Rationale and Methods for Regional 3D Geological Mapping

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Outline

Rationale
Background
Data compilation
Data acquisition
Model construction
Geostatistical methods
Properties, heterogeneity, & uncertainty
Delivery & applications
Examples
Strategies
Rationale

Why do I need to do this?

Role of geological mapping

Current societal needs

How surveys need to respond
Geological mapping

- Geological mapping is a mature field
- Analyses show large positive economic returns
- National, multi-resolution, updated 2D mapping is needed
- 2D maps commonly are accompanied by a cross section
- A 3D map can consist of a sufficient number of cross sections
- All principles that apply to plan view apply to section view
- 3D mapping thus is based on the same principles as 2D
Societal needs

- groundwater capacity & vulnerability
- anticipation of ground conditions in engineering
- assessment of sedimentary basins re energy & waste injection
- mineral resources, hazards
- fundamental understanding of earth material, process, and history
Needed response

- Accelerated progress toward national, regularly-updated, well-coordinated, multi-resolution, seamless, 3D, material-properties-based geological mapping

- Mapping is evolving to 3D due to data, technology, intensified land use, and escalating societal expectations
Background

What do I need to understand?
Applications
Stratigraphy
3D mapping
Layers vs. basement
Information
Applications

- Aquifer sensitivity
- Wellhead protection
- Hydrogeological conceptual modeling
- Hydrogeological property attribution
- Qualitative groundwater modeling
- Quantitative groundwater modeling
- Engineering
- Sedimentary basin assessments
- Minerals, hazards
**Stratigraphy**

- Facies & basin analysis guide all work
- Inferred lithology is needed as a basis for property attribution
- Users need continuous tracing of the extent, thickness, and properties of lithologic units
- Combined allostratigraphic and lithostratigraphic approaches may apply
- Naming should be orderly & minimized
- Need to extend our work to hydrostratigraphy
3D mapping

- Structure symbols, x-sections, structure contours, isopachs, stack-units
- Mathers and Zalasiewicz (1985) - regularly spaced, orthogonal cross-sections
- 3D GIS - Vinken, 1988; Turner, 1989; Raper, 1989; Vinken, 1992
- Bonham-Carter (1994) – 2D GIS systems differs from 3D; 3D has x, y, and multiple z values, unlike plan view 2D, or perspective 2.5D methods based on a single z per site
- Houlding (1994) – comprehensive conceptual structure for 3D GIS
- Soller, Price, Berg, & Kempton (1998) worked out a method for regional 3D geological mapping based on geological maps, stratigraphic control points, and large public drillhole databases
- Hydrocarbon industry – e.g. Zakrevsky (2011)
- Applied hydrogeology – e.g. Kresic and Mikszewski (2012)
- 3D workshops since 2001
Layers vs. Basement

- **LAYERS** - strata whose thickness can everywhere be mapped, and for which underlying geology can be drawn.

- **BASEMENT**: Complexly deformed strata, older rocks over younger rocks, as well as igneous and metamorphic rocks, are depicted as a basement map, with increasing depiction of 3D geometry of selected structures as well as discretized basement physical properties.
Preliminary Bedrock Geologic Map of Minnesota
Minnesota Geological Survey
Open-File Report OFR10_02
2010
M. Jirsa, T. Boerboom, V. Chandler, J. Mossler, and A. Runkel
Information

Commission for the Management and Application of Geoscience Information
Data compilation

What do I need to compile?

- Topography
- Bathymetry
- Soil mapping
- 2D geological mapping
- Drillhole data
Topography
Bathymetry of Lake Huron with Topography
Soil mapping

UN/FAO Soils Map of the U.S.
Soils Ranked by FCC Limiting Factors
Plan view geological mapping
Drillhole data

- acquire
- digitize
- georeference
- categorize
Data acquisition

What field work is needed?

Geophysics
Drilling
Geophysics

- EM
- Seismic
- Radar
- Borehole geophysical surveys
- Marine geophysics
Drilling

- Stratigraphic benchmarks
Model Construction

*How do I draw layers?*

- Resolution
- Data adequacy
- Lithological data
- Stratigraphic data
Resolution

- Global
- Continental
- State/National
- County/Quadrangle
Lithological data

- the model is anchored at stratigraphic benchmarks
- strata are drawn by a geologist through lithological data
- a facies model guides interpolation
- strata are drawn at a resolution supported by data
Stratigraphic data

- modeling may proceed directly from regularly spaced, correlated data
Two-layer models & regional cross-sections

- Depth to bedrock & depth to basement maps motivate data compilation and clarify data collection priorities

- Regional cross-sections from onshore to offshore and from neighbor to neighbor are a crucial early step in reconciling stratigraphy

Gao et al., 2006
Legacy stratigraphic models

- many regions have stratigraphic atlases in need of digitizing

Keller et al. (2009)
Cross-sections drawn through lithologic data

- A common scenario is a region in which regional 3D mapping is needed to support groundwater management, and the available basis for modeling consists of scattered cores and geophysical surveys, along with an abundance of water well data.

