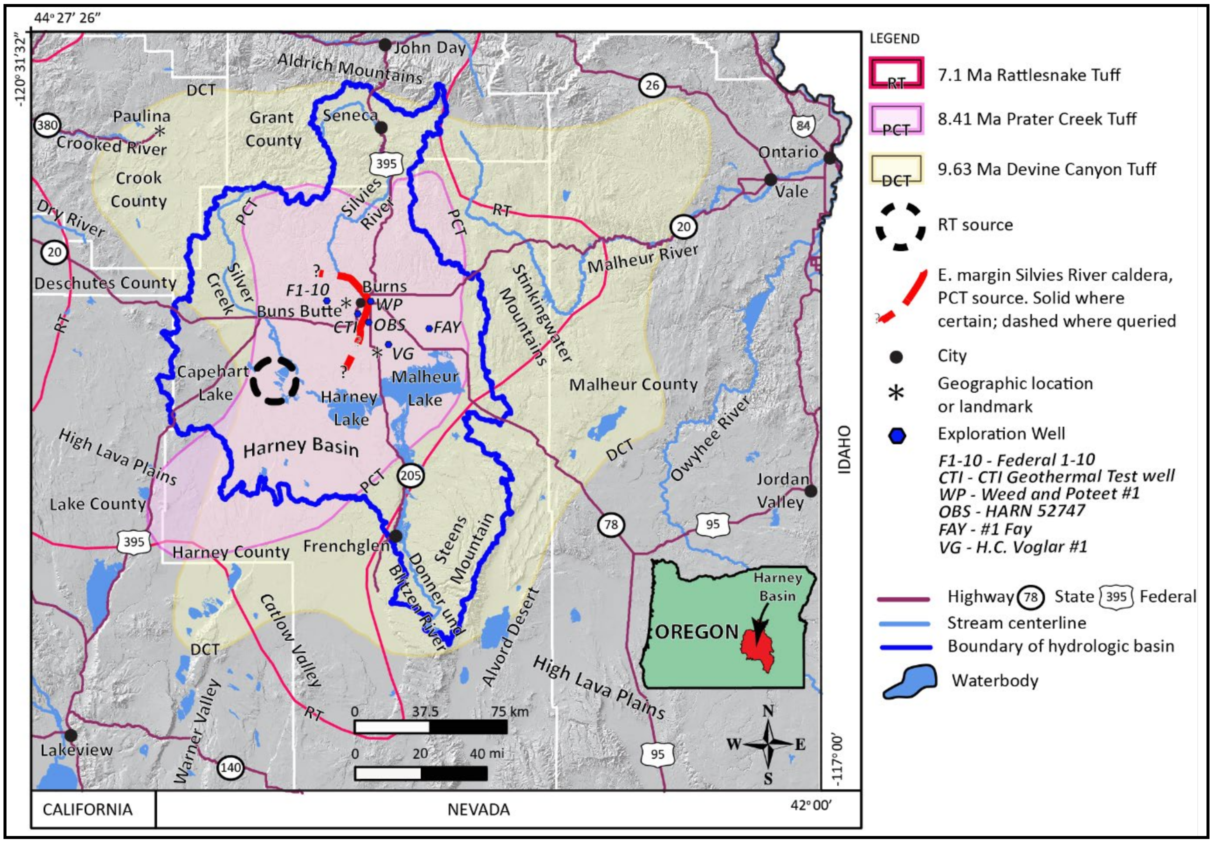

Figure 1. Outcrop distribution and proposed source areas for late Miocene tuffs in the Harney Basin.

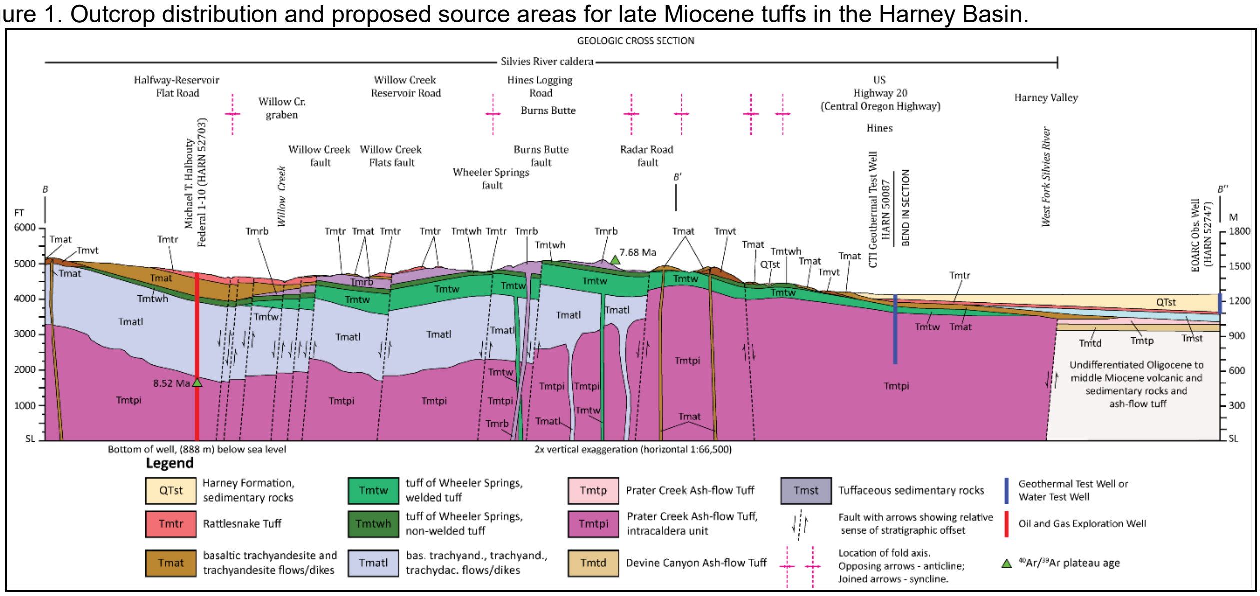

Figure 2. Northwest to southeast geologic cross section, drawn through the Federal 1-10 and CTI wells.

Reference:

McClaughry, J.D., Duda, C. J. M., and Ferns, M. L. 2019. Geologic map of the Poison Creek and Burns 7.5′ quadrangles, Harney County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS 123, 127 p., 2 plates, scale 1:24,000. https://www.oregongeology.org/pubs/gms/p-GMS-123.htm

MONTANA'S 1:500,000 AND 1:100,000-SCALE SEAMLESS GEODATABASES: PROGRESS AND CHALLENGES

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The Montana Bureau of Mines and Geology (MBMG) maintains seamless geologic map geodatabases at 1:500,000- and 1:100,000-scale. The 1:500,000-scale geodatabase is the digital version of the Geologic Map of Montana (Vuke et al. 2007). In 2012, the MBMG worked with the U.S. Geological Survey to create the digital map, which is available on our website as a simple ArcGIS map package consisting of three feature classes (lines, faults, and polygons). In 2019, the MBMG received supplemental funding through the STATEMAP program to convert the 1:500,000-scale digital map data to a GeMS-compliant geodatabase. The conversion is underway and will be available in 2021. Concurrently, the MBMG will update the map based on new geologic mapping completed since 2007. Updating the map is a priority, in part because our ongoing collaborative work with the Idaho Geologic Survey has resulted in major revisions to cross-border structures and the stratigraphy of the Mesoproterozoic sedimentary rocks in southwest Montana. The updated map will also guide the MBMG in reviewing and developing a plan to identify and address edgematching issues with surrounding states and Canadian provinces.

The seamless 1:100,000-scale geologic map geodatabase is an ongoing project that currently covers approximately 85 percent of the State. The geodatabase was originally created by migrating existing ArcInfo coverages of our legacy 1:100,000-scale geologic maps into the NCGMP09 template. Geologists and GIS staff worked to edgematch around the map boundaries, review and recode line types as needed, and develop a master geologic unit list. The geodatabase is available on the MBMG website and is updated annually. Current work includes adding and refining glacial deposits in large areas of north-central and northeast Montana where original maps were bedrock only, reviewing and updating codes and unit descriptions (around 900 units and counting) for non-spatial tables associated with the geodatabase, and reviewing the geology to ensure the digital data accurately capture the original mapping. Figure 1 shows the current extent of our seamless 1:100,000-scale geologic map, including four new maps that are in the process of being added and in-progress maps. The long-term goal of the MBMG and our STATEMAP advisory committee is to complete the seamless coverage at 1:100,000-scale and to make the geodatabase GeMS-compliant.

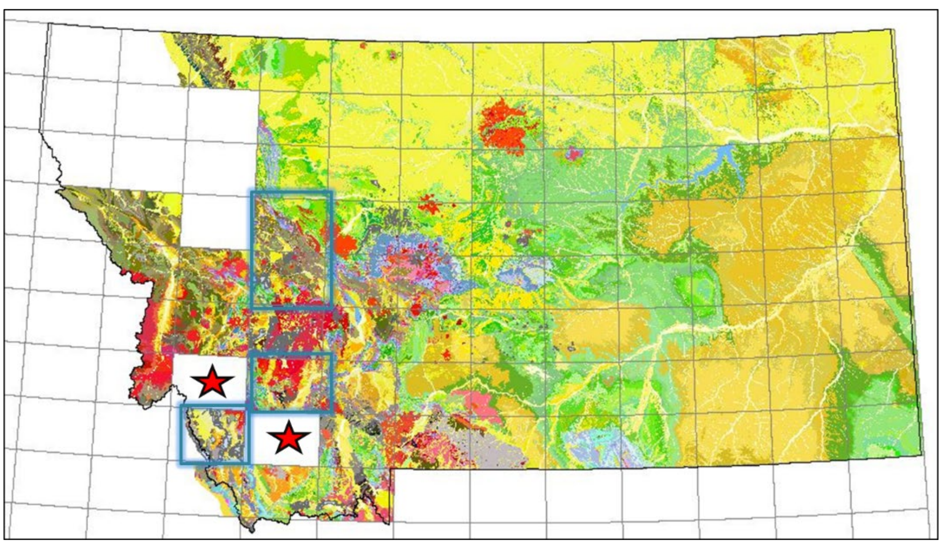

Figure 1. Status of Montana's 1:100,000-scale seamless geologic map geodatabase (November 2020). Blue boxes are new maps that are being added to the geodatabase but are not yet in the version available on the website. Stars are in-progress maps.

Vuke, S.M., K.W. Porter, J.D Lonn, and D.A. Lopez. 2007. Geological Map of Montana—Geologic Map 62: Montana Bureau of Mines and Geology, Geologic Map 62, p. 1–73.

