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

See Presentations and Proceedings
from the DMT Meetings (1997-2021)

http://ngmdb.usgs.gov/info/dmt/

Mapping the geology of the world in the 2020s

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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.

- 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

Introduction

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

FGDC
FEDERAL GEOGRAPHIC DATA COMMITTEE

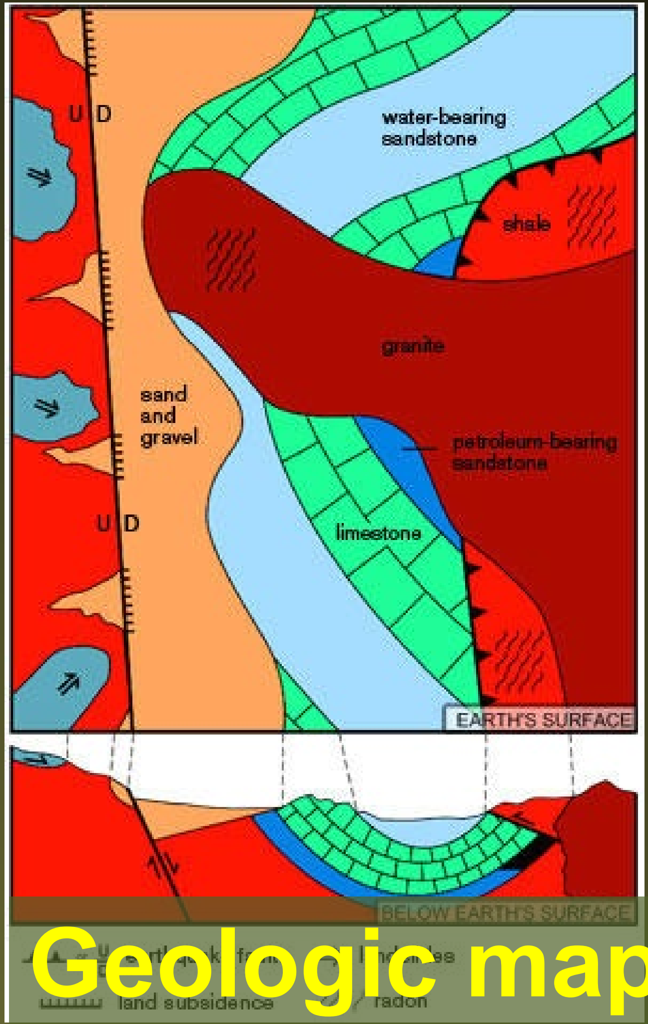
Mapping

Geology

- 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

http://www.geologypage.com

Geologic maps

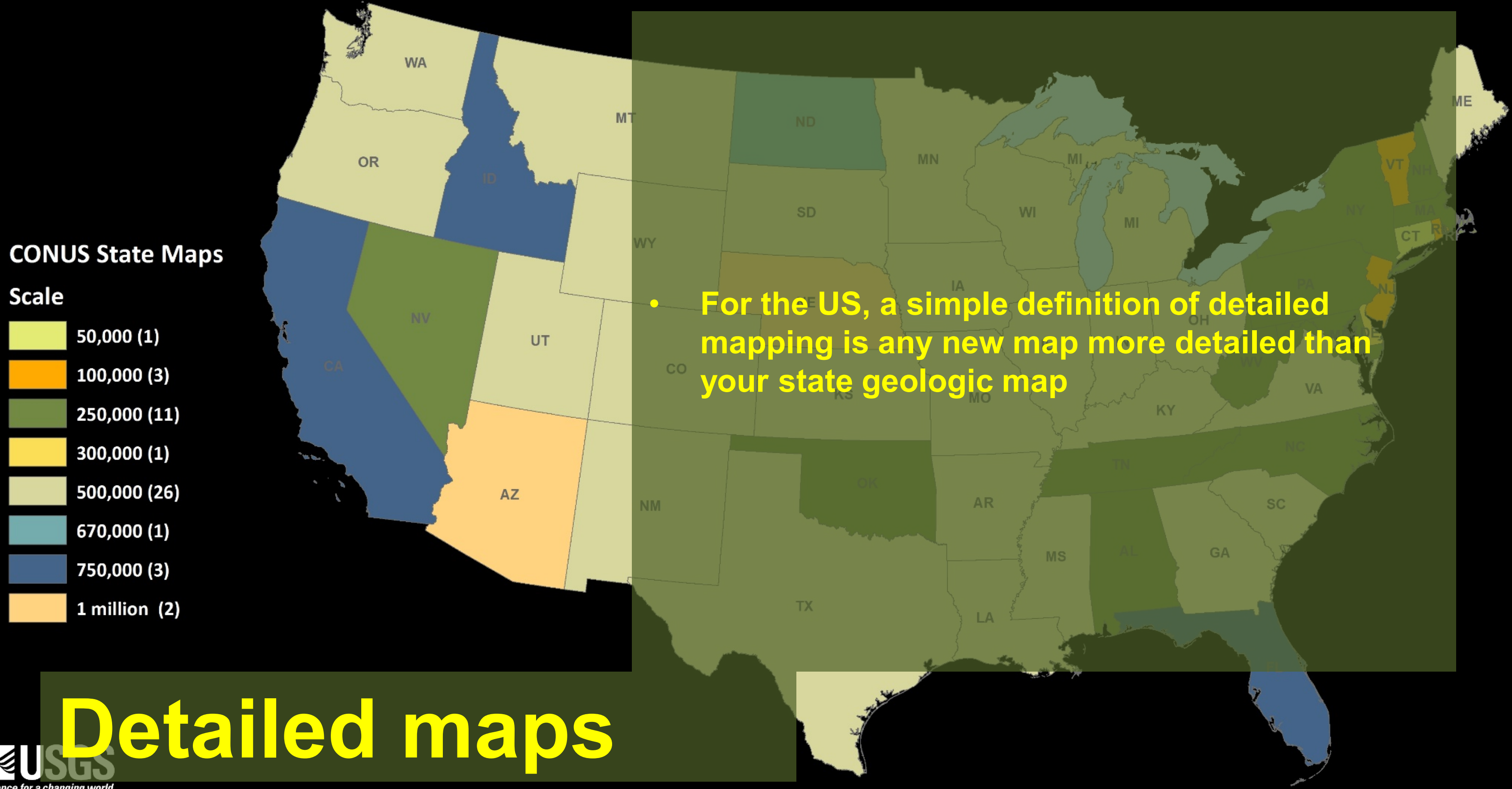


- In geological mapping, we have focused on 2D maps that are not necessarily positioned vertically nor fully categorized, although each is seamless and includes some 3D

Derived maps

- In resources, hazards, and engineering, geological maps need to be translated and augmented as derived maps

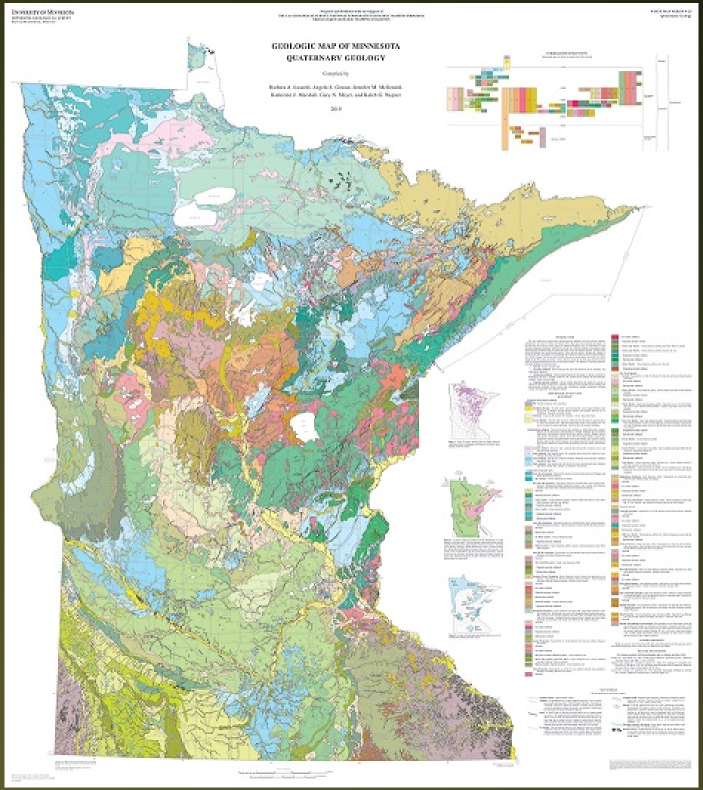
Detailed maps



- 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

Detailed maps



- Compilations are based on assembly and reconciliation of multiple published maps

Compilations

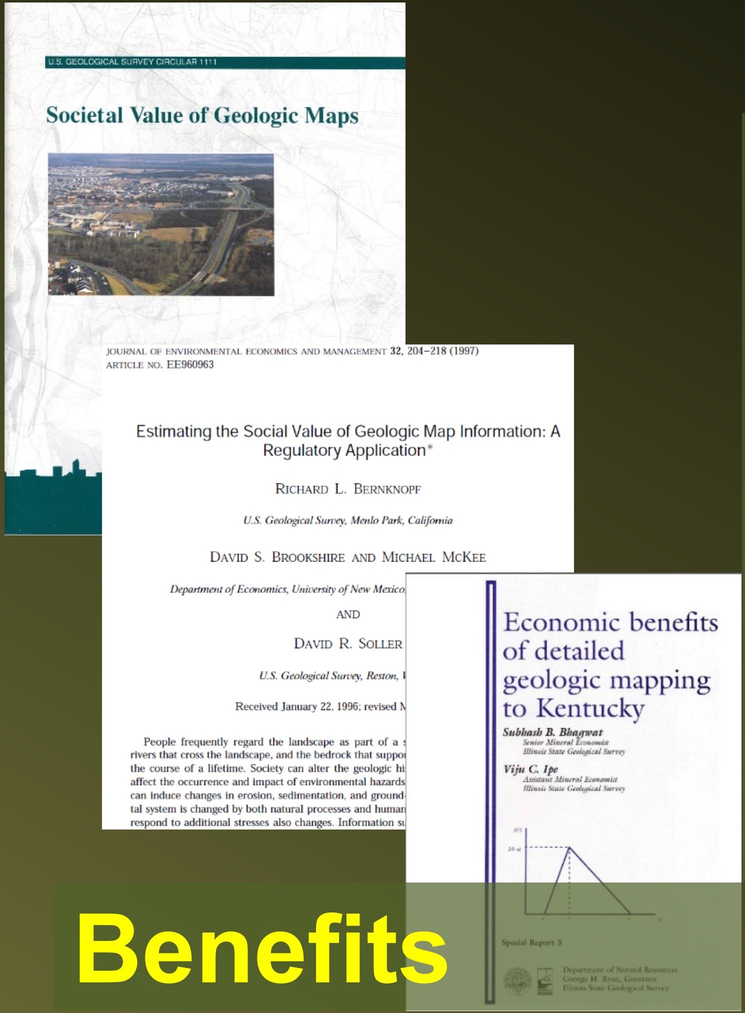
Cross-border coordination

- Coordination with neighbors is an essential activity that leads to efficiency and consistency needed by users

Paper maps

- Paper-format 2D geological maps have distinct advantages, and in the future will be more important than ever

Benefits



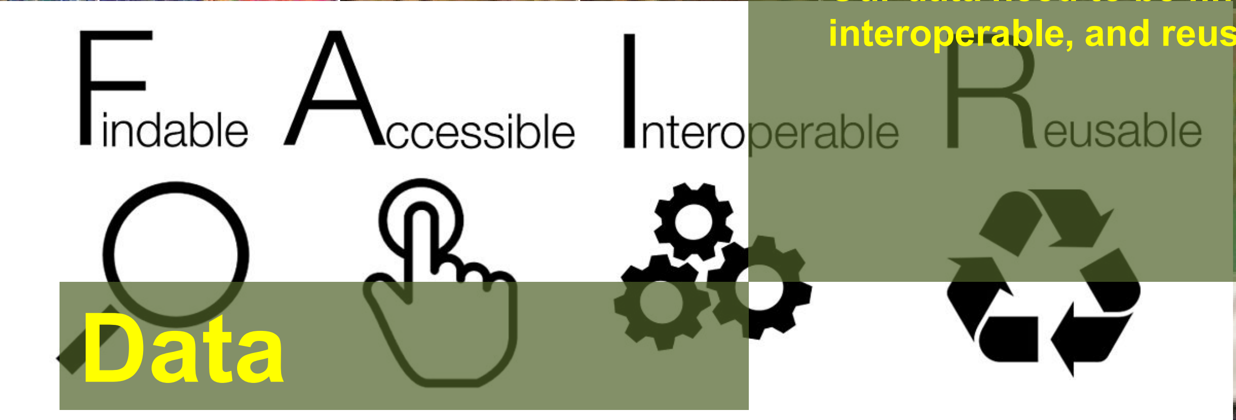
- Geological mapping returns a very positive cost/benefit

