Applying 3D Geological Modeling to Infrastucture Design

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Introduction

- Background
- Geological Modeling Process
- Applications Involve Predictions: this involves risk and leads to decision making
- Three United Kingdom Examples
- 3D for Urban Infrastructure Planning
  - Sustainable Cities
  - Geo-BIM Concepts
- A Look Forward

Why Is Modeling & Visualization Important?

The World of the Geoscientist Is Multi-dimensional

- Current interpretation methods limit this view
- Digital versions of traditional maps are not sufficient
- Increased efficiency demands computer-based methods to:
  - *Integrate and Manage* the data
  - *Interpret* geological features
  - *Visualize* attributes spatially and temporally
  - *Model* dynamic Earth processes

Importance of This Topic …

- 3-D subsurface modeling first became feasible in late 1980’s with the introduction of high-performance Unix-based graphical workstations

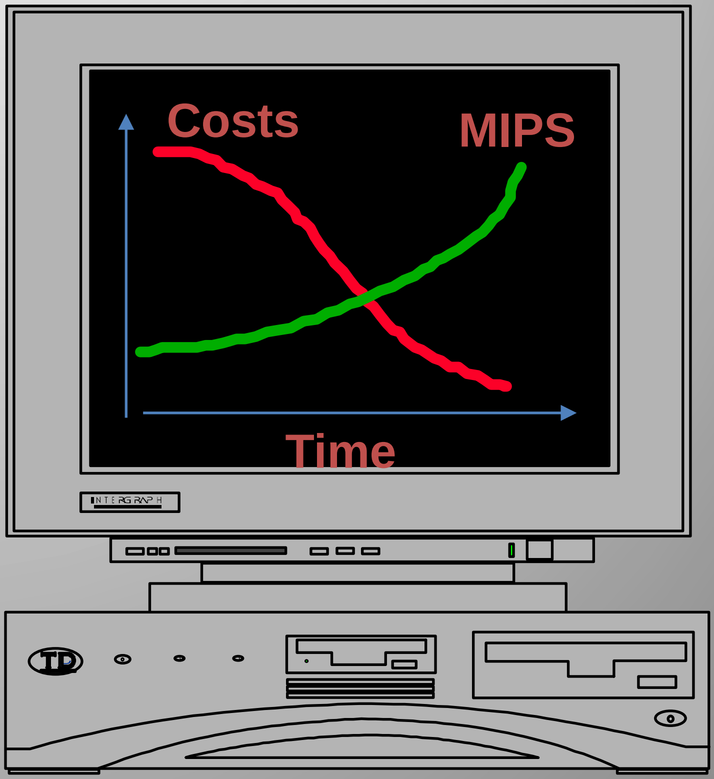
- Developing digital representations of the subsurface does not ensure high-quality and efficiently managed projects

- Society is increasingly demanding:
  - multi-scale, multidisciplinary, integrative projects
  - a shift from passive data collection and archiving to dynamic information management and dissemination

Since 1990

Enormously more powerful computers and data storage have vastly reduced costs!

- Continuing, rapid advances in computer HARDWARE and SOFTWARE technologies
- Modeling & visualization increasingly integrated
- Increasingly realistic models possible

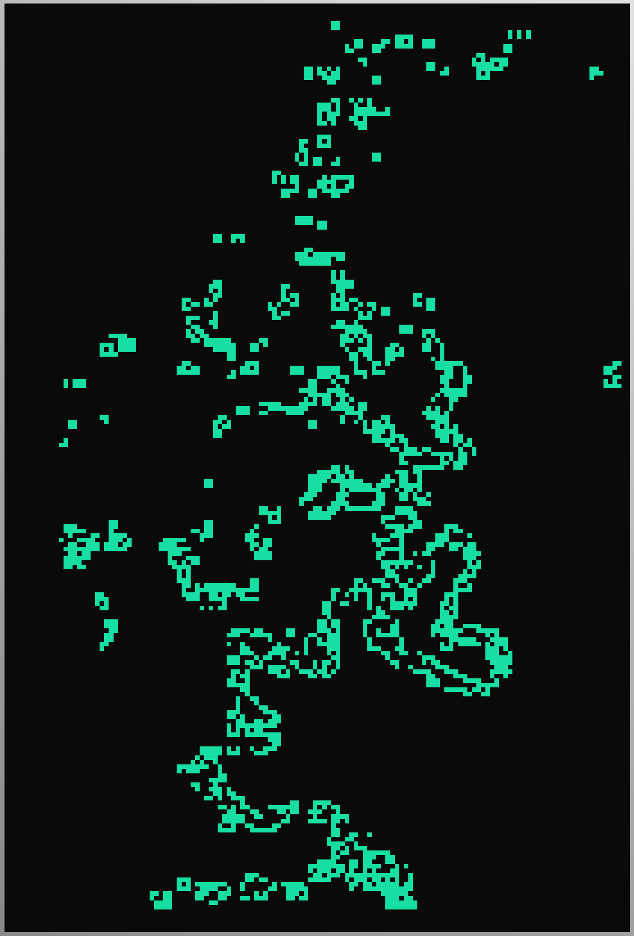


Problems in Subsurface Investigation are Unique…

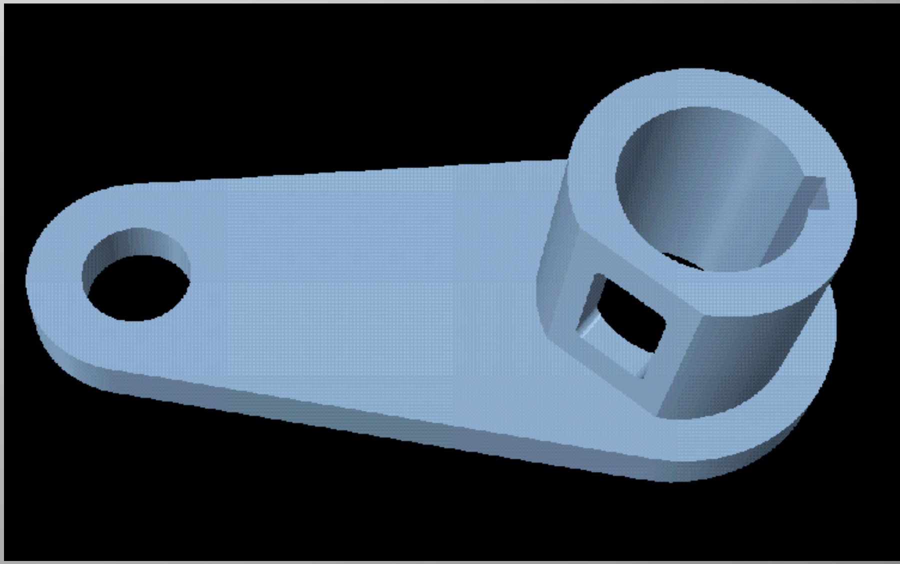
- Subsurface information is often incomplete and conflicting;
- The subsurface is naturally complex and heterogeneous;
- Sampling is most often insufficient to resolve all uncertainties; and
- Scale effects on rock , fluid, and other properties are usually unknown.

