Geologic Mapping Forum 2018 summary: At the Geologic Mapping Forum in Minneapolis from March 27th to 29th, 2018, 100 geological map authors, program managers and allied professionals from geological surveys and associated agencies met to discuss the status and future of geological mapping in the USA – with a focus on the Decadal Strategic Plan of the USGS National Cooperative Geologic Mapping Program (NCGMP). The meeting was hosted by Minnesota Geological Survey at the University of Minnesota. 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 submitted a 1 to 2-page abstract. The meeting commenced with registration and a reception at the hotel on Monday from 5 to 7 PM, followed by conference sessions from 8:30 AM Tuesday until 4:30 PM Thursday. Meeting participants included 43 from state geological surveys other than Minnesota (MN), 23 from US Geological Survey (USGS), including 10 from terrestrial geologic mapping, 6 from leadership, 5 from other sectors, 1 from planetary geologic mapping, and 1 editor, 23 from MN Geological Survey mapping staff, 2 from Geological Survey of Canada (GSC), 2 from federal partners, 2 from academic partners, 1 from industry, 1 from a provincial geological survey, and 1 from a nonprofit.

Pre-meeting poll: Responses to a broadly distributed pre-meeting poll dealt with the foundational role of geologic mapping in human activity, including energy, minerals, water, infrastructure, hazards, and research, with states cited as being closely tuned to needs. Regarding the need for improvement, respondents discussed the need for realistic goals, identification of scientific questions, greater emphasis on planning of progress on 1:24K/100K, the need for drillhole data including water wells, workforce planning, and funding. Additional discussion mentioned public outreach, depth to bedrock, database standards, innovative approaches, need for more meetings, peer-review, detailed basis for inference of properties, data adequacy for 3D goals, keeping focus on priority areas for detailed mapping, training, Europe is way ahead of us, and need for both consensus and strong leadership.
Opening Plenary

Meeting overview: The first speaker was University of Minnesota Professor Harvey Thorleifson, Director of Minnesota Geological Survey, State Geologist of Minnesota, member of the National Geospatial Advisory Committee, Association of American State Geologists (AASG) Mapping Chair, and councilor for the Commission for the Management and Application of Geoscience Information (CGI).

He suggested that in many ways, geological mapping hasn’t changed since publication of the first formal map in 1815. He contended that authored, peer reviewed, innovative paper geological maps with a thorough legend are a durable format that will remain the foundation of our activity, although he then stated that concurrently, everything is becoming a database, including all mapping. He placed geological mapping into the context of meteorological mapping, topographic and bathymetric mapping, and soil mapping. He then expanded on soil mapping, including history, procedural manuals, their shift a decade ago from static printed soil mapping to a dynamic national database, annual meetings, and training.

He suggested that 2D geological mapping methods are very mature, while 3D geological mapping – with features vertically georeferenced as well as thickness and properties specified where possible - is in its infancy. He noted efforts to educate the public about how to read a geologic map, and then suggested a focus on how hard it is for us all to comprehend meteorological maps, and hence our reliance on weather forecasts as a query on the maps. He presented the idea that someday, people
will query a point, and receive a drillhole forecast down to basement, accompanied by an indication of high, medium, or low confidence based on data and complexity.

He summarized a recent paper on the state of geological mapping by German and British authors that highlighted the shedding of constraints through digital capture of field data, application of geoinformatics, and 3D methods, thus allowing greater contributions to science and planning, largely through modeling made possible by improved 3D mapping that is well-coordinated with spatial data infrastructure, and well-supported by global initiatives designed to avert duplication of effort on standards, arrangements, policies, and dissemination tools. He suggested that geological mapping is an essential service that is part of a spectrum of activities that serves society – from research to mapping to monitoring to modeling to management to societal benefits.

Thorleifson then summarized a topic that will be covered at the AASG annual meeting in Delaware in June, and a topic that John Brock was to expand on in the 2nd talk - how is geologic mapping in the US planned, funded, and administered? He noted that geological mapping, like all of the mapping we do, is an essential service, in relation to energy, minerals, water, hazards, environment, waste, engineering, and research. He observed that geologic mapping results in lives saved, resources discovered, costs avoided, increased efficiency, and fundamental understanding. He mentioned that very favorable benefits relative to costs have been quantitatively demonstrated.

He described how the current approach to geological mapping in the USA was outlined in the 1980s by USGS, AASG, and advisory committees, starting with a meeting in Illinois in 1982. As a result, the National Geologic Mapping Act (NGMA) became Law in 1992; the purpose of this Act being to expedite the production of a geologic-map data base for the Nation, to be located within the USGS. He described how the NGMA mandated the NCGMP, consisting of geological mapping by federal, state, and university partners, made consistent and available as the National Geologic Map Database (NGMDB). Under NCGMP, about $25M is distributed annually to support geological mapping; partners in the US spend about an equal amount, for a total of ~$50M/year.

To summarize planning, he noted that in 1998, the 2000-2010 plan for USGS geology cited the need for basin-scale, nationally consistent maps showing the 3D distribution of hydrogeologic properties. In 2011, the 2010-2020 plan for USGS geology called for development of the interpretations, protocols, and standards needed to provide seamless geological maps, while foreseeing that 3D geologic maps of continental and offshore areas will become the standard. In 2013, USGS planning called for collaboration leading to 1) seamless nationwide geological maps, 2) 3D maps that will for example improve understanding of sedimentary basin processes, and 3) 4D modeling that will elucidate the operation of processes through time.

He then noted our federal system, USGS funding and staffing, and state geological survey funding that has been consistent at about $230M/year. He then indicated that AASG unanimously passed a resolution on geologic mapping that is fully compatible with USGS planning in Lexington, Kentucky on June 11, 2014. He outlined the provisions of the Lexington Resolution, including user needs, planning,
detail where needed, jurisdiction-wide completion, reconciled from onshore to offshore with topographic and bathymetric data, coordinated with soil mapping, based on full data compilation, sound stratigraphic naming, broadly accepted terminology, committed to regular updating, assembled as jurisdiction-wide seamless compilations, 3D, material properties-based, coordinated with state, continental, and global-scale maps, accessible, and linked to other information.

He then mentioned the December 2017 Critical Minerals Executive and Secretarial Orders, that contended that the nation is limited by a lack of comprehensive, machine-readable data concerning topographical, geological, and geophysical surveys, thus indicating a need for renewed planning. He also described the emerging commitment to national 3D geology, as a scientific infrastructure in which to link spatial information, along with administrative and legal functions – with the Netherlands, UK, Canada, France, and Finland leading the way, although the concept is now known as EarthMap in recent USGS planning.

Returning to NCGMP, he described how the Decadal Strategic Planning Workshop, from August 9th to 11th 2016 in Denver, was held under John Brock’s leadership. The Decadal Plan was completed in May 2017, with goals including 1) excellence in NCGMP performance, with maximized beneficial partnering, 2) preeminence in field, remote sensing, and geophysical technologies, and 3) a national, consistent, 3D digital geologic framework database by the year 2030.

Thorleifson then asked the question - what is the information science infrastructure that we need to deliver geologic mapping to society – a topic that would be expanded on by Dave Soller in the 3rd talk, and that will be addressed at the annual Digital Mapping Techniques (DMT) meeting this June in Kentucky. He described how mapping is now part of information science. Regarding standards, he noted that users expect standardization; a standard launched too early will be overtaken; if too late, the cost to reconcile competing solutions is great; industry consortia play important roles; and international solutions are the best approach. He observed that a conceptual data model defines concepts, their relationships, and how they are represented as data; semantic elements define terminology, while syntactic elements define structure. In addition, markup language encoding allows system-independent storage and transfer, and registers hold definitions. He observed that in the US, geology is listed as one of the National Geospatial Data Assets.

As part of NCGMP, the NGMDB Project has coordinated development of standards and databases under the leadership of Dave Soller, including information standards – metadata standard, cartographic standard, digital map standard, and database standard, as well as databases for publications, paleontology, and lexicon, and the planned NGMDB Phase Three database for mapping. He noted that the NGMDB metadata standard was complete in 2001. The cartographic standard was complete in 2006. The digital map standard was completed in stages, while the database standard is a major ongoing activity. NCGMP09/Gems is now the preferred database format for geologic maps in the US, while CGI works with the Open Geospatial Consortium (OGC) to develop international geological map standards. GeoSciML 4.1 is now an OGC data transfer standard for all geological data.
from mapping to other complex geological databases, and an outcome of the June 2016 OGC meetings in Dublin is a group examining 3D geologic map database standards, including application of Building Information Modeling (BIM) to geology, as well as Geo3DML, and RESQML.

In the US, we have over 100,000 published geological maps in the NGMDB publication database, although many users now simply want one database. Work on the NGMDB paleontology database has been reconciled with multiple initiatives in the research community. Regarding the Lexicon Database, we are proud to have defined over 16,000 strata, although consideration is needed on how many can be mapped in 3D GIS; nevertheless, the searchable source maps will retain all defined strata. It now is time to launch NGMDB Phase Three, the carefully-planned, seamless, multi-resolution mapping database. A challenge is to ensure that the mapping is accessible and usable.

Having discussed definition of geologic mapping, administration, and information science, Thorleifson then discussed the Geologic Mapping Forum theme – the geology of geologic mapping. He suggested that whether 2D or 3D, geological mapping ideally is built by a capable field geologist, or a team, based on all available observations – including topography and bathymetry, field data, remote sensing, drillhole data, geophysical surveys, as well as new drilling and analyses. The stratigraphic code, facies models, basin analysis, and hydrostratigraphic methods guide our work. The geology hangs from and is partially inferred from elevation data and bathymetry – the topic of the current 3D Nation Elevation Requirements and Benefits Study.