USGS
science for a changing world

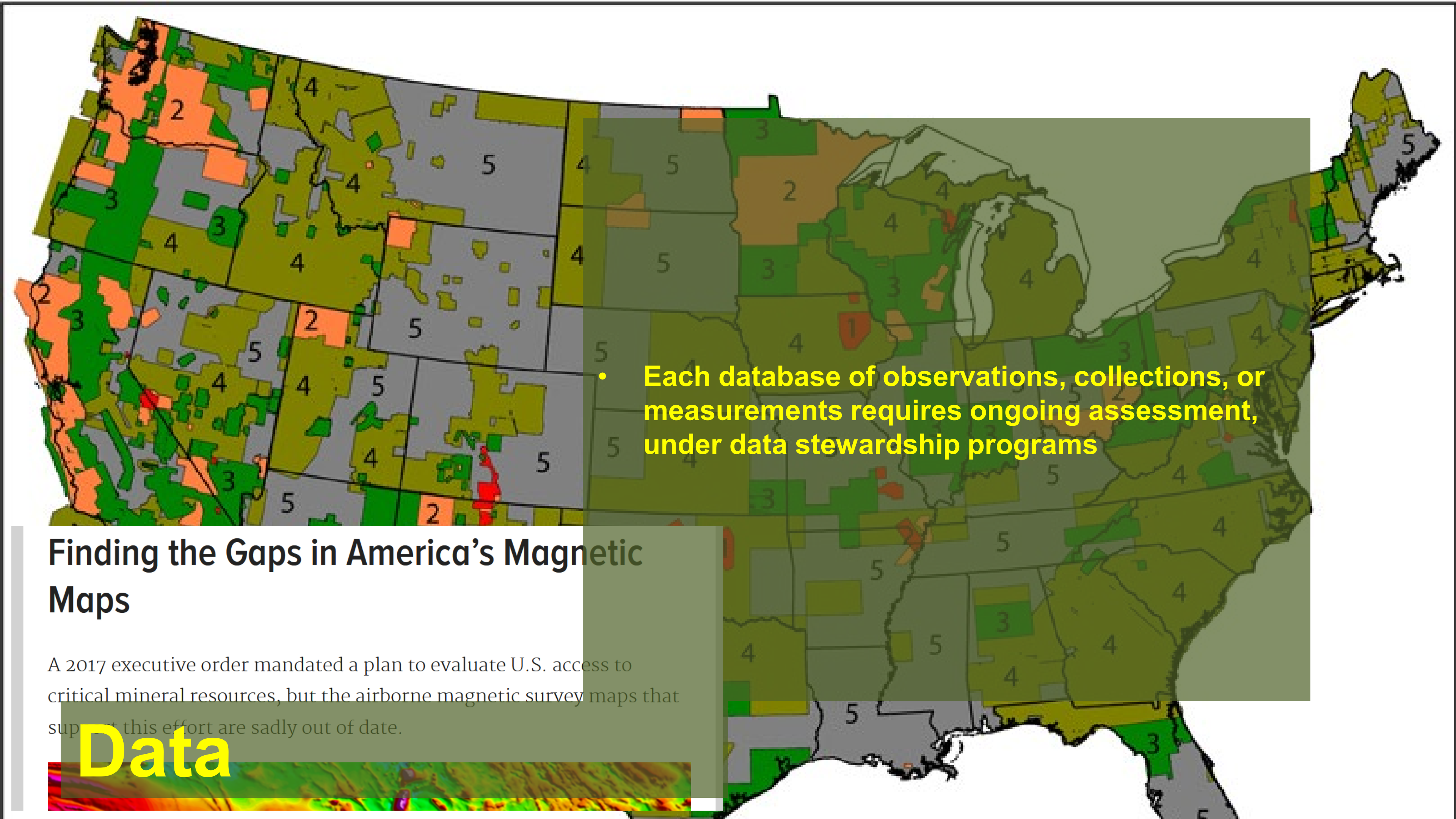
The U.S. Geological Survey Geologic Collections Management System (GCMS)

A Master Catalog and Collections Management Plan for
U.S. Geological Survey Geologic Samples and Sample Collections

- 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



Data



- Each database of observations, collections, or measurements requires ongoing assessment, under data stewardship programs

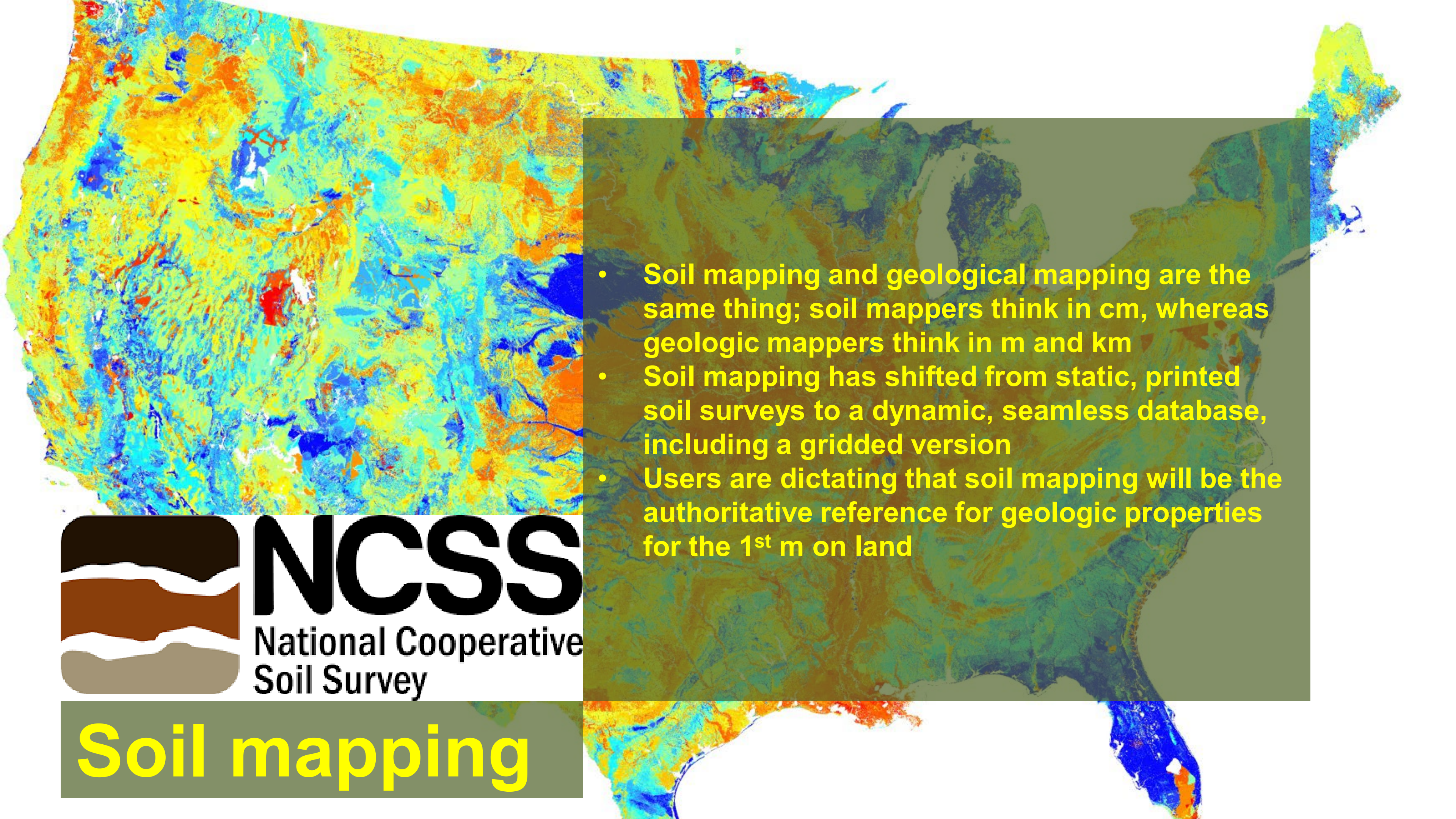
Finding the Gaps in America's Magnetic Maps

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.

Data

- 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



NCSS
National Cooperative Soil Survey

Soil mapping

- 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

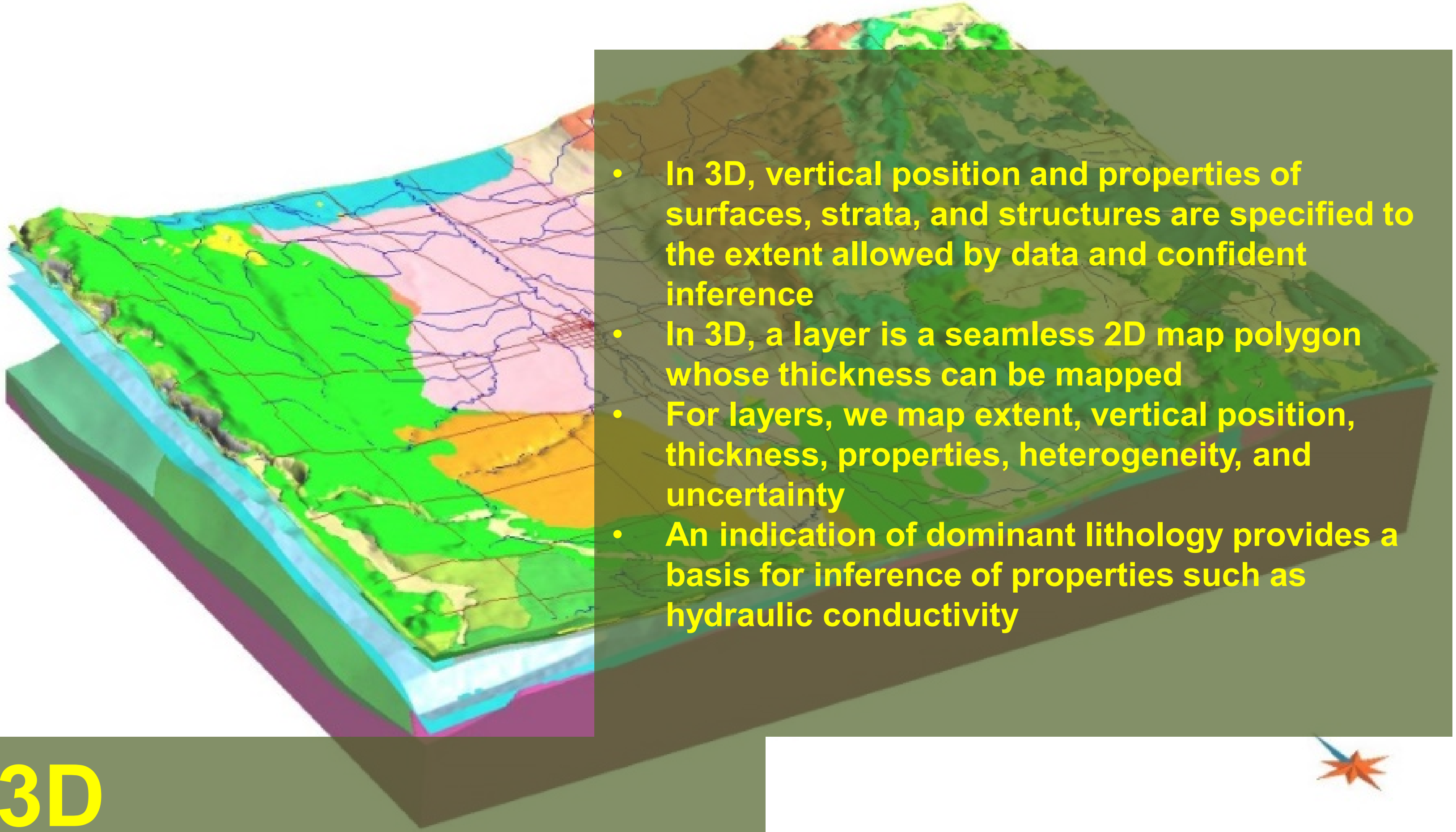
- **Concurrently, there is accelerating coordination between geology and underground mapping of pipes, wires, and tunnels**