Why We Need Special Modeling and Visualization Tools and Not Just CAD

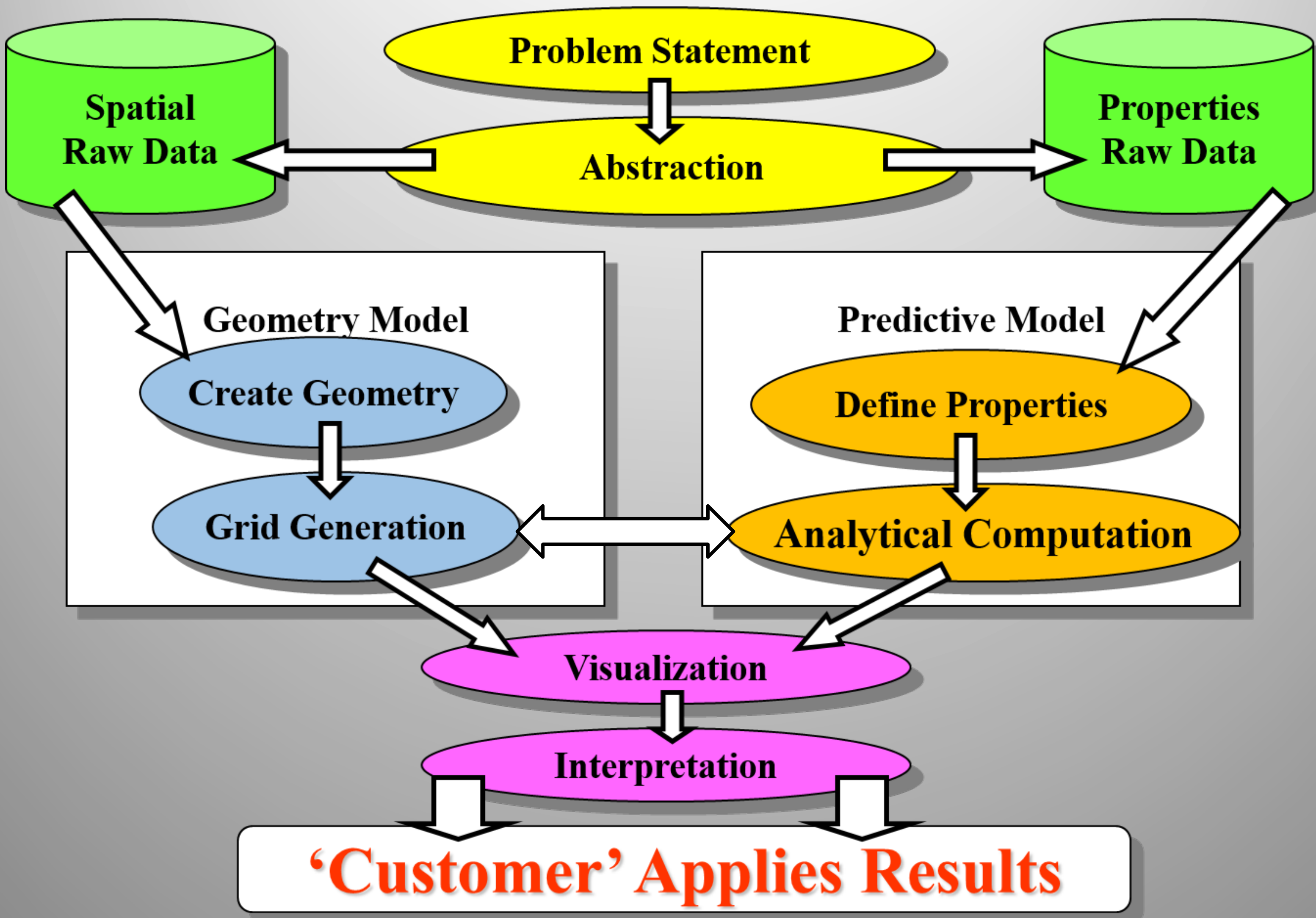
GEO-OBJECT



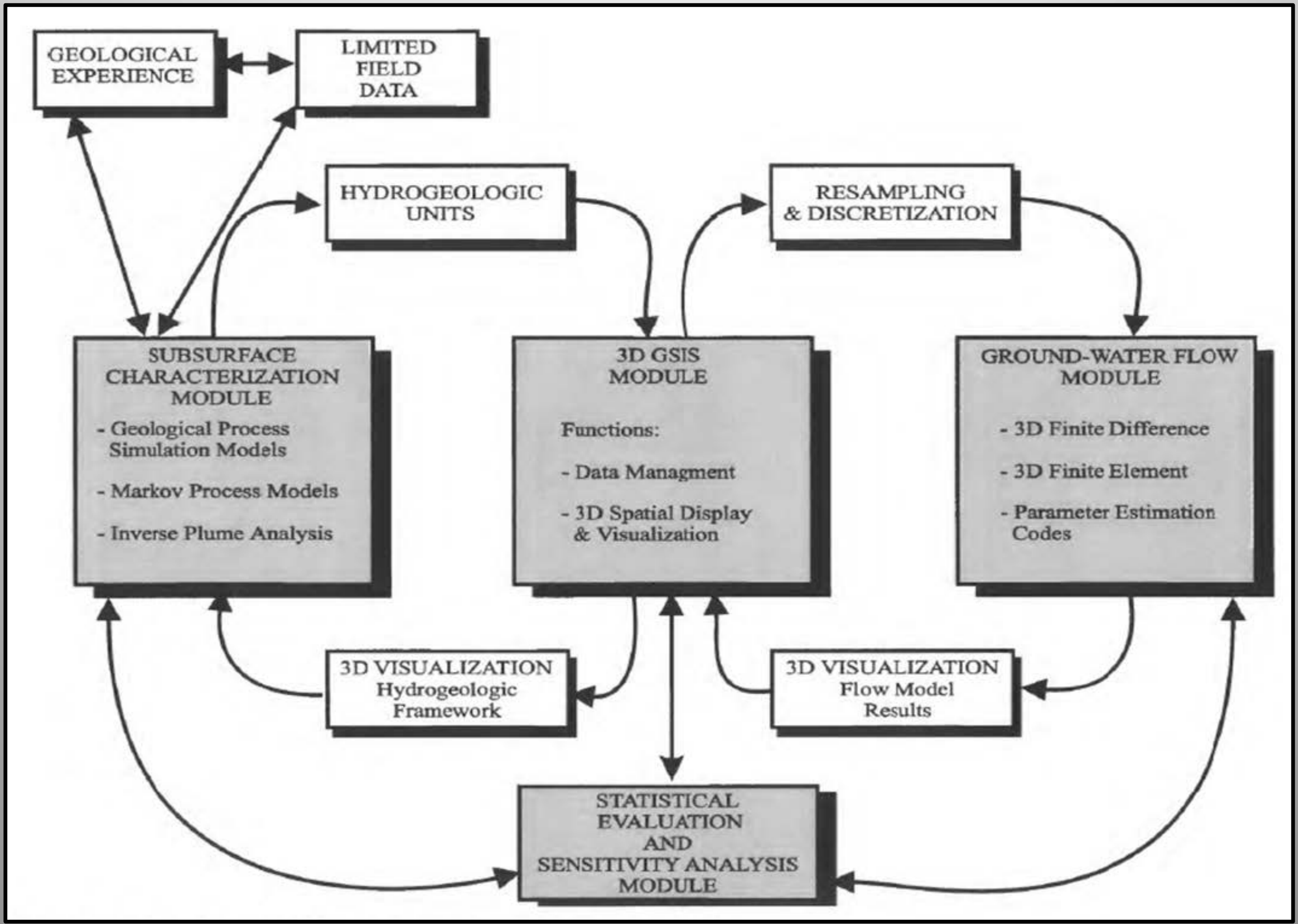
ENGINEERING OBJECT



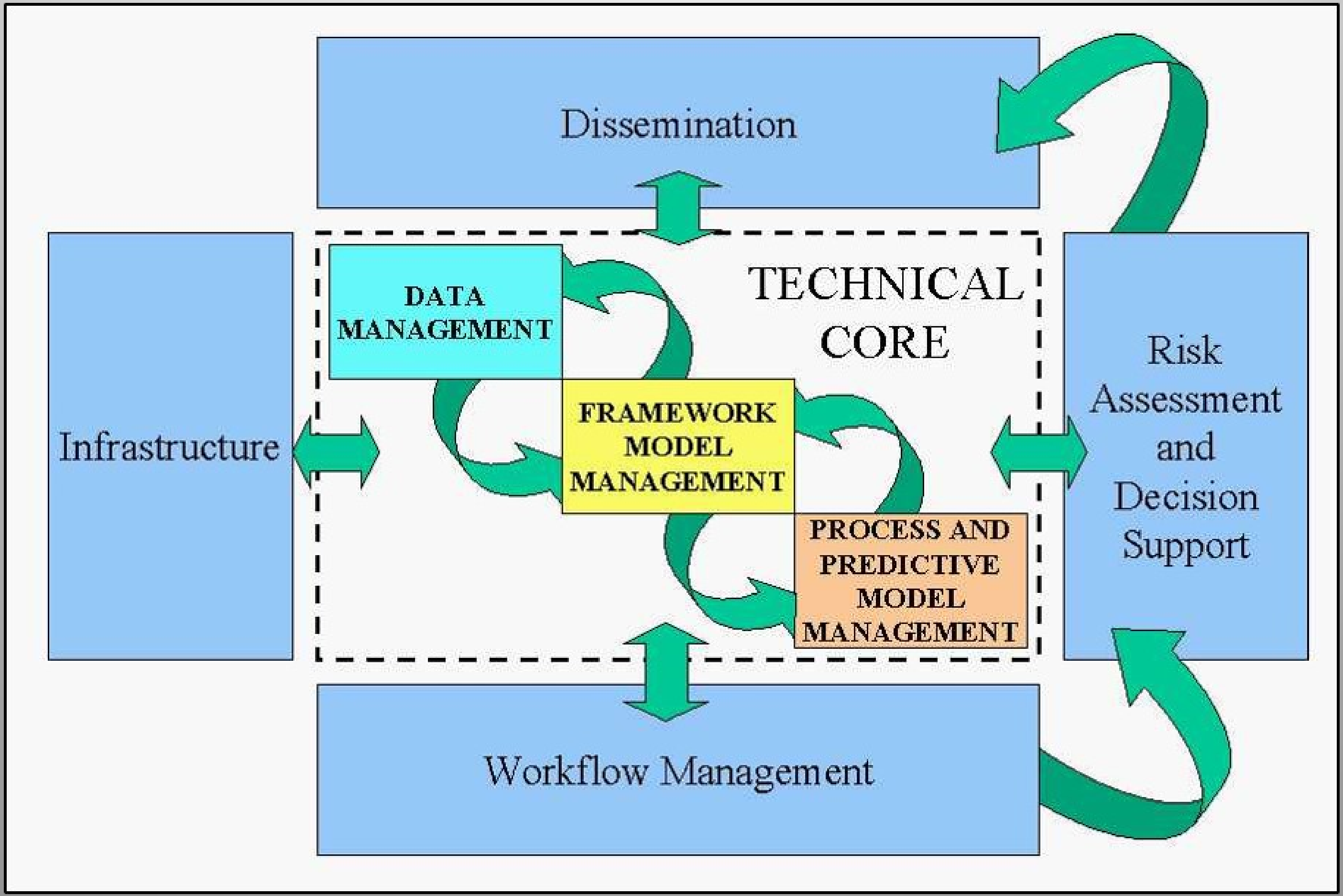
Overview of the Geological Modeling Process



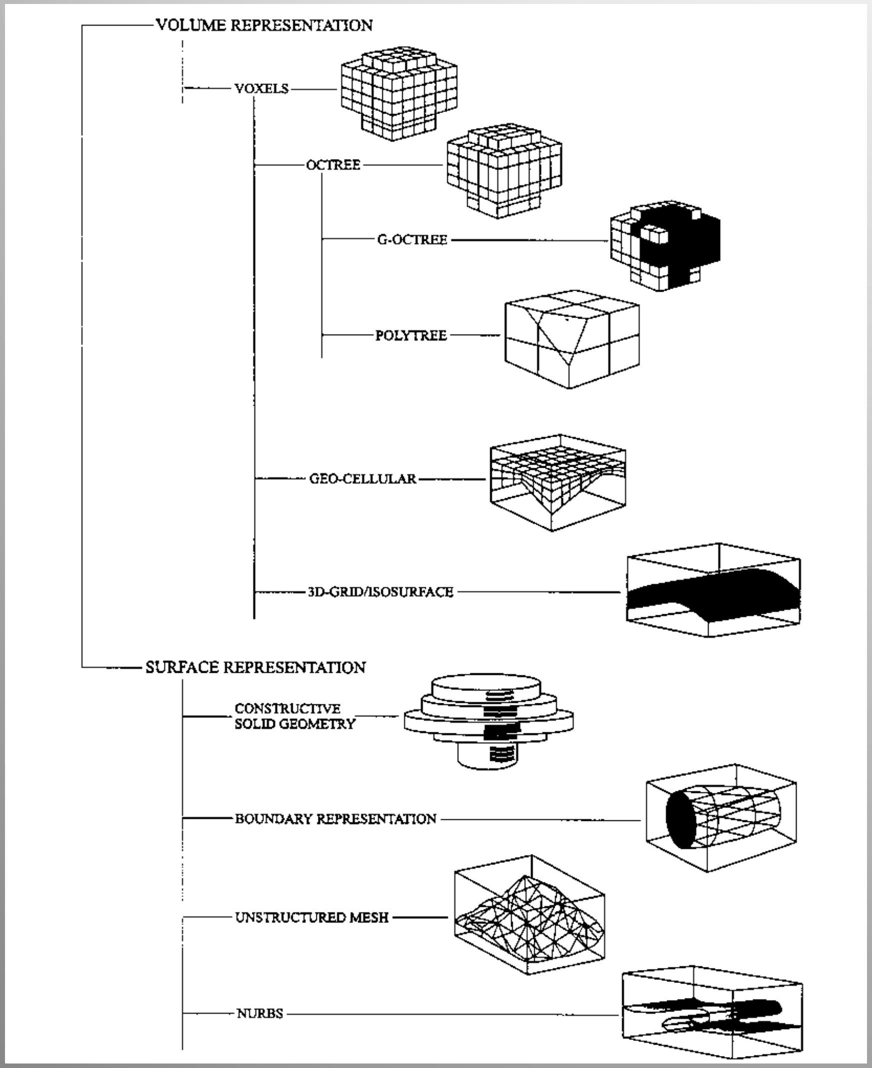
3D Modeling Workflow Concept circa 1994



Modeling & Data Management Concept circa 2002



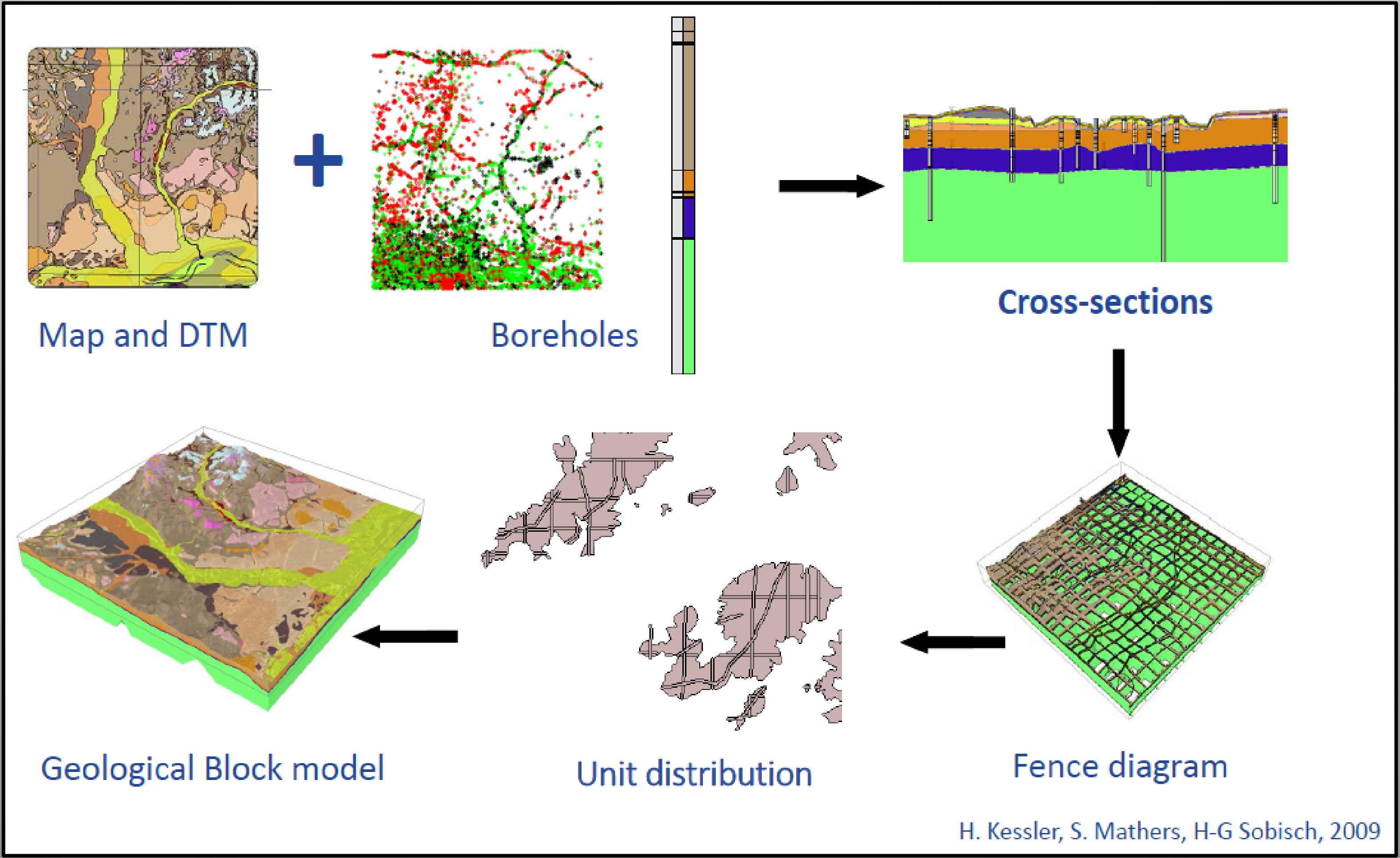
Many Model-building Techniques



- **Volume Representation**
  - **May be used as primary model construction**
  - **Frequently used during a 2nd stage of DISCRETIZATION**
  - **Important inputs to many applications**
- **Surface Representation**
  - **Often used to define geological framework**
  - **CSG not very suitable for geology – useful for man-made objects (so in CAD products and BIM)**