Remote sensing has roles in some areas. Ideally, all public domain drillhole data is compiled – with the steps being to acquire, digitize, georeference, and categorize. Crowdsourcing is of growing relevance in all fields – and perhaps our best example of crowdsourcing is water well data. Field geology is fundamental to geological mapping, while management of data that supports our mapping in the US is coordinated by the National Geological and Geophysical Data Preservation Program (NGGDPP). A range of geophysical methods is being applied to geological mapping – including EM, seismic, radar, borehole surveys, marine geophysics, gravity, and magnetics. Some coring is required for 3D geological mapping. He described how 3D geological mapping varies according to resolution, data adequacy, lithological data, and stratigraphic data. He outlined the history of 3D, and he defined layers as strata whose thickness can everywhere be mapped, and for which underlying geology can be drawn, while the underlying rocks are basement - deformed rocks, which are depicted as a 2D basement map, with 3D depiction of selected structures and discretized physical properties. He suggested that in the layers, we start with polygons, we add thickness, we specify properties, we indicate heterogeneity, and we convey uncertainty. 3D mapping of layers starts with stacking, then thickness. With lithological data, the model is anchored at stratigraphic benchmarks, strata are drawn by a geologist through lithological data, a facies model guides interpolation, and strata are drawn at a resolution supported
by data. With stratigraphic data, modeling may proceed directly from regularly spaced, correlated data. In 3D, geostatistics will play an essential and greatly varying role in all work, whether inference of solids directly from lithological data, at least a 1st draft, or property attribution following definition of hollow strata. In two-layer models and regional cross-sections, depth to bedrock and depth to basement maps motivate data compilation and clarify data collection priorities, while regional cross-sections from onshore to offshore and from neighbor to neighbor are a crucial early step in reconciling stratigraphy. Many regions have stratigraphic atlases in need of digitizing. With interpolated stratigraphic data, well-distributed drillholes correlated by means such as micropaleontology or lithological trends may be ready for machine modelling, although expert-generated synthetic profiles may be required in data-poor areas for an acceptable result to be obtained; new data are more readily incorporated into iterations than with lithologic data. With solid models, a progression from surfaces to attributed volumes will be needed for applications; this may require data collection and transfer to another software platform, depending on nature of the discretization and attribution; solid models may also be constructed from geophysical data. In summary, at each resolution level, we need to start with a 2D map, then construct cross-sections to resolve a stratigraphic model, then build 3D for the layers as extent, thickness, and properties, and then build a basement map, with 3D geometry of basement structures and discretized properties.

Likely zoom levels seem to be global, continental, national, 1:24K/100K, and urban, with good planning on the stratigraphic resolution at each level being needed. Global geological mapping is coordinated by the Commission for the Geological Map of the World (CGMW), where Randy Orndorff is our delegate. The magnificent Reed, Wheeler, Tucholke map is the current continental 2D map for North America. State geologic maps are being assembled by the USGS Mineral Resources Program. Much cross-section work has been done, and more is needed. Basement maps underlie the removable layers.

States are assembling seamless ~1:100K/1:24K mapping, resulting in greater use of and support for the source maps, which remain the more information-rich documentation for the seamless database. For two decades, the Great Lakes Coalition has developed protocols for 3D geological mapping. In urban settings, we can communicate with infrastructure design, though languages such as BIM.

In summary, Thorleifson indicated that our planning indicates that future geological mapping needs to be well supported and coordinated, regularly updated, zoomable, queryable, complete, seamless, 3D, and continuous from onshore to offshore. Our research underpins and optimizes our mapping; while our academic colleagues balance research and teaching, survey geologists balance research and mapping. Rather than replacing paper maps, seamless compilations, while not capturing all information on the paper maps, will dramatically increase the usefulness of our mapping, and will cause escalating demand for and support for the source maps. Going 3D makes our mapping vastly more relevant to, for example, groundwater management, as well as hydrological or tectonic modeling. In the past, geological maps could only be consumed by a trained eye; now, many users prefer a 2D or 3D grid of properties such as hydraulic conductivity that will be machine readable.
He then outlined his proposed Decadal Plan implementation goals –

- a multi-resolution 3D geology of the USA by 2030
- stratigraphic correlation and rationalization
- new analyses, geophysical surveys and drilling
- coordination with CGMW global mapping
- retain a commitment to paper maps
- for the US, focus on 3 seamless resolution levels - 5M/500K/100K
- develop an interface with infrastructure design
- meet only as needed
- state role in seamless 2D 1:100K & increasing 3D
- seamless national 2D 1:500K bedrock and surficial by end of FY22
- continental 1:5M 3D by end of FY22
- national 3D 1:500K geology by FY30

He discussed the NGMA, and its $64M authorization, thus reaffirming the national need for geologic maps. He then described Fedmap work on world-class digital geologic maps and 3D framework models based on state-of-the-art observation and interpretation directed by high priority national issues. He then discussed Statemap funding, matched by states, and guided by each State Mapping Advisory Committee (SMAC). He then outlined the Edmap role in training the next generation of geologic mappers, and the role of NGMDB as a public archive of geologic maps for the Nation.

He described the 2018 – 2030 NCGMP Plan, which outlines a renewed vision to create an integrated, 3D, digital geologic framework model and derivative maps of the US and its territories to address the changing needs of the Nation by the year 2030, with goals to:
1. Achieve excellence in the performance and relevance of the FEDMAP, STATEMAP and EDMAP Program components, and maximize beneficial partnering between all Program Components;

2. Optimize the use of field-based, remote sensing and geophysical technologies, and construct the infrastructure to house a national integrated 2D/3D geologic framework model;

3. Build a national integrated 2D/3D geologic model that enables the seamless construction of geologic maps within user-defined regions-of-interest across all of US by the year 2030.

He then outlined near-term actions, starting with actions with Program-wide Relevance:

1. Update and maintain a database of completed and ongoing geologic mapping;

2. Develop and maintain an effective and detailed NCGMP Implementation Plan that guides the definition of the annual FEDMAP Prospectus, and the STATEMAP and EDMAP annual announcements, and thereby directs all NCGMP resources towards fulfillment of the listed goals;

3. Plan the location of NCGMP-funded projects years in advance, such that targeted field areas can become part of requirements for LiDAR funding, and can guide the development of base maps;


He then described the process for development of implementation plan chapters organized by geologic provinces. David Spears, recently the AASG Past-President, is now on part-time assignment as the NCGMP Strategy Implementation Plan Liaison to State Geological Surveys, with primary responsibility for the inclusion of State Geological Surveys and other State government agencies in the development of an Implementation Plan for the new NCGMP Strategy.

The position involves interaction with State Geological Surveys to enhance mutually beneficial partnerships that provide an expanding set of modern geological information products to the public. The chief duties related to the State Liaison activity include: establishing the in-depth involvement of State Geologists in Implementation Plan Working Groups convened for multi-state geologic provinces across the U.S.; and aiding in the facilitation of Implementation Plan Working Group meetings.

Included in the planning process, according to present expectation, will be working groups on basement, stratigraphy and cross-border correlation, enterprise GIS workflow, standards and formats, protocols for resolution and compilation, and geospatial infrastructure.

He then described the Critical Minerals Executive Order of December 2017, and related activity that comes under the informal name 3DEEP. He noted that in the context of critical minerals, the order calls for ensuring access to the most advanced topographic, geologic, and geophysical data within US territory, in part through a plan to improve this mapping, and making it electronically accessible, within 60 days of completion of the final critical minerals list.

Current discussions under the informal name 3DEEP – 3D mapping economic empowerment program – are focused on complete topographic, geologic, and geophysical 3D mapping of the Nation to
identify these important mineral resources within our borders in order to strengthen national security, create jobs in the private sector, and generate economic and social benefits in value-added products and services. Shovel-ready activity building on existing USGS programs such as 3DEP and NCGMP is the focus.

3DEEP activity may include advanced elevation surveys such as Lidar under the 3DEP program, detailed geological mapping to support mineral resource evaluation and exploration by providing the data needed to recognize favorable terranes for various types of mineral deposits, along with applications to energy exploration, construction, natural hazards detection, and groundwater resources. In addition, airborne geophysical surveys are foreseen - primarily aeromagnetics, thus providing information on the geology beneath the Earth’s surface, which can be used to construct geological models required to begin targeting buried mineral resources. A 2015 Australian government report indicates $20 of private sector economic activity for every $1 of government investment in this type of geoscience data.

John Brock also discussed additional emerging opportunities to enhance national geologic mapping through internal partnering with other USGS Core Science Systems mission area programs, including, within the National Geospatial Program (NGP), 3DEP, Alaska Mapping, National Hydrography Dataset-High Resolution (NHD+HR), US Topo, and Federal Geographic Data Committee; as well as, within the Science Synthesis, Analysis & Research Program (SSAR), High Performance Computing, Biogeographic Mapping, Geological & Geophysical Collections, and Data Integration and Synthesis.

The NGP organizes, updates, and publishes the geospatial baseline of the Nation’s topography, natural landscape and built environment through The National Map, along with geospatial research on new approaches for updating and using geospatial data and for reducing costs. The National Map is a compilation of the foundational data layers for the entire Nation, maintained in the public domain.

The Science Synthesis, Analysis and Research (SSAR) Program provides analysis and synthesis of scientific information, long-term preservation of scientific data, and library collections, thus accelerating research and decision making through data science, information delivery, advanced computing, biodiversity analytics, and preserved geoscientific samples.

This activity underpins USGS science, through nationally-consistent, foundational geological, geophysical and biogeographic data, high performance computing; accelerates research and decision making, through analytical tools, maps and data synthesis provide decision makers with actionable intelligence, and high performance computing that expands the scope of research thus enabling greater scientific discovery, thus creating efficiencies by decreasing processing time; and provides long-term preservation of scientific data and collections, through the USGS Library, geological and geophysical collections, ScienceBase - Trusted Digital Repository, and the National Ice Core Lab. John Brock also discussed GeoSTEM education, and NCGMP funding.
National Geologic Map Database: Dave Soller of USGS, Chief of the National Geologic Map Database (NGMDB) project, then outlined the status and future of the cooperative USGS/AASG NGMDB, which was specified by the National Geologic Mapping Act (NGMA) and implemented in 1996.

He quoted USGS Director John Wesley Powell, who said that “...the maps are designed not so much for the specialist as for the people, who justly look to the official geologist for a classification, nomenclature, and system of convention so simple and expressive as to render his work immediately [understandable]...”.

He credited the NGMDB project staff, and summarized development strategy:

- Focus on content - that’s why users come to the website;
- Keep the technology simple; this isn’t research; don’t build a site beyond the interest, skill, and technology of our users; focus on clarity of presentation and navigation, and speed of delivery;
- Customer service; listen to the user, and interact with them; ensure that they get the answers and data they need; as a result, we learn how to improve the system;
- Plan for the long term; focus on preserving information; work with the library community, to ensure NGMDB content is compatible, and addresses generally-accepted, long-term objectives.

He then outlined the vision for the NGMDB that has been commonly held since about 1996:

- The NGMDB should be a repository of GIS data for geologic maps and related information, managed in a complex system distributed among the USGS and State geological surveys;
- It should offer public access to attributed vector and raster geoscience data, and allow users to perform queries online, create derivative maps, and download source and derived map data;
- Further, all information, including GIS features, in the database would retain metadata that clearly indicates its source.

He stated that this vision was not fully feasible in 1996, but now the vision for NGMDB Phase Three can be realized – to build an online database of digital geologic map information.