Underground structures

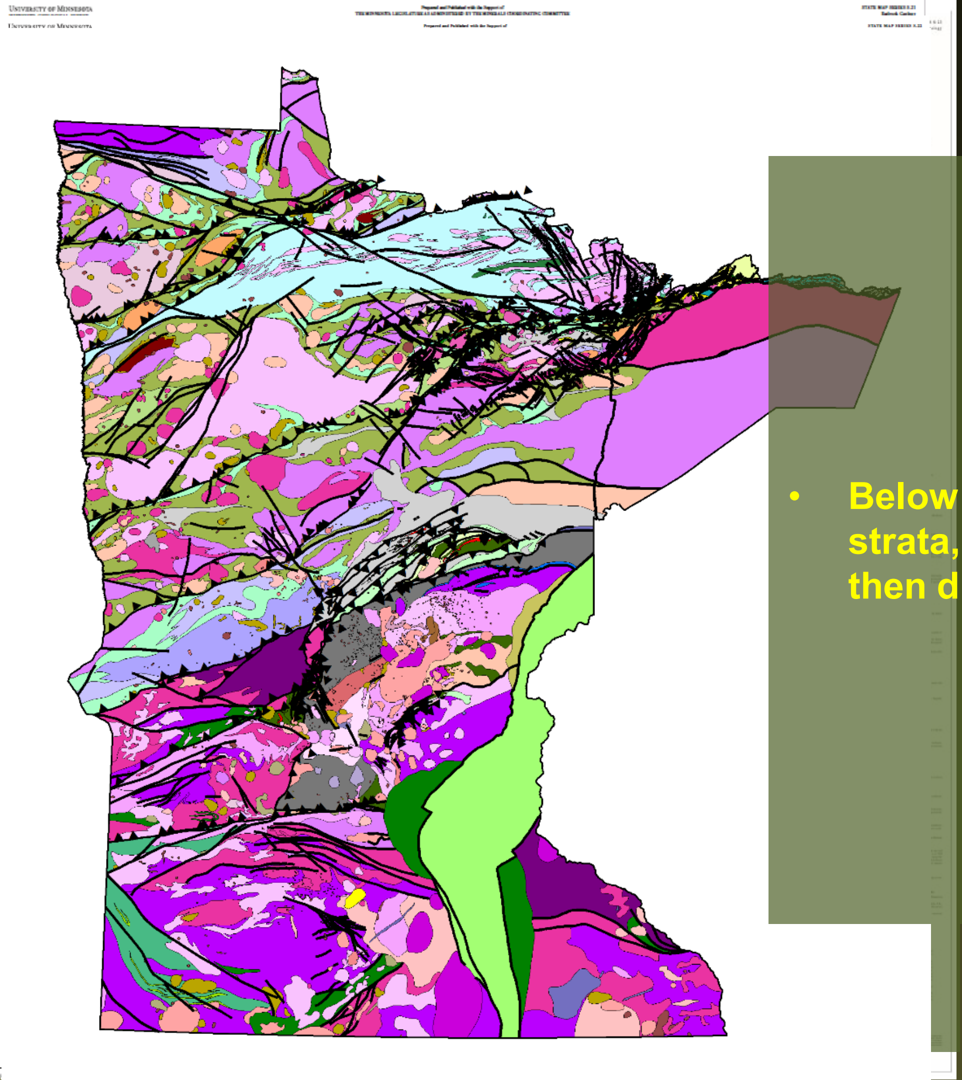
Seamless

- 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

3D



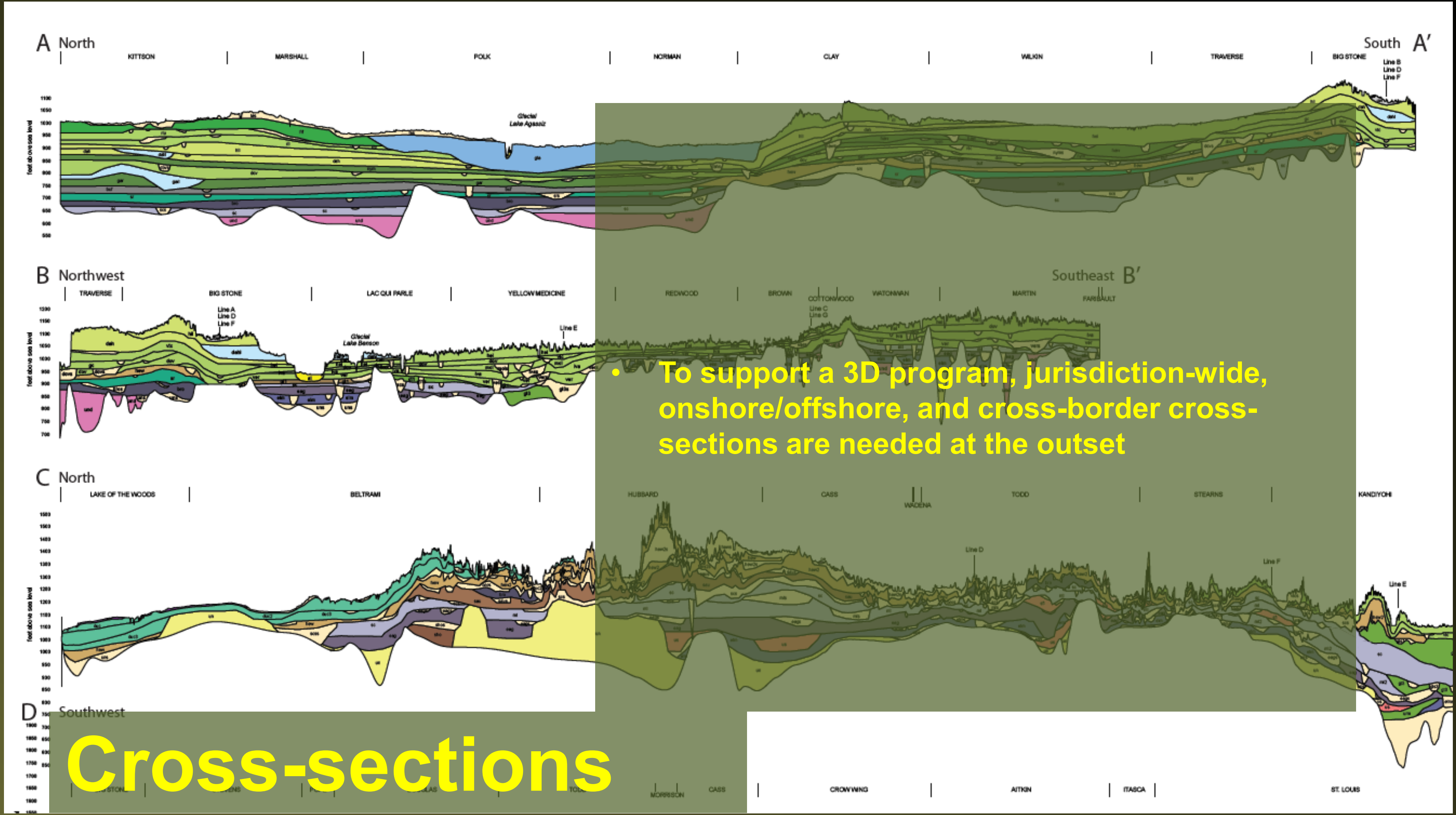
- In 3D, vertical position and properties of surfaces, strata, and structures are specified to the extent allowed by data and confident inference
- In 3D, a layer is a seamless 2D map polygon whose thickness can be mapped
- For layers, we map extent, vertical position, thickness, properties, heterogeneity, and uncertainty
- An indication of dominant lithology provides a basis for inference of properties such as hydraulic conductivity

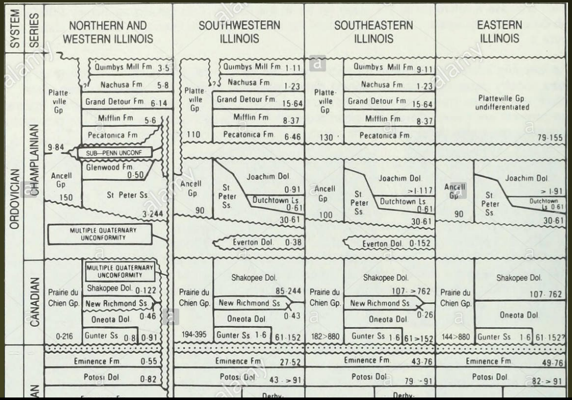


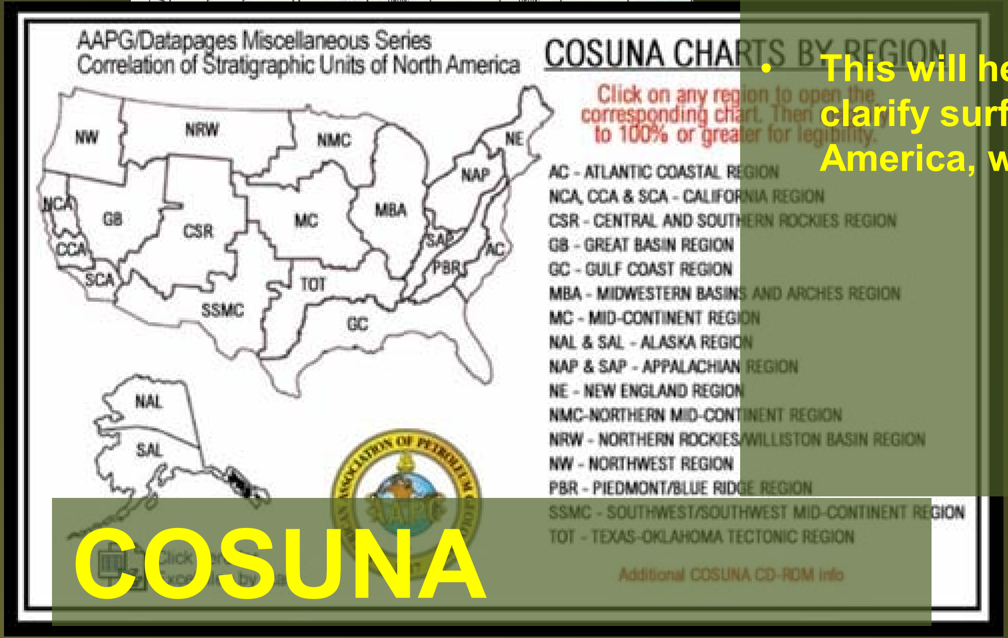
- Below the layers is basement; in layers, we map strata, and in basement, we map structures, then discretized properties

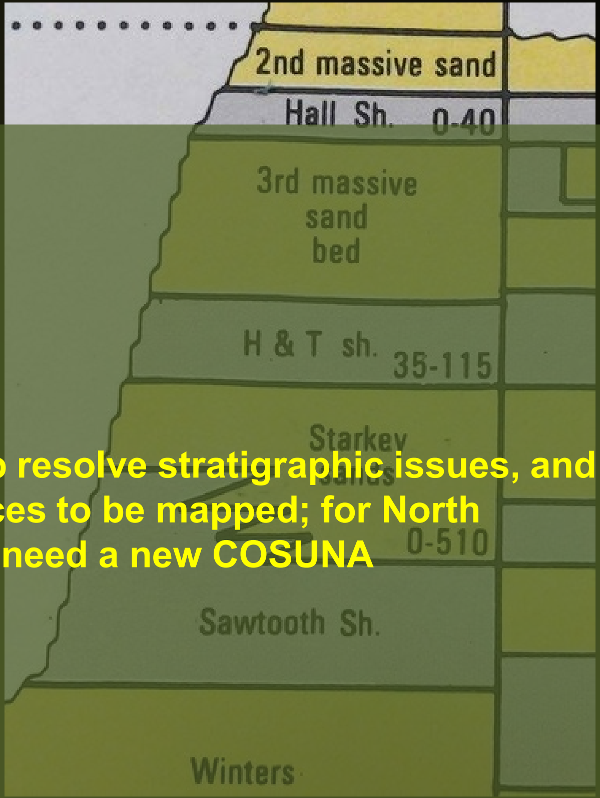
Cross-sections

- To support a 3D program, jurisdiction-wide, onshore/offshore, and cross-border cross-sections are needed at the outset



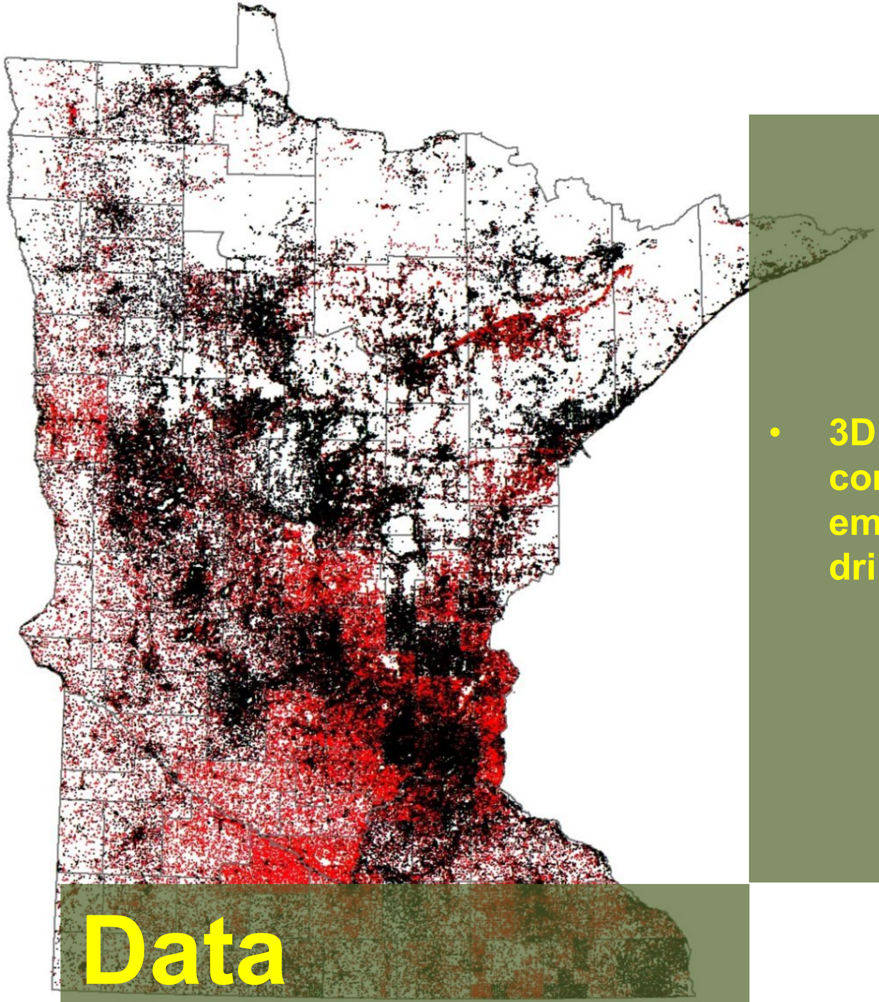






- This will help resolve stratigraphic issues, and clarify surfaces to be mapped; for North America, we need a new COSUNA

COSUNA



Data

- 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

Synthetic drill holes

- It is clear that everything is becoming digital and quantitative, and that mapping is essential for modeling and management