Typical 3D Model Creation Workflow

- This is GSI3D Workflow at BGS -



Creating a 3-D Model Involves Two Stages

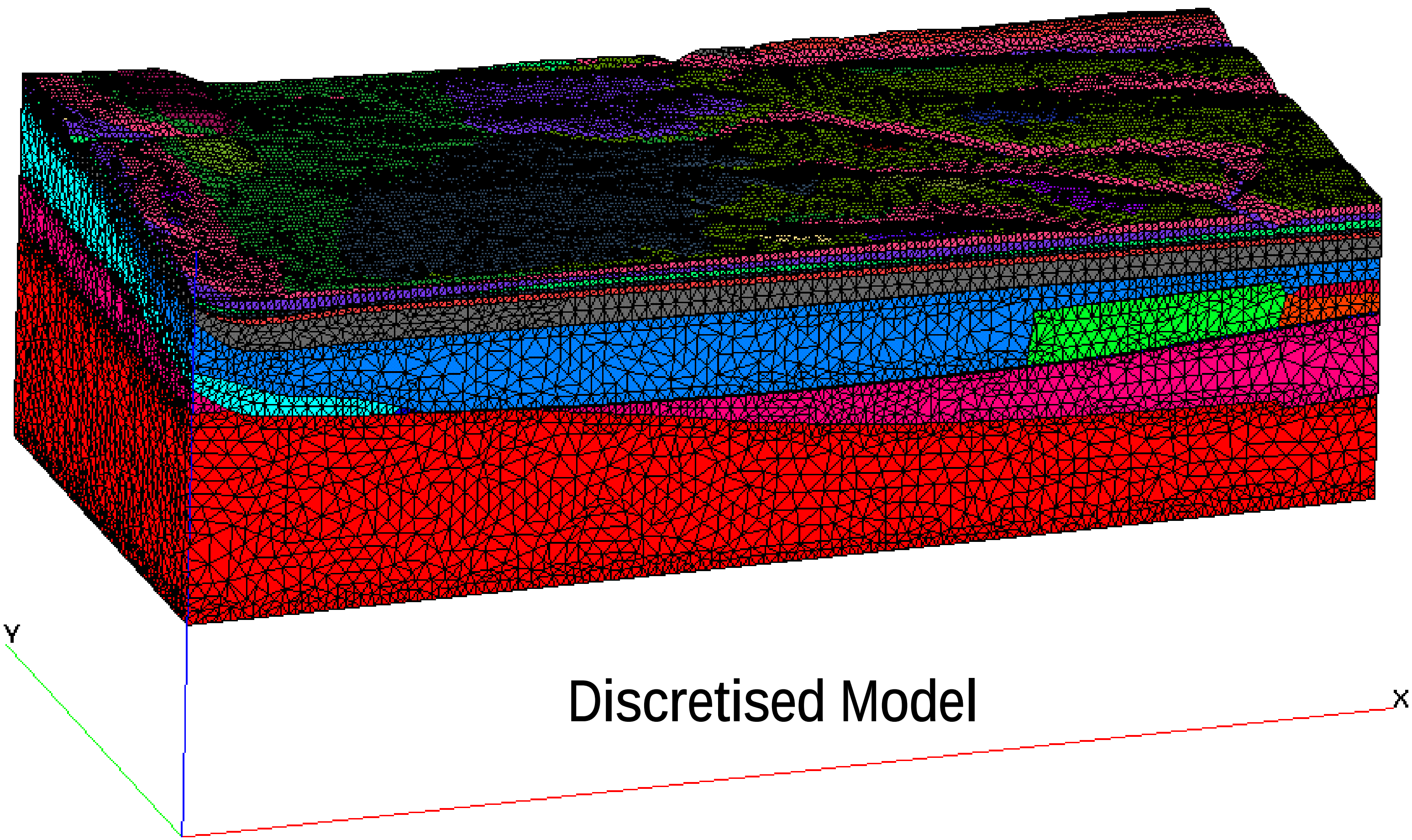
Framework Definition

- Borehole and isolated sample data
- Triangulated surfaces
- 2-D grids and meshes
- Iso-volumetric models
  - from triangulated surfaces
  - from cross-sections
  - from grids and meshes
  - parametric (NURBS, etc)
  - Boundary Representations

Discretisation and Property Distribution

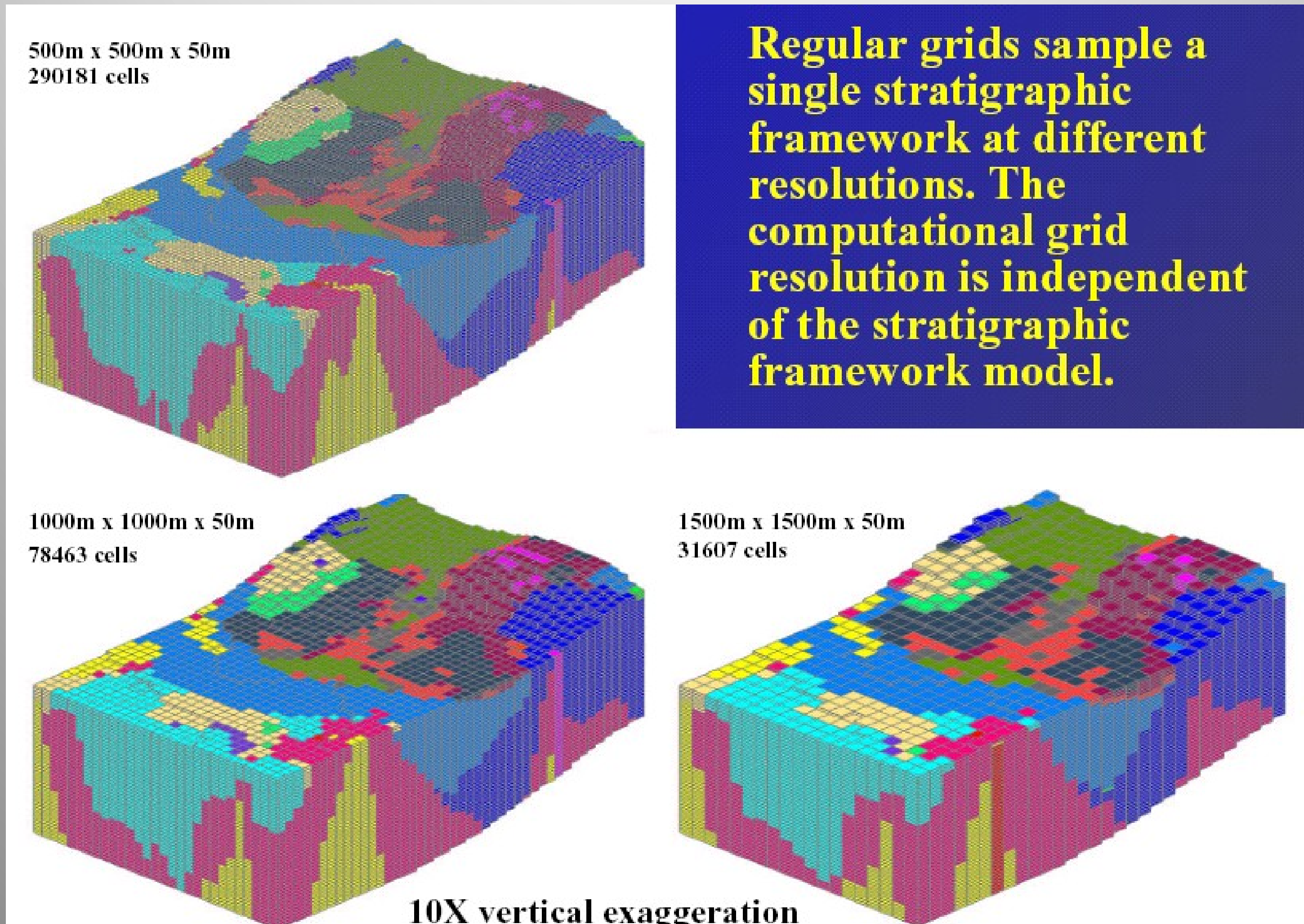
- 3-D grids and meshes
  - regular hexahedral
  - octree variable
  - geocellular
  - tetrahedral unstructured meshes

Framework Models require Grids or Meshes to assign Property Distributions

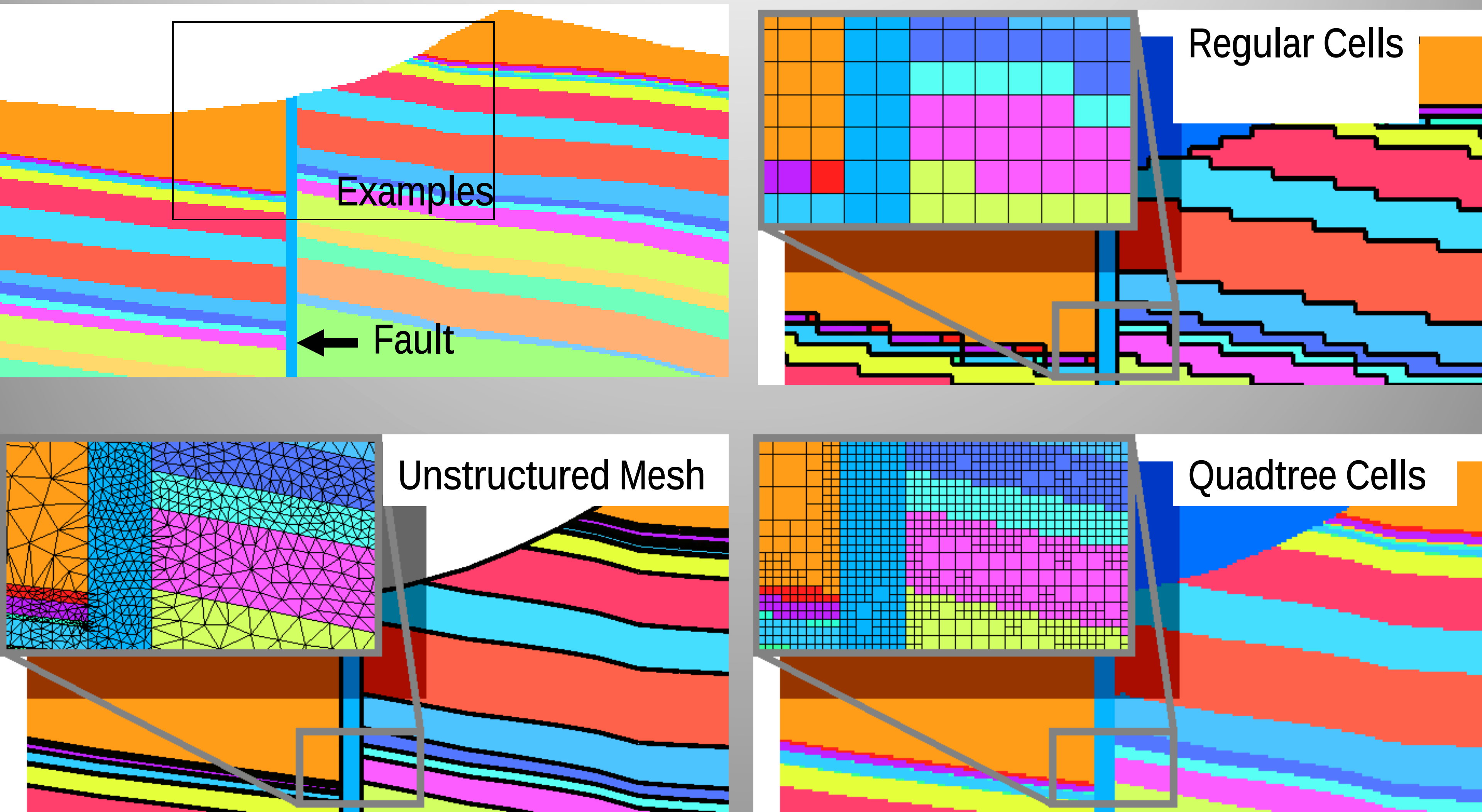


Discretised Model

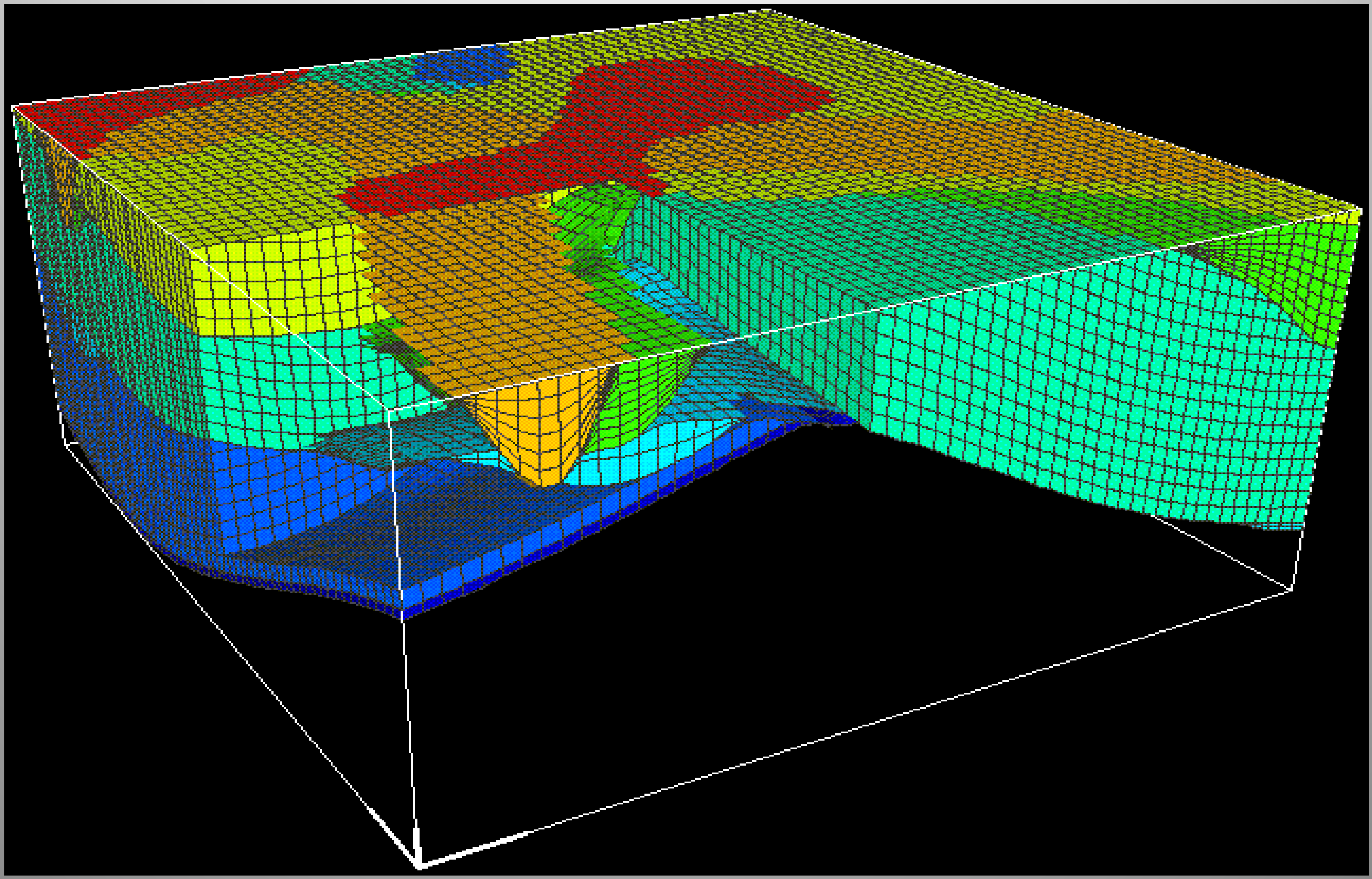
Geological Framework Defined First – then Grid Resolution