The steps are to first build the foundation:

- Inventory all maps and related information in the Map Catalog;
- Identify best-available maps for each scale range in mapView;
- Maintain standards for geologic names (Geolex), database design, controlled terms, scientific confidence, and cartography;
• Build a geologic content database linked to Map Catalog, mapView, and Geolex;
• Vectorize maps, create full databases using the GeMS database standard, reconcile differences into an enterprise-level seamless database; and
• Parsing each map’s geologic content into a GeMS-compliant database.

**Opening breakouts**

After the morning break, meeting participants first divided up, for 40 minutes of general discussion on a regional basis - Great Lakes, Northeast, Plains, Southeast, and West. Then, before lunch, attendees regrouped for additional discussion on a topical basis - Appalachian, Cordilleran, Precambrian, Quaternary, and Sedimentary Cover.

**Opening breakout reports**

After lunch on the first day, it was reported that Great Lakes discussion had focused on water wells, multistate correlation, and drilling. Northeast participants focused on the role of a broad NCGMP implementation plan in leveraging funding, and for measuring success, along with a focus on drillhole data and groundwater-related subsurface work. Plains discussion addressed drillhole data and geophysical surveys. Consolidated and unconsolidated sedimentary deposits are an important mapping unit for the Plains area, with aerial/airborne electromagnetic (AEM) surveying being an exciting and important focus. The method was developed for mineral resource exploration and is now an emerging tool for aquifer characterization in Cenozoic continental deposits. The ideal environment is where there are high resistivity differences between geologic units, such as clayey beds vs. sandy beds. Pros are cost at ~$9/acre, depth of penetration at ~200-300m, while cons are that most vendors are geared toward the mineral industry, the method doesn’t always produce resolvable imagery, and heavy post acquisition processing. Work in Nebraska is a model for use of EM surveying in aquifer characterization. Southeast people talked about drilling, GIS, lidar, geochronology, and cross-border coordination. West people talked about cross-cutting topics such as renewed interest in minerals, so long as we recognize multiple issues of similar importance, growing 3D while dealing with varying levels of resolution, unclear definition of what is bedrock, need for lidar although it is challenging to coordinate planning of geologic mapping and new lidar, our role in infrastructure, and transportation corridors.

Appalachian discussion focused on workforce planning, more cross-sections, need for more drilling and drillhole databases, depth to bedrock and depth to water table, need for a geochronology database, sedimentary basin thickness, perfluorocarbon issue, fractured rock and fracture mapping, and groundwater. Cordilleran and Precambrian people merged, and talked about water well data, remobilization of structures, and mineralization, assembly of disparate data, uncertainty, staffing 3D expertise, and software. The large Quaternary group talked about selling our role to nongeologists, the importance of soil mapping, GIS, and sharing of database templates. Sedimentary cover people
talked about geophysical surveys, terminology, data sharing, differing audiences, varying expectations, lidar, and definition of top of rock.

Resulting general discussion in the early afternoon breakout report session included need for compelling graphics, communication with engineers, apps, and the need to examine varying mapping techniques and topo base usage, including which base to adapt the geologic mapping to.

**Plenary talks**

Continental resolution geological mapping: Continental resolution geological mapping: The scope of this talk was expanded from initially being about 1:5M mapping, to being about information system linkages. Andrew Zaffos of Arizona Geological Survey spoke on behalf of the University of Wisconsin-based Macrostrat team that is led by Shanan Peters. His talk included an overview of the utility of integrated databases for the geologic mapping community. He suggested that an integrated database is not universal metadata or data collection standards, nor a data aggregation service; but rather different data sources joined by common attributes and redistributed in a homogenized schema.

Integrated databases of geologic information can benefit many different domains: academic research, the digital economy (e.g. real estate websites), digital mapping efforts (e.g., diagnose regions or nomenclature requiring revision), and public outreach (e.g., rockd and flyover country). As an example of integration, Andrew described how joining geochronological measurements, geologic maps, and stratigraphic columns from different research projects together could better constrain the age and extent of a unit than any single source.

Andrew posited that we already have all of the technology and data required to build integrated databases. We do not need to wait for the adoption of universal data standards. Instead, it is possible to build probabilistic models of how different data sources should be linked based on common attributes - e.g., stratigraphic nomenclature, lithologies, ages, and geolocation. Data only needs to be machine and human readable, and freely available, for this approach to work. Last, Andrew encouraged geologists to link their map descriptions and other field observations directly to the digital map data, as these additional field observations are invaluable and greatly add to the quality of both the geologic maps and integrated databases.
National 3D geology: Oliver Boyd of USGS spoke on the National Crustal Model (NCM) that is needed for improved seismic hazard assessment. The first priority is on site response in the national seismic hazard maps. He credited the project team, advisory committee, and state advisors. He indicated that the USGS National Seismic Hazard Map (NSHM) is used for building codes, emergency preparedness, insurance, and development. Knowing the seismic hazard accurately and precisely reduces costs and saves lives. There are several sources of uncertainty in the USGS maps, and one of the most significant is site response, or more generally, everything the Earth does to modify the seismic waves between the source and receiver. The NSHM is presently produced with a uniform site condition, that being a VS$_{30}$ of 760 m/s, and practitioners either apply National Earthquake Hazards Reduction Program (NEHRP) site amplification factors or do a more site-specific analysis.

The NSHM also does not fully account for differences in source to site path along which rays can 1) be focused or defocused due to lateral and vertical variations in subsurface velocity; and 2) have different amounts of attenuation. Further, waves can be converted to other phases along the ray path, for example, basin edge generated surface waves, and this too is not accounted for in the model. There is minimal regionalization although it could be argued that some of these path and site effects are accounted for in the most minimal way in that one set of ground motion prediction equations are implemented in the central and eastern U.S. and another set in the west.

It is known, however, that some amount of observed ground motion variability is due to specific geophysical properties at each site, and we can estimate this and improve our basic hazard model. This is not intended to replace site specific analysis where geotechnical firms measure geophysical properties directly and do additional research specific to a particular site.

But we know from 3D earthquake simulations in, for example, Seattle, and 1D site response analysis in, for example, Memphis, that 3D variations in subsurface geophysical properties can strongly impact seismic hazard. There is work being performed to mitigate the path problem in the maps by making use of 3D simulations in several urban areas. Incorporation of results from urban hazard assessments into the NSHM is being led by Morgan Moschetti.

Developers of ground motion prediction equations recognize the influence of 3D variability of geophysical parameters and manage this by including terms for the time-average shear-wave velocity in the upper 30 meters, termed VS$_{30}$, and the depths to 1.0 and 2.5 km/s shear-wave velocity,
termed Z1.0 and Z2.5. These latter terms were included to account for basin amplification at longer periods.

With a NCM, we will be able to provide these site response metrics for current GMPEs uniformly across the US as well as be able to provide new metrics for future GMPEs, such as fundamental period, allow for more regionalized GMPEs, and better account for source, path, and site variability through 1D, 2D, and 3D numerical methods. Further, having this model will provide consistency between ground motion model development and their application in the national maps.

A significant amount of work has already gone into producing regional models, for example in the Bay Area, and we are working to incorporate aspects of these models to maximize the consistency between the National Model and these regional efforts. It has been noted that NCGMP now has the goal to produce a successor national 3D geologic model by 2030—this will be used when available.

The current NCM consists of a set of profiles defined on a 1-km grid across the U.S. with depth varying geology, petrology, and geophysical information including bulk and shear modulus, density, porosity, and p- and s-wave quality factors; plans call for uncertainty in these parameters to be included.

The foundation of the NCM is Biot-Gassmann and mineral physics theory, which predict how moduli and density vary as porosity, pressure, temperature, saturation and mineralogy change with depth. It is assumed that porosity is an exponentially decreasing function of the normalized differential pressure, which increases with depth, like what has been observed in various sediments and rocks.

We currently assume that temperature increases linearly with depth, but this could be improved significantly using, for example, the 3D temperature model developed at SMU. Pressure is simply the integrated weight of the material above.

The 3D geologic model is constructed from: near surface maps of porosity and composition obtained from the National Soil Survey; maps of surface geology from the USGS Mineral Resources program with modifications to remove differences across state borders and improvements recommended by State Geologists as well as extrapolations for subsurface geology; maps of the depths to bedrock and basement compiled from various sources; inclusion of more local and detailed 3D geologic models; and a petrologic model to couple geology to mineralogy and to be able to make use of the mineral physics calculations.

Depth to bedrock is based on modifications to the work of Pelletier and others (2016) and depth to basement based on improvements to Mooney and Kaban (2010). Improvements include, for example, gravity-based surveys in the western U.S. and depth to Precambrian basement in the central U.S. from the Marshak et al. (2017).

Within the framework of Biot-Gassmann and mineral physics theory, we calibrate four constants to be functions of geology. For example, unconsolidated sand is going to have greater surficial porosity
than a granite. We’ll also find that for a given porosity, rocks containing more mafic minerals will be faster and denser than rocks containing primarily felsic minerals. To perform this calibration, we use as constraints measurements of VS30, sonic logs, density logs, and shallow and deep velocity profiles.

Once calibrated, we will need to validate the model. For the first application of maps of Z1.0 and Z2.5, we will attempt to reduce the variance of intra-event ground motion residuals from the NGA-West 2 dataset. Further validation for additional applications will involve modeling ground motion time histories for small earthquakes, likely in the Bay Area and Southern California where extensive validation has already occurred for other velocity models.

Planned improvements for depth to bedrock include: incorporation of gSSURGO soil mapping root zone and minimum bedrock depths as minimum constraints; include Pelletier and others (2016) regolith model; use IHS well logs for Quaternary horizons; and inclusion of additional state maps and well logs, for example from the USGS National Water Information System.

Planned improvements for depth to basement include: implementation of additional gravity surveys throughout the US; incorporation of IHS well logs as minimum depth constraint; and coordination with Mike Brudzinski’s NSF basement mapping project for the central and eastern U.S.

Planned improvements for surface models include: obtain or derive better surficial porosity model (e.g. Michael E. Wieczorek with USGS Water Resources); obtain or develop more detailed and consistent surface geology map, particularly for the central and eastern U.S.

Planned improvements for subsurface geology models include: obtain bedrock and basement geology maps where available; obtain and implement locally constructed 3D geologic models such as for the San Francisco Bay area; and coordinate with North American state and federal geoscientists for the shared vision of producing a 3D geologic model.

Next steps in the western US for the 2020 NSHM include: complete calibration and validation and publish by June 2018 for Z mapping application. Next steps in the western US beyond the 2020 NSHM include: model improvements; additional validation; ground motion simulations; and completion of the first version of the central and eastern U.S. in FY19.

The bedrock geology map will use surface geology maps with unconsolidated sediments removed and nearest neighbor interpolation; the nearest neighbor method will have problems where bedrock outcrops are far apart. The basement geology map will use a bedrock map with sedimentary rock removed and nearest neighbor interpolation; nearest neighbor will also have problems in this case as basement outcrops are farther apart.

