

MINNESOTA GEOLOGICAL SURVEY

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Geologic Mapping Forum 2019 Abstracts

Edited by: Harvey Thorleifson, Minnesota Geological Survey



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**MINNESOTA
GEOLOGICAL SURVEY**



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INTRODUCTION

Welcome to the Geologic Mapping Forum

April 10 - 12, 2019, Minneapolis, Minnesota

GMF'19: At the Geologic Mapping Forum in Minneapolis from April 10th to 12th, 2019, ~100 geological map authors, program managers and allied professionals from geological surveys and allied agencies met to discuss the status and future of geologic mapping in the USA. The meeting was hosted by Minnesota Geological Survey on the University of Minnesota campus.

LOCATION: The meeting was held near the Mississippi River, at the Humphrey School of Public Affairs on the West Bank campus, in the Humphrey School Conference Center at 301 19th Avenue South, Minneapolis, MN 55455.

PRESENTATIONS: Unless they had been invited to speak in a plenary, all participants were urged to present a 15-minute talk in a concurrent session or a poster. Plenary, concurrent session, and poster presenters were asked to submit a 1 to 2-page abstract.

PROGRAM: The meeting commenced with registration and a reception at the hotel with light food and drinks on Tuesday from 5 to 7 PM, followed by conference sessions from 8:30 AM Wednesday until 2:30 PM Friday, with regional meetings following, in Friday afternoon and Saturday.

Poster: KARST IN THE LILLEY FORMATION, PEBBLES 7.5-MINUTE QUADRANGLE, OHIO

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Abstract

During the 2017–2018 field season, karst was mapped in the northern half of the Peebles 7.5-minute quadrangle (Aden and Parrick 2018). This is a continuation of eight years of detailed karst mapping in Ohio to update the statewide karst database. Sinkholes are located by extracting enclosed depressions from a Digital Elevation Model (DEM) generated from Ohio's statewide Light Distance and Ranging (LiDAR) data. Depressions are then reviewed digitally and subsequently checked in the field. By the end of 2019, statewide karst data will be available online as an interactive map, which will allow the public and consultants to directly access this regularly updated data and download it for use in a Geographical Information System (GIS).

In southern Ohio, the primary karst-forming bedrock is mapped as a single, undivided, Silurian-age unit. However, more detailed bedrock mapping was completed for the Peebles quadrangle, which differentiates these units (Swinford, 1991). This mapping, in combination with field observations, suggests that the Lilley Formation is the most karst-prone in the quadrangle (Swinford, 1985). To determine what percentage of sinkholes occur in the Lilley Formation, mapped karst was intersected with Swinford's detailed bedrock mapping for the Peebles quadrangle (Figure 1). A composite of the detailed bedrock and karst maps illustrates that 82% (1,336 out of 1,637) of sinkholes occur in the Lilley Formation, 7% in the Nolan and Brassfield Formations Undivided, 5% in the Estill Shale, 4% in the Peebles Dolomite, and the remainder in other formations.

A review of measured sections in the area shows that the Lilley Formation varies locally from limestone to dolomite. Limestone is more susceptible to dissolution than dolomite (Liu et al. 2005) which may explain the concentration of sinkholes in the Lilley Formation, relative to the surrounding dolomites. The Nolan and Brassfield Formations Undivided also contain limestones and have the next largest percent of sinkholes. The presence of sinkholes in the Estill Shale is counterintuitive, owing to its insoluble nature. Sinkholes in the Estill Shale are generally found adjacent to mapped areas of the Nolan and Brassfield Formations Undivided. These sinkholes may be forming by the collapse of the Estill Shale into the underlying dissolved carbonate. Alternatively, the sinkholes' appearance in the Estill Shale could be an error in the location of the mapped contact. This could be confirmed with additional field work, although no shale outcrop was observed in any of these sinkholes

Studying which units are the most susceptible to sinkhole formation allows for hazard mitigation by potentially avoiding the most at-risk units. Although field checking is incomplete for the southern half of the Peebles quadrangle, this relationship appears to be maintained here as well. Future detailed bedrock mapping could use sinkhole locations from detailed karst maps to extrapolate the location of the Lilley Formation in nearby quadrangles and map it separately from its adjacent Silurian-age carbonates.

Aden, D.J., and B.D. Parrick. 2018. Karst of northern portions of the Peebles and Jaybird 7.5-minute quadrangles, Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Open-Fine Report 2018-3, 40 p., 37 maps.

Liu Z., Yuan D, Dreybrodt W. 2005. Comparative study of dissolution rate-determining mechanisms of limestone and dolomite. *Environmental Geology* 49 (2): 274–279.

Swinford, E.M. 1991. Geologic map of the Peebles quadrangle. Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Digital Map Series BG-2 Peebles.

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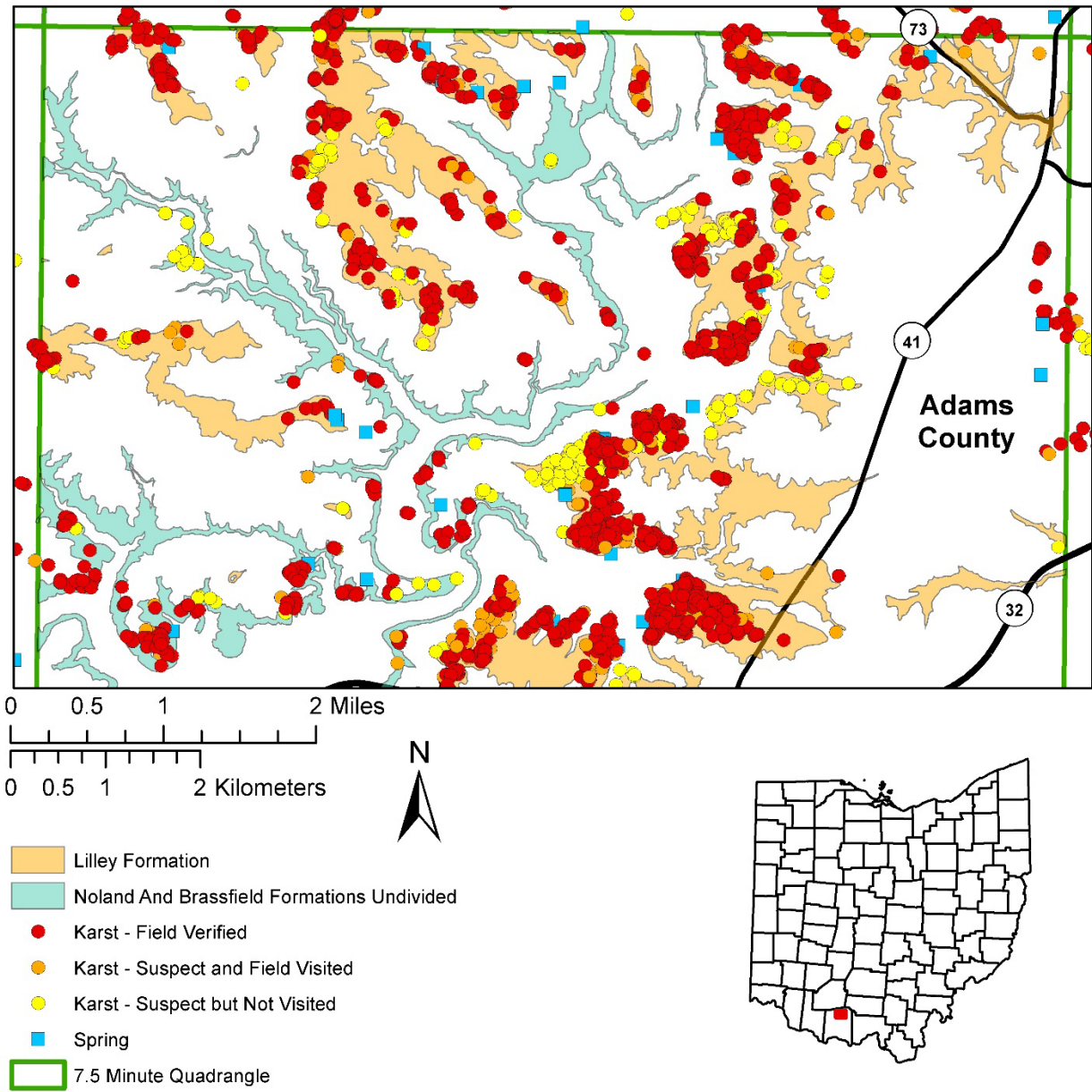


Figure 1. The northern half of the Peebles 7.5-minute quadrangle showing karst points largely occurring within the Lilley Formation.

Plenary: LESSONS LEARNED IN A POST-MAPPING STATE GEOLOGICAL SURVEY: ONGOING MAPPING, THE DIGITAL WORLD, AND DERIVATIVE MAPS

William “Drew” Andrews and Bill Haneberg, Kentucky Geological Survey, University of Kentucky, 228 MMRB, Lexington, KY 40506-0107, wandrews@uky.edu

Kentucky is fortunate to have a statewide set of published 1:24,000-scale geologic maps. A joint USGS-KGS program produced 707 geologic quadrangle maps between 1960 and 1978. The KGS subsequently vector-digitized most of the lines and polygons from the statewide maps, and since 2010 has served the detailed digital geologic map data free of charge through a robust online digital map service. In the more than 40 years since completion of the USGS-KGS program, many benefits have been realized and valuable lessons learned.

Lesson 1: we are finished but we will never be finished with our geologic mapping. Updates, new details, and refinements to the geologic data set are necessary to respond to shifting societal priorities. Moreover, a mapper never has enough data to completely document all possible detail available in the natural geologic setting; there is always room to add more information as new data becomes available. Additionally, the original Kentucky maps focused primarily on bedrock and only acknowledged surficial or unconsolidated geologic units where they were so thick the field mapper was forced to admit their presence. These surficial geologic units are critical to resolving modern geotechnical and environmental management applications, and are the focus of our active field mapping program.

Lesson 2: the geologic map data are incredibly valuable and have a high benefit/cost ratio. An economic study by the Illinois State Geological Survey concluded that there is a > 25x return on investment for the paper maps, and demonstrated their status as a public asset. As digital data have become available, the market for published paper maps has diminished. This is due to both the fact that many established users of the maps now own their own library set of the maps and the preference of many of our audience for holding a digital version or just accessing the data on demand through the web, and not keeping their own paper copies of the data.

Lesson 3: the full value and benefit of the geologic map data are only realized when a complete jurisdiction-wide data set is available, regardless of scale, and every part of the country has jurisdiction-wide geologic maps. The complete coverage allows our diverse audiences to anticipate that geologic information is available for their area of interest and to plan the use of that data into their processes and procedures. We will always be improving the scale and detail of our maps, but in the meantime our audiences need geologic information to help solve their problems NOW, and will not or cannot wait years or decades for better information to be available. It is critical to provide the best available information NOW so that geologic input is incorporated into critical decisions. The State Geologic Map Compilation currently provides the best-available data framework from which to move forward with our nationwide geologic information and provide a data foundation for necessary applications and addressing national priorities. Our effort must continue to be focused on resolving cross-border discrepancies, improving the detail of the component maps, and keeping the system updated with new information as it becomes available. The National Geologic Map Database is the logical (and legislated!) place to do this; we should continue to support and use and promote the NGMDB to the fullest extent possible.

Lesson 4: it is important to have predictable standards and data structures for your audiences, so they can develop applications for the map information and so that they know what information they can expect to access when they utilize our data. GEMS is a critical and useful tool to achieve that goal. Despite having a robust pre-existing geologic map dataset, and because we embraced implementation and did not treat compliance with GEMS as an after-project activity, implementation of GEMS has been a (relatively) painless and productive exercise for the KGS. It has allowed implementation of a team matching approach which has increased our field mapping efficiency and can facilitate faster integration of new geologic map data with our web services. The predictable data structure has facilitated deployment of digital field data collection tools, and our field mappers generate GEMS-compliant data and metadata in the course of day-to-day field mapping. The primary struggle for us, and one which will not likely go away in the short term, has been standardization of terminology and definitions.

Lesson 5: In a modern, digital world, it is important to have modern, digital-capable field mappers. KGS does not separate GIS duties from the field responsibility of our geologic mappers. Each field mapper records their own observations and data digitally, eliminating the extra time for a GIS technician to re-handle and manually enter the data. We treat the GIS proficiency as an essential, and learnable, skill much as we would any other field tool such as a rock hammer or a compass. Our GIS specialists are then able to focus on developing online tools for field data collection,

managing compilation of our digital data, generation of cartographic products, and on effective and efficient dissemination of the data.

Lesson 6: Although it is being superseded for our typical audience in favor of digital data sets and online databases, the published paper (or PDF) map is critical for explaining techniques and context for the geologic map data and is essential for documenting intellectual property of the mappers involved. The properly published, cataloged, and archived PDF or paper map will not receive lots of use from modern standard audiences. However, academic audiences and those interested in a deeper understanding of the data will rely on access to the published map.

Lesson 7: We must not think ONLY in terms of the published paper map. The jurisdiction-complete digital data is much more valuable and is the foundation for critical applications, and therefore is the cornerstone of our modern relevance. Our 21st-century audience is digital and works and makes decisions in a digital world. The practical goal of the USGS-KGS GQ mapping program was publication of 1:24,000-scale paper maps. The original goal of the digitization process at KGS was production of compiled 1:100,000-scale geologic maps. Neither program fully anticipated the full value of the geologic information as a database resource. In both programs, some poor decisions were made based on the anticipated aesthetics of a published paper map which led to valuable detailed information being discarded or disregarded because it was “too small to map” for the intended published scale. The cost of trying to recover or rediscover that information has been disproportionately and distressingly high; these costs could have been avoided if the database potential of the information had been considered. We needed to think ahead, and in some cases we did not. Our modern reputation as a relevant state geologic survey is heavily dependent on our audiences’ access to and use of our digital databases, so the depth and quality of those databases is key.

Lesson 8: there is no such thing as a single complete and comprehensive geologic map. Our modern societal concerns for energy, environment, hazards, geotechnical issues, etc, often require separate consideration of consolidated and unconsolidated geologic materials. These materials are tested, characterized, and utilized in different ways, and our geologic maps should reflect that. At a minimum, complete geologic mapping should involve at least two to three separate maps: unconsolidated/surficial geology, bedrock (layered?) geology, and basement geology.

Lesson 9: the geologically trained audience is limited, but the technical non-geological audience is vast and needs our input. These audiences need quality geologic information tailored to their applications; they have their own vocabularies, their own training, and their own procedures and processes to address the questions they must solve for their businesses. We as geologists know that their processes should include geologic input, and to varying degrees some form of geologic information is used, but we know it can definitely be better. However, these audiences cannot and will not wait years for better geologic data; they have projects and questions that need geologic input NOW. They will work with the best available data, at whatever scale they can find. Although in many cases these non-geological audiences are highly skilled and highly trained, they are not trained in GEOLOGY. Thus, it is critical for geologists to engage with audiences, to understand their vocabulary and business practices, and to work collaboratively to develop geologic information that facilitates execution of their business process and address the problems they solve. Derivative maps are a critical tool for translating basic geologic map information for non-geological technical audiences. Over many decades, KGS has used geologic maps to support production of maps related to karst potential, energy assessment and regulation, aggregate availability, radon potential, landfill suitability, seismic soils, landslide assessment, ecoregion delineation, aquifer characterization, and land-use planning. By generating the applied derivative maps and engaging with the external audiences, we demonstrate our value and support better societal decision making. All parties involved benefit from the interaction.

Lesson(?) 10: The next frontier for KGS is improved data integration and development of a holistic, spatially referenced data system to relate our disparate databases into one interactive system. This will help to eliminate silos in our data processes and to break down impediments to public data discovery. The goal will be to develop a three-dimensional data system that can be used to answer on-demand inquiries through the KGS website, as well as be available for immediate(?) export into modeling systems for various applications and research. This will include incorporation of our extensive geologic map information, highway roadcut data, as well as robust inventory of rock cores, well cuttings, and other physical samples. New web interfaces will be developed to support public inquiries that will interrogate this 3D database.

We must know our audiences, speak to them, and listen to them, if we are to survive and thrive in our modern digital world. We as state geologic surveys do not exist for the map, for the data, or for ourselves. We exist for the public—for society—to provide quality information and to support the informed solution of local and state problems. We exist in a digital world, and must accept and embrace that fact to survive the ever-increasing rate of change around us. We must not be a cult of mapping.

Poster: PLANS AND GOALS FOR INTEGRATED THREE-DIMENSIONAL DATABASE AT THE KENTUCKY GEOLOGICAL SURVEY

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Data integration and three-dimensional data are key elements of the recently implemented Kentucky Geological Survey strategic plan (May 2017). A team of KGS geologists and data managers have begun to develop data structures and inventories of available 3D-ready datasets as a first step to compiling an integrated three-dimensional database of Kentucky geological information. The ultimate goal of the program will be to integrate numerous isolated or independent existing KGS databases into a spatially referenced whole to facilitate holistic data discovery and more robust modeling results. Ideally, data structures will be designed to be compatible with other state and province geological surveys actively producing 3D data, so that future data could be contributed to a common database when the opportunity arises. Concepts from the GEMS geologic map data model such as uncertainty and feature-level metadata will also be key elements of the resulting database. KGS will be compiling information from existing geologic map data (contact elevations, structure contour maps, detailed fault locations), data from physical rock core and cuttings samples, road cut information, as well as water well logs, petroleum well records, a database of inferred stratigraphic tops, borehole and profile geophysics, and available hydrologic and geochemistry data. The program will deliberately record, evaluate, and report estimations of uncertainty. Sources of information for empirical determinations of uncertainty will be multiple generations of interpreted surfaces, stratigraphic picks by multiple operators over the years, and quantification of variability in road cuts and clusters of closely-spaced subsurface data. Inevitably multiple software packages will be used in the project, but a goal of the project is for the database to be as software-independent as possible and will be designed to be exportable/importable between different software platforms. Independent users should be able to access the data regardless of which software they do or do not own. Data and products will be served on the KGS website with tools for audiences to use or interrogate the data without owning expensive software. Export options will be available for those who do wish to use sophisticated 3D software platforms for their own research models.

Talk: MINNESOTA AGGREGATE RESOURCES MAPPING PROGRAM

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In 1984, the Minnesota legislature directed the Department of Natural Resources (DNR), with cooperation from the Minnesota Geologic Survey (MGS) and the Department of Transportation (MnDOT), to map aggregate resources outside of the seven-county metropolitan area. The purpose of the program is to protect aggregate resources by promoting orderly and environmentally sound development and by spreading the burden of development through the introduction of aggregate resource protection into local comprehensive planning and land use controls. The DNR Aggregate Resource Mapping Program (ARMP) pairs traditional geologic mapping techniques with geospatial modeling to qualify aggregate resource potential in user-friendly formats.

Construction aggregate resources consist of crushed stone as well as natural sand and gravels. In Minnesota, the distribution, quality, and abundance of aggregate resources are predominantly the result of glacial and glaciofluvial processes. As a result, Minnesota heavily relies upon locally sourced natural sand and gravel to supply its aggregate demand. Despite Minnesota's median rank in population, the state ranks as the 6th largest producer of construction sand and gravel in the US (USGS, 2019). Approximately half of the aggregate produced supplies publicly-funded projects.

Geomorphological mapping techniques, such as the landsystems approach, are widely-used methods to characterize glaciated landscapes that can be used to derive sand and gravel-bearing landform assemblages. (Eyles, N, 1993; Ellingson, J.E, 2001). In applying this method, the DNR compiles existing sources of information, where available, such as 2-meter LiDAR digital elevation models, 1:100,000 surficial maps from the Minnesota Geologic Survey County Atlas Series, USGS 7.5 minute topographical maps (1:24,000), DOQs from multiple years and scales, digital soil information from NRCS soils survey and the Soil Survey Geographic Database (SSURGO), and Mn/DOT Aggregate Source Information System as well as interpreting driller logs from the Minnesota Well Index. Additional data is gathered from reconnaissance-level fieldwork using Collector for ARCGIS. Drilling programs are employed to confirm inferred geologic processes responsible for creating a landform and to predict the unexposed distribution of sediment within the landform (Jennings, et. al, 2014).

However, understanding the ice flow mechanisms; transport lengths; thermogradients; and marginal hydrostatic pressure gradients of ice lobes; is helpful to predictively characterize texture, uniformity, and quality of associated sand and gravel deposits. For example, models have been developed showing the distribution of Pierre Shale in Des Moines lobe sediment. Shale exceeding 3% by volume exceeds MnDOT specifications for concrete.

Aggregate resource maps are produced at a scale of 1:100,000 with associated geodatabases. The characteristics used to classify aggregate potential include landform, major sediment, minor sediment, sand and gravel probability, unit certainty, texture, quality, depositional variability, provenance, observed sand and gravel thickness, observed overburden thickness. Additional databases include gravel pit inventory, field observations, and drill holes. Non-technical users with limited access to geospatial software are considered the primary consumers of aggregate resource data. Therefore access to data and text in plain language are important considerations. To facilitate public access to databases and geospatial information, ARMP uses ARCGIS web maps that allows for interactive display and querying of tabular data.

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Plenary: THE USGS NATIONAL CRUSTAL MODEL FOR SEISMIC HAZARD STUDIES; 2019 UPDATE

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Abstract

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 porosity and attenuation 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 are nearly ubiquitous throughout the United States, and risk can be significant for some communities. 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 (Petersen et al., 2015) 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, as was done in a 2018 publication (Shumway et al., 2018) for the 2014 NSHM, 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 just 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 States (WUS); and Phase 2 for the central and eastern United States (CEUS).

Elements of the NCM

Depth to Bedrock and Basement

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. This process enables update to layers as results from new studies become available and as efforts to build the NCM move to the CEUS.

Geologic Framework

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 being developed based on a 1:250,000 to 1:1,000,000 State Geologic Map Compilation (Horton et al., 2017), the Geologic Map of North America (Garrity and Soller, 2009), 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

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

The temperature model is more relevant to the reduction of seismic velocities and amplitudes at greater temperatures where melt may be present and seismic attenuation can be high. This typically occurs 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 and Attenuation Models

Porosity and seismic attenuation 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. Attenuation is assumed to result from fluid flow within porous rocks in the upper crust and temperature-dependent mechanisms generally present in the mid-to-lower crust. Calibrating these models uses compilations of V_{S30} , estimates of shallow S-wave velocities from indirect methods, borehole observations of P- and S-wave velocity and density, surface-wave dispersion at broadband seismic stations, and tomographic models of crustal velocity and attenuation.

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 $Z_{1.0}$ and $Z_{2.5}$ in the WUS for use with the NSHM. Therefore, the first validation exercise is to see how well maps of $Z_{1.0}$ 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.

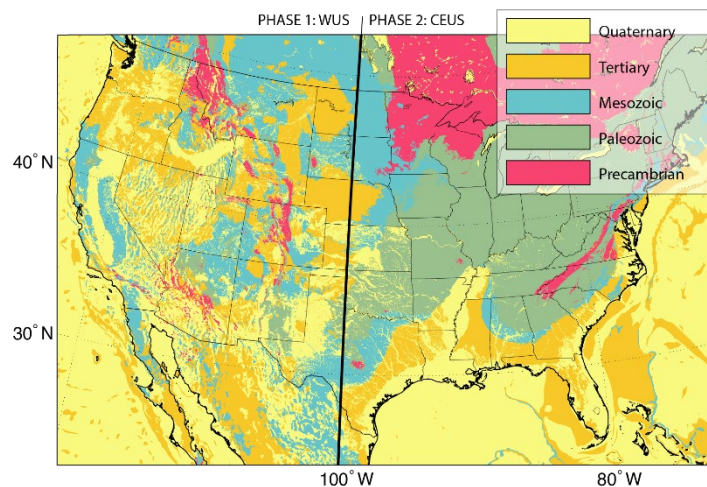


Figure 1. Merged geologic map from the National Crustal Model showing rock age. Note that state maps from the State Geologic Map Compilation for several states around the Great Lakes show only bedrock geology, such that young glacial deposits are underrepresented on this map.

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Poster: BEDROCK MAPPING AS A TOOL FOR EVALUATING THE RISKS OF UNDERGROUND GAS STORAGE

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New 1:24,000 scale mapping of the bedrock and surficial geology of the Accident and McHenry quadrangles in Garrett County, Maryland sheds light on the subsurface geology of the Spectra Energies Accident gas storage field and thus represents an important step towards the detailed evaluation of the risks associated with underground gas storage at this location.

Covering approximately 53 square miles in the Appalachian Plateaus Physiographic Province of Maryland, the Accident gas storage field is a former natural-gas well field that was converted in 1962 into a gas-storage facility. Today, natural gas gathered from elsewhere in the United States is injected into the field during low-demand months and extracted during the winter when demand is higher (Bolton et al., 2016). Risks associated with underground gas storage in the Accident gas storage field include methane and saltwater contamination of shallow fresh-water aquifers, atmospheric emissions, and seismic risks. An evaluation of these risks and the general suitability of the site for future gas storage requires a detailed understanding of the subsurface geology of the site, unavailable until now.

The current storage field is situated within the Accident Anticline, a gentle structural dome formed by subhorizontal Paleozoic strata including the Devonian Oriskany Formation sandstone reservoir rock and the overlying Devonian Marcellus shale source rock (Brezinski, 2012). New bedrock mapping (Brezinski, 2019), partially funded by the USGS STATEMAP program, indicates that several faults previously thought to be blind faults within the Lower Devonian strata actually penetrate to the surface. Due to limited exposure and an absence of exposed fault surfaces, accurate mapping of the surface traces of the faults and estimations of offset required detailed mapping of local stratigraphy.

The new geologic bedrock map (Brezinski, 2019) and associated structure cross-sections depicting the faults represent a critical contribution to our understanding of the subsurface geology of the Accident gas storage field. In addition to mapping bedrock, Maryland Geological Survey staff have begun gathering gas well data from the area and mapping surficial geology. Future studies of the site may include analysis of detailed LiDAR data, soil gas data, geophysical logs, water well gas data, and the geochemistry of deep brines polluting shallow aquifers. The Maryland Geological Survey ultimately envisions combining the results from these various studies (Fig. 1) to serve as the basis for a larger evaluation of the risks and benefits associated with underground gas storage at the Accident gas storage field.

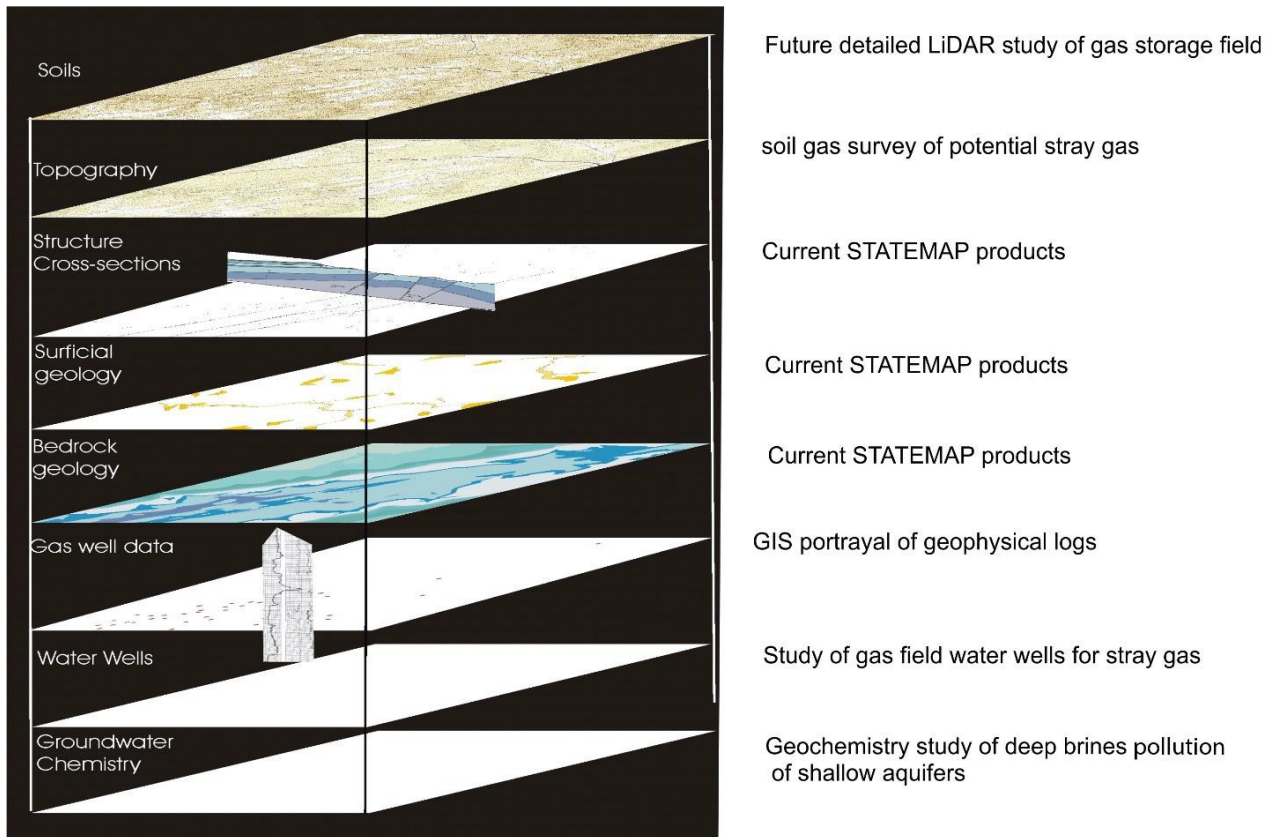


Figure 1 Various spatial datasets envisioned, proposed, or completed (see text) for the evaluation of the risks of underground gas storage at the Accident gas storage field

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Plenary: 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 interdisciplinary studies, geologic mapping and training by federal (FEDMAP), state (STATEMAP), and university (EDMAP) partners, made consistent and available as the National Geologic Map Database (NGMDB). All four components of NCGMP share the common responsibility identified in the NGMA to expedite the production of a geologic database for the Nation, so that appropriate geologic maps can be developed containing information applicable to land-use management, assessment, and utilization and/or conservation of natural resources, groundwater management, and environmental protection. In close partnership with the Association of American State Geologists, NCGMP continues to lead the Nation toward a safer, healthier and more sustainable future through geologic mapping.

The new NCGMP Strategic Plan outlines a renewal of the program as the Nation's authoritative source for foundational geologic knowledge, and is centered on a vision to create an integrated, three-dimensional (3D), digital geologic map of the United States to address the changing needs of the Nation. In carrying out our mission, the NCGMP will work towards achieving preeminence in field mapping and utilization of state of the art remote sensing and geophysical technologies, thereby attaining the infrastructure needed for efficient and effective construction of a 3D National Geologic Framework Model. NCGMP will lead efforts toward the completion of a seamless 3D nationwide geologic map by 2030, based on renewed fieldwork, compilation, and enhanced 3D geologic map standards, and enabled by the NGFM.

Talk: UTILITY OF GEOPHYSICAL DATA FOR GEOLOGIC MAPPING AT THE MINNESOTA GEOLOGICAL SURVEY

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For over a century geophysical methods have been used to explore and map the Precambrian bedrock geology of Minnesota, most of which is hidden beneath glacial sediments. At the beginning of the last century, magnetic dip needle surveys were extensively used in the search for iron ore which, among other things, led to the discovery and development of the Cuyuna Iron Range in 1904. While these early surveys were tightly focused on finding iron ore, the follow-up drilling provided important framework information for geologic mapping, often in areas where outcrop control was completely lacking. Eventually some of these magnetic exploration methods were utilized exclusively for geologic mapping; in the 1940's G. M. Schwartz, Director of the Minnesota Geological Survey (MGS), used a series of Schmidt Balance profiles to map the basal contact of the Duluth Complex in the large, virtually unexposed area between Aurora and Duluth, Minnesota (Schwartz, 1943). After World War II interest continued in using magnetic data to map geology, and a regional-scale, state-wide aeromagnetic surveying program was initiated by the U. S. Geological Survey. MGS Director Schwartz and his successor, P. K. Sims, qualitatively used contour maps of the aeromagnetic data, in conjunction with rock-property data, to help compile bedrock geologic maps, most commonly at a scale of 1:250,000. During this time gravity data also began to be used in compiling geologic maps, and in the mid-1960's a systematic program of gravity surveying at 1-2 mile intervals along drivable roads and trails was begun at the MGS by R. J. Ikola. State-wide aeromagnetic coverage was completed by the U. S. Geological Survey in 1970, and state aeromagnetic (Zietz and Kirby, 1970) and bedrock geology (Sims, 1970) maps were published at 1:1,000,000 scale. The gravity survey program continued during the 1970'S through efforts by the MGS and Northern Illinois University.

In 1979 a new aeromagnetic survey program was begun by the MGS under the Directorship of Matt Walton. This program was primarily financed by the Minnesota Legislature as recommended by the Legislative Commission on Minnesota Resources (LCMR), with significant data contributions from the U. S. Geological Survey, the Geological Survey of Canada, and U.S. Steel Corporation. The new data were acquired using specifications that were then considered to be high resolution, with most of the surveying conducted using 380-500 meter (0.24-0.31 mile)-spaced lines flown north-south at 91-213 meters (299-656 ft.) above the surface. All data were digitally acquired, enabling direct access to the computer-based compilation, processing, and graphical schemes that were becoming available. The Aeromagnetic program also provided limited support for acquiring rock-property data, completing state-wide gravity coverage, and drilling to test preliminary interpretations. The test-drilling program, which was active between 1980 and 1995, was also supported by the Minnesota Legislature as recommended by the Minerals Coordinating Committee (MCC). Aeromagnetic surveying was completed over the state in 1991, resulting in a total of 561500 line-km of aeromagnetic data that have been made available as various maps and digital products (Chandler, 1991). During 2005-2007 the MGS conducted an MCC-funded program to upgrade the aeromagnetic database, which included recovering missing data, improving line leveling, and producing an improved state-wide grid of aeromagnetic data (Chandler, 2007). The rock-property and gravity databases were also upgraded during 2009-2011, with support from MCC (Chandler and Lively, 2011a; Chandler and Lively, 2011b). Acquisition of rock-property and gravity data has continued up to the present, mainly on an as-needed basis.

The impact of the MGS aeromagnetic program on bedrock mapping has been tremendous. Since 1987 aeromagnetic data have been used in over 90 published maps. Most these maps were published at scales ranging from 1:24,000 to 1:250,000, and were part of either the MGS Miscellaneous Map Series or the County Geologic Atlas Series. Of these maps more than half also used gravity data, and over 20% used gravity and magnetic model studies to investigate sub-surface geology, mainly for the compilation of cross-sections. The aeromagnetic and gravity data are primarily used to map Precambrian geology, but in several instances they have been helpful in tracing structures in Paleozoic rocks, which have resulted from re-activation of Precambrian structures. Most geophysics-based bedrock mapping at MGS is based on derivative-enhanced grid-images of the aeromagnetic and gravity data. One popular combination is the first vertical derivative of the magnetic data in gray scale and the second vertical derivative of the gravity data in color. Such a combination is useful in recognizing lithodemic units, on the basis of their magnetization and density characteristics. Most commonly the higher-resolution aeromagnetic derivative data is used to define contacts and other features, although the gravity data is still helpful in mapping these features in areas where the rocks lack magnetic signatures. Other enhanced grid-images of the magnetic data, including tilt derivative and analytic signal, have also been made available for geologic mapping, as have more quantitative treatments, including Werner deconvolution of line data and Euler deconvolution of gridded data. The use of aeromagnetic and gravity data for bedrock mapping culminated with the publication of 1:500,000-scale state-wide maps presenting Bedrock Geology (Jirsa et al., 2011) and Precambrian Bedrock Geology (Jirsa et al., 2012).