THE FLORIDA GEOLOGICAL SURVEY MAPPING INITIATIVE (FGSMI)

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The Florida Geological Survey Mapping Initiative (FGSMI) serves as the framework for accomplishing a long-term goal set by the Florida Geological Survey (FGS) to update the statewide surficial geologic map of Florida. The last published statewide surficial geologic map of Florida was published by Scott, et al. (2001). Since then, the FGS has gathered additional geologic data, mapped about half of the state at higher resolution through the STATEMAP program, and developed LiDAR-based elevation models. As a result, the FGS is poised to complete and publish an updated surficial geologic map of Florida.

To accelerate the timeline for completion of a new surficial geologic map of the state, an additional non-grant funded surficial geologic mapping program, called the Florida Geologic Mapping Program (FLAGMAP), began mapping in 2017. Due to competing priorities and workforce limitations, FLAGMAP progress was limited until 2019. Concurrent with FLAGMAP is initiation of a subsurface 3D mapping/modeling pilot project associated with the 3D Florida initiative. The intent of the FGSMI is to complete a new statewide surficial geologic map within the next six years through the continued work of the STATEMAP program and coordinated mapping efforts of FLAGMAP and the 3D Florida pilot. This discussion will primarily focus on the FLAGMAP and 3D Florida components of FGSMI since most conference attendees are familiar with STATEMAP. The FGS has developed a Project Management and Implementation Plan to frame the path forward for FGSMI.

Some of the key overarching goals of FGSMI include the characterization of Florida's uppermost geological layers, description of core and cuttings housed in the FGS Repository, verification of borehole data, entry of borehole data into the GEOlogic Data Enterprise System (GEODES), and the dissemination of geological information for maximum societal benefit. GEODES provides the digital infrastructure for FGSMI, making it an essential component of this initiative. Other projects may also advance FGSMI toward its completion, including Earth MRI-funded projects in Florida focus areas.

STATEMAP

To date, the FGS has mapped approximately 31,700 square miles of Florida under grants from the USGS STATEMAP program, totaling a state-plus-federal investment of more than $6.6M as of 2020 (Figure 1). The STATEMAP team has been comprised of 3.5 full-time staff (includes grant match positions) and is guided by a STATEMAP Advisory Committee (SMAC), which annually defines a five-year mapping plan. STATEMAP nearly doubled its rate of mapping around 2011. Even with that increase, STATEMAP alone would not be able to complete mapping the entire state until nearly 2035. Additionally, those areas mapped prior to 2005 will need to be revisited in the context of LiDAR availability, consideration of newly acquired geologic data and use of shallow 3D stratigraphic models that are valuable for geologic mapping in Florida.

FLAGMAP

FLAGMAP, as envisioned herein, is designed to parallel STATEMAP toward the completion of FGSMI. FLAGMAP accomplishes this through new geologic mapping within those parts of Florida not covered by STATEMAP, yet broadly follows the STATEMAP model. Data density will vary according to local complexity of topography and stratigraphy. Data sources will include strategically selected borehole samples, including newly drilled boreholes, to establish a network of wells serving as data control for surficial and subsurface geological modeling.

3D Florida

3D Florida will include a three-dimensional characterization of Florida's surface and subsurface geological attributes including: a land surface digital elevation model (DEM), a new surficial geologic map, and a model of subsurface lithostratigraphy. These attributes, when combined, will allow the FGS to proceed with the 3D Florida initiative. The subsurface model will inform subsequent development of a statewide hydrostratigraphic framework, as well as facilitate a more comprehensive understanding of the geology of Florida. 3D Florida, in the context of FGSMI, will include a pilot area in peninsular Florida where STATEMAP and other FGS research has gathered a robust dataset over the past two decades. New software for 3D Florida will be considered, tested, and chosen based on the results in the pilot region to demonstrate the value of developing a three-dimensional characterization for the entire state.

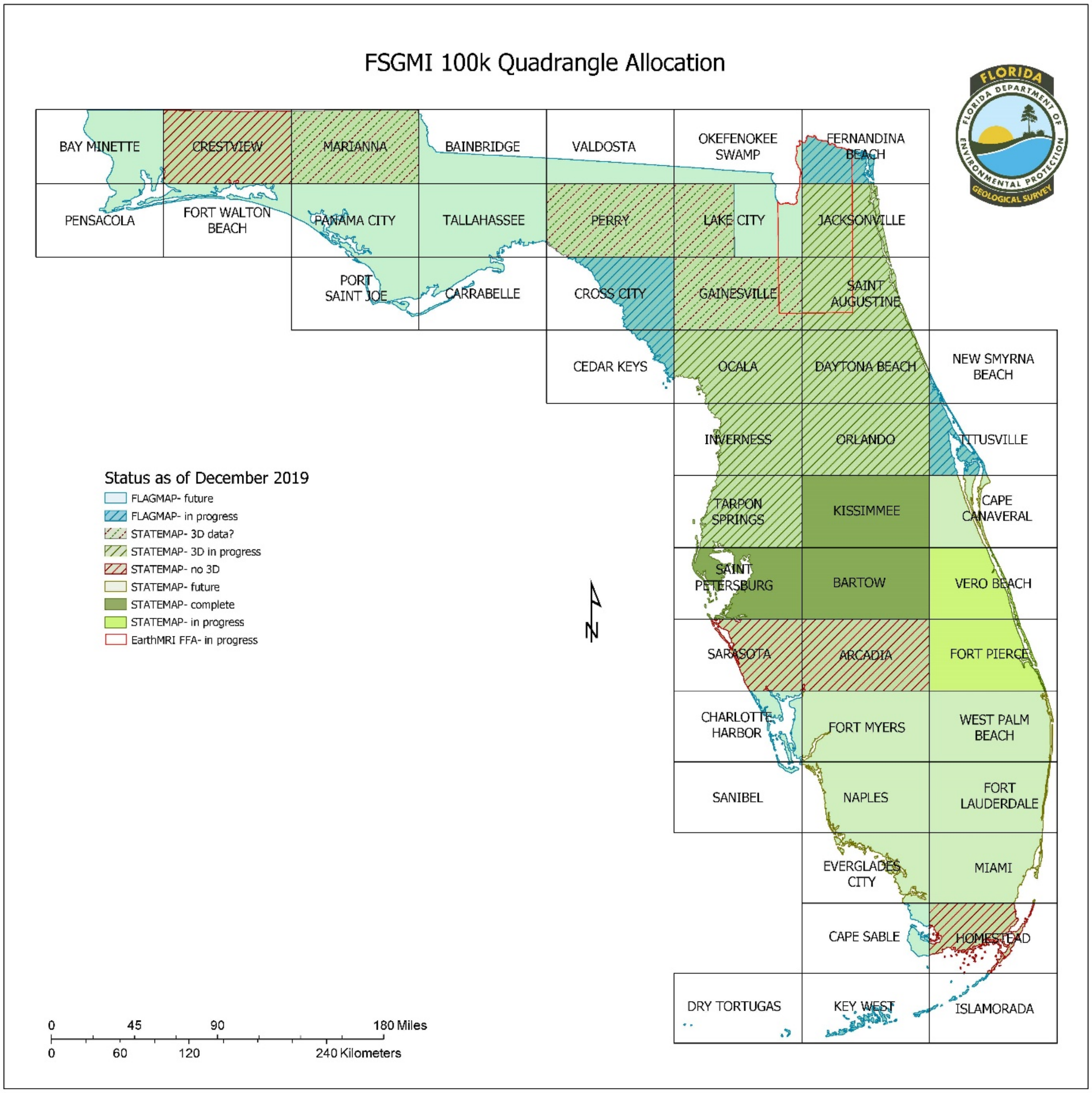

Figure 1 – USGS 1:100,000 scale quadrangles in Florida showing which component of FGSMI is responsible for surficial geologic mapping in each.

FUNDAMENTAL FRAMEWORK GEOLOGY IN THE SOUTHERN APPALACHIAN CRYSTALLINE CORE: THE U.S. GEOLOGICAL SURVEY NATIONAL COOPERATIVE GEOLOGIC MAPPING PROGRAM (FEDMAP COMPONENT) PIEDMONT-BLUE RIDGE PROJECT

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The USGS NCGMP Piedmont-Blue Ridge (PBR) Project aims to develop 4D geologic framework models across the southern Appalachian orogen. The primary objective of the Project is to construct geologic maps and accompanying GeMS geodatabases at scales of 1:24K and 1:100K across the VA-NC-TN state lines where existing geologic map coverage is not adequate (>1:250K) to solve societal and scientific challenges. Two tasks and regional field areas comprise the PBR Project: (1) Piedmont Geology Along the Southeastern Fall Zone, Virginia and North Carolina focuses on eastern Piedmont geology from Richmond, Virginia to Rocky Mount, North Carolina; and (2) Blue Ridge-Inner Piedmont geology covers from the junction of Virginia, North Carolina, and Tennessee eastward into the Piedmont. Both areas host potential critical mineral deposits, including rare earth elements (REE), lithium, tin, and others (e.g., Ti, U, Ta, Nb, Be, Mn, Ba, Zr). Radon in groundwater is a concern in northwestern North Carolina and southwestern Virginia where preliminary investigation suggests a correlation between REE concentration and radon/uranium in certain rock units and major shear zones. The Fall Zone in southeastern Virginia and northeastern North Carolina is the recharge area for the largest aquifer (Cretaceous Potomac Group) on the southeastern seaboard; this region also hosts marketable deposits of REE-bearing heavy minerals. Slope-stability and earthquake hazards are issues in both areas. Developing the 4-D geologic framework of these relatively unexplored regions and producing seamless geologic maps and geodatabases is necessary to address societal needs and resolve “state-line border faults”. Both Tasks work closely with USGS NCGMP STATEMAP and EDMAP components to further the overall goals of the Program.

Although the COVID-19 pandemic significantly impacted field work for FY2020, the PBR Project received funding from Earth MRI and NCGMP-NGS for acquisition of high-resolution airborne radiometric and magnetic surveys along the Fall Zone from Richmond to Rocky Mount for heavy mineral and REE exploration. This new dataset will significantly improve geologic mapping capabilities on the west half of the Emporia 30x60-minute quadrangle and provide valuable data for VDGMR and NCGS Earth MRI regional projects. These data, however, will not be available until FY2022, and the PBR staff are focusing all efforts in FY2021 on the Blue Ridge-Inner Piedmont task area.

