AN AGENDA FOR DEVELOPMENT OF VERTICALLY GEOREFERENCED, WEB-OPTIMIZED SUBSURFACE INFORMATION

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Geological mapping is an essential service provided by geological survey agencies at the federal and state/provincial level. The mapping represents an authoritative prediction regarding the composition, structure, and origin of sediments and rocks, based on observations and inferences backed by research on material, process, and history. This spatial accounting is needed to support the progress of research and societal applications related to energy, minerals, water, climate change, waste disposal, construction, and hazards.

Through most of the nearly 200 years of geological mapping history, the printing press was our means for preparing information for dissemination, customarily as a map and a report. Three-dimensional aspects of the geology were accommodated by publishing surficial geological maps to depict the uppermost sediments, bedrock maps to depict the uppermost rocks, structural symbols to indicate geometric trends that could be projected into the subsurface, an accounting of superposition conveyed by the legend, along with selected cross sections.

To be regarded as legitimate, these maps and reports have undergone peer review in a manner dictated by the workings of government agencies that are obliged to ensure that something is produced for any funded project. The publications have clear authorship to provide credit, and to indicate responsibility for the work. Geological survey agency culture differs from the anonymous authorship of, for example, less interpretive meteorological and topographic mapping.

Having been packaged as maps and reports that are authored and peer-reviewed, our products were then made ready for the printing press, an appropriate number of copies were produced, and they were then distributed to libraries and sales outlets. Upon depletion of sales outlet inventory, the publication was declared out of print, and users were referred to libraries. To facilitate storage, discovery, and unique identification, a series number was assigned, thus becoming the entry point to the information, through a library card catalog or publications catalog.

From the 1980s through the millennium, digital methods were adopted, and we learned how to make a paper map or a paper report with the aid of a computer. This took a great effort, and those responsible for the success of this transition are commended. Concurrently, databases produced in association with geological mapping, or as products of geophysical and geochemical surveys, greatly increased in prominence alongside our paper maps and reports.

Throughout this transition to digital methods, however, geological mapping has remained committed to the paper map and paper report format. This is good, and we should continue to do so, as these formats are familiar to our existing user community, these are formats that unquestionably will be usable decades in the future, we have meticulously developed procedures for detailed legends to be affixed to each map, and these formats facilitate authorship and peer review. Whether actual paper, a vector layout, or a raster copy, we will continue to use map formats that were designed for the printing press indefinitely.

This being said, we are all aware that we now live in the Web paradigm. We produced paper maps using photomechanical methods in the 1980s, we learned how to make paper publications with a computer in the 1990s, and with the turn of the millennium, we increasingly made digital versions of our publications available via the Web. As we enter the second decade of the millennium, however, we increasingly recognize that we can serve our users more efficiently and effectively if we optimize our content for the Web, rather than for the printing press.

Web users now seek conceptual information such as news, temporal information such as weather forecasts and stock prices, and when they seek spatial information, their entry point is location, rather than a keyword search for a series-numbered publication. Users are accustomed to Web mapping sites, in which they first choose an area, and then select the topic of interest. Users now assume that they can zoom out for context, and zoom in for detail. Some sites provide a text message advising the user to zoom back if a more detailed layer is not available.

It also is customary to browse Web maps laterally, whether across a county or across a continent, while double-clicking a symbol generally is seen as a natural way to obtain information about a feature. This method of query is now a way of life for a growing segment of the population, many of whom have never experienced a library card catalog, nor are they interested in ordering a copy of a map or a report. They simply want the fact or the figure that will allow them to move on toward their actual objective, while using a Web service that they happily take for granted.

While geological survey agencies have made much progress in making our standard information products Web accessible, we have barely begun the process of Web optimization. To do so, we must vertically georeference all of our content, and optimize it for zoom, browse, and query.

As we structure our maps as zoom layers, we likely will rely on 1:25M global mapping, 1:5M continental mapping, regional mapping at scales of about 1:1M, and detailed mapping at scales of about 1:100,000, although varying from 1:24,000 to 1:125,000.

Geological survey agencies are rightly proud of the hundreds of maps we have produced. But Web-savvy users do not want hundreds of maps; they want one browsable and queryable map at each zoom level. This means that we must stitch our detailed mapping together as a single, queryable layer for a given jurisdiction, bringing together both onshore and offshore mapping, at each zoom level relevant to that level of government. This can begin as an unreconciled mosaic, followed by gradual progress toward full harmonization. These map layers will also facilitate needed jurisdiction-wide analyses, such as the material along proposed pipeline corridors.

Each layer must be queryable, and to do this efficiently, every legend needs to be coded to a one-word lithology, as well as other attributes parsed from the full legend. In addition to the standard legend, we will be able to make multiple languages and multiple derived maps available on the fly by allowing a choice of legends, each adapted to the needs of a different user community.