ARCUSER

ArcGIS: A Foundation for Digital Twins

SPECIAL

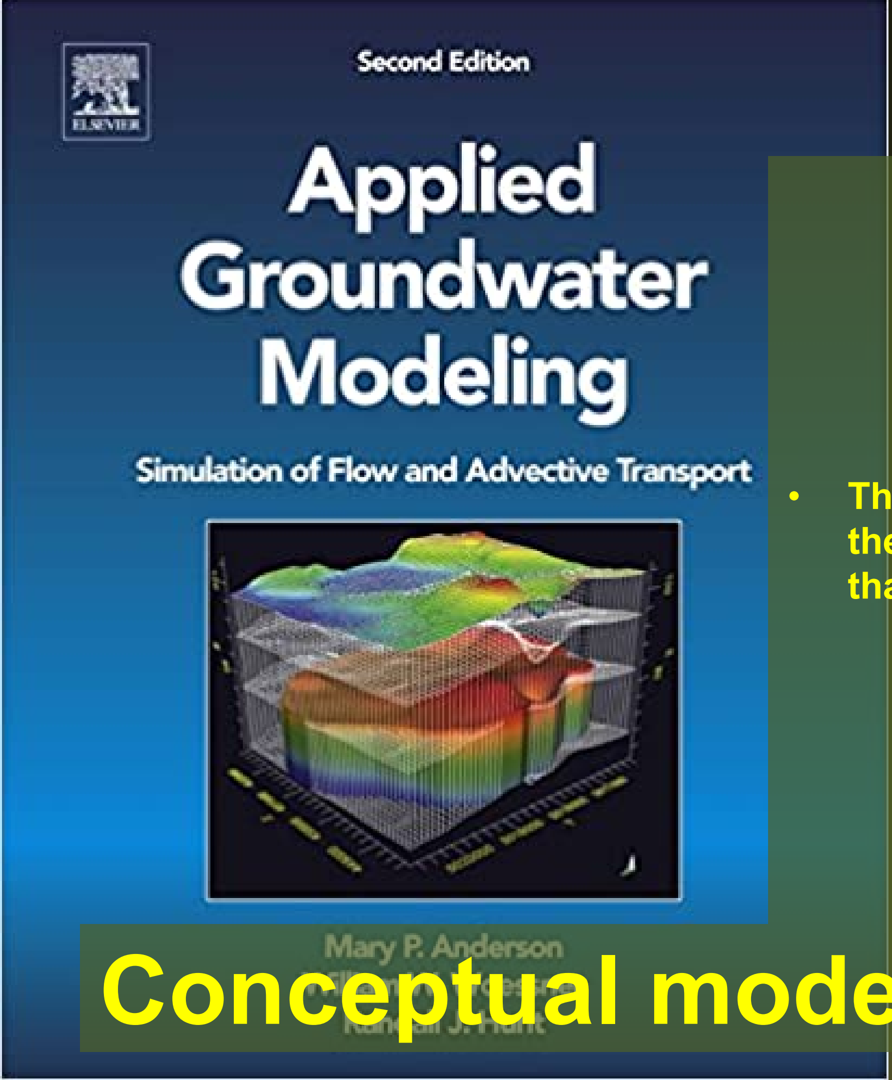
ArcUser Spring 2021

Chris Andrews

In the last several years, the convergence of geospatial technology, building information modeling (BIM), and interactive 3D has driven a conversation about digital twins and how they may be used to simulate single facilities, entire cities, and even large natural systems. Digital twins are virtual representations of the real world including physical objects, processes,

- Modeling may be done on a one-time project basis, or as an indefinitely maintained digital twin

Digital twins

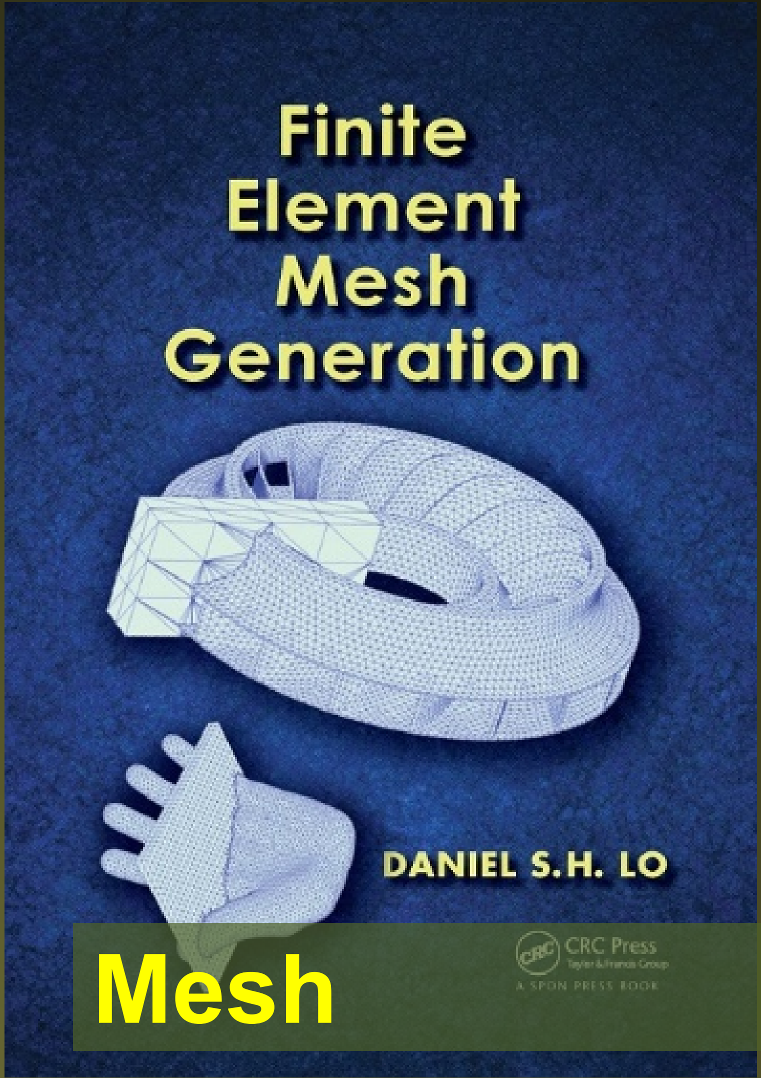


Conceptual model

- The 1st and most important step in modeling is the conceptual model, a qualitative depiction that guides quantification

Standards

- All information is most usable if standardized, and users demand standardization



Mesh

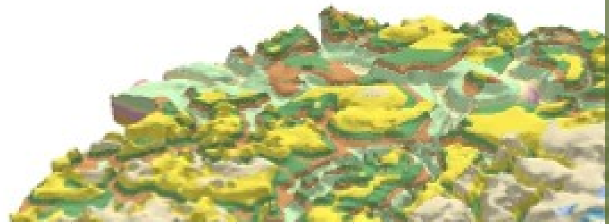
- The 2nd step in modeling is mesh, for all space of interest, varying in resolution if necessary, with uncertainty specified

- Geological mapping thus now involves:
  1) maps,
  2) standards,
  3) seamless and 3D

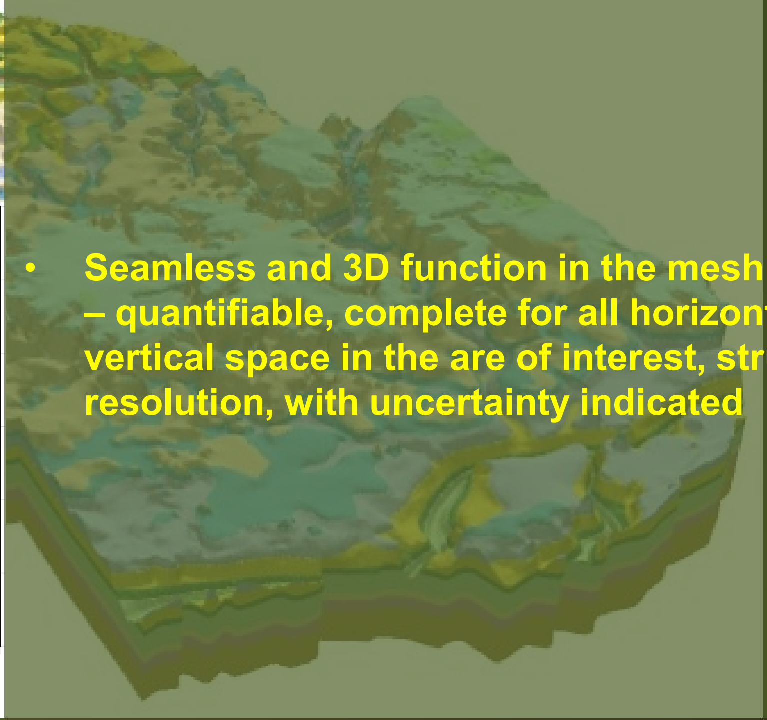
Maps, standards, seamless and 3D

- Geological maps function in the conceptual model paradigm – primarily designed to be used by eye, not necessarily positioned vertically, and often not fully categorized

Conceptual model



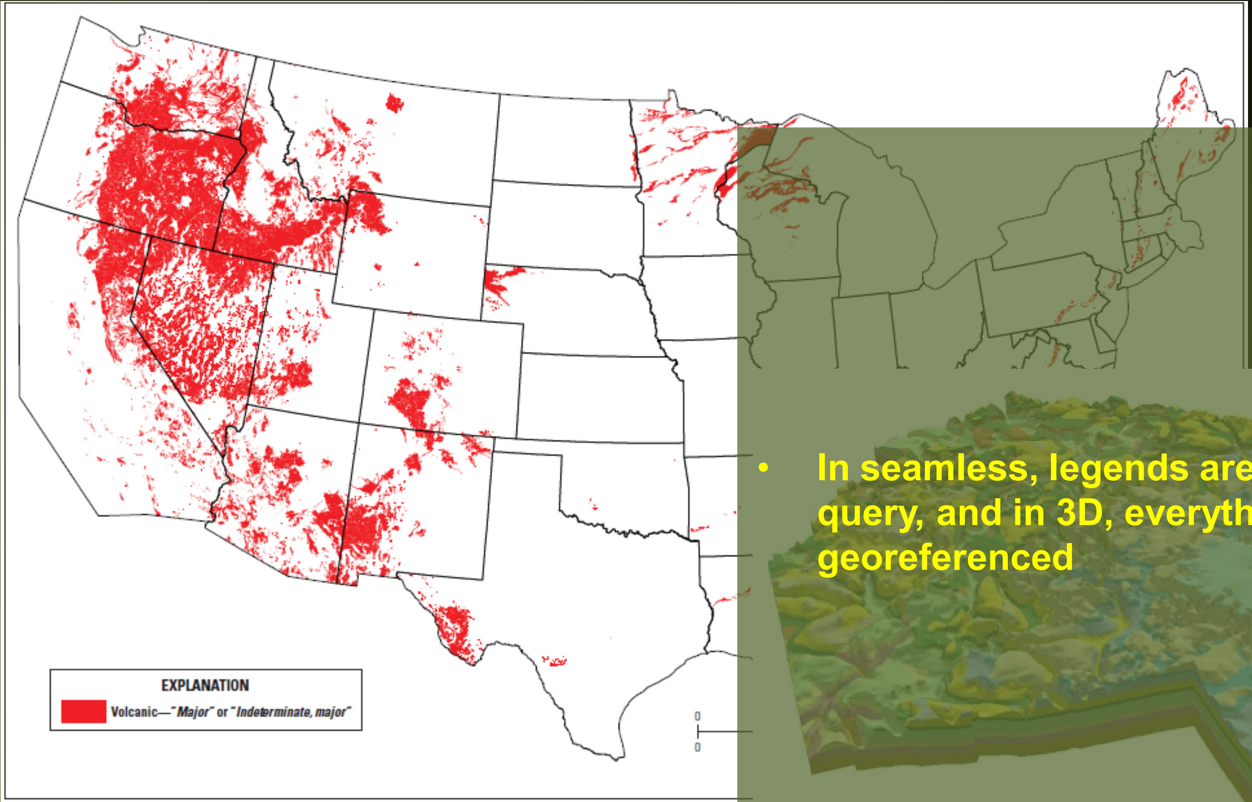
		Uncertainty		
Data	*High*	3	2	1
availability	*Medium*	4	3	2
	Low	5	4	3
		High	*Medium*	*Low*
		Geological complexity		



- **Seamless and 3D function in the mesh paradigm – quantifiable, complete for all horizontal and vertical space in the are of interest, structured resolution, with uncertainty indicated**

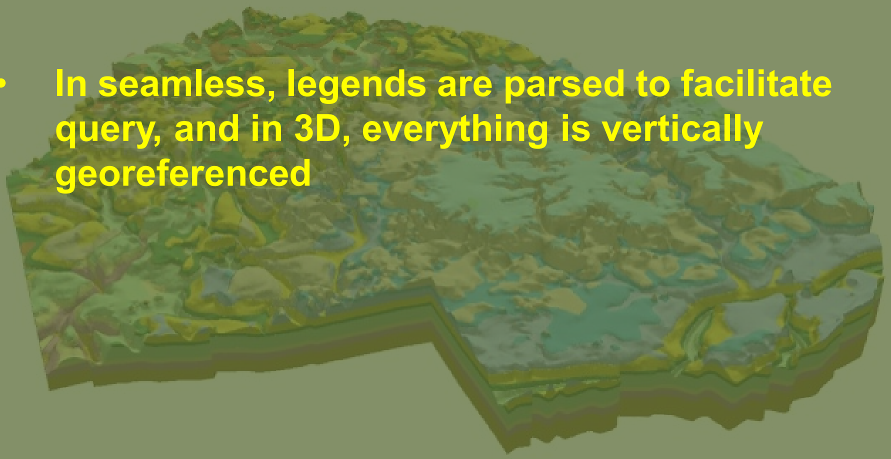
Mesh

Parsing, vertical georeferencing



State boundaries derived from U.S. Geological Survey Digital Line Graph boundary layer quadrangles, 1:100,000, 2007
Standard paralleLs 29°5′ N. and 45°5′ N.
USA Contiguous Albers Equal Area Conic Projection.
Central meridian, 96° W., latitude of origin, 23° N.
North American Datum of 1983.