Planning in March 2020 highlighted the need for detailed mapping on the Sparta East and Sparta West quadrangles to complete the southern tier of the Wytheville 1:100,00-scale quadrangle; five months later, a M5.1 earthquake struck just southeast of the town of Sparta, North Carolina (Fig. 1). This is the largest quake to strike the eastern US since the M5.8 earthquake in Mineral, Virginia in 2011 and the largest to strike North Carolina since at least 1916. This event demonstrates yet again why there is such a direct need for high-quality geologic data in this region.

In the meizoseismal area of the Sparta quake, over 500 buildings and infrastructure were damaged (Fig. 1). Surprisingly, the quake also produced surface rupture (Fig. 1), which has now been traced for more than 3 km by PBR Project staff and collaborators from the North Carolina Geological Survey, North Carolina State University, and University of North Carolina–Chapel Hill. Detailed mapping through the PBR Project in the epicentral area to support earthquake hazards studies will consist of both detailed (1:24,000) surficial and bedrock mapping, with supporting geochronologic studies (the fourth component of the 4-D framework). To assist in geologic mapping, the USGS through Core Science Systems, NCGMP and NGTOC is funding new LiDAR acquisition in the ~100 sq. mi epicentral area; these new data will be compared with existing LiDAR datasets to accurately map the surface rupture and deformation. Additionally, the USGS Florence Bascom Geoscience Center contracted 7.98-cm (3.14 in.) resolution georectified vertical aerial imagery (with greater than 60% stereo overlap) over the epicentral area (38.7sq. km) and low-oblique aerial imagery focused on a smaller area (~5 sq. km) along the trend of the rupture to help map the rupture (Fig. 1) and assess structural/infrastructure damage. Collectively, the multiple datasets being acquired and applied through a collaborative effort with State and University partners represent a significant opportunity to learn about the regional geology, structural controls of the Sparta earthquake and their broader relations to eastern intraplate seismicity and neotectonics.

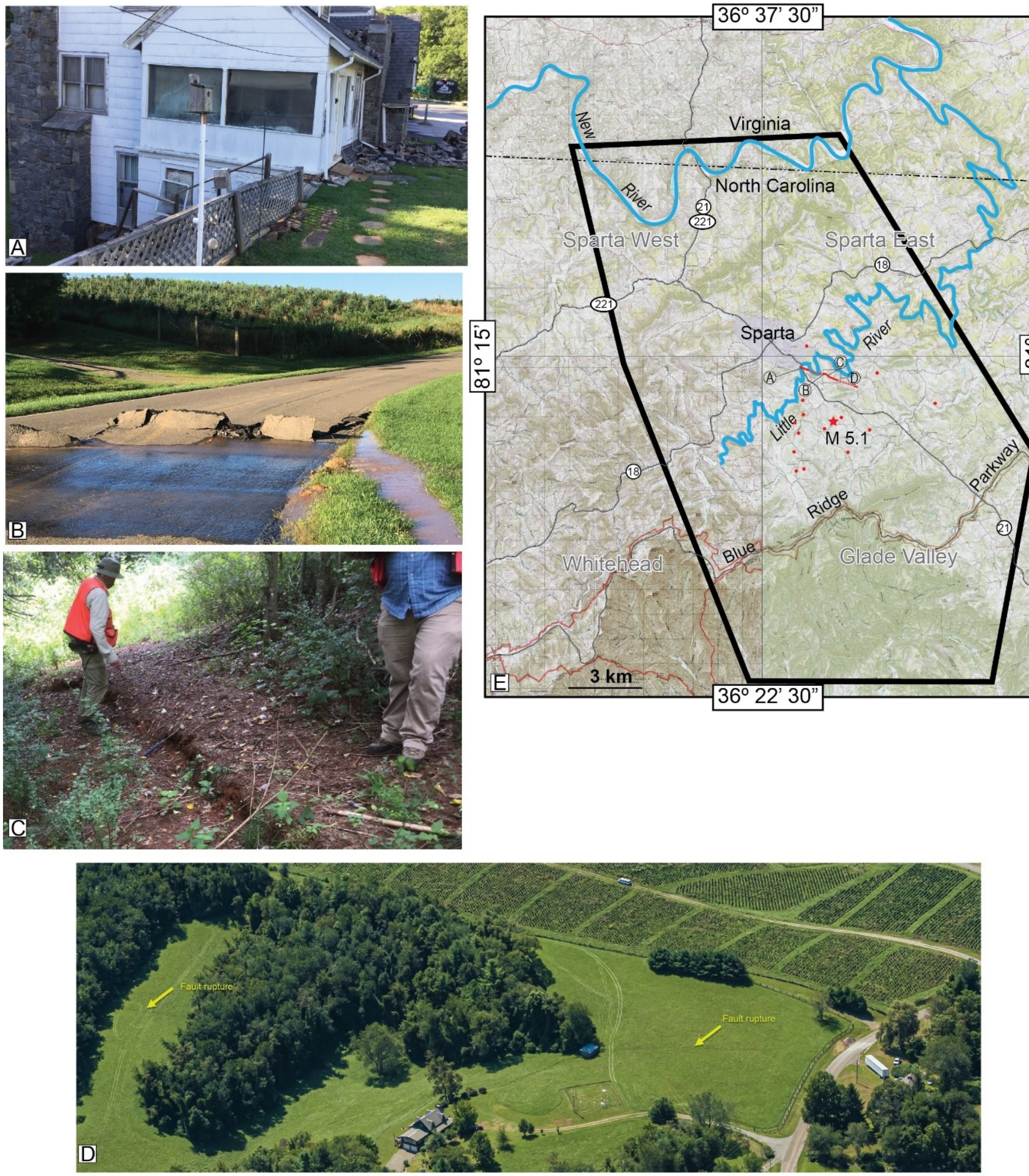

Figure 1. Photographs and maps of damage and deformation from the M 5.1 Sparta, NC earthquake. (A) House condemed after two chimneys collapsed and the house shifted off its foundation during the earthquake. (B) Rupture at Rivers Edge Road produced chevron-shaped folds in the asphalt and broke a Town of Sparta water line. (C) 10-20 cm extensional scarp on the downslope, northeast side of the Little River fault. (D) High-oblique image of Rivers Edge Road, Sparta, NC, (view towards south), acquired on September 7, 2020, 1:600 scale, ~3 in. (7.98 cm) pixel resolution. The surface rupture is marked with yellow arrows. Imagery courtesy of the US Geological Survey (acquired by DC Aerial Photos Inc.), Reston VA, 2020. (E) Simplified map of the Sparta West, Sparta East, Whitehead and Glade Valley 7.5-minute quadrangles including the meizoseismal area of the M 5.1 Sparta earthquake (red star), foreshocks and aftershocks > M 2.0 (red circles), mapped extent of the Little River fault (red line), and area of post-earthquake acquisition of LiDAR (black box). Locations of pictures (A-D) are shown. Sparta East and Sparta West are proposed FY2021 mapping area.

FROM POLLUTION POTENTIAL TO GROUNDWATER VULNERABILITY MAPPING: CHANGES BENEATH THE SURFACE

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The Ohio Department of Natural Resources (ODNR) began county-by-county mapping of groundwater "pollution potential" using the DRASTIC system in the mid-1980s (Weatherington-Rice et al. 2006). Originally developed by the National Ground Water Association (NGWA) with funding from the U.S. Environmental Protection Agency (EPA), DRASTIC evaluates an area using seven key parameters: Depth to Water, Recharge, Aquifer Media, Soil Media, Topography/Slope, Impact of Vadose Zone Media, and Hydraulic Conductivity (Aller et al. 1987). It then weighs and sums these parameters to produce a pollution potential index indicating the area's overall vulnerability to groundwater contamination. Because it is straightforward and standardized, DRASTIC has been widely used and is regarded as a useful tool for evaluating general groundwater vulnerability (Jang et al. 2017). It is not, however, always reliable at predicting the behavior of specific contaminants or capturing the complicated nature of stacked and/or heterogenous aquifers. Nevertheless, modifications to DRASTIC methodology have been shown to significantly improve its predictive capability (Holden et al. 1992; Akhavan et al. 2011; McLay et al. 2001).

Under the ODNR Division of Water Resources Ground Water Pollution Potential Mapping Program (GWPP), the State of Ohio published its first DRASTIC map, *Ground Water Pollution Potential of Madison County, Ohio*, in 1987 (Hallfrisch and Voytek 1987). Methodology improved over the subsequent decade as mappers incorporated new research and, by 1995, ODNR had modified its DRASTIC methodology to account for fractured glacial deposits, till as a distinct vadose zone media, the impact of till weathering, and double-block porosity (Weatherington-Rice et al. 2000; Angle 1994; Angle 1995; Williams 1991). Earlier maps were not always revised to match the new methods. At present, 77 of 88 county pollution potential maps are published for Ohio. Their regulatory use is extensive. The Ohio Environmental Protection Agency (OEPA)'s Source Water Assessment and Protection Program uses them as a primary data source in the "Resource Characterization" phase of its assessments and delineations (OEPA 1999; OEPA 2014). Environmental consultants, local governments, and federal agencies have used them in their natural resource plans and site assessments (EMH&T 2017; ILGARD 2005; McKenna Associates Inc. 2007; USACE 2000). The recharge and hydraulic conductivity components of DRASTIC-based maps are also of great application in groundwater modeling and hydrogeologic site assessment.

In 2018, the ODNR Division of Geological Survey (Division), with grant funding from the Ohio Water Development Authority, initiated a 3-year project to create from the previously published Ground Water Pollution Potential maps, a statewide, seamless groundwater vulnerability map using a highly modified DRASTIC model. The project's primary objectives were to 1) complete the 11 unfinished counties, 2) establish a standardized, statewide groundwater vulnerability rating system, and 3) revise and update the 77 previously completed maps according to the new system. By standardizing hydrogeologic settings, correcting county boundary errors, and modernizing mapping methods, the Division will produce a seamless groundwater vulnerability coverage that can be used reliably for permitting, siting, and planning purposes across the state. As a secondary objective, the Division will generate several derivative products, including statewide recharge and hydraulic conductivity maps.

Since 2018, the Ohio Geological Survey has made extensive modifications to DRASTIC and the "pollution potential" methodology. Hydrogeologic settings have been removed, modified, added, or expanded; soil classifications standardized; aquifer media classifications and ratings standardized by geologic unit, conductivity range, and well yield; vadose zone media standardized by thickness and material; and recharge and depth to water parameters modified to consider more complicated flow regimes. In addition to improving the accuracy of the vulnerability ratings throughout the state, specific modifications to DRASTIC have been used to more accurately characterize two groundwater systems that exist in Ohio but were not considered when DRASTIC was first implemented. For example, karstic groundwater systems have special hydrogeological characteristics that are not easily captured by the original DRASTIC model. The interconnectivity between the surface and the aquifer and seasonal variability of the depth to water require special consideration when parameters are defined in Karst regions. Vulnerability values in areas of flowing wells are overestimated when not assessed as a confined aquifer by an unmodified DRASTIC model. To more accurately evaluate the vulnerability in areas of flowing wells, an additional depth to water value named "flowing" has been added to the modified DRASTIC model to reflect the upward hydrologic gradient in areas of flowing wells. This "flowing" value reduces the impact of the depth to water value on the vulnerability rating.