As we produce these Web-optimized layers, we will remain committed to the scientifically more rigorous and comprehensive content that will continue to reside in our authored, peer-reviewed maps and reports. In the Web paradigm, the logical way to access these publications would be, for example, by right-clicking a feature.

The paper map format in this context becomes the documentation for a Web-optimized color polygon coded with a one-word lithology, and a raster of the paper map would be an ideal format for the few knowledgeable users who need detailed information, and who comprehend formal geological maps. Ideally, the text in the raster would be searchable, through some sort of optical character recognition (OCR) procedure.

Concurrently, a Web-optimized geological mapping layer ideally would also link to reports. Whereas geological mapping agencies previously were able to declare a publication to be out of print, and thus the responsibility of libraries, we now must again take responsibility for our page content, as page scans now will become the universal format at least for our legacy content. While some of us will wait to have this done for us, others will take control of their future, and have the page scans done. To do this, every geological survey agency needs a complete listing of every publication they have ever produced, and they need to scan every map and every page. The least expensive, most consistent, and most efficient way to do this is in large batches sent to a capable contractor. While OCR-searchable pdf files available as whole-file downloads are an established format, formats for digital books that are Web–accessible a page at a time are not.

In the printing press era, we were able to justify two color maps, surficial and bedrock. In the digital era, there is no reason to be constrained in this manner, as the number of color maps that can be produced is unlimited. We thus can now transition from a focus on surficial and bedrock, to strata and basement. In this approach, polygons for undeformed strata can be superimposed, and thus made removable, to reveal what is below, to the extent that it can be mapped. Eventually, deformed rocks are encountered, and these can be declared basement. In this approach, decisions on what are strata, and what is basement, will be required early in a project.

This style of mapping is, in a way, an established activity for geological mapping agencies, who have been producing surficial geology maps, depth to bedrock maps, and bedrock maps for decades. Bedrock maps commonly had large blanks in them, until we began to use airborne geophysical surveys. As 3D mapping of strata matures, we will similarly develop guidelines for the amount of information that is required to justify full 3D mapping.

Earth surface mapping is a well-known activity, in the form of topographic maps depicting roads and rivers, and these features can readily be vertically georeferenced by draping them on a terrain model. Similarly, 3D mapping of the atmosphere is well-developed, and virtual globes now offer near-real-time clouds and precipitation depicted in some manner above ground. These Web services also have begun to show water depth, thus beginning to enter the 3D subsurface world.

As geological survey agencies enter this paradigm, we similarly will recognize that the first layer of subsurface information is bathymetry. Jurisdiction-wide water layers at multiple zoom levels therefore need to become a well-known institutional resource. By making this layer available on the Web, emergency response teams dealing with an offshore plane crash, for example, or someone pondering offshore coring or drilling, will be supported.

The second layer of subsurface information is agricultural soil mapping. This is a highly mature activity, but it operates in a world and a culture quite separate from geological mapping, with respect to academic traditions, terminology, and user communities. Nevertheless, soil mapping and geological mapping are the same thing, with the former measuring depth in centimeters, and the latter making measurements in meters and kilometers. Despite this similarity in method and topic, there is little coordination between these two worlds.

Despite these cultural barriers, however, soil mapping and geological mapping will have to be reconciled. As users such as land-use planners more and more expect the integration of Web-accessible information, they will demand that the two be made to work together. While soil mappers may claim that their mapping is relevant to multiple meters of depth, and geological surveys will present competing claims that imply that their surficial maps are relevant to the surface, our users will likely be better served if we simply declare soil maps to be the official government prediction for the top meter, while the surficial geology map is the authoritative word for the second meter. Both soil maps and surficial geology maps readily can be made queryable to the same one-word lithologies, although soil mappers will protest that they map soil development rather than parent material composition.

We thus can now begin to build maps with superimposed polygons, depicting a stack of extents. The next step in this process then is to specify the thickness of each layer, thus producing a 3D map, which can be conveyed in the form of an extent and a grid of tops for each layer. This can then be followed by progress toward production of a 3D grid of discretized properties for each layer, thus producing a 3D map ready for modeling.

We then will need Web interfaces that can optimally make 3D maps available. Development of capable Web interfaces will be frustrating for us all. We know that a suitable interface could readily be programmed, but we all have learned about the in-house software syndrome, in which custom software works well for a small community for a few years, but staff turnover and technological progress eventually cause the demise of the procedures. Thus we do not want to be producers of Web interfaces any more than we have to. We would prefer to be pure content providers, not maintainers of interfaces.