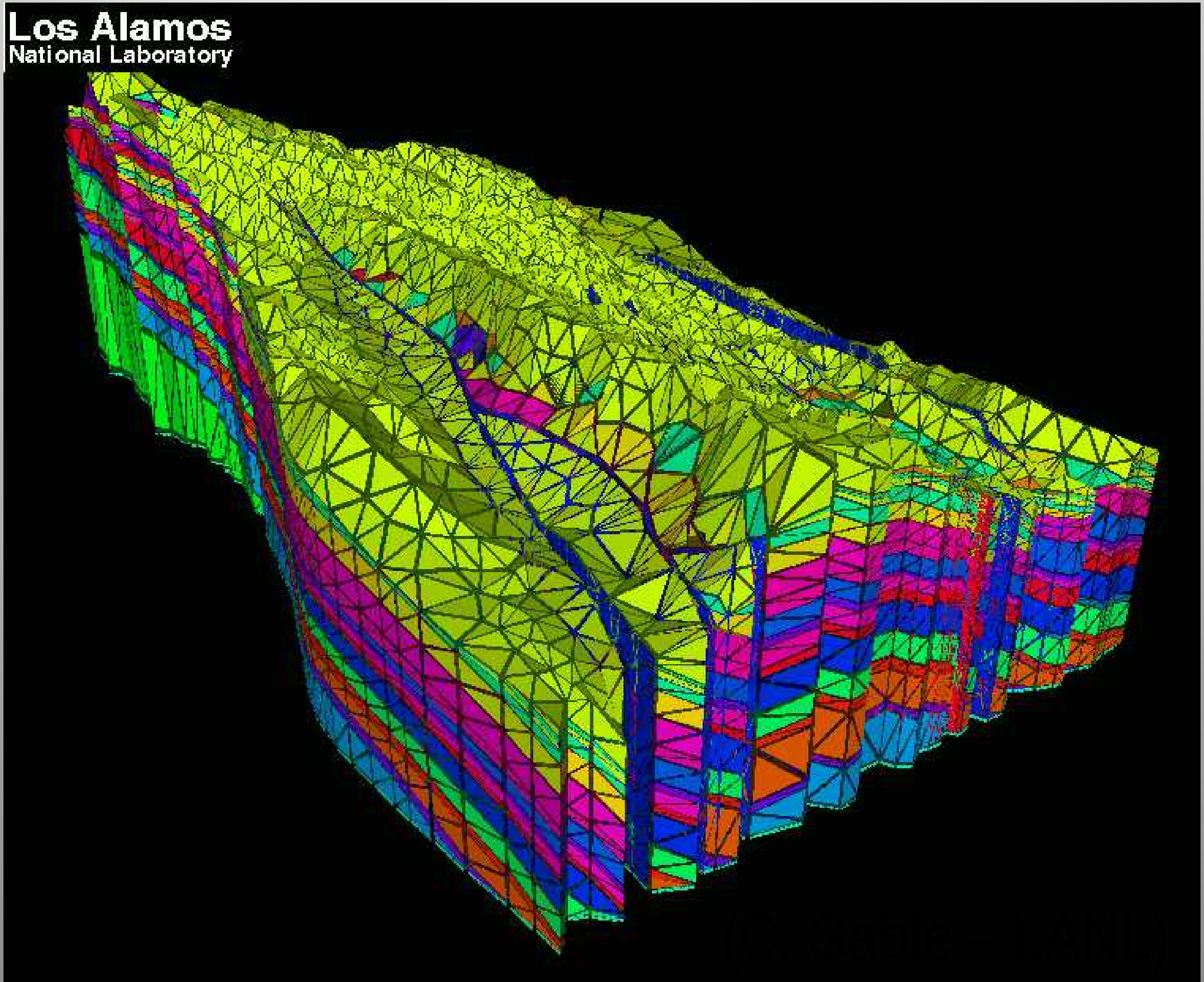
Discretisation may involve “structured” and “unstructured” meshes



“Geocellular” Volumetric Model

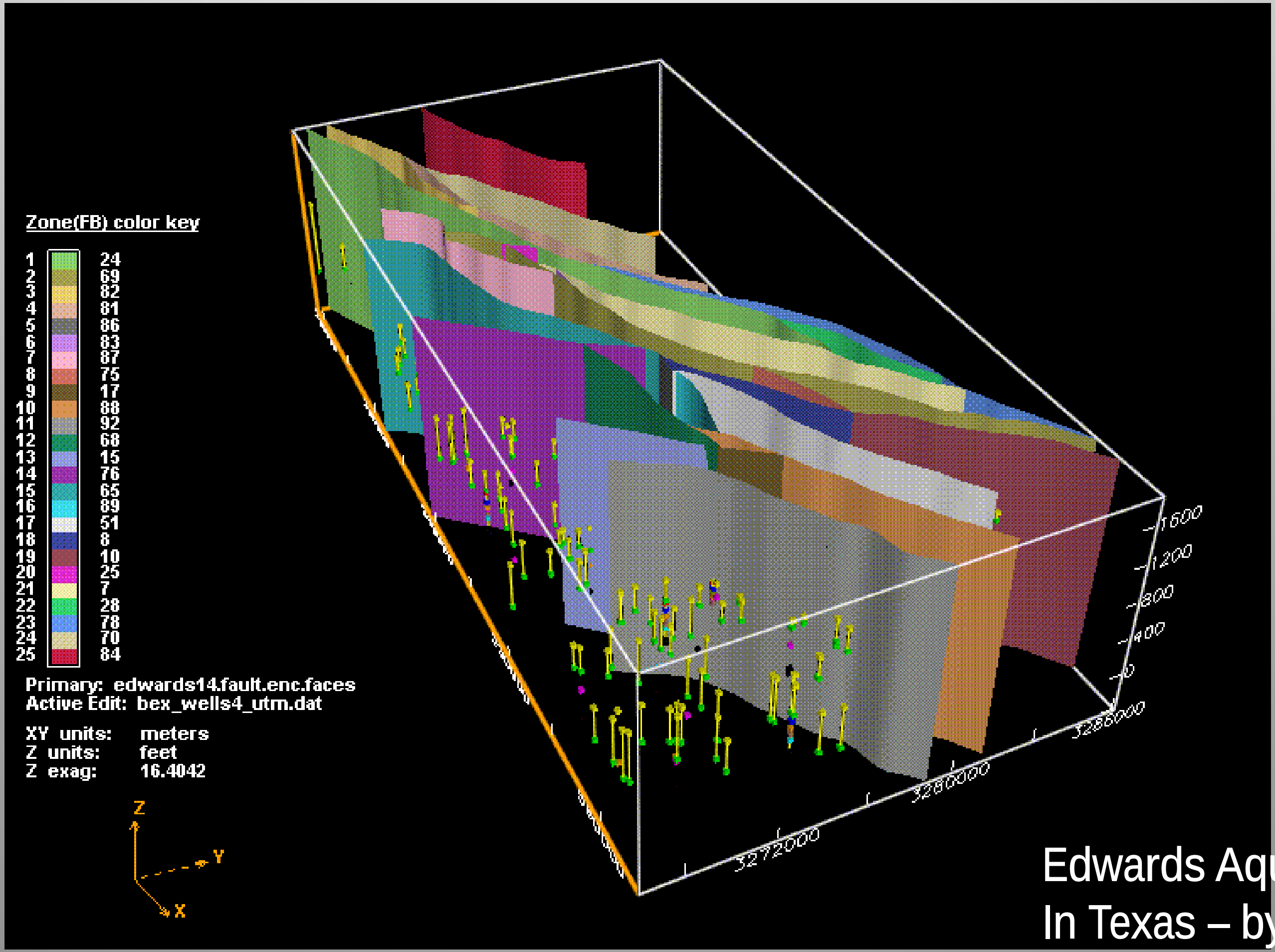


Yucca Mountain Represented by a Tetrahedral Mesh Model



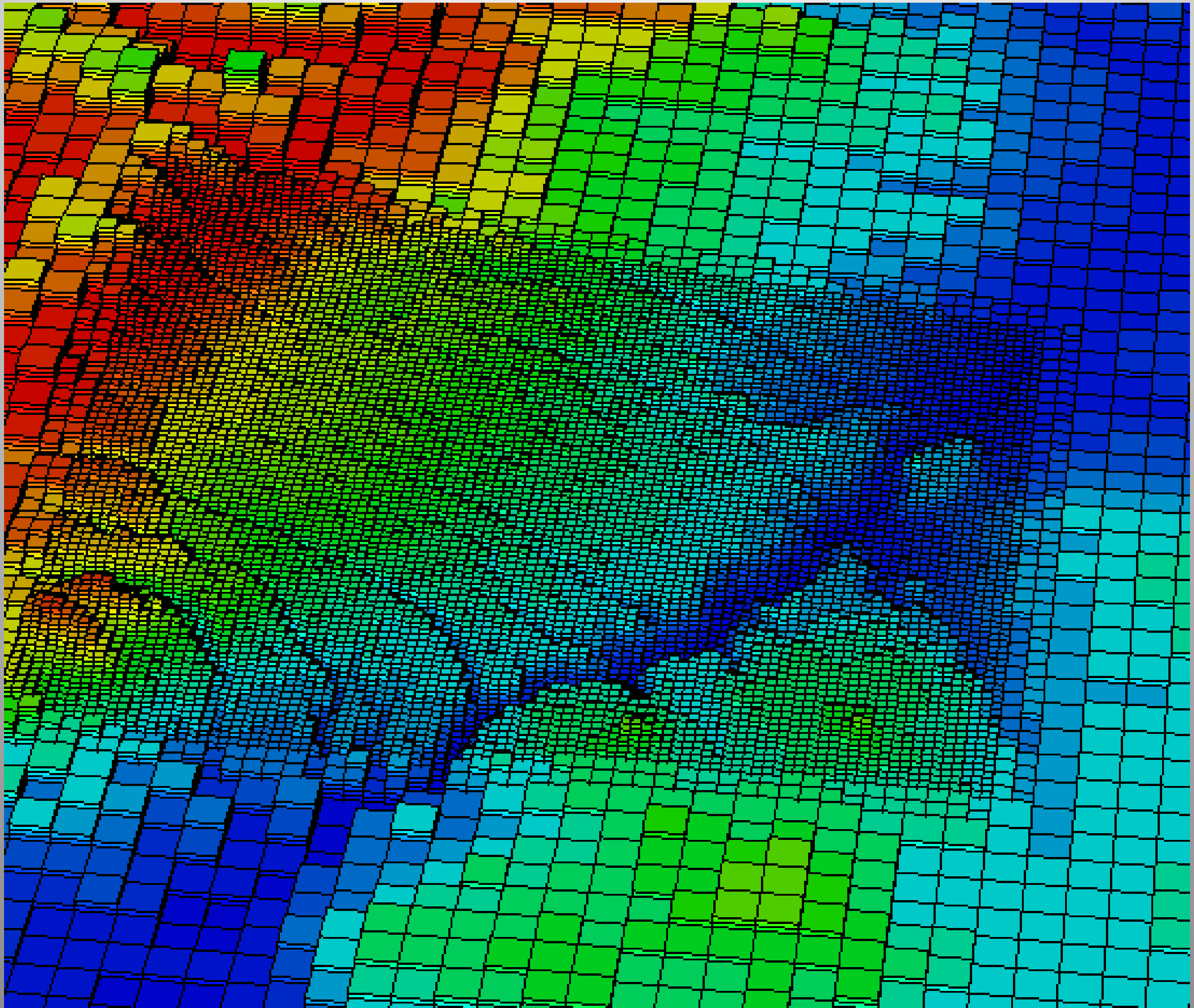
Accurately Modeling Faults is a Challenge

- Near-horizontal thrust faults form additional surfaces
- Steeply inclined Faults commonly shown as vertical