The statewide, seamless groundwater vulnerability map will be published in 2021 as both 1:500,000-scale maps of vulnerability index and hydrogeologic setting, and as GIS shape files with metadata. Improvements made to the DRASTIC model used in Ohio and the normalization of the parameters across the state will improve the accuracy of the groundwater vulnerability ratings in the new statewide map.

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TRACKING MINERAL EXPLORATION WITH THE MINNESOTA DNR'S CONSOLIDATED MINERALS DATABASE PROJECT

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Minnesota Department of Natural Resources, Division of Lands and Minerals (DNR) is home to decades of document and data collections containing diverse mineral exploration information. Physical collections include resource and exploration maps, geophysical surveys, lab results, drill logs, and reports. With over 12 million acres of mineral estate and hundreds of active mineral leases, these data continue to be submitted to the DNR. To manage these collections, DNR is in the process of developing a data preservation and content management system to curate, digitize, and publish these public records for access to all users.

The Consolidated Minerals Database (CMD) project has created an application that allows staff to record detailed geologic, origination, lineage, and subject matter attributes for each document in the historic collections, as well as with new annual submissions that accompany terminated mineral leases. The application further facilitates value-added content creation including finding aid documents and geospatial products.

In its next stage, the CMD project will develop public interfaces and content delivery modules. Oriented toward and built by geologists, the CMD product will deliver original source documents with attribution and context that provide confidence and efficiency to experts, and high accessibility to broader public users. The project will provide explorers and scientists a tool for discovery of data from historical and contemporary exploration projects. Benefits to the state include supporting informed state land management decisions and new opportunities for research and mineral exploration.

NATIONAL SURVEY OF ENGINEERING GEOLOGY MAP SYMBOLOGY AND DATA REPOSITORIES

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In support of the US GeoFramework Initiative, the Illinois State Geological Survey has been tasked by the United States Geological Survey to (a) characterize existing standards and guidelines used by individual states related to the visualization and dissemination of engineering geology, geotechnical, and land use data for map products and, (b) inventory available engineering properties databases. The USGS recognizes the need for standardization and, in some cases, education to provide the American populace, government, and businesses with engineering data that is crucial for safe and resilient infrastructure development and to maintain environmental standards. The broad goals of the project are to assess the use or non-use of this valuable primary data for geologic and derivative map projects, and to establish standardized terminology, map symbology, and best practices for the representation, dissemination (data exchange formats), and storage (database formats) of engineering geology and geotechnical data. Gathering this formative data will enable future extension of the USGS GeMS structure to these data types. We will query by on-line survey the practices and repositories at geological surveys, state departments of transportation, federal geologic, geotechnical, and transportation agencies, and industry groups across the nation. Survey construction is informed by the experiences of Arrington et al. (2020) in their recent survey of the capabilities of state Surveys to implement GeMS.

We are aware of a wide range in availability, accessibility, and use of engineering data in mapping across the Nation. At ISGS, geotechnical data compiled from local- to state Departments of Transportation, sewerage districts, utilities, and consultants are vital to our surficial geologic mapping activities. Our wells and borings database, ILWATER (https://isgs.illinois.edu/ilwater), provides a public view of about 228,000 geotechnical borings that were compiled over decades and digitized from the original paper or pdf records, as well as from common digital geotechnical data exchange formats. The records were largely provided to ISGS upon our request as opposed to any programmatic exchange with industry drillers, consultants, and government agencies. The data include descriptive boring logs and, when available, strength parameters, water content, and standard penetration test (SPT) blow count data. The ISGS is currently developing a new database specific to engineering geology and geotechnical data. The database will accommodate ingestion of modern digital geotechnical data exchange formats and support new geotechnical datasets such as those collected by our cone penetration test with hydraulic profiling tool (CPT-HPT) soundings.

The database is hardly complete: many records in areas where we are not actively mapping are still to be digitalized or have not been added to in decades. A significant initial task in any mapping project is to manual geospatial verification of the well or boring locations (early entries were often located in our database only to the nearest quarter-quarter-quarter but can be located to within a few feet even from paper records), and estimate absolute elevations for those records that were based on local datums. Once quality-assured, the data provide much more detail (color and standardized textures as well as geotechnical parameters) and more consistent subsurface information than do water well records, although water wells are more numerous and extend deeper. Differentiating till (strength >3 tsf; moisture content typically <15%) from lake sediment (strength <2 tsf; moisture content typically >20%), for example, can be straightforward although local correlations must be determined. We have begun work with consulting companies in Chicagoland to develop a more active and current data exchange, with compiled data to be made available through an ISGS server.

Engineering geology maps provide significant value to the public and help inform decisions of land use planning and identification of geohazards. Engineering geology maps include slope stability hazards, subsidence hazards, excavatability, foundation conditions, collapsible soils hazard, liquefaction hazards, and many others. Examples of engineering geology maps that we will present include 1) An early STATEMAP-derivative slope stability map of a degrading watershed east of St. Louis; (2) A regional database of past landslides along the Illinois, Mississippi, and Ohio-Wabash river valleys; 3) A compilation of STATEMAP data in Metro-East St. Louis was developed into a liquefaction susceptibility map for the USGS CUSEC program (Cramer et al. 2017).

Our survey of engineering map standards will have two stages: The first-stage survey will be an email sent to agency directors, who may answer the questionnaire as they see fit or may identify the people in their organization best suited to address the survey. The survey will be short with yes/no and multiple-choice responses. The objective will be to broadly characterize use of engineering data and map products by mapping agencies and identify the best contacts for the second-stage survey. Those who do not respond will be reached by telephone. The second-stage survey, using an interactive webform that we are developing, will comprise more detailed questions on maps and map standards, as well as on the source data: the existence of repositories, locational data accuracy, geographic coverage, data exchange formats, and database structures. The surveys will be supplemented by our own on-line and library investigations, and by direct communications with practitioners and agencies. The compiled information will be analyzed to develop guidance for best practices for storage of engineering properties data in relational databases or geodatabases, and their associated benefits for development and storage of map products.

We encourage you to respond to the surveys when they arrive at your virtual doorstep.

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No abstract.

TRANSFORMING GEOSCIENCE RESEARCH THROUGH DIGITAL–NATIVE APPROACHES TO DATA CAPTURE, INTEGRATION, AND DISPLAY

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For centuries, innovations in print media have underpinned the creation and dissemination of geoscienceresearch. Graphical formats such as geologic maps, cross-sections, and stratigraphic columns have evolved to encapsulate new geological concepts and fully utilize techniques such as offset printing, standard symbology, andpatterns to maximize the information content of research results.

Computers and networked systems significantly broaden the range of “media” available for data archival and display. While data storage formats can still be tightly coupled to the representation of information (e.g., PDFs for papers and maps), the innate separation between data storage and display in computer systems allows considerable evolution beyond print-centric paradigms for conveying information. At the Macrostrat lab, we are building many tools that harness fast-emerging strengths of digital media to capture, connect, and convey geological information.

Aggregation and discovery. The Macrostrat data system stores stratigraphic column data for thousands oflocales within a common framework, and Macrostrat’s map interface aligns hundreds of geologic maps together into atopologically and semantically harmonized product. Digital aggregation allows coordinated data analysis (e.g., an internally consistent age model across heterogeneous stratigraphic data). Well-built data systems significantly streamline information retrieval at scale: our flagship example is *xDD* (formerly *GeoDeepDive*), built in collaboration with computer scientists. This system supports direct text search, computer-vision, and natural-language machine learning against over 13 million scientific articles.

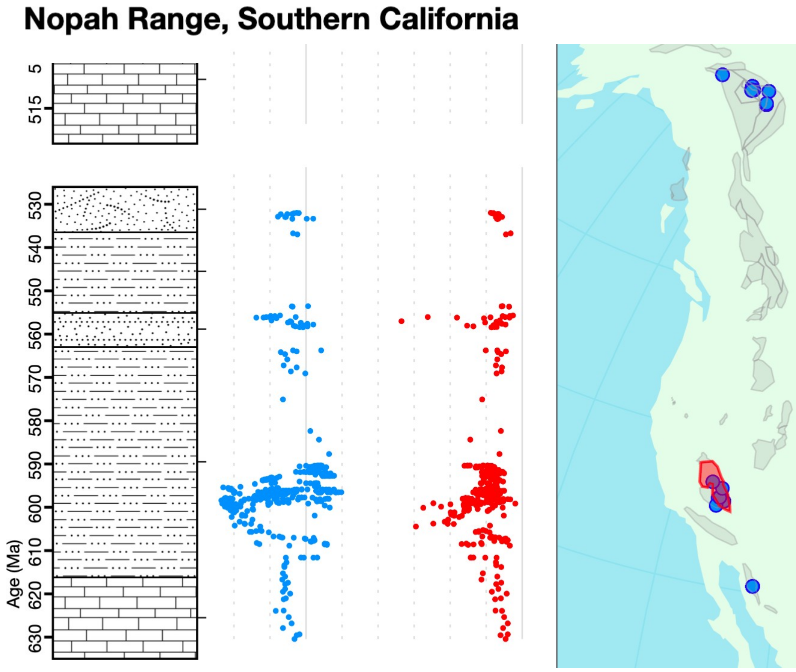
Integration. Digital media offers new opportunities to overlay heterogeneous data. Increasingly sophisticated data systems allow Macrostrat to build integrations between stratigraphy and paleogeographic, paleoenvironmental, ocean-drilling, and geochronology archives. The community-wide push to unify mapping and subsurface data into 3D structural models is another example of the new capabilities available with digital informationdisplays.

Visualization. New digital techniques, layered atop strong data system foundations, enable important evolutions in visualization and communication. Macrostrat, like other modern mapping systems, is scale-independentand supports high-fidelity visualizations such as satellite overlays and 3D terrain.

