Challenges to be addressed in continental-scale geological models

Zbigniew Małolepszy, Tomasz Gogołek*, Omar Akkawi
** presenting author*

Polish Geological Institute – National Reserach Institute, Poland



Geological Map of Europe, 1875



3D Geomodel of Europe, ca. 2030

Challanges associated with European-scale 3D geomodel

- Harmonization of geological structure across the borders (lithostratigraphy and tectonics)
- Harmonization of semantics and vocabularies across the borders
- How to fill the model continuously across the borders considering legacy, fragmented or missing data?
- Managing uncertainities.
- Institutional, governance, and resource constraints.
- Spatial reference and geometry.
- Scale and resolution.

Covered in this presentation

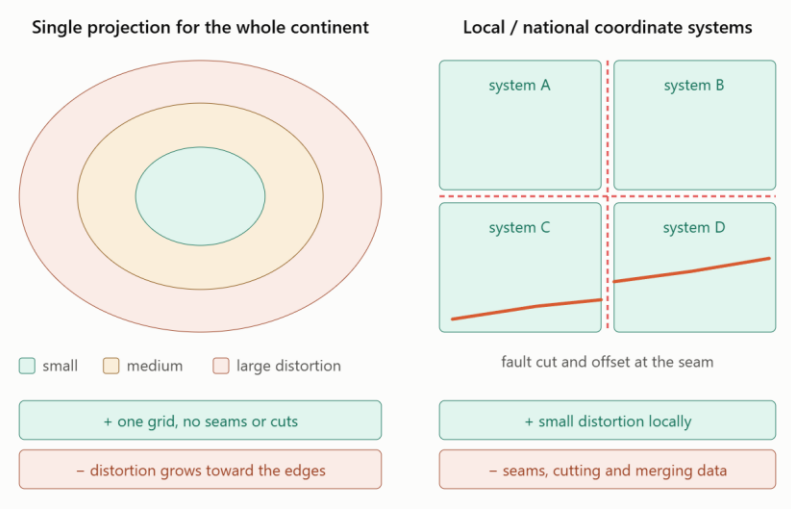
We hope many of you agree that the Earth is not flat ☺

So, considering the size and nature ot the European-scale 3D geological model we should move on from 2D traditional approach of cartography to a full 3D representation of lithosphere including the Earth curvature.

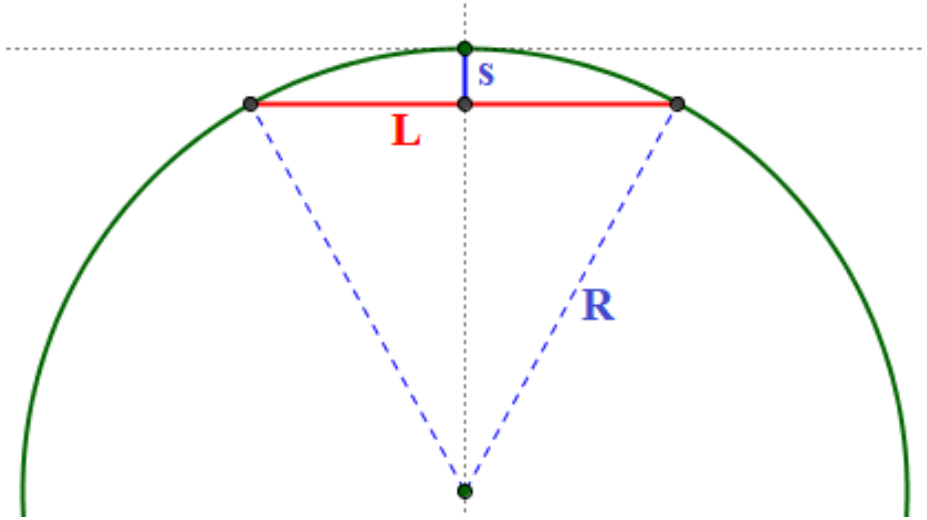
This is main challange as most 3D geological models are created in metric projections of Cartesian space.