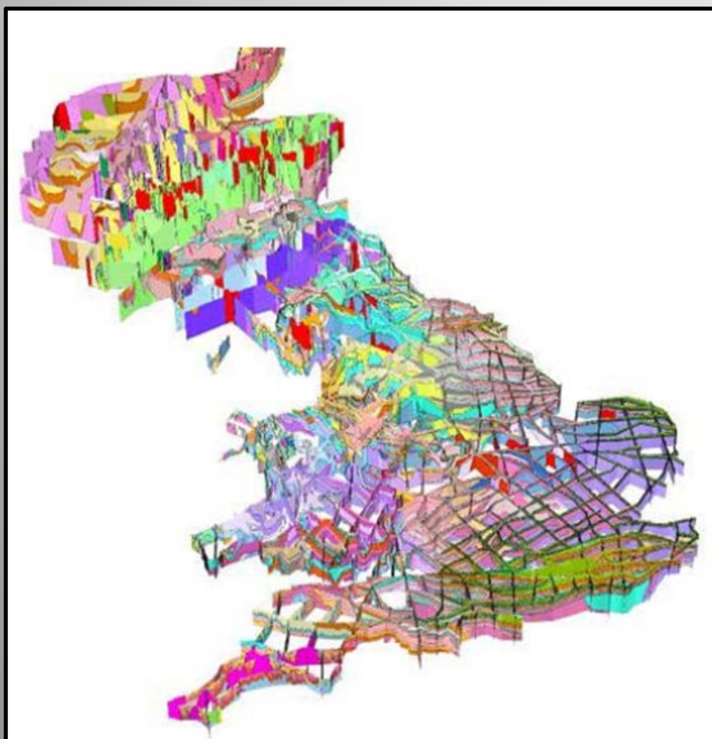
Edwards Aquifer Model
In Texas – by USGS

Models may be "Nested" from Regional to Local Scales

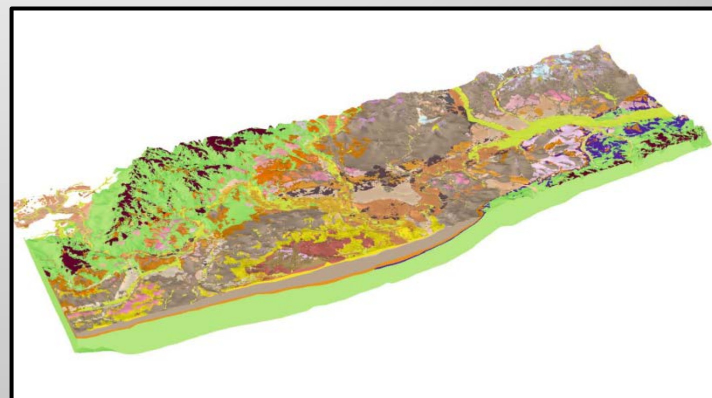


Model Applications at Many Scales

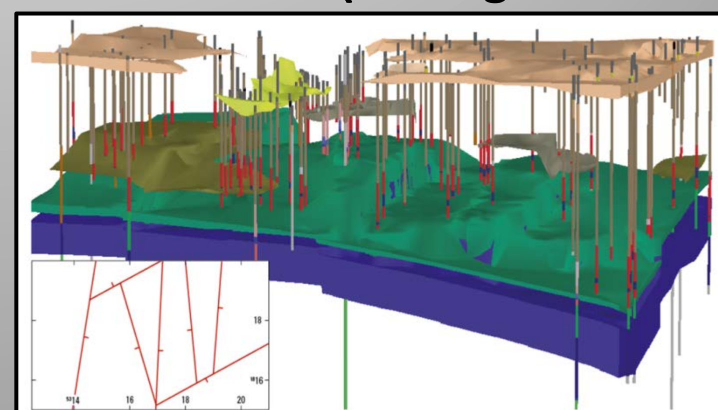
National 3D UK Model



Regional 3D Model (London)



Site 3D Model (Farringdon Station)



The Ultimate Purpose of 3D Geological Modeling is Prediction…

Prediction has an ***extrapolative*** rather than ***interpolative*** character…

- Involves risk
- Leads to Decision-making

Three Recent United Kingdom Examples

1. Planning for Electrification of Railway between Leeds and York (2015)
2. Farringdon Station for London CrossRail Project (2009-2015)
3. Aquifer Recharge Assessments in an Urban Environment (in Manchester in 2006)

Planning for Electrification of Railway between Leeds and York (2015)

- 28 km (17.5 miles) existing railway line is planned for electrification.
- Concern for foundations of support masts
  - Depth to bedrock, type of rock, weathering
  - Old mine workings, karst features, fault structures
- Long narrow 3D model created along railway
  - 28 km long; 80 m wide, 30 m deep
  - Outputs transferrable to Bentley Microstation
- BGS completed/delivered model in 1 month

Planning for Electrification of Railway between Leeds and York (2015)

- A 4 km long section of central portion of route

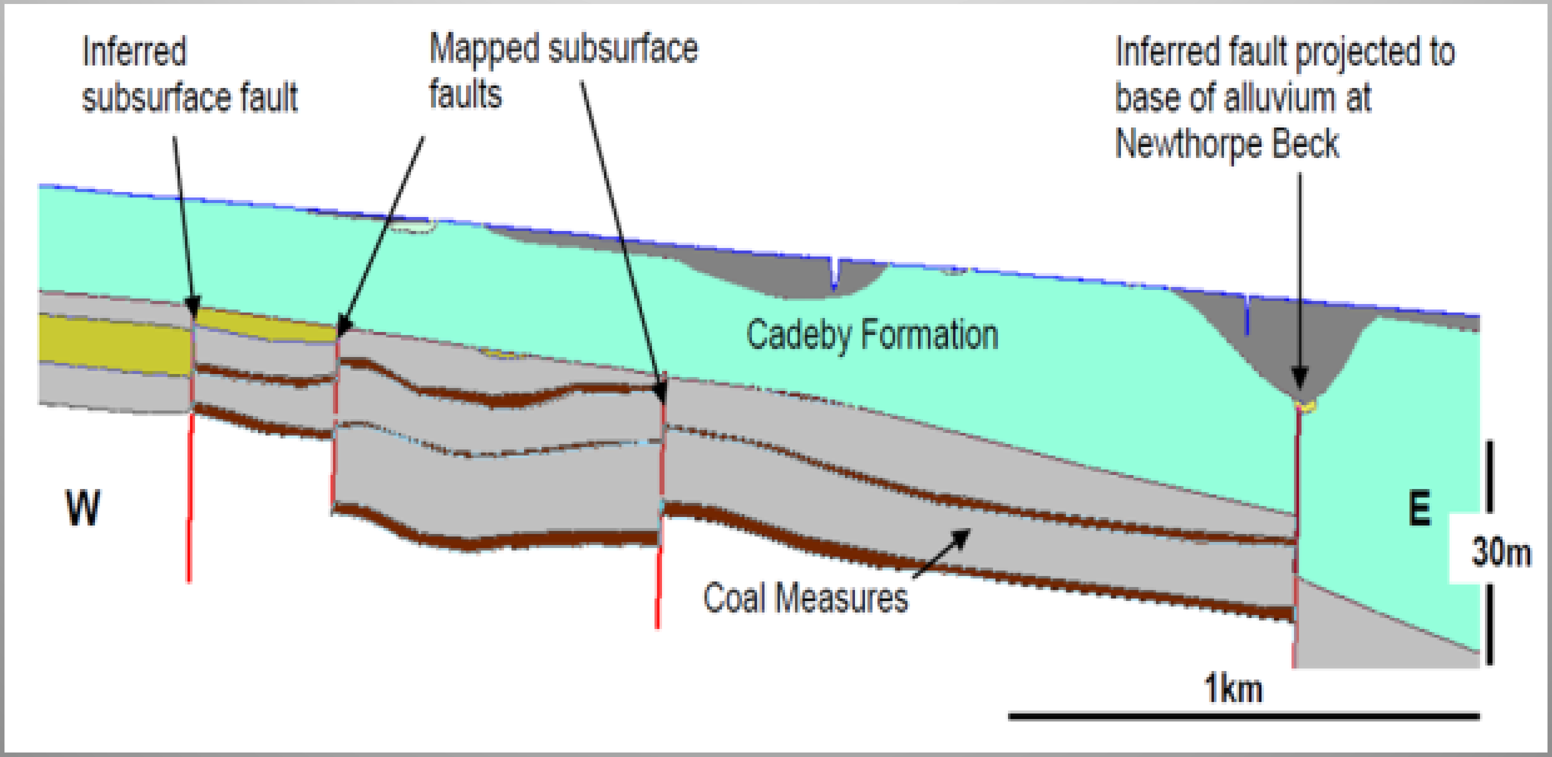
- Model consists of 3 parallel sections, and numerous short "rung" sections (25 shown in this portion of route)
- Model based on 1:10,000 BGS maps and 102 borehole logs
- Model contains 57 geological units, 11 coal seams, 29 faults

Planning for Electrification of Railway between Leeds and York (2015)

- **Isometric view of 3D model (central 4 km section)**

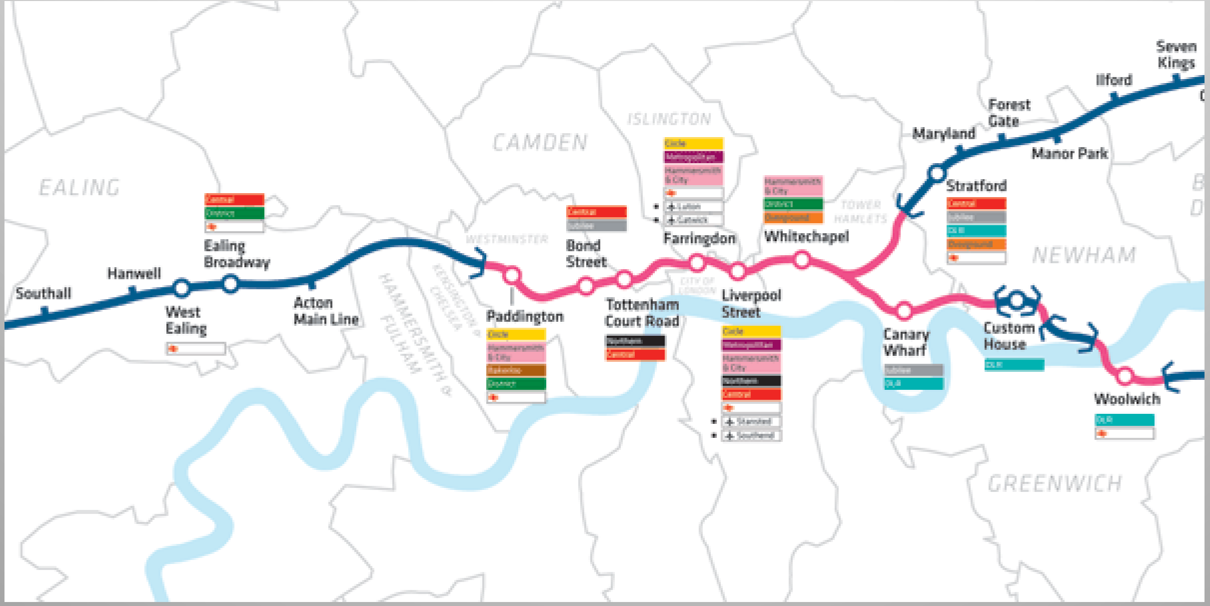
Planning for Electrification of Railway between Leeds and York (2015)

- Center-line Cross-section of 3D model (central 4 km section)
  - showing faults



Farringdon Station for London CrossRail Project (2009-2015)

- Crossrail will link Reading and Heathrow in the west with Shenfield and Abbey Wood in the east via new tunnels under central London