In spite of the great success of aeromagnetic data for geologic mapping in Minnesota, various limitations must be remembered. For example, geologic interpretations cannot be placed any more accurately than the magnetic data that they are based on; recovery of flight lines was primarily based on photo-recovered points that were located every 2-5 km along flight lines to within an error of +/- 50 meters, which represents the optimum locational accuracy of the data. In areas between easily spotted points the error could be +/- 100 meters or more. In addition, use of derivative data to map features like contacts usually assumes simple, vertical sources, which may produce misleading results if the sources are actually complex and non-vertical. Also, strong anomaly gradients are much better defined along flight lines (50-75 meter sampling) than across flight lines (380-500 meter sampling), which may bias interpretational schemes that are based on anomaly gradients. Finally, before any magnetic data are used for geologic mapping, they should be reduced to vertical polarization, which places anomalies more directly over their sources. This is not a problem in most areas where source magnetization can be assumed to be parallel to the earth's magnetic field, but igneous rocks of the Mid-Continent Rift System have a strongly varying remanent magnetization that is oblique to the earth's field, making proper reduction to vertical polarization problematic.

Much geophysical work remains to be done in Minnesota. Doubtlessly this will include further investigations using aeromagnetic and gravity data; magnetic surveys using modern technology and current high-resolution specifications would certainly benefit geologic mapping in many areas. However, because glacial sediments contain one of Minnesota's most valuable resources--water--it is likely that more geophysical effort will be spent looking at these sediments, instead of through them. Recent MGS investigations with passive seismic data (Chandler and Lively, 2014) represent a step in this direction.

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Talk: THREE-DIMENSIONAL HYDROGEOLOGIC AQUIFER MAPPING IN SOUTHEASTERN NEW MEXICO

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Since 1927, the New Mexico Bureau of Geology and Mineral Resources, as the state's geologic survey, has conducted pure and applied geologic mapping research with emphases and methods adapting to evolving societal needs and technological advances. At present, water resource management and conservation is a priority concern for the state and its residents, as water resources are scarce, and much of the state's residents and commercial and agricultural activities are dependent on groundwater resources. These resources are generally poorly characterized, however, particularly with respect to their extents, interconnections, and variations in quality at depth. Advances in computing technology, data processing and visualization software, and computational methods facilitate addressing this critical information gap, and recent initiatives at the Bureau's Aquifer Mapping Program seek to leverage these advances to better address the water resource needs of the state.

I present an on-going study of the geology and hydrogeology of southeastern New Mexico that seeks to characterize the hydrogeology of the area by utilizing modern 3-dimensional (3D) geologic data processing methods. The area encompasses several geologic and aquifer settings, including limestone bedrock aquifers of the Pecos slope (eastern flank of the Sacramento Mountains), alluvial basin aquifers along the lower Pecos River valley, and portions of the southern Ogallala aquifer (Figure 1). It also covers regions of distinctly variable data density, quality, and type (e.g., formation picks from oil and gas well logs versus interpretational cross-sections). This study 1) develops a digital 3D geologic framework model of these various aquifers (Figure 2); 2) estimates the known extents of water resources using both the geologic model and hydrologic data (Figure 3); and 3) assesses the variability in water quality through this region. An overall objective of the study is to develop methods that can be adapted throughout the state to better characterize all of the aquifer systems of New Mexico in 3D.

The challenges, advances, and methods used or experimented with to date include:

- 1) Data management: the size and variability of data necessary for this project required the development and use of a structured-yet-expandable relational database schema.
- 2) Data quality and compatibility assessment: the variable ages, origins, and types of data require not just an assessment of data quality but also compatibility between data. Geostatistical methods, particularly cross-validation of geostatistical models, were used to identify outlier or influential input data that are potentially erroneous or incompatible.
- 3) Data densification: incomplete datasets, particularly well records with only some geologic units identified, can be improved by using the existing data to inform "best guesses" for the missing data. Geostatistical models of geologic unit apparent thickness and contact elevation trends, for example, can be jointly leveraged to densify the dataset.
- 4) Data interpolation: current interpolation strategies use geostatistical (kriging) models.
- 5) Water resource extent delineation: particularly with bedrock aquifers, the extents of water resources are not necessarily governed by the extents of each aquifer's geologic unit. We are experimenting with clustering algorithms such as density-based spatial clustering of applications with noise (DBSCAN) and Gaussian mixture model (GMM)-based methods to group water wells based on the 3D location of their total depths or screened intervals, and subsequently using hull-calculating algorithms to produce digital volumes of known water resource extents.
- 6) Water quality delineation: water quality is highly variable through the area as a function of distance from recharge zones and the geology of the aquifers. We are experimenting with GMM and 3D Gaussian kernel density functions to estimate the extents of regions dominated by waters of various salinity levels.

An overall project challenge is the multiple steep learning curves for the variety of specialized-yet-necessary techniques that are being combined in this project. This project has been generously sponsored by the Healy Foundation and the Aquifer Mapping Program.

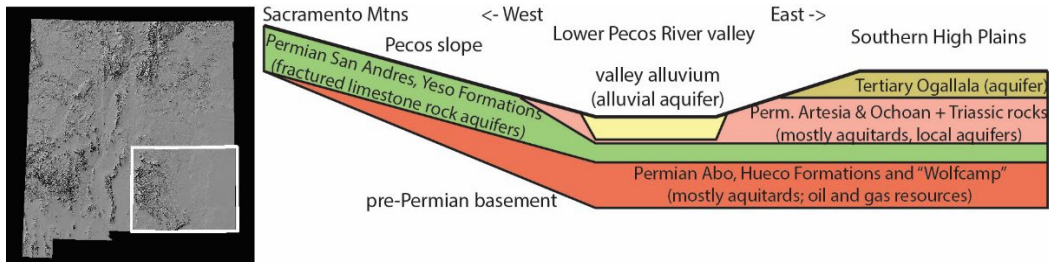


Figure 1: Location of the study area and the hydrostratigraphic conceptual model. Valley alluvium, Ogallala sediments, and the San Andres-Yeso aquifer system are intensively used for water resources here, but each are variously water quality-limited, and resources in bedrock aquifers are not continuous throughout each geologic unit.

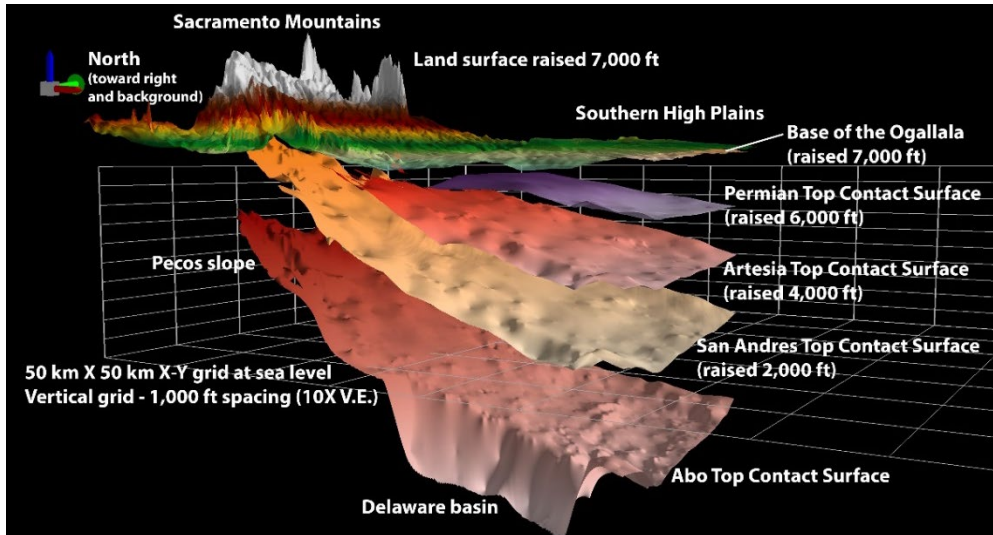


Figure 2: Exploded view of the preliminary geologic model showing a subset of the contact surfaces. Note the progressive decrease in structural deformations upsection from the Abo contact surface. V.E.: vertical exaggeration.

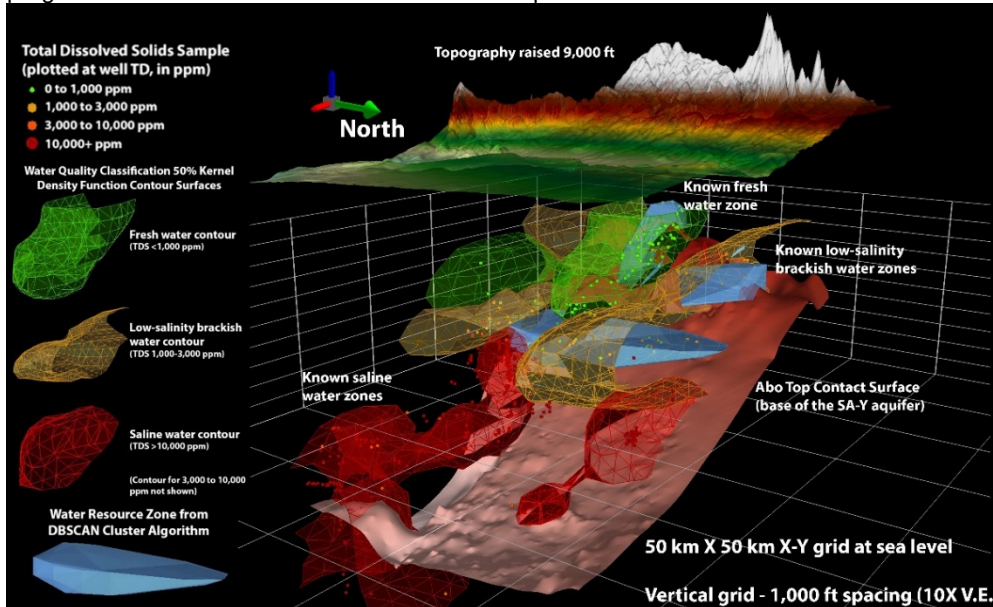


Figure 3: Hydrogeologic model for the San Andres-Yeso (SA-Y) bedrock aquifer system beneath the Pecos slope and lower Pecos River valley, showing the known extents of groundwater resources overlain with 3D contour surfaces defining regions dominated by varying levels of water quality, as measured by total dissolved solids (TDS). TD: total depth, V.E.: vertical exaggeration.

Talk: MITCHELL COUNTY, IOWA: AN EXAMPLE OF CHALLENGES WHEN MAPPING ALONG STATE BORDERS

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Since its inception in 1993, the U.S. Geological Survey (USGS) National Cooperative Geologic Mapping Program (STATEMAP) has provided the Iowa Geological Survey (IGS) with an avenue to conduct detailed geologic mapping across Iowa. For more than a decade the IGS has taken a paired mapping approach where each selected area, quadrangle or county, is mapped for surficial and bedrock geology simultaneously. This approach has allowed for IGS mappers to share mapping efforts such as combined field work activities, updated well point data, and revised bedrock topography, which facilitates a more efficient use of STATEMAP funding and generating more valuable mapping products.

The Bedrock Geologic Map of Iowa (Witzke et al. 2010) serves as the standard by which all subsequent geologic maps in Iowa are measured, providing a robust foundation from which to build. However, at a mapping scale of 1:500,000 many stratigraphic units had to be mapped at the group level. For example, the Devonian Cedar Valley Group consists of four formations: Little Cedar, Coralville, Lithograph City, and Shell Rock (in ascending order). Recent STATEMAP projects in north-central Iowa have split the Cedar Valley and underlying Wapsipinicon groups into their respective formations on quadrangle-scale (1:24,000) and county-scale (1:100,000) maps. Not until mapping in Mitchell County, Iowa, in 2014 had the IGS been faced with the opportunity to map an area of Iowa that abutted an area of a neighboring state that had already been mapped at a high resolution.

Mower County, Minnesota, is situated immediately north of Mitchell County, Iowa (Figure 1). The geology of Mower County was mapped in 1998 by the Minnesota Geological Survey (Mossler, J.H. 1998) as part of the County Geologic Atlas program. The program aims to compile, assess, and interpret all near-surface and bedrock geologic information that is then utilized by the Minnesota Department of Natural Resources (MDNR) to incorporate into their hydrogeological assessments. The majority of the bedrock surface of Mower County is comprised of Middle Devonian rocks of the Cedar Valley and Wapsipinicon groups (Figure 1). The map does identify formations that correspond with the revised Devonian stratigraphy defined by Witzke et al. (1988), which are the same units that the IGS uses when mapping the Cedar Valley and Wapsipinicon groups.

The primary difference between the Bedrock Geologic Map of Mitchell County, Iowa (Clark et al. 2016) and the Mower County map is that each bedrock formation is its own map unit, whereas the Mower County map units lumped some formations together when insufficient data precluded their separation. The Mitchell County map relied heavily on lithologic logs from well chip samples whereas the Mower County map utilized down-hole geophysical logs as the primary subsurface data source. Producing maps based on different data types can make edge-matching difficult. If compiling "seamless" geologic maps is in our future, figuring out how to work around differing data sets and interpretations will need to be a priority.

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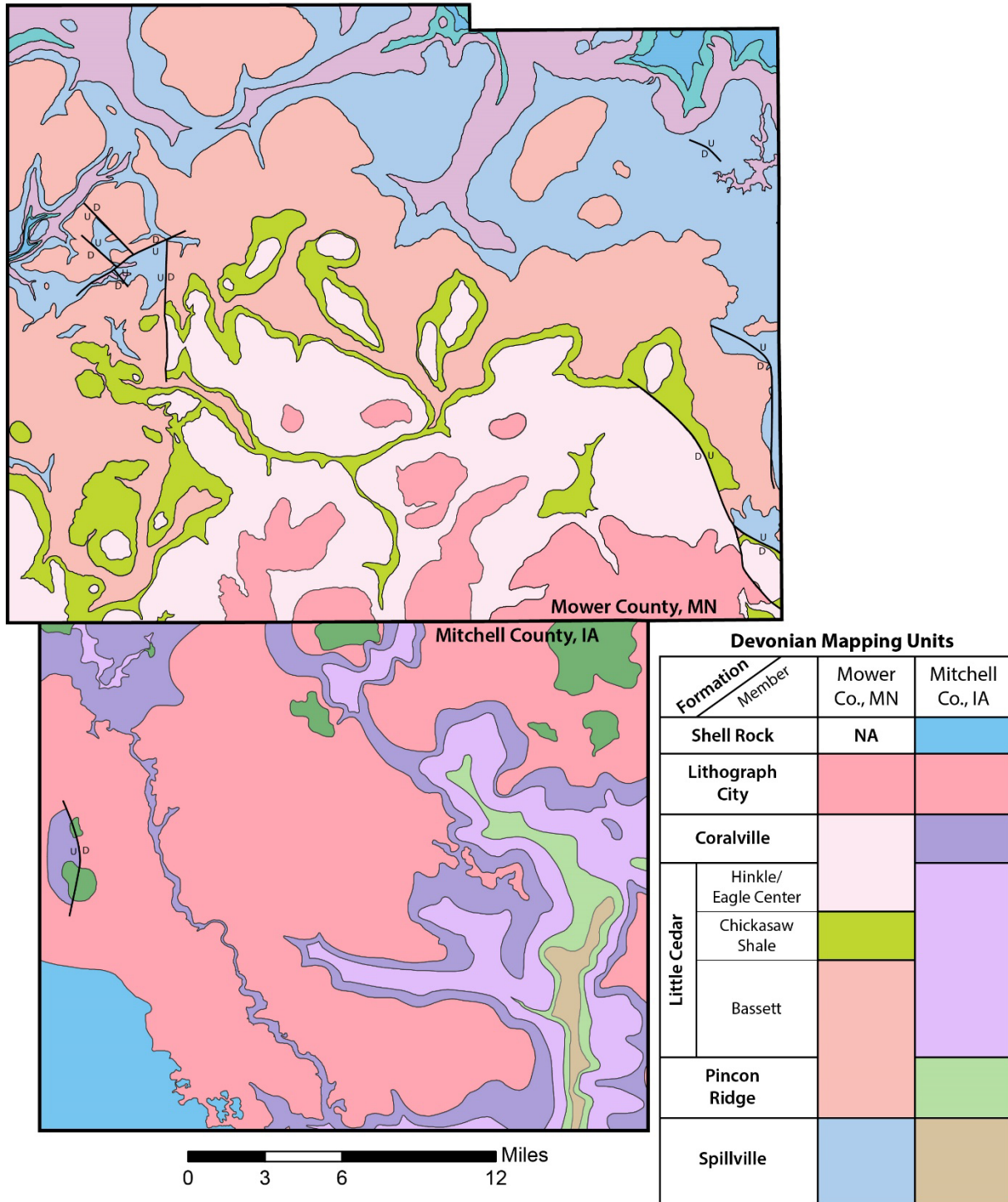


Figure 2: Bedrock geologic maps of Mower County, MN (top, modified from Mossler, 1998) and Mitchell County, IA (bottom, modified from Clark et al., 2016). Devonian bedrock units dominate each map, however, there are differences in how each map displays the Devonian mapping units. Dark green patches on the Mitchell County map are undifferentiated Cretaceous outliers. Cretaceous mapping units are not shown on the Mower County map. Black lines on both maps represent faults with up/down thrown blocks indicated with “U” and “D”.

Talk: GEOLOGIC MAPPING IN YOUR U.S. NATIONAL PARKS; 21 YEARS OF SUCCESS STORIES WITH USGS, AASG, AND ACADEMICS TO MAP PARKS, AND READY TO IMPLEMENT “INVENTORIES 2.0”

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Beginning in 1998, The U.S. National Park Service (NPS) implemented the Geologic Resources Inventory (GRI) Program as part of their Inventory and Monitoring (I & M) Program to obtain much needed datasets related to park specific geology for 270 “natural area” parks (today there are 419 total units). This included producing a digital geologic map (GIS-based), an encompassing geologic report on each park’s features, issues and processes, and a comprehensive geologic bibliographic reference list of known publications related to the parks geology. To-date (April 2019) for the natural area parks, 265 / 270 maps are completed, and 175 / 270 reports are published with accompanying geologic bibliographies; all are discoverable and downloadable from <https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm>

The geologic mapping initiative was initiated in 1998 with initial test piloting of a scoping process for NPS areas in Colorado, Utah, and North Carolina. The fruits of that process led to very successful relationships with the USGS, Colorado-, Utah- and North Carolina Geological Surveys, as well as numerous academics, and paved the way for the development of a robust Geology GIS-based data model that has been discussed at numerous forums over the years (annual Geological Society of America meetings, Digital Mapping Techniques, ESRI user conferences, etc.). Because NPS units occur over varying geologic terranes (active glaciers, paleontological resources, geothermal areas, volcanoes, shorelines, Colorado Plateau, coral reefs, cave and karst, lakes, arches, faults, etc.) it became necessary to often be pioneering in how best to capture these various attributes schema-wise. To this end, the NPS began another successful partnership with Colorado State University, whose staff have helped us develop a very robust digital geologic map model to portray geologic features adequately in the digital GIS arena, that is constantly evolving with the need to portray new geologic attributes, as well as keeping up with the latest software versions, and using the best available technologies to simplify the portrayal of geologic maps (Google Earth visualization). The joint NPS-Colorado State University Geology Data Model can be found at <https://www.nps.gov/articles/gri-geodatabase-model.htm>.

Over the years, NPS used best available “geologic” maps that featured varying amounts of detail to portray bedrock, surficial, geomorphology, geologic hazard, coastal, etc., as well as variable scales (1:24,000; 1:100,000; 1:250,000 etc.) to accomplish the goal of providing geologic mapping for parks. In the lower 48 states and territories, larger-scale data (>1:100,000) was the target; in Alaska, often a coarser scale (1:250,000) was relied upon. As time goes on, in areas where we used coarser data and variable detail of bedrock, surficial, and other features, we hope to refine and improve both on scale and detail as well as utilize more soil information to assist in resource characterization, understanding of the subsurface, and overall management of park resources.

Additionally, the NPS recognizes the need to provide for visitor safety with proper knowledge and identification of geologic hazard areas for properly citing infrastructure (visitor centers, trails, roads, etc.) and protecting millions of visitors annually. To accomplish this, large-scale, best available technology (LIDAR, 3-D, etc.) for adequate geologic mapping of bedrock and surficial units (as well as soils) to portray hazards is becoming increasingly necessary, and is a goal of the next major NPS initiative with regards to inventory and monitoring, currently termed “Inventories 2.0”. This initiative will allow for new scoping opportunities to address the creation of hybrid maps that help to manage various “geo” resources, and will require assistance from entities like USGS, AASG and academics. 3-Dimensional mapping is of great interest to the NPS, and these Geologic Mapping Forum meetings are providing a path to that end. The NPS looks forward to partnering again in the future with entities interested in helping us create powerful state of the art tools to best showcase and manage our nations spectacular geologic heritage that is contained in NPS sites.

The NPS has recorded webinars (less than one hour) on both the service-wide Geologic Resources Inventory and Soil Resources Inventory for those interested in delving into greater detail on current NPS efforts in these arenas as follows:

GRI: The NPS Geologic Resources Inventory (March 2014): Practical Geologic Products for Normal People:
<https://youtu.be/cxUe7iLgMmM>

SRI: NPS Soil Resources Inventory (July 2018) https://www.youtube.com/watch?v=TEqLv09rH_s&feature=youtu.be

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Plenary: THE EARTH RESOURCES MAPPING INITIATIVE (EARTH MRI)—FIRST STEPS OF A LONG-TERM EFFORT TO SECURE CRITICAL GEOLOGIC FRAMEWORK INFORMATION FOR THE NATION

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The U.S. Geological Survey (USGS) is embarking on a new effort, the Earth Resources Mapping Initiative (Earth MRI), in partnership with State geological surveys and industry that will acquire new geologic maps, geophysical surveys, and lidar data to better understand the fundamental geologic framework of areas across the Nation with potential for hosting critical mineral resources. Initially, the Earth MRI will focus on preserving and making available to the public geologic information currently held by the State geological surveys relevant to mineral deposits that host critical minerals. New data acquisition will concentrate on regions that have potential for hosting mineral deposit types that contain rare earth elements (REEs) as co- and by-products. The USGS has developed a series of maps that highlight areas with known or suspected REE-rich nonfuel mineral deposits. Ten nonfuel deposit types were considered, of which five were chosen for further investigations on the basis that, if developed, would have the potential for making the largest impact on the Nation's supply of REEs. The initial deposits include those associated with carbonatites and peralkaline rocks, iron oxide-apatite deposits, monazite-bearing placers, and REE-enriched phosphorites. In subsequent years, Earth MRI will expand to include mineral systems that contain other critical mineral commodities. Information acquired through this initiative will also advance our mineral resource datasets and understanding of other economically valuable mineral resources (such as copper, zinc, gold, and industrial minerals), energy and groundwater resources, and geologic hazards. It will also provide critical geoscience information that addresses other pressing societal issues and needs, such as identifying earth resources needed for revitalizing the Nation's roads, bridges, and other infrastructure systems. A general description of the Earth MRI effort can be found at <https://pubs.er.usgs.gov/publication/fs20193007>.

Talk: BACK TO BASICS: QUALITY MAPPING WITH FUNDAMENTAL TECHNIQUES

Jeffrey Crews, Trevor Ellis, and Vicki Voigt, Missouri Geological Survey

Bedrock mapping throughout the state of Missouri is a core mission of the Missouri Geological Survey (MGS). The collection and analysis of high-precision field data is critical to the production and quality of bedrock maps. Maps are compiled with new data collected in the field and with historic data housed at MGS. Staff is currently integrating new technology for field data collection. In-situ data collection methods have advanced and paper maps, notebooks, and cameras are now augmented by tablets that allow field notes, locational data and photos to be accurately captured in a single device. In-house data is evaluated for additional information to augment the quality of mapping products.

Geologic mappers at MGS use a variety of methods to analyze field data collected while mapping to provide a more detailed interpretation of local geology. Biostratigraphic analyses, thin sections, and core drilling provide valuable insights when discriminating between similar map units or map units that exhibit high variability. Throughout the 2017-2018 field mapping season, biostratigraphic analysis was useful in discerning Kinderhookian-age strata from Meramecian-age strata. Previously unrecognized outliers of unexpected map units were also identified by conodont analysis. Thin sections of various map units identified trace minerals, textures, and fossils within the units, providing insights on depositional systems and histories of the units.

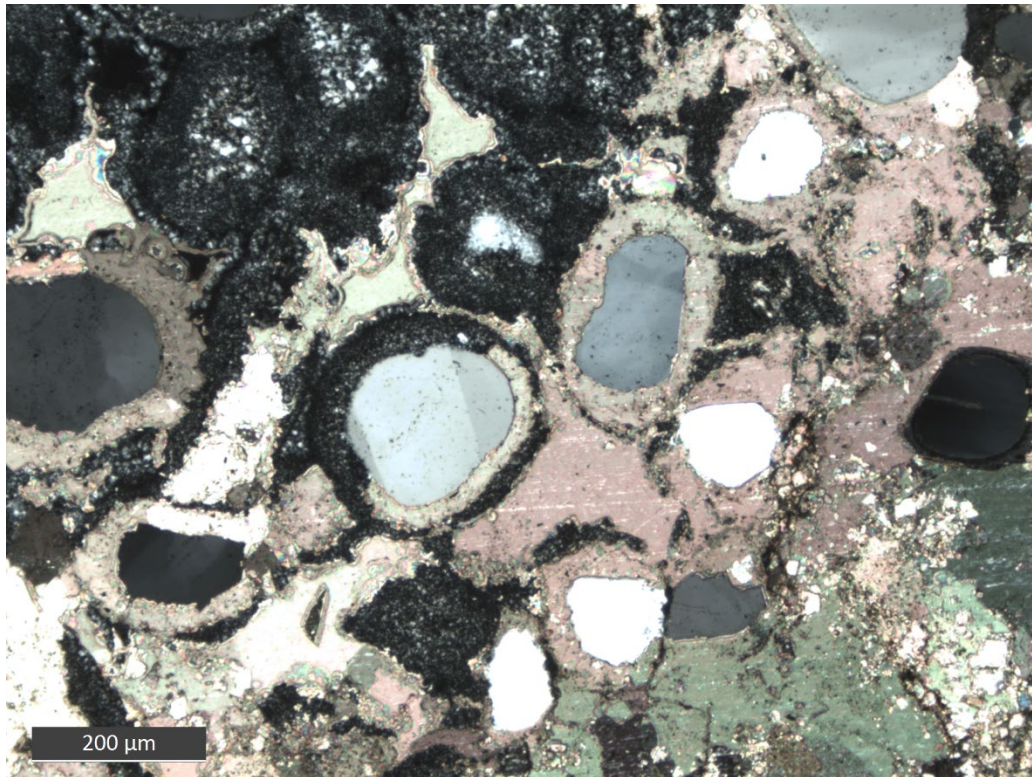


Figure 1. Photomicrograph of Cedar Valley Limestone. Crews. 2018



Figure 2. Example conodont after digestion of sample. Courtesy Dr. David Bridges, MGS

Currently, MGS mappers are working in areas that have little to no topographic relief and map units form poor outcrops. Interpretation of in-house data is proving to be valuable for supplementing map data that cannot be seen or collected in the field. Cuttings from water wells allow for defining or reinterpreting stratigraphy and stratigraphic boundaries. Drill core obtained on the quadrangles allows for the detailed study of the units as well as the compilation of the local stratigraphic section. Academic and professional studies, including M.S Theses and project-specific reports, provide insights into lithologies, thickness of bedrock units, and structural features. Numerous MGS databases provide mappers with a large volume of geologic information including measured sections, historic mining and quarrying efforts, surficial material thickness, and karst features.

MGS continually aims to improve mapping products through the inclusion of clear and concise data. Continued advancements in data-collection technology as well as the inclusion and reinterpretation of in-house data allow for the most comprehensive geologic interpretations.

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Talk and Poster: GEOSPATIAL FRAME DATA MODEL TO SIMPLIFY DIGITAL GEOLOGICAL MAP COMPILATION AND INTEGRATION

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Since 2005, when the British Columbia Geological Survey first completed digital coverage of bedrock geology for the entire province, we have been faced with the challenge of integrating new field mapping into our corporate database. Digital maps in the Earth sciences have long-used polygons to define bedrock units. However, polygons are prone to topological errors when used to compile, update, and integrate digital maps. These errors include gaps, overlaps, slivers, and discontinuities in the data that are hard to detect and fix. Using polygons also makes it time consuming to reconcile geometric differences at shared boundaries such as faults. To avoid these problems, we developed a geospatial frame data (GFD) model that dispenses with polygons at the map compilation and integration stages. Instead, the GFD model consists only of two data components: centroids describing geological units, and lines defining geological boundaries. Polygons representing geological units are not part of the GFD but are generated from GFD at the data production stage in the finished map products. Implementing the GFD model in a spatial database allows us to develop a fully automated data 'checkout' process and 'anchoring' mechanism to simplify data integration and eliminate boundary problems when maps are updated and merged. With only linework and point geometries, GFD also simplifies other processes, such as map generalization, without losing data integrity or introducing topological errors. Furthermore, the bedrock polygons in finished maps are the result of spatial database 'views' or 'materialized views' of the GFD data. These 'views' and 'materialized views' can be used to customize a map by, for example, reducing coordinate precision, re-projecting the map coordinate system, simplifying lines, and generalizing bedrock units, without changing the source data in GFD.

The GFD data checkout process first extracts the geology that extends beyond the limits of new work and includes all units and structures that may be affected (Figure 1). The outermost boundaries of this extended area are then tagged as 'anchor lines', the nodes on outermost boundaries are tagged as 'anchor points', boundaries connecting the anchor points are tagged as 'rode lines', and bedrock units as points are tagged for 'revision' (Figure 2A). Then, all the data within the extended area, including the GFD data components and the bedrock polygons, are extracted and packaged for update (Figure 2B). When update is complete and ready for integration, the first step is to retire the GFD data components in the corporate database (Figure 3A). After anchor lines in the updated GFD package are removed, the new geology is then uploaded into the corporate database. Rode lines in the updates are snapped to the anchor points in the corporate database (Figure 3B). The geological map products with bedrock polygons are automatically updated when the database view or materialized view are refreshed from the updated corporate database.

The GFD data checkout process leaves no room for introducing topological errors because polygons are not split when data are extracted, and there is no edge matching between polygons in map integration. It also reduces the risk of introducing unit or structure discontinuities at the map boundaries. The GFD model can be applied to any discipline that uses polygons and lines in digital mapping.

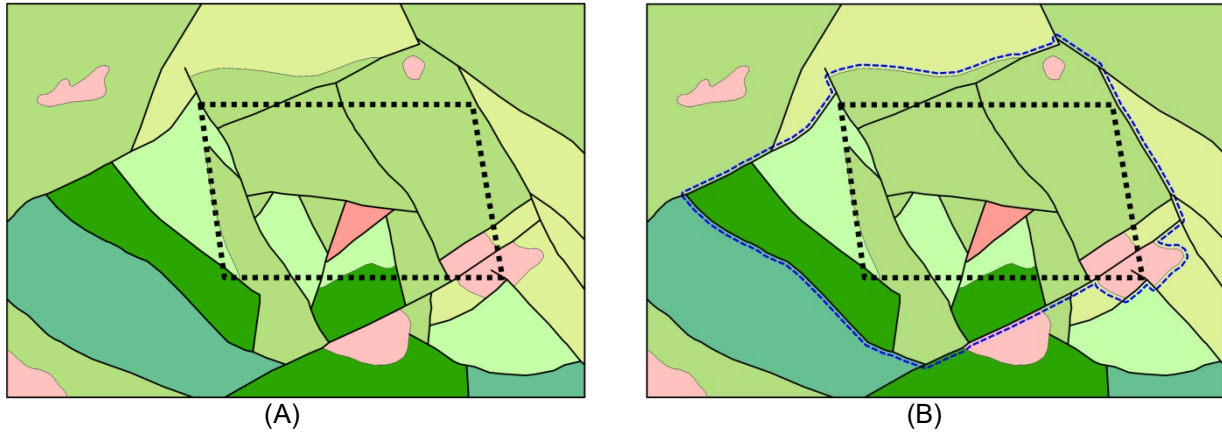


Figure 1. GFD data 'checkout' step 1. (A) Limit of new mapping shown as black dotted line is used to intersect bedrock units and structures. (B) Buffer area (blue dashed line) extends beyond the limit of mapping and includes all units and structures that might need revision.

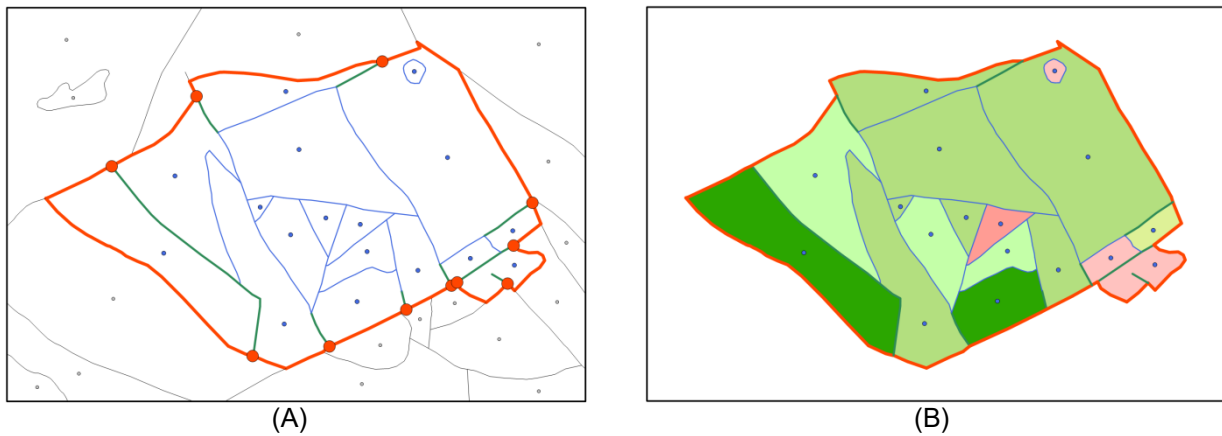


Figure 2. GFD data 'checkout' step 2. (A) GFD data components are tagged as anchor lines (in red), anchor points (red dots), rode lines (in green), and bedrock units are tagged for revision (dots in blue). (B) The GFD data components and bedrock polygons are extracted.

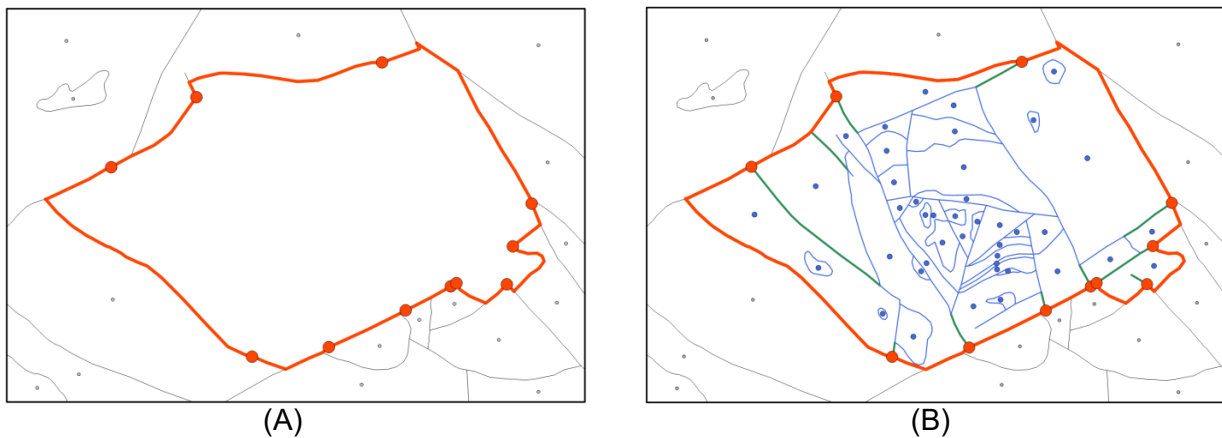


Figure 3. Data integration processes. (A) Outdated GFD data components are retired from the corporate database. (B) Updated data are loaded to the corporate database, and rode lines (in green) are snapped to anchor points (red dots).