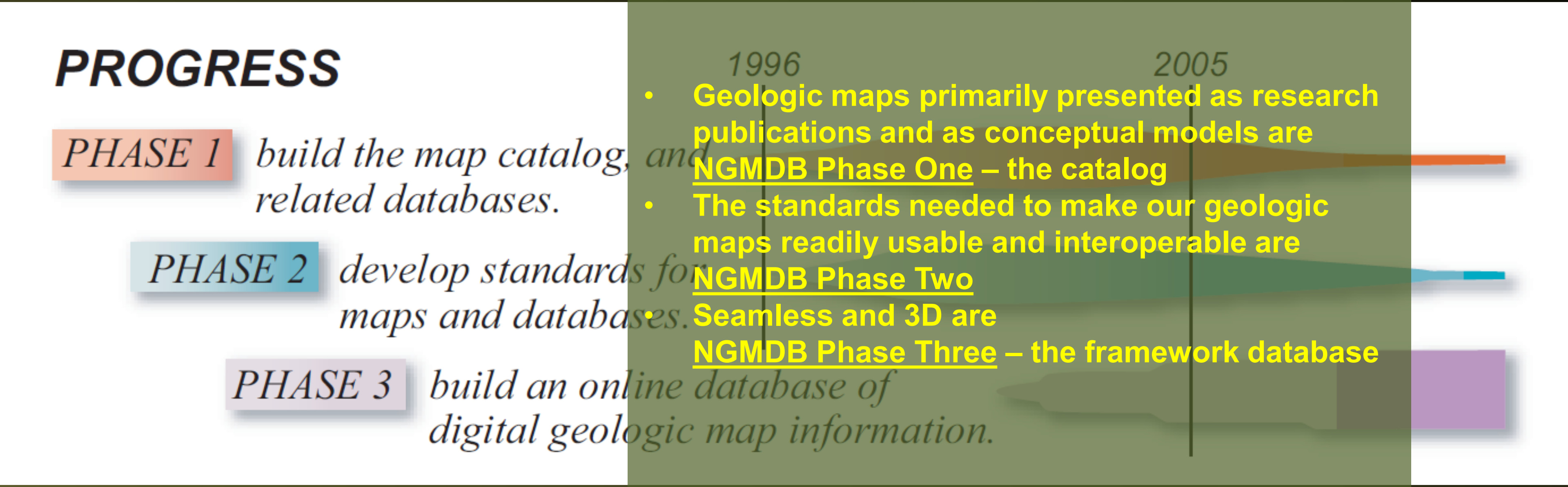
Figure 5. Major volcanic lithology from the State Geologic Map Compilation using the query "LITH2 = 'Volcanic' AND (LITH_RANK = 'Major' OR LITH_RANK = 'Indeterminate, major')" from the *Lithology* table.



- 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

Geology

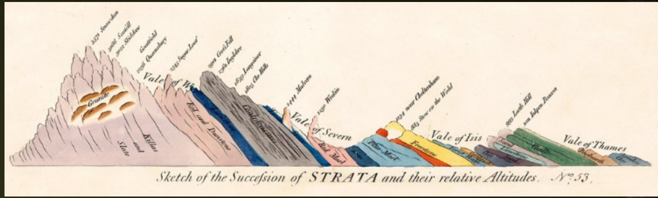


- Geologic maps primarily presented as research publications and as conceptual models are <u>NGMDB Phase One</u> – the catalog
- The standards needed to make our geologic maps readily usable and interoperable are <u>NGMDB Phase Two</u>
- Seamless and 3D are <u>NGMDB Phase Three</u> – the framework database

NGMDB

- 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

Culture

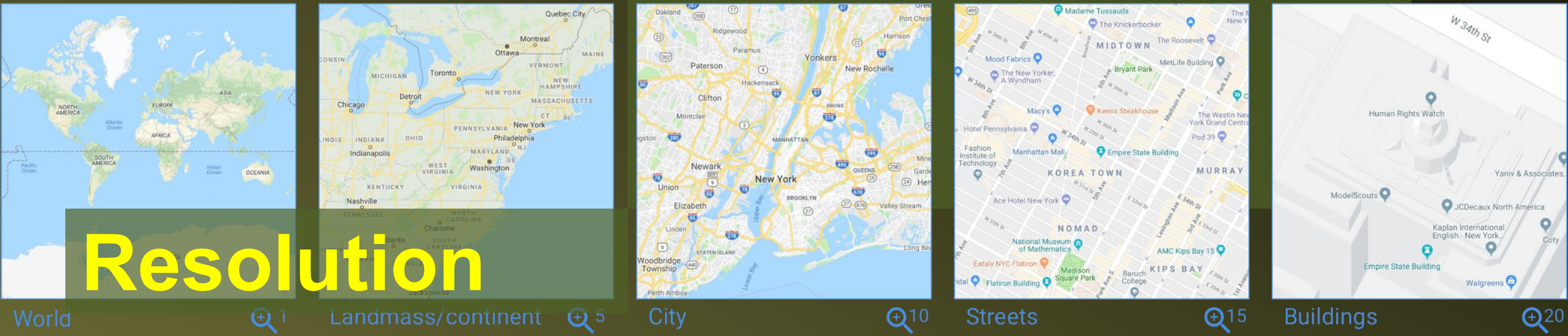


- Geological mapping as we know it began with the 1815 William Smith geology of England and Wales
- Our 1st century involved national surveys and hand-colored wall maps; our 2nd century involved the printing press
- We have evolved since 1990 from photomechanical paper maps, to digital paper maps, to 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

History

Resolution

- **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

Resolution

- 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

Federal and subnational roles

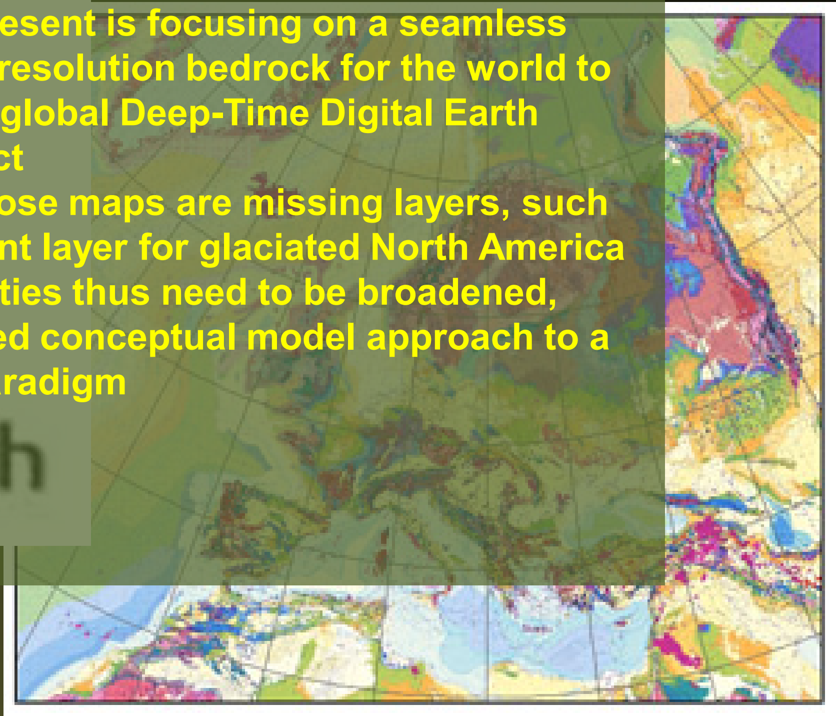
- These federal roles are based on broader thinking, as well as specialized research and technology
- While the subnational role can focus more on completeness, the federal role can be more focused on consistency
- Federal roles in detailed mapping include cross-border, federal priorities, and mapping needed to optimize synthesis
- Federal roles also include housing national databases, standards, and research need to optimize the program

CGMW

- 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)

Deep-time Digital Earth

- 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



DDE

CGI

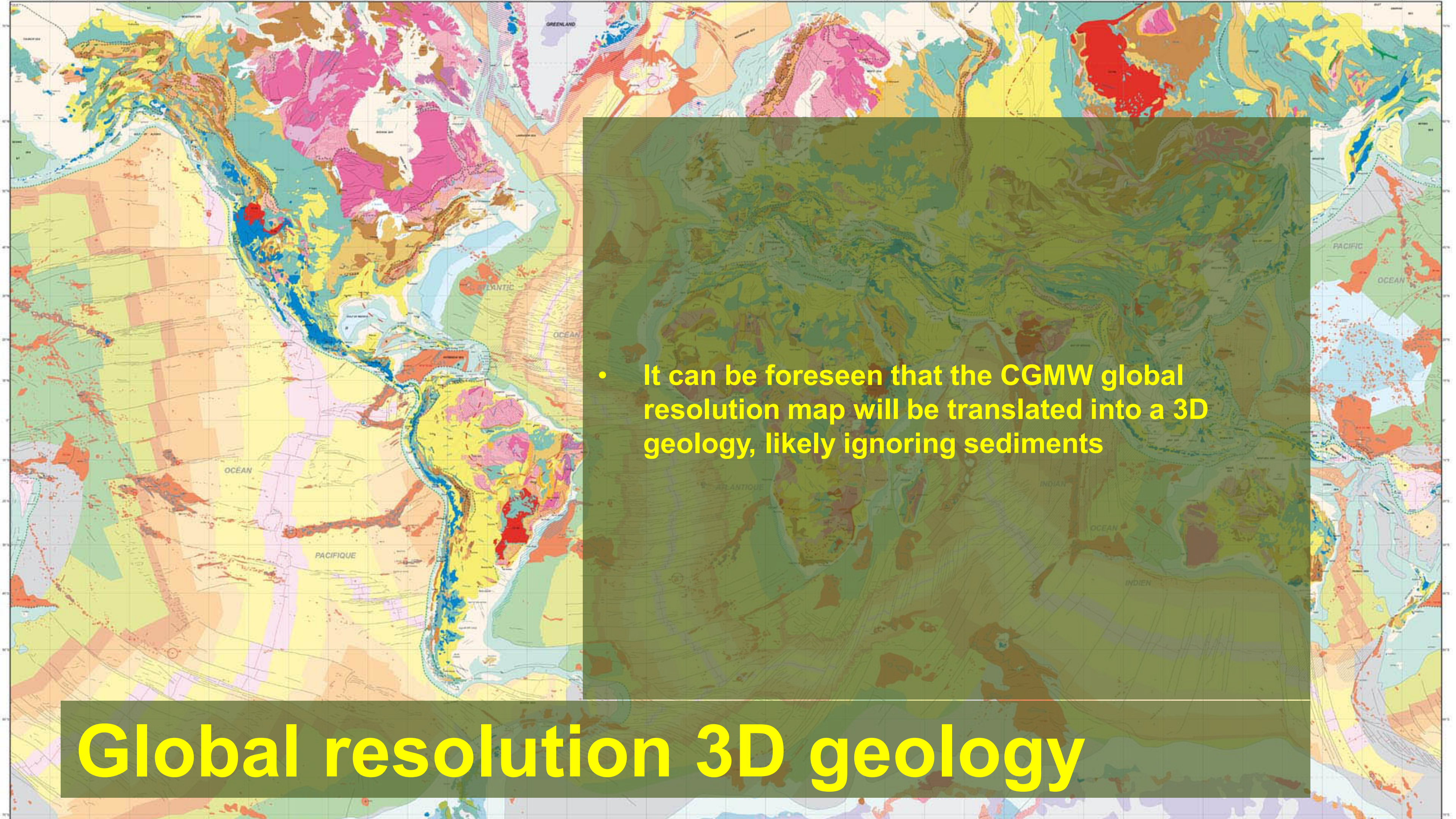
- International geologic map standards are led by the Commission for the Management and Application of Geoscience Information (CGI)

OneGeology

- 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

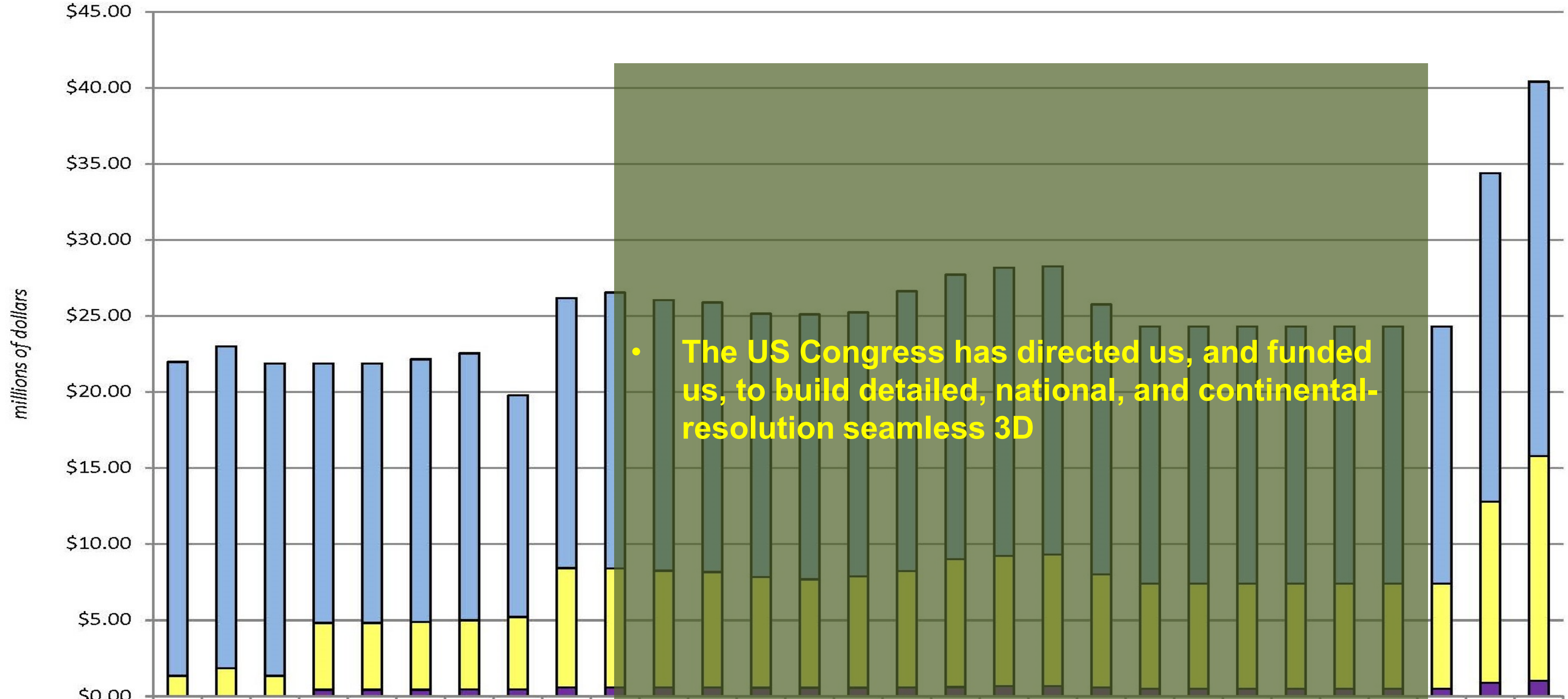
Global resolution 3D geology

- It can be foreseen that the CGMW global resolution map will be translated into a 3D geology, likely ignoring sediments