There also will be refinements in surface geology age, bedrock age, basement age, bedrock depth, and basement depth. All these refinements are needed to better calculate bulk and shear moduli and density, as well as seismic velocity, within the context of Biot-Gassmann theory. The key to this
theory and its ability to model p- and s-wave velocities rests with the Biot coefficients, Beta_p and Beta_s, which are functions of porosity.

Calibration data consists of various measures of p- and s-wave velocity and density including VS30, direct measurements from boreholes and well logs, and shallow and deep velocity profiles from indirect methods. Calibration is not complete. With both density and p-wave velocity we solve for phi_not, a, and alpha in the Biot-Gassmann equations. Phi_not controls the offset of the curves, how quickly porosity decreases and velocity increases with depth, and the ratio of p-wave velocity to density and s-wave velocity.

The preliminary geologic model can be compared to, for example, the Seattle model, and USArray tomographic models. In the case of the Seattle seismic model, surfaces define depth to bedrock and basement, and P-wave velocities increase along linear segments within Quaternary sediments and are defined by tomographic results within Tertiary basins. S-wave velocity is assigned by a Vp/Vs ratio that decreases from 2.5 to 2.2 in the unconsolidated sediments and is 2 in bedrock. Density is based on Vp using Brocher’s (2008) relations. Shen and Ritzwoller (2016) and Schmandt and Lin (2015) show similar shear wave velocities but are less sensitive in the near surface.

Oliver summarized by first indicating that forthcoming enhancements to the model will be coordinated with NCGMP plans for a successor 3D geologic model for the Nation. In addition, plans also include performing tomographic inversion with NCM as the starting model to better capture spatial variability in geophysical parameters; additional calibration using Love and Raleigh wave dispersion curves from broadband stations; calibration using additional VS30 and well log data; validation to reduce the variance of intra-event ground motion residuals relative to default values using the NGA-West2 database and ground motion prediction equations; and reproduction of long-period waveforms and phase arrival times with 3D simulations of western U.S. earthquakes.

Hazen Russell of Geological Survey of Canada (GSC) spoke on behalf of lead author Boyan Brodaric, and co-authors David Snyder and Marc St-Onge, regarding Canada-3D (C3D): toward national surface and subsurface compilations of the geology of Canada.

He cited as rationale advances in data and methods regarding 3D modeling, a trend toward large area models, as well as coordination of regional, national, continental,
and global models being applied to topics such as plate motion, as well as big science applications in climate, water, energy, natural hazards and other topics. Their objective is to build a National onshore/offshore 3D geology for Canada, developed incrementally as an Open Geoscience project.

C3D is a GSC-led project of the National Geological Surveys Committee (NGSC), which consists of the federal, provincial, and territorial surveys. It is foreseen as an online, authoritative, and evergreen knowledge synthesis of Canadian geology and thus a national geoscience library and compilation that will form the basis of a next generation view of the Canadian land mass. The synthesis is expected to be a positive influence on topics such as mining, exploration, natural hazards, groundwater, research, education, and others.

On the international scene, the subsurface seems to be a strategic trend, and the next frontier, as indicated by bold initiatives in the US, France, the UK, Australia, China, and elsewhere. A formal NGSC arrangement asserts that C3D will be authoritative, accredited, collaborative, evergreen, incremental, integrated, multi-resolution, open, standards-based, and voluntary.

At the outset, C3D is a 3-layer model – surficial topography and geology, bedrock, basement, and Moho. A new Arctic bedrock map is a step toward a new national bedrock geology. The model is tiled in a PostGIS database, and existing regional 3D models are insets. Methods to convey uncertainty are in development.

Geological maps, cross-sections, field observations, and geophysics underpin the model, along with knowledge in the form of geological concepts, rules, histories, and processes. Plan are in place for the gradual enhancement of Canada3D.

**Basement geological mapping:** Laurel Woodruff of USGS spoke for the authors of the US basement presentation, who were led by Karen Lund of USGS. She noted that USGS was established in part to assess mineral resources, and to this day, consistency is the challenge for National-scale mineral resource assessments. This is due to traditional geologic maps often portraying only surface geology, maps often concealing mineralized rock and structures beneath
younger materials, and maps often ending at arbitrary political boundaries. These deficiencies in available geologic mapping distract from the accuracy and validity of mineral resource models and assessments.

The goal of constructing a basement map of the US is to provide a base layer for National-scale mineral resource assessments, particularly identification of contrasts in crustal composition, architecture, and tectonic history; crustal-scale structural zones that may have acted as pathways for hydrothermal and/or magmatic fluids through the crust; controls on the composition and metallogeny of igneous rocks younger than underlying basement rocks, and metallogenic provinces as defined in 2001 by Titley. Titley explored the possibility that the metallogeny of ore deposits was related to crustal affinities. He demonstrated that different mineral deposit compositions formed in crustal domains of different ages and origins, and that mineral deposit types in the different crustal domains were different, and that deposits had different produced metal ratios.

Significant interactions of ore-forming processes with lower crustal materials such as mantle melts interacting with the lower crust can result in significant contributions of metals from distinctly different basement crustal rocks. Understanding the extent and nature of basement domains across the country, and their metal endowments are critical to understanding metallogeny at broad scales, and thus, for mineral resource assessments.

Some existing basement maps show regional Precambrian crust in the Midcontinent, such as the basement geologic map of Wisconsin, Minnesota, and Iowa. Other existing basement maps show more detailed regional Proterozoic evolution in the west, such as the generalized map of major basement provinces of southwestern Laurentia. Additional basement maps show Precambrian basement structures, such as maps showing Archean and Paleoproterozoic accretionary crustal provinces, Late Proterozoic and Mesoproterozoic provinces formed during intracontinental deformation, and Late Proterozoic and Mesoproterozoic provinces formed during intracontinental deformation. Other basement maps model the growth of the Precambrian crust, such as a plate-scale model for the Precambrian growth and evolution of the North American continent. Additional types of existing basement maps show the Phanerozoic crust as accretionary complex maps, such as the lithotectonic terrane map of the North American Cordillera. Some basement maps are constructed as complex lithotectonic terrane maps, such as the lithotectonic terrane map of the Appalachian orogen. Grossly simplified maps also play a role, such as the simplified lithotectonic map of the Appalachian orogen.

Each of the existing maps of basement blocks, cratons, terranes were constructed using different philosophies and for different purposes. A basement map reflecting the long-lived tectonic history of the entire continental U.S., however, requires a consistent concept of basement. The guiding concept of basement chosen for the current basement map of the US is compatible with the American Geological Institute definition: “...The crust of the Earth below sedimentary deposits extending downward to the Mohorovičić discontinuity. In many places, basement rocks are igneous and
metamorphic of Precambrian age, but in some places, they are Paleozoic, Mesozoic, or even Cenozoic.”

For the current map, 77 basement domains were identified for the conterminous US and Alaska. The term ‘basement’ as used here comprises the fundamental crustal elements of all ages, including transformed juvenile rocks, based on previous basement, terrane, and lithotectonic maps; conventional geologic maps; isotopic and age data; as well as national-scale gravity and aeromagnetic data.

Basement domains boundaries can be overlain on the North American magnetic map to illustrate a basis for the mapping. The map is meant to be used at 1:5M, particularly as a base layer for National-scale mineral resource assessments, in which primary metal endowments of geologic environments that may be present in each crust type are interpreted as basement domain. Development in a GIS allows conceptualization of derivative products, such as a derivative map illustrating domains classified as crust type, time-slices, or crust formation ages; examples are a derivative map highlighting domains with geologic environments conducive to formation of porphyry type Cu-Au deposits, and basement domains layered with locations of principal metal deposits.

Compositions, architecture, and original metals endowments of each domain are important for assessments of primary mineral deposits. Deposits in this compilation include those deposits primary to basement (original deposits) as well as much younger deposits. Additional forward-looking products using the basement domain map include a derivative map showing locations of 1.4-Ga granitoid rocks in relation to basement domains, as well as global associations between 1.4-Ga granitoid rocks and a variety of important ore deposit types that demonstrate the need to develop a definitive geochemical, modal, and geochronologic database.

The 77 basement domains identified in the conterminous United States and Alaska are only one possible template for basement domains, but it provides a consistent dataset for evaluating types, distribution, and origins of metal endowments. Therefore, along with other data, this map can be used for continent-scale mineral resource potential.

At the end of Day One, Dave Snyder of GSC spoke on 3D basement mapping in Canada. He credited his co-authors, and he began by discussing extension of polygons as prisms, as in the Macrostrat project. He also focused on surfaces primarily constrained by outcrop data, and also by structural field data, drill hole data, cross-sections, seismic data, and magnetic/gravity data. A
recurring regional 3D geological mapping challenge is either too many fault surfaces or too few measurements. He also outlined geostatistical treatment of geophysical data as a basis for a moho map. The resulting 3D geological maps provide a framework for GSC geological information.

**Sedimentary basin stratigraphy and modeling: Chris Swezey** of USGS spoke on alloegenic controls on lithostratigraphy, and implications regarding the geologic mapping of black shale in sedimentary basins of the eastern US. He outlined how thinking on the lithologic character of strata that accumulate in a sedimentary basin has evolved from a focus on tectonics in the 1960s–1970s, sea level in the 1980s–1990s, and climate in the 2000s–present.

As an example, from the Cambrian through Pennsylvanian, the Appalachian, Michigan, and Illinois Basins were a carbonate world; the presence of non-carbonate strata denotes an unusual event related to orogeny, or an unusual change in climate and/or sea level. He also discussed changes in sea level and glaciations during the Phanerozoic, following the writings of Crowell. For Cretaceous through Eocene, he discussed onset of Laramide Orogeny, and mainland North America siliciclastics separated from carbonates of Florida. For an Oligocene through Present example, he discussed siliciclastics becoming more common, followed by Antarctic glaciation, regional unconformity, influx of siliciclastic sediments, Gulf Stream moved to present location, Mid- Pliocene Arctic glaciation, another regional unconformity, and another influx of siliciclastic sediments.

He then outlined how this understanding of stratigraphy helps us with geologic mapping, through prediction of the distribution of certain lithologies throughout the stratigraphic record, in relation to societal applications. He then illustrated these points, using black shale as an example. In summary, Chris outlined how tectonic changes create basins, and create uplifted areas that may have been sources of siliciclastic sediments, while climate and sea level changes govern the nature of lithologies that accumulate as a stratigraphic record in a sedimentary basin. For a given lithology such as black shale, there are a limited number of settings in which that lithology may accumulate to form part of a stratigraphic record. Finally, he noted that our ability to build these reconstructions is strengthened by field experience.
**National resolution geological mapping:** *Carma San Juan* of USGS presented the USGS State Geologic Map Compilation (SGMC). This ~1:500K partially reconciled compilation of state geologic maps that has been assembled since 1997 plays a crucial role in Mineral Resources Program analyses of nonfuel mineral resources that are important to the economy and security of the Nation.