Poster: TOWARD INTERNATIONAL GEOSCIENCE STANDARDS AND INTEROPERABLE WEB SERVICES FOR BRITISH COLUMBIA GEOLOGY AND MINERAL RESOURCES

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The British Columbia Geological Survey (BCGS) is implementing the international geoscience standard GeoSciML and its extension EarthResourceML, to deliver geoscience data products and to develop interoperable geospatial web services compliant with these standards. As a first step, the bedrock geology map of the province is available in the Web Map Service (WMS) interface, using vocabularies adopted by the IUGS Commission for the Management and Application of Geoscience Information (CGI). We also have mineral occurrences from our MINFILE database available as WMS, compliant to EarthResourceML Lite, with details converted to the CGI vocabularies. Our next step is to make these data available on OneGeology, the portal for worldwide geoscience data. Our current geology and mineral occurrence data are maintained using BCGS specifications in data collection, compilation, and data production, and will continue to be accessible through MapPlace 2, the Survey's geospatial web service. However, it will take significant effort and time to have our data, specifications, and web services fully compliant with the international geoscience standards. We take this as an opportunity to update our data models and specifications, to produce consistent data with standardized classification systems and terminology, and to eventually enable interoperability in data sharing, data exchange, and data integration.

Commonly, different classification systems and terminology are used to capture geology and mineral occurrence data, causing difficulties in data sharing, data exchange, and data integration. At the British Columbia Geological Survey, we integrate data not only from our mapping projects, but also from other groups such as the Geological Survey of Canada and universities. Inconsistent and incompatible geologic and mineral occurrence data will prevent advanced computation including machine learning at scales expanding multiple jurisdictions or globally. To address these issues, the Open Geospatial Consortium (OGC) has published open standards on geospatial data and interfaces to enable interoperability and data exchange. Based on the OGC Geography Markup Language (GML), the International Union of Geological Sciences (IUGS), through its sub-committee Commission for the Management and Application of Geoscience Information (CGI), developed international geoscience standard Geoscience Markup Language (GeoSciML) and its extension EarthResourceML.

GeoSciML is a data model and data transfer standard for exchanging digital geological data, from basic map data to complex relational geological features, based on GML. The latest version of GeoSciML (4.1) was accepted by OGC and adopted by the IUGS in 2017. The IUGS-CGI provides vocabularies to encode geological details with standardized classification systems and terminology. To make it easier to implement, a simplified version of the standard, GeoSciML Lite, is available to deliver a small subset of the full GeoSciML model. GeoSciML Lite has simple map schema for geological units, faults, contacts, boreholes, geomorphological units, geological specimens, and site observations. EarthResourceML, an extension to GeoSciML, is designed to exchange digital mineral resource data, such as mineral occurrences, mines, and mining activities. The model can include details such as geological features, commodities, mineral resources and reserves, production of concentrates, refined products, and waste materials. To ease implementation, EarthResourceML Lite is simplified from the most recent version (2.0.1). OneGeology has a portal to deliver compliant geoscience and earth resource data globally.

The British Columbia Geological Survey has begun to test and experiment with implementation of the Lite versions of these standards. We have transformed our data models to the GeoSciML and EarthResourceML Lite models, and matched our bedrock geology and mineral occurrence classifications and terminology to the CGI vocabularies (Figure 1). The results are available as OGC Web Map Service (WMS) and Web Feature Service (WFS).

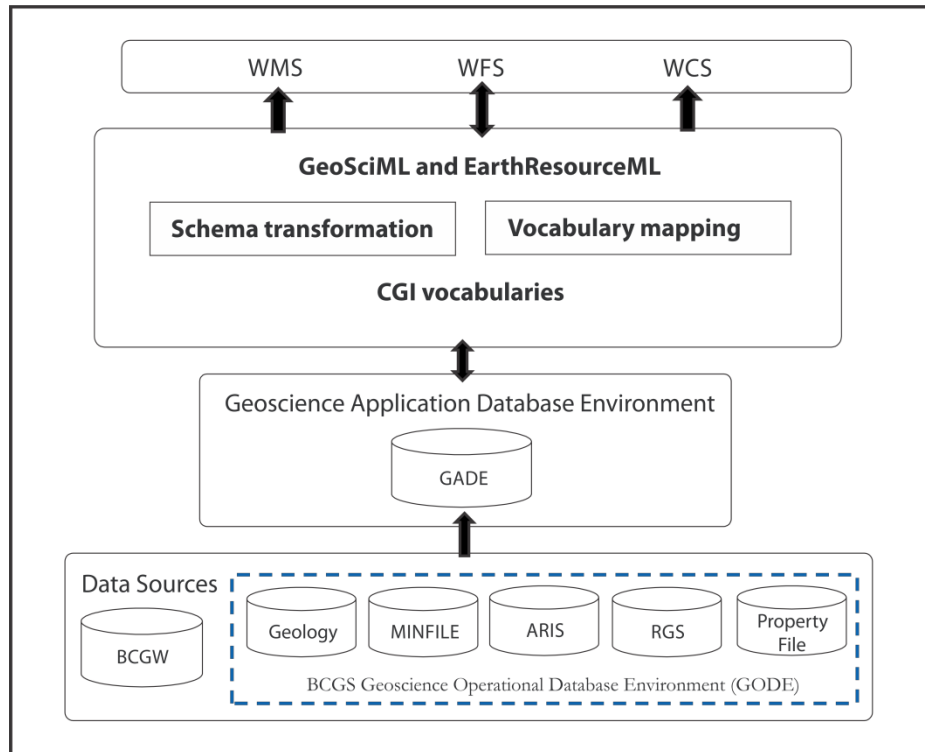


Figure 1. Transforming the British Columbia geoscience data models to the GeoSciML and EarthResourceML models, and matching bedrock geology and mineral occurrence classifications and terminology to the CGI vocabularies.

From our limited work, we recognize that significant effort and time are required to make our data fully compliant to the GeoSciML and EarthResourceML models and the CGI vocabularies. Some of the BCGS data lack certain feature types and requirements set out in the international geoscience standards. For example, in our mineral occurrence inventory database, start and end dates of mineral exploration may be lacking. Similarly, the simplified Lite versions and CGI vocabularies lack terminology to adequately represent all our data. For example, the CGI vocabularies for rock types and ages are simple and unable to represent heterogeneous rock units or those that formed during a protracted time span.

Although WMS is useful, it requires the technical capacity at the client side to build sophisticated information systems and benefit from WFS and WCS. There are many challenges in exchanging data at the feature or coverage levels, including impediments in web-based authentication. Currently the OneGeology portal is slow and its functions are rudimentary. Most geological maps available on OneGeology are at scales of 1:1 million or smaller, which are of limited use to the mineral exploration and mining industry. Nonetheless, we remain optimistic about future developments, and the British Columbia Geological Survey will continue to contribute to the OneGeology effort.

This poster presentation is available for download from this link:
<https://www2.gov.bc.ca/gov/content?id=4A39AD525D2444DDACB0DCC01E046EAA#GF2019-09>.

Poster: STRABOSPOT DATA SYSTEM FOR GEOSCIENCE RESEARCH AND DIGITAL MAPPING

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Abstract

StraboSpot is a geologic data system that is designed to allow researchers to digitally collect, store, and share both field and laboratory data (Walker et al., 2019). It was designed originally for structural geology data, and the program is available (without cost) to the community. It is being expanded to field-based sedimentology, field-based petrology, experimental deformation, and – importantly – thin sections. The field-based sedimentology and petrology will launch in Fall 2020, although both will be available in beta versions for Summer 2019.

The data system uses two main concepts - spots and tags - to organize data. A spot characterizes a specific area at any spatial scale of observation. Spots are related in a purely spatial manner, and consequently, one spot can enclose multiple other spots that themselves contain spots. Spatial data can thus be tracked from regional (100 km) to microscopic scale (nano-m). Tags provide conceptual grouping of spots, allowing linkages between spots that are independent of their spatial position. A simple example of a tag is a geologic unit or formation. Multiple tags can be assigned to any spot, and tags can be assigned throughout a field study. The advantage of tags is their flexibility, in that they can be completely defined by individual scientists. Critically, tags are independent of the spatial scale of the observation. Tags also can be used for more complex and complete descriptions in the way lookup tables are used with GIS and databases. Examples include the naming of orogenic events (e.g., Laramide) or concepts such as enveloping surfaces (for fold trains). Finally, tags can be modified as additional information is collected.

The StraboSpot data system uses a graph database, rather than a relational database approach. This approach increases its flexibility and allow the system to track geologically complex relationships. StraboSpot currently operates on two different platform types: (1) a field-based application that runs on iOS and Android mobile devices, functioning in either Internet-connected or disconnected environments; and (2) a web interface (Internet-connected settings only).

We are presently engaged in incorporating field-based (sedimentology, petrology) data types into StraboSpot. Based on community feedback, these two additions have required a complete redesign of StraboSpot field interface (StraboSpot 2 – a prototype is in development). The strength of the StraboSpot platform is its flexibility, and it can be linked to other existing and future databases in order to provide integration with other digital efforts in the geological sciences. The StraboSpot data system – in coordination with other digital data efforts – will allow researchers to conduct types of science that were previously not possible.

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Talk: Mineral Potential Evaluation in Support of Sound Natural Resource Management

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Minnesota's Commissioner of Natural Resources administers state-owned mineral rights as a fiduciary for University, School and Tax Forfeit trust lands, as well as mineral rights of lands acquired for state natural resource program purposes. Together, some 12,000,000 acres (300,000 parcels) of mineral rights are managed by the Department of Natural Resources (DNR). To support sound management of this land asset and land value portfolio, DNR's Lands and Minerals Division provides mineral potential evaluation reviews for state land real estate transaction proposals, which include sales, exchanges, acquisitions, leases, licenses, easements, condemnations, and restrictive use designations. The goal is to maintain access for the discovery of mineral resources and to direct encumbering activities, where possible, into areas having low mineral resource potential. Mineral potential management practices are similar to other natural resource best practices: avoid impact where possible, minimize impact where unavoidable, and require mitigation for unavoidable loss. Mineral potential evaluation activities in Minnesota inform private sector investment decisions involving billions of dollars, inform agency land use decisions involving billions of dollars of land assets, and inform multi-million dollar research investment decisions made by university and other research organizations. These evaluation activities rely heavily on geoscientific maps, data and interpretations compiled by state, national and international geological surveys and institutions; and require productive analysis in an environment containing significant uncertainty. Essential ingredients for mineral potential evaluation are fourfold: an **occurrence layer**, which depicts locations of known mineralization; a **geologic map**, which controls extrapolation of occurrence locations into under-sampled areas; a **mineral deposit model**, which outlines characteristics of occurrence; and a **rating system**, which classifies resource potential and attendant uncertainty. Mineral potential evaluation projects, whether qualitative or quantitative, produce a rating of the likelihood that a mineral deposit exists in an area, and a rating of the potential consequence of such occurrence. Together, these ratings inform a land investment decision of some type ranging from exploration to real estate transaction to special use designation. With respect to the occurrence layer, dimension of occurrence has become a clean and reliable means for classifying, mapping and communicating occurrence status at sites of known mineralization (Table 1). For dimensional perspective, at the scale of a mine, a grab sample is effectively a zero-dimensional point. Table 1. A classification of mineral occurrence at levels lower than a Mineral Resource, based on dimension of occurrence (at the scale of a mine). Modified from classification approaches used by Ontario Geological Survey (Wilson et al, 2008), and British Columbia Geological Survey MINFILE (2007).

Occurrence Status:	Rate of Occurrence:	To Reach This Status:	Definition Notes:
Deposit (3-D)	1 in 10 zones	Infill/step out	A deposit is a site of mineral occurrence that has achieved a 3-dimensional volumetric estimate based on intercepts, expressed in terms of grade and tonnage.
Zone (2-D)	1 in 10 intercept sites	Delineate extent	A mineralized zone is a site of mineral occurrence that has identified a 2-dimensional area of intercept, and is prospective for volume.
Intercept (1-D)	1 in 10 showing sites	Discover thickness	An intercept is a site of mineral occurrence that intercepts occurrence grade material over an interval length typically greater than 1 meter (approaching the range of minimum mineable width).
Showing (0-D)	1 in 10 anomaly sites	Discover in situ	A showing is a site of found (<i>in situ</i>) mineralized material, sufficiently enriched to show that a mineral system has acted with intensity to yield material of interest, though the dimension of occurrence is unresolved.
(Anomaly)*		Detect target(s)	Anomalies are geophysical, geochemical or geologic features that may be associated with or point toward a site of mineral occurrence.

*Anomalies are not mineral occurrences. The entry is included only to distinguish *in situ* showings from anomalies.

With respect to the rating system, Likelihood-Consequence diagrams as used in the ISO-31000 international risk management framework, slightly modified for mineral potential use (Figure 1), have proven particularly suitable for communicating mineral potential ratings, which are typically logarithmic, against other ecological, economic and social ratings systems which are typically linear. The advantage of the likelihood-consequence framework is that it provides a visual tool for comparing low probability-high consequence portfolio values like mineral potential against higher probability-lower consequence portfolio values. The mineral occurrence classification described in Table 1 can be directly appended to the right side of the likelihood-consequence diagram to help provide this comparison.

With respect to the geologic map, it is becoming increasingly important to provide map users with both the factual basis of the map (with its uncertainty) and the modeled/interpreted geology (and its uncertainty). Some type of sensitivity analysis for the various map factors would help both users and compilers better work within data quality bounds, without overstepping data resolution and geologic interpretation.

With respect to deposit models, deposit models are great (they rock!).

Likelihood of Event		Consequence (financial) for a 40 acre parcel					
		Insignificant \$1,000	< Minor \$1,000 - 10,000	Moderate \$10,000 - 100,000	Major \$100,000-\$1million	Highly Significant \$1 million - \$10 million	Exceptionally Significant \$10 million - \$100 million
~ 1 in 1	Almost Certain			Timber	Peat	Aggregate	Metallics
≥ 1 in 10	Likely	Moderate	Moderate	High	High	Critical	Critical
≥ 1 in 100	Possible	Low	Moderate	Moderate	High	High	Critical
≥ 1 in 1,000	Unlikely	Low	Low	Moderate	Moderate	High	High
≥ 1 in 10,000	Rare	Inconsequential	Low	Low	Moderate	Moderate	High
≥ 1 in 100,000	Exceptionally Rare	Inconsequential	Inconsequential	Low	Low	Moderate	Moderate

Figure 1. A Likelihood-Consequence diagram, modified from ISO-31000 examples, calibrated for mid-spectrum landowner royalty values on 40 acre parcels. For management purposes note the addition of iso-risk contour lines in this modification of the diagram, and note that each colored category crosses an area two magnitudes in likelihood by two magnitudes in consequence.

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Poster: INSIGHTS INTO MESOZOIC CONTRACTION, CENOZOIC EXTENSION, MINERALIZATION, AND EARTHQUAKE HAZARDS FROM GEOLOGIC MAPPING OF THE PEQUOP MOUNTAINS, NE NEVADA

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The Ruby Mountains-East Humboldt Range (REHR) metamorphic core complex, and adjacent ranges including the Pequop Mountains, in NE Nevada expose a unique crustal section that records a history of Mesozoic contraction and Cenozoic extension in the North American Cordillera (Coney and Harms, 1984). Our geologic mapping in the area, largely supported by the USGS STATEMAP program, is focused on addressing basic and applied research questions, including: 1) age and magnitude of crustal thickening as part of an inferred Mesozoic orogenic plateau, 2) timing of Cenozoic extension and orogenic collapse, 3) origin of Carlin-type gold deposits within the study area, and 4) characterization of earthquake hazards along range-bounding Quaternary faults. Resolving these questions requires detailed geologic mapping to elucidate critical field relationships and sophisticated analytical methods to test geologic models.

Various tectonic models dispute the timing, magnitude, and style of Mesozoic crustal thickening in NE Nevada (e.g., Thorman et al., 1991; Camilleri and Chamberlain, 1997). The REHR core complex is integral in this complex history, but different investigative approaches yield numerous disparate interpretations. For example, classic geobarometry studies suggest deep Mesozoic peak burial (>20-30 km) of the Paleozoic stratigraphy (Hodges et al., 1992; McGrew et al., 2000), which is more than double the estimates from palinspastic reconstructions based on mapping and field relationships. These conflicting interpretations require dissimilar peak geotherms that vary by a factor of two: 20-25°C/km or 40-50°C/km. To resolve these discrepancies, we have conducted detailed geologic mapping in the least deformed eastern part of the REHR system in the Pequop Mountains. New 1:24,000 geologic mapping across three quadrangles, complemented by growing peak temperature (i.e., conodont alteration index and raman spectroscopy on carbonaceous material) and time (i.e., Ar-Ar and U-Pb dating) datasets, address these issues (Henry and Thorman, 2015; Dee et al. 2017; Zuza et al., 2018; and Zuza et al., 2019). Important observations include: (1) cross-cutting relationships suggest dominantly Jurassic contractional deformation with negligible Cretaceous shortening or related crustal thickening; (2) temperature-depth correlations are inconsistent with deep burial of Paleozoic stratigraphy; and (3) numerous small Jurassic, Cretaceous, and Eocene intrusions locally metamorphosed the Paleozoic section and led to a relatively high observed geothermal gradient (>40°C/km). This underappreciated Jurassic phase of deformation is probably coeval and kinematically related to deformation to the west, associated with Luning-Fencemaker thrusting (Wylde et al., 2002), and east in western Utah (Allmendinger and Jordan, 1984; Miller and Hoisch, 1995).

The history of crustal thickening has implications for the magnitude of subsequent Cenozoic extension and denudation of the REHR core complex. Traditional models of deeply buried Paleozoic stratigraphy require 20-30 km of denudation whereas shallower burial estimates require <15 km of exhumation. The timing of Cenozoic extension and tilting is constrained on the east side of the Pequop Mountains by 40°E dipping 41-39 Ma volcanic rocks that are concordant with underlying Paleozoic rocks (Henry and Thorman, 2015). The concordance of these volcanic rocks with uppermost Paleozoic rocks precludes major pre-41 Ma extension. West-dipping frontal faults along the range's west side accommodated extension since middle Miocene, based on thick deposits of that age containing megabreccia of footwall rocks (Dee et al., 2017). The existence and magnitude of extension between ~39 and 17 Ma are poorly constrained because of the lack of rocks in that age range but may be resolved by ongoing thermochronologic investigation.

The Long Canyon gold deposit in the eastern part of the Pequop Mountains greatly expands the known occurrence of Carlin-type deposits (CTD) geographically east and into a new geologic setting. Geologic mapping constrains the Long Canyon mineralization to an anticline that focused and trapped hydrothermal fluid flow. Mineralization is focused in reactive, ductile silty limestones where they flowed around less reactive, dolomite boudins. Similar structures are found throughout the Pequop Mountains and are likely Jurassic in age. The Long Canyon CTD has not been dated, but other CTDs are Eocene in age (~42-36 Ma; Muntean et al., 2011; Ressel and Henry, 2006), and the presence of Eocene rhyolite dikes and dacite lavas in the Pequops indicate an underlying pluton could have driven hydrothermal flow and associated mineralization.

Both the Pequop Mountains and the East Humboldt Range are bound by range-front normal faults with scarps in late Quaternary deposits. The Pequops are bound on the west by the Independence Valley fault zone with scarps up to 3 m high mapped in late Pleistocene alluvial fan deposits (Dee et al., 2017). The west side of the East Humboldt Range is bound by the Ruby Mountains frontal fault zone with scarps up to 7 m high in latest Pleistocene glacial outwash deposits (Dee and Ressel, 2016). The difference in scarp heights suggests significant variability in late Quaternary exhumation rates, earthquake recurrence, and associated seismic hazard for active faults in the area.

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Poster: GEOLOGIC FACIES MAP OF THE SOUTH CAROLINA COAST: WHERE DETAILED GEOLOGIC MAPPING AND DATABASES MEET

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In South Carolina, detailed geologic mapping at 1:24,000-scale is the basis for compiling regional scale maps. This new coastal compilation was produced using detailed geologic maps of 76 7.5-minute quadrangles and represents more than 30 years of mapping effort. Map data were collected from surface exposures, subsurface borehole drilling and lithologic logging. Facies assignments were determined from lithologic interpretations and include estuarine (mud, fine sand, and possible shell material), barrier island (fine-medium sand and shell material with possible cross- or planar-bedding), and fluvial (fine to very coarse sand with massive or graded bedding). In the past these units were referred to as formations, morphostratigraphic units or terrace-formations- all now classified as alloformations.

Previous work by Earl Sloan (1908), C.W. Cooke (1936), D.J. Colquhoun (1974), J.R. DuBar et al. (1974) were refined by R.E. Weems and W.R. Doar, III during their extensive mapping campaigns. One mapping goal was to provide reliable geologic maps for industry, researchers, land-use planners, the general public and land-use historians. For example, estuarine deposits commonly have low relief and drain poorly making them suitable for impounding water. A local land-use historian used our new regional compilation to identify areas likely used for impounding water at historic rice plantations.

To generate this compilation, detailed geological mapping data was assembled using GIS and the new USGS database model "Geologic Map Schema" (GeMS). GeMS takes GIS map data, including all information on standard geologic maps – geologic units, descriptions, ages, field observations, etc. – and relates it back to geospatial data. Then using GIS, the geologic units were queried, grouped, and colored by age and depositional environment. The maps were compiled in a short period of time and the output is this facies map. This compilation demonstrates the power of robust map databases populated with detailed geologic data and GIS.

Plenary: AIRBORNE GEOPHYSICAL SURVEY DESIGN FOR GEOLOGIC MAPPING

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When designed properly, airborne geophysical surveys are a highly cost-effective way to provide physical property information (magnetic properties, electrical resistivity, density, radioelement properties etc.) that are related to geology. Geophysical data directly assist geologic mapping at both the ground surface and at depth. Simply put, airborne geophysics is foundational for constructing 3D geologic models that can be used to address society's geoscientific needs.

Multiparameter surveys can be a powerful tool, simultaneously acquiring multiple types of geophysical data from the same airborne platform. Such surveys offer the possibility of mapping geology at a range of depths from surficial deposits to covered crystalline basement, and addressing a variety of different issues that may include water quantity and quality, hazards, minerals, and more. It is natural to consider such possibilities in the context of EarthMRI, a new program providing support for airborne geophysical surveys in addition to geologic mapping and lidar. But how are airborne geophysical surveys, including multiparameter surveys, best designed to support geologic mapping? What are the strengths, limitations, and costs of different types (methods) of geophysical data? In what situations does it make sense to combine different methods on the same airborne survey?

Effective airborne survey design is focused squarely on the research needs that must be addressed— i.e., what aspect or aspects of the geology must be mapped?— as well as the overall geologic and topographic setting. Geophysicists and geologists need to work closely at this stage to ensure that the science questions and mapping goals come first, and then the choice of methods and survey design ideally follow. The topographic setting determines what type of aircraft must be used: gentle terrain permits the use of fixed-wing aircraft, but mountainous regions require a helicopter (at significantly greater cost).

The most commonly used airborne geophysical method is the magnetic method, in which passive measurements of the ambient magnetic field are used to map geology inferred from variations of rock magnetic properties. Using aeromagnetic data is a highly effective mapping tool in geologic settings that involve exposed or covered crystalline rocks (i.e., igneous and metamorphic rocks) or magnetic sediments (common in tectonically active regions). Aeromagnetic surveys are generally not useful for mapping weakly magnetized sedimentary rocks, such as the marine Paleozoic rocks common across the central US. Magnetic interpretation is mainly carried out in map view, which imposes requirements on the sampling of the magnetic field that must be met for the data to meet modern standards. Terrain clearances should be low (<150 m, for example), and the ratio of line spacing to the depth of shallowest anomaly-producing sources below the aircraft is ideally 1:1 and must not exceed 2:1 (Reid, 1980). Magnetic data are highly cost-effective to acquire. Fixed-wing magnetic-only surveys in the contiguous 48 states have recently cost \$5-\$10 per line km, with helicopter surveys \$35-\$60 per line km. The airborne geophysics component of EarthMRI is naturally focused mainly on magnetic surveys, because most critical mineral deposit types are found in crystalline rock settings amenable to magnetic mapping, and the surveys are relatively low cost.

The airborne electromagnetic (AEM) method is an active-source technique for investigating Earth's subsurface in support of geologic mapping, hydrologic, and infrastructure studies. AEM measures changes in electrical resistivity, which is often related to different sediments or rock types, pore-fluid salinity, or thermal state (i.e. frozen/unfrozen.) Interpretations provide depth-specific information that extend from a few meters down to 300-500 m below ground, depending on the characteristics of the instrument used. Results can be viewed as cross-sections or interpolated to depth slice maps and three-dimensional volumes. AEM data are often acquired by helicopter using slung-load systems with nominal instrument elevation 30 m above ground and typical cost from \$80 - \$300 per line km, depending on site logistics and survey size. Fixed-wing systems can be used for regional surveys in gentle terrain, with nominal terrain clearance approximately 150 m, and costs closer to \$50 per line km. Survey design considerations for AEM flight line spacing mainly consider the scale of features to be mapped, as opposed to the map-based spatial sampling rules that apply to magnetic surveys. Very high-resolution AEM surveys may have flight line spacing less than 100 m, and regional geologic mapping may have flight line spacing of 10 km or more. Geologic features with characteristic variability at smaller length-scales than the flight line spacing may be captured along individual cross-sections, but will not be mapped on interpolated depth slices. Simultaneous measurement of

magnetic data is almost always included in the cost of acquiring AEM, and radiometric data can be added at a nominal additional cost; however, it is important to consider the survey design requirements for magnetic data acquisition that may not be compatible with typical AEM flight line spacing.

Airborne gamma-ray (or radiometric) surveys measure the naturally emitted gamma radiation derived from three radioelements: K, U, and Th, via daughter radionuclides for the latter two. Gamma-ray surveys essentially yield geochemical maps of K, U, and Th; concentrations of these elements are primarily related to the mineralogy and geochemistry of rock and soil within the uppermost 30 to 40 cm of the regolith. Changes in the K, U, and Th of rocks and soils are often the result of a different lithology or alteration process that has affected the concentrations of these radioelements. Hence, gamma-ray surveys can be used for a wide range of applications, but the most common use is for helping produce geologic maps. The cost of adding gamma-ray measurements to other surveys is typically small, at a few dollars per line km. A properly designed airborne magnetic survey with the specifications such as described above will result in a gamma-ray survey that can be used to aid surface geologic mapping.

Airborne gravity gradiometry (AGG) is a relatively new method that involves passive measurements of the Earth's gravity field to map variations of rock density. AGG data are profoundly useful for geologic interpretation in areas where different rock types can be distinguished on the basis of density and have superior resolution compared to traditional gravity methods (both ground and airborne gravity). As with magnetic data, interpretation is carried out largely in map view, and the same sampling requirements apply to the survey design. Unfortunately, AGG data are rarely acquired to support public-domain research, due to very high costs. Fixed-wing AGG surveys in the contiguous 48 states commonly cost \$100-\$150 per line km, with helicopter surveys over \$250 per line km.

Lidar surveys provide high resolution digital elevation data, highly useful for a variety of geologic mapping and land use studies. Lidar data are also acquired from airborne platforms, and in principle can be acquired along with geophysical data. However, 3DEP-sponsored lidar surveys are normally flown at much higher terrain clearances (~2 km or more) than would be appropriate or useful for simultaneous geophysical data acquisition.

When considering a multiparameter survey design, careful consideration must be given to the mapping goals, the geologic and topographic setting, and the costs presented by different methods. In principle, multiparameter surveys are attractive because multiple issues, possibly including issues beyond those envisioned by the initial investigators, can be simultaneously addressed. Multiparameter surveys can also attract funding from multiple disparate sources that have different research goals and thus don't normally work together. However, in many geologic settings a geologically and economically sensible multiparameter survey design may not be possible. This situation commonly arises when different methods (i.e., mapping goals), with different flight specifications and different costs, are pitted against each other. In a simpler sense, even if the geologic setting is favorable, multiparameter surveys involving AEM and/or AGG can be very expensive, and thus are often limited by budgetary concerns alone.

The cost of a multiparameter survey is driven by the most expensive method(s) used. For common types of multiparameter surveys, this means that the high costs associated with AEM or AGG data are normally the driving and limiting factors, due to those methods having much greater costs than magnetics or radiometrics. For example, a fixed-wing survey that combines all four methods may cost \$150-\$250 per line km, depending on the survey size (larger surveys offer better value per line km). A large fixed-wing survey combining AEM, magnetic and radiometric data may cost \$50 per line km, whereas a large magnetic-radiometric survey will likely cost less than \$10 per line km.

The confluence of costs, geologic setting, and mapping goals comes into play when choosing the line spacing and terrain clearance for a multiparameter survey. A common conundrum arises with combined AEM-magnetic surveys in geologic settings that involve shallow magnetic anomaly sources. Magnetic (and AGG) surveys, with their spatial sampling rules, often require a tighter line spacing and somewhat higher terrain clearance than what makes sense given the cost and spatial sampling requirements of AEM data. Thus, the temptation is strong to break the magnetic spatial sampling rules and use a wider line spacing and lower terrain clearance that make more sense for the AEM economics. While the AEM data will be unharmed, the magnetic data quality will suffer. If the mapping goals indicate a need for high-quality magnetic data, then a better approach is to decouple the AEM and magnetic data acquisitions into separate surveys with different designs. The conundrum presented in this example is eased when the magnetic anomaly sources are buried more deeply, allowing the magnetically-appropriate line spacing to be relaxed.

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Poster: CREATING A 3D GEOLOGIC MAP OF AN AREA OF EATON COUNTY, MICHIGAN

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Many areas of Michigan have not had surficial mapping completed since Leverett and Taylor (1915) first mapped the state. Updating these areas using modern mapping techniques would be beneficial to further the understanding of glacial geology in Michigan. One such area located west of Lansing, MI contains the Hoytville, Needmore, Chester, and Charlotte 1:24,000 quadrangles (Quads). Updated mapping products using modern mapping methods and remote sensing (LiDAR) data tools is needed to support groundwater and natural resource assessments and management. Using an array of remote sensing and geotechnical information available, a 3-dimensional (3D) model and map will be produced in order to identify surficial stratigraphic units. These stratigraphic units can then be used to interpret and draw conclusions about the glacial history of the study area. Detailed 3D maps will also provide resource estimation tools for aggregate and groundwater resources, important for local industry. Such a mapping deliverable is also valuable to environmental professionals and regulators working on sites with current and potential contamination issues. All stakeholders would be better able to conceptually characterize the subsurface regime and site contamination if a detailed 3D geologic framework is available, leading to better informed decision making. Examples of the early results are presented at this time.

Surficial mapping is currently being conducted using LiDAR derived digital elevation models (DEM), soils, water well, and historical maps. Passive seismic (HVSr-Tromino) geophysical data area also being collected in the study area and being incorporated into the map to better define the glacial drift and bedrock interface. Additional subsurface information, in the form of rotosonic boreholes, is expected to be collected in the spring of 2019.

Once a surficial map is complete subsurface polygons will be created in 1.5-meter intervals down to the top of bedrock. Subsurface information used to map the packages include existing water well records, passive seismic data, and any other available subsurface information. These packages will be converted to raster surfaces and then extruded into the subsurface using the DEM as a datum. This will be the framework of the 3D model which will be used to interpret stratigraphic units.

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Talk: ICE-WALLED LAKE PLAIN DISTRIBUTION IN MICHIGAN

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Abstract

Before the availability of LiDAR in Michigan, Ice-Walled Lake Plains (IWLP) were rarely recognized in the state. IWLPs in Michigan are generally subtle so they typically are not easy to distinguish on 7.5 minute topographic maps, aerial photos or county soils surveys. In fact they are often unrecognizable even when standing in the middle of one. Recent surficial geological mapping and the increasing availability of LiDAR in Michigan made their identification possible. These supraglacial ice stagnation features appear as relatively flat to slightly bowl shaped plateaus slightly elevated above the surrounding morainal uplands. They have steeper outward facing ice-contact slopes down the surrounding land surface. Most occur on hummocky uplands, end moraines, with some on till plains. They are not found in outwash plains, glacial drainage-ways or lowlands.

They most commonly occur in clusters but occasionally are seen as a single isolated IWLP. Some are clearly distinct features and others appear as a compound IWLP made up of a number of coalesced IWLPs or as smaller satellite IWLPs within larger one. They come in a wide variety of sizes, averaging 43 acres (17.3 hectares) and shapes but are commonly rounded.

There is some debate as to their origins. One of the theories is that they form as a short-lived lake in a depression on a stagnating ice surface, where generally fine grained materials are deposited from the surrounding higher stagnating ice. Overtime as the glacier melts and as more sediment is deposited in the lake, eventually the lake sediments are deposited on the land surface resulting the elevated low relief plateaus above the surrounding land surface.

The IWLPs were digitized from LiDAR DEMs, hillshades, shaded relief, and slope maps. Often a simple grey scale color ramp of the DEM is effective for broad scale reconnaissance of IWLPs because they commonly show up as distinctly white because they are generally high on the landscape but also for their relative flatness. Only a handful of them have been cored and several have been hand augered, with textures widely ranging from clay to fine sand to coarse sand. OSL samples have been collected from two of them for age dating. There are features seen on the landscape that have an ILWP like appearance but tend to be flatter, lack the slight bowl shape and occur in lowlands, outwash plains, and glacial drainage ways. These pseudo-IWLPs likely are not IWLPs and probably have a different origin.

The Saginaw Lobe has significantly more IWLPs than the Lake Michigan and Huron Erie Lobes. Certain moraines or portions of moraines have IWLPs while others have none. They can be cored to find fossils for minimum age dating of the moraine the IWLP is sitting on. Because they occur in a distinct depositional environment, mapping their distribution assists in interpreting the glacial history of an area and may assist in differentiating subtle moraines and ice margins from others.

Plenary: THE ACQUISITION AND APPLICATION OF GEOLOGIC DATA FOR ENERGY RESOURCE ASSESSMENTS

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The U.S. Geological Survey's (USGS) Energy Resources Program (ERP) addresses the challenge of increasing demand for energy sources by conducting basic and applied research on geologic energy resources. This work includes research and assessments on the geology, geochemistry, and geophysics of oil, natural gas, coal, uranium, gas hydrates, and geothermal resources, including the produced waters associated with oil and gas drilling and production. USGS data and the results of USGS research are used to inform policymakers regarding domestic and foreign energy resources and to manage energy resources on Federal Lands.

The National and Global Assessment Project (NAGA) within the ERP conducts national and global research and assessments of undiscovered, technically recoverable oil and gas resources. In the U.S., these assessments are limited to the U.S. onshore and underlying State-owned waters. Resource assessments for petroleum resources in priority basins of the U.S. are based on a geologic-framework, necessitating a variety of geologic information for a robust basin-wide assessment. To conduct resource assessments in the subsurface, it is essential to obtain a range of geologic data; the USGS often obtains this information from state geological surveys, other federal agencies, publicly available and purchased databases, industry, and academia, as well as internally from USGS labs, publications and databases. These diverse datasets are integrated to create a regional geologic compilation in support of an assessment. Specific data that feeds these assessments include well logs, geochemical data, regional cross-sections, geologic maps, isopach- and structure-contour maps, seismic data and sedimentary basin models. The subsurface data are utilized to create maps of Total Petroleum Systems and Assessment Units, which are critical components of the USGS methodology for conventional and continuous (unconventional) accumulations.

