DIGITAL MAPPING TECHNIQUES 2021

The following was presented at DMT’21
(June 7 - 10, 2021 - A Virtual Event)

The contents of this document are provisional

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Mapping the geology of the world in the 2020s

Harvey Thorleifson
Director, Minnesota Geological Survey
Chair, AASG Information Committee
Chair, Commission for the Management and Application of Geoscience Information

This draft discussion was prepared by a CGMW-CGI-1G working group, to stimulate and support broad discussion and consensus development under the global governance of CGMW, CGI, and 1G
This draft discussion was prepared by a working group, to stimulate and support broad discussion and consensus development under the global governance of the Commission for the Geological Map of the World (CGMW), CGI, and OneGeology. People strive for safety, health, wealth, and respect for their human and natural heritage. Geological knowledge is needed by society to fulfil all of these aspirations. We provide this geology through research, mapping, monitoring, modeling, and management. These efforts are meant to clarify energy, minerals, water, hazards, civil engineering, and research. There is an urgency for us to better enable management of these topics. Examples of pressing applications that now need queryable and model-ready geology include sedimentary basin analyses, mineral resource assessment, inclusion of groundwater in regional water resource management, hazards modeling such as for earthquake propagation and magnetic storm vulnerability, infrastructure design, and all research on our planet and its life. This presentation therefore will focus on the current state and anticipated future of geological mapping that is needed by society.
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Geological knowledge is needed by society to fulfil all of these aspirations.

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These efforts are meant to clarify energy, minerals, water, hazards, civil engineering, and research.

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Introduction
Examples of pressing applications that now need queryable and model-ready geology include sedimentary basin analyses, mineral resource assessment, inclusion of groundwater in regional water resource management, hazards modeling such as for earthquake propagation and magnetic storm vulnerability, infrastructure design, and all research on our planet and its life. This presentation therefore will focus on the current state and anticipated future of geological mapping that is needed by society.
All mapping is guided by a specification, and ongoing assessment of progress.

Mapping encompasses the atmosphere, land surface, water depths, soil, and geology.

Geological mapping thus is an asset in our geospatial knowledge infrastructure.
• Due to sparse data and the need for interpretation, geologic maps are authored by active researchers who can visualize the geology
• Our research informs our mapping, and our mapping informs our research
• While academics balance research, teaching, and service, survey geologists balance research, mapping, and service
In geological mapping, we have focused on 2D maps that are not necessarily positioned vertically nor fully categorized, although each is seamless and includes some 3D.
In resources, hazards, and engineering, geological maps need to be translated and augmented as derived maps.
• For the US, a simple definition of detailed mapping is any new map more detailed than your state geologic map.
Detailed geological maps are based largely on fieldwork, or by assembling data such as a bedrock map in an area of complete sediment cover.
• Compilations are based on assembly and reconciliation of multiple published maps
Coordination with neighbors is an essential activity that leads to efficiency and consistency needed by users.
Paper-format 2D geological maps have distinct advantages, and in the future will be more important than ever.
• Geological mapping returns a very positive cost/benefit
Observations enable the inferences we convey as mapping, for the purpose of supporting applications.

These data enable our mapping, and our mapping is a window to the data.

Our data need to be findable, accessible, interoperable, and reusable.
Each database of observations, collections, or measurements requires ongoing assessment, under data stewardship programs.

Finding the Gaps in America’s Magnetic Maps

A 2017 executive order mandated a plan to evaluate U.S. access to critical mineral resources, but the airborne magnetic survey maps that support this effort are sadly out of date.
• In the digital era, compilations no longer have to be generalized to fit on paper
Queryable seamless databases that can be updated therefore have emerged, in all mapping fields.

It seems likely that paper-format geologic maps in the future will mainly be used as PDFs by eye, and GIS users will mainly use seamless.

We have to ask whether it will be possible, or even desirable, to save the GIS files for every paper map, forever.
Soil mapping and geological mapping are the same thing; soil mappers think in cm, whereas geologic mappers think in m and km.

Soil mapping has shifted from static, printed soil surveys to a dynamic, seamless database, including a gridded version.

Users are dictating that soil mapping will be the authoritative reference for geologic properties for the 1st m on land.
Concurrently, there is accelerating coordination between geology and underground mapping of pipes, wires, and tunnels.
Seamless is a standardized compilation, without generalization, and with ongoing harmonization and facilitation of query.

Seamless shows gaps, for reasonably consistent resolution, to show where mapping is needed, and to attract funding.

Lower resolution mapping can be used to infill gaps to make a best-available map for some users.
• In 3D, vertical position and properties of surfaces, strata, and structures are specified to the extent allowed by data and confident inference.

• In 3D, a layer is a seamless 2D map polygon whose thickness can be mapped.

• For layers, we map extent, vertical position, thickness, properties, heterogeneity, and uncertainty.

• An indication of dominant lithology provides a basis for inference of properties such as hydraulic conductivity.
Below the layers is basement; in layers, we map strata, and in basement, we map structures, then discretized properties
To support a 3D program, jurisdiction-wide, onshore/offshore, and cross-border cross-sections are needed at the outset.

Cross-sections
This will help resolve stratigraphic issues, and clarify surfaces to be mapped; for North America, we need a new COSUNA.
• 3D also requires much long-term effort on data compilation and new geophysical surveys, with emphasis on jurisdiction-wide public-domain drillhole data.
• 3D mapping can be expressed as a grid of synthetic drill holes, that may be linked to a gridded version of the 2D map
• It is clear that everything is becoming digital and quantitative, and that mapping is essential for modeling and management
Modeling may be done on a one-time project basis, or as an indefinitely maintained digital twin.
The 1st and most important step in modeling is the conceptual model, a qualitative depiction that guides quantification.
• All information is most usable if standardized, and users demand standardization
The 2nd step in modeling is mesh, for all space of interest, varying in resolution if necessary, with uncertainty specified.
Geological mapping thus now involves:
1) maps,
2) standards,
3) seamless and 3D
Geological maps function in the conceptual model paradigm – primarily designed to be used by eye, not necessarily positioned vertically, and often not fully categorized.
Seamless and 3D function in the mesh paradigm – quantifiable, complete for all horizontal and vertical space in the area of interest, structured resolution, with uncertainty indicated.