From 1997 to 2007, 48 state geologic maps were coded by lithology and age, and original line work was maintained. Since 2015, the geologic map of AK has been added, the map has been structured as a single geodatabase, 7 new state maps (ID, IL, IA, MN, MT, NV, VT) have been incorporated, and 5 states (CA, IN, NJ, NM, NC) have been updated. Original line work continues to be maintained, and the **SGMC** is on the [National Map web viewer](#). No GIS required to explore data. The state geologic maps vary by scale, publication date, map type, author agency.

San Juan then discussed options for how to make the GIS assembly a seamless map, in part based on her understanding of experience elsewhere, such as in Australia and New Zealand. Key ingredients were a clear, long-term commitment, and strong leadership by persons with a deep understanding of the task, supported by comprehensive programs of geophysical surveys and geochronology. She also discussed the experience of the Alaska state geologic map.
San Juan then reviewed the status of Cosuna stratigraphic columns – for the Silurian, for example, regional transects show position of regional unconformities, thicknesses of unconformity bound packages, facies characteristics that redefine Silurian basin and tectonic evolution, and sea level fluctuations associated with Silurian climate-oceanic events. A prototype was shown to demonstrate the feasibility of redefining the stratigraphic architecture of the US. Finally, she showed the profound significance of up-to-date geophysical and geochronological surveys.

Aquifer mapping: Eddie Haj of USGS discussed their maps showing properties of Quaternary sediments and aquifers in the glaciated conterminous United States, part of the USGS National Water-Quality Assessment (NAWQA) Program Cycle 3 study of the Glacial Aquifer. Publications meant to convey the work are in the final stages of review, with release expected in Summer 2018.

Their goal is to develop a hydrogeologic framework that presents a nationwide picture of the glacial aquifer system, provides generalizations concerning the nature of aquifers, such as confined vs. unconfined, and denotes similarities and differences in distinct parts of the aquifer system that relate to water use, quality and aquifer vulnerability.

They sought a balance between spatial coverage and detail, they relied on State Geological Mapping efforts, they used the Fullerton and Richmond Quaternary Atlas, as well as the Soller and others Surficial Materials Map Database. They developed new attributes that consolidate similar depositional units in terms of lithology and hydrologic characteristics.

Bedrock geology was derived from the Minerals Program SGMC - each spatial element was given a value of noncarbonate sedimentary rock, carbonate rock, noncarbonate metamorphic rock, volcanic rock, plutonic rock, or sediment.

Each of the hydrologic terranes contains Quaternary sediment that is generally derived from a common depositional history and characterized by similar texture and thickness. The mapping is viewed as highly generalized, and to be used only to give a sense of the relative potential for encountering buried aquifers.
They distinguished lower complexity - thin cover, generally less than 15 meters, from relatively higher complexity - thick sediment cover, generally greater than 60 meters. Map unit categories were translated to map unit values: alluvial, colluvial, eolian, lacustrine, marine, organic, outwash, ice-contact deposits, island, residual soils, soliflucted sediment, till, bedrock, fill, and water. Sediment texture maps are divided as sandy, sandy-silty, mostly silty, silty-clayey, mostly clayey, and mostly organic.

Subsurface information is from state well log databases, including lithology, and other aquifer subsurface metrics. Statistical analysis was conducted on metrics based upon the terrane and map unit spatial relationships to determine a likelihood of encountering an aquifer, its nature, and its water use potential. Probability of encountering an aquifer-material interval was mapped, as was the probability that aquifer-material interval is confined by at least 7.5 m of fine-grained material.

Next steps are public release this summer of data and reports, groundwater flow modeling applications, and future updates of the database.

![Graph](image)

**Geophysical surveys and drillhole databases:** Paul Bedrosian of USGS spoke on geophysical surveys, and Harvey Thorleifson of MN spoke on drillhole databases.

Paul focused on geophysics for regional and national-scale geologic mapping. He suggested that 3D mapping goes hand-in-hand with geophysics, that scale needs to be carefully considered, that geophysical models can be translated to inferred geologic structure, that there isn’t a one-tool-fits-all approach, and that national-scale mapping is regionally-driven.

He suggested that the activity demands regional experts to efficiently and economically define the primary needs and goals; determining the right mix of geologic mapping, geophysics, drilling, geochemistry, and geochronology; and leveraging interest/funding across disciplines to produce 3D products with maximum return on investment. He illustrated these points with examples ranging from basement mapping to aquifer mapping.

He indicated that CONUS magnetic data coverage in general is appropriate for 1:500k investigations, at best; magnetic data quality ranking for basement mapping in 7.2% of CONUS has data appropriate
for mapping or minerals investigations at a resolution of 1:50k. He also outlined coverage of AEM and magnetotelluric surveys that are crucial for certain applications.

**Harvey Thorleifson** then spoke on use of drillhole databases in geological mapping. As an example, he presented work with others in Manitoba, where a 3D geology was needed to support a regional groundwater model.

In order to use data from 110,000 water well records, it was necessary first to assign x, y, and z coordinates – in this case, in low relief terrain, legal survey polygon centroids, although actual locations would have been highly preferable.

Secondly, it was necessary to convert the lithological data to a classification and terminology that could be queried and mapped. The lithological data were converted by correcting spelling, obtaining an inventory of words, deleting unusable words, identifying synonyms and changing them to a single term, and parsing and interpreting the remaining information into 25 categories based on lithological, colour, structure, consistency, hydrogeological, and stratigraphic variables. The resulting database exceeded expectations with respect to apparent location accuracy and geological coherence.

Thorleifson stressed that in the past, people were urged not to use water well records for geology, as the user had little basis to assess reliability when using one record at a time. Now, as water well records are georeferenced and made queryable, concepts from big data and crowdsourcing can be used. By looking at dozens to hundreds to thousands of water well lithologic profiles at once, in a 2D or 3D graphic environment, an experienced professional geologist can instantly assess the reliability and usability of the data. A stratigraphic model can be defined on the basis of well-analyzed cores, and interpolation between cores can then be guided by geophysical surveys, along with water well data, in areas where water well industry practice, depth of wells, and the nature of the geology happen to result in regional geological trends being apparent in the water well data. To assess whether the data are usable, however, it is necessary to make the data mappable and queryable, and to look at the data.
Sediment thickness mapping: Dave Soller of USGS spoke on sediment thickness mapping. He stress that we need to: focus on science, not technology; begin by identifying major surfaces; engage regional experts to define and refine what is being mapped; and develop a collaborative, distributed system within which the experts can add detailed geologic data and refine the modelling.

He noted that there are sufficient published cross-sections, stratigraphic columns, and contour maps to compile the geometries at regional/national scale. Nationwide mapping of sediment thickness seems straightforward, but in the various geologic settings, there are varying views on what is the sediment/rock interface. A major subsequent question upon completion of a national map will be how to update it.

3D geological mapping: Don Sweetkind of USGS and Kelsey MacCormack of Alberta Geological Survey spoke on 3D. Don focused on basin- and regional-scale 3D geological mapping methods. He stressed that 3D geological mapping is of increasing importance within State and Federal Surveys, although everyone is at a different stage of development. The USGS is not necessarily leading, as there is no central core of 3D expertise nor a long-term focused research project on the methods. Nevertheless, Don asserted that USGS has a long history of applying 3D frameworks, to support groundwater simulations, and for energy and mineral resource assessment, and hazard assessment.
He cited an example from regional groundwater systems and springs to stress that the regional integrator is the geologic system, so to understand and manage regional aquifers, for example, we need a regional-scale understanding of the geologic framework – in three dimensions.

He stated that geological survey agencies can provide a data-rich, materials-properties-based digital 3D geologic map that has immediate utility and tangible benefits – and that this is something that other agencies cannot produce for themselves. Don added that 3D framework models differ depending on their purpose, for example, a model of seismically-active faults that may be of crustal scale.

Like a 2D geologic map, 3D geology is a mixture of point observations and interpretations used to create lines and polygons; 3D maps integrate data, interpretations, conceptual models such facies models, basin history, structural models, as well as numerical methods for modeling scattered data.

Surface geologic maps fulfills only a small part of these requirements. Compared to surface geology, the subsurface is under-sampled in terms of meeting these requirements.

In 3D geologic mapping, a typical workflow involves a surface DEM, 2D geologic map, borehole data, cross-sections, fence diagrams, unit extents, to geological block model. The ultimate goal is to get to a series of XYZ points for each unit of interest with which to construct the 3D environment.

USGS regional aquifer assessments have produced important 3D geology, including baseline data, as well as thickness and extent of subsurface units. The occurrence and juxtaposition of permeable aquifer units or low-permeability confining units in three dimensions are critical factors that determine the potential location and direction of groundwater flow.

Don described how the development of a digital 3D hydrogeologic framework is a necessary and significant step in improving the conceptualization of groundwater flow at the basin and regional scale and provides the fundamental geologic input for the development of numerical hydrologic models.

Don then drew from a synopsis volume edited by Berg and others to summarize what states and nations are doing in 3D - in regional to national-scale 3D geologic mapping and modeling. He noted that features of most of these modeling efforts include: (1) geospatially correct, (2) based on numerous datasets including digital geological linework at all scales, subsurface contour and isopach maps, existing framework models and surfaces, and geophysical data; also tied to databases, dictionaries and lexicons for boreholes, stratigraphic and rock terminology.

He observed that although some superb work is being done, overall the US is not a leader in this field. He stressed that 3D geologic maps define the physical geometry - elevation, thickness, and extent - and material properties of the surface and subsurface materials and structures, for all locations in the volume of interest – thus, not just a pretty picture.
Kelsey MacCormack of Alberta Geological Survey then spoke on mapping the geology of Alberta in 3D, to enhance science-based decision-making and communication of complex geoscience information to stakeholders. Their 60-person staff is focused is on being an internationally recognized source for credible, innovative and integrated geoscience data, information and knowledge for Alberta.

Their province-wide 3D geology east of the Rockies provides an innovative tool to more efficiently and effectively communicate consistent and reliable 3D geology and surface/subsurface information, to support economic diversity as well as safe and sustainable development.

The framework allows them to communicate their vast data holdings, advanced state of science and technology, and their diverse resource potential, in the form of consistent and credible scientific information.

Concurrently, their model supports regulatory excellence by ensuring that decisions are based on sound scientific information, providing a system for holistic characterization of geological, environmental, social and economic factors to support and inform regulatory agencies, land-use planning, and geoscience decision-making, thus optimizing the value of Alberta’s natural resources while minimizing risk.