Software-driven visualizations that are decoupled from underlying datasets can be adapted for different enduses: Our common rendering components for stratigraphic columns simultaneously support regional stratigraphy, ocean-drilling cores, and measured sections of rock outcrop (Figure 1). We have repurposed Macrostrat’s experimental 3D geologic map renderer (Figure 2) to showcase Jezero Crater, the landing site of the Mars 2020 Perseverance rover. The adaptive capabilities of digital media can be used to modify visualizations depending on audience (e.g., focused displays for technical workers alongside general-purpose displays for the public). This potentially has huge implications for public outreach and science communication.

Capture. Recently, geologic data capture has been moving towards digital methods, in part due to the increasing power of mobile computing devices. Macrostrat’s Rockd app provides context from existing databases andliterature archives to assist with capture of outcrop geologic data (Figure 3). The Mapboard GIS app (in beta) allows users to draw mapping data in a familiar manner while capturing the results in a scale-independent, topologically- enabled GIS database. These novel approaches harness the power of digital data systems to augment geologists’ data-collection capabilities, much as other techniques have expanded capabilities for modeling and visualizing geologic information.

Developing new techniques to fully utilize the capabilities of digital media is a long-term task with many technical hurdles to overcome (e.g. timescale synchronization, automated map labeling). These approaches are being worked on in the private sector, government, and academia, but transformative work can require coordinated expertise in both software and geoscience. Luckily, bringing datasets together in common, addressable formats prepares them for use in all types of next-generation data displays. The hard work of curating and systematizing dataand conducting new field studies remains of vital importance and takes on added value when coupled with next- generation digital media techniques.



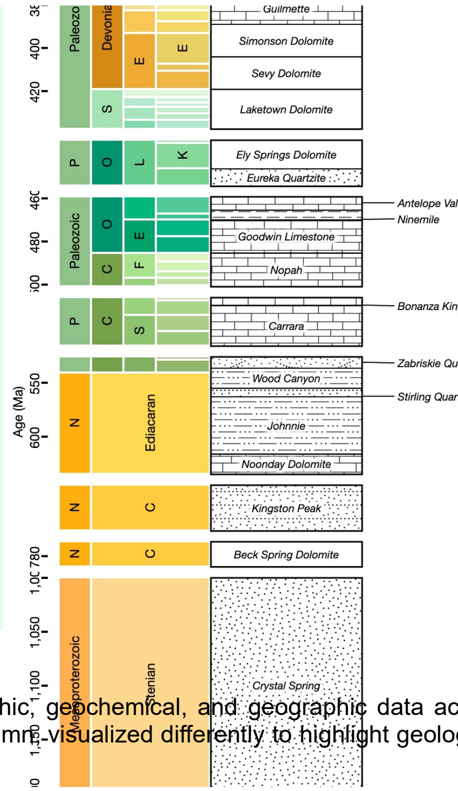
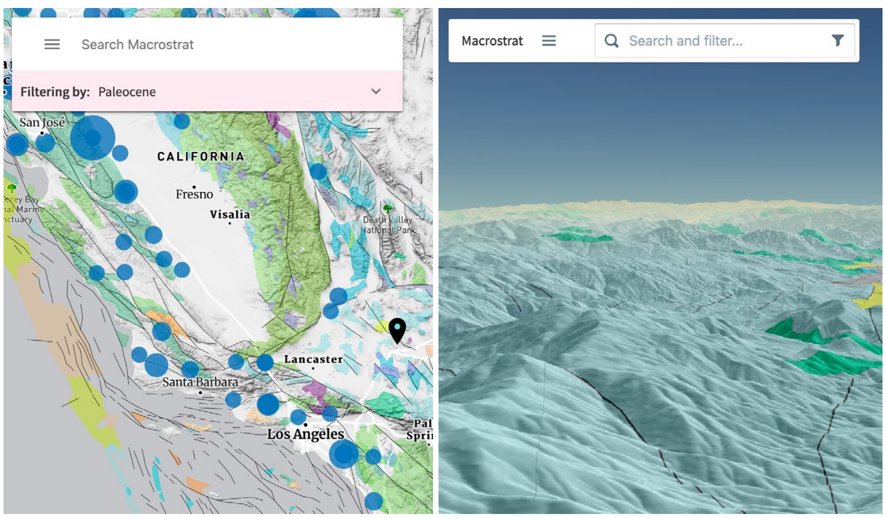


Figure 1. *(above)* Digital media techniques for display of coupled stratigraphic, geochemical, and geographic data across large datasets(focused on the Ediacaran in North America). *(right)* Same column visualized differently to highlight geological timescale and unit names.



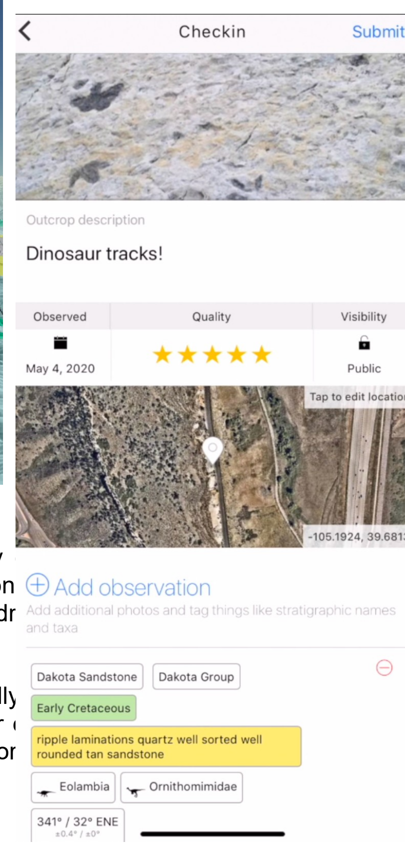


Figure 2. *(above)* Innovations in display of geologic mapping data enabled by ... l: a regional view of our geologic map filtered by units with some Paleocene compon ... rom the PBDB. Second panel: same geologic mapping dataset in close-up view, dr ... ving interface.

Figure 3. *(right)* The Rockd app check-in interface, which allows users to rapidly ... and other contextual information forwarded by Macrostrat, the PaleobioDB, and other ... the potential of digital media techniques to drive new ways of capturing geological infor

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STATUS OF THE USGS STATE GEOLOGIC MAP COMPILATION AND THE NORTHERN ROCKY MOUNTAINS TRANSECT

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The U.S. Geological Survey (USGS) Mineral Resources Program (MRP) sponsored a project from 1997 – 2007 to convert State geologic maps to digital GIS data. A lithologic classification scheme to facilitate querying the data at a national scale was developed by the MRP and applied to the 48 datasets comprising the conterminous U.S. These data sets were appended, updated, and republished as the State Geologic Map Compilation (SGMC) 2012 - 2017. Reconciliation of differences in scale, description of map units, and fault and contact traces between States was beyond the scope of either effort.

Consistent and extensive usage of the SGMC prompted the National Geologic Map Database Phase 3 to sponsor a third effort to update the SGMC to the Geologic Map Schema (GeMS) in 2020. Because discontinuities in linework and map unit descriptions across State map boundaries remained, a pilot project was concurrently launched to explore integration methods for geologic maps. The Northern Rocky Mountains Transect (NRMT) pilot project will integrate 1:250,000-scale USGS geologic maps in northern Idaho and Montana to start. The NMRT will use the new Seamless Integrated Geologic Map (SIGMa) extension to GeMS for its database structure, and will incorporate legacy and modern geologic maps, geochemistry, geochronology, borehole, and Lidar data where possible. Data and workflows from both efforts will inform and aid the mission of the National Geologic Synthesis project, which aims to construct a seamless, integrated, 2D geoframework of the Nation by 2030.

THE USGS NATIONAL GEOLOGIC SYNTHESIS: NEXT-GENERATION GEOLOGIC MAP FOR THE NATION

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In 1882, 3 years after the formation of the U.S. Geological Survey, it was directed by Congress "to complete a geological map of the United States". This assigned USGS the responsibility to prepare and maintain a national geologic map. The first such map published by USGS was included in the “Fifth Annual Report of the Survey” in 1885, and USGS has continued to embrace and address this mandate ever since. The most recent, and still widely used, national geologic map published by USGS was compiled by Philip B. King and Helen M. Beikman and published in 1974. Advances in the science of geology, the technology of map production, and availability of new or updated geologic mapping have necessitated updating the national geologic map at least every 40-50 years.

The National Geologic Synthesis (NGS) project is a new component of the National Geologic Map Database (NGMDB) Phase 3 Initiative, with a mission to construct a modern, seamless, integrated, queryable representation of the surface (2D) and subsurface (3D) geology of the Nation, coupled with a robust database of stratigraphic and lithologic information, by 2030. To accomplish this, the best new and existing geologic data will be compiled from multiple sources, synthesized into a seamless and internally consistent digital geospatial data product, and served in standardized formats that can be visualized and used in ways defined by the users’ needs.

For the initial NGS product, we plan to compile 2D geologic mapping at an intermediate level of detail approximately equivalent to what is displayed on conventional geologic maps at scales of approximately 1:100,000 to 1:250,000. Subsurface geologic data, which typically lends itself better to gridded data formats, is being compiled with an initial grid cell resolution of 10 km, with a goal to generate surfaces with 1 km or smaller cell sizes in the future. An inventory of published subsurface geologic models and data is being compiled for incorporation into the NGMDB catalog. We will also explore avenues for integrating data from disparate and currently incompatible subsurface geologic modeling applications into a national framework.

The primary creators of new geologic maps and data in the United States are the USGS National Cooperative Geologic Mapping Program and state geological surveys, but geologic maps and subsurface geologic models are also created by other programs in USGS, other federal agencies, and universities. Therefore, an important role of the NGS project is coordination and collaboration with partners. Partnerships and collaborations will also be important for reviewing map sections, for resolving stratigraphic and other types of map discontinuities, and for developing and testing data viewing and analysis tools. By “crowdsourcing” the best available geologic mapping across the country, we plan to build a modern, seamless, national geologic database that will be continuously updated as new mapping becomes available.

NATIONAL GEOLOGIC MAP DATABASE

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From its mandate in the Geologic Mapping Act of 1992, the U.S. Geological Survey (USGS) and the Association of American State Geologists (representing the State geological surveys) have worked together to build the National Geologic Map Database (NGMDB, http://ngmdb.usgs.gov/). The NGMDB is stipulated to be a standardized, "national archive" of geoscience information (maps and reports, both published and unpublished), made available to the public to support decisionmaking, research, and other needs. The website for this resource launched in 1996. Each month, it serves more than 85,000 users, who visit the site roughly a quarter-million times.