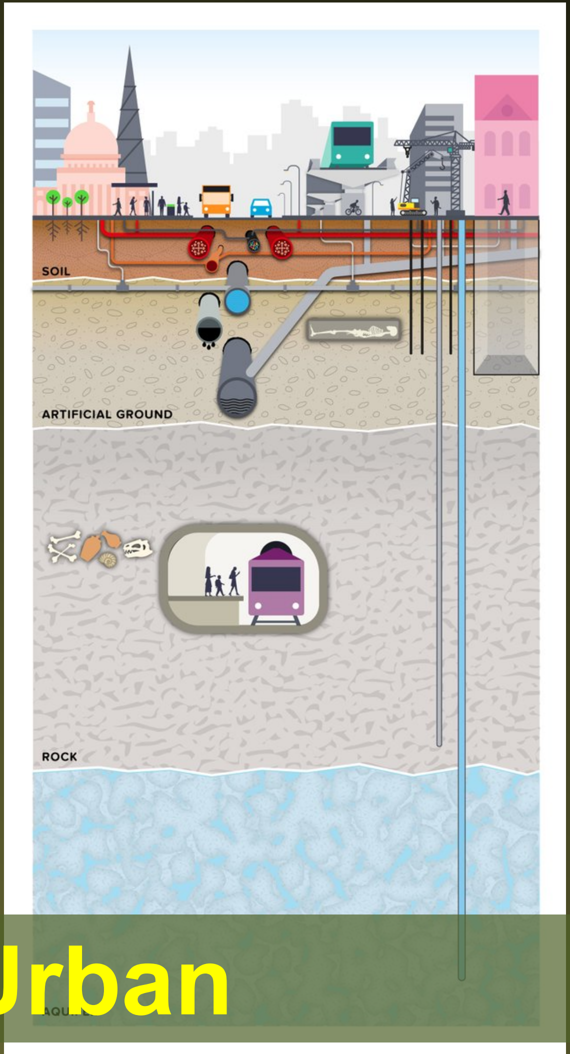
Funding

National Cooperative Geologic Mapping Program - Funding 1993-2021



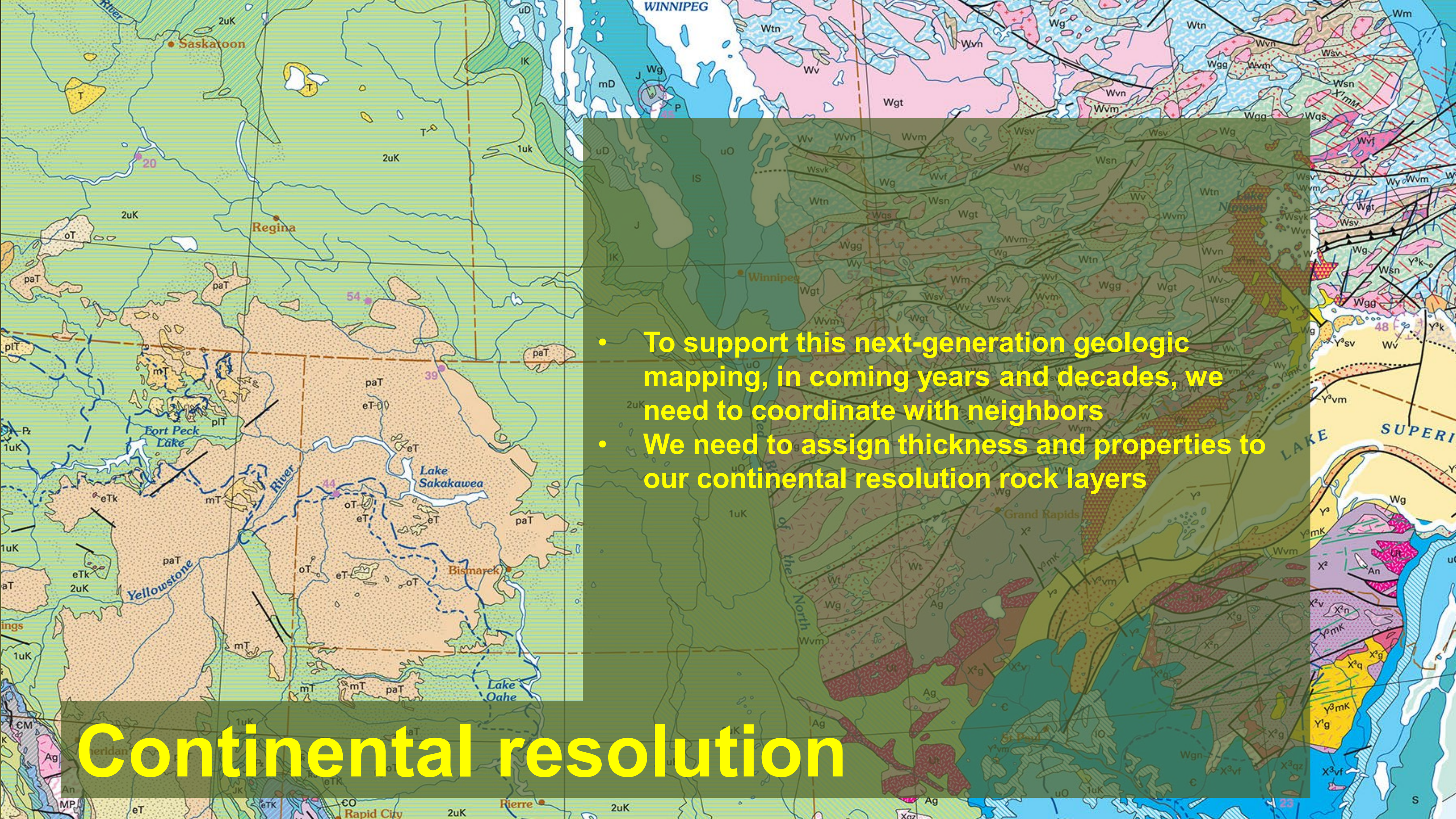
	FY 93	FY 94	FY 95	FY 96	FY 97	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15	FY 16	FY 17	FY 18	FY 19	FY 20	FY 21
FEDMAP	20.6	[illegible]	[illegible]	[illegible]	17.0	17.2	17.5	14.5	17.7	18.1	17.8	17.7	17.3	17.4	17.3	18.3	18.7	18.9	18.9	17.7	16.9	16.9	16.9	16.9	16.9	16.9	16.9	21.6	24.6
STATEMAP	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.44	4.54	4.76	7.84	7.83	7.67	7.59	7.29	7.13	7.32	7.66	8.41	8.57	8.64	7.44	6.90	6.90	6.90	6.90	6.90	6.90	6.90	11.9	14.7
EDMAP	0.00	0.00	0.00	0.44	0.44	0.44	0.45	0.46	0.59	0.59	0.58	0.58	0.56	0.56	0.57	0.58	0.61	0.67	0.67	0.58	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.90	1.02

- The US Congress has directed us, and funded us, to build detailed, national, and continental-resolution seamless 3D



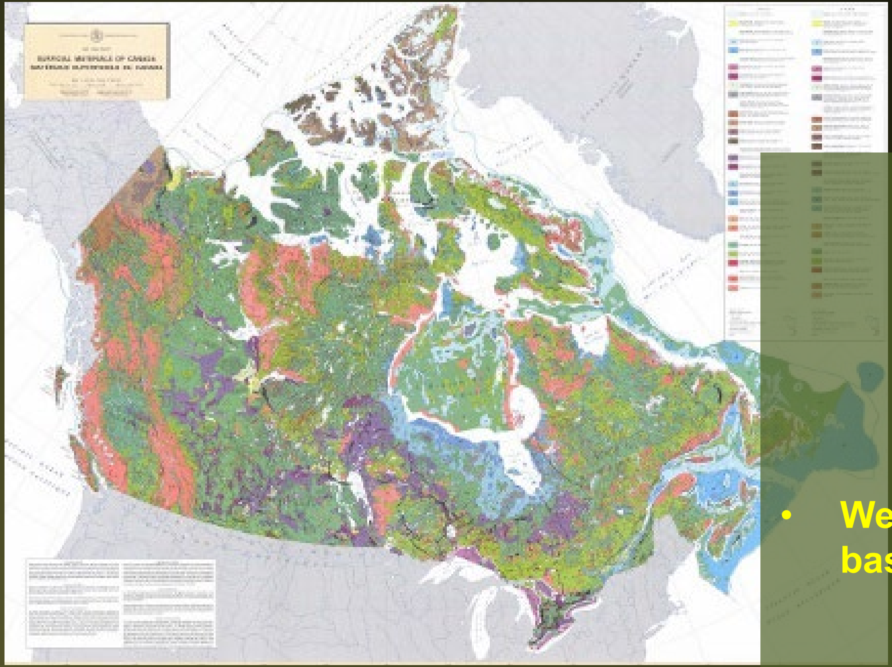
- Urban applications largely will be addressed by stewards of primary data, mostly as public domain drillhole data