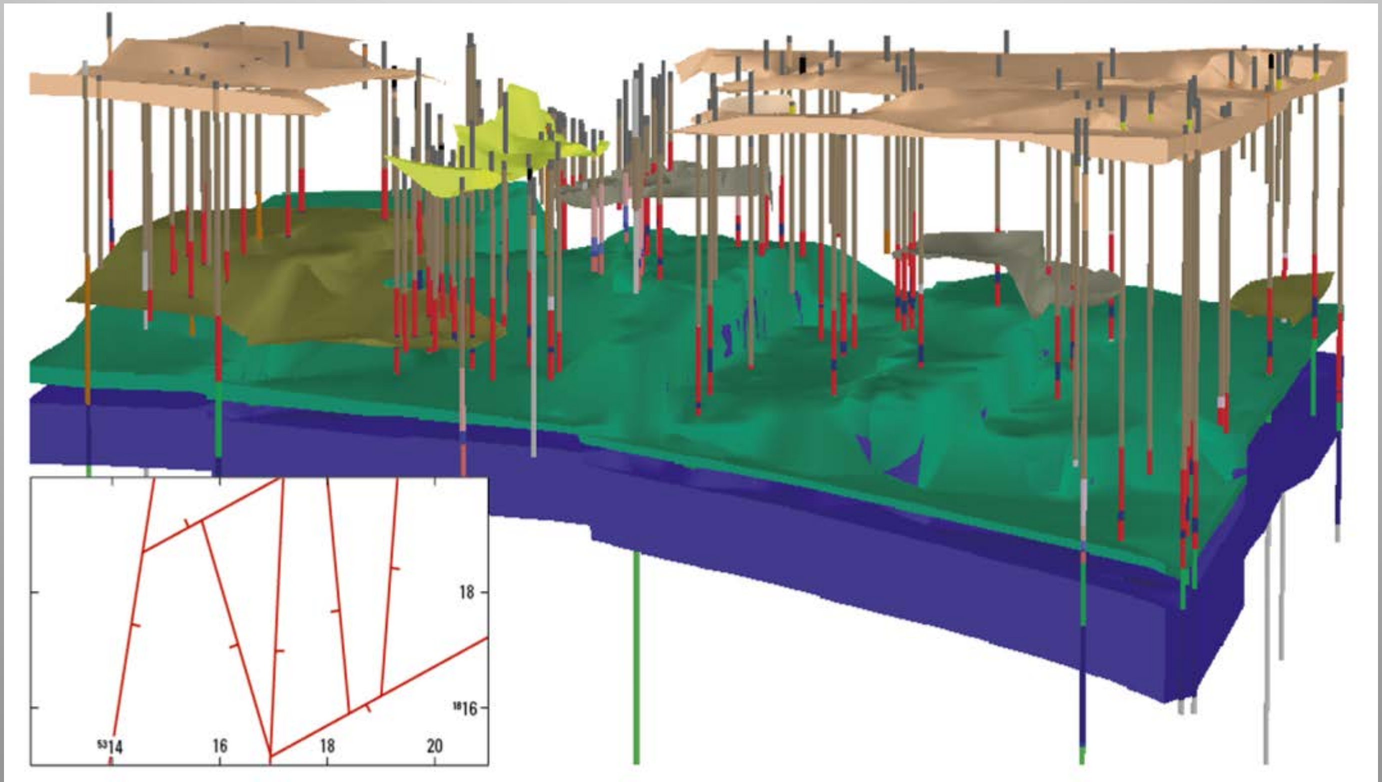
- Crossrail will bring 1.5 million more people within 45 minutes of central London.
- When it opens fully in 2019 , Crossrail will increase London's rail transport capacity by 10%

Farringdon Station for London CrossRail Project (2009-2015)

- In 2009 the BGS developed an initial 3D geological model of Farringdon station
- Model based on previous London 3D model, plus additional Crossrail data
- In 2013, this model was handed over to the design consultants and was integrated in the site supervision workflow
- Model updated on daily basis as station excavated
- Geotechnical Risk reduced
- Station excavation completed 3 months early

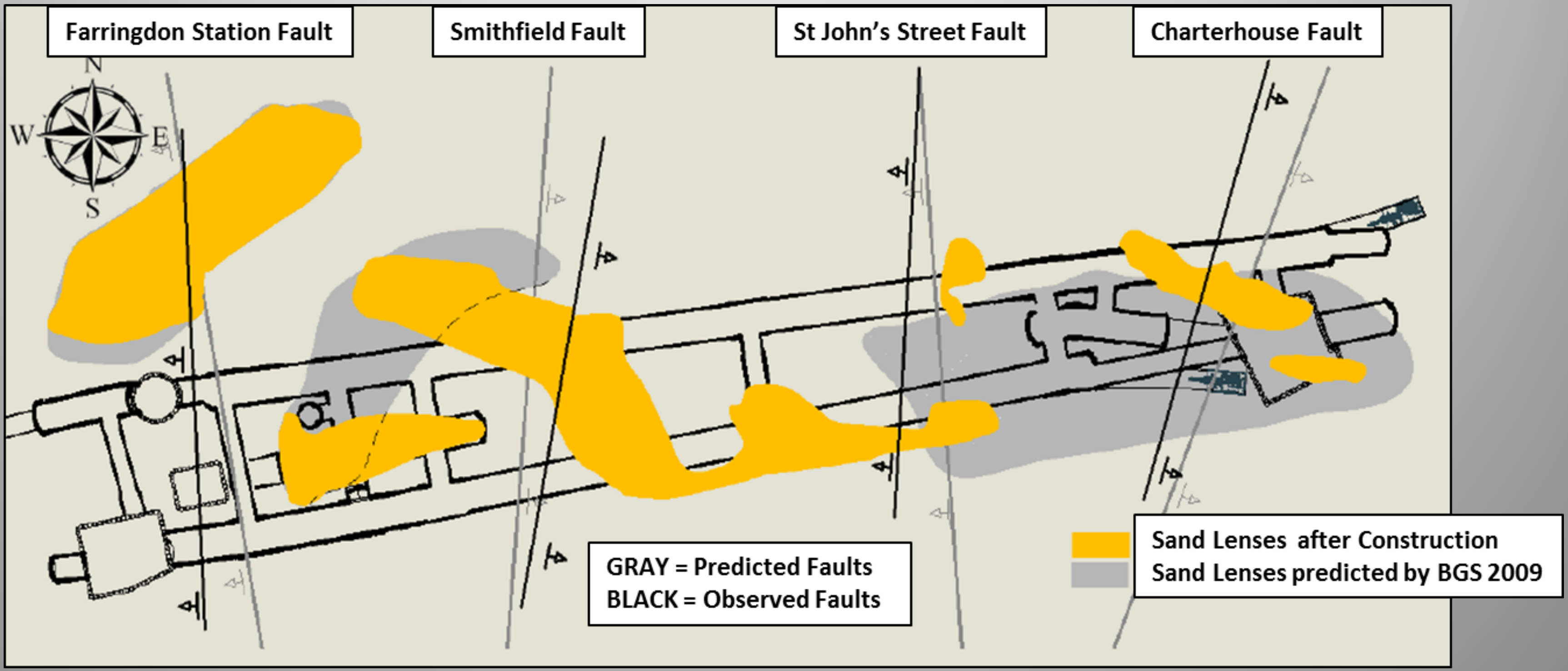
Farringdon Station for London CrossRail Project (2009-2015)

- **3D model display of sand and gravel (water-bearing units encountered at Farringdon**



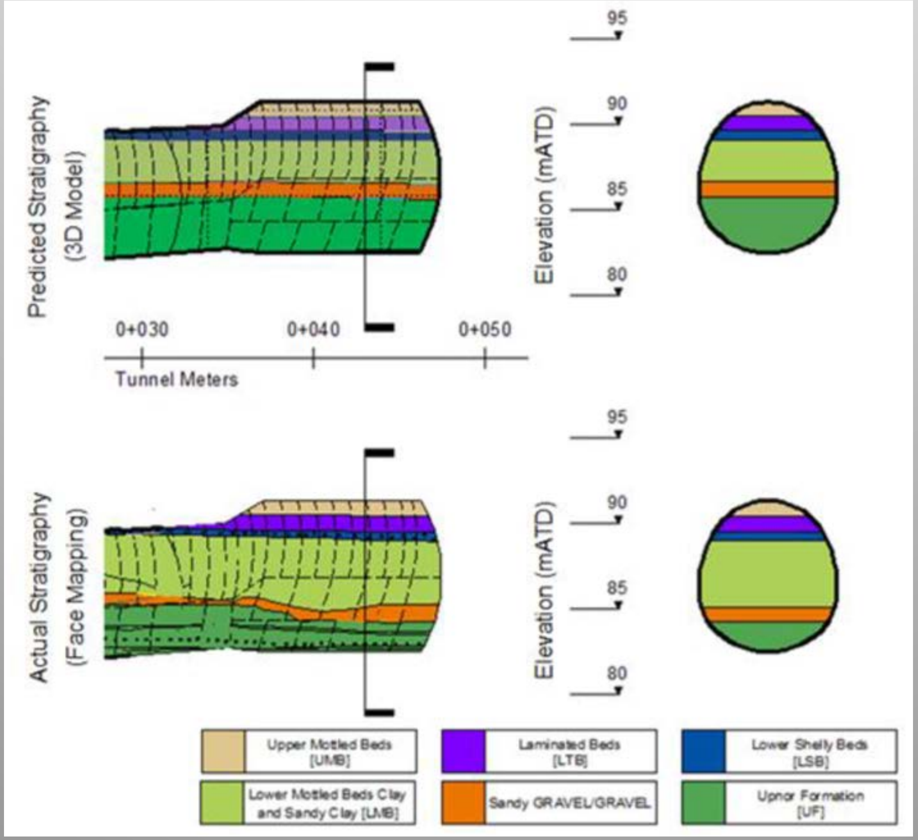
Farringdon Station for London CrossRail Project (2009-2015)

- **Predicted and Observed locations of sand lenses and faults**



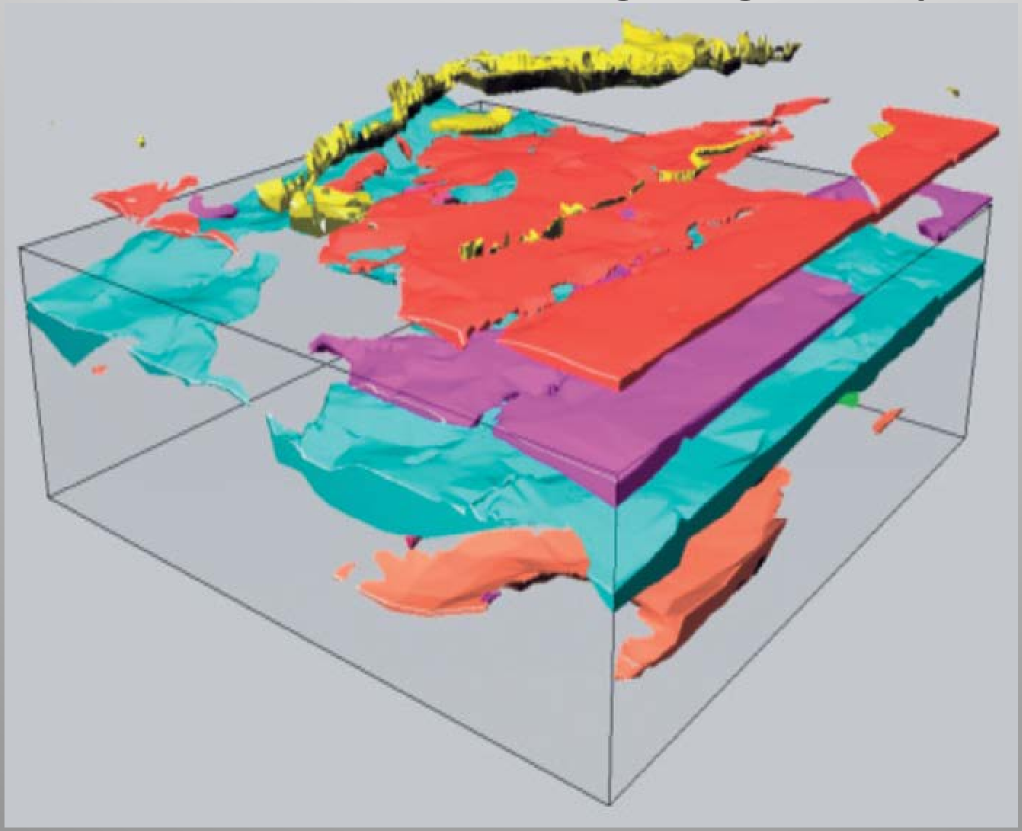
Farringdon Station for London CrossRail Project (2009-2015)

- **Geological predictions prior to excavation vs. actual observed conditions (in one section of Farringdon station)**



Aquifer Recharge Assessments in an Urban Environment (in Manchester in 2006)

- Relatively early application of 3D models
- Model of 75 sq km of old industrialized area now being redeveloped
- Based on 2000 boreholes & 1:10,000 geological maps



3D Models for Urban Infrastructure Planning

- **Within urban environments, 3D geological models can assist both urban planners and designers of individual infrastructure projects.**
- **Two broad classes of application:**
  1. **Regional planning for subsurface land uses:**
     - **Tunnelling & underground space**
     - **Geothermal heating & cooling**
     - **Location of utilities (water, sewer, electrical, gas)**
     - **Geohazards and resources (subsidence, groundwater, etc.)**
     - **"SUSTAINABLE CITIES"**
  2. **Site Investigation assistance:**
     - **Pre-investigation phase**
     - **Site investigation phase**
     - **Data management and risk reduction in the design/build phases**

Sustainable Cities

"With urbanisation comes pressure on space and resources and, increasingly, the underground. So understanding the subsurface beneath our cities is a key focus for a modern geological survey"

The Current Infrastructure Challenge in the United Kingdom

37%

of project overruns cite ground problems as a major contributor

National Economic Development Office

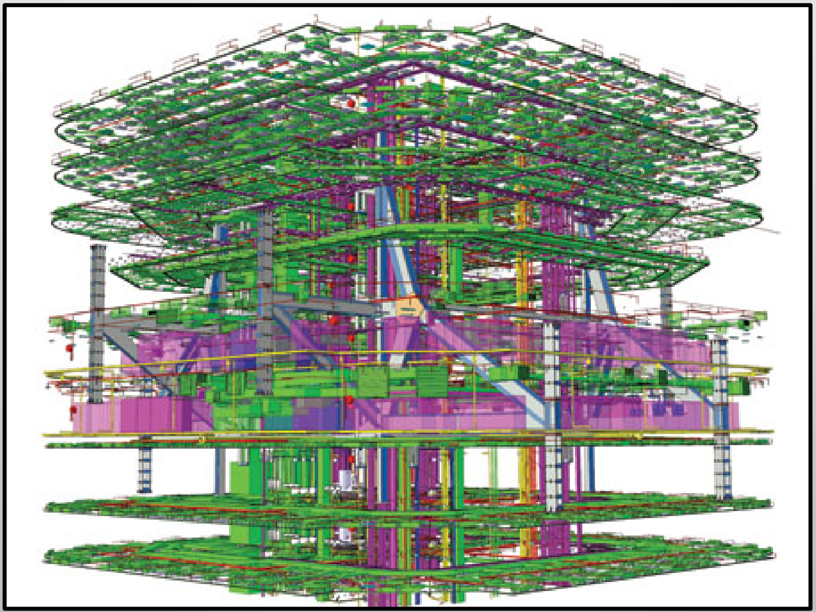
70%

of public projects were delivered late and 73% were over the tender price

National Audit Office

Building Information Modeling (BIM)