Why Rectangular Grids Fail at Continental Scale

- Every flat projection distorts angles, areas or distances - it is impossible to preserve all of them at the same time
- Cell size varies with latitude/location
- Artificial division into zones or national coordinate systems - geological features (faults, formations) that cross zone boundaries must be cut or transformed
- Rectangular grids are inherently 2D, and depth is added separately. The curvature of the Earth means that a ‘layer at a constant depth’ is not a plane on a continental scale



Saggita – indicator of Earth curvature



$$s = R - \sqrt{R^2 - \left(\frac{L}{2}\right)^2}$$

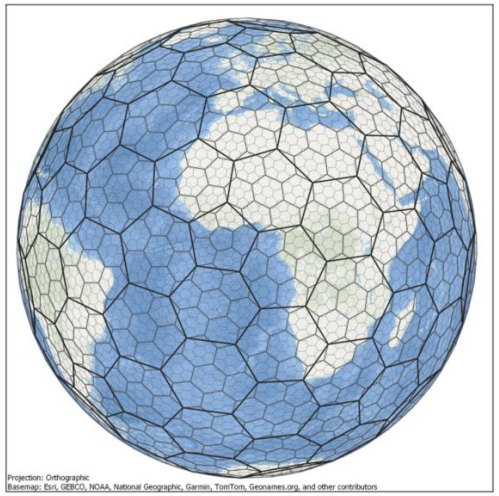
L = distance across the area and $R \approx 6{,}371$ km

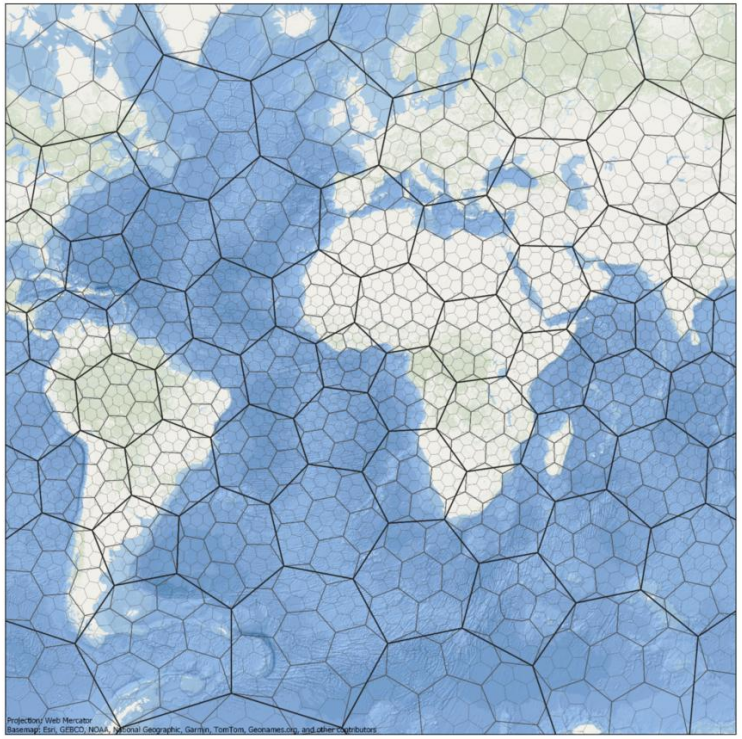
Scale	Span	Sagitta
Local	100 km	**0.2 km**
Country	500 km	**4.9 km**
Large country	1,000 km	**19.7 km**
Europe (Giblartar to Nord Cap)	ca. 4,400 km	**ca. 390 km**

At continental scale, curvature is not a negligible detail but a fundamental property of the geological data space.

Spatial Reference & Geometry Challenges

One of the technologies that may provide the spatial framework needed by the solution is **Discrete Global Grid Systems (DGGS)** - an established OGC standard for global spatial referencing and data organization.





Spatial Reference & Geometry Challenges

- Conceptually, our framework follows OGC DGGS principles (such as ISEA hexagonal tessellations) to discretize the geological continuum into equal-area volumetric prisms.
- To achieve real-time, in-browser 3D rendering and querying for this proof of concept, we implemented the system using H3. It provides an optimized icosahedral hexagonal indexing engine with negligible area distortion over continental Europe and one pentagonal cell anomaly within our area depicted in the model (off the coast of central Norway, in the Norwegian Sea / Trøndelag shelf).
- In further steps ISEA/IVEA would be used in place of H3.