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<th>Geological complexity</th>
<th>Uncertainty</th>
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In seamless, legends are parsed to facilitate query, and in 3D, everything is vertically georeferenced.
• Geology is best done by geologists, rather than modelers, resulting in model-ready, machine-readable geology
Geologic maps primarily presented as research publications and as conceptual models are NGMDB Phase One – the catalog.

The standards needed to make our geologic maps readily usable and interoperable are NGMDB Phase Two.

Seamless and 3D are NGMDB Phase Three – the framework database.
Maps, standards, and seamless each have their own paradigm, culture, and language; although we need to unify 2D and 3D.

Paper maps and accompanying digital files are static, authored publications that undergo one-time peer-review.

Standards are developed by consensus in a professional community, commonly guided by standards organizations.

Seamless undergoes regular audits rather than peer review, and will be revised indefinitely as versioned databases.
Geological mapping as we know it began with the 1815 William Smith geology of England and Wales. Our 1st century involved national surveys and hand-colored wall maps; our 2nd century involved the printing press. We have evolved since 1990 from photomechanical paper maps, to digital paper maps, to catalogs, the web, standards, seamless, and 3D. Soil mapping has moved on to gridded, raster, and dynamic soil survey. It can now be seen that our 3rd century likely will focus on enabling model-ready geology, especially for digital twins.
• All mapping has resolution levels, each with appropriate generalization
• Resolution levels for geology are urban, detailed, national, continental, and global
To support query, completeness and consistency are needed for each level of resolution, which will be fulfilled for urban by data rather than mapping. We therefore need a geologic mapping specification that can be completed in foreseeable time. Each 3D geology level of resolution will have a data-availability-related floor below which the next level will prevail. The 2D map dictates the stratigraphic resolution of accompanying 3D, to allow consistent query. The 2D mapping will have higher horizontal resolution than the 3D it is paired with, due to the sparsity of subsurface data.
• 1) standards to support interoperability
• 2) ongoing assessment of progress
• 3) synthesis in part to test harmonization
• 4) iteration to incorporate ongoing updates

In federal systems, much of the geological mapping is done by subnational surveys that are focused on local needs
• Subnational surveys will indefinitely edit their jurisdiction-wide seamless, as often as daily
• Maintenance of seamless requires standards to support interoperability, ongoing assessment of progress, synthesis in part to test harmonization, and iteration to incorporate ongoing updates
• Federal surveys have essential roles in detailed mapping, required research, compilation, and information management

Federal and subnational roles
These federal roles are based on broader thinking, as well as specialized research and technology.

While the subnational role can focus more on completeness, the federal role can be more focused on consistency.

Federal roles in detailed mapping include cross-border, federal priorities, and mapping needed to optimize synthesis.

Federal roles also include housing national databases, standards, and research need to optimize the program.
Increasingly, researchers and resource managers need usable GIS data for applications ranging from urban to global. Data largely comes from local governments, mapping to a large degree from subnational surveys, and synthesis might preferentially be done by federal geological surveys. Concurrently, most multinational geological maps are published by the Commission for the Geological Map of the World (CGMW).
CGMW at present is focusing on a seamless continental-resolution bedrock for the world to support the global Deep-Time Digital Earth (DDE) project.

However, those maps are missing layers, such as a sediment layer for glaciated North America.

These activities thus need to be broadened, from a limited conceptual model approach to a full mesh paradigm.
• International geologic map standards are led by the Commission for the Management and Application of Geoscience Information (CGI)
Seamless 3D now needed for urban to global digital twins is a task for OneGeology, which presents itself as the provider of global geoscience data.
It can be foreseen that the CGMW global resolution map will be translated into a 3D geology, likely ignoring sediments.
The US Congress has directed us, and funded us, to build detailed, national, and continental-resolution seamless 3D.
• Urban applications largely will be addressed by stewards of primary data, mostly as public domain drillhole data
To support this next-generation geologic mapping, in coming years and decades, we need to coordinate with neighbors. We need to assign thickness and properties to our continental resolution rock layers.
• We also need to add sediment 2D and 3D, and basement

Continental resolution
For the US, we need to immediately accelerate work on making the State Geologic Map Compilation (SGMC) seamless, and then we need to make the layers 3D.

National resolution
At the detailed level of resolution, we need to immediately accelerate field geology, new mapping, and 2D seamless.
Status mapping is required, to develop consensus on goals, to monitor and manage our progress, to identify priorities, to stimulate funding, and to cause us all to strive. A status map differs from a publication index, which indicates the spatial footprint of published maps, including obsolete, superseded maps. Status mapping requires local knowledge, judgement about needs, a composite index, and thus an indication of progress toward evolving goals.
This nationally standardized, annually updated status procedure, implemented in stages, will require consideration of 2D mapping, depth to bedrock and basement or equivalent, subsurface data and mapping of sediment and rock layers, and basement mapping.
These developments in geological mapping will rely on a great acceleration in data compilation and geophysical surveys.
Concurrently, we need to accommodate appropriate roles for geostatistics and methods such as machine learning.

We need to work on all resolution levels concurrently, with emphasis by far on detail, in a planned, stepwise manner.
In conclusion, I suggest that to think about the future of geological mapping, we need to think about nested dynamic models.

I now request your advice.
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