- An approach in this case is data compilation, acquisition of stratigraphic control sites using coring and geophysics, and construction of cross-sections

Modified from Ross et al., 2005
Cross-sections drawn through lithologic data

- this results in depiction of a fully plausible geology that conforms to the geological conceptual model, and from which data issues have been filtered by the geologist

- incorporation of new data is challenging
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
Solid Models

- Progression from surfaces to fully attributed volumes will be needed for applications

- This may require data collection & transfer to another software platform, depending on nature of the discretization and attribution

- Solid models may also be constructed from geophysical data
Can I use geostatistical methods to infer solids and their properties?
Principles

- Geostatistical methods infer or characterize solids based on 3D data

- Introduction: McKillup and Dyar (2010)

- Overview: Houlding (1994) and Kresic and Mikszewski (2012)

Methods

- simple kriging; ordinary kriging; universal kriging; block kriging, training image-based multiple-point geostatistics, support vector machines

- cellular partitions, tessellations, discrete smooth interpolation, differential geometry, piecewise linear triangulated surfaces, curvilinear triangulated surfaces, stochastic modeling, discrete smooth partitions
Role of geostatistics

• inference of solids directly from lithological data, at least a 1st draft

• property attribution following definition of hollow strata
How do I specify the characteristics of layers?

Properties

Heterogeneity

Uncertainty
• 3D mapping seeks relatively homogeneous strata

• We assign properties

• We then revisit strata, to better recognize heterogeneity

• With heterogeneity adequately considered, uncertainty can somehow be indicated
Properties

- infer properties from lithology
- use measurements to guide inference from lithology
- interpolation and extrapolation from measurements such as hydraulic conductivity values, while respecting the geological model to the appropriate degree

Anderson (1997) concluded that most porous media are heterogeneous, that simulation of facies patterns using depositional models is appealing but difficult, and that indicator geostatistics with conditional stochastic simulations are a promising approach to quantifying connectivity, thereby inferring preferential flow paths.
Uncertainty

- uncertainty in 3D varies inversely with data density, while data requirements vary with geological complexity

- uncertainty thus relates to data, complexity, and interpretation

- stochastic techniques may be used to compute the probability for each grid cell to belong to a specific lithostratigraphic unit and lithofacies
Delivery & applications

How do I ensure that my output will be readily discovered & used?

Format
Accessibility
Guidance to users
Applications
Examples

What have other people done?

Australia, New Zealand
Denmark, Finland, France, Germany, Italy, Netherlands, Poland, UK
Canada, USA
What have other people done?

8th EUREGEO
Barcelona | Catalonia | Spain | June 15th - 17th 2015
EUropean Congress on REgional GEOscientific Cartography

SAVVING GOODBYE TO A 2D EARTH
INTERNATIONAL CONFERENCE AUGUST 2 - 7, 2015
QUALITY INN, MARGARET RIVER, WESTERN AUSTRALIA

CALL FOR PAPERS
Submission deadline: 1 November 2015
Building complex and realistic geologic models from sparse data
One of the most challenging tasks in digital geologic modeling is to build realistic and useful earth models in situations when the underlying geologic data is sparse or sparse. In cases like this, the common interpolation techniques do not produce adequate results and the model needs to be “sculpted” by the model builder. This task has to be accomplished in a 3D digital environment, while including and honoring all available information. This special section is intended to provide an insight to the reader on what techniques, best practices, and methodologies are at the disposal of geoscientists to tackle these challenges. Case studies on model building from sparse data are also welcome.

Interpretation
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Open 3D Geological Modelling Community
956 members
Proceedings
Examples
Examples
Examples
Examples
Strategies

What should I do next?

Focus on societal needs
Assess status of data and mapping
Raise expectations among users
Long term planning
Institutional databases
Reconcile stratigraphy
Harmonize seamless 2D mapping
Geophysics & drilling
Choose an appropriate approach
Make a plan; build support
Rationale and Methods for Regional 3D Geological Mapping – summary of topics

Rationale - *Why do I need to do this?*

Background - *What do I need to understand?*

Data compilation - *What do I need to compile?*

Data acquisition – *What field work is needed?*

Model construction - *How do I draw layers?*

Geostatistics - *Can I use geostatistical methods to infer solids and their properties?*

Properties, heterogeneity, & uncertainty - *How do I specify the characteristics of layers?*

Delivery & applications - *How do I ensure that my output will be readily discovered & used?*

Examples - *What have other people done?*

Strategies - *What should I do next?*
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