For more information about the USGS Energy Resources Program:

energy.usgs.gov

Talk: GEOLOGICAL MAPPING IN BRITISH COLUMBIA: FROM THE FIELD TO YOUR DESKTOP

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British Columbia Geological Survey (BCGS) is British Columbia's oldest science organization, and after nearly 125 years, mapping remains a fundamental mandate of the Survey. The BCGS has adopted a mapping workflow from the field to public dissemination that is efficient, accessible, at no cost to the end user. Geological mapping remains a field based activity where the geologist is on the ground collecting measurements and samples, and documenting the relationships amongst various rock units and surficial materials. What has changed as a result of technology is how the data is captured and the portable analytical tools geologists have at their disposal. Like other geological institutions, the BCGS has embraced digital data capture through tablet GIS technology as the preferred way to navigate, display data in the field, collect new information, and map in real time. Once data is captured, samples analysed and integrated, and interpretation completed, maps are compiled and released as standalone products either as traditional hardcopy maps or digital products such as PDF files and GIS ready layers (polygons and points). From there, data is integrated into several of the publically available databases such as lithogeochemical, regional geochemical survey (RGS; mostly stream and lake sediments), geochronology, till geochemistry, ice-flow indicators, and coal ash chemistry. Ultimately, new geology is incorporated in to the provincial geological compilation through our geospatial frame data (GFD) model developed by the BCGS. These data are then made available through MapPlace our geospatial web interface that enables efficient browsing, displaying, searching, reporting, and generation of custom results from multiple province-wide geoscience, mineral resource and tenure databases. These data sources, including our bedrock geology, can be queried and supports computation. The BCGS is now focusing on moving these data toward international geoscience standards, allowing for more versatile integration into machine learning and artificial intelligence based applications. This workflow ensures industry, academia, and society's decision makers in government, communities, and the general public have equitable access to British Columbia's most recent geological information.

Plenary: SOIL DATABASES

David Hoover, Director, USDA-NRCS National Soil Survey Center, Federal Building, Room 152, Mail Stop 32, 100 Centennial Mall North, Lincoln, Nebraska 68508-3866, Dave.Hoover@lin.usda.gov

Utilizing the national soils database for science applications. Soils database structure (map unit, component, horizon). Methods of data aggregation (dominant component, dominant condition, most limiting layer, etc.). Examples of use of soils data in natural resource science projects, public health interpretations, urban applications, etc. Using the database in groundwater recharge modeling. Levels of expertise needed to use the databases and potential for assistance.

Talk: SOIL DATA JOIN RECORRELATION PROCEDURE

David Hoover, Director, USDA-NRCS National Soil Survey Center, Federal Building, Room 152, Mail Stop 32, 100 Centennial Mall North, Lincoln, Nebraska 68508-3866, Dave.Hoover@lin.usda.gov

What was the SDJR initiative and how has it set a standard for all future soils work. Life before SDJR – why it was so badly needed. Time frames. Technical approaches. QC and QA. Map and database adjustments. Immediate work versus long term field projects. Continued work after the initiative.

Talk: WORKSHOP ON THE DEVELOPMENT OF A VEGETATION, SOIL, AND GEOLOGY APP

David Hoover, Director, USDA-NRCS National Soil Survey Center, Federal Building, Room 152, Mail Stop 32, 100 Centennial Mall North, Lincoln, Nebraska 68508-3866, Dave.Hoover@lin.usda.gov

Brainstorming session on a merger of SoilWeb, EDIT, and ROCKD to a one-stop app for land resource managers (info from the sky to the Moho). Development of business requirements. Identification of subject matter experts. Identification of funding sources. Initial state measures versus single national ones.

Talk: LANDSLIDE INVENTORY AND MAPPING IN MINNESOTA

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Landslides in Minnesota present a natural resource management challenge by loading sediment to surface waters and have caused considerable damage to infrastructure and even loss of life. Emergency managers and planners have asked for information on landslides in Minnesota to incorporate into planning and mitigation strategies, but to date there has been no systematic mapping effort.

Recent events led to our focus on five study areas that cover most of the landslide-prone terrain in Minnesota: 1) the Mississippi River in southeast Minnesota where in August 2007, a year's worth of rain fell in 36 hours causing extensive slope failure; 2) the Minnesota River valley from New Ulm to Chaska where in June 2014, widespread landslides occurred after a two-week rainy period; 3) the Lake Superior watershed where in June 2012, a two-day rain event generated hundreds of landslides, extensively damaging Jay Cooke State Park and limiting access to the Thomson Dam, which was in jeopardy of failing; 4) the Red River Valley where weak clay soils frequently fail, undermining homes and roads, and 5) the 7-county Minneapolis/St. Paul metropolitan area where a rainy period in June 2012 resulted in landslides that caused two deaths.

A team of faculty, students, and researchers are characterizing the distribution, failure mechanisms, and frequency of landslides to provide the background for sound planning and mitigation decisions within the five regions. We are 1) developing an historical inventory of the locations of recent landslides, 2) identifying landslide scars from high-resolution lidar and derivative maps including red relief imagery created for this project, and 3) describing the types of landslides, their geologic and topographic settings, and probable contributing factors. This landslide inventory can be used to help prepare susceptibility maps. Monthly coordination meetings, regular field reviews, and U.S. Geological Survey collaboration aim towards a cohesive final product.

Historical inventories are nearly complete in all five study areas. They were conducted using 1) archival research using newspapers and other historical descriptions, 2) Soil Water Conservation District records, 3) Minnesota Department of Transportation records, 4) city and county records, 5) consulting firm records, 6) sediment stressor reports from state and local agencies, and 7) identification of characteristic landforms associated with historical and prehistoric landslides from lidar topographic data. The completion of the landslide inventories is scheduled for summer 2019, and we aim to release final products in 2020.

Poster: PRE-AND POST-LIDAR MAPPING: EXAMPLES FROM SOUTHERN MICHIGAN

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Abstract

The use of LiDAR elevation data has greatly improved the ability to resolve and map subtle surficial geologic features, especially in glaciated areas. In southern Michigan, with LiDAR DEMs mappers can discern numerous previously unidentified landforms such as ice-walled lake plains, ice-marginal features, wind-blown dunes, small eskers, streamlined erosional forms, shoreline features and many more (e.g. Esch, 2018).

In Calhoun County, LiDAR enabled recognition and mapping of subtle ice-marginal positions of the retreating Saginaw lobe for the first time, mainly by the heads of outwash fans deposited along the ice margin and at the termini of tunnel valleys. In Cass County, an ice margin was mapped using the presence of stacked, proglacial thrust slabs. These had been previously known from one particularly dramatic example, but can now be used to map an ice margin over a distance of tens of kilometers. On 10-ft. contour interval topographic maps, these parallel ridges appeared to be normal hummocky moraine topography. In Calhoun County, an upland area mapped as end or recessional moraine on maps going back to the early 1900s is now shown to be covered by streamlined forms and drumlins, which are not ice-marginal landforms. New scrutiny of drumlins in the same large drumlin field indicates that many of them are long, linear forms better interpreted as MSGSLs, which requires streaming flow of the lobe at the time of formation.

St. Joseph County was mapped in the 1990s under the STATEMAP program using topo maps, air photos, and traditional field techniques. This county includes the Sturgis moraine, a large Saginaw-lobe moraine formed at the end of a major re-advance. The mapping is currently being updated with a composite LiDAR image of the county. Although a few large ice-walled lake plains were recognized on the moraine in the original mapping, the LiDAR shows dozens of smaller IWLPs. These can now be targeted for fossils which could provide a minimum age for the moraine. On a large fan sequence deposited on the distal side of the moraine, there is an area which has a chaotic contour pattern on the topo map. This was mapped in the 1990s project, for lack of a better interpretation, as a supraglacial (collapsed) lake plain. With the LiDAR, it is clear that this is a low relief dune field. The LiDAR mapping is so transformational that we should consider re-mapping or updating all pre-LiDAR maps.

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Poster: GLACIAL GEOLOGIC MAPPING IN CAYUGA COUNTY, NEW YORK: FOOTPRINT TO FRAMEWORK

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Cayuga County on the eastern shores of Cayuga Lake is representative of many communities in the Finger Lakes in central New York. Although, rural in nature with agriculture as a dominant land use activity the small communities such as Union Springs have not been spared by a legacy of industrial activity in the region. In response to groundwater contamination geologic models were developed that largely ignore the glaciated landscape produced by the Ontario Lobe of the Laurentide Ice Sheet.

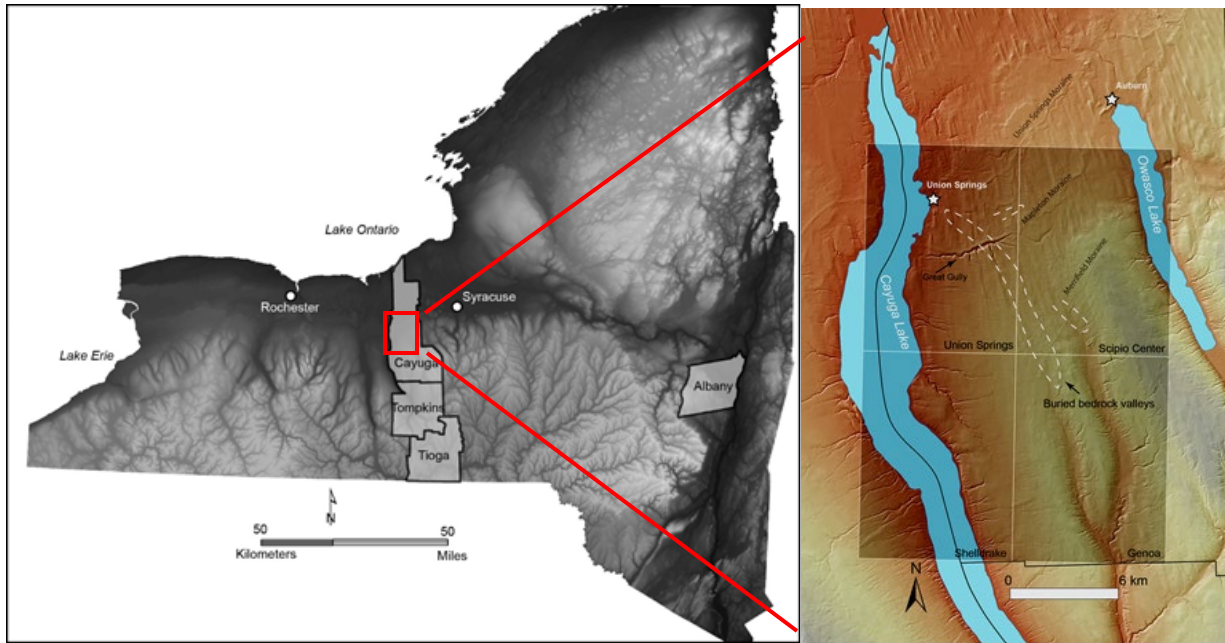
Our work initially began in the Montezuma Wetland Complex (MWC) located at the north end of Cayuga Lake in and amongst the Weedsport Drumlin Field. Mapping glacial landforms and stratigraphy targeted hyper-concentrated brine springs and hydrogeology to address ecosystem management with the US Fish & Wildlife Agency. Later with expanded LiDAR coverage our Mapping efforts were expanded to the rest of Cayuga County, mapping at 1: 24,000 scale. Mapping efforts in the MWC resulted in identification and detailed lithostratigraphic framework, new data on formation of drumlins (Gentoso et al., 2012; Hopkins et al. 2015) new chronologies and extent of proglacial lake phases (Bird and Kozlowski, 2016). New Mapping in the south-central portion of the county utilized high resolution lidar data to discriminate morphologic variations in recessional and readvance moraines and correlate chronologies to glacial phases elsewhere in the Great Lakes (Feranec and Kozlowski, 2016; 2018 and Kozlowski et al., 2018).

The Village of Union Springs and surrounding communities on the east shore of Cayuga Lake receive their drinking water supply via pipeline from the City of Auburn located 10 miles to the northeast. Industrial contamination by dense solvents in the City of Auburn has adversely impacted many of the private wells of the Union Springs Community. Both the Environmental Protection Agency (EPA) and NY Department of Environmental Conservation (NYDEC) have been involved with the initial identification of the Superfund site, and characterization of the regional extent of pollution. The municipal water supplies from Auburn are derived from Owasco Lake. In the last year algal blooms in this Finger Lake have elevated to the point where the water treatment cannot effectively achieve treatment objectives with standard chlorination. Attempts to chlorinate elevated concentrations of blue –green algae result in daughter products that are known carcinogens. A city report in September 2017 indicated chlorophyll, considered one of the indicators for harmful algal blooms had reached levels off of Peterson Point in Owasco Lake (Fleming Township) that were more than 1,800 times the NYDEC's threshold of 25 micrograms per liter. The City of Auburn is struggling with this issue and facing the prospect of exceptionally expensive new treatment facility, the cost of which will be passed down to towns and communities such as Union Springs. The same problem utilizing surface water as drinking water supplies exists within Cayuga Lake. Thus, the community of Union Springs has been seeking alternative options to the expensive treatment of surface water. Groundwater supplies are not susceptible to problems of blue-green algae and tend to be much less problematic in regard to treatment as long as they have not been degraded by pollution.

South of the Village of Union Springs the New York Geological Survey has compiled detailed lithologic data from outcrops and exploration cores, geophysical data and lidar terrain models to provide the requisite data to construct a comprehensive 3D geologic framework (Kozlowski et al., 2016). The detailed mapping reveals the discovery of a buried bedrock valley system more than 10 km in length located on the upland between adjacent Finger Lake troughs. Gravel and sand deposits contained within the buried valley system may serve as an untapped groundwater supply.

The combined stratigraphic analysis from extensive exposures within Great Gully an east-west oriented tributary to Cayuga Lake and continuous sonic and wireline cores demonstrate laterally continuous glacial and non-glacial sequences more than 77 meters in thickness. These deposits include paleosols, sub till organic rich sands and multiple diamictons interpreted as till deposits. In addition, many of the buried till sequences and associated deposits are overconsolidated and display various heterogeneities, such as jointing and large-scale deformation.

The recovery of pollen from buried peats, plant macrofossils and logs from in situ stratum provide a remarkable context for paleoenvironmental reconstructions. Through the extensive application of radiocarbon and optically stimulated luminescence dating a time-stratigraphic model has been developed in conjunction with the geologic framework and indicates deposits in the quadrangle span Marine Isotope Stages (MIS) 1-6 and thus provides one of the most comprehensive records of Late Pleistocene glacial events in the Finger Lakes Region. The completed mapping provides a context to illustrate both the complexity of glacial geology and the need for such detail to guide societal decisions when addressing natural resources.



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Plenary: THE USGS 3D ELEVATION PROGRAM (3DEP) AND 3D NATION STUDY

Jim Langtry, National Map Liaison, US Geological Survey, National Geospatial Programs User Engagement, 5231 S. 19th Street, Lincoln, NE 68512, 402-328-4128, jlangtry@usgs.gov

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The detailed topography of lidar-derived bare-earth Digital Elevation Models has greatly improved hazard mapping by allowing scientists to see underneath the tree canopy to identify faults, historical landslides, volcanic lahars, and other geologic features. Lidar is used in geologic mapping to inventory and analyze hazards, and to map geologic processes such as coastal erosion. Lidar also supports geologic mapping, which enable assessment of critical mineral resources in the United states in support of the USGS Earth Mapping Resources Initiative (Earth MRI).

The USGS developed the 3D Elevation Program (3DEP) to respond to growing needs for high-quality topographic data. The primary goal of 3DEP is to collect elevation data from lidar over the Nation over an 8-year period. The 3DEP initiative is based on the results of the assessment that documented more than 600 business uses. 3DEP provides more than \$690 million annually in benefits. This would result in a nearly 5:1 return on investment, save lives, and improve our environment through informed decisions. Key components of 3DEP are cooperative funding, options for upgrades to meet State and local needs, and partnerships to bring Federal agencies, academia, states, tribes, and communities together to gather elevation data of the Nation. In preparing for the next phase of collections, USGS is conducting a new study called 3D Nation to gather information on realized benefits from the current program and to determine new uses and requirements.

Talk: QUATERNARY MAPPING ALONG THE LATE WISCONSIN MARGIN, CENTRAL INDIANA

Henry Loope, José Luis Antinao, Robin Rupp; Indiana Geological and Water Survey, Indiana University, 611 N. Walnut Grove Ave., Bloomington, IN 47405; hloope@indiana.edu

Geologic mapping near the late Wisconsin glacial limit in central Indiana (Figure 1) over the past six years has focused on improving the chronologic and stratigraphic framework with the aim to build a robust 3-D model of the subsurface. Focused deep (wireline) and shallow (direct push) drilling combined with radiocarbon and luminescence dating have improved the litho- and chronostratigraphic framework in central Indiana. In addition, lidar digital elevation models have greatly improved our ability to trace ice-margin positions and identify other subtle glacial features. Recent mapping has focused on Morgan and Bartholomew Counties, both bisected by the late Wisconsin maximum limit south of Indianapolis. Two late Wisconsin tills (24.0 ka and 21.5 ka) and Illinoian till are present in both counties, along with associated ice-marginal sediments (outwash and glaciolacustrine sediments). The chronology of deposition of two late Wisconsin tills (24.0 ka and 21.5 ka) and Illinoian glaciolacustrine sediments (127 ka) by radiocarbon and luminescence dating, respectively, has allowed us to correlate these units with those to the north in Marion County (Indianapolis), which has been previously mapped. Several bedrock paleovalleys (ca. 120 ft in depth) are present in the mapping area, and coring indicates that the fill of these paleovalleys is composed of Illinoian and Wisconsin till, outwash, and glaciolacustrine sediments. Outside of the bedrock paleovalleys where glacial drift is thinner, Wisconsin glacial sediments generally dominate, and older sediments are found in isolated patches owing to spatial variability of glacial erosion and accommodation space controlled by the bedrock surface. Future coring efforts will attempt to target deeper paleovalleys (>250 ft) to the north of the current map area to identify potential pre-Illinoian glacial sediments.

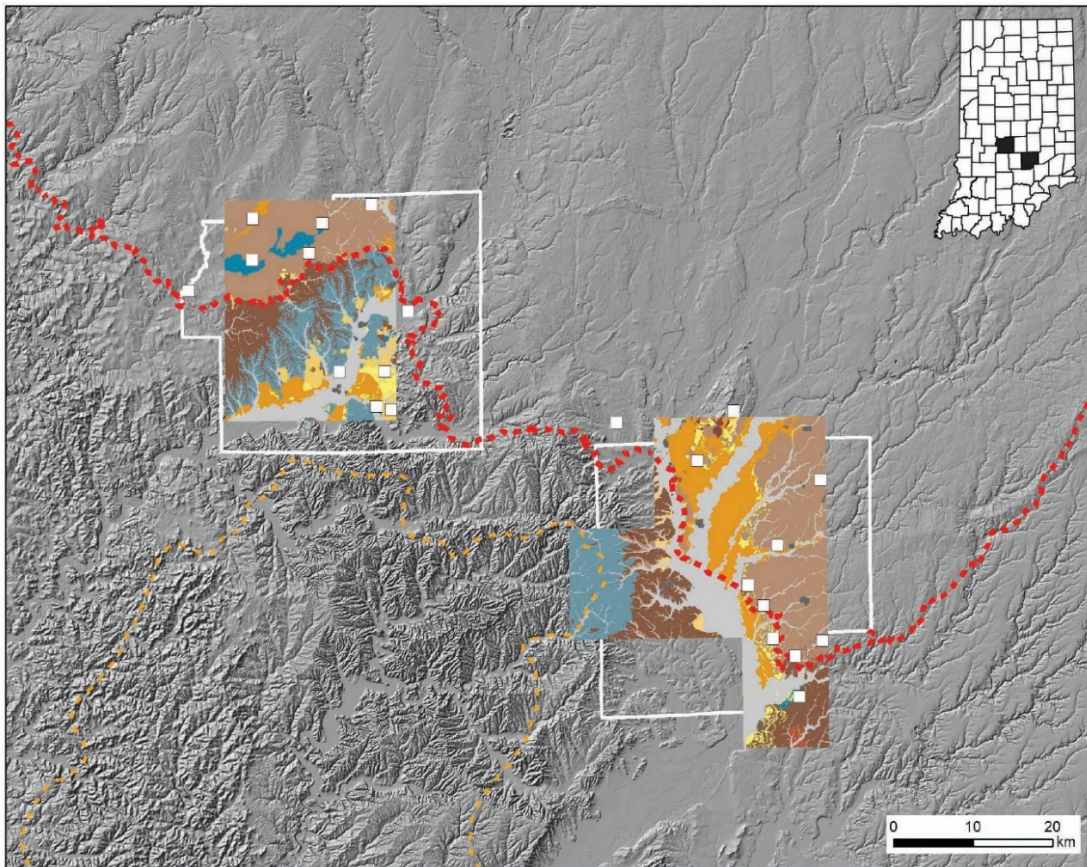


Figure 1. Lidar hillshade digital elevation model and recent surficial geologic mapping (1:48,000-scale) of south-central Indiana. White squares indicate deep cores (>100 ft) that were collected and described during the mapping of Bartholomew and Morgan Counties (outlined with white border). Dashed red line is late Wisconsin glacial maximum limit and dashed orange line is pre-Wisconsin glacial limit. Brown color on geologic mapped areas is till, orange is outwash, yellow is eolian sand, gray is Holocene alluvium, and blue is thin sediment over bedrock.

Talk: PILOT TO PUBLICATION—TRIALS AND TRIBULATIONS OF COMPILING A NEW SURFICIAL GEOLOGY MAP AND DATABASE

Barbara Lusardi, Geologist and Associate Director, Minnesota Geological Survey, 2609 Territorial Road, St. Paul 55114, lusar001@umn.edu

The Hobbs and Goebel map “Quaternary Geology of Minnesota” was published in 1982 and remains the go-to map for glacial geologists in the upper Midwest. In that same year, the Minnesota Geological Survey (MGS) initiated the County Geologic Atlas program, which provides counties a comprehensive map package at 1:100,000-scale. Thirty-seven years later, we have mapped (and remapped, or are in the process of mapping) 56 of Minnesota’s 87 counties with an emphasis on supporting groundwater management.

The time has come to compile the last 37 years of work into a new statewide map of the Quaternary Geology of Minnesota. Our goal is to combine the detailed county geologic atlas maps into a seamless, digital map that retains the detail of the 1:100,000-scale individual maps, and also include a simplified version at 1:500,000-scale, which will be useful for statewide modelling.

Our initial steps started several years before the map compilation began. In 2016, after 10 years of effort, the MGS published a report in which 47 glacial stratigraphic units were formally defined, revised, or redefined. This gave all of us—geologists, hydrologists, and users in general—a common surface and subsurface framework that helps ensure that we’re talking about the same units in our maps and models.

Next, the MGS was tasked with assigning a USDA texture to our surficial geologic map units. While widely variable, texture is an integral component that enables us to infer hydrogeologic properties of glacial sediments. It was during this phase that all the map legends from all of our previous maps were compiled into a single database populated with detailed information such as texture, deposit type, age, provenance, and formal lithostratigraphic name.

All that remained was to put it all together (simple, right?). It has taken four years, nine staff members, and at least a million challenges to overcome. How is a consistent level of detail achieved? Should lines or polygons be edited? Should eolian sand be included as a unit or a pattern? Those are just a few of the questions that have gone into the map compilation.

This project now includes a printed 1:500,000 scale map—a static snapshot of the compilation—and a living database at two levels of resolution, updated as each new county atlas map is completed. And that introduces a new set of challenges, not the least of which is how do you keep the different versions separate?!

Talk: INTEGRATING OUTCROP AND SUBSURFACE DATA IN SOUTH-CENTRAL WYOMING THROUGH STATEMAP AND NCRDS

Ranie M. Lynds, Wyoming State Geological Survey, PO Box 1347, Laramie, WY, 82073, ranie.lynds@wyo.gov

Laramide deformation segmented the western interior foreland basin in Wyoming into a series of intermontane basins and Precambrian basement-cored uplifts during the Late Cretaceous through early Eocene, interrupting the east-flowing drainage systems from the Sevier hinterland. The timing of Laramide deformation and its impact on drainage patterns remain under debate. In 2014, the Wyoming State Geological Survey (WSGS) began a multi-year endeavor to study the Upper Cretaceous and Paleocene strata in the eastern Greater Green River Basin (EGGRB) and Hanna Basin, including formations with significant oil, natural gas, and coal resources. These formations record the transition from (and potential overlap of) the thin-skinned faulting of the Sevier orogeny to the basement-involved faulting of the Laramide orogeny. Determining depositional controls on these formations helps constrain the timing and magnitude of Laramide deformation in south-central Wyoming.

The WSGS project leverages resources provided by the U.S. Geological Survey's STATEMAP and National Coal Resources Data System (NCRDS) programs. Since 2015, the WSGS has completed six 1:24,000-scale quadrangles in the study area as part of STATEMAP. Five of these maps are located on the eastern rim of the EGGRB along a band of outcrops that dip west into the basin. The sixth map is further east, on the western rim of the Hanna Basin. All maps complement previous U.S. Geological Survey mapping in the region. STATEMAP cooperative funding allows for on-the-ground description, interpretation, and analysis of strata that compose a significant portion of the subsurface and are otherwise difficult to assess.

Subsurface interpretation for EGGRB Paleocene strata was accomplished through the NCRDS program, which provided funding for detailed coal correlation. For this aspect of the project, Paleocene coals were correlated from mapped outcrops along the basin margins (both WSGS STATEMAP mapping and previous U.S. Geological Survey mapping) into and throughout the subsurface. Coal correlations guided much of the subsequent stratigraphic interpretation, which in turn resulted in a series of structure contour and isopach maps.

With funding for the NCRDS program no longer available, the WSGS will continue outcrop mapping in the central Greater Green River Basin as part of STATEMAP 2019. Current results include:

- Laramide deformation occurred in two distinct phases, documented by a significant increase in 1,800–1,600 Ma zircon grains at about 79 Ma and again at 70 Ma.
- The closest source for 1,800–1,600 Ma zircons is the Sierra Madre, a mountain range that flanks the southeast part of the EGGRB, suggesting uplift of the Sierra Madre as early as 79 Ma.

The strata with the greatest potential to host significant natural gas accumulations include the China Butte Member of the Fort Union Formation (Paleocene) and the lower zone of the lower member of the Lance Formation (Upper Cretaceous). These are two distinct plays.

- Fort Union Formation thermogenic gas reservoirs are expected in the deepest parts of the southern EGGRB, and are up to 2,800 ft thick.
- Lance Formation thermogenic gas reservoirs are expected in the deepest parts of the southern EGGRB (500–1,000 ft thick) and northern EGGRB (up to 3,400 ft thick), and possibly updip in lesser accumulations.
- Correlation of more than 80 coal beds from the Paleocene Fort Union Formation were uploaded to the NCRDS database.
- Total Paleocene coal resources in the area are 256 BT, of which 89.1 BT are economic and 70.2 BT are marginal. Approximately 82.3 BT of coal are recoverable.

WSGS publications produced as part of the NCRDS and STATEMAP programs, to date, include:

Carroll, C.J., Lynds, R.M., Ratigan, D.R., and Palkovic, M.J. 2015. Report on the preliminary geologic maps of the Shamrock Hills and Rawlins Peak SW quadrangles, Carbon County, Wyoming: Wyoming State Geological Survey Open File Report 15-8, 33 p., 2 pls, scale 1:24,000.

Carroll, C.J., Ratigan, D.R., Lynds, R.M., and Palkovic, M.J. 2015. Preliminary geologic map of the Rawlins Peak SW quadrangle, Carbon County, Wyoming: Wyoming State Geological Survey Open File Report 15-6, scale 1:24,000.

Carroll, C.J., Spaeth, L.J., and Carnes, J.D. 2016. Preliminary geologic map of the Dixon quadrangle, Carbon County, Wyoming, and Moffat County, Colorado: Wyoming State Geological Survey Open File Report 2016-5, 33 p., 1 pl., scale 1:24,000.

Carroll, C.J., Stafford, J.E., Kehoe, K.S., Loveland, A.M., Taboga, K.G., Cola, E.C., Ratigan, D.R., and Spaeth, L.J. 2019. Coal availability of the Fort Union Formation in the Great Divide and Washakie basins, south-central Wyoming: Wyoming State Geological Survey Report of Investigations 76, 35 p.

Lichtner, D.T., Carnes, J.D., Wittke, S.J., and Carroll, C.J. 2017. Preliminary geologic map of the Bridger Pass quadrangle, Carbon County, Wyoming: Wyoming State Geological Survey, Open File Report 2017-6, 41 p., scale 1:24,000.

Lynds, R.M., and Carroll, C.J. 2015. Stratigraphic cross sections and subsurface model of the Lance and Fort Union formations, Great Divide Basin, Wyoming: Wyoming State Geological Survey Open File Report 15-3.

Lynds, R.M., and Lichtner, D.T. 2016. Stratigraphy and hydrocarbon potential of the Fort Union and Lance formations in the Great Divide and Washakie basins, south-central Wyoming: Wyoming State Geological Survey Report of Investigations 73, 70 p., 2 pls.

Lynds, R.M., Palkovic, M.J., Carroll, C.J., Ratigan, D.R. 2015. Preliminary geologic map of the Shamrock Hills quadrangle, Carbon County, Wyoming: Wyoming State Geological Survey Open File Report 15-7, scale 1:24,000.

Lynds, R.M., Pisel, J.R., Hoppes, K.L., Taboga, K.G., Wittke, S.J., and Kehoe, K.S. in prep. Preliminary geologic map of the Garden Gulch quadrangle, Carbon County, Wyoming: Wyoming State Geological Survey Open File Report, scale 1:24,000.

Lynds, R.M., and Slattery, J.S. 2017. Correlation of the Upper Cretaceous strata of Wyoming: Wyoming State Geological Survey Open File Report 2017-3.

Lynds, R.M., and Wrage, J.M. 2017. Preliminary geologic map of the Fort Steele quadrangle, Carbon County, Wyoming: Wyoming State Geological Survey Open File Report 2017-5, 25 p., scale 1:24,000.

Plenary: STATUS OF 3D GEOLOGICAL MAPPING AND MODELLING PROGRAMS AT INTERNATIONAL GEOLOGICAL SURVEY ORGANIZATIONS

Kelsey MacCormack¹, Dick Berg², Hazen Russell³, Harvey Thorleifson⁴, Holger Kessler⁵
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In 2011 the “Synopsis of Current Three-dimensional Geological Mapping and Modeling in Geological Survey Organizations” (<http://library.isgs.illinois.edu/Pubs/pdfs/circulars/c578.pdf>) was published providing an overview of 3D mapping and modelling activities taking place at 9 Geological Survey Organizations (GSOs). Since the publication of this volume there has been phenomenal uptake of 3D mapping and modeling methods by GSOs around the world at provincial, territorial, state, and federal levels. This mirrors a growing recognition of the societal value of geoscience data management, geological mapping, visualization, and modeling applications to support science-based decision making to support sustainable resource development and public safety. Thus we decided it was time to update the 2011 publication to highlight the recent successes, accomplishments, and challenges experienced by GSOs in the development and deployment of their 3D programs.

The 2019 update includes updates on 3D modelling programs from 6 GSOs included in the 2011 synopsis, as well as information from 16 additional jurisdictions on topics such as;

- Organizational Structure and Business Model
- 3D Modelling Activities
- Resources Allocated to 3D Modelling Activities
- Overview of Regional Geological Setting
- Availability and type of Data used for 3D modelling
- 3D Modelling Approach
- Clients
- Recent Case Studies
- Challenges
- Lessons Learned
- Next Steps

These contributions represent information on modelling programs from GSOs representing diverse geological settings. Below are some interesting initial statistics to highlight the diversity of the GSOs, the jurisdictions they are responsible for, and their 3D modelling programs;

- Area that each GSO is responsible for ranges from 31,895 km² to 9,985,000 km²
- 6 out of 17 GSO reported that they have (or will have by the end of 2019) 3D models covering 100% of their jurisdictions, however almost all of these GSOs indicated that they either intended to include additional geological units or increase the resolution of their jurisdiction-wide models.
- The number of staff responsible for building 3D models ranges from 1 – 60 (Figure1)

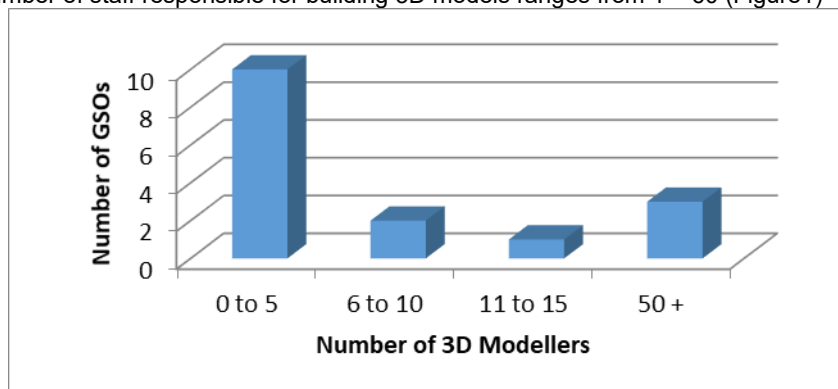


Figure1: Graph showing the number of 3D modellers employed by Geological Survey Organizations

- 9 GSOs have dedicated modelling teams
- Based on the information provided by 17 GSOs, they have been building 3D models for an average of 13.6 years, with some programs as young as 4 years and others as old as 25 years (Figure2)
- Staff are leveraging between 1 and 10 different software programs to complete their modelling activities
- GSOs are typically using both explicit and implicit modelling methodologies
- 17 of 20 GSOs reported that they are building 3D models at a variety of scales
- Borehole, seismic, and map data were the most typical sources identified to construct models
- The main clients/stakeholders for these 3D models are government, regulators, industry (mining and oil & gas), environmental agencies, academia, and the public (education and communication).
- Budgets allocated to 3D modelling activities varied from ~\$36,000 USD to over \$8,500,000 USD per year.

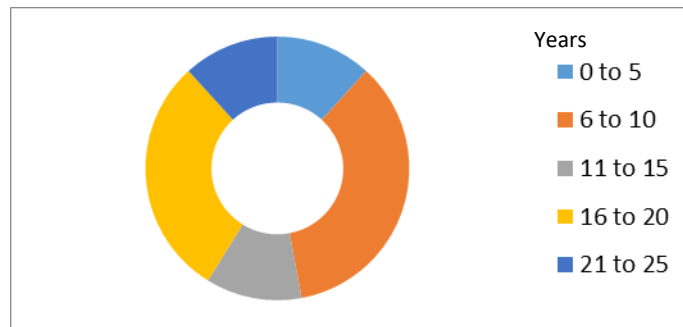


Figure 2: Graph showing the number of years 3D modelling has been conducted at various Geological Survey Organizations

The information provided by the contributing jurisdictions makes it clear that as a consequence of differences in government organization, geographic scale, geological complexity, and economic development, many GSOs have taken a variety of approaches to developing 3D modelling programs within their organizations. Multiple solutions have been implemented with some organizations creating large modelling teams and development of multi-resolution models, while other surveys are working hard to gain support from their leaders or government to initiate 3D modeling pilot studies.

Take Home Message: characterizing geospatial data in 3D is no longer an opportunity or a ‘nice to have’, it is quickly becoming the standard for evaluating and communicating geoscience information. A quote from the Swedish chapter - *“As our experience grows with 3D-modelling and it becomes incorporated in all our workflows, it becomes less and less relevant to single out ‘3D’ as being a specific subject area.”* (Stolen, L.K., et al., *in press*).

There are many challenges and hurdles to making the transition to 3D and 4D models, and it may never seem like the right time to take the plunge. However, we are hoping that this publication It will provide context for organizations looking to gain support within their organizations to build 3D modelling programs by leveraging the business cases and approaches highlighted by international surveys with successful 3D modelling programs.

Plenary: DELIVERING CONSISTENT, RELIABLE, AND CREDIBLE MULTI-DIMENSIONAL GEOLOGICAL INFORMATION; QUEST FOR A SINGLE MODEL TO RULE THEM ALL

Kelsey MacCormack, Alberta Geological Survey, Alberta Energy Regulator, 4999 98th Avenue, Edmonton AB, T6B 2X3 kelsey.maccormack@aer.ca

The Alberta Geological Survey (AGS) is responsible for providing geological information and advice about the geology and resources to the Government of Alberta, the AER, industry, and the public to support public health and safety, exploration, sustainable development, regulation, and conservation of Alberta's resources. The AGS delivers geoscience in several key areas, including surficial mapping, bedrock mapping, geological modelling, resource evaluation (hydrocarbons, minerals, groundwater), disposal and storage potential, and geological hazards. We also are responsible for providing geoscience outreach to stakeholders ranging from professional colleagues and academia to the general public.