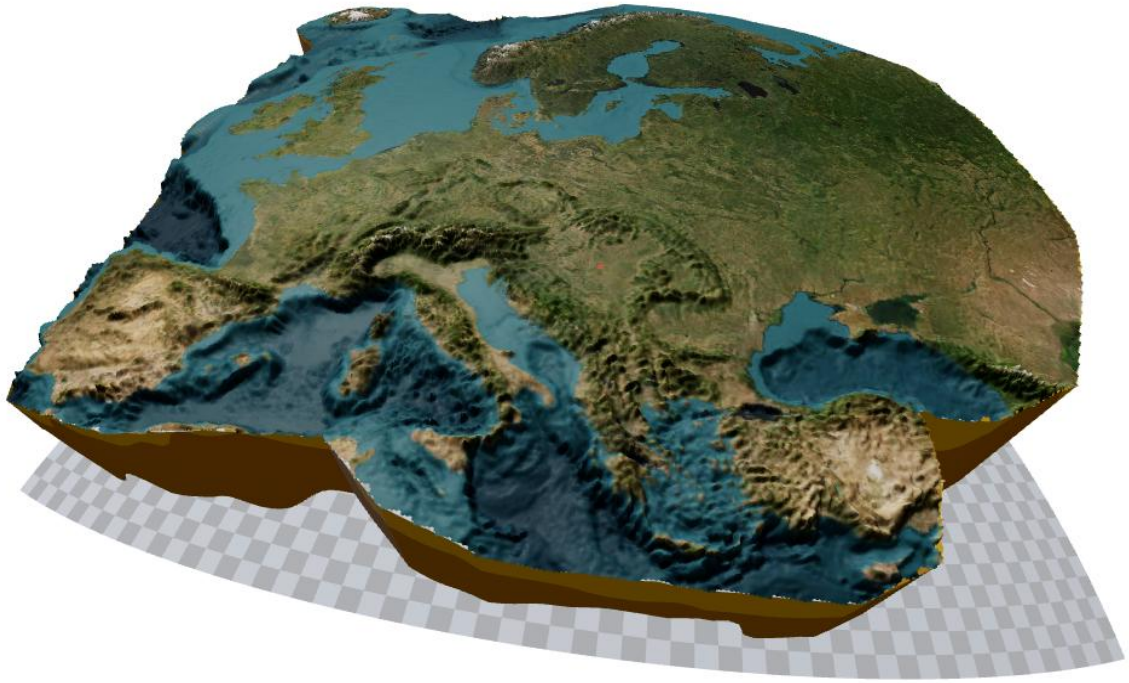
Scale & Resolution Challenges

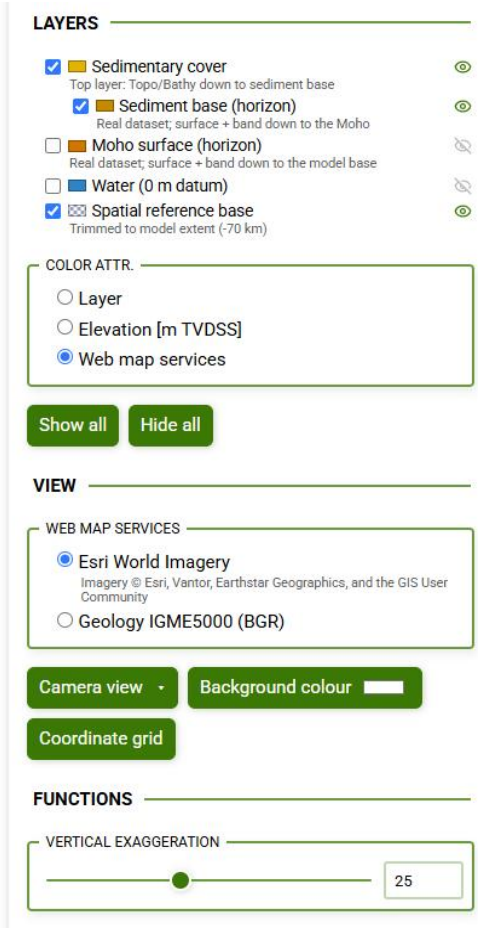
Multi-Resolution Framework (LOD): Structuring a single platform capable of dynamically managing multiple Levels of Detail (LOD) from coarse continental baselines down to high-resolution local features.