To support scientists, decisionmakers, and the general public, the NGMDB provides numerous resources including: the U.S. Geologic Names Lexicon (Geolex); the Geoscience Map Catalog; standards and guidelines for compilation and production of geologic maps and databases; and an interactive viewer and downloader for topographic maps (topoView). The NGMDB also is developing new capabilities including a certified Trusted Digital Repository that will manage all geologic map databases published in the new standard schema known as “GeMS” (Geologic Map Schema), a revised back-end database for managing all NGMDB citation content, and two map-based interfaces for browsing and using the publications available through the NGMDB’s Catalog.

USING AIRBORNE GEOPHYSICS TO MAP POORLY EXPOSED ROCKS IN THE CENTRAL VIRGINIA SEISMIC ZONE

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The Mw5.8 Mineral Virginia Earthquake of August 2011 was Virginia's largest earthquake in historical times and the largest earthquake to affect the eastern U.S. in over 70 years. It was felt from Montreal to Florida to Chicago and caused nearly $300 million in damage, including millions of dollars of damage to Washington DC's National Cathedral and Washington Monument. Hundreds of aftershocks were recorded in the following months. The earthquake occurred in the Central Virginia Seismic Zone, a diffuse cluster of historic epicenters that spans the entire width of the Appalachian Piedmont and multiple tectonic terranes. At the time of the earthquake, the most detailed geologic map of the epicentral area was a 1:100,000-scale map produced by the Division of Geology and Mineral Resources (DGMR), Virginia's geological survey. Incomplete or unpublished mapping was available in adjacent 7.5-minute quadrangles to the west and southwest. Existing mapping was adequate to locate the epicenter within the Chopawamsic terrane, an Ordovician-Silurian volcanic-plutonic arc unconformably overlain by sedimentary successor basins preserved in synclines. Although the terrane was bounded by major faults, the earthquake and its aftershocks did not appear to be associated with those faults. Additional mapping was needed to fully characterize the geologic setting of the earthquake.

Because the epicenter was in the Richmond Metropolitan Statistical Area, one component of DGMR's long-range mapping plan, the area was eligible for a STATEMAP-funded mapping project. The U.S. Geological Survey (USGS) assigned FEDMAP resources as part of the federal science response to the earthquake, and cooperative state-federal geologic mapping commenced within months. The USGS also commissioned a high-resolution airborne radiometric, magnetic, and gravity survey covering approximately 650 square kilometers with 200 meter line spacing and nominal height above ground of 125 meters. NW-SE-oriented flight lines were chosen because they were perpendicular to the strike of regional structures; the footprint of the survey was carefully selected to cover aftershock clusters. Acquisition was complete by the one-year anniversary of the earthquake. The survey covered portions of eight quadrangles that were the subject of collaborative STATEMAP and FEDMAP efforts.

The processed geophysical dataset was delivered in time to contribute to the geologic mapping effort. Previous mapping in adjacent quadrangles and post-earthquake mapping already underway, along with magnetic susceptibility measurements of bedrock outcrops, enabled rapid correlation of geophysical signatures with map units. Magnetite-rich units such as greenstone, ferruginous quartzite, and diabase displayed high magnetic susceptibility. Magnetite-poor units such as granite, metarhyolite, and amphibolite displayed low susceptibility. The K channel of the radiometric dataset responded to potassium-rich units such as pegmatite and granitic gneiss; the Th and U channels showed a distinct response to mica schist and mylonitic biotite gneiss. Using these aeromagnetic and aeroradiometric datasets in tandem facilitated field mapping, starting with prioritization of field traverses. Field checking an extremely bright radiometric feature resulted in identification of a syenite intrusion, an entirely new map unit. Structural details of a complex synclinorium readily apparent in the radiometric dataset were later confirmed by field mapping. The final products were traditional 7.5-minute geologic quadrangle maps, but ones that were informed by high-resolution airborne geophysics. The availability of geophysical datasets accelerated the mapping effort and resulted in better quality geologic maps.

3D GEOLOGIC MAPPING AS A TOOL TO ASSESS ARSENIC RISK IN GROUNDWATER WELLS, EASTERN WISCONSIN

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The Wisconsin Geological and Natural History Survey uses geological mapping to address both fundamental and applied research questions. In some counties in eastern Wisconsin, including Fond du Lac county (population 102,000) and Dodge County (population 89,000), mapping is being used to model and predict detection of low to moderate levels (2-50 µg/L) of arsenic in drinking water wells. In these counties, approximately 49% of wells queried in the Wisconsin Department of Natural Resources (WDNR) online database recorded As values above 2 µg/L. We demonstrate the application of bedrock geologic mapping to assessment of the probability of arsenic detection in large numbers of untested groundwater wells at both the regional and local scale.

1:100,000 scale bedrock mapping in Dodge and Fond du Lac counties provided a framework for modeling arsenic risk. These counties are underlain by glacial sediments, Precambrian Quartzite, and Cambrian through Silurian siliciclastics and carbonates (Figure 1). Within bedrock units, arsenic is hosted by both sulfides and Fe-(hydr)oxides. Regionally, all Paleozoic units dip gently east into the Michigan Basin. Geologic mapping (Batten, 2018; Stewart, in press) and the construction of 3D rasters of bedrock surfaces delineated subtle (100-200 feet) bedrock folds that overprint the regional dip (Figure 1). Increased fracturing associated with the overprinting folds may be important as a mechanism to oxidize sulfide-bearing siliciclastic and carbonate rocks, thereby locally changing the dominant mineral host for arsenic from sulfide to Fe-(hydr)oxide. Systematic changes in arsenic host may drive systematic changes in the probability of arsenic release within the well borehole. Hydraulic conductivity (K) estimates for the middle Ordovician St. Peter sandstone from Dodge County, calculated from water well construction reports using specific capacity tests (Bradbury and Rothschild, 1986), seem to support this hypothesis, showing that elevated K values generally occur within 2 km of mapped folds (Figure 2).

Potential explanatory variables for arsenic detection were tested for statistical significance with a step-wise multivariate binary logistic regression. Statistical significance for each variable was assessed using calculated p-values. A p-value <0.05 was considered significant. Variables included the distance between the nearest mapped fold and groundwater wells analyzed in the WDNR database for arsenic, geologic units the wells draw water from, as well as various well construction parameters. Values at or above 2 µg/L were considered positive results.

Logistic regression identified 2 statistically significant variables in the western portion of Fond du Lac and Dodge counties, but did not yield significant results in the east. In the west, where Precambrian through middle Ordovician strata occur at the bedrock surface (Figure 1), the distance to nearest mapped structure, and casing depth-depth to bedrock were determined to be significant variables. Both are likely related to the development of an oxidation front below the bedrock surface. In the east, where upper Ordovician shale and Silurian dolomite occur at the bedrock surface (Figure 1), the approach was unsuccessful, yielding no statistically significant variables. In the west, the calculated coefficients to the variables (Figure 1) can be used to estimate the probability of detecting arsenic for every well in the area with a known location, depth to bedrock, and well casing depth. Because these variables are known for thousands of wells, this approach has the potential to provide individualized arsenic risk assessment for thousands of private wells in the area, and/or to generate risk assessment maps. It also provides guidance on reducing risk in future well construction.

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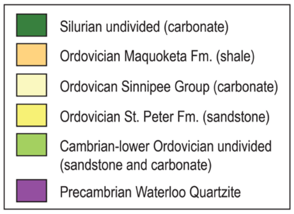

Western Domain Multivariate Solutions (2 ug/L cutoff)

Variable	Coefficient	p-value	Odds Ratio
b_0 Intercept	1.366	N/A	N/A
b_1 Distance to mapped folds	-0.4239	<0.0001	0.6545
b_2 Casing depth-depth to bedrock	-0.005	0.0015	0.995

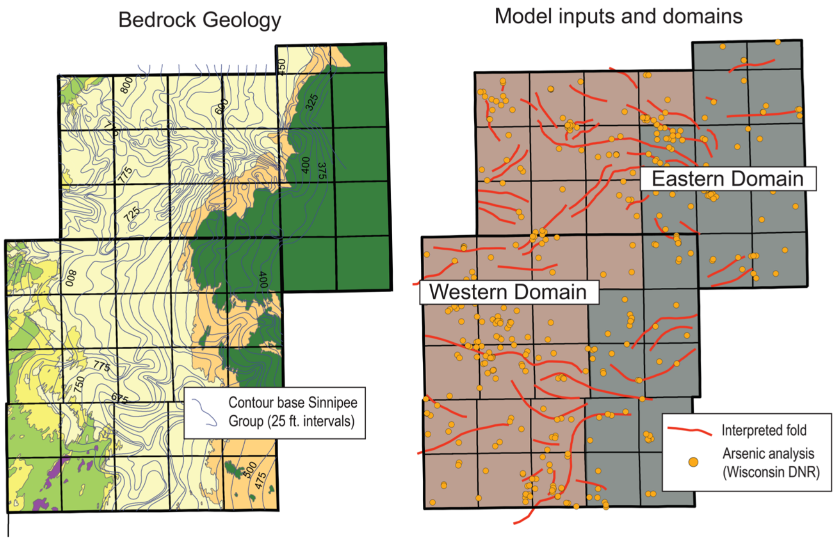

Figure 1 – Bedrock geology (left) and model domains, interpreted folds, and arsenic sampling sites (right).

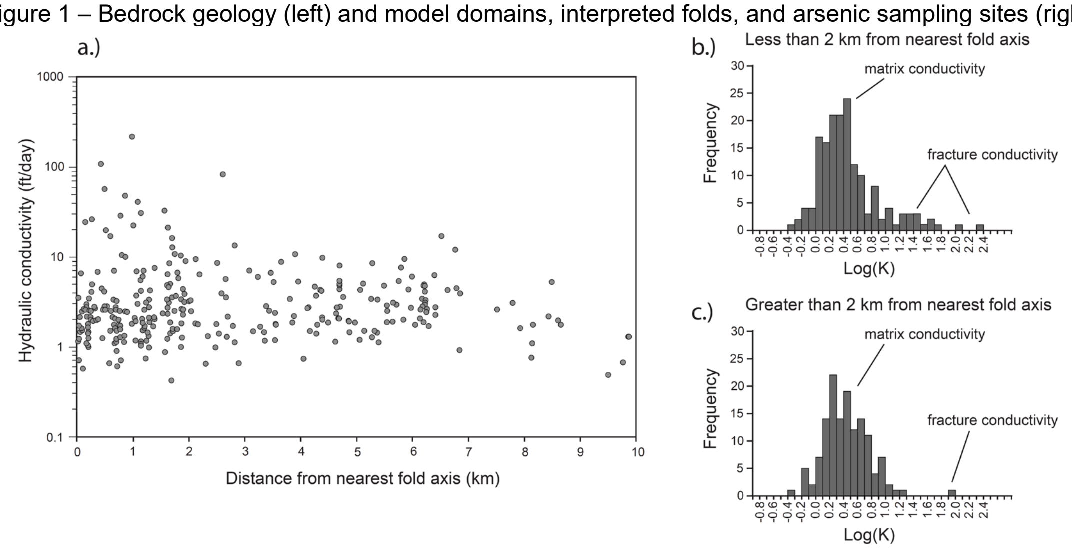

Figure 2 – a.) Hydraulic conductivity (K) calculated from well construction reports from Dodge County, Wisconsin drawing water exclusively from the St. Peter sandstone. 9.1% of wells within 2 km of folds have values exceeding 15 feet/day, compared to 1.5% of wells greater than 2 km from the nearest fold. b.) Histogram of log(hydraulic conductivity) within 2 km of the nearest mapped fold. In an unfractured medium, matrix conductivity generally resembles a bell-shaped curve. Here, the elongate tail at higher values is interpreted to result from elevated fracturing related to the map scale folds. c.) Histogram of log(hydraulic conductivity) for wells greater than 2 km from the nearest mapped fold. Greater than 2 km from folds, the histogram, with minor exceptions, approaches a bell-shaped curve.