Their 3D geology for now consists of 32 geologic units, based on data from 620,812 sites. Numerous sub-models are maintained to meet specific stakeholder requirements.

The starting point was proper management and optimization of data from over 450,000 wells, along with stratigraphic reports, maps, cross-sections, and conceptual models.

They are striving to create a single source of geological information – to develop a multi-dimensional, interdisciplinary, multi-scalar, geostatistically optimized, probabilistically parameterized, uncertainty characterized, geocellular model of Alberta to effectively communicate and disseminate geological information to meet the needs of their diverse stakeholder groups.
This is seen as a way to efficiently share geoscience information, thus averting duplication of efforts, minimizing potential for inconsistencies, making efficient use of staff resources, and promoting consistency and credibility.

Efficient ways of sharing the 3D geomodels were sought, to move away from multiple staff producing similar products, thus resulting in duplication of efforts; cost effective methods for sharing geomodels with staff outside AGS were needed to evaluate information within a geological context; so they moved towards a single source of geologic information to improve efficiently and credibility in our work.

Their 3D modelling workflow involves characterizing uncertainty, through listening to their geologists, providing information to decision-makers, and supporting strategic planning.

Automated workflows have decreased model build time from 2 days to less than 2 hours, resulting in increased efficiency, and reduced chance of error.

The concept for their current 3D geology was developed in 2011; 2.5D grids were completed in 2012; a full-time geomodeller was hired in 2013; a preliminary provincial model was produced in 2014; 23-layer submodels for strategic priorities were complete in 2015; they reorganized as a geomodelling team, with 5 modelers, in 2017; they completed v.1 of the provincial model as 32 layers, while also publishing Minecraft version of the Petrel models, and 3D prints, in 2018; and they now have v.2 of the provincial 3D model online in a free 3D viewer.

The iMOD open-source 3D viewer allows visualization of 3D models by users, who can import their own geospatial data into their models; this will be released in May. The Minecraft models have been valuable in engaging the public.

Next steps are to continue to build the 3D Provincial Geological Framework Model, with the next update planned for Fall 2018. They also will strategically prioritize zones and regions that will benefit from having 3D property models of aquifers and reservoirs, and they will assess new methods for characterizing geology of the Rocky Mountains in 3D.

Their 3D Geological Framework is used to build trust and confidence in regulatory systems among stakeholders, government, and the 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.

As they continue to disseminate their 3D geological models with users, they will assess whether additional functions are required to meet the needs of our stakeholders. Their vision thus is to develop a tool to efficiently and effectively integrate information and communicate credible geoscience knowledge with anyone.
Field and GIS methods: Kyle House of USGS spoke on integrating and invigorating geologic mapping, by integrating the activity, and fully utilizing GIS resources. He asserted that field data collection and map development can occur within or in association with any database, while an enterprise-style database is the best option, with some caveats. Subsequent integration can occur with other databases, for compilation and progressive generalization for seamless portrayals. He suggested that fundamental changes are required in mapping workflows, with the proposed seamless map of the USA in mind, and a revamped regional approach to the USGS mapping strategy is needed.

He then spoke on mobile devices in the field; data storage; observations, measurements, photos, and notes; original field mapping; assimilation of data into workflows; recording GPS tracks and waypoints; apps; scan handwritten notes; taking geotagged photos of everything; understanding data export formats; changing the conventional toolkit; entering the field armed with data, literature, and tools on a single digital device, as Kyle and authors such as Whitmeyer et al. have written about.

He conveyed that you can’t sign your name with a computer mouse, so why do you map with one? He thus strongly recommended appropriate drawing tools, such as a digitizing tablet, or even better, a digitizing LCD Panel such as the Wacom Cintiq 21ux. He also advocated a revolution in our base maps, with lidar playing a key role.

He then focused on enterprise GIS; according to ESRI, this is “A geographic information system that is integrated through an entire organization so that a large number of users can manage, share, and use spatial data and related information to address a variety of needs, including data creation, modification, visualization, analysis, and dissemination.”

Kyle used a Nevada project as an example; he said, to do this right, you need a lot of people, including GIS specialists, a database administrator, and IT support. For it to work efficiently, it requires a more lenient firewall structure than is possible at USGS, for example.
He then discussed the geologic map production and management system, with some emphasis on integrating GIS and IT professionals into cartographic, graphic art, and publication services.

He contended that a fully integrated geologic mapping effort from 1:24k field mapping to seamless geologic portrayals at any scale requires coordination of mappers, GIS specialists, coders, and cartographers. This will require a training and R&D program on digital field methods, GIS for geologic mapping, and analysis of remote-sensing data.

He suggested that mapping institutions need to focus on integrating GIS and IT professionals into what was once solely the realm of cartographic, graphic art, and publication services.

He then added detail on enterprise workflows, and versioned database structures; including standard data attribution and databases consistent and developed with foresight toward integration with other geologic databases; standard schema; and scalable attribution schemes.

He summarized by saying that to support mappers’ needs, project-level or higher setups of appropriate types of base map materials could be organized and provided through a centralized service that can be reached in GIS editing sessions. High-resolution elevation data and imagery are essential in this case, and other types of remote-sensing data can be extremely useful if tailored to specific geologic settings and project goals.

Next steps in a digital mapping program from field to data distribution could be to transfer new, topologically correct, and stratigraphically consistent geologic mapping to a higher tier for compilation, stratigraphic harmonization, and generalization. This would contribute toward attaining geologically and topologically legitimate portrayals at smaller, less detailed scales. This will inevitably be a process requiring much coordination between geologists and GIS professionals. It will involve discussions of the implementation of geologic feature attribution schemes that can be ‘easily’ scaled up or down to accommodate multi-scaled, seamless portrayals that are geologically consistent and legitimate.

Ideally, it would be updateable and in sync with active geologic mapping efforts. Digital geologic map data must be developed in accordance with some type of data attribute and organization standards.

Finally, Kyle contended that standard data attribution and database structures must be consistent and developed with foresight toward integration with other geologic databases in compilation and more efficient development of progressively smaller scale/larger extent portrayals of geology.
Seamless 1:100,000 geological mapping: Drew Andrews of Kentucky Geological Survey (KGS) presented a talk with the title, 'Seamless but not faultless, lessons learned from statewide digital mapping in Kentucky.'

He described complete, statewide paper publication of 1:24k geology, from 1960 to 1978. This was due to an unprecedented cooperative USGS-KGS geologic mapping program. A total of 707 1:24k USGS GQs were published, using photomechanical methods. Over 18 years, over 200 field geologists played a role, consisting of 661 person-years, in multiple field offices. Cost in 1978 dollars was $20.9M, or about ~$65-70M in today's dollars. The result was a dramatically improved understanding of Kentucky geology. In addition, a manually generalized 1:250k compilation was done, as well as a manually generalized 1:500k compilation, which was used by USGS in the SGMC.

Complete digitization of the 1:24k geology paper maps was completed from 1996 to 2004. This was supported in part by STATEMAP, and over 8 years, cost $3.6M. All 707 1:24k USGS GQs vector were digitized, a GIS compilation was done, and most features were captured. There is some regret over the early focus being on 1:100k maps.

Drew then outlined key lessons, starting with the need for separate bedrock and surficial mapping. Multiple applications require separate consideration of bedrock versus overlying unconsolidated material. They need to remove alluvium from their statewide mapping, and then complete bedrock polygons, which will be a tedious and time-consuming task. They also need to complete reconnaissance mapping for statewide surficial geology, including alluvium/colluvium/residuum, as a temporary stop-gap. In addition, they need to pursue critical ongoing detailed field mapping for surficial geology in high priority areas, which will be slow but accurate. In association with this, he outlined interstate correlation issues, due to termination or thinning of units, subtle transitions or nomenclature issues, and issues in mapping system or status.
The second key lesson was to talk to neighbors. Some state to state discrepancies represent honest representation of geologic knowledge, due for example to termination of marker beds. Others are due to nomenclature or descriptive discrepancies; these can be easily resolved through open communication. There also was a need to share methods for LiDAR, characterization, data collection, etc. Other issues will take more in-depth consideration: framework of mapping criteria, including choice of contacts; and map-unit hierarchies, whether chronostratigraphy or lithostratigraphy, for example. There also are what-to-map issues, including lumping and splitting. He stressed the need to attribute the original source of the mapping, as pride of work and accountability results in better edge-matching - there thus is a need for feature level metadata.

Thirdly, Drew indicated that significant lessons were learned regarding money and time. Field work by professionals is relatively expensive; field work by students is cheap; you get what you pay for. GIS manipulation or digitization is much less expensive than field mapping, but it does not produce new field observations/data. Good field data is critical to provide a solid foundation for everything else, such as GIS products, derivatives, etc. He urged us all to pay for it, as it is worth it.

The fourth lesson was about return on investment (ROI). Drew indicated that the huge documented ROI for the Kentucky geologic maps stems partly from their wide applicability to multiple technical fields. The mapping is needed by a broad range of users, in part because availability resulted in expectation and reliance.

A key aspect for ROI is in being complete. Every jurisdiction and project area in Kentucky has detailed maps available, and technical professionals can plan to use the maps, incorporate them into their planning and process, etc.

Nevertheless, he advocated that we not wait for complete detailed mapping, as technical professionals are intelligent people and are not helpless; they will use the best available scale. So he recommended that we deliver what we have now, and not a decade from now.

Finally, Drew noted that done isn’t done. Needs and issues change. The reason we are mapping is not the reason someone will use the map. He stressed that we all need to plan for the database, not the map. In a digital world, the hard-copy map is a static art piece and a critical marker of intellectual property. Nevertheless, it is the digital mapping database and supporting analytical/characterization data that will be used.

**Quaternary geological mapping:** Hazen Russell of GSC spoke on Quaternary geological mapping. He outlined their working group, societal applications, interregional correlation and nomenclature, subsurface geology, stratigraphic issues, groundwater issues, 3D aquifer mapping, depth to bedrock mapping, national compilations, remote predictive mapping, and national 3D geology.

He described their commitment to authoritative and accessible geoscience, and continuously improved understanding of earth dynamics. Drivers include increasing land use pressures,
infrastructure, seismic hazard assessment, landslides, subaqueous mass transport deposits, and
dynamic landscape change. He stressed that 21\textsuperscript{st} century issues call for 21\textsuperscript{st} century solutions.

He then outlined the history of national Quaternary geology maps, as well as applied mapping such as peatlands, permafrost, and hydroregions. He described consolidation of detailed mapping, the latter being 1:50K in the south, and 1:250K in the north.