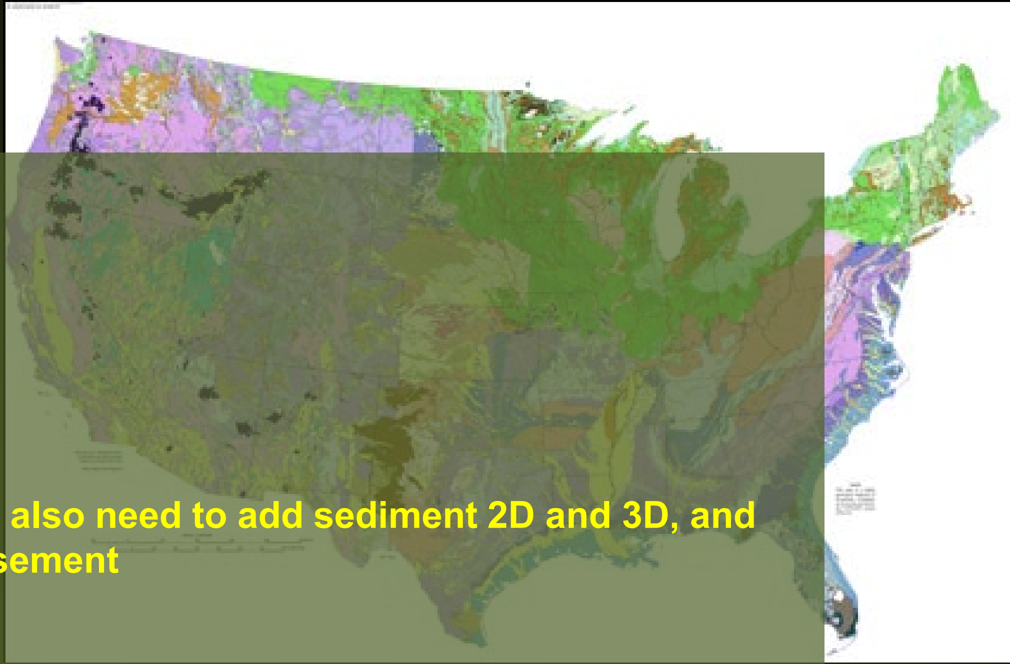
Urban



- 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

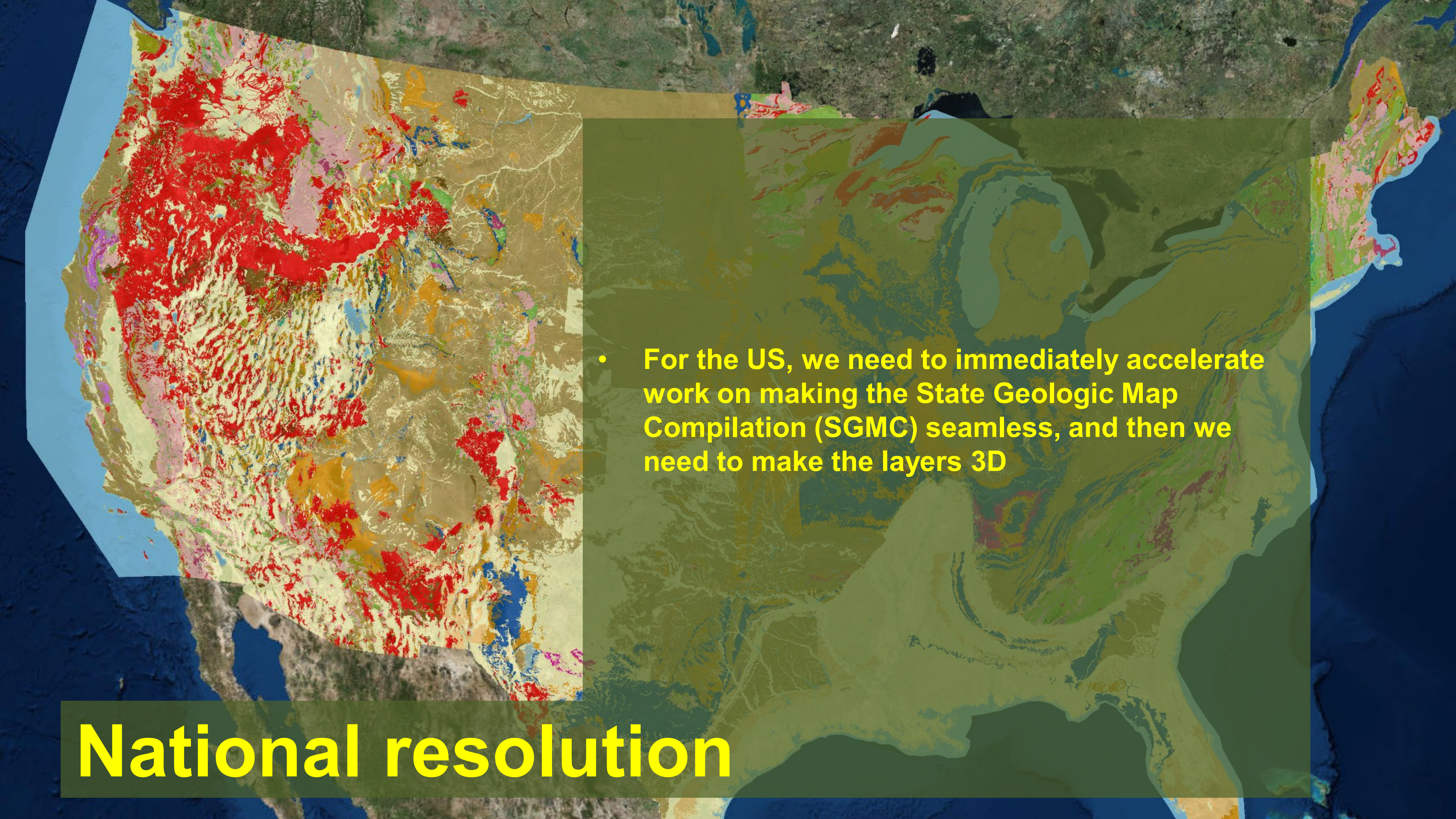
Continental resolution





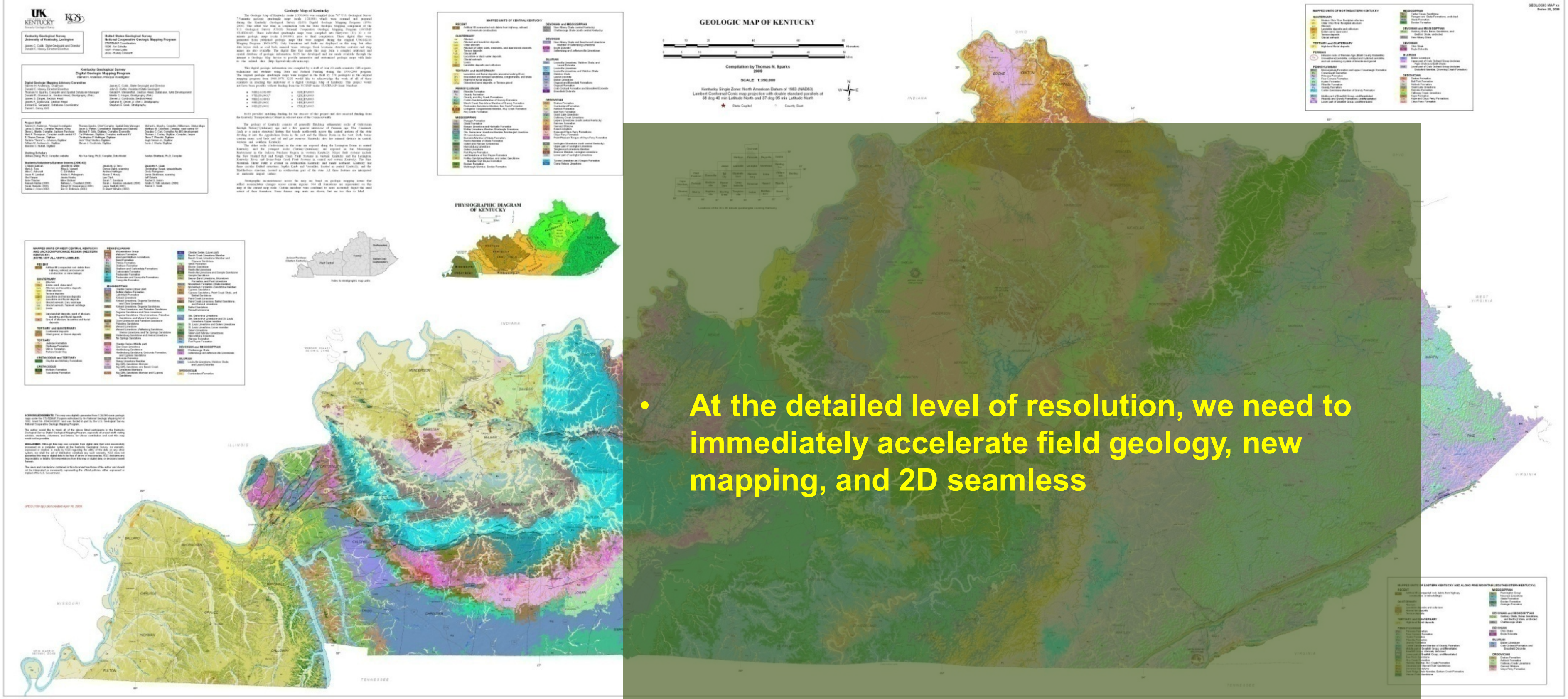
- We also need to add sediment 2D and 3D, and basement

Continental resolution



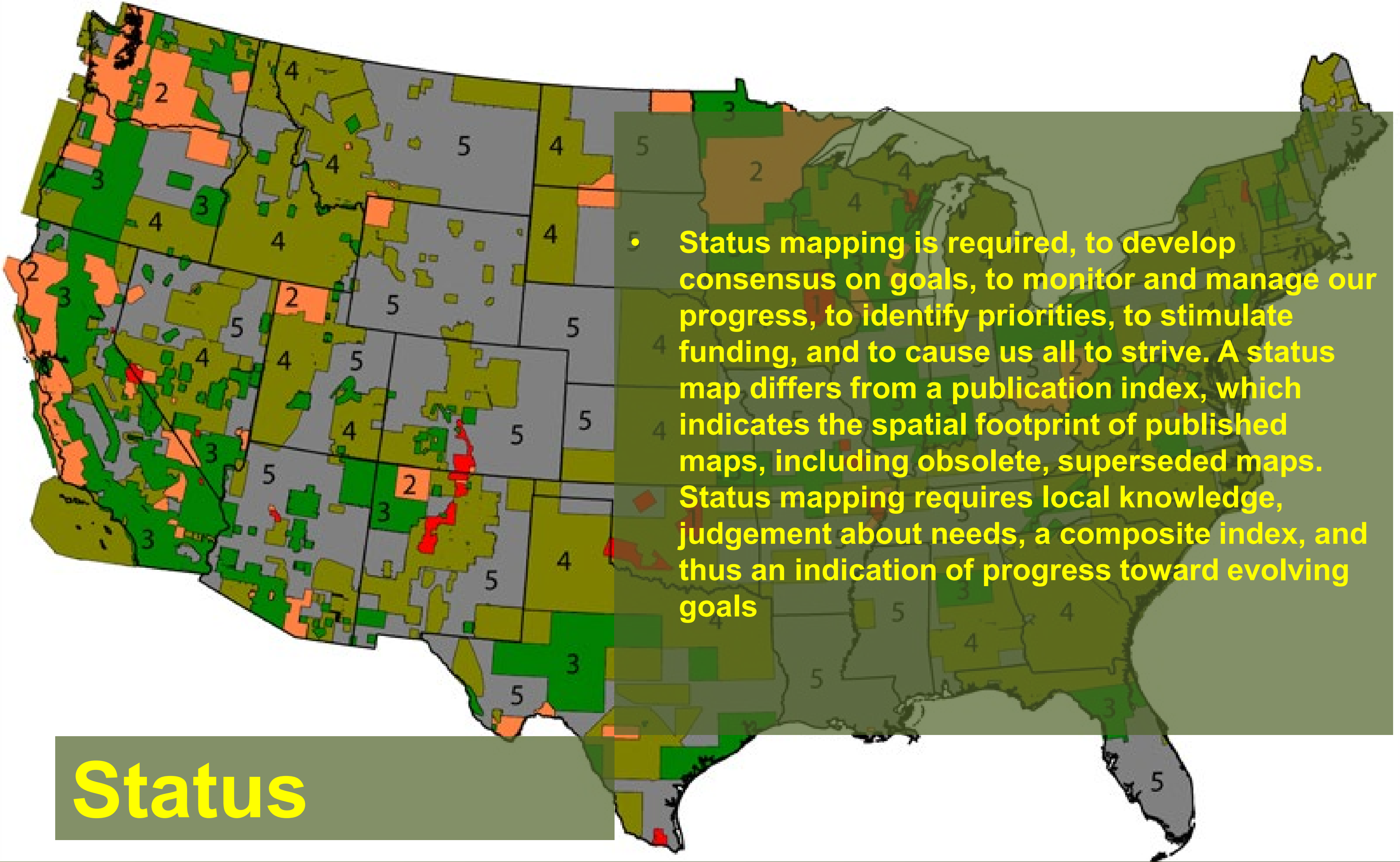
National resolution

- 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



- At the detailed level of resolution, we need to immediately accelerate field geology, new mapping, and 2D seamless

Detailed resolution

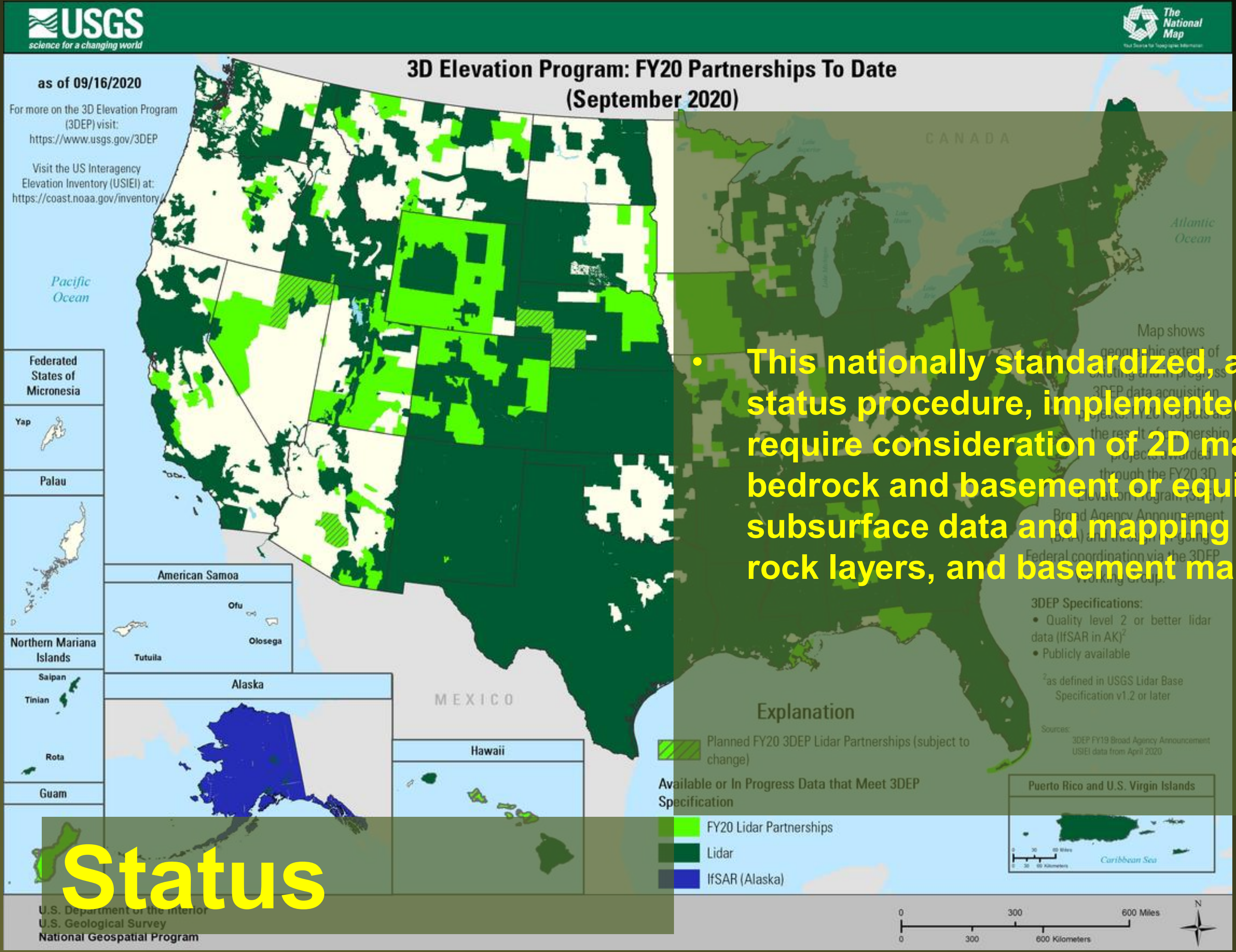


- Status mapping is required, to develop consensus on goals, to monitor and manage our progress, to identify priorities, to stimulate funding, and to cause us all to strive. A status map differs from a publication index, which indicates the spatial footprint of published maps, including obsolete, superseded maps. Status mapping requires local knowledge, judgement about needs, a composite index, and thus an indication of progress toward evolving goals