To help deliver on our mandate we are developing a multi-scalar, multi-dimensional, geostatistically optimized, and probabilistically parameterized 3D geological model of Alberta to serve as the single-source of geological truth, providing a consistent and reliable 3D geospatial context to facilitate the integration and evaluation of data and information within a credible geospatial context. The objective of the 3D Geological Framework model of Alberta is to ensure that risk-based strategic and operational decisions are based on sound science and credible evidence. This will significantly improve our ability to effectively integrate and evaluate geospatial data to facilitate science-based decisions in support of land-use planning, safe and sustainable resource development, environmental protection, economic diversification and public safety (Figure 1).

Our 3D models have been used to support science and evidence based decision making with respect to regulating and protecting Alberta's energy resources, such as investigating the occurrence of natural and induced seismic events, assessing the potential for subsurface gas migration in proximity to potable groundwater resources, and evaluating competing priorities for subsurface resources. We have also leveraged our 3D models to help communicate complex geological and environmental information to our stakeholder groups and the public, which often have quite variable levels of background knowledge, to build trust and confidence using tangible graphics and visualizations, which are transparent, easy to understand, and based on scientific evidence.

Recent Developments

Our current 3D Geological Framework model of Alberta covers 602,825 km² and includes both provincial- and local-scale 3D models, which have been constructed at a grid cell resolution of 500m x 500m or less. Our current provincial-scale model (version 2) contains 62 geological units and was interpolated using approximately 1,235,761 data points (Figure 1B, C, D), which represents a two-fold increase over Version 1 (released in 2018) that leveraged 620, 812 data points to characterize 32 units. The ability to efficiently integrate new data and information and update our models has been significantly improved by the development workflows, which have

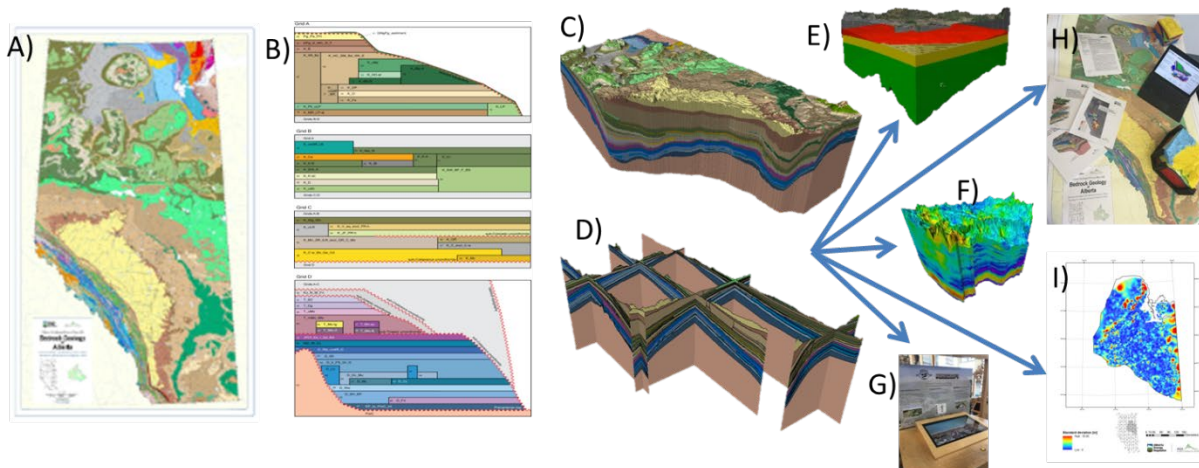


Figure 1: Our Provincial scale 3D geological model provides a transition from our A) 2D bedrock geology map, and B) Version 2 now contains 62 units in represented as a C) 3D model at a D) 500m x 500m grid cell size across much of the province. Our 3D geological models are increasingly being used to support development of E) risk assessments, and F) 3D property models. The models are also being leveraged to support development of G) geoscience education exhibits at science centers, H) a variety of published products including 3D prints, and I) maps to communicate estimates of uncertainty in the model predictions.

proven to reduce the amount of time required to rebuild 3D models from 2 days to less than 2 hours, which represents a 87.5% reduction in time. However, despite the time savings gained by using workflows, we quickly realized that we needed to consolidate our 3D models into a single multi-scalar model to further improve our ability to efficiently and effectively update our 3D models with new data and information as it becomes available rather than needing to update multiple models. Although building a large and complex multi-scale model certainly comes with many challenges, it allowed us to efficiently target our staff resources, avoid potential inconsistencies between models covering the same area, and removed the requirement for the modelling team to update multiple models.

The team has also leveraged the 3D Geological Framework models to provide the spatial context for allocating data necessary for building 3D property models, which provide detailed predictions for the internal variability of rock properties (porosity, TOC, water saturation, etc.; Figure 2F). These property models have been very helpful for defining the location of resources (groundwater, oil, gas, condensate) within geological formations, as well as the lateral and vertical variability of key properties needed to assess parameters such as thickness of caprock, subsurface storage potential, etc.

Another fairly recent development in our modelling program is the use of machine learning and deep learning to optimize available data from a variety of sources and enhance our model results. The team has successfully applied machine learning techniques to predict areas of landslide susceptibility across the province (Pawley et al., 2018a), evaluate the geological parameters associated with seismic susceptibility (Pawley et. al, 2018b), and is currently being applied to update our provincial bedrock topography model (results will be published later this year).

Enhancing Geoscience Information Communication

Over the past few years, we have observed the benefits of building 3D geological models to support decision making, and the immense value of these models to facilitate communication and education related to complex geological and environmental information with stakeholders (Figure 2E and G). The demand for these models to support a wide variety of applications continues to grow. A key objective of the team has been to find efficient ways of getting our 3D models into the hands of subject matter experts to share work that has already been done, allow them to integrate and evaluate their own data within our models, and support decision making within the province. We are publishing our models in a variety of formats such as ESRI points, grids, and shapefiles, as well as in open-access program formats to facilitate the uptake and use of our data and models to a wide range of stakeholders (Figure 2H). We provide a methodology report for every model that we publish to provide users with information on the data and algorithms that were used to build each surface, criteria used during model construction, as well as maps and values for local and global uncertainty respectively (Figure 2I). This information and model metadata is provided to ensure transparency in our models to allow users feel more comfortable about using our model to support their work and decisions.

Next Steps

The AGS is in the process of initiating a number of projects within the Geological Framework Program to advance development and innovation of our 3D models and associated products. Some near-term objectives of the program include integrating all of our local-scale submodels within our large provincial-scale model to create a single multi-scalar source of geological information that can be easily updated as additional information becomes available and ensure that we are as efficient as possible with our staff resources. The team is also working to improve upon our current modelling methodologies and look for efficiencies within our workflows as we continue to refine our geological characterization in areas of strategic importance, and integrate surface and subsurface resources. Our plan is to continue to evaluate opportunities to leverage machine learning and deep learning methods to optimize our data and enhance our mapping and modelling results. We also have projects underway to leverage innovative and emerging technology (augmented reality, virtual reality, serious-gaming, and 3D prints) to enhance communication of our geoscience information and products to stakeholders.

This presentation will focus on how AGS developed a 3D geological modelling program, and how our 3D Geological Framework is being used to build trust and confidence with stakeholders, government, and the general public by facilitating transparent communication of complex geological and environmental issues using tangible graphics and visualizations, which are easy to understand and are based on scientific evidence.

Talk: UAS APPLICATIONS AT THE NORTH DAKOTA GEOLOGICAL SURVEY

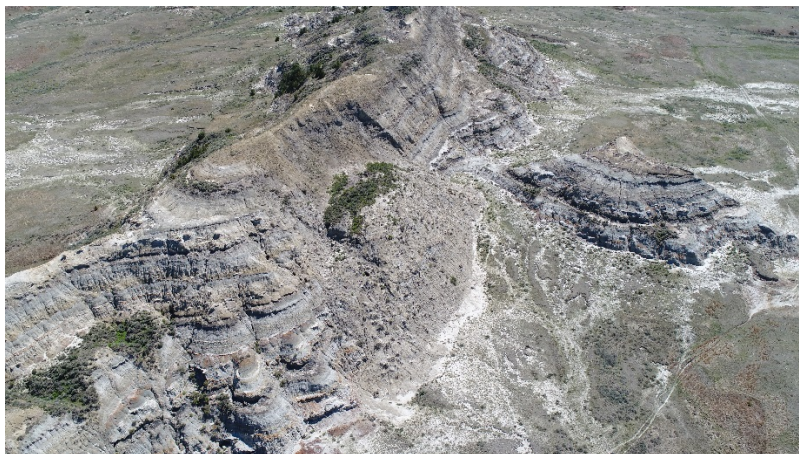
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ABSTRACT

The North Dakota Geological Survey (NDGS) began using unmanned aerial systems to support its various missions in May of 2017. This new technology has allowed NDGS geologists to gain perspectives previously only seen from planes and satellite imagery. The NDGS is a part of the North Dakota Department of Mineral Resources (DMR) which also houses The Oil and Gas Division. The DMR has 10 drone pilots, 2 in the NDGS and 8 in the oil and gas division. All Pilots are FAA Part 107 Certified and follow all rules and regulations. The DMR has five Phantom 4 Pro drones in operation. It is an easy platform to operate and provides high quality imagery for the cost of the drone (\$2,000 for drone and tablet).

Currently, the NDGS is using drone technology to support various applications including landslide mapping, pipeline spills, site inspections, reclamation, stratigraphic correlation, depositional environment reconstruction, and rare earth element (REE) and sand proppant reconnaissance. The technology has proven tremendously useful for geotechnical overviews of landslide areas, such as acquiring imagery to gain perspectives into an old landslide impacting I-94 in Valley City, ND. This on-demand aerial image source is also a highly effective aid in the assessment of oil pipeline spills, such as the 2016 Ash Coulee spill in Billings County, North Dakota where over 12,500 barrels of oil spilled. Drone imagery has two distinct advantages over Google Earth and satellite imagery due to its much higher resolution and more timely acquisition. The drone saves geologists time and provides a safer environment while working in the field. In the exploration for sand proppant and REEs, for example, drones are used to reconnoiter coal seams and sandstones at the tops of buttes and other previously inaccessible or potentially dangerous locales.

Since 2017, the NDGS has collected 6,625 photos and 69 videos of various parts of North Dakota, helping support our regulatory and mapping operations. In addition to its own missions, DMR drone pilots work in a support role with other state agencies including the North Dakota Department of Transportation, the North Dakota Department of Health, the Southwest Water Authority, and the North Dakota Department of Trust Lands.



NDGS Drone Photo of landslide in western North Dakota

Talk: QUATERNARY GEOLOGICAL MAPPING IN MINNESOTA: PAST, PRESENT AND FUTURE

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Understanding the Quaternary geology of Minnesota is especially important because much of the state relies on "glacial" aquifers for its drinking water. Minnesota was glaciated numerous times during the Quaternary Period (2.6 million years to present), and as a result left behind a thick, complex succession of deposits. Mapping the Quaternary stratigraphy and surface sediments of the state remains the primary method to characterize and manage these glacial aquifers. The purpose of this talk will be to highlight the past, present and future mapping methods the Minnesota Geological Survey (MGS) used, uses, and will use to unravel the complex glacial stratigraphy of the state.

Mapping the Quaternary sediments in Minnesota began in the late 1800's, when scientists such as N.H. Winchell and W. Upham traipsed across the countryside on horseback and provided a first glimpse into the complexity of Minnesota's glacial history. In the early 1930s, Leverett and Sardeson (1932) created a Quaternary Geology map that depicted the surficial deposits of across Minnesota and parts of adjacent states. A half century later, Hobbs and Goebel (1982) compiled a more detailed statewide map of surficial sediments. This map is still a key reference for Minnesota's glacial geology. Also around this time, the MGS produced the first County Geologic Atlas. In the more than 30 years since, the MGS has completed atlases for 29 more counties and projects are under way in 12 more counties. These atlases, with maps at 1:100,000 scale, provide even greater resolution of the surficial geology.

Currently, the County Geologic Atlas remains the main MGS mapping program, but our products have come a long way since the program first started in the early 80s. Although each atlas we produce includes a variety of plates (database, bedrock, surficial, Quaternary stratigraphy, sand distribution model, and a bedrock topography/depth to bedrock plate) this talk will focus on the current methods we use to create our surficial geology maps and Quaternary stratigraphy cross sections.

Mapping surficial sediments (the geologic material located just below the soil horizon) helps us understand the geologic conditions at the interface between precipitation and infiltration. Our surficial geology maps are created by interpreting the landforms based on 1 meter resolution lidar elevation imagery (available from the Minnesota Department of National resources, 2016). The geologic interpretations are drawn using GIS software on 1:24,000 scale U.S. Geological Survey topographic maps overlain on a 30-meter digital elevation model of the county.

To delineate our map units, we use various large data sets; including the soils maps (Natural Resources Conservation Service, 2016); well logs included in the MGS County Well Index (CWI) and Quaternary Data Index (QDI), bridge borings (Minnesota Department of Transportation) and U.S. Geological Survey scientific test holes. Fieldwork typically includes one to two summer seasons and consists of describing and sampling exposures such as excavations, road cuts and natural outcrops. These data are supplemented by Giddings powered auger borings drilled to an average depth of 14ft (40-100 holes drilled per county) and 4-6 rotary-sonic drill cores drilled to an average depth of 250ft.

Our Quaternary stratigraphy plates represent the unconsolidated materials between the land surface and bedrock surface. To construct our 1-km spaced cross sections, we utilize information from rotary-sonic drill holes, water-well driller's logs, cuttings-set descriptions, bridge-boring logs, exposures and auger samples.

Because ice brought sediment from a number of recognized regions outside of Minnesota, understanding the provenance of sediments, through grain counts of the 1-2mm sand fraction, color, and texture, remains the primary method we use to delineate our Quaternary units. Luckily, the provenance of these sediments is distinct enough to allow us to trace the direction from which the ice came. Generally, red, rocky till was derived from the northeast; sandy, carbonate-poor till from the north-northeast, and loamy shale-rich till from the northwest. Beyond the limit of Late Wisconsinan glaciation, in the southeastern and southwestern corners of the state, older tills are exposed that are dominantly derived from the north-northwest and contain a moderate level of carbonate and a low level of shale.

Quaternary geologists at the MGS are continuously exploring new methods to provide detailed geologic products to the public. Through the support of the Great Lakes Geologic Mapping Coalition, we are currently producing a new 1:500,000 Quaternary map as well as new seamless digital compilations of our 1:100,000 County geologic atlas maps. Both include a surficial and sub-surface component. In another active project we are using geochemical signatures of Quaternary units in an effort to improve correlation. Current MGS mappers are the first

generation of mappers who are able to create maps with two large, state-wide databases (CWI and QDI) at their fingertips. We strive to understand how to manipulate multiple datasets to improve our products.

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Plenary: HIDDEN COMPLEXITY OF THE MISSISSIPPI RIVER ALLUVIAL AQUIFER ILLUMINATED LIKE NEVER BEFORE USING REGIONAL-SCALE AIRBORNE GEOPHYSICS

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In 2018, the Mississippi Alluvial Plain water availability project began a multiple-year airborne geophysical mapping initiative, incorporating both regional and high-resolution airborne electromagnetic (AEM), magnetic, and radiometric surveys. The initial high-resolution survey comprised approximately 2,500 line-km of airborne geophysical data over a 1000 sq. km survey block near Shellmound, MS, using the CGG Resolve helicopter system in March 2018. Later that year, the first phase of the regional AEM survey began- also with the Resolve AEM instrument- and acquired nearly 17,000 line-km of data mainly along west-east flight lines separated by 12 km in the northern and southern portions of the study area, with 6 km-spaced lines in the central portion of the study area (Figure 1). As part of the regional survey, approximately 2,000 line-km were acquired along several rivers in order to better characterize the connectivity between surface and groundwater. Each year, additional flight lines will be flown to increase the resolution of the regional hydrogeologic framework. The target resolution for the completed regional survey is 3 km-spaced flight lines.

Comparison of preliminary resistivity data to the existing base of Mississippi River Valley alluvial (MRVA) aquifer maps and borehole data indicate that the EM sensor was able to fully penetrate the Quaternary alluvium, exposing the spatial extent of underlying Mississippi Embayment units. Resistivity data below the MRVA base indicate several subcropping aquifer (high resistivity) and confining (low resistivity) units from the Mississippi Embayment sequence. Resistivity data also show that the Quaternary-Tertiary contact may have more topographic relief than previously observed from boreholes.

We will illustrate the tradeoffs between the high-resolution survey block that is able to map a relatively small area with great detail, with the more widely spaced regional survey grid that captures regional details of the entire alluvial plain. Interpretations of the resistivity models will be used to refine digital surfaces of the base of aquifer, subcropping units, and shallow confining layers that can be incorporated into groundwater models. By better quantifying and reducing uncertainty in the geologic framework, we hope to produce better estimates of hydrologic uncertainty that can help to inform management decisions.

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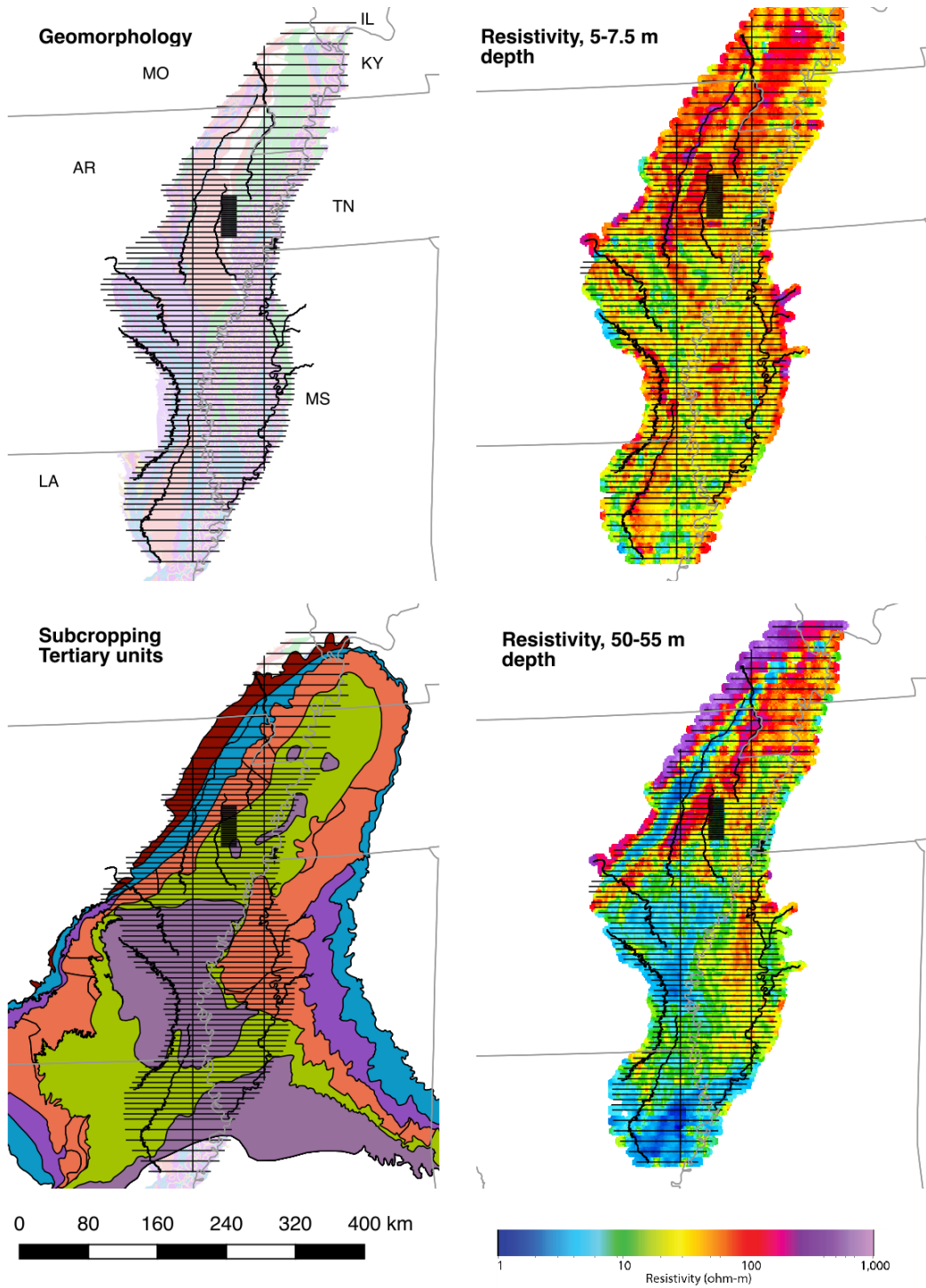


Figure 3. Maps of the regional MAP airborne geophysical study. Features in the shallow resistivity (top right) correspond with many mapped geomorphological features (top left; Saucier 1994). Deeper structures mapped by the AEM system (lower right) correspond with the subcropping Tertiary units (lower left; Hart et al. 2008).

Talk: UTILIZING LEGACY DATASETS TO IDENTIFY CRITICAL MINERAL DEPOSITS (AND JUSTIFY NEW GEOLOGIC MAPPING): AN INTEGRATIVE APPROACH IN SOUTH CAROLINA

Robert H. Morrow IV, Piedmont Geologist, South Carolina Department of Natural Resources, Geological Survey, 5 Geology Road, Columbia, SC 29212, Morrowr@dnr.sc.gov

Executive Order (EO) 13817: “A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals” was signed by the current administration in late 2017. Subsequently, the U.S. Department of the Interior and the U.S. Geological Survey (USGS) published a list of 35 elements that are the focus of the USGS Critical Minerals Mapping Initiative (Fortier et al. 2018). In early 2019, the USGS offered funding to support state efforts to identify potential sources of those critical minerals as part of the National Geological and Geophysical Data Preservation Program (NGGDPP). Under the NGGDPP, states can use funds to make unpublished and published mineral resource information, drill core data, and historical and contemporary mining operations concerning the 35 elements covered under the EO available digitally.

The South Carolina Geological Survey (SCGS) is working with state universities to identify offshore heavy mineral resources as a supplementary part of an ongoing project with the Bureau of Ocean Energy Management (BOEM) to identify sand resources. Part of this work involves U/Pb detrital zircon geochronology to determine the age characteristics of the sand and to fingerprint potential source rock for heavy minerals. The overall goal of the project, in addition to locating sand resources, is to produce a source-to-sink model for the weathering, transport, and deposition of critical minerals across the state of South Carolina.

The USGS has published similar work exploring the potential for rare earth mineral deposits onshore in the southeastern Atlantic Coastal Plain. Shah et al. (2017) analyzed airborne radiometric data collected during the National Uranium Resource Evaluation (NURE) program, ground-based geophysical surveys, magnetic susceptibility, and heavy mineral separates from grab samples to evaluate concentrations of heavy minerals and REEs. The USGS work focused primarily on identifying sources of radiometric equivalent thorium (eTh), a proxy for the minerals monazite (Ce, La, Nd, Sm, Th)(PO₄, SiO₄) and xenotime (Y, Yb)PO₄. Both minerals are found in igneous and high grade metamorphic rocks.

The SCGS is also exploring the use of the NURE and the National Geochemical Databases, as well as other legacy data, to identify critical mineral resources in the Piedmont and Atlantic Coastal Plain. Preliminary interpolation maps of concentration of Th (ppm) derived from the NURE dataset support some of Shah et al.'s (2017) conclusions, namely that Thorium and several other critical minerals are concentrated southeast of the Fall Line, the geomorphological boundary between the Coastal Plain and Piedmont.

Based on the location of the eTh and Th hotspots and the network of river basins draining the adjacent Piedmont, it is possible that the rocks immediately west of the Fall Line are the source material for several of these potential critical mineral deposits. The rocks immediately west of the Fall Line are a group of high-grade metamorphic rocks termed the Kiokee Belt. Much of the information that the SCGS has on the Kiokee Belt exists in the form of regional compilation maps, and several of the quadrangles that contain these rocks have not been mapped at 1:24K-scale. The emphasis on critical-mineral resources at the Federal level provides the justification needed to complete new geologic mapping of the Piedmont along the Fall Line in western South Carolina.

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Poster: LANDSLIDE MAPPING OF NORTH DAKOTA; AN INVENTORY OF 23,500 FAILED SLOPES

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Documenting existing slope failures is the first step in furthering our understanding of which slopes are at risk of new or continued failure. The North Dakota Geological Survey (NDGS) began a 1:24,000-scale landslide mapping program in 2003, which now provides the local observational landslide inventory for all oil and gas fields, wind farms, and major cities in North Dakota. Over 23,500 distinct earth flows, slumps, and areas of soil creep have been delineated. As the program now exceeds coverage of half of the state, the regional geologic context of these failures and their potential impact to infrastructure has never been more clear.

Since 2007, increased oil and gas development in the Williston Basin has required the construction of extensive new infrastructure into the highest-relief terrain in the state. Badlands topography along the Missouri and Little Missouri rivers commonly features steep slopes over 100 meters high in the Paleocene strata of the Fort Union Group, which is prone to rotational slumping. Even in the low-relief, glaciated terrain of eastern North Dakota, slumps and slides are common where rivers have incised into weak Cretaceous shales. Near Valley City, for example, Interstate 94 and multiple surrounding highways are impacted by slow-moving landslides along the steep walls of the Sheyenne meltwater trench. Surficial glaciolacustrine clays in the Red River Valley are prone to creep and flow down even minor grades along waterways and engineered slopes.

The accurate and precise identification of these features across North Dakota's 70,762 square miles (183,273 square kilometers) is a substantial undertaking, but recent advancements in the quality of digital imagery and elevation datasets have greatly expedited the mapping process. Since the program began, the primary dataset used to identify failed slopes is the NDGS's collection of 1:20,000-scale aerial photographs viewed in stereo pairs. This historical imagery provides statewide coverage from the 1950's and 1960's, often preserving the details of slopes prior to overprinting by modern development. In recent years, the resolution and collection frequency of digital aerial imagery from the National Agriculture Imagery Program (NAIP) and other publicly available sources have become an invaluable reference. The NDGS can now capture site-specific aerial imagery on demand with the use of small unmanned aircraft systems (drones). New Light Detection and Ranging (LiDAR) data, provided by the North Dakota State Water Commission and compiled into 7.5-minute quadrangles by the NDGS, provides bare-earth (vegetation removed) imagery of the state's surface in three dimensions. As of 2018, elevation data approaching 1 meter resolution is available for the entirety of North Dakota.

With the use of these datasets and a focused effort, an additional 29% of the state has been mapped since the start of 2017. The size of the average landslide mapped has decreased from 10.5 to 8.8 acres (42,562 to 35,467 m²), reflecting the increased precision possible with these tools as smaller slides are identified.

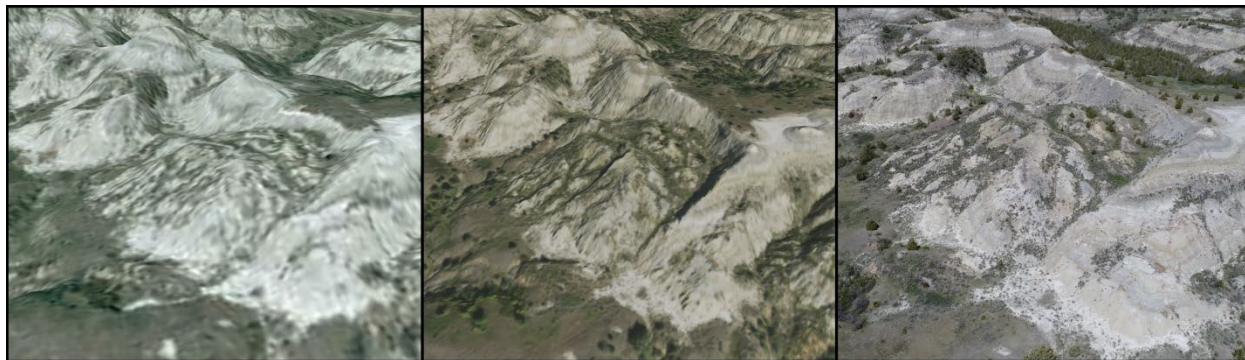


Figure 1. A four-acre (16,000 m²) slump in Billings County viewed with (A) 2003 NAIP projected in Google Earth, (B) 2017 NAIP overlain on 2017 1-meter LiDAR, and (C) a NDGS drone photo taken in 2017.

Poster: SURFICIAL GEOLOGY OF EIGHT 7.5-MINUTE QUADRANGLES NEAR COSHOCTON, OHIO

Nash, Thomas A., Jr. and Aden, Douglas J.

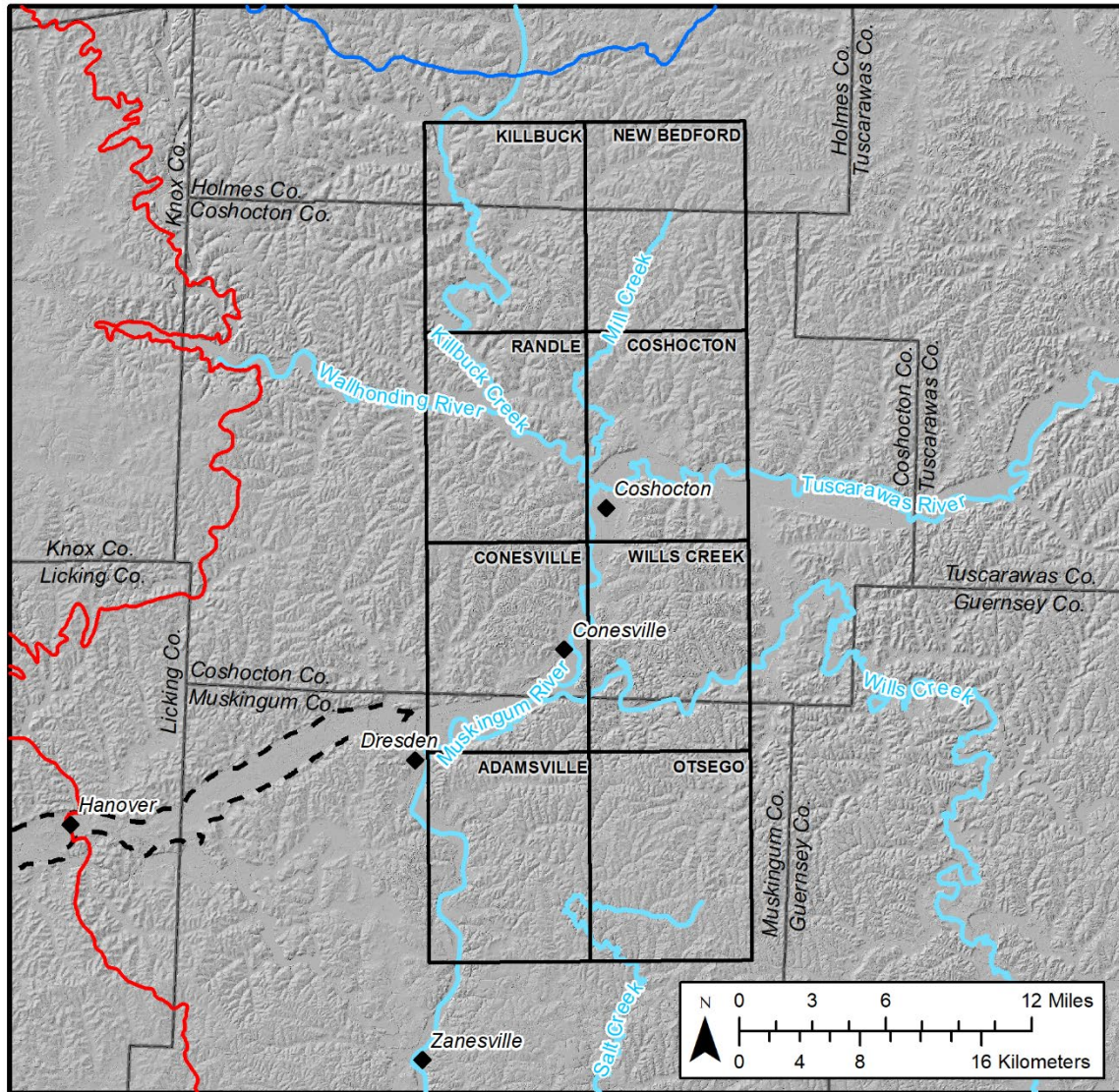
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Abstract

Three-dimensional surficial mapping is a vital tool for visualizing the relationships between unconsolidated materials, at both the surface and the subsurface. This type of mapping is useful for a variety of applications including natural resource management, groundwater flow modeling, and geohazard risk assessment. In 2018, the first detailed, three-dimensional mapping of the surficial geology was completed in the Adamsville, Conesville, Coshocton, Killbuck, New Bedford, Otsego, Randle, and Wills Creek 7.5-minute Quadrangles. This mapping is part of the Ohio Department of Natural Resources, Division of Geological Survey's plan to complete a seamless, statewide, 1:24,000-scale surficial geology map by 2021. Data from field observations, geotechnical boring logs, passive seismic measurements, water well logs, county soil reports, and LiDAR were compiled in a GIS. These data were used to delineate the surface and sub-surface contacts between different unconsolidated lithologic units overlying bedrock.

Although the area surrounding Coshocton, Ohio was never overridden by ice during the Pleistocene, the effects of glaciation were still instrumental in shaping the present-day landscape. The mapping area is located on the western edge of the unglaciated Appalachian Plateau, about seven miles east of the Scioto Sublobe maximum advance and two miles south of the Killbuck Sublobe maximum advance (Figure 1). Stream dissection has created a generally hilly landscape with a total relief of about 600 feet. Some of this dissection has been filled with aggrading packages of glacial outwash and glaciolacustrine sediment from the Wisconsinan and Illinoian Glaciations. The thickness of these unconsolidated sediments reaches almost 280 feet near the town of Conesville. These valleys are partially buried and are bounded by bedrock hills on both walls of the valley. Loess was deposited on ridgetops east of the Muskingum River while sediment was aggrading in the valley. The landscape was flattened to its present state by the infilling of valleys with outwash and glaciolacustrine materials, which also altered the flow direction for multiple nearby rivers.

Multiple drainage reversals occurred within the mapping area during the Pre-Illinoian and Illinoian Glaciations. These drainage modifications were identified using a LiDAR derived digital elevation model based on observations of valley widths and the presence of barbed tributaries. The most significant drainage diversion occurred within the pre-glacial Cambridge River Valley. Pre-Illinoian ice dammed the river near present-day Hanover, which created a lake that flooded the major Teays River tributary. Water overtopped a col north of present-day Zanesville that cut a spillway for the proglacial lake, leading to the creation of the modern Muskingum River. This drainage modification is apparent from the abrupt southward turn that the Muskingum River makes into a narrow valley east of the town of Dresden. Similar processes of drainage reversal occurred on Wills Creek, Killbuck Creek, Mill Creek, and Salt Creek, although the damming of these drainages was from aggrading outwash in higher order rivers, not from ice damming. The mechanisms behind these drainage reversals have resulted in several different terrace systems identified through these mapping efforts. However, the timing of these drainage modifications is still poorly understood and should be studied further.



- Illinoisian Glacial Limit
- Wisconsinian Glacial Limit
- Rivers
- - - Cambridge River Valley
- ◆ Cities



Figure 4: Location map depicting the mapping area including the eight 7.5-minute Quadrangles and important points of reference.