A national standardized legend has been developed, and 3D mapping is gradually accelerating. Offshore surveys are being compiled. Planning for a national 3D geology is being based on regions, with initial progress close to applications such as regional groundwater planning. Finally, he noted the need for us to deliver the best mapping we can achieve; otherwise, someone will do this for us, in a manner that will not please us.

**Offshore geological mapping:** Walter Barnhardt of USGS described their coastal and marine geology activity. They map submerged lands using a broad range of ever-evolving technology, using multidisciplinary approaches. There are many reasons to map offshore geology, such as an increasing number of resource and environmental issues. In the context of expensive logistics, Walter emphasized a map once, use many times approach.

He then described ocean management plans, and the history of offshore surveys. He described how multibeam/swath bathymetry was a dramatic step forward, comparable to lidar on land, as well as other developments in fields such as sidescan sonar, subbottom profilers, and sampling gear. He outlined how advancing technology is enabling advancing science, while at the same time, a focus on lesser water depths presents logistical challenges that slow progress. He then described coastal process investigations.

He summarized by stressing that geologic mapping is critical to management of ocean resources and coastal-change research; that understanding the processes that shape and maintain the seafloor and adjacent coast requires an integrated approach; and that results of oceanographic observations (measuring) and numerical simulations (modeling) are consistent with changes determined from repeat mapping.
Soil mapping: David Hoover, Director of the NRCS National Soil Survey Center, spoke on soil mapping in the US. He discussed the considerable similarities between geologic and soil mapping. Both describe a layer of the earth, both need field observations, both need model development, both are mental and computer generated; they have similar covariate data for terrain analysis; both involve extrapolation of site data; both are in high demand; both require substantial funding; and both rely on partnerships. In addition, both soil mapping and geological mapping are a national investment. An expenditure of $22B has been invested in soil mapping, and $80M is invested annual to maintain it.

The authorization for a Federal soil survey dates to the establishment of the Department of Agriculture in 1862. The Agricultural Appropriation Act of 1896 authorized the soils investigations; and the 1903 Act expanded the activity. The Soil Conservation Act of 1935 made the authority for soil surveys explicit. A 1953 memorandum established the federal leadership for the National Cooperative Soil Survey (NCSS).

David then described soil survey fieldwork, and increased use of quantitative analysis such as mid infrared (MIR) spectrometry. He then described digital maps and information delivery, validating the data through field correlation and national standards, laboratory data, database maintenance and harmonization through the soil data join recorrelation (SDJR) procedure, major land resource area (MLRA) projects, new products, digital soil mapping, disaggregation mapping through subdivision of polygons using data such as lidar, coastal zone soil survey, urban soil survey, and subaqueous soils.
He closed by stressing that the discontinuation of paper soil maps a decade ago had been an agonizing transition, and that their current commitment to their national database is delivering immense benefits to their user community.

**Urban geological mapping:** Dick Berg of Illinois State Geological Survey described the importance of geological mapping in urban areas, as well as the great logistical challenges in attempting to do so. He suggested that we know more about planetary geology than the geology of our cities. Geology is crucial for our food supply, water supply, ecosystems, waste disposal, construction materials, infrastructure design, energy, and minerals.

Once detailed geologic information is available, particularly in urban areas, data are provided to answer critical questions that will lead decision makers to wise decisions that balance economic development with environmental protection and sustainable water, land, and mineral use.

Cities are pervasively contaminated, resulting in a large brownfields professional community. The cost of cleanup is high. The long-term performance of waste disposal sites needs to be assessed.

In urban geology and the field of brownfield reclamation and redevelopment, issues include effectiveness of large-scale groundwater flow models to assist in pump and treat decontamination processes; ability of groundwater to recharge aquifers, coordinated efforts to increase recharge/decrease runoff, and paving alternatives; foundation conditions that support a city’s skyline and infrastructure; favorable/unfavorable construction conditions - construction designs and bidding accuracy; leads to cost-effective plans with future lower liabilities for economic development, environmental protection, and remediation; susceptibility to urban hazards - building settlement, piping, flooding, and earthquake shaking; costs of excavation and fill required for infrastructure; where the highest quality, closest, and least expensive sand, gravel, and rock can be obtained for building/infrastructure upgrades; development of underground space to quarry rock, tunnels for transportation or drainage control, or create warehouse space; coastal issues of shoreline erosion, protection, and redevelopment strategies, sedimentation, beach replenishment; and suitability of land for preservation, restoration, or creation of open spaces, wetlands, and surface water bodies.

Building information modeling (BIM) is a design protocol whose use is spreading, and European geological surveys are beginning to express geology in this language. These initiatives are part of movements such as Smart Cities, and other activity such as optimized use of underground space, and new tunneling initiatives.
Concurrent sessions talks:

AN OVERVIEW OF BEDROCK GEOLOGIC MAPPING IN THE EASTERN UNITED STATES FROM THE FEDMAP PERSPECTIVE, Gregory J. Walsh, USGS, Montpelier, VT

BEDROCK GEOLOGIC MAPPING IN PENNSYLVANIA – PAST, PRESENT, AND FUTURE, Stuart O. Reese and Gale C. Blackmer, Pennsylvania Geological Survey

BEDROCK TOPOGRAPHY AND SEDIMENT THICKNESS MAPPING IN INDIANA WITH AN EXPANDED EFFORT TO SYNTHESIZE MAPPING EFFORTS THROUGHOUT GLACIATED NORTH AMERICA, Shawn Naylor, Indiana Geological and Water Survey

DIGITAL BEDROCK TOPOGRAPHIC, DRIFT THICKNESS, AND 3-D SURFICIAL GEOLOGIC MAPS OF THE GLACIATED COUNTIES OF NORTHWESTERN PENNSYLVANIA, Stuart Reese and Gary Fleeger, Pennsylvania Geological Survey

GEOLOGIC MAPPING IN KANSAS: OVERVIEW OF PROGRAMMATIC DIRECTIONS AND CURRENT PROJECTS, Jon J. Smith, Greg A. Ludvigson, Anthony Layzell, and John W. Dunham, Kansas Geological Survey

GEOLOGIC MAPPING IN SOUTH CAROLINA: A STATUS REPORT, Robert H. Morrow IV and Tanner Arrington, South Carolina Department of Natural Resources

GEOLOGIC MAPPING IN THE OZARK PLATEAUS OF ARKANSAS, Chandler, A.K. and Hutto, R.S., Arkansas Geological Survey

GEOLOGICAL MAPPING WITH AIRBORNE ELECTROMAGNETICS, Jared D. Abraham, Ted H. Asch, James C. Cannia, Aqua Geo Frameworks, Mitchell, NE

GLACIAL GEOLOGIC MAPPING IN CAYUGA COUNTY, NEW YORK: FOOTPRINT TO FRAMEWORK, Andrew Kozlowski, Geological Mapping Program, NY

GLACIAL GEOLOGY OF LEEANAU COUNTY, MICHIGAN, Kevin Kincare, USGS

GLACIAL LAKE NANETTE: A MIDDLE WISCONSIN (MIS 4 – 3) PROGLACIAL LAKE IN THE CAYUGA BASIN, Andrew Kozlowski, Director of Geological Mapping Program, NY

GLACIAL MAPPING OF WESTERN WAUSHARA COUNTY, WISCONSIN, J Elmo Rawling III, Wisconsin Geological and Natural History Survey

IMPROVING THE AVAILABILITY AND QUALITY OF SURFICIAL GEOLOGIC MAPS IN VIRGINIA, Heller, Matthew J., Virginia Department of Mines, Minerals, and Energy

INTERPRETING STRATIGRAPHY AND SEDIMENT TEXTURE FROM LITHOLOGICAL DATABASES: EXAMPLES FROM CALIFORNIA GROUNDWATER BASINS, D.S. Sweetkind, U.S. Geological Survey, Denver

MAPPING MINNESOTA’S BEDROCK GEOLOGY, Mark A. Jirsa, MN Geological Survey
MINNESOTA GEOLOGICAL SURVEY GEOLOGICAL MAPPING, Harvey Thorleifson, Minnesota Geological Survey

NEW INSIGHTS INTO LATE-PLEISTOCENE GLACIATION AND RANGE-FRONT FAULT VERTICAL SEPARATION RATES USING GEOLOGIC MAPPING AND TERRESTRIAL COSMOGENIC NUCLIDE EXPOSURE AGES IN THE EAST HUMBOLDT RANGE, NEVADA, Seth Dee, Nevada Bureau of Mines and Geology, and Benjamin J.C. Laabs, Department of Geosciences, North Dakota State University

NEW SURFICIAL GEOLOGICAL INTERPRETATIONS FOR THE EASTERN PORTION OF CASS COUNTY, MICHIGAN, John Yellich, Alan Kehew, John Esch, and Sita Karki

QUATERNARY GEOLOGICAL MAPPING IN MINNESOTA, Barbara Lusardi, Minnesota Geological Survey

QUATERNARY MAPPING ALONG THE LATE WISCONSIN MARGIN, CENTRAL INDIANA, Henry Loope, Jose Luis Antinao, and Robin Rupp, Indiana Geological and Water Survey

RADIOCARBON IN ILLINOIS, Curry, Brandon, Illinois State Geological Survey

Reconciling regional stratigraphy from Kentucky through multiple applied interstate projects, Drew Andrews, Kentucky Geological Survey

SUPPORTING THE USGS AND DOI MISSIONS THROUGH GEOLOGIC MAPPING IN THE WESTERN UNITED STATES, Colin F. Williams, US Geological Survey, Menlo Park, CA


THE NEW MEXICO GEOLOGIC AND AQUIFER MAPPING PROGRAMS: INTEGRATED 4D RESEARCH TO BETTER UNDERSTAND THE STATE’S GROUNDWATER AQUIFER RESILIENCIES, J. Michael Timmons, New Mexico Bureau of Geology and Mineral Resources

THE OHIO GEOLOGICAL SURVEY’S GREAT LAKES GEOLOGIC MAPPING COALITION PROJECTS IN 2018, J. D. Stucker, Ohio Department of Natural Resources Division of Geological Survey

THE UTAH GEOLOGIC MAPPING PROGRAM, LESSON LEARNED, FUTURE PLANS, Grant Willis, Mapping Program Manager, Utah Geological Survey

VISIONS OF NEW, SMALL-SCALE GLACIAL SURFICIAL GEOLOGIC MAPS FROM LESSONS LEARNED AT 1:24,000, Byron D. Stone, U.S. Geological Survey, East Hartford, CT

Posters

1:24,000-SCALE GEOLOGIC MAPPING OF BASIN DEPOSITS EXPOSED IN HADRIACUS CAVI, MARS, J. A. Skinner, Jr., Astrogeology Science Center, USGS, Flagstaff, AZ