3D GEOLOGY AND PHASE THREE OF THE NATIONAL GEOLOGIC MAP DATABASE

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U.S. Geological Survey (USGS) science planning documents (Gunderson and others, 2011; Bristol and others, 2017) and decadal strategic plans for the USGS National Cooperative Mapping Program (NCGMP) call for geologic mapping across the Nation to become increasingly three-dimensional (3D) in nature—a plan that has been endorsed by the Association of American State Geologists (AASG, 2014; 2019). However, at the Federal level relatively little organized effort toward this goal has occurred. Recent increased funding and guidance to NCGMP described in House Report 116-100 direct the USGS and state partners to "launch Phase Three of the National Geologic Map Database (NGMDB Phase 3) that will bring together detailed, national, and continental-resolution 2D and 3D information produced throughout the Survey and by federal and state partners". This legislation should serve as an impetus for greater programmatic effort to compile, synthesize, and distribute 3D data at varying scales.

A necessary Federal role in implementing NGMDB Phase 3 is to develop and administer a digital infrastructure for the intake, curation, and dissemination of 3D geomodels and model-relevant subsurface data generated by the USGS, by state geological survey partners, and by other Federal programs. Similar to the development of the NGMDB for 2D geologic data (e.g., Soller and Berg, 2003), digital infrastructure for 3D data might take the form of two separate but related platforms: (1) a catalog and digital image library of published 3D models and 3D-related subsurface data, and (2) an online, vector-based digital database to store 3D geomodels or the subsurface geologic data that serve as input to such models.

The inventory and catalog activities are a natural extension of the current capabilities of the NGMDB which could be extended to incorporate 3D data in a straightforward manner. Numerous items in the existing map catalog are of value (for example, structure contour maps created as parts of geologic maps or for regional stratigraphic or aquifer studies) and simply need to be tagged appropriately to be discoverable. The cataloging activity establishes a durable link to peer-reviewed, authored, published reports that are foundational to the compilation and synthesis of 3D datasets and the creation of 3D geomodels. Inventory and cataloging also are the basis for status maps so that the 3D geomodeling community in the US has a searchable record of existing models and where data exist for the creation of new models.

For regional- to National-scale 3D mapping, it is useful to subdivide geomaterials into three broad categories: (1) unconsolidated to poorly-consolidated sediments, where definition of stratigraphy is typically difficult and units may be defined primarily on the basis of lithology and physical properties rather than by age and stratigraphic names; (2) layered consolidated rocks, both sedimentary and volcanic, where tops are defined as stratigraphic units with age formation name assigned; and (3) basement, consisting of crystalline or complexly deformed rocks that cannot be easily subdivided and modeled. It is anticipated that a national 3D map might proceed with mapping key layers and become progressively more complex, first by adding layers and then progressively incorporating properties, heterogeneity, and uncertainty. Two layers that might be a sensible starting point for 3D mapping at the national or continental level would be (1) top of crystalline or highly deformed rocks ("basement") and (2) top of consolidated rocks ("bedrock"), which also defines thickness of unconsolidated deposits.

National-scale 3D mapping requires a method of storing, compiling, and serving 3D data that is updateable, scalable, non-propriety, and has a flexible data structure. Like the GeMS data schema for 2D geologic map data (*https://ngmdb.usgs.gov/Info/standards/GeMS/*), feature-level metadata should ideally be attached to each feature, allowing for attribution of data type, spatial uncertainty, and maintaining linkage to original published sources and authors. Serving 3D models directly is problematic: 3D models in their native format do not allow open access or manipulation of geomodel data by users; serving 3D model data as XYZ point clouds creates large files and does not allow for tagging of each node with multiple attributes. One potential solution is to use a 2.5D approach where surface or layer information is stored and served as a fishnet of polygons that emulate a raster layer in appearance, but where each cell (or cell centroid) has a set of map coordinates and a unique set of descriptive attributes. This method is an extension of an approach for representing three-dimensional map information as raster-based stacked surfaces (Soller and Berg, 2003). Locally refined grids can be sampled to update any part of the National-scale polygon network and all or part of the polygon array could be exported as a raster layer using standard GIS tools. Multiple fishnet polygon arrays could be maintained to capture detailed, national, and continental resolution; the different arrays could be made consistent by downsampling the most detailed array using spatial geostatistical tools. Maintaining subsurface data in vector form allows for rapid updating of depth, thickness, and unit characteristics attributes and ready export as raster datasets. An alternative vector-based approach would convey 3D geology as a dense network of virtual, vertical drillholes, which present a predicted stratigraphy for each point in a regular grid. Each stratigraphic top could be linked to a rich set of attributes, including properties of the underlying interval.

An example of the 2.5D approach using polygonal arrays will be discussed using the top of crystalline basement surface (Domrois, 2013; Marshack and others, 2017) where the surface is attributed and updated with more detailed framework data from in-progress 3D geomodels of the Colorado Plateau. The example will show how this data format could allow for dynamic, updatable data structure that, at least for geologic surfaces or layers, could be flexible in terms of input data format required for updating, since the polygons/centroids just sample a surface. In the future, it is envisioned that such a data structure could lead to the production of rasters-on-demand for user-defined areas.

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THE IDENTIFICATION OF MISSISSIPPIAN EOLIAN STRATA IN PENNSYLVANIA, WEST VIRGINIA, INDIANA, AND ILLINOIS

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The recognition of sands in the rock record as being of eolian origin has been hampered by numerous misconceptions in the geological literature. Some criteria for identifying eolian sands that have been considered but have subsequently been discarded as incorrect or unreliable include:
(1) sand grain surface textures, specifically the presence of "frosted" grains (proven incorrect by Kuenen and Perdok 1962; Magee et al. 1988);
(2) sand composition, specifically the presence of mica or feldspar (proven incorrect by Bagnold 1941);
(3) relative abundance of heavy minerals (proven unreliable by Shepard and Young 1961; Giles and Pilkey 1965; Flores and Shideler 1982);
(4) size of heavy minerals (proven unreliable by Stapor 1973; Slingerland 1977; Schuiling et al. 1985);
(5) size of cross-bedding (proven unreliable by Kocurek and Dott 1981); and
(6) grain-size distribution data, including bivariate plots of grain-size data using mean grain size, sorting, kurtosis, and skewness (proven unreliable by Solohub and Klovan 1970; Amaral and Pryor 1977; Tucker and Vacher 1980; Ehrlich 1983) – Although many eolian sands consist of moderately-sorted to well-sorted fine sand, bivariate plot field boundaries for depositional environments have proven to be subjective and not reliable, and poor sorting and coarser grain sizes are common for eolian sand in colder environments (Swezey et al., 2016).

In contrast, the correct identification of certain sedimentary structures has proven to be a reliable and robust method for identifying eolian sandstones (Hunter 1977, 1981; Kocurek and Dott 1981; Swezey 1998). Specific details of these eolian sedimentary structures include:
(1) <u>Grainfall strata</u> (grains in saltation transported beyond the dune brinkline to fall on the dune lee face): Grainfall occurs in both subaqueous and eolian settings, but is rarely preserved in subaqueous settings.
(2) <u>Grainflow strata</u> (former grainfall deposits that reach an "angle of initial yield" and avalanche down the lee slope to rest at an "angle of repose"): Subaqueous grainflow deposits are typically in contact with one another and extend from top to bottom of the slipface, whereas eolian grainflow deposits are commonly separated from one another by grainfall deposits that wedge out upwards.
(3) <u>Ripple Laminations</u>: Subaqueous ripple laminations are normally graded, whereas eolian ripple laminations are inversely graded. Also, eolian ripple laminations are typically thinner and of more uniform thickness than subaqueous ripple laminations.

Sedimentary structures that are diagnostic of eolian deposits are present in Mississippian (Chesterian) strata in both the Appalachian and Illinois Basin. In the Appalachian Basin, mixed siliciclastic-carbonate "redbed" strata of eolian origin are present in southwestern Pennsylvania (mapped as the Loyalhanna Member of the Mauch Chunk Formation; Ahlbrandt1995; Krezoski et al. 2005) and in northern West Virginia (mapped informally as the "Greenbrier Big Injun" sandstone). In these units, sedimentary structures include: (1) cross-stratified sandstone with grainfall and grainflow structures (interpreted as eolian dune deposits); and (2) coarsening-upward laminations of extremely uniform thickness (interpreted as eolian ripple laminations). These features are found in association with wavy-laminated sandstone interbedded with mm-scale silty laminations (interpreted as sabkha deposits) and nodular sandstone with carbonate micrite matrix interbedded with discontinuous beds of micrite (interpreted as a calcrete pedogenic features).

In the Illinois Basin, carbonate grainstone of eolian origin is present in the upper part of the Ste. Genevieve Limestone along State Highway 135 near Corydon, Indiana (Hunter 1993) and at an outcrop along Interstate I-57 near Balcom, Illinois. In these units in Indiana, sedimentary structures include: (1) cross-stratified sandstone with grainfall and grainflow structures (interpreted as eolian dune deposits); and (2) coarsening-upward laminations of extremely uniform thickness (interpreted as eolian ripple laminations). These features in Indiana are found in association with micrite-clast breccias and cylindrical structures (interpreted as calcrete pedogenic features). At the outcrop in Illinois, the sedimentary structures are mostly coarsening-upward laminations of extremely uniform thickness (interpreted as eolian ripple laminations).