Talk: IMPROVING GEOLOGIC MAPPING OF LOW-RELIEF QUATERNARY STRATA ON THE TEXAS COASTAL PLAIN USING AIRBORNE LIDAR AND NEAR-SURFACE GEOPHYSICS

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Detailed geologic mapping on Quaternary coastal plains worldwide has been hindered by extremely low relief and limited surface exposure. Historically, these areas have been mapped using aerial photography, low-resolution (typically 5-ft contour interval) topographic maps, soil maps, and limited field observation, which makes delineating the lateral and vertical extents of siliciclastic fluvial, deltaic, estuarine, and marine depositional features difficult. Coastal plain depositional units control lithologic distribution in the shallow subsurface, affect infrastructure design and construction, and are an important repository of information about large-scale climate change that has occurred during Quaternary glacial-interglacial cycles. The lateral and vertical lithologic and stratigraphic complexity of these depositional units and their response to climatic and sea-level change are poorly understood, making it difficult to predict lithologic distribution, characterize the ground-water resources that these strata host, and to place historical and anticipated future climate and sea-level change in a natural geologic context. High-resolution airborne lidar surveys, along with surface and borehole geophysical measurements, are being used to augment aerial imagery and field mapping to identify subtle lateral and vertical boundaries of lithologic units on the Texas Coastal Plain within Quaternary strata. High-resolution digital elevation models (fig. 1) obtained from airborne lidar surveys reveal previously unrecognized topographic detail that aids identification of surficial features such as sandy paleochannels, clay-rich interchannel and overbank deposits, levees and crevasse splays, bay-margin deltas, accretionary features on Pleistocene barrier islands, and subtle topographic offsets associated with recent movement on active growth faults. Ground surface time- and frequency-domain electromagnetic induction

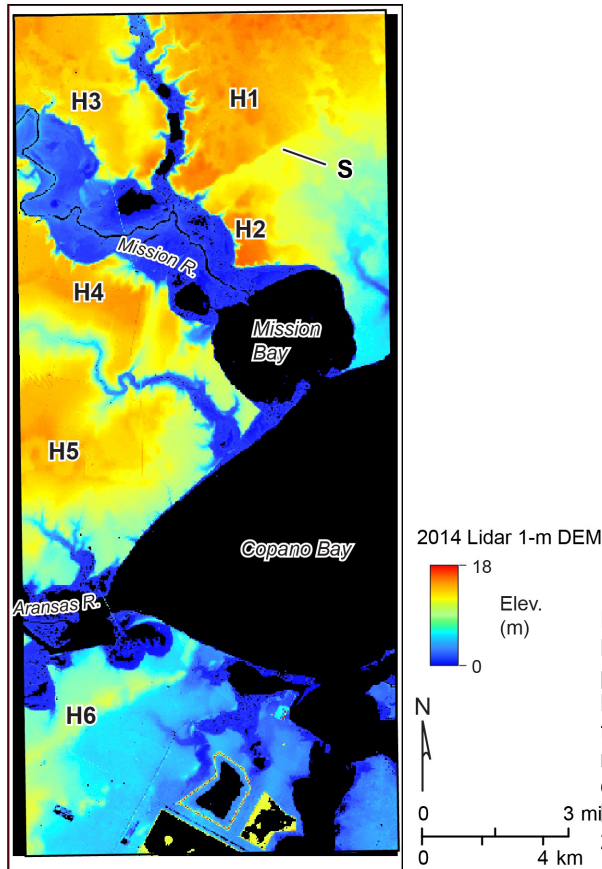


Figure 1. Digital elevation model (1-m cell size) of the Bayside and Mission Bay quadrangles on the Texas coastal plain constructed from airborne lidar data acquired by the Bureau of Economic Geology in 2014. Areas labeled H1 through H6 indicate local elevation highs that correspond to relatively sandy Pleistocene channel courses. Feature S denotes a scarp where there is an abrupt elevation change likely associated with an active fault. From Paine et al., 2018b.

(TDEM and FDEM) surveys help discriminate sandy barrier island and fluvial and deltaic channel deposits from muddy floodplain, delta-plain, and estuarine deposits (fig. 2) and can help characterize ground-water resources to depths of 100 m or more. Borehole conductivity and natural gamma logs similarly distinguish distinct lithologic units in the subsurface, identify salinized ground water, and can help detect erosional unconformities and associated paleosols that likely separate units deposited during different glacial-interglacial stages. An optimal approach to identify lithologic and stratigraphic distribution in low relief coastal-plain environments employs (1) an initial lidar survey to produce a detailed elevation model; (2) selective surface sampling and geophysical measurements based on preliminary mapping derived from lidar data and aerial imagery; and (3) borehole sampling, logging, and analysis at key sites selected after lidar and surface measurements are complete (Paine et al., 2018b).

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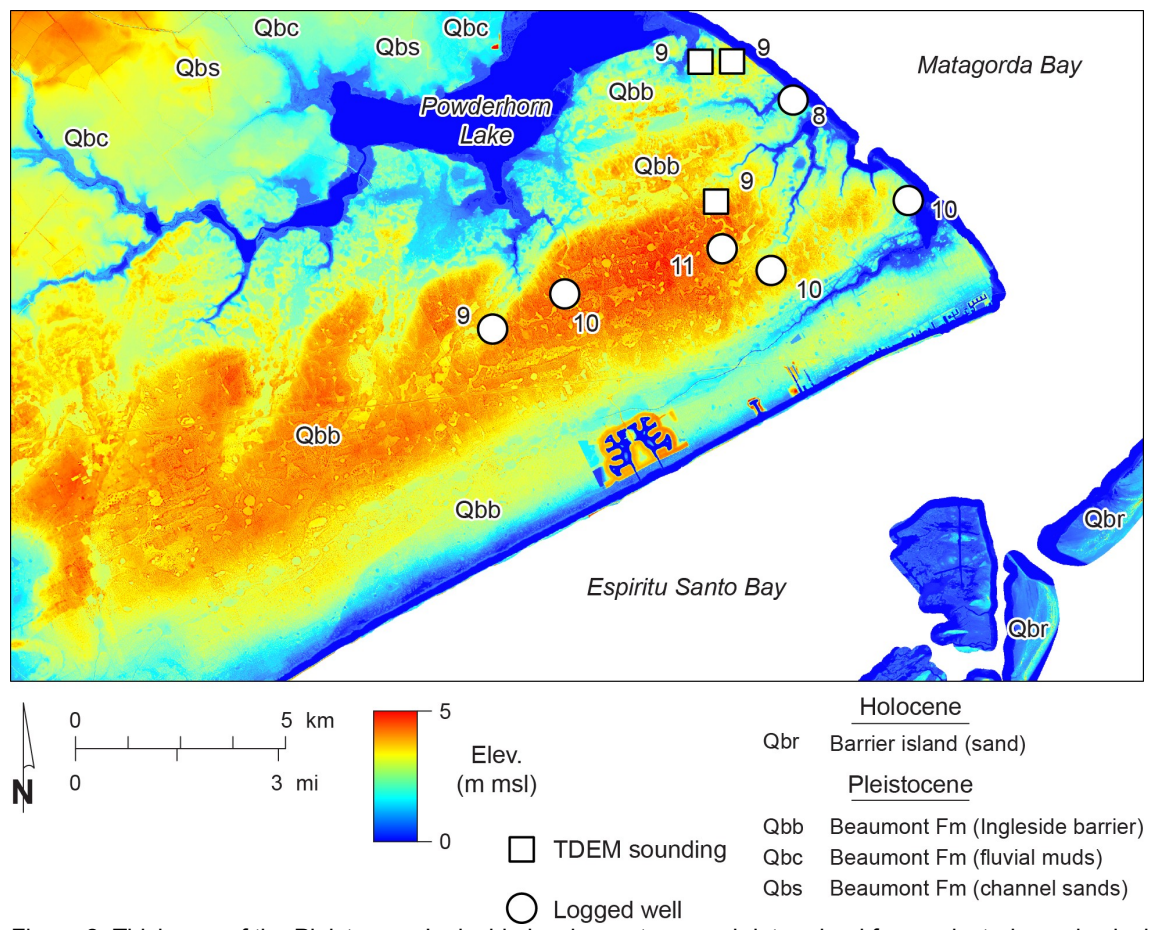


Figure 2. Thickness of the Pleistocene Ingleside barrier system sand determined from selected geophysical logs and TDEM soundings on and near Powderhorn Ranch, Matagorda Bay area, Texas coastal plain. Thicknesses are superimposed on topography from a 3-m grid cell lidar survey conducted by the U.S. Geological Survey in 2011. From Paine et al., 2018a.

Plenary: BUILDING BRIDGES BETWEEN GEOLOGIC MAPS, STRATIGRAPHY, AND SAMPLE-BASED MEASUREMENTS TO FACILITATE INTEGRATIVE GEOSCIENCE

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Geologic maps are foundational to many applications in the geosciences because they provide actionable models describing the spatial distribution, lithological properties, and structural fabrics of rocks and sediments at the Earth's surface and in the shallow subsurface. Most geologic maps make spatially continuous predictions. (i.e., there is an explicit or implicit prediction at every point over the entire map area). These predictions are made by experts with an understanding of regional geology that is further informed by spatially discontinuous observations, measurements and, often, remote sensing information (e.g., DEMs or satellite/air photogrammetry). As such, geologic maps constitute "Level 4" knowledge products that aim to represent the physical state of the world (to borrow the definition of data and data products from EarthScope's science plan). All geologic maps are, therefore, models that will be subject to revision and improvement as more and better data and constraints are obtained. All geologic map models operationally define rock units/sediment bodies that are mappable at the chosen map scale, with attention focused on spatial and physical relationships of those mappable units. Characterizing those mappable units by linking them to additional data and information on properties (physical, chemical, lithological, paleontological, etc.) can increase the value and utility of high-quality geologic map models and lead to new insights.

The Macrostrat Project is an academic effort to integrate geological data of multiple different fundamental types from across geoscientific domains (e.g., geochronology, mineralogy, stratigraphy, paleontology) into a database that is both human and machine readable. The foundational organizational principle of this database is space-time-lithology, with additional attributes appended to this core data structure, including lithostratigraphic nomenclatural hierarchy (often separately represented in canonical stratigraphic lexicons), sample-based measurements and observations, and continuous time models for the chronological distribution of space-lithology units. There are two separate but explicitly joined representations of space-time-lithology in Macrostrat: geologic maps and chronostratigraphic columns. Geologic maps focus primarily on the surface expression of mappable rock/sediment bodies, often with less chronological acuity than is known, whereas chronostratigraphic columns focus entirely on the temporal distribution of divisible chronological rock units, at the expense of spatial constraints.

Columns in Macrostrat include lithology units from the subsurface and subsurface and aim to provide complete representations of the subsurface into and including "basement" rocks (crystalline igneous and metamorphic rocks are often also subdivided). The column data model can accommodate any scale of representation of chronologically ordered rock units, from detailed measured sections/core logs to regionally composited, generalized geological columns. Units in these columns are correlated using standard methods to chronostratigraphic time intervals and then basic principles of temporal ordination (e.g., superposition) are used to construct a continuous time age model capable of making explicit predictions for any relative position within the unit. The Macrostrat geologic map data model is also multi-scale and currently contains over 85K map units from over 210 separate map sources; all original vector-based map data have been transferred into a common open-source PostgreSQL PostGIS environment and ported to a basic common structure, with original citation information and links to original sources provided.

A database that combines spatially-focused map data with chronologically-focused column data allows for many different geoscientific models, such as geologic maps, to be dynamically augmented as new information is collected. Existing examples of dynamic model enhancement include Macrostrat's continuing refinement of stratigraphic ages and correlations through its continuous time-age model and the linkage of geologic map data back to millions of documents from the primary scientific literature, an essential first step for more sophisticated machine learning-based approaches to map unit characterization. New major advancements under development in Macrostrat are development of a data pipeline to facilitate the semi-automated transfer of geochronological constraints from laboratory facilities (and scientific publications) to space-time-lithology rock units in way that can test and refine the continuous time age model. Machine learning approaches to automating the characterization of map and column units by locating and extracting linked data from scientific publications, including images and data from tables, is also under active development.

Search Macrostrat

Geologic map via providers, Macrostrat

Name: Decorah Shale, Galena Group

Age: Upper Ordovician (458.4 - 443.8Ma)

Stratigraphic name(s): Decorah Shale

Description: Primarily grayish-green, fissile to blocky, fossiliferous shale that contains interbedded, thin, grayish-yellow, coquina limestone and calcareous shale beds. It is subdivided into two members. The upper unnamed member is about 90 feet thick (27 meter...)

Comments: Twin Cities Basin; Ordovician

Source: Mossler, J.H., 2013, *M-194 Bedrock Geology of the Twin Cities Ten-County Metropolitan Area, Minnesota*: University of Minnesota Digital Conservancy. 55 / 2388592

Macrostrat-linked data via Macrostrat

Age: Sandbian - Katian 457.925Ma - 451Ma

From original map source; note "Upper Ordovician"

Citation and link

Macrostrat column age model-derived age

Search Macrostrat

Primary Literature via GeoDeepDive

Palaeogeography, Palaeoclimatology, Palaeoecology Elsevier

Williams, Mark, Floyd, James D., Salas, Maria Jose, Siveter, David J., Stone, Philip, Vannier, Jean M.C., 2003. Patterns of ostracod migration for the 'North Atlantic' region during the Ordovician.

Ludvigson, Greg A, Witzke, Brian J, González, Luis A, Carpenter, Scott J, Schneider, Chris L, Hasiuk, Franciszek, 2004. Late Ordovician (Turinian-Chatfieldian) carbon isotope excursions and their stratigraphic and paleoceanographic significance.

...As before, positive excursions in the **Decorah Formation** occur in the lower Spechts Ferry interval (up to about 0700) and the Guttenberg interval (up to about +2.5 ‰)

...This drill site is located outward beyond the downlap limits of the Guttenberg Limestone Member of the **Decorah Formation** , and is shown as locality 7 in Figs

...As before, two distinct positive excursions occur in the **Decorah Formation** , in the lower Spechts Ferry Member (up to about +2 ‰) and the Guttenberg Member (up to about +2.5 ‰)

...Unlike the southeastward stratal downlap interpreted for the overlying **Decorah Formation** , the Quimby Mill downlap apparently is oriented to the northwest (and possibly Nachusa as well)

Automatically-recognized publications mentioning map unit

Talk: SURFICIAL GEOLOGIC MAPPING FOR GREEN INFRASTRUCTURE SITING AND SUITABILITY

Phillips, A.C.¹ (aphillips@illinois.edu), D.A. Grimley¹, M.P. McGuire², R. William³, J. Shen², A.S. Stillwell³, P. Szocinski¹, A.J. Clark¹; ¹Illinois State Geological Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, ²Department of Landscape Architecture, University of Illinois at Urbana-Champaign, ³Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign

Geologic mappers, landscape architects, soil surveyors, and civil engineers are collaborating in design of green stormwater infrastructure (GSI) to reduce stormwater impacts for two municipalities in southern Cook County, IL, just south of Chicago's city limit. Calumet City and Midlothian undergo regular stormwater flooding because existing gray infrastructure is inadequate. The flooding occurs with increasing frequency and duration as storms have intensified over past decades. With insufficient funding to expand the gray infrastructure, GSI solutions are desired to complement existing systems, and to provide more resilient stormwater benefits for communities over time (Center for Neighborhood Technologies 2016, 2017). A key strategy is to retrofit the land for GSI (e.g. through the reduction of imperviousness), but there is a perception that the region is dominated by impervious soils, a perception that has limited the design and implementation of GSI in these communities. It is also not usual for natural soils to be considered in typical GSI designs. Rather, in practice, traditional GSI design relies on amended soil layers rather than on native soils. The interface of these two design and performance components—the amended upper layer of GSI, and the subsurface native soils—is an underdeveloped area of soils-based GSI design. By contrast, with high-resolution mapping of the near-surface geology and soils and their hydrologic properties, we demonstrate that recognition of natural soil conditions can improve site-specific GSI planning and design.

The landscape of southern Cook County is bounded by the Valparaiso Moraine in the southwest, and Lake Michigan on the east, with glacial Lake Chicago covering much of the area between them. Bretz constructed 1:48,000 surface geologic maps in the mid-20th century, mapping mostly “Glacial Lake Bottom”, with undifferentiated surficial materials interrupted by sandy beach ridges. Midlothian lies mostly on the glacial lake bottom, lapping up onto the Valparaiso Moraine, whereas Calumet City lies on beach ridges. In the latest soil survey, Caslyn et al. (2012) mapped large areas of low-permeability soils, including natural and urban soils, with seasonally high water table, i.e., <6 ft below ground surface. To more precisely map the surficial geology in 3 dimensions, we added hundreds of new geotechnical borings to our database, and worked with the NRCS to measure hydraulic conductivity *in situ*. We found considerably greater textural variability in the lake bottom landscape than first assumed. In addition, *in situ* hydraulic conductivity (Ksat) varied over several orders of magnitude, likely a result of textural variability, soil horizonization, and soil macroporosity (Fig. 1). We divided the Ksat measurements into three classes representing fine (~0.10 cm/h), mixed (~0.90 cm/h), and coarse textured sediment (~9.0 cm/h), respectively. The measured Ksat values were significantly lower than published values for the finer soils. Nonetheless, engineering analysis of design prototypes demonstrates several promising GSI designs for rain gardens and permeable pavements that could be used in the target municipalities and, by extension, in similar urban landscapes in the region (Fig. 2). A key finding is that the loading ratio (surface area run-off treated in the GSI design) matters significantly to the resilient performance of GSI with implications for retrofitting the regional landscape under increasing rainfall scenarios.

Amoozegar, A, 1989. A compact, constant-head permeameter for measuring saturated hydraulic conductivity of the vadose zone: Soil Science Society of America Journal, v. 53, p. 1356–1361.

Calsyn, D.E., L.P. Reinhardt, K.A. Ryan, and J.L. Wollenweber. 2012. Soil Survey of Cook County: United States Department of Agriculture, Natural Resources Conservation Service, Champaign, Illinois, 764 p.

Center for Neighborhood Technologies. 2016. Rain Ready Midlothian Plan: Accessed online at https://www.cnt.org/sites/default/files/publications/CNT_RainReady%20Midlothian%20Plan.pdf, 20190311.

Center for Neighborhood Technologies. 2017. Rain Ready Calumet Corridor, IL: Access online at http://www.cnt.org/sites/default/files/publications/CNT_RainReadyPlan_CalumetCorridor_CalumetCity_Plan.pdf, 20190311.

Figure 1. Results of *in situ* hydraulic conductivity measurements (following Amoozegar 1989) in Midlothian and Calumet City.

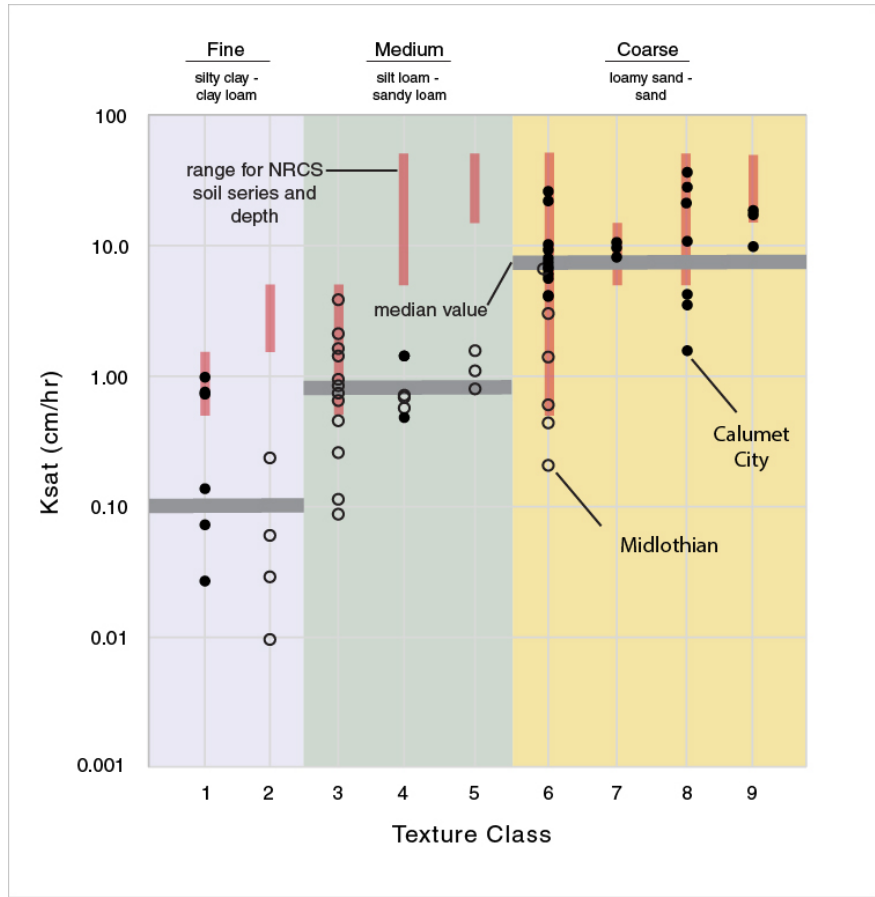
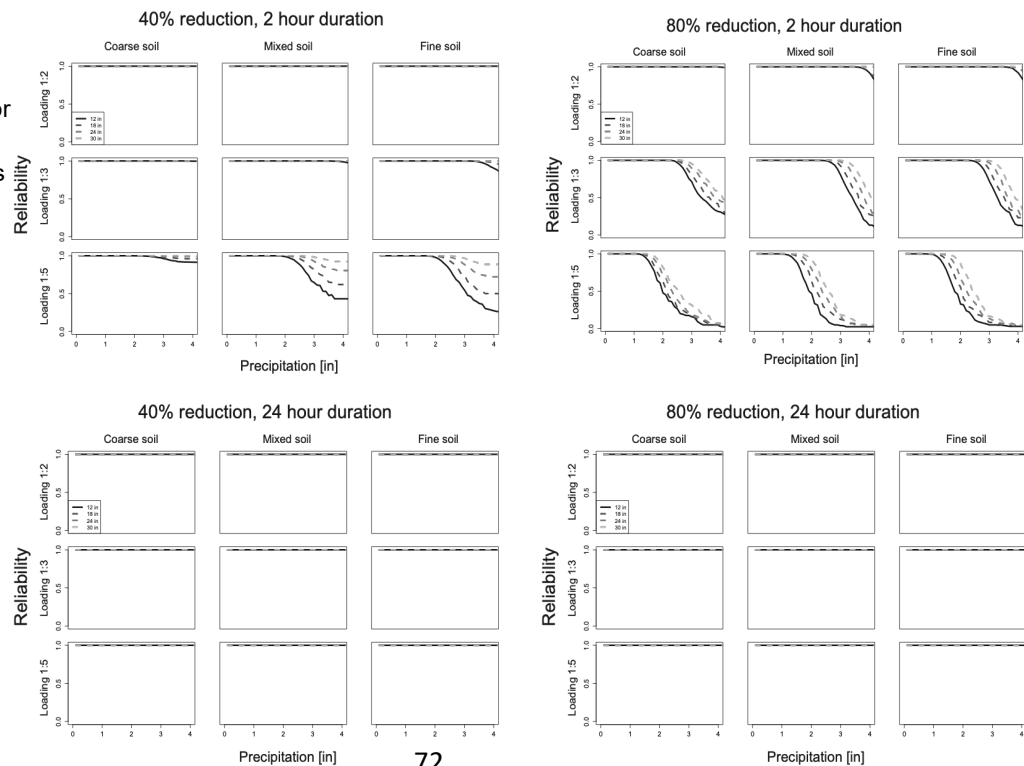


Figure 2. Sample reliability curves for rain gardens. Functional designs are possible even in fine soils



Poster: A 1-METER PERSPECTIVE ON GEOLOGIC MAPPING UTILIZING A NEWLY-RELEASED LIDAR DATASET IN THE APPALACHIAN VALLEY AND RIDGE OF VIRGINIA

Philip S Prince, Virginia Division of Geology and Mineral Resources

A new 1-meter LiDAR elevation dataset (USGS) for southwest Virginia highlights the application of high-resolution surface imagery to all aspects of geologic mapping and public outreach. Hillshades developed from the elevation data are particularly useful as a means of enhancing feature visibility in previously mapped areas as well as in locations yet to receive detailed (*i.e.*, 1:24K) mapping. Usability of hillshade imagery is further enhanced by creating Google Earth overlay *.kmz* files that permit non-specialist users without ArcGIS access to utilize imagery in a real-time 3-D setup.

Hillshades prepared from 1-meter elevation data show particular applicability to 1) identification of prehistoric or ancient landslides and other mass wasting features, 2) correlation of stratigraphic units across large areas where outcrop may be limited, and 3) communication of geologic mapping goals and outcomes to the general public. Inspection of the new hillshade imagery has revealed dozens of previously unmapped landslide and colluvial features in the Appalachian Valley and Ridge and Plateau. These features range in size from 10's of meters to 100's of meters across and involve up to a 100+ meter thickness of rock and overlying regolith and soil. Reexamination of large mapped blockslides (*e.g.*, Schultz, 1986) has revealed features such as tensional cracking on slide toe anticlines that would not be visible by any other means, including field inspection. Variations in facies and thicknesses of sedimentary units associated with these slides as well as in valley-forming units are revealed in equal clarity, providing a new means of distinguishing between stratigraphic variation and structural separation of subtly different but otherwise age-correlative horizons. Communication of these concepts and observations to the general public through a variety of social media outlets has been highly successful, engaging both specialist and non-specialist audiences within and beyond the study area. Continued production and utilization of high-resolution surface imagery may pave the way for more effective public engagement and thus increased collective support for geologic mapping in coming years.

Poster: FIELD PRODUCTION AND DIGITAL ASSEMBLY OF MULTISCALE GEOLOGIC MAPS AND STRATIGRAPHIC COLUMNS FOR REGIONAL STRUCTURAL STUDIES

Daven P. Quinn and Shanan E. Peters, Dept. of Geoscience, University of Wisconsin-Madison, Madison, WI 53706

Geologic maps are critical knowledge products that underpin all types of regional geologic studies. They are data-rich and encode critical information about an entire study area: lithologic makeup, structural fabrics and surfaces, and relevant landscape features. To now, the production process of geologic maps has generally been dictated by the capabilities of static media. It is typical for maps to be compiled atop a pre-existing basemap at a single predefined scale. Revising aspects of the map's target scale and the definition of "mappable units" comes at significant cost in re-drafting, and in some cases, renewed fieldwork to capture missing data.

For exploratory field projects without an initially defined "best" map scale, the sensible strategy of conducting field mapping at the highest scale necessary for interpretation and synthesis requires laborious preparatory work and inhibits field flexibility. The appropriate specificity of unit definitions changes depending on the level of detail captured. Increasingly, techniques such as UAV photogrammetry make the generation of high-resolution contextual data part of the field-study process itself. These factors make it difficult to tie a mapping projects to a single scale for interpretation and visualization; they also complicate the linearity of mapping workflows.

New web-based digital platforms (e.g. Google Maps, Apple Maps, and others) are ubiquitous and widely accepted interfaces to mapping data. These platforms are based around a common digital-interface paradigm for interacting with maps across a range of scales. The software tooling for such mapping approaches is increasingly standardized, with commercial offerings from ESRI and Mapbox, among others, and open-source tools (e.g. Leaflet, Mapnik, and PostGIS) and formats (e.g. the Web Mercator projection). Such new visualization techniques are straightforwardly adapted to display geologic maps by projects such as *Macrostrat*, which integrates regional, state-level, and continent-scale geologic maps from the literature to form a scale-independent visualization tool.

Adapting this new multiscale paradigm to the production of regional geologic maps holds clear advantages for the flexibility of collection and display of geological mapping data. We detail a field methodology and GIS data-management system that enables the digital collection of contacts and unit definitions in the field, closely coupled with a map-production software pipeline that allows iterative assembly of a geologic map from multiscale data.

In the field, tablet-based software such as Midland Valley *FieldMove* allows the rapid and accurate capture of structural measurements, but only supports basic input of map contacts and relations. We have supplemented this software with a custom application, *Mapboard GIS* (currently in beta testing) that allows stylus-based digitization of UTM mapping data directly into an on-device GIS database, atop a familiar zoomable map interface. This field-portable software produces linework and unit definitions that can be mirrored to a PostGIS database on a laptop or desktop computer. This database is coupled with open-source software (<https://github.com/davenquinn/postgis-geologic-map>) that solves topological relationships between map edges in real time, allowing linework to be expanded into space-filling unit polygons as digitization progresses. Unit definitions are adaptable across scales, allowing detailed member-scale mapping to be dissolved into formation and tectonic block units for display.

This novel workflow allows the composition of geologic maps at high resolution and across large areas, with full visualization of output during map creation. It was successfully deployed to create a preliminary geologic map of the Naukluft Nappe Complex, Namibia, where it was coupled with a parallel multiscale workflow for preparing summary stratigraphic columns for ~2000 m of measured section (Quinn et al., 2017; Quinn, 2018). The software pipeline was used without its field component to draft a geologic map of NE Syrtis Major, Mars (Quinn and Ehlmann, 2019), demonstrating its use with arbitrarily-projected data. Looking forward, this new paradigm will allow collaborative mapping by several workers, mapping across project scales in a single interface, and management of evolving mapping data over time, using modern, open-source data-management tools. Chronostratigraphic representations of map units (e.g. stratigraphic columns) have similar multi-scale properties and can be integrated into the same data system.

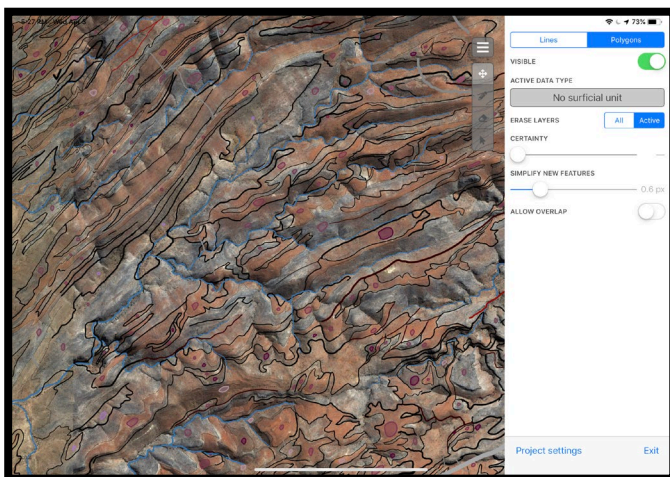
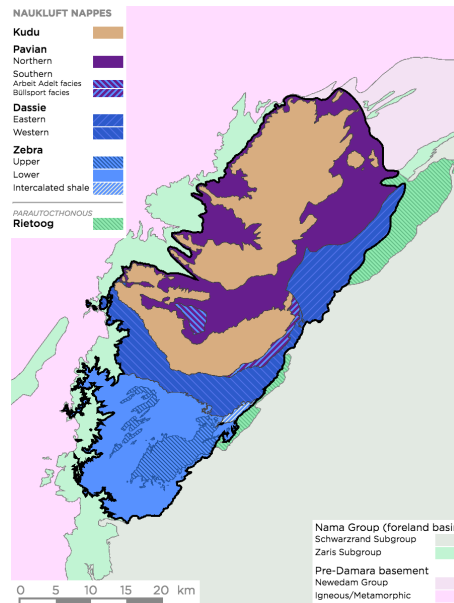
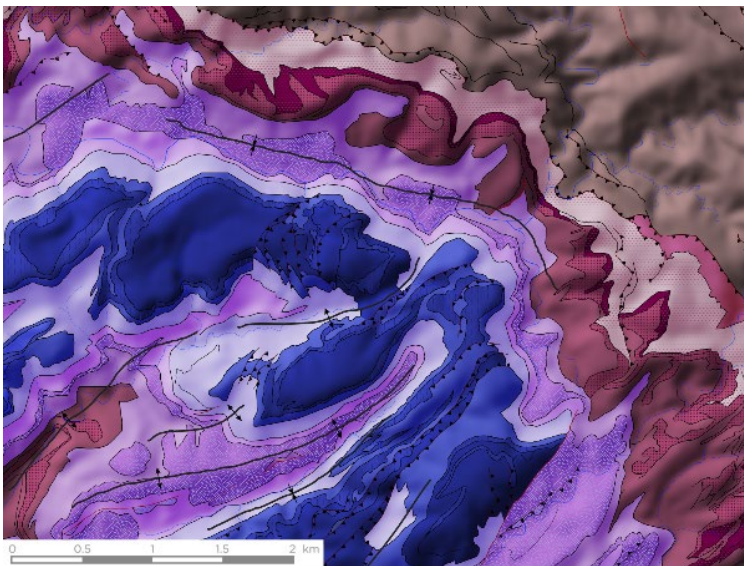
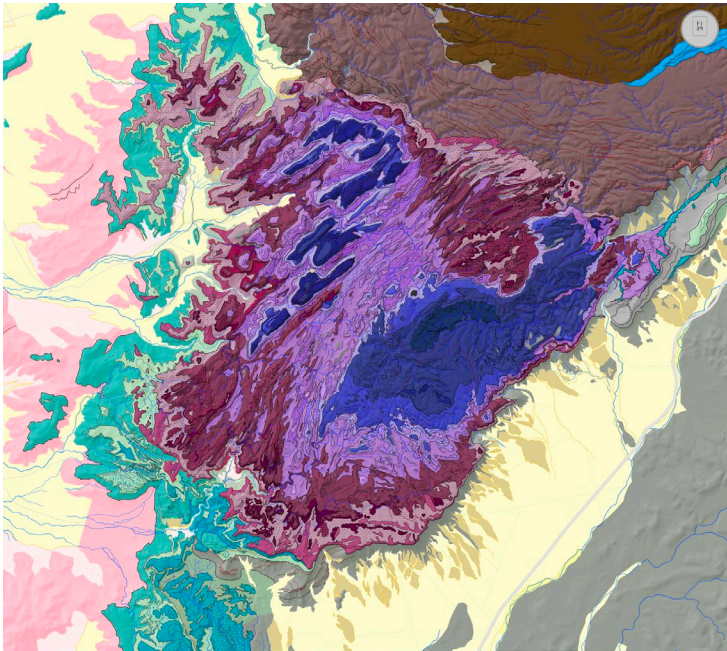
The field component of this system, the *Mapboard GIS* iPad application, was tested by several workers during fieldwork in Namibia in summer 2018 and is undergoing active development. Ongoing work to define its pricing strategy, code availability, and governance model will be crucial to its release and community uptake.

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Geologic and tectonic maps maps at multiple scales visualized from the same PostGIS mapping database



User interface of the prototype Mapboard GIS geologic mapping application

Talk: MAPPING MINNESOTA'S PRECAMBRIAN GEOLOGY

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ABSTRACT

Precambrian rocks representing more than 2.5 billion years of Earth's history form the geologic 'basement' across all of Minnesota. During roughly the last 150 years, the Minnesota Geological Survey (MGS) has produced hundreds of geologic maps across a wide range of scales (see Fig. 1) to portray the Precambrian geology of the state. Most Precambrian mapping in recent years has focused on individual counties at a scale of 1:100,000 as components of our County Geologic Atlases (CGA). This talk describes the myriad mapping techniques and datasets geologists at MGS use to construct Precambrian bedrock topography and geology maps for CGAs. A brief introduction will set the stage with a review of the major Precambrian rock packages in MN. We will then shift focus to the datasets used in Precambrian mapping, before discussing the specifics of how the MGS constructs bedrock geology and topography maps. Discussion will touch on the role of numerous datasets including: outcrop, hand samples, thin sections, gravity and magnetic data, seismic reflections and refractions, and the County Well Index.