Status

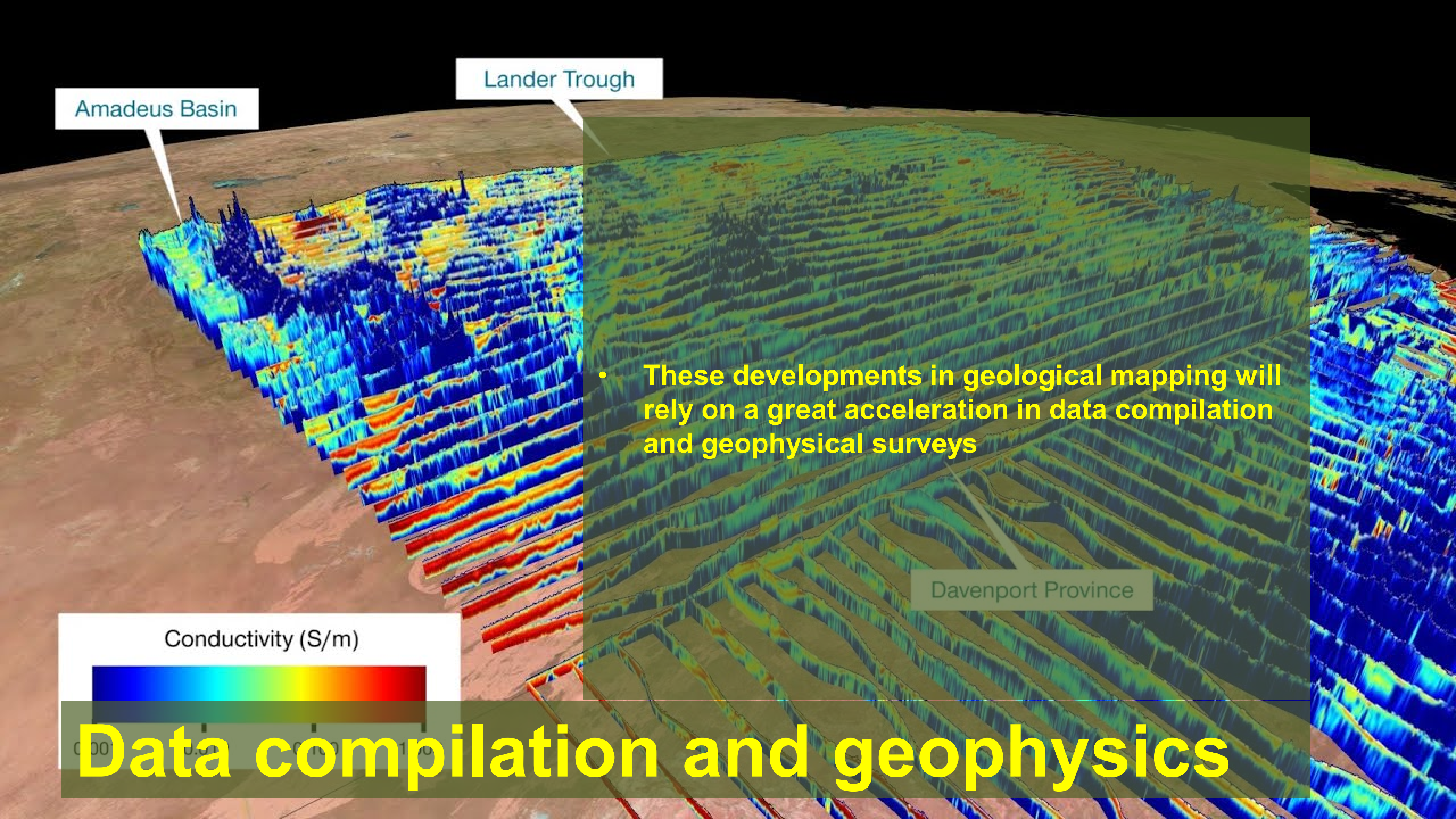
Status

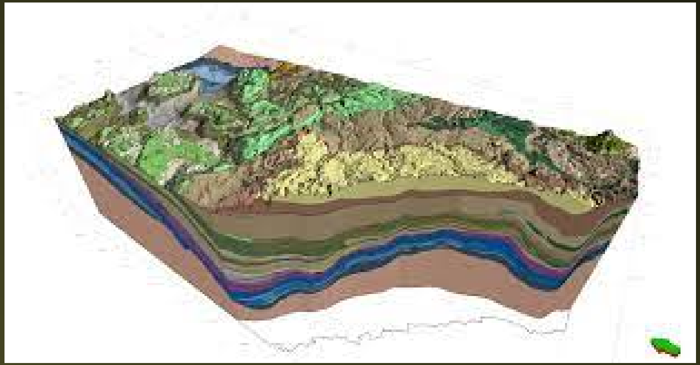
- This nationally standardized, annually updated status procedure, implemented in stages, will require consideration of 2D mapping, depth to bedrock and basement or equivalent, subsurface data and mapping of sediment and rock layers, and basement mapping



Data compilation and geophysics

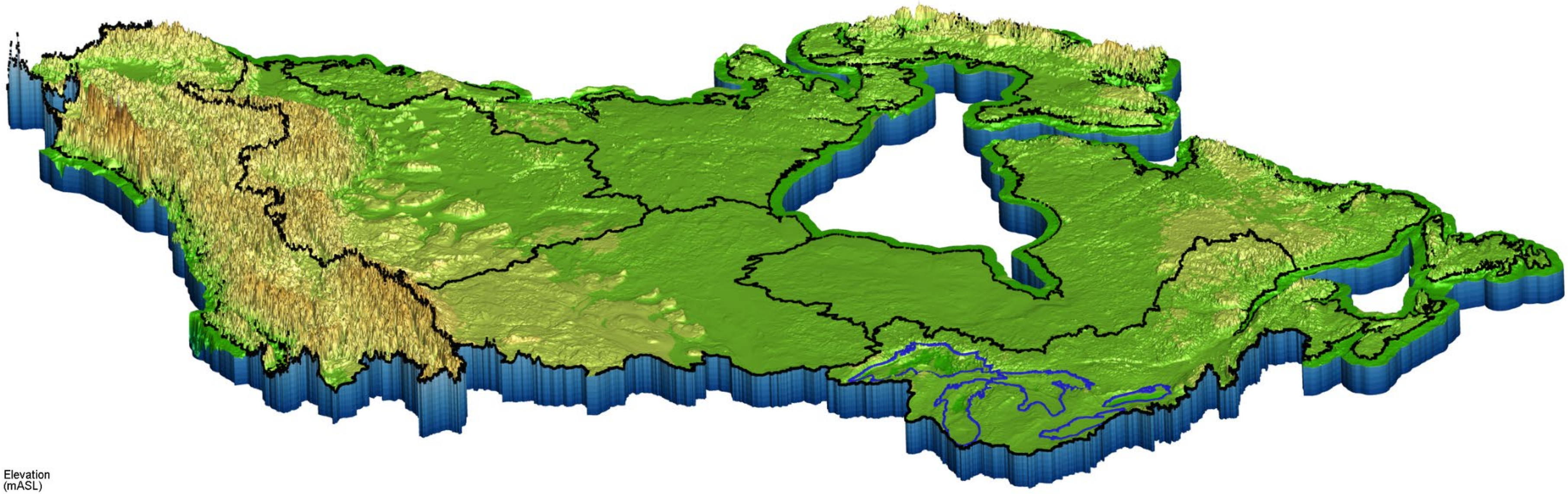
- These developments in geological mapping will rely on a great acceleration in data compilation and geophysical surveys

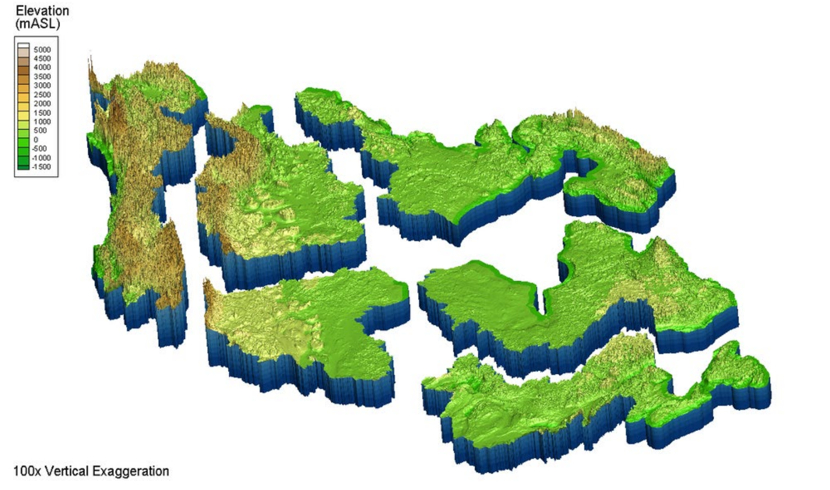


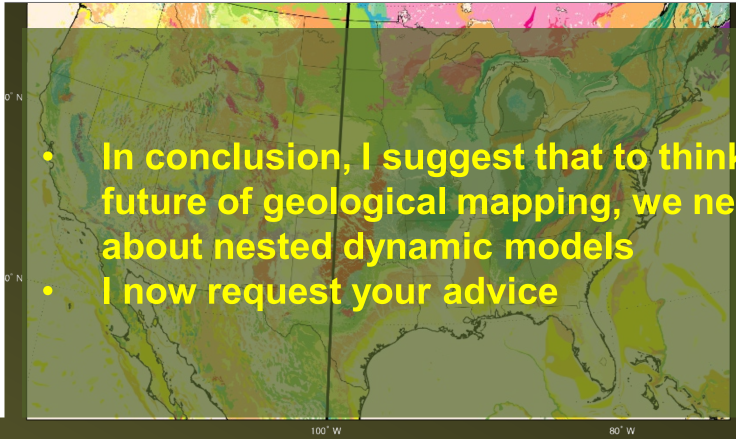


		ACTIVITY	PLANNED START	PLANNED DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	SETUP YEARS, FOLLOWED BY MAINTENANCE 1 2 3 4 5 6 7 8 9 10 11 12
1	USGS	Set up infrastructure	1	3	1	3	0%	
2	USGS	Amend Statemap program accouncement	1	1	1	1	0%	
3	States	Annual update of status	1	3	1	3	0%	
4	USGS	Construct continental surficial geology	1	3	1	3	0%	
5	USGS	Amend continental bedrock geology	1	3	1	3	0%	
6	States	Submit updated state geologic maps	1	1	1	1	0%	
7	States	Submit detailed surficial geology	1	1	1	1	0%	
8	States	Submit detailed bedrock geology	1	1	1	1	0%	
9	States	Submit continental (10-km) bedrock elevation	1	1	1	1	0%	
10	States	Submit continental rock 3D layers	1	1	1	1	0%	
11	USGS	Compile detailed surficial lithology	2	1	2	1	0%	
12	USGS	Compile detailed bedrock lithology	2	1	2	1	0%	
13	USGS	Compile national bedrock geology	2	4	2	4	0%	
14	USGS	Compile continental (10-km) bedrock elevation	2	1	2	1	0%	
15	USGS	North American 3D GIS	2	3	2	3	0%	
16	USGS	Reconcile continental rock 3D layers	2	1	2	1	0%	
17	States	Submit continental rock 3D	3	1	3	1	0%	
18	States	Submit national (1-km) bedrock elevation	3	1	3	1	0%	
19	States	Submit continental basement elevation	3	1	3	1	0%	
20	USGS	Construct continental basement geology	3	3	3	3	0%	
21	USGS	Compile continental rock 3D	4	1	4	1	0%	
22	USGS	Compile continental basement elevation	4	1	4	1	0%	
23	USGS	Compile national (1-km) bedrock elevation	4	1	4	1	0%	
24	States	Submit continental sediment 3D layers	4	1	4	1	0%	
25	USGS	Compile national surficial geology	4	3	4	3	0%	
26	USGS	Reconcile continental sediment 3D layers	5	1	5	1	0%	
27	States	Submit detailed (0.1-km) bedrock elevation	5	1	5	1	0%	
28	USGS	Compile detailed (0.1-km) bedrock elevation	6	1	6	1	0%	
29	USGS	Construct continental basement 3D geology	6	3	6	3	0%	
30	States	Submit continental sediment 3D	6	1	6	1	0%	
31	States	Submit national rock 3D layers	6	1	6	1	0%	
32	USGS	Compile continental sediment 3D	7	1	7	1	0%	
33	USGS	Reconcile national rock 3D layers	7	1	7	1	0%	
34	States	Submit national sediment 3D layers	7	1	7	1	0%	
35	States	Submit national rock 3D	8	1	8	1	0%	
36	USGS	Reconcile national sediment 3D layers	8	1	8	1	0%	
37	States	Submit national basement elevation	8	1	8	1	0%	
38	USGS	Compile national rock 3D	9	1	9	1	0%	
39	USGS	Compile national basement elevation	9	1	9	1	0%	
40	States	Submit national sediment 3D	9	1	9	1	0%	
41	USGS	Compile national sediment 3D	10	1	10	1	0%	
42	All	Consider feasibility of detailed rock 3D	10	3	10	3	0%	
43	All	Consider feasibility of detailed sediment 3D	11	3	11	3	0%	

- 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

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