A NEW SURFICIAL GEOLOGICAL MAP FOR CALHOUN COUNTY, MICHIGAN, Kehew, Alan E., Western Michigan University; Esch, John, M., Michigan Department of Environmental Quality; Linker, John S., Kelloggsville, Michigan High School; Kozlowski, Andrew L., New York Geological Survey; Karki, Sita, Western Michigan University, and Yellich, John A., Michigan Geological Survey

ADVANCES IN 3-D GEOLOGIC MAPPING OF NORTHERN INDIANA USING 3-D GEOLOGICAL INTERPRETATION SOFTWARE, José Luis Antinao, Robin Rupp, Indiana Geological and Water Survey

AN ALTERNATIVE APPROACH TO SUPPLEMENTING GEOLOGICAL MAPPING OF THE ALABAMA PIEDMONT: CONVERTING EDMAP PRODUCTS TO GEOLOGICAL SURVEY OF ALABAMA QUADRANGLE SERIES GEOLOGIC MAPS, Dane S. VanDervoort1, Gregory M. Guthrie1, and Mark G. Steltenpohl2, 1Geologic Investigations Program, Geological Survey of Alabama, 420 Hackberry Lane, Tuscaloosa, Alabama 35486; 2Department of Geosciences, Auburn University, 2050 Memorial Coliseum, Auburn, Alabama 36849


AN OVERVIEW OF GEOLOGIC MAPPING IN MISSOURI, Vicki Voigt, Trevor Ellis, and Kyle Ganz, Missouri Geological Survey

DEVELOPING THE BEDROCK LAYER FOR CANADA 3-D: THE PRECAMBRIAN-PHANEROZOIC BOUNDARY, de Kemp, E.A.1, Schetselaar, E.M.1, Hillier, M.1, Montsion, R.2, 1Geological Survey of Canada, 2PhD. Student, MERC, Laurentian University, Sudbury, Canada

FIELD TRIP BASED ON EXTENSIVE MAPPING EFFORTS IN WILL AND COOK COUNTY, ILLINOIS, Caron, O., Curry, B., and Thomason, J., Illinois State Geological Survey

GEOLOGIC MAPPING ACTIVITIES AT THE CALIFORNIA GEOLOGICAL SURVEY, Delattre, Marc P., California Geological Survey

GEOLOGIC MAPPING AT THE WYOMING STATE GEOLOGICAL SURVEY, Seth J. Wittke, Wyoming State Geological Survey

GEOLOGIC MAPPING IN MIAMI COUNTY, KANSAS, Anthony Layzell1, K. David Newell1, Stephen Oborny2, Greg Ludvigson1, John Dunham1, 1Kansas Geological Survey, 2Department of Earth and Environmental Sciences, University of Iowa

GEOLOGY OF THE DURHAM QUADRANGLE, MADISON AND WASHINGTON COUNTIES, ARKANSAS, Hutto, R.S. and Hatzell, G.H., Arkansas Geological Survey

GEOTHERMAL RESEARCH AT UIUC; SUPPORTING FUTURE ENERGY NEEDS, Stumpf, Andy, Illinois State Geological Survey

LIDAR AND STRUCTURE FROM MOTION-ENHANCED GEOLOGIC MAPPING, EXAMPLES FROM OREGON, Carlie J.M. Duda, Jason D. McCloughry, Robert A. Houston, Clark A. Niewendorp, Oregon Department of Geology and Mineral Industries

NEW BEDROCK GEOLOGIC MAPPING, DODGE COUNTY, WI, Esther Kingsbury Stewart, Kathy Roushar, and Eric Stewart. Wisconsin Geological and Natural History Survey


STRABOSPOT: A NEW GEOLOGIC DATA COLLECTION SYSTEM, Bunse, Emily1; Tikoff, Basil2; Walker, J. Douglas1; Newman, Julie3, 1Department of Geology, University of Kansas, 2 Department of Geoscience, University of Wisconsin- Madison, 3Department of Geology and Geophysics, Texas A&M University


THE SURFICIAL GEOLOGY OF FIVE 7.5-MINUTE QUADRANGLES IN THE PERRY COUNTY AREA, OHIO, Nash, Thomas A., Jr. Ohio Department of Natural Resources, Division of Geological Survey
Closing plenary

To start the closing plenary, Harvey Thorleifson provided a brief review of the plenary talks. Ensuing general discussion included the following topics:

- need to sell what we do
- measure importance and prioritize
- need for more Edmap projects
- ask users what they need
- need for updated cost/benefit economic assessments
- need a white paper for future of geological mapping
- role of geological mapping in reducing risk for society, and efficiency
- need to clarify the question before prescribing the solution
- funding goes to the why, not the what
- infrastructure
- how to make new maps match old maps, without being constrained by the old maps
- seamless
- we are now in a database era; the database is the ultimate solution; new maps are static documentation for an increment to the seamless database; new maps can stimulate revision of adjacent old mapping in the database; published maps can’t change, but the increasingly seamless database can be constantly evolving
- structure database can underpin progress
- maybe don’t publish a map until the adjacent one is done
- need version numbering
- creation of seamless is a natural step in regional compilation; in coming decades, we will keep going back for more detail, having compiled the previously completed level of resolution
- need the white paper to communicate outside geology
- lidar is infrastructure for the geological mapping
- geological mapping is infrastructure for engineering
- Statemap remains foundational to our activity
- White paper needs to address who the mapping is for
- Future funding likely will come from unanticipated sources
- Successor to EarthScope
- Potential NSF role
- Critical minerals prioritization will influence activity
- Everything needs to be 3D
- Need to work more with counties and county associations
- New faculty and students can cooperate on mapping-related research spinoffs
- Need enhanced data workflow from field to survey to user
• Need for content in phone apps
• Homeland Security and emergency planners need mapping, to help prevent disasters; linear infrastructure, need actuarial data
• Need community-based sourcing of depth to bedrock
• Support future earth science research and training
• Database versioning needs to reconcile conflicting paper maps
• Need to keep metadata in the database compilation, for source
• Need new cartographic standards for web portrayal
• Need for recurring Geologic Mapping Forum meetings
• Need to be cautious on overuse of depositional models
• Separate data from interpretation
• Lidar causes a leap in our knowledge
• Can’t resist mapping in much greater detail as soon as you get lidar
• Need to remember key role of drillhole data and subsurface, though
• USGS mrdata plays a key role
• Need persistent institutional databases
• Need compelling graphics to sell the activity
• This is inspiring but daunting; maybe go home and focus on drillhole data
• Curious there was not more discussion on oil and gas-related work
• 3D geology is foundational to everything
• You will never have enough data
• This is all about teamwork
• Collaboration with neighbors
• Raise public awareness of value of 3D; groundwater applications critical
• Geologic mapping is foundational to groundwater modeling
• 3D workshops are held regularly – next one is Vancouver in June
• Regarding 3D, everyone can get a start
• Upcoming synopsis volume update will sum up where nations, states, and provinces stand on 3D
• We need a geologic mapping listserv like the one that serves the DMT community
• We are building an infrastructure that all of our spatial information can hang in

Post-meeting feedback

Post-meeting feedback submitted through an online survey was positive. Regarding aspects of the meeting that were most pleasing, participants noted networking among a broad attendance, well planned sessions covering national to local topics, positive mood, superb presentations, good discussion, and good venue. Later feedback submitted after March 30 also noted great talks by knowledgeable people with big-picture goals; shared sense of urgency for getting up-to-date geologic maps at a scale useful for decision makers and the public; interaction with broad attendance, on a
broad range of topics; networking; learning that we are all in the same boat; well-organized, good program.

Regarding aspects of the meeting that could have been improved, attendees noted the frustration of dueling concurrent sessions, the need for facilitation in the breakouts, perhaps a day too long, low turnout from bedrock mappers, need for more focus on broad findings, increased focus on issues, detailed mapping and methods as opposed to national themes, need for dedicated poster viewing time, need for more attention to education and outreach, need for more learning from industry practice, the need for more diversity, more students, users, and industry attendance, greater attendance overall, and the need for short courses and a field trip. Later feedback submitted after March 30 also noted that dedicated time was needed for posters; need for PM coffee; day one breakouts not valuable and inadequately guided, though interesting points were stated; emphasis was on digital geology rather than geologic mapping; need for female and young speakers; need for more focused breakouts; focus on 3D/subsurface not relevant to all, although nice to see this happening; need for session on Statemap administration, and more on traditional mapping.

Regarding future Geologic Mapping Forum meetings, participants endorsed a recurrence of the meeting. Four suggested every other year, 2 suggested every 1 or 2 years, 2 suggested alternation of GMF and DMT, with attendance funded by Statemap, 2 suggested a merger with DMT, 1 suggested irregular, 1 suggested alternation of national and regional, and 1 said every year. Later feedback submitted after March 30 also suggested sessions on hazard mapping; more about the west; more program time on importance of geologic mapping and further evolution to be more than just the paper map; decide whether the meeting is going to be about digital compilations or geologic mapping; every 2 years seems about right; keep all topics on the table each time and let one or two emerge as worthy of more talks and discussion each forum; not sure whether moving the meeting around to allow field trips or a consistent venue is most appropriate and likely to attract a broader, diverse and younger group of attendees; program overviews were good – need to add some workshop component that would identify technical areas where states need help, such as database, field data capture, remote sensing applications, web applications, story maps etc., to allow for some organic networking to share insights and workflows so surveys can emulate or model their programs accordingly; to extent possible, topics and talks should build on and expand from the most well organized parts of presentations from this meeting; need for more stratigraphers and bedrock mappers next time.

Draft meeting summary

A draft meeting summary was distributed to meeting participants on April 6th, with a request for edits. Reports on talks by Andrew and Oliver were revised. In addition, the post-meeting feedback was supplemented. In addition, meeting participants were asked to write a few bullet-format conclusions, synthesis points, recommendations, and observations, based on their reflection and reading. One person responded, to provide the following: - shouldn't be afraid to edge-match maps.
Many times the older maps were made with less information and their maps were what is known at
that time. New maps presumably are based on information of new outcrops and boreholes. The new
mapping might require updating of geological frameworks. The maps should be considered living
documents and are changed as required.

- should encourage interactions/collaboration between surficial and bedrock mappers; especially
  when making bedrock topography maps.

- urban geology new frontier for NCGMP. We might encourage direct conversations with cities, since
cities they may have a different opinion on geologic mapping than county, state, and federal
agencies. Might ask John to make presentations at conferences where majors or city representatives
meet (e.g., US Conference of Mayors and National League of Cities - NLC are looking for workshop
proposals for their 2018 meeting in November - deadline April 27,). Also, might talk with cities with
detailed sustainability programs http://www.c40.org/ and http://icleiusa.org/. They would might be
interested in integrating geologic mapping into their planning programs... or at least develop channel
to share surface and subsurface information.

Meeting participants:

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