But commercial interface providers will not build an interface until the content and user community are there. In a classic chicken and egg situation, we will not prepare the content until the interfaces are adequately available. For Web accessible 3D geological mapping, we thus may have to emulate the great success of the OneGeology portal, which was built as a community project of the geological surveys of the world, largely to a stimulate coordinated effort on a standard format for Web-accessible 2D geological maps. Soil mapping agencies have built similar portals.

A solution will be found, however, and capable interfaces will offer our increasingly comprehensive 3D maps. As we make available our 3D layers, we will want the user to be able to concurrently query databases such as drillhole data and geophysical databases, as well as databases of geological observations.

This information depicting the world beneath our feet could be called geology, or perhaps words such as subsurface or underground will be more accessible. Varying ways to Web query 3D geological mapping will be found. A location could be specified, and a drillhole forecast down to basement could be produced in a window. Layer one would be water if present, or commonly the top meter would be the one-word lithology derived from the soil map, followed by a prediction of material in the second meter derived from the surficial geology map. Areas lacking full 3D mapping would then have a layer of unspecified sediments derived from the depth to bedrock map. Forecasts for rock layers would follow, either multiple layers, total thickness of strata, and/or finally perhaps a meter-thick interval presenting uppermost basement lithology would complete the drillhole forecast.

This drillhole forecast would be accompanied by an indication of reliability, perhaps an accompanying column that would be green to indicate a high confidence prediction based on much previous drilling of simple geology, yellow for a medium confidence prediction in an area of little previous drilling, and red for low confidence in an area lacking drilling. These confidence levels could be built quantitatively by dividing a region into cubes, perhaps 10 km square by 10 meters think, and by inferring a score based on a combination of number of drillhole intersections penetrating that cube, balanced by a consideration of geological complexity. Few drillholes are required to allow good predictions of unvarying horizontal strata, while more drillholes are required to adequately characterize areas of greater complexity.

Beyond drillhole forecasts for a mouse-clicked point, a postal code, or an address, we can readily obtain additional ideas for optimal future Web accessibility of 3D geological maps by considering the procedures now readily available in a 3D GIS. Ideally, these 3D GIS procedures will some day be Web enabled, thus allowing lift-off of strata, or removal of cut-out blocks or wedges.

Our thinking on scales of geological maps is stable, and four zoom layers are here proposed – ~1:25M, ~1:5M, ~1:1M, and detail at ~1:100K. Our thinking on varying scales of 3D mapping is less mature. Much new 3D mapping in the geological survey agency world is being done at the county scale to support groundwater management. In an earlier phase of 3D geological mapping in the 1980s and 1990s, atlases were produced for hydrocarbon-producing sedimentary basins, as well as for regional groundwater systems. These were done at a lesser level of detail than present-day county-scale 3D mapping, but we have a limited ability to characterize this varying level of detail.

To consider this topic of 3D scale further, we can consider a user browsing a 1:25M geological map of the world, who might wish to query various points around the world, to clarify varying of a sedimentary basin thickness. Similarly, a user browsing a 1:5M continental map might want to query and view variations in Mesozoic thickness relative to Paleozoic thickness, for example. Someone looking at a state or provincial bedrock map might be interested in depth to bedrock, or in the thickness of Silurian relative to that of Devonian. When viewing a county geologic map, the user would want the highest level of detail, typically at the formation level, or lithological depiction of aquifer and non-aquifer materials.

It would seem logical to marry the 3D strata to the polygons on the map, although it might not be possible to match the two. Commonly, a 2D map will show more detail than the 3D map that it will logically be matched to. We thus need to develop thinking, perhaps on four levels of 3D detail that can be associated with the four levels of 2D zoom proposed here. Sediments might only appear in the one or two most detailed scales.

The Web revolution thus has made people hungry to have all information at their fingertips, so they can do their jobs, and quickly get on with their lives. The questions before us are: (1) how far Web optimization can go in the world of geology, (2) how quickly geological survey agencies can reformat their information for this style of Web query, (3) whether we can assemble consistent information world-wide, (4) whether we can 'go underground' in Web interfaces, (4) the business models that will cause needed Web interfaces to be supported, and (5) whether we will be able to successfully coordinate with bathymetric and soil mapping.

While clearly authored and peer-reviewed geologic maps and reports will remain the foundation of our knowledge on regional geology, users increasingly will demand the ability to quickly and efficiently obtain geologic map information via the Web in order to efficiently do their jobs on a day-to-day basis.

New layers of Web-optimized mapping therefore will be required to facilitate efficient Web accessibility, and also to act as a gateway to more detailed maps and reports. We thus require consistent and readily queried geologic map data layers, at 1:25M, 1:5M, 1:1M, and 1:100K, each matched appropriately to accompanying 3D content.