These Mississippian eolian strata are interpreted as having formed after a eustatic drop in sea level that resulted in subaerial exposure of marine sediments, which were then mobilized by eolian processes. The eolian strata were then preserved in the rock record via a subsequent rise in eustatic sea level. The observation that the eolian units in Illinois and Indiana are composed of carbonate grains whereas the eolian units in Pennsylvania and West Virginia are composed of relatively equal amounts of carbonate grains and quartz sand suggests the presence of a terrigenous source to the east and (or) northeast.

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NEW GENERATION GEOLOGIC MAPPING – A FUNCTION OF TIME, SCALE AND PURPOSE

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Geologic mapping at all scales embraces three critical components: time, scale and purpose. Fixing one variable inevitably leads to constraints on the other two. The adage that any geologic mapper must know how to map anything, at an appropriate scale, given a time constraint, is testament to the balancing act facing individuals and organizations engaged in generating geologic map data. The National Cooperative Geologic Mapping Program has set forth a challenge to the geologic mapping community to construct a seamless, integrated, geologic framework model for the Nation, encompassing both 2D and 3D components, on an unprecedented decadal-scale timeframe. This requires an assessment of source materials, methods, and technology necessary to achieve this vision.

Cursory examination of the geologic map data catalog of the National Geologic Mapping Database (NGMDB) recovers nearly 25,500 geologic map records at various scales encompassed by the lower 48 United States. Preliminary assessment of the percentage of the lower 48 states covered by mapping at 1:24k, 1:100, and 1:250k between 1880 to 2015 is approximately <20%, <35%, and <75%, respectively. Consequently, the challenge of constructing a singular, integrated geologic framework model lies not only in integration of geologic thinking reflected in a century of geologic mapping, but also in integration across regions of variable geologic complexity and data representations manifesting variable scale and data density. The inevitable conclusion is that no single scale, with rare exception, is suitable for integrated national scale geologic map coverage within the decadal scale timeframe, based on current rates of map production. Utilizing data from best available sources and extrapolation beyond existing dense datasets into regions of sparse data can be combined with limited new mapping to yield high resolution, variable-scale, regional geologic maps suitable for National scale compilations. This approach is derived from the methodology and database model developed by the Geologic Framework Intermountain West project and can serve as the basis for a strategy to achieve national-scale geologic map coverage on a decadal scale.

The Geologic Framework of the Intermountain West project addresses the challenge of creating a regional compilation designed to be delivered digitally via a web-based interface. Our approach incorporates as many aspects of the explanation of map units as possible within the database structure so it can be queried efficiently and customized for a user’s needs. One challenge faced in a regional compilation with hundreds of units across a wide variety of tectonic settings is how to preserve the correlation of map units, typically present on a paper map. A solution to this challenge is a geologic province hierarchy. Geologic provinces are tectonic or magmatic events or depositional settings. They have defined spatial and temporal characteristics but are not necessarily fixed in absolute age or map space. Geologic provinces are encoded in the GeolProvince1, GeolProvince2, and GeolProvince3 database fields and must maintain hierarchical integrity in order to establish unique map units and provide a representation of stratigraphic order in tabular format. Additionally, incorporation of fields to capture feature-specific attributes, such as SourceVolcano or EruptiveCycleTiming, allow for user-defined map representations to be generated for a given area or a specific need.

The focus on material and process unit characterization provides an inherent flexibility that supports user-defined map representations and derivative products to facilitate regional to sub-regional geologic studies. Current associated research on the IMW project includes analysis of magmatic cycling as proxies for crustal column evolution, volcanic manifestation of arc-to-rift tectonic evolution, and tectonic and climatic influences on landscape evolution. A similar map-based analytical approach could be utilized for regional and national-scale mineral systems-based, critical mineral assessments.

SEAMLESS 3D MAPPING

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Research, mapping, monitoring, modeling, and management contribute to benefits. Geology is mapped by administrators, geologists, and information professionals. In federal systems, subnational surveys focus on completeness, and the federal role can be research, technology, and mapping needed to ensure consistency. Procedures are mature for static paper-format maps. Concurrently, all information is transitioning to regularly-updated, multi-resolution, machine-readable, seamless, standardized databases. Nations now foresee a national 3D geology and a 4D digital twin that will house observations and inferences, while supporting monitoring and management. Our work thus consists of publications, standards, and seamless databases. Paper maps are the best reference within a map area, as seamless will never capture everything. Standards will ensure interoperability. Jurisdiction-wide seamless geology is a synthesis of published maps, with steps toward harmonization and facilitation of query. Reconciliation of maps may require fieldwork, if the basis of the mapping differed. Seamless does not have authors, it undergoes audits, and contributors receive credit. In 3D, a layer is a 2D map polygon whose thickness can be mapped, which becomes removable by mapping extent, thickness, properties, heterogeneity, and uncertainty. In layers, we map strata, and in basement, we map structures, then discretized properties. Cross-sections are needed to resolve stratigraphic issues. 3D requires a jurisdictional commitment to databases, collections, and geophysical surveys, with emphasis on public-domain drillhole data. Horizontal resolution is about 100 km for global, 10 km for continental, 1 km for national, 100 m for detailed, and 10 m for soil mapping. Soil mapping is used by modelers to infer properties for the 1st meter. Status mapping based on local judgement will help to clarify goals, to monitor and manage our progress, to stimulate funding, and to cause us all to strive. We are ready to build seamless 3D from mature 2D for continental resolution, after regional experts clarify what will be layers, and what will be basement. We can begin national resolution seamless 3D within a few years, when we have seamless 2D surficial and bedrock. Detailed seamless will now focus on 2D, and seamless 3D may be geostatistical.

INTEGRATED BEDROCK GEOLOGIC MAPPING IN THE ADIRONDACK HIGHLANDS OF NEW YORK

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The Adirondack Highlands are underlain by complexly deformed Mesoproterozoic granulite facies rocks, presenting significant challenges for adequate assessment of natural and environmental resources. The vast ~30,000 km2 area contains the fewest published modern bedrock maps in the northeastern United States. Despite over a century of topical research, no peer-reviewed 1:24,000-scale bedrock geologic maps exist in the Adirondack Highlands, and few maps have been published in the last 50 years. The USGS FEDMAP Northeast Bedrock Mapping Project will integrate detailed 1:24,000-scale bedrock geologic mapping (the first of its kind in the Highlands) with new LiDAR, new airborne geophysics, geochemistry, petrology, geochronology, economic geology, stratigraphy, and paleontology to improve our understanding of the Adirondack Mountains and the Champlain Valley. The research provides a new framework for investigations into the tectonic evolution of the Grenville orogeny and historically significant mineral occurrences in the eastern Adirondacks including REE-bearing apatite, iron oxide, and graphite deposits.

GEOLOGIC MAPS AS DATABASES FOR RESOURCE AND TECTONIC ANALYSIS – AN ALASKA EXAMPLE

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At the U.S. Geological Survey Alaska Science Center, we have compiled geologic map databases to serve many uses, analysis being one of the most critical. Individual studies attempting to resolve tectonic or mineral resource questions can be assisted by map databases tailored for analytical queries. We have designed an expandable spatial and text geologic database for Alaska as a multi-layered tool (Wilson and others, 2015) that allows for queries that enable rapid delineation of rock units and also enables searches based on a variety of characteristics of geologic units that meet the user's criteria. These queries rely on a map unit key that ties similar or related map units together from more than 1,000 source maps ranging in scale from 1:63,360 to 1:500,000. Accompanying the source maps and their unit descriptions in the database are locations and data for more than 8,000 radiometric age determinations, and a series of hierarchically structured relational tables that describe age and lithology. Additional information, such as geologic setting, terrane designations or locally, engineering properties for each map unit are also included in the tables. The core database and related tables preserve the original data from the source maps in the database. The structure of the database allows users to create a variety of products depending on need. Information from the database has been released in several different products ranging from a simplified and generalized poster for public consumption (Wilson and Labay, 2016), to various levels of detail for bedrock geology, and surficial deposit maps (Wilson, 2015). These products are all derived from the same set of map database tables.

It has been long recognized that considerable potential for undiscovered mineral resources exists in Alaska. The Alaska geologic map database is one of the key components utilized in data-driven GIS-based prospectivity analyses of Alaska. The database was used with other publicly available geospatial databases in a study that evaluated undiscovered resource potential for critical minerals using six mineral deposit types in Alaska (Karl et al, 2016). One of the key criteria used to evaluate prospectivity is the presence of appropriate lithology as either the source of components or as a trap for mineralization. Mineral systems are often associated with particular tectonic settings, so identification of tectonic setting assists in prospectivity analysis. The Alaska map database can be queried by selecting distinct lithologies, locations where a lithology is a major or minor component of a map unit exposed in an area of interest, or where key word searches of textures, or other important characteristics of the rock identify prospective environments. Examples of these types of queries include the following: geologic units containing mafic or ultramafic rocks (PGE); units where alkalic granitic rocks are a major component (REE); and unit descriptions that mention "barite," and /or "sphalerite" in the source map unit description (Pb-Zn) deposits. Based on the selected criteria, if an area contained the selected map unit, it was scored as favorable for the prospective commodity.

Paleontologic analysis utilizing the Alaska Geologic Map databases is possible by use of the "fossil" field in the geologic unit database. As an example, many of the Triassic rock units from the source maps incorporated in the state map report fossils of the species, *Monotis*, which is an important Triassic index fossil. Querying the database for source maps mentioning *Monotis*, one can display the distribution of map units containing known *Monotis* occurrences. Additionally, because equivalent geologic map units from other source maps are linked in the database, the user can also show map units where *Monotis* may potentially occur though not explicitly reported. Maps generated using explicit and related data can assist in paleo-environmental and tectonic analysis.

References:

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REVISING THE GREYS RIVER FAULT TRACE

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The Holocene-aged Greys River fault is located in northern Lincoln County, Wyoming. Recently, an unrecognized northern extend was mapped, extending the trace 10km (6 mi) to the north (Wittke et al., 2019). This study looks in detail at the newly mapped extent. The mapping was completed using a combination of photogrammetry, Unmanned Aerial System (UAS) terrain modeling, and fieldwork. Scarp profiles and field photos were taken in the field to confirm digital profiles harvested from the digital elevation models. This preliminary report summarizes the results from this investigation.

Reference

Wittke, S.J., Mauch, J.P., and Lichtner, D.T., 2020, Preliminary surficial geologic and landslide maps of the Blind Bull Creek and Pickle Pass quadrangles, Lincoln County, Wyoming: Wyoming State Geological Survey Open File Report 2020-5, 16 p., 4 sheets, scale 1:24,000.