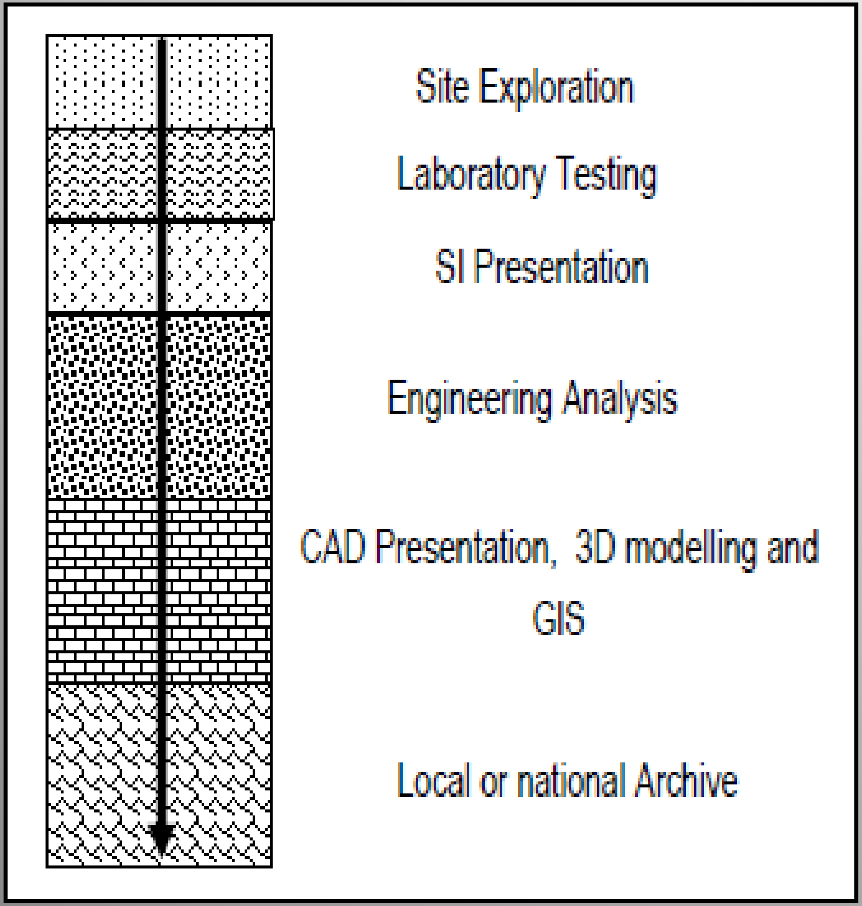
But Where is the Geology?



- Process involving the generation and management of digital representations of physical and functional characteristics of places
- BIM files can be exchanged or networked to support decision-making about a place.
- Used by individuals, businesses and government agencies who plan, design, construct, operate and maintain diverse physical infrastructures.

Current Challenges for Geotechnical Site Investigation - 1

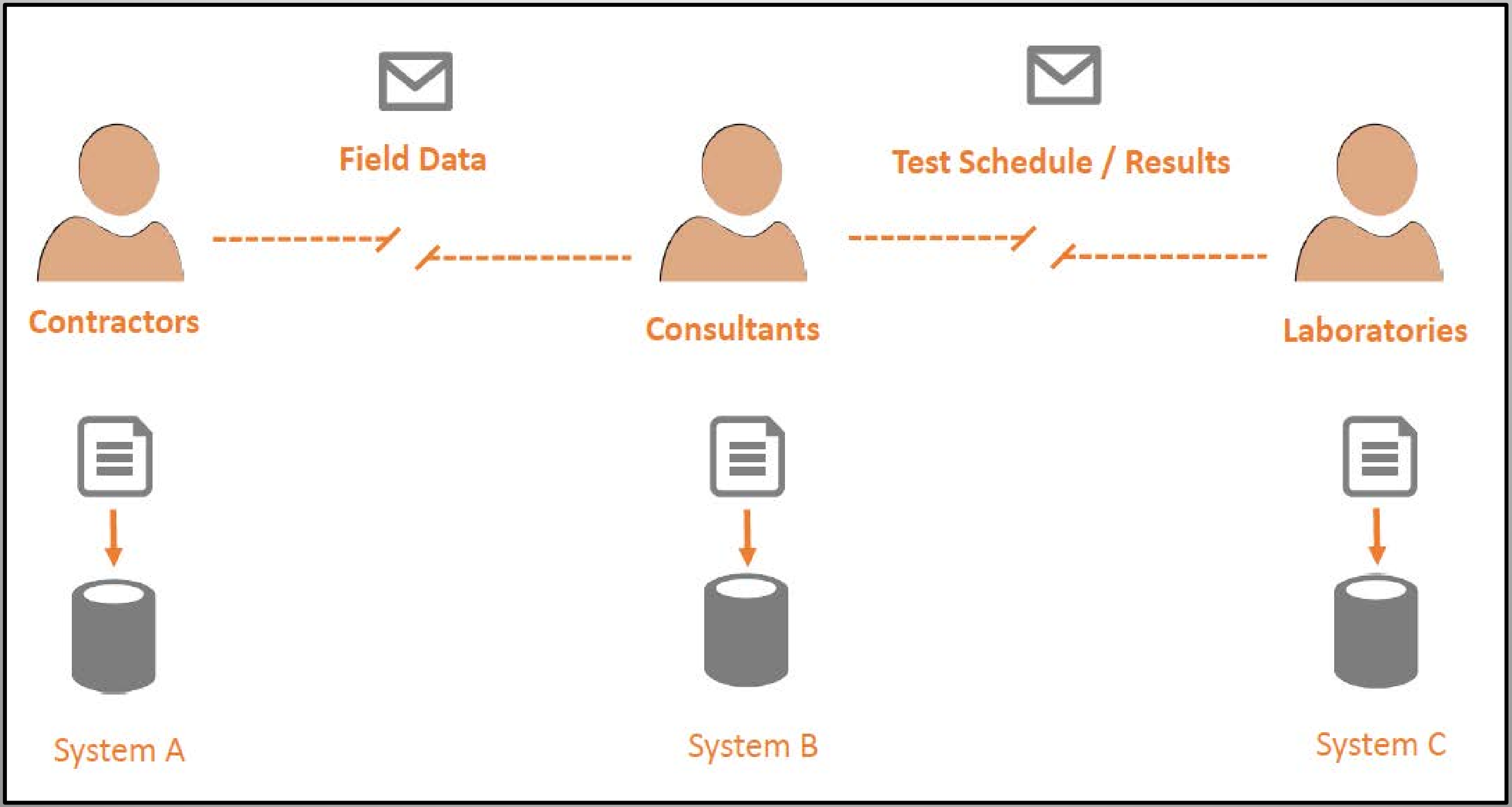
Traditional Geotechnical Data Journey (Chandler & Hutchinson 1998)



- **Linear/waterfall process**
- **Significant delays receiving data**
- **Inefficient desk studies & planning**
- **Data re-entered multiple times**
- **Data often not retained or reused**

Current Challenges for Geotechnical Site Investigation - 2

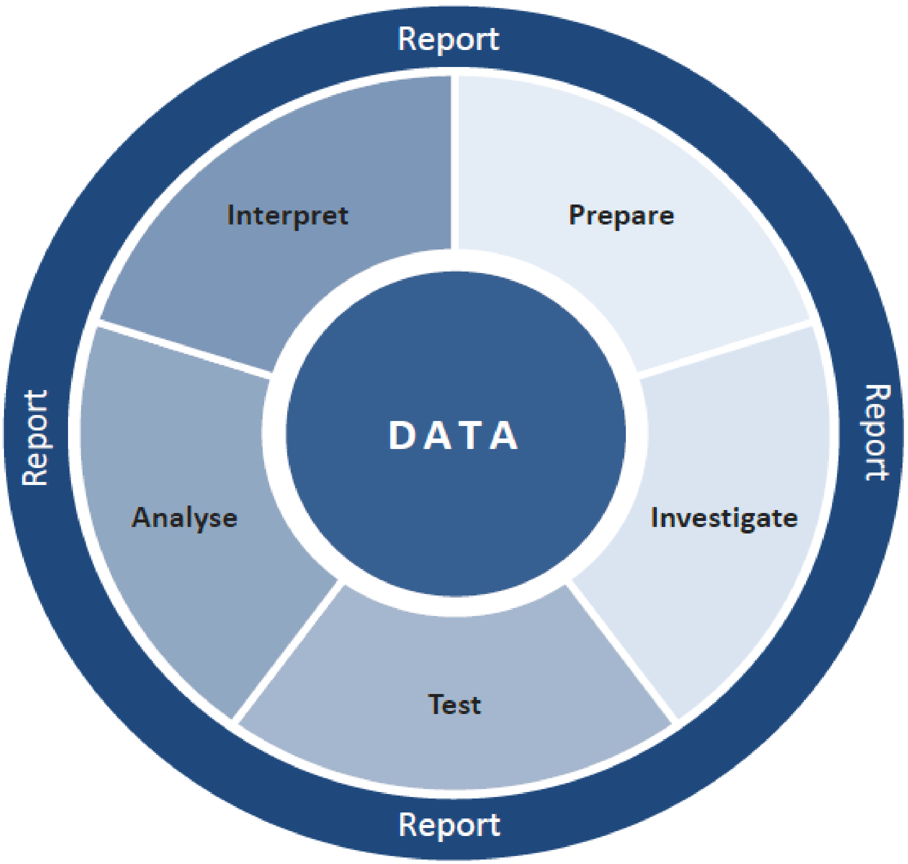
Limited availability of quality geotechnical data



How long does this take? – Days, weeks, months?