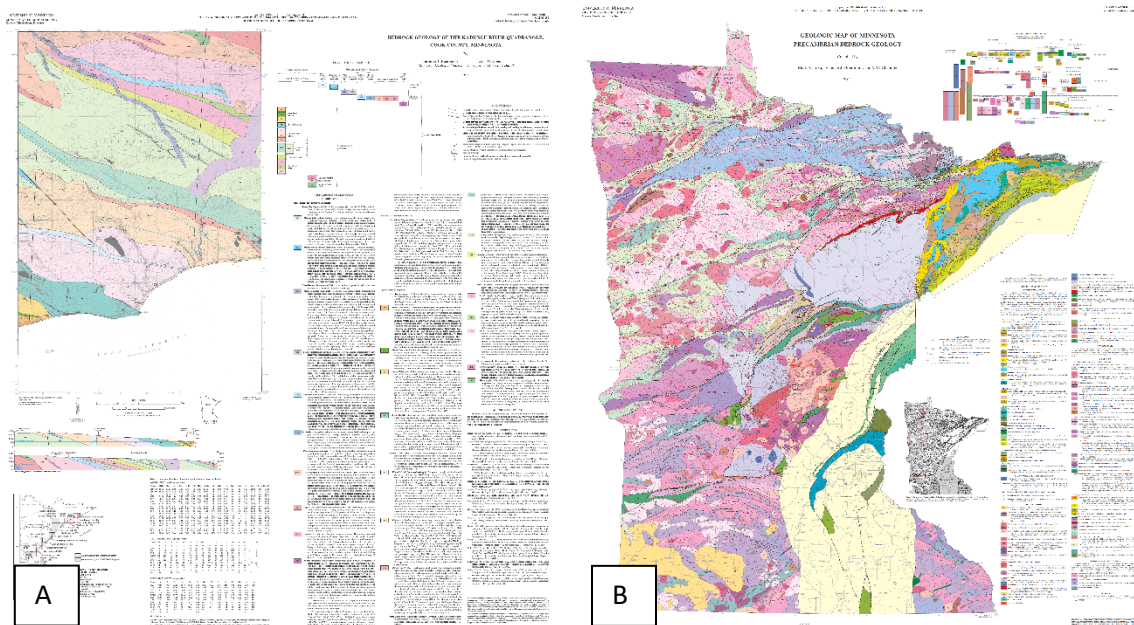


Figure 1. Maps of Precambrian bedrock in Minnesota at large and small scales. A. Kadunce River Quadrangle, scale 1:24,000. Boerboom and Green (2011). B. Precambrian bedrock geology of Minnesota, (scale 1:1,000,000) with all Cambrian and younger strata removed. Jirsa et al. (2012).

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Talk: UPDATE ON GLACIAL MAPPING OF WESTERN WAUSHARA COUNTY, WISCONSIN

J Elmo Rawling III and Stef Dodge, Wisconsin Geological and Natural History Survey, University of Wisconsin-Extension, 3817 Mineral Point Road, Madison, WI 53705, elmo.rawling@wisc.edu;

Abstract

A long-term goal of the Wisconsin Geological and Natural History Survey (WGNHS) is to map the Quaternary geology of the state at a scale of 1:100,000. This mapping coverage is nearly completed along the late Wisconsin (MIS 2) ice margin. This two-year project will complete surficial mapping of western Waushara County, the only remaining area in central Wisconsin unmapped along the MIS 2 ice margin. The Quaternary geology of the eastern half of the county was mapped recently by WGNHS staff and faculty at UW-Oshkosh for a project that investigated the Quaternary geology of the Fox River lowland. The completion of mapping in Waushara County will facilitate publication of the entire county as a single 1:100,000-scale map. All of the counties surrounding Waushara County are mapped at the 1:100,000 scale; as such, the area proposed to be mapped lies in a location that is key to linking the geology of central Wisconsin to the Fox River lowland.

Western Waushara County is located in central Wisconsin and straddles the drainage divide between the Wisconsin and Fox Rivers. The divide is formed by end moraines of the Green Bay Lobe of the MIS 2 Laurentide Ice Sheet during the Hancock, Almond and Elderon phases (Fig 1) (Attig et al., 2011). To the west, the Central Sand Plain consists of melt-water stream sediment that prograde into lacustrine nearshore sand and offshore silt of glacial Lake Wisconsin (Clayton and Attig, 1989). These are locally covered with eolian sand including dunes formed approximately 12 kya (Rawling et al., 2008). To the east, the Fox River lowland includes silt and clay of glacial Lake Oshkosh, interstratified with glacial and melt-water stream sediments (Hooyer, 2007). In addition, there are several tunnel channels formed by subglacial drainage while active ice was at the margin (Fig 1).

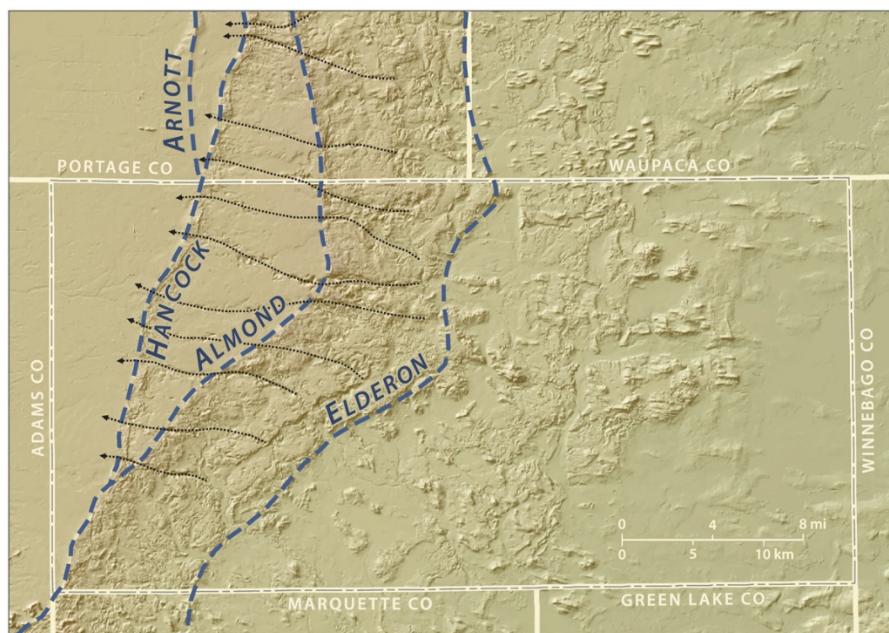


Fig 1. Hillshade image (USGS, 2015) centered on Waushara County showing the location of the Arnott, Hancock, Almond and Elderon phases of glaciation (Attig et al., 2011; dashed lines), and the location of tunnel channels (dashed arrows) in the proposed mapping area. Phases east of the Elderon are not shown.

The deliverable product for the Great Lakes Geologic Mapping Coalition will consist of a 1:100,000 scale map showing the preliminary interpretation of the Quaternary geology for the portions of the Coloma, Hancock, Plainfield, Richford, Wautoma, and Wautoma NE topographic quadrangles (scale 1:24,000) within Waushara County. This project is a collaboration with students and faculty from UW-Madison, UW-Oshkosh, UW-Milwaukee, and Temple University. In addition to the mapping, investigations include active seismic stratigraphy across one of the tunnel channels (Zoet et al., 2019), collection of a 126.7 meter rotosonic core thru the center of the tunnel channel, and cosmogenic dating of a Marine Isotope Stage 3 (MIS 3) Moraine previously thought to be Illinoianan (MIS 6) or older (Ceperley et al, *in press*).

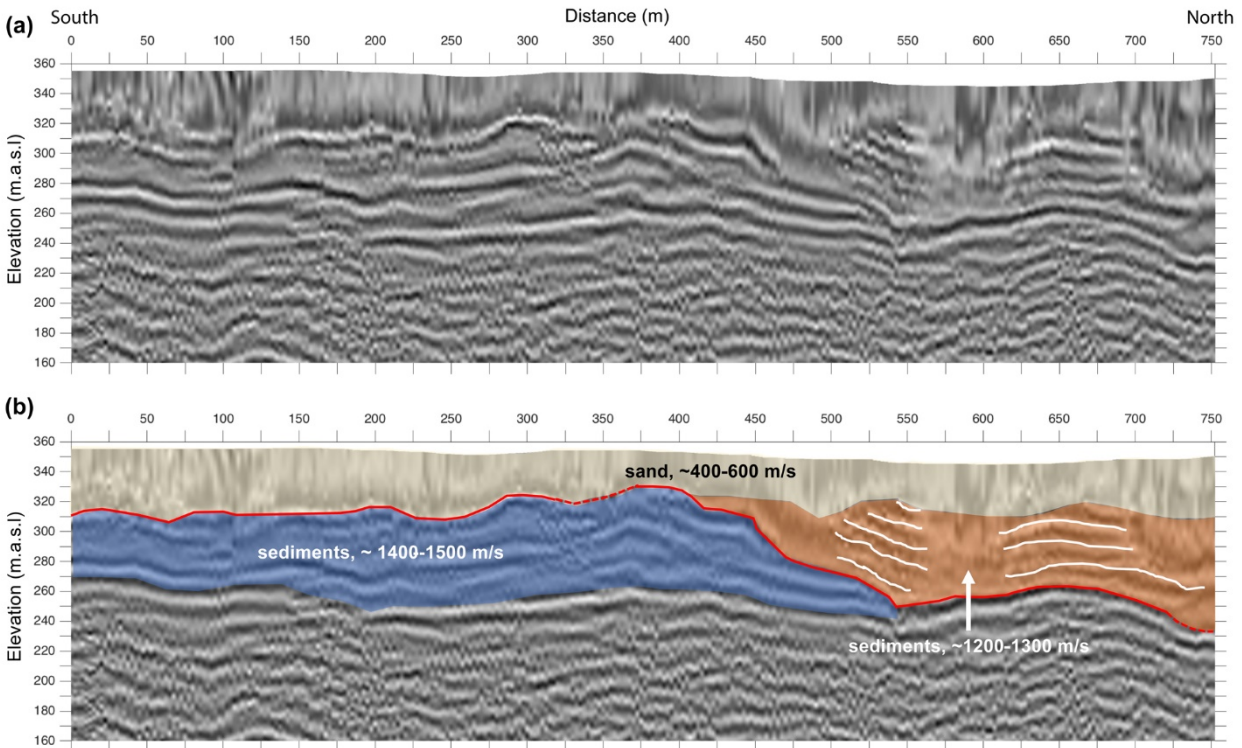


Fig 2. Seismic profile across a tunnel channel (from Zoet et al., 2019). Upper panel has no interpretation while the lower panel has interpretations of seismic reflectors. Red line is the inferred subglacial surface following the excavation of the tunnel channel indicating ca. 65 m of excavation. The blue region is preexisting subglacial sediments (likely a coarse diamicton) and the orange region is material that filled the channel following the melt out of buried ice. Seismic velocities are indicated by the white numbers. Seismic velocities of the sediments with the channel are slightly lower than those of the surrounding blue region. Rotosonic core was collected to ~125 meter depth as the 600 meter distance.

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Hooyer, T.S., ed. 2007. Late-glacial history of east-central Wisconsin: Wisconsin Geological and Natural History Survey, Open-File Report WOFR-2007-01, 95 p.

Rawling III, J.E., Hanson, P.R., Young, A.R., and J.W. Attig. 2008. Late Pleistocene dune construction in the Central Sand Plain of Wisconsin, USA: *Geomorphology*, v. 100, p. 494-505.

Zoet, L.K., Muto, A., Rawling III, J.E. and Attig, J.W. 2019: The effects of tunnel channel formation on the Green Bay Lobe, Wisconsin, USA. *Geomorphology* 324, 36-47.

Talk: GEOHERITAGE SITES - BLAZING THE TRAIL OF GEOLOGY WITH THE PENNSYLVANIA NATURAL HERITAGE PROGRAM

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The Pennsylvania Geological Survey (PaGS) published the two-part Environmental Geology Report 7 (EG 7) as a compilation of scenic geological features of the state (Geyer and Bolles, 1979, 1987). This report was a “best-seller” for many years. EG 7 describes 514 sites of particular geologic significance or interest. Rock cities, scenic views, landforms, waterfalls, springs, and geologic outcrops are typical of the sites described. In the late 1980s, natural diversity program managers in Pennsylvania became aware of the report and ultimately included more than 100 of the EG 7 scenic features as geoheritage sites or “geologic species” into the Pennsylvania Natural Diversity Index (PNDI). PNDI evolved into the Pennsylvania Natural Heritage Program (PNHP), which began in 1988. The PNHP program presents information on biological diversity, protected lands, streams and other natural resources through conservation planning. PaGS completes conflict reviews as part of the PNDI process, though now through online tools (PNHP, 2019). Geology sites as “species of special concern” may be listed side by side with rare, threatened, and endangered species, or species with particular habitat needs or declining populations. In the late 2000s, additional sites were added to the geology species list, expanding the list to 214 sites. PNHP geologic species include “anticlines, boulder belts, drainage patterns, erosional remnant, esker, fossil plants, invertebrate fossil animals, kettlehole, life history, meandering channels, mineralization materials, Paleozoic Earth history, pingo scar, potholes, sand dune, springs, tufa, vertebrate fossil animals, and waterfalls and rapids.” Caves are treated separately as “supporting landscapes.” In the past two decades, PaGS has been increasingly incorporated into the environmental project review process, and has participated in the development of the matrix of activities that trigger reviews and the assignment of appropriate geographic buffers.

After EG 7 went out of print, PaGS revisited the scenic features in the mid-2000s and found many to be degraded by vegetation, local development, graffiti, etc. PaGS turned to sites on public land to direct attention to such exceptional features. In the early 2010s, PaGS developed 93 short publications for selected outstanding geological features. The summaries, designed as portable documents and written for the public, included coordinates, parking locations, inset maps, photographs, geologic overviews, and references. The development of department online-mapping tools including PaGEODE (Pennsylvania GEOlogic Data Exploration, 2019) coincided with the summaries. As more feature summaries were completed, the data layer became one of the most-heavily accessed web pages. By 2017, the summary pages and other geologic park guides were merged into a new Trail of Geology publication series (Reese, 2017), which currently contains 119 publications (Figure 1). The sites are typically accessible places and overlap with the geoheritage sites.

For conservation planning, inclusion of original scenic features with PNHP has been a connector with conservation agencies and particularly relevant for the conservation of some sites. The conservation planning and PNDI environmental review system in PNHP uses an online tool (Pennsylvania Conservation Explorer, 2019), which identifies specific land-use activities and project locations that intersect geoheritage site buffers (Figure 2). Although current law does not provide geoheritage features any special protection, numerous notifications have led to PaGS action to conserve sites or provide recommendations to reduce potential impacts. The adoption of scenic geologic features into the world of conservation and ecological planning provides the PaGS an inroad to conservation concerns and organizations. Additionally, the Trail of Geology series provides a means to promote geologic education while highlighting outstanding geologic features of the state.

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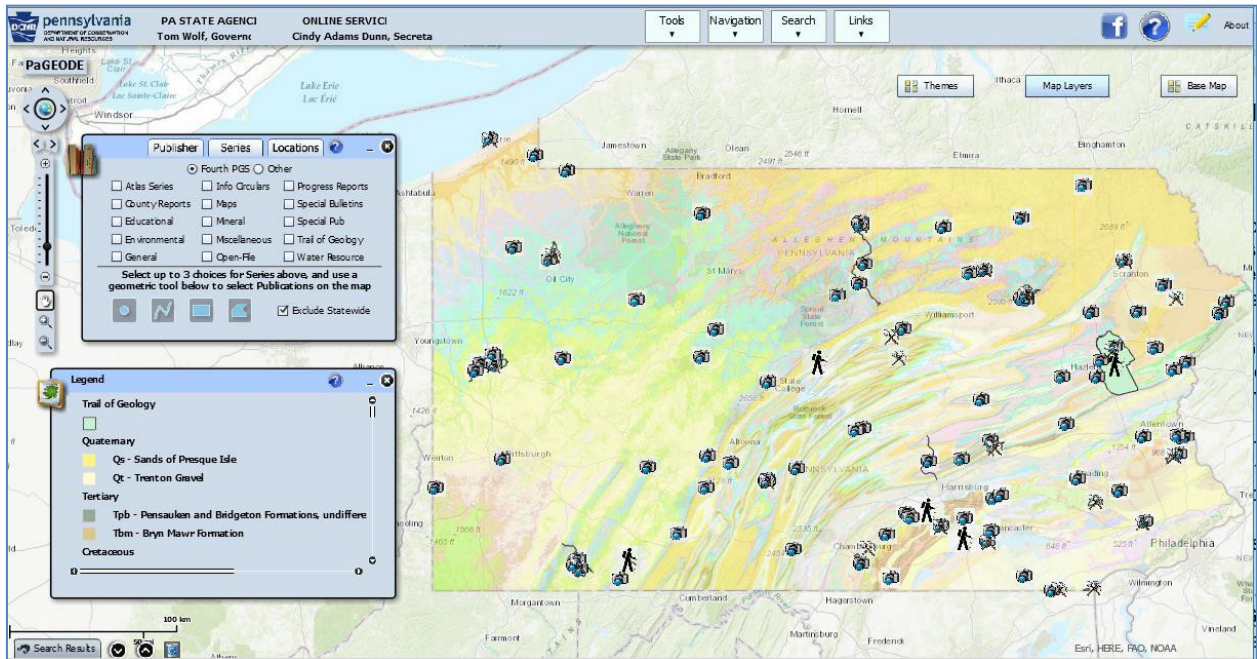


Figure 1. Screenshot of PaGeode online mapping tool showing locations of Trail of Geology features.

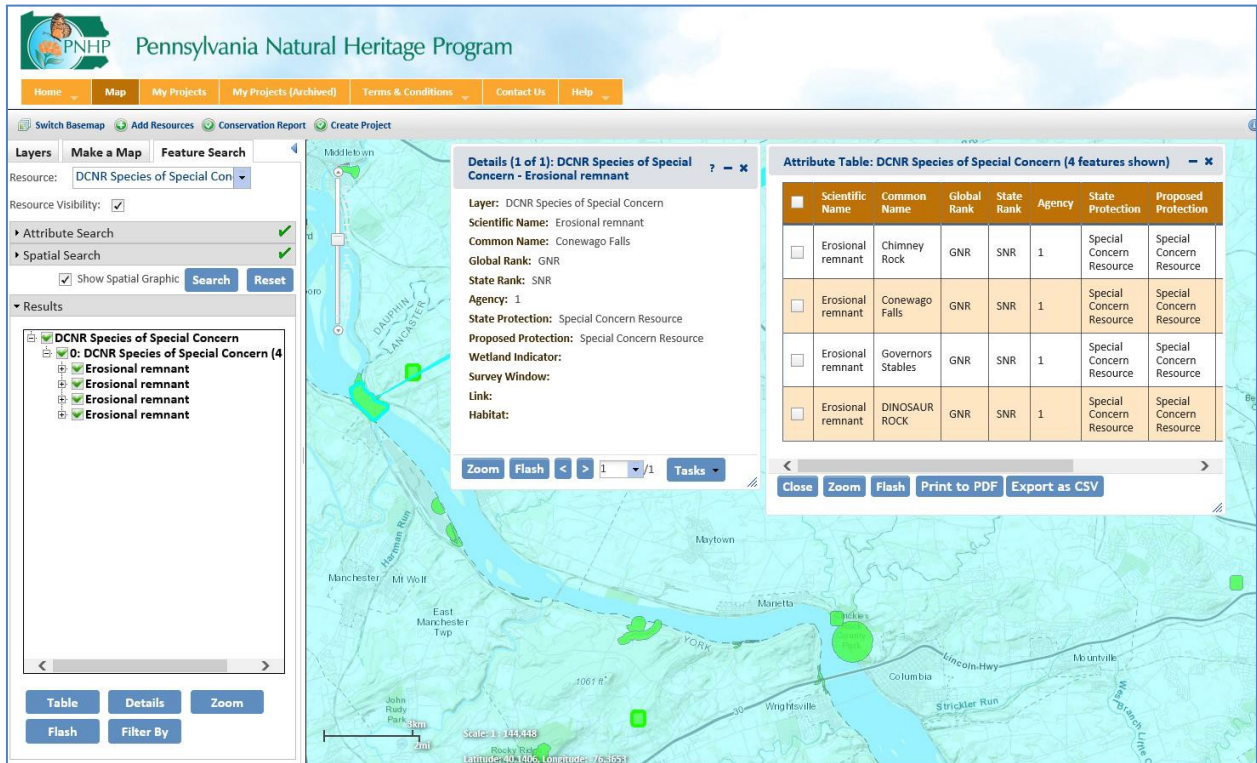


Figure 2. Screenshot of PNHP Conservation Explorer online mapping tool showing selected geology features.

Talk: PALEOZOIC & MESOZOIC BEDROCK MAPPING AT THE MINNESOTA GEOLOGICAL SURVEY: AN OVERVIEW OF CURRENT PROCEDURES

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ABSTRACT

About 75% of Minnesota's drinking water and 90% of agricultural irrigation is groundwater—a significant portion of which is drawn from various sedimentary bedrock units of Paleozoic and Mesozoic age (Minnesota Environmental Quality Board, 2010). Perpetual geologic mapping of these units is crucial to refining their extent, thicknesses and hydrogeologic boundaries when faced with ever-increasing amounts of new and old geologic data. As of 1982, the primary vehicle for geologic mapping at the Minnesota Geological Survey (MGS) has been our County Geologic Atlas (CGA) program. While the overall goal of this geologic mapping has not changed, the available datasets and methodology have. This talk provides a general overview of the current procedures for mapping the Paleozoic and Mesozoic bedrock as part of the CGA program, with an emphasis on currently available datasets, 3D geological products, modern pitfalls and speculative ways to further streamline and evolve our geologic mapping methods at the MGS.

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Poster: COMPILATION AND MAPPING OF GEOLOGIC DATA IN USGS COAL RESOURCES AND RESERVES ASSESSMENTS USING INTEGRATED DATABASE AND GEOLOGIC MODELING SOFTWARE

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The U.S. Geological Survey's U.S. Coal Resources and Reserves Assessment Project has long relied on separate software packages originally developed in the 1980's to compile, process, and map geologic data utilized in coal resources and reserves assessment studies. These separate software packages quickly became outmoded, ran on obsolete or non-compliant IT operating systems and used outdated VGA graphics. Additionally, because of their vintage, the software packages were no longer supported by their original developers. The absence of continual software development and support left little possibility to upgrade or update these applications to meet evolving USGS coal resources and reserves assessment needs. USGS management initiated the process to acquire state-of-the-art coal resource evaluation software that was IT compliant, integrated multiple features, and met the increasingly complex needs of the Coal Resources and Reserves Assessment (CRRA) Project.

After review of several commercial coal resource evaluation software packages, the CRRA Project acquired Carlson Software (Carlson Software, 2018) as an integrated database and geologic modeling package. Carlson Software, originally named SurvCAD, is a geologic database, geologic modeling, and mine planning software package developed in the 1990's specifically for the coal industry. The software capability has been continually maintained, improved and expanded to meet the complex requirements of the coal industry. The software runs seamlessly with AutoCAD (Autodesk, 2017), a widely-used computer-aided drafting and design software package. Carlson Software does not require any special operating systems or high-end computer hardware, so it was not prohibitively expensive to acquire and install.

The Carlson Software package enhances the ability to compile geologic data, update stratigraphic correlations, generate grids, and prepare geologic maps without having to use separate software packages. Additionally, with AutoCAD running in the background, editing and drafting modifications can be done easily and quickly, without exiting the Carlson application. A supplemental module for Carlson Software was purchased by the USGS to interface with ArcGIS (ESRI, Inc., 2017). This allows shapefiles and other data to be easily transferred between ArcGIS and Carlson Software and augments the spatial evaluation of coal resources and reserves.

A recent CRRA study completed for the Bureau of Land Management (BLM) in Montana demonstrates the abilities of Carlson Software as an integrated database and geologic modeling package. The BLM requested an assessment of coal resources in the eastern Montana portion of the Williston Basin to determine coal deposits in that area may have economic potential. Drill hole data from eastern Montana were downloaded from the National Coal Resources Database System in spreadsheet form and then were loaded into Carlson Software. The base map for the project was imported into Carlson Software from ArcGIS, using shapefiles. Once the data were loaded, geologic correlations were reviewed and edited, then confirmed by generating geologic cross-sections through the study area. Inclusion areas, where at least one coal bed is 10 ft thick or greater, were delineated from the drill hole data. Grid files were generated in Carlson Software for cumulative stripping ratio. Maps were generated

from the grid files with isopach lines within the inclusion areas that show good economic potential (less than or equal to 5:1 cumulative stripping ratio), marginal economic potential (5:1 to 10:1 cumulative stripping ratio), and poor economic potential (greater than 10:1 cumulative stripping ratio). The economic potential is based on economic modeling that was generated for the Powder River Basin (Luppens, et al. 2015), which is located southwest of the BLM study area. The inclusion areas and isopach lines were exported as shapefiles to ArcGIS. The ArcGIS shapefiles were then provided to the BLM to be overlaid into their GIS maps.

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Plenary: THREE-DIMENSIONAL GEOLOGICAL MAPPING AND MODELING ACTIVITIES IN THE U.S. GEOLOGICAL SURVEY— OPPORTUNITIES, CHALLENGES, AND CONSIDERATIONS FOR THE FUTURE

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The U.S. Geological Survey (USGS) is the national geological survey for the United States and the sole science agency within its cabinet-level bureau, the Department of the Interior. The USGS has a broad mission, including: serving the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect quality of life. USGS scientific activities are organized around major topics, or Mission Areas, aligned with distinct science themes, including Land Resources, Core Science Systems (which includes the National Cooperative Geologic Mapping Program), Ecosystems, Energy and Minerals, Environmental Health, Natural Hazards, and Water Resources. Three-dimensional (3-D) modelling typically supports research and project work within a specific Mission Area; 3-D modeling activities are decentralized, spread across USGS Mission Areas. The vastness, diversity, and complexity of the geological landscape of the United States has resulted in the creation of 3-D geological framework models that are local or regional in scale; a National-scale 3-D model is only beginning to evolve.

Overview of 3-D Modelling Activities

Within the USGS Energy and Minerals Mission Area, a wide variety of 3-D data management, modeling, and visualization tools are applied as part of resource assessments. In Energy, 3-D geologic models are built as stand-alone research projects for reservoir characterization and as geologic input to 4-D pressure, volume, temperature models that are used in petroleum geology assessments to understand and delineate areas that are thermally mature for oil and gas generation, evaluate timing of generation and migration relative to tectonic events and trap formation, and determine volumes of generated hydrocarbons for each modeled petroleum source rock. Within the USGS Minerals Mission Area, 3-D modeling includes representation of geophysically-derived surfaces and forward modeling of geophysical data to create 3-D geologic models to support mineral-resources assessments and research. To extrapolate below ground, various geophysical datasets are integrated with surface geologic and borehole data to develop a 3-D geologic model of the region. In areas of thick cover where borehole data are sparse, much of the region's geology and mineral potential is poorly constrained and geophysical methods are a primary means of developing a 3-D subsurface representation. Within the Water Resources Mission Area, the USGS frequently develops regional-scale 3-D hydrogeologic framework models as part of regional hydrologic assessment of principal aquifer systems. These 3-D framework models are in some cases comparable in areal size to national-scale models produced by other national geological agencies. At the groundwater basin scale, 3-D modelling activities focus on the thickness and extent of specific aquifers, the configuration of the basin, and the geometry of faults that affect the aquifers. Within the USGS Hazards Mission Area, 3-D geologic modelling activities include building geologically realistic fault-block models used for incorporating geology into hazard scenarios and the development of crustal-scale 3-D fault surfaces to help characterize complex patterns of fault interactions and 3-D deformation. National scale three-dimensional geophysical structure based on knowledge of surface and subsurface geologic variations will assist with earthquake hazard risk assessment by supporting estimates of ground shaking in response to an earthquake.

Resources Allocated to 3-D Modelling Activities

An estimated 50 to 100 people within the USGS routinely or occasionally conduct geological 3-D modelling activities. These scientists are dispersed across the organization and 3-D geological mapping efforts occur on a project-by-project basis. A far greater number of staff are able to visualize data in 3-D, including the analysis and use of airborne and ground-based LiDAR and using animations, fly-throughs, and data-discovery tools to help researchers conduct science and communicate results. The USGS uses a myriad of 3-D modeling and visualization programs (Jacobsen et al. 2011) due to the variety of 3-D applications, the distributed nature of scientific projects throughout USGS, and differences in scientific focus between Mission Areas. As a result, implementing a single organization-wide software platform is challenging and perhaps not even desirable.

Current Challenges

Current challenges are in part related to the broad overall mission of the USGS and the focused nature of individual Mission Areas within the organization, which lead to decentralized 3-D modeling activities. Pockets of 3-D modeling expertise develop on a project-by-project basis, but there may not be enough knowledge transfer between projects. Across the USGS individual researchers and teams acquire 3-D technologies with little to no knowledge or bureau-level coordination of other similar efforts. Although projects and Mission Areas add 3-D applications as analysis tools, there are few forums for sharing ideas, data, products, and knowledge of emerging technologies. Although cost efficiencies could perhaps be realized using a standardized, organization-wide modeling platform, the use of multiple software platforms in general supports the diverse needs of the Mission Areas and, in and of itself, is not a major challenge. The bigger challenge is in developing datasets that are accessible, transferrable and importable into multiple software platforms.

Considerations for the future

At the Federal level, abundant opportunities exist to develop a long-term strategy for optimization of the data that will be needed for 3D geological mapping throughout the United States. Bureau-level guidance or infrastructure could be directed to support the following:

- National-scale efforts to catalog and maintain already-developed 3-D framework models, beyond the release of models in publications
- Guidance on archiving procedures for 3-D models in retrievable, exportable formats
- Guidance on database standards for 3-D data
- Development and maintenance of robust status maps that show the status of developed 3-D data and 3-D models across the nation
- Development of regional or National-scale drill-hole databases in a standard format and partnerships with state oil and gas offices for the digital retrieval and revision of oil and gas stratigraphic information
- Improvement of stratigraphic assignments in national water-well database (USGS NWIS)
- Development of national databases of gravity, magnetic, seismic observations, and depth-to basement models that could support framework model development
- Systematic digitization of geologic cross section, structure contour, and isopach data from published USGS reports
- Foster coordination and communication between scientists conducting 3-D modelling at the Federal level with similar activities at the state level and in other countries
- Long-term investment in (a) staff with stratigraphic, structural, and 3-D modeling expertise, and support staff, (b) 3D modeling software and maintenance (c) staff training and professional development

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Talk: USING A GIS TO POPULATE 3D GEOCELLULAR GEOLOGIC MODELS

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Three-dimensional (3D) geologic framework models are digital representations of a conceptual geologic model; they serve as a digital repository for geologic datasets and as digital geologic input to many applications. Increasingly, numerical hydrologic models use sophisticated 3D geological frameworks as their geologic input. Digital 3D geologic models represent the geometry of the geologic system by defining three framework elements: faults, the elevation of the top and bottom of each geo-unit, and boundary lines depicting the subsurface extent of the geo-unit. The workflow for creating a digital 3D geologic model is depicted in Figure 1. Gridded surfaces representing the geo-unit tops may be created by combining data from: a digital elevation model (DEM); geologic map and cross section data; water, oil, and gas well data; and other user-defined data derived from subsurface geological or geophysical methods (fig. 1). The gridded surfaces of geo-unit tops may then be stacked in stratigraphic order using 3D modeling software. The 3D geologic solid-volume model is calculated as a 3D array of orthogonal, vertically stacked cells referred to as a geocellular model. The 3D volume is populated by volume elements, called voxels, that completely define each model-generated geo-unit at all points in space, filling the volume defined by the gridded unit extents, top, and base (fig. 1). Each voxel has a defined x, y, z location at its center and is assigned an attribute that corresponds to a geo-unit name based upon the location of each voxel with respect to the gridded top and bottom bounding surfaces.

Digital 3D geologic models are labor intensive to build, can require expensive software and skilled personnel, and can be difficult to distribute to cooperators and stakeholders. With a variety of geological and hydrologic modeling platforms and no specific standards for 3D data, it is useful to have a simple, convenient method to transfer geologic framework data to a numerical modeling platform. Use of the 2.5D nature of a GIS (x and y dimension plus multiple z attribute values) can make creation of a volumetric geologic model more accessible to project geologists and stakeholders alike. Here we describe a straightforward approach that uses the 2.5D aspect of a GIS to “flatten” the framework model into a 2D polygonal array of cells (and cell centroids) that have x, y coordinates and multiple z attribute values. Geo-unit elevation, thickness, and extent data are mapped to the centroids of the x-y cells and stored with multiple attributes in a 2D polygon array (fig. 1). Model cells are populated manually in a GIS with multiple attributes that can represent the identity of stratigraphic unit, lithologic type, stratigraphic tops, and thicknesses. The x,y,z data are exported to 3D visualization and modeling software to compute a cell-based solid model where the 3D volume is populated by regular rectangular volume elements that completely define each geo-unit at all points in space. Storage of framework data in a GIS facilitates data transfer for other uses, such as numerical groundwater simulation.

Representation of a geologic framework as an array of 2.5D polygonal cells has the following positive aspects: (1) the geologic framework can explicitly honor the x,y dimensions and cell size of the numerical hydrologic model and explicitly incorporate the numerical model's DEM, (2) the use of a GIS facilitates the incorporation of geologic map data using selected sets of the digital map data, (3) ease of error checking—consistency of thickness and elevation can be explicitly calculated and visualized, (4) for much of the workflow users do not need to work in a 3D geologic modeling program, most of the work can be done within a GIS, and (5) geologic framework output is immediately useful in a numerical hydrologic model. Negative aspects of this workflow include: (1) framework construction is labor intensive, (2) errors may be introduced because of the large amount of hand-editing and the multiple manual steps needed to complete each surface, and (3) relying on a GIS does not take advantage of powerful aspects of a 3D geologic modeling software tools, such as using geologic rules like onlap and unconformities to generate realistic layering schemes.

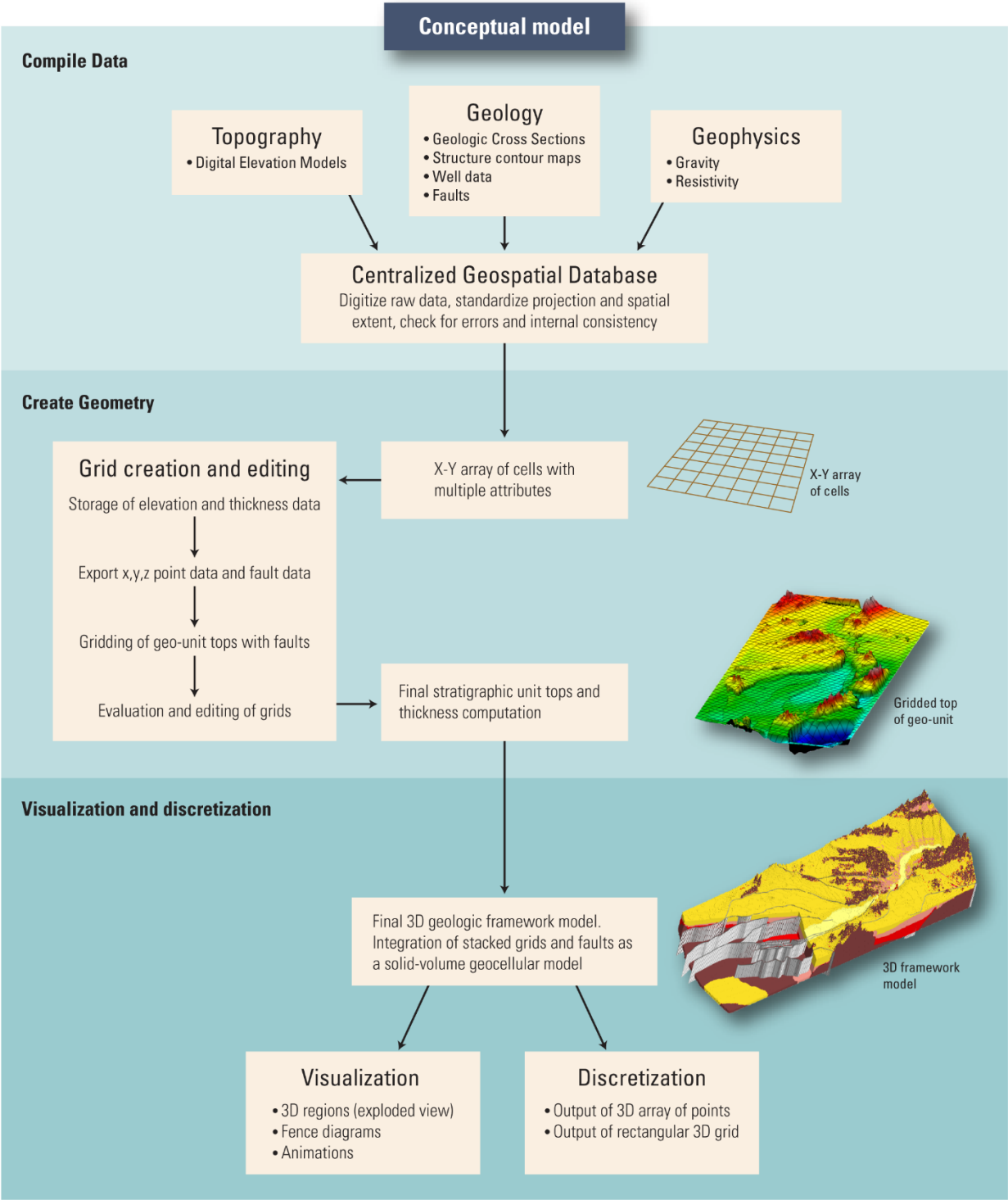


Figure 1. Chart showing process of development of digital data for the 3D geologic framework model.