Hierarchical Data Ingestion: Establishing automated workflows to aggregate, generalize, and harmonize 3D models across all operational tiers—from local field studies to national-scale frameworks.

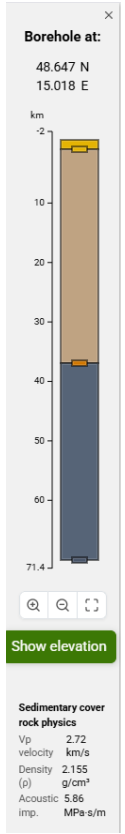
Vertical Dynamic Range: Balancing high-resolution, parameter-rich shallow near-surface data with deep, geophysical-driven crustal units within a single unified model.

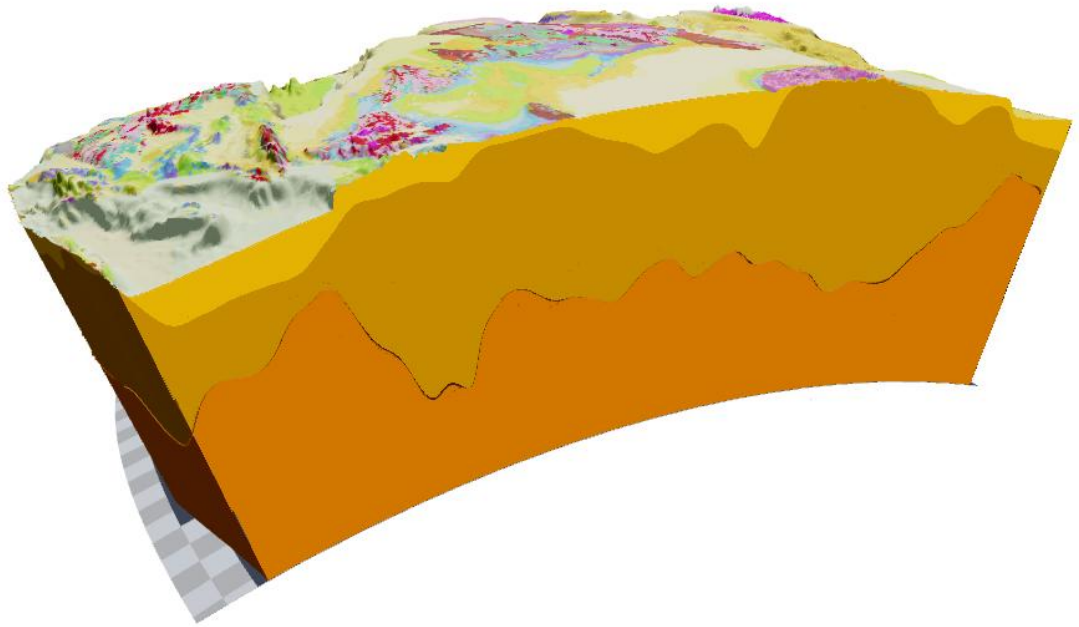
Conceptual Framework of European-scale 3D Geological Model





Conceptual Framework of European-scale 3D Geological Model





- Easy to outline having Geo3D viewer
- DGGS H3 spatial reference system
- Multiresolution and Level of Details
- Depth to 70 km
  - Layering by global grids:
  - Sedimentary cover
  - Upper crust
  - Litospheric mantle
- Smart vertical exaggeration
- Virtual drilling
- Cross-sections

Closing remarks:

We face the spatial & geometric challenges by:

- Moving from projected Cartesian models to a discrete global grid of equal-area volumetric prisms.
- Using hierarchical indexing (H3 now → ISEA later) for seamless multi-resolution aggregation.
- Treating Earth curvature as a fundamental property of the data space, not a correction.
- Keeping one unified column structure from surface to a given depth (70 km in the prototype).
- We create this proof of concept for visualisation and dissemination of European-scale 3D geological model.
- Time will show if building the model or its national parts can be done in this new approach.

Demo

3D Geological Model of Europe - DGGS proof of concept

https://geo3d.pgi.gov.pl/Europe_3D_test/index.html

Thank you for your attention!

We are waiting for your feedback