Talk: QUATERNARY EOLIAN SEDIMENTS AND CAROLINA BAYS OF THE U.S. ATLANTIC COASTAL PLAIN PROVINCE

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Under modern conditions, the Atlantic Coastal Plain province of the eastern United States is not very conducive to widespread eolian sediment mobilization because of a humid and mesothermal climate, relatively low mean surface wind velocities (~1–3 m/sec), and relatively dense vegetation. LiDAR data, however, have revealed the presence of widespread eolian dunes and sand sheets (now covered by vegetation) at many inland locations throughout the U.S. Atlantic Coastal Plain (Swezey, in press). To date, a total of 89 optically stimulated luminescence (OSL) ages ranging from ~92–5 thousand years ago (ka) have been published from these eolian sediments, and 61 of these 89 OSL ages occur within or near the interval of the last glacial maximum (LGM).

Quaternary eolian sediments have been identified in the following four inland settings of the U.S. Atlantic Coastal Plain: (1) on interfluvial upland areas of the northern coastal plain (Delaware, Maryland); (2) in the Carolina Sandhills region; (3) within river valleys throughout most of the coastal plain; and (4) adjacent to low relief elliptical depressions known as Carolina Bays. Most of these eolian sediments are composed of fine to medium quartz sand, although a substantial component of silt is present in the northern coastal plain, and a substantial component of coarse sand is present in the Carolina Sandhills region.

The eolian sediments in interfluvial upland areas of the northern coastal plain form both sand sheets and parabolic dunes (with dune tails pointing to the northwest). These eolian sediments in the northern upland areas were probably remobilized from any loose sediments that were available in the area. The location close to the southern margin of the LGM ice sheet is similar to extensive Quaternary eolian sand and loess deposits in Europe, China, and the central United States.

The eolian sediments in the Carolina Sandhills region form mostly sand sheets and some linear dunes of relatively short extent (< 2 km). These eolian sediments are thought to have been derived from sand of the immediately underlying Cretaceous fluvial strata (Swezey et al. 2016).

The eolian sediments within river valleys form parabolic dunes that are located to the east of the modern river channels. The tails of these eolian dunes within river valleys point northwest in the northern coastal plain (Delaware, Maryland) and they point west in the southern coastal plain (North Carolina, South Carolina, Georgia). These eolian sediments within river valleys are thought to have been derived from fluvial sand in the nearby river channels (Swezey et al. 2013).

The eolian sediments associated with Carolina Bays form arcuate ridges on the east and south sides of the depressions ("bays"). Some Carolina Bays show cross-cutting relations with other Carolina Bays. Other Carolina Bays show different stratigraphic relations with respect to eolian dunes within river valleys. For example, Bear Swamp (Marion County, South Carolina) is a Carolina Bay that is inset into (i.e., younger than) eolian dunes in the valley of the Great Pee Dee River. As another example, Big Bay (Sumter County, South Carolina) is a Carolina Bay that is overlain by (i.e., older than) eolian dunes in the valley at the confluence of the Congaree and Wateree Rivers. Cores in Carolina Bays and their associated ridges reveal a few meters of sand and (or) muddy sand above an unconformity on various older fine-grained substrates that do not show signs of disturbance. Most published OSL ages from Carolina Bay sand ridges range from ~45–8 ka. For individual bays with multiple sand ridges, the ridges closer to bay yield younger OSL ages.

In summary, Quaternary eolian sediments are widespread throughout the U.S. Atlantic Coastal Plain province, and the OSL ages suggest that most of these sediments were mobilized around the time of the LGM when conditions were much colder, drier, and windier. These eolian sediments are thus interpreted as relict features that have subsequently been stabilized and degraded by vegetation and pedogenic processes as the climate became warmer and wetter. The range of OSL ages, however, suggests that eolian sediment mobilization probably occurred episodically at any given site. The presence of parabolic dunes and the abundance of sand sheets suggest that some vegetation was present when the eolian sediments were mobilized. The orientations of the parabolic dunes and the locations of the Carolina Bay eolian sand ridges suggest that winds that mobilized the sediments blew from the northwest in Maryland and Delaware, and that these winds blew from the west in North Carolina, South Carolina, and Georgia. These inferred prevailing wind directions are consistent with climate models for the LGM winter,

suggesting that eolian sediment mobilization may have occurred preferentially during winter. Eolian sediment mobilization would have been facilitated by LGM conditions of stronger wind velocity (at least 4–6 m/sec is required to mobilize most eolian sand), lower air temperature, lower air humidity, and reduced vegetation cover.

Likewise, on the basis of stratigraphic relations and OSL ages, the Carolina Bays are interpreted as relict features that did not form during one event of limited duration. Instead, they are thought to have formed episodically during the same time interval as other eolian sediments of the Atlantic Coastal Plain (e.g., mostly during the LGM when conditions were colder, drier, and windier). This interpretation of the Carolina Bays as relict features that formed under a colder and windier climate associated with the LGM suggests that they may be relict thermokarst lakes. Such lakes develop as a result of thaw and collapse of ice-rich ground, with subsequent modification by lacustrine and eolian processes. Various examples are present today in many high-latitude regions (e.g., near Barrow, Alaska). The distribution of Carolina Bays thus may provide information about the former distribution of permafrost (and may also provide an upper boundary on temperature during this time). Although the southern limit of continuous permafrost in the U.S. Atlantic Coastal Plain during the last glaciation is generally thought to have been located in Virginia approximately 230-320 km south of the LGM ice margin (French et al. 2009), permafrost in Europe during the last glaciation is thought to have extended approximately 800-1200 km south of the LGM ice margin and permafrost in Asia is thought to have extended approximately 2000-4500 km south of the LGM ice margin (Ballantyne 2018). Thus, it is quite possible that discontinuous and (or) sporadic permafrost may have extended much farther south into areas of the U.S. Atlantic Coastal Plain where Carolina Bays are present.

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Talk: MAPPING THE MIDDLE WISCONSIN SHELDON CREEK FORMATION BOUNDARY IN NORTH CENTRAL IOWA

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Geologic mapping in north central Iowa has redefined the Middle Wisconsin Sheldon Creek boundary. Work was initiated during a cooperative mapping project with the Natural Resources Conservation Service (NRCS) during a soil survey update of Worth County. This work indicated the Sheldon Creek extended beyond the margin mapped by Hallberg et al. (1991). Subsequent work by the Iowa Geological Survey (IGS) as part of the USGS STATEMAP program has substantially moved this boundary to the east (Quade et al. 2012; Tassier-Surine et al. 2015, 2016; Kerr et al. 2018).

Limited exposures of the Sheldon Creek Formation in Iowa make it difficult to evaluate, as much of its surface is covered by the Late Wisconsin Des Moines Lobe glacial advance. Further complicating identification of the eastern extent is the abundance of shallow bedrock and the pervasive erosion that occurred during the Last Glacial Maximum when the Iowan Surface landform region formed. Therefore, differentiating the Sheldon Creek glacial deposits from the much older Pre-Illinoian till can be difficult in this region. Due to this complexity, a varied set of characteristics was used to define the Sheldon Creek Formation boundary including physical properties, radiocarbon age dating, geomorphology, LiDAR, soil types, and drainage orientations.

The IGS and NRCS drilled over 200 borings in the study area over a 10 year period. Drill core descriptions, analytical data (grain-size, clast lithology, and pXRF data), and radiocarbon dates were used to constrain the stratigraphic framework. Samples for radiocarbon ages were collected in the mapping area from wood or soil organics in till. When combined with results from previous studies, these ages indicate that two Middle Wisconsin advances of the Sheldon Creek Formation are present in north central Iowa. The first advance occurred between 46,000 and 40,000 years ago with a younger advance between 34,000 and 29,000 years ago (Kerr, 2018).

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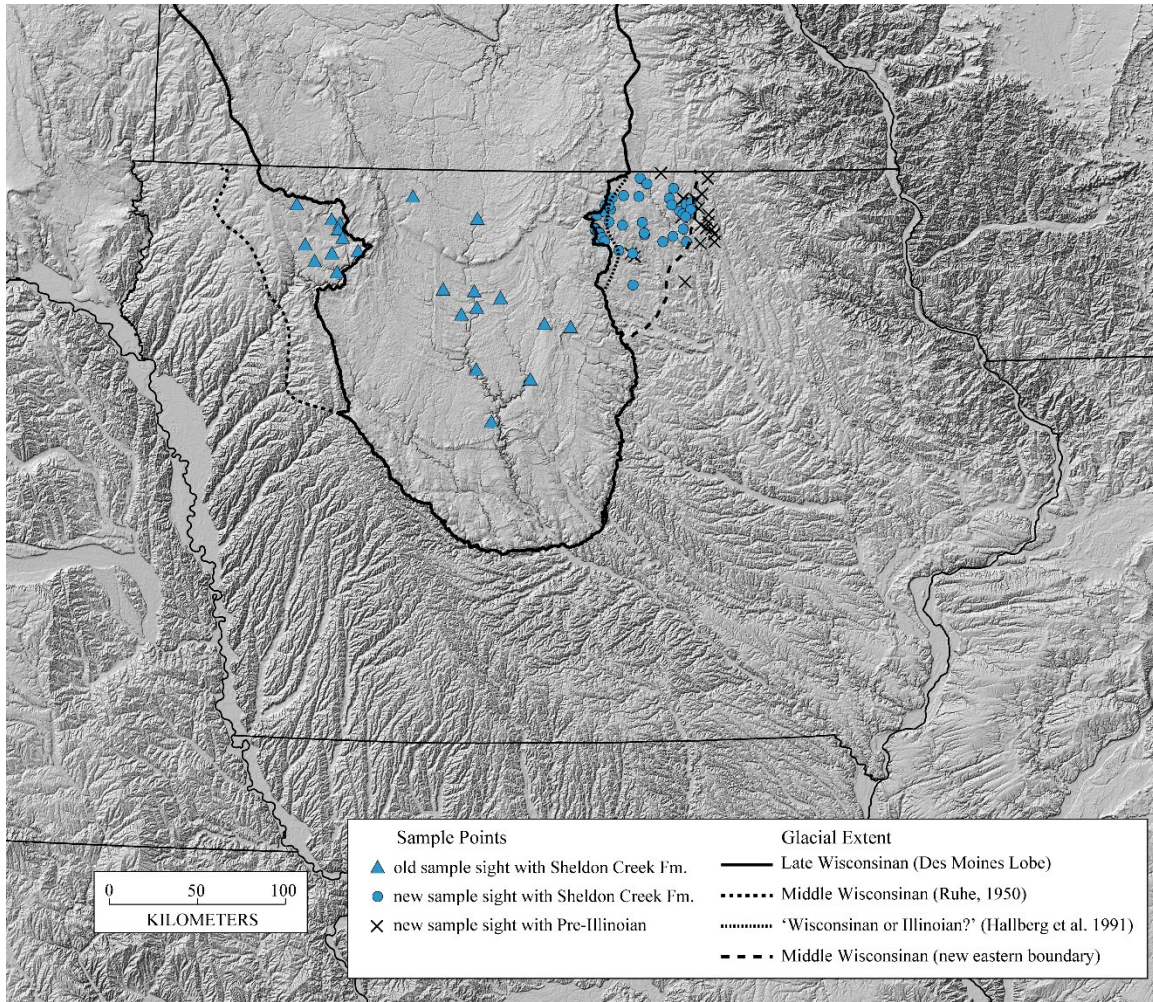


Figure 1: Hillshade map of Iowa showing the outline of the Des Moines Lobe, the previous 'Wisconsinan or Illinoian' boundary defined by Hallberg et al. (1991), and the current Sheldon Creek boundary established by the IGS. Blue triangles are Sheldon Creek sample sites from previous studies. Blue circles (Sheldon Creek) and black x's (Pre-Illinoian) are data points from more recent IGS and NRCS mapping.

Plenary: MEETING OVERVIEW

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In Lexington, Kentucky, on June 11, 2014, members of the Association of American State Geologists (AASG) unanimously passed a resolution that endorsed planning by U.S. Geological Survey (USGS), and that cited pressing issues related to energy, minerals, water, hazards, climate change, environment, waste, and engineering, as well as research priorities, to call for accelerated progress on a national, regularly-updated, well-coordinated, multi-resolution, seamless, 3D, material-properties-based geological mapping database.

Researchers and land use managers increasingly rely on and therefore need to invest in geologic mapping that will return benefits, including lives saved, resources discovered, costs avoided, increased efficiency, and improved understanding of earth composition, structure, and history. Provision of standardized and accessible geologic mapping is facilitated by the National Geologic Map Database (NGMDB), which is managed by USGS in cooperation with AASG, with proven arrangements for administration, data, stratigraphy, and standards. Mapping at state and national scales in the US is complete, although in need of updating. At scales needed for planning, coverage is only about 50%, and these maps typically are unreconciled relative to each other. Subsurface mapping needed for groundwater management and sedimentary basin assessments is even less complete. The superb nature of completed mapping, and compelling user needs, thus call for acceleration and enhancement of this activity.

Users now expect maps to be zoomable, and to be queryable over broad areas. In addition, the demands of modelling increasingly call for a focus on material properties such as lithology and hydraulic conductivity. The public sector role commences with county and quadrangle-scale 2D mapping, the most important scale for land use planning. Each state geological survey can determine the most appropriate scale for their focused investigations, and also the intermediate scale that will be achievable state-wide. State-wide seamless compilations of quadrangle- or county-scale mapping are being built on an incremental basis, in part to make GIS resources manageable. Links to source information, at least as scanned versions of both maps and reports, provide documentation for advanced users, as well as credit and responsibility for the source map authors. Accompanying 3D geological mapping that depicts extent, thickness, properties, heterogeneity, and uncertainty of strata is based on data compilation and acquisition, facies modelling, and basin analysis. Model construction, including use of geostatistics, varies depending on resolution, complexity, as well as data format and adequacy. A basement map also is needed, with geometry of selected structures, along with discretized physical properties. The urgency of user needs calls for mapping of this nature to be completed nationally at appropriate levels of resolution within a decade or two, and updated periodically, in some areas every two decades or so, owing to increasing access, new topographic mapping, accumulation of data, as well as progress in science and technology.

There thus is an urgent need for geological mapping to be progressively more: focused on user needs while accommodating unanticipated applications; conducted as part of a well-planned program based on ongoing assessment of required databases; focused on the most detailed mapping where needed; committed to jurisdiction-wide completion at an appropriate level of resolution; reconciled from onshore to offshore with topographic and bathymetric data; coordinated with soil mapping; based on compilation of drillhole and other data, along with strategic drilling and newly acquired geochronology, geochemistry, and geophysics; based on sound stratigraphic naming; categorized using accepted terminology; committed to regular updating; assembled as state-wide seamless compilations; 3D, in which the extent, thickness, and properties of layers, and geometry of selected basement structures are distinguished; material properties-based; coordinated with 3D versions of state, continental, and global-scale maps; accessible through open-source software; and linked to databases as well as searchable publications. Surveys need to aggressively transition to this approach, to better fulfil their essential role in society.

Poster: THE USGS APPALACHIAN BASIN GEOLOGIC MAPPING PROJECT

Weary, David J., Doctor, Daniel H., Orndorff Randall C., and Parker, Mercer

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The Appalachian Basin Geologic Mapping Project (ABGMP), starting in fiscal year 2019, is a 12-year effort under the FedMap part of the National Cooperative Geologic Mapping Program (NCGMP) that is focused on producing a seamless geologic map database and integrating science of the Valley and Ridge and Appalachian Plateaus physiographic provinces. The Appalachian Basin region has many societal issues where there is a critical need for a geologic framework to provide data necessary for development of solutions and best practices. Some of the issues facing land managers in the Basin include infrastructure for growth areas, transportation and pipeline corridors, aggregate resources, groundwater resources and quality, energy and mineral resources, and karst and other natural hazards. The Project area includes parts of 11 states and adjoins the Blue Ridge and Piedmont Provinces along its eastern boundary (NCGMP Piedmont-Blue Ridge Project area), and the Adirondacks and New England Provinces along its northern boundary that comprise the (NCGMP Northeast Bedrock Mapping Project).

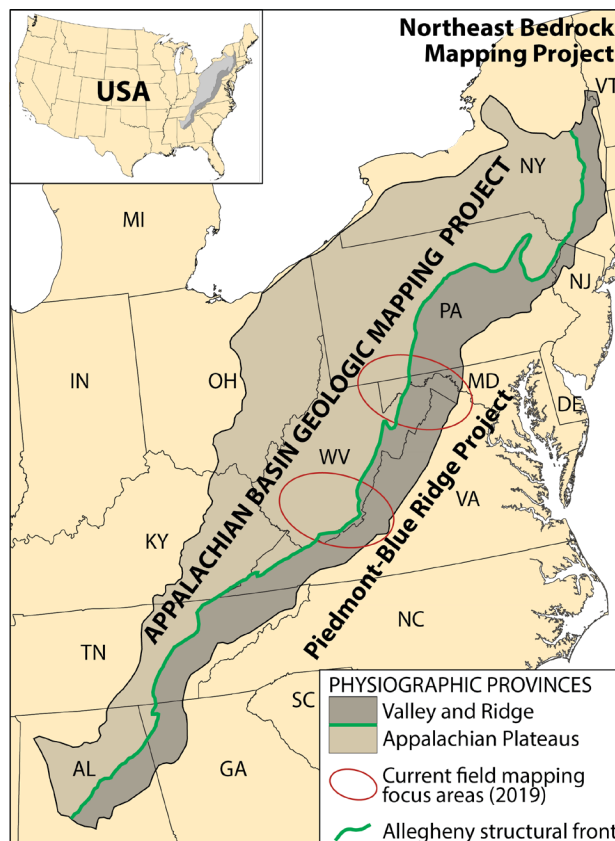


Figure 1. Area of the Appalachian Basin Geologic Mapping Project (ABGMP) and location of current focus areas for mapping and lithostratigraphic analyses.

This Project will focus on research that will contribute to better understanding of the distribution of sedimentary facies and lithologies on a regional scale and identifying and defining criteria for placing key stratigraphic contacts across our constituent state lines. This research includes traditional geologic mapping at scales of 1:24,000 and 1:100,000, and geologic compilations based on State scale data. Regional cross sections, key borehole logs, and integration of geophysical data (where available) will provide data controlling the 3-D framework of the basin. The ultimate goal is to provide a database of seamless geologic data that will support a 3-D model of the Appalachian Basin.

As a federal project, we have latitude to work across state lines and are uniquely positioned to address discrepancies in mapped geologic features and disparities in correlation and nomenclature. ABGMP will work closely with the State Geological Surveys to understand the history of mapping and stratigraphic nomenclature to provide the best possible solutions for this integration.

It would be a relatively simple task to simply connect contacts and redraw lines in a GIS compilation of state geologic data. However, this provides only a pleasing graphic solution that is without scientific basis. We will not smooth out discrepancies or move previously mapped contacts without scientific justification. Our approach to resolving interstate discrepancies will be to first compile and examine state level data to identify discrepancies between adjacent states. We will then make attempts to resolve problems via literature research, analysis of more detailed mapping where available, and remote analysis via GIS data viewers over high-resolution topographic models (Lidar, etc.).

As required, we will target field work in cooperation with state geological surveys to actually look at the rocks in field context and determine best practices for placing contacts; we will then publish those criteria. This field work may include traditional quadrangle mapping or cooperative field trips. For example, Project geologists are actively mapping Middle and Upper Devonian clastic rocks of the Catskill clastic wedge along the Virginia/West Virginia border; these rocks also extend northeastward across Maryland, Pennsylvania and into New York. This research is centered around the Winchester 30' x 60' quadrangle. Mapped contacts between units, like the Brallier and the Foreknobs Formations have been inconsistently placed and vaguely defined. Close examination of the rocks, application of Lidar topographic models, and consultation with members of the Virginia, West Virginia, and Maryland geological surveys have enabled us to more precisely define contact markers and to characterize the topographic expression typical of the contact interval.

Another area of focused mapping and research is an east-to west transect from the Valley and Ridge Province of southern Virginia into the Appalachian Plateaus of West Virginia; it is centered on Craig and Giles counties, Virginia, and Monroe County, West Virginia. This study area includes part of the structural orocline marking the transition between the central and southern Appalachians. Current detailed mapping in Upper Paleozoic strata includes the thick succession of Late Mississippian age carbonates of the Greenbrier Group in southeastern West Virginia. These karst-prone rocks include an important ground water aquifer, vulnerable ecosystems, areas of potential subsidence and flooding hazards, as well as chemical lime and aggregate resources. The Greenbrier Group and its equivalents extend along the strike of the Appalachian Basin from Alabama into Pennsylvania. The type areas and sections of most of the formations that comprise the Greenbrier Group occur in Monroe County, West Virginia. Rocks of the Catskill clastic wedge also occur along and across the border into Virginia in the eastern part of our mapping area. We are currently engaged in mapping at 1:24,000 and 1:100,000 scale in the Monroe County area in consultation with the West Virginia Geological Survey which is mapping in areas underlain by the same rocks along strike in counties to the northwest. Our quadrangle mapping extends across the border into areas of Virginia. Lithostratigraphic units and contacts in these rocks were vaguely defined in work done largely in the early part of the 20th Century (e.g. Reger and Price, 1926). Later studies have not sufficiently resolved some of the stratigraphic relationships and nomenclatural questions that remain about the Greenbrier Group.

Our project also has in-house capability for conodont sampling, processing, and analysis. These data are valuable for resolving mapping questions via biostratigraphic correlation in Paleozoic carbonate rocks. Additionally, USGS conodont collections will be analyzed for conodont Color Alteration Index (CAI) values which will then be added to the USGS Appalachian Basin CAI database (Repetski et al., 2008). CAI values indicate the bulk thermal maturity of the enclosing rock and are used to help estimate hydrocarbon source resource potential and in the delineation of regional structural trends (Harris et al., 1978).

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Talk: GEOLOGIC MAPS -- STRENGTHS AND WEAKNESSES IN A DIGITAL WORLD

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Geologic maps have been the foundation of the geologic sciences for over 200 years. Efforts to convert geologic maps into standardized digital databases are bumping up against map features and practices that were never intended to be pigeon-holed into "pick-lists." While many practices and protocols have been "standardized" for many decades (though some work well and some don't), many others are more a function of personal preference. In addition, field mappers are by tradition an independent bunch who are always struggling, and experimenting, with too little data and too many options. Efforts to get them to map the same way meets with limited success. Earlier mappers are seldom available to explain "what they meant" on older maps. This talk will discuss (with few answers) some of the challenges, successes, and failures we have faced as we have attempted to standardize mapping practices and convert older maps into digital map databases.

Talk and Poster: COMPILATION OF A GEOLOGIC MAP OF THE GREATER ANTILLES AND VIRGIN ISLANDS

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As part of an ongoing mineral resource assessment, we are compiling a digital database and geologic map of the Greater Antilles and Virgin Islands. The Greater Antilles include the islands of Cuba, Hispaniola (Haiti and Dominican Republic), Jamaica, Puerto Rico (and outlying islands), and the Cayman Islands. While geographically part of the Lesser Antilles, the Virgin Islands are included in this compilation because they share greater geologic affinity with the Greater Antilles. In undertaking this compilation, several issues have arisen not generally faced by geologic map compilers in North America. The primary issues are language and mapping style. The Cuban and Dominican Republic source materials are in Spanish, though the Cuban information is in Russian-influenced Spanish. The Haitian materials are in French and the materials for the remaining islands are in English. An initial step in the compilation was translation of source materials and interpretation of the various ways in which geologic features were described. For translation, we used Google Translate with assistance from language dictionaries and in the case of Spanish, a few checks by a native Spanish speaker. Interpretation of translated descriptions was commonly necessary as geologic terms often did not translate correctly (breccia translated as “gaps”) or the geologic terms used were at times different than those commonly used in North America. For example, the Cuban source (Pushcharovsky et al., 1988) used the terms “aleurolite” (siltstone), “silicite” (chert), and “granosyenite” (quartz syenite?).

Mapping style issues were more impactful. Map patterns appear to suggest thrust faulting is an important process, especially in Cuba, yet no thrust faults are indicated on the Pushcharovsky et. al. (1988) Cuban geologic map. During a field trip taken by some members of the project, the Cuban guides seemed to indicate that they did not map features seen by our project members as thrust faults. On many of the source maps, the nature of fault offset is not indicated, nor are cross-sections common.

On both the Haitian and Dominican Republic geologic maps (Vila et al., 1985; Toloczyki and Ramirez, 1991), though stratigraphic units are mentioned in some unit descriptions, the map units used are generalized and do not reflect specific stratigraphic units. We infer that other defined stratigraphic units may also be included in their map units. The mapping does not indicate the specific outcrop areas of any stratigraphic units mentioned. The map descriptions associated with these two maps as well as the spatial data indicate a clear break across the international border; logic dictates no such break exists. We have done our best to eliminate this break where the data allow. Igneous and especially intrusive map units tend to be lumped regardless of age; this is in part likely due to the very limited radiometric dating undertaken during or prior to mapping, especially in Cuba and on Hispaniola.

There is an extensive catalog of stratigraphic nomenclature in Jamaica and only in the last few years (Mitchell et al., 2016) has there been a concerted effort to revise and rationalize the nomenclature. Prior to this some variants of unit names applied to different units and some units had multiple names.

An important part of our compilation is the correlation of map units throughout the region. Unit descriptions upon which these correlations can be made are variable in detail and in some cases, correlations have been made using the spatial distributions of rock units.

We have compiled a database of radiometric age determinations to accompany the map database. A major problem in compiling this database is the common lack of good location descriptions for the samples. Where location maps are provided in the papers reporting age determinations, they commonly lack registration and location coordinates can only be determined approximately. In Haiti, a very large number of $^{40}\text{Ar}/^{39}\text{Ar}$ age determinations were made on units that define the Tertiary-Cretaceous boundary; strangely, none of the reports provide any location information. Additionally, analytical data are rarely available for some of the earlier determinations which were typically conventional K/Ar determinations for which decay constants were not reported. We had to make some assumptions in order to recalculate the age determinations to modern decay constants (Steiger and Jager, 1977). Some of the earliest age determinations dated materials no longer considered acceptable or reported analytical

errors greater than 10 percent. A few age determinations were made using the now discredited Pb-alpha technique. Recently, modern U/Pb age determinations are becoming more common.

Present plans are to issue our initial compilation as a USGS Open-file Report and subsequently release an enhanced compilation using more detailed sources.

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Whetten, J.T. 1961. Geology of St. Croix, U.S. Virgin Islands: *Geological Society of America Memoir* 98, p. 177-239, 1 plate, scale, 1:31,680.

Vila, J.-M., J. Butterlin, T. Calmus, B. Mercier de Lépinay and, B. van den Berghe. 1985. Carte Géologique d'Haïti au 1/1,000,000 Avec Notice Explicative Détaillée (Geologic Map of Haiti at 1:1,000,000 With Detailed Explicative Notes), in: Girault C., ed., *Atlas d'Haïti*: Talence, France, Centre d'etudes de geographe tropicale (CNRS) et Universite de Bordeaux, France, scale 1:1,000,000.

Poster: SURFICIAL GEOLOGIC MAPPING IN WYOMING

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The Wyoming State Geological Survey (WSGS) produces surficial geologic maps focused on surface materials, geomorphology, and geologic hazards. Mapping priorities are based on individual projects, not regional coverage, and are completed at either the 1:100,000 or 1:24,000 scale. WSGS has previously focused on regional 1:100,000 scale surficial maps, publishing 47 in total. Recent work has focused on specific areas, creating 1:24,000 scale surficial geologic maps. Creation of a surficial map shares a number of methods with bedrock mapping, including compiling existing mapping, photo interpretation, and field work. The primary difference between surficial and bedrock mapping is the mapped geologic units and descriptions.

The WSGS classification system for surficial geologic maps makes use of 26 unique surficial designations combined into a multi-element surficial "unit." The multi-element unit is based on a combination of surficial units within a specific area, where unit designations are listed in diminishing abundance. For example, a surficial unit mapped as "rsc" (r = residuum, s = slopewash, and c = colluvium) is primarily residuum with secondary amounts of slopewash and minor colluvium deposits. Surficial units can range from having a single unique designation to up to four combined designations.

Visual presentation of the surficial designations is based on the first two letters of each unit. The first, or primary, unique designation sets the hue of the unit, while the second mapped unit sets the pattern. A unit mapped as "rsc" would have the hue assigned to residuum (r) and the pattern assigned to slopewash (s). This method allows for visual association of similar units by either hue or pattern.

All WSGS digital surficial data follow the U.S. Geologic Survey's Geologic Map Schema (GeMS) template. Much of the schema is not applicable to surficial designations or maps, but the general framework, including metadata, is employed to maintain consistency across all WSGS maps.

In an effort to produce a more user-friendly product, the WSGS is currently developing a hybrid surficial-bedrock map. In areas where bedrock outcrop (R) is mapped at the surface, the bedrock unit or formation will also be noted, simplified as necessary. This will provide users critical geologic information and reduce the need to reference multiple maps. These hybrid maps will also include outcrop data, including strike and dip, to show local structures and their relationship to surficial units and geologic hazards.

Talk: ASSESSING POTENTIAL WATER RESOURCES UTILIZING INDIRECT AND DIRECT METHODS OF MAPPING FOR BURIED BEDROCK AND TUNNEL VALLEYS, A DEMONSTRATION SUCCESS

John Yellich*, Tyler Norris, Alan Kehew, William Sauck, Robb Gillespie, John Esch

Water resources are unquantified in many areas of Michigan because of a lack of subsurface geological information. Less than 10 percent of the surficial geology of the State has been mapped in detail to assess the natural resources and subsurface geology is poorly known. Further, ~ 60% of the water resources in the Lower Peninsula are derived from the glacial sequence. The Michigan Geological Survey (MGS) is charged with providing sufficient scientific information to sustain and protect the state's natural resources. The majority of groundwater resources in use in glaciated areas are extracted from the upper 200 feet despite known depths to bedrock of up to 1200 feet in some parts of the state. The lower part of the glacial section and the bedrock topography are poorly characterized in most areas.

Oil and gas exploration and production takes place in many areas with thick glacial drift and the presence and characteristics of aquifers are not known. In addition, there is a limited amount of data on the location of buried bedrock valleys throughout Michigan, many in the energy production areas. Michigan energy companies were contacted to determine if 2D seismic data could be provided in the study area and approximately 1500 feet of interpreted 2D data on the glacial –bedrock interface (~180 ms) was released to MGS. This collaboration between MGS and the energy companies was very positive.

Typical geological mapping for buried bedrock and glacial valleys can be limited by the high cost of widespread drilling; however recent advances in geophysical techniques (passive seismic, gravity, resistivity, EM, and now industry 2D seismic) has allowed the presentation of mapping products not achievable, just 10 years ago and more importantly, at a lower cost.

MGS proposed a demonstration project to the Groundwater Research Education Foundation (GWREF) and received a grant for a demonstration project to use indirect geophysical methods to define bedrock valleys, many which have no surface expression and have unknown aquifer potential. This project was successful in mapping bedrock valleys that can be assessed for aquifer potential in the future. Test drilling for validation of the passive seismic method showed excellent correspondence between actual and predicted depths to bedrock.

Societal interests can be addressed with new information that includes resource delineation and identification of potentially vulnerable aquifers that should be protected. For example, the agriculture industry will definitely benefit if these areas are shown to have sufficient aquifer occurrence to support expanded irrigation in the identified areas.

Talk: BENEFITS OF AN INTEGRATED COLLECTIONS MANAGEMENT SYSTEM FOR MAPPING

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Abstract

The Arizona State Geological Survey (AZGS) is currently developing a new collections management system for holding all of its text reports, images, field notes, and digital geologic maps within a single database. While the many benefits of a digital database for the preservation, dissemination, and curation of information are well-known, there are also many ways that an integrated database can benefit the creation of new geologic maps.

Here, AZGS demonstrates several capabilities of its new system for geologic mapping: 1) intelligent identification of mislabeled map features within a geologic map or among different geologic maps; 2) validation of recognized geologic vocabularies such as lithologies, stratigraphic nomenclature, or geologic intervals against recognized authorities such as the USGS National Geologic Map Database Geologic Lexicon; 3) linking map observations to external references such as published papers or laboratory results; and 4) on-the-fly creation of new map variants that cover different geographic subsets or emphasize different geologic information. These are among the simplest uses of an integrated database and many can be implemented by non-programmers with relatively minimal training; for example, the entire AZGS script used to identify mislabeled polygons is <2/3 the length of the opening paragraph of this abstract (Fig. 1).

The free, open-source technology (i.e., PostgreSQL, PostGIS) used to create the AZGS collections management system are battle-tested products used by many major organizations – e.g., Apple, Microsoft, MasterCard, Instagram, LinkedIn – and are fully compatible with ESRI commercial GIS software. AZGS is prepared to work in-person with other geological surveys to set-up simple testing environments where surveys can experiment with building their own integrated systems.

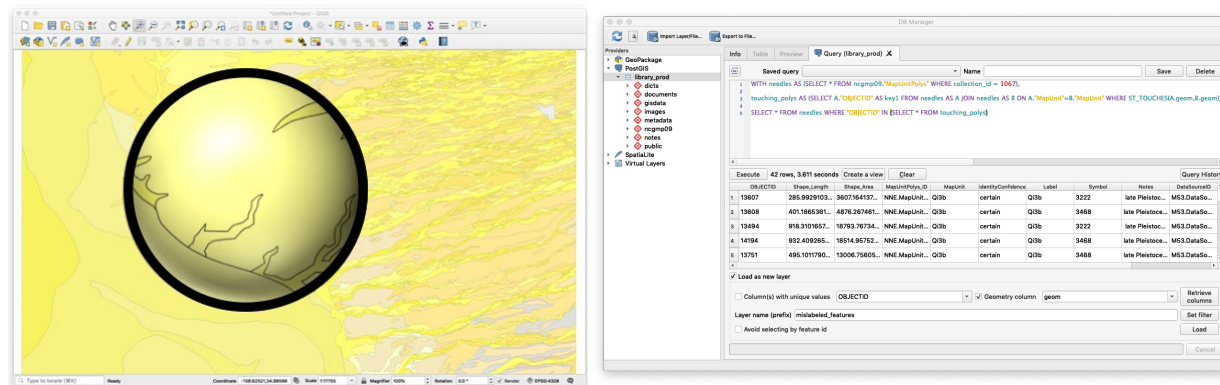


FIGURE 1. A magnification of a mislabeled feature in an AZGS geologic map (Pearthree 2007). The small size of the mislabeled feature and the similar colours of the surrounding polygons make it unlikely that this mistake will be caught and fixed by manual proofreading before publication. A properly structured geologic map database (left), however, allows this process to be automated in a reliable and reproducible manner. The particular query used to identify this erroneous feature was also able to identify 20 other mislabeled polygons in the map (affecting ~1% of map area) in 3.6 seconds.

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