Possible Solution

Apply BIM principles throughout the Geotechnical Data Journey

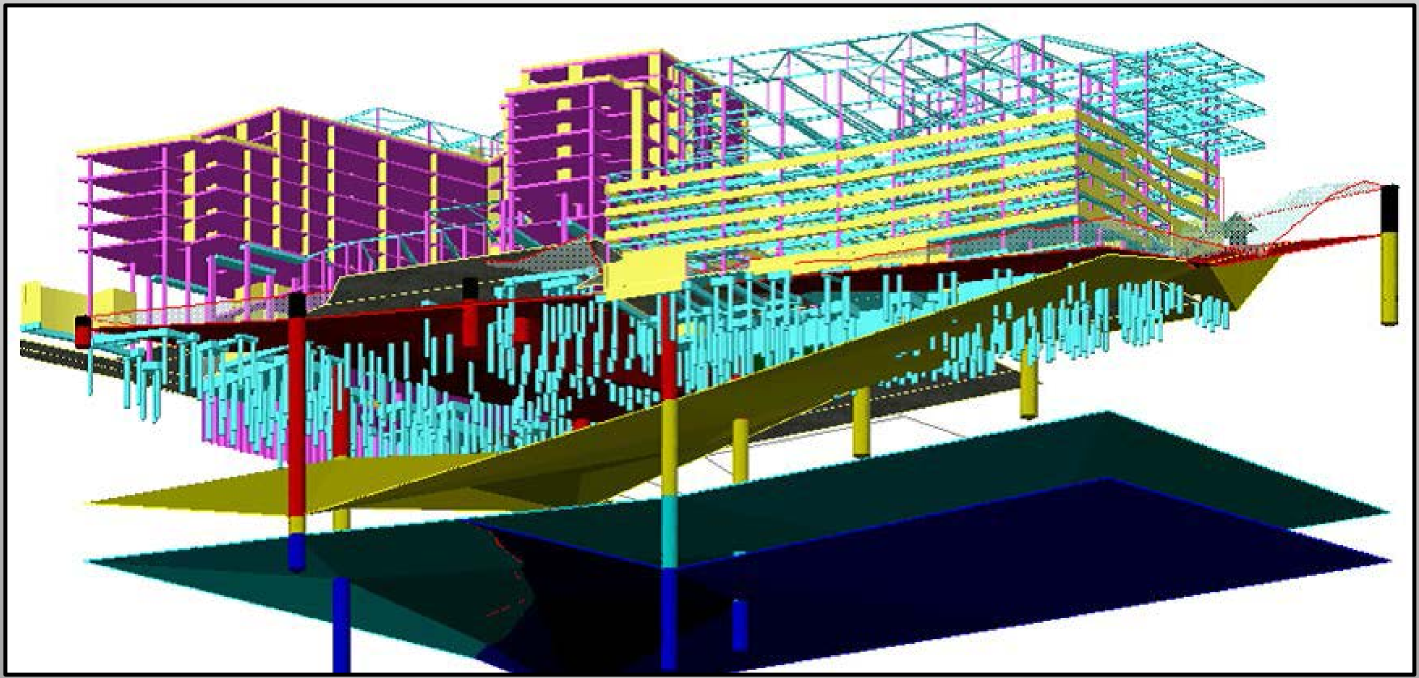


Geotechnical Data Journey - Transformed

P. Child, C. Grice, R. Chandler 2014

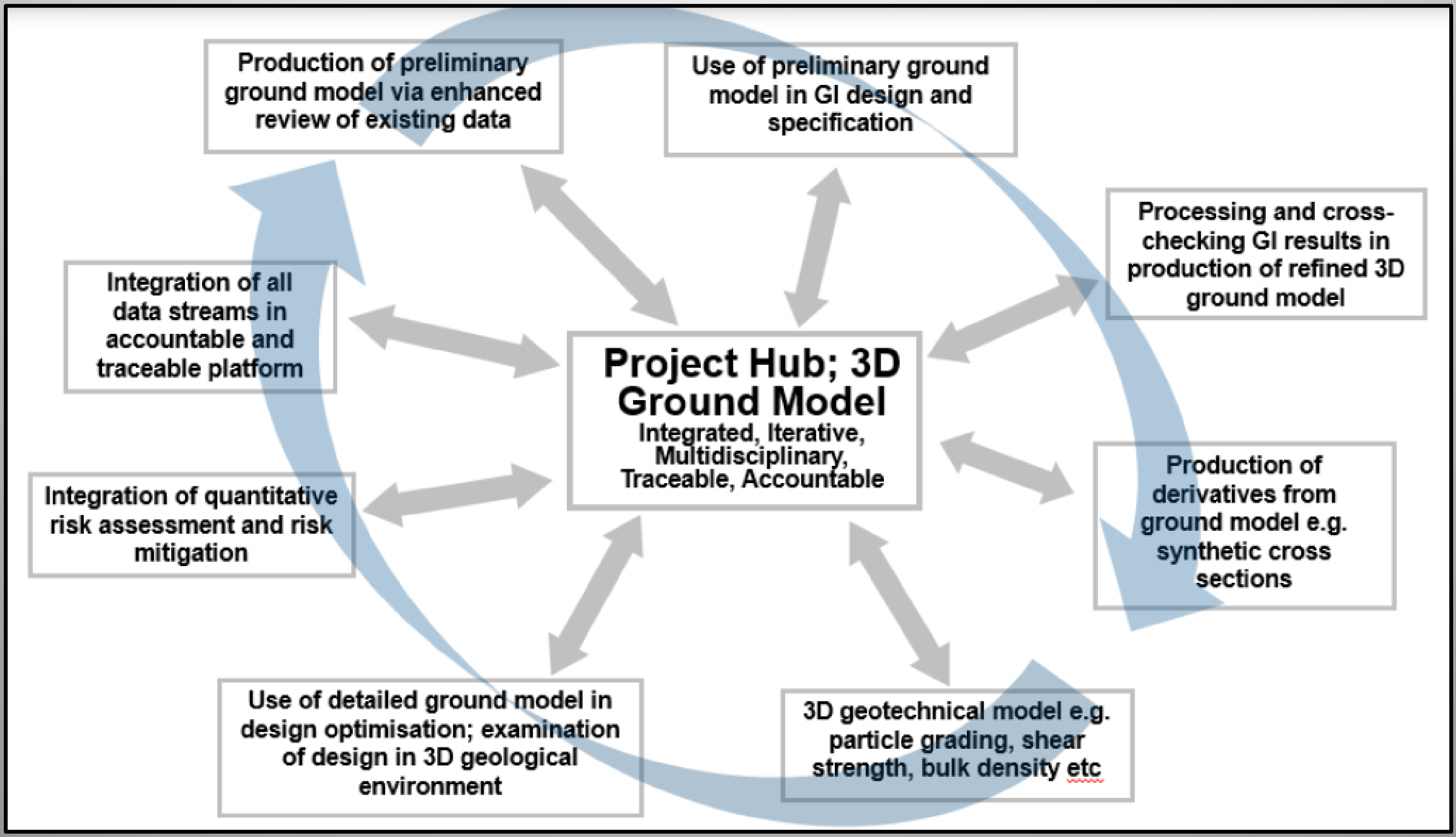
- Geotechnical BIM
- Historic data & 3D models utilised throughout
- Centralised data repositories
- Incremental data delivery and iterative refinement
- Data reuse and collaboration

“Geo-BIM” – BIM and the Subsurface

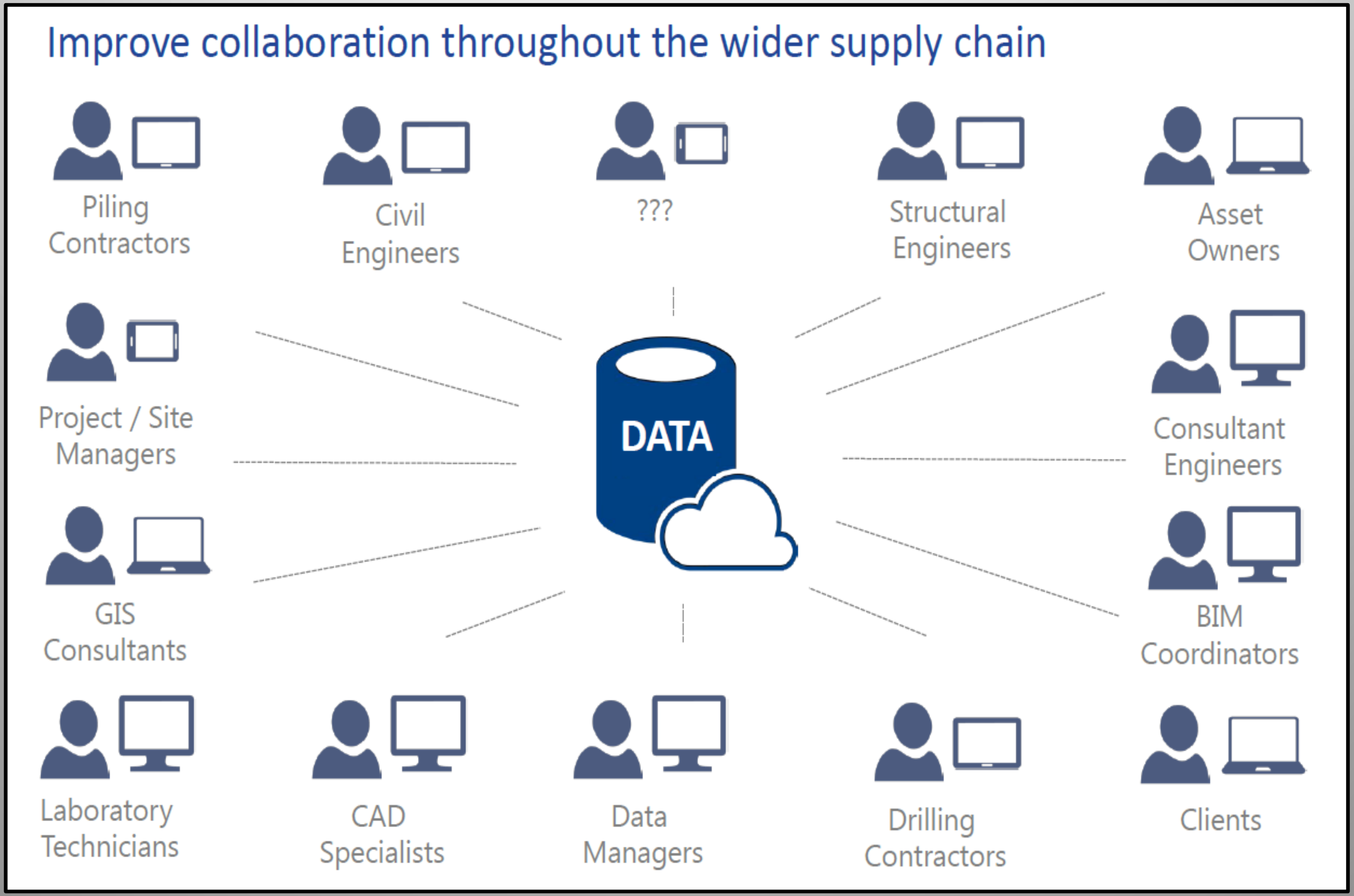


- **Extend/Integrate 3D Geological Modeling techniques to the BIM environment**

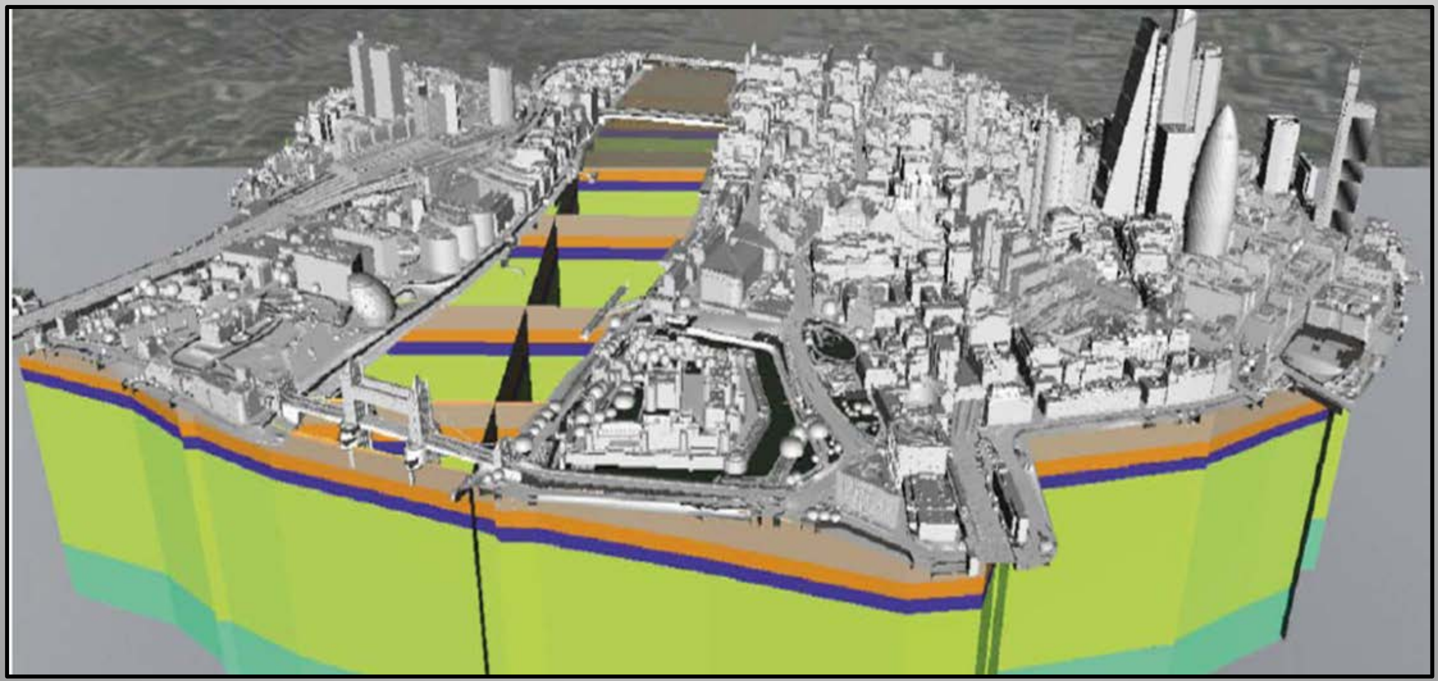
Potential Integrated Geo-BIM Workflow
(source: CH2MHill)



Geo-BIM can support Collaborative Modelling



Current Capability:
City of London on 3D Geology Model



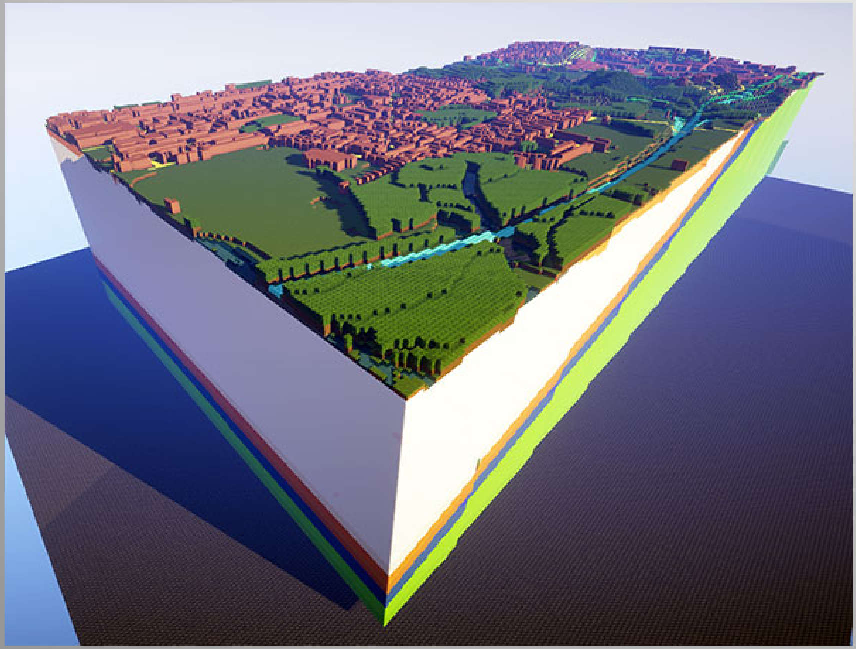
City model courtesy of ARUP

BGS Converting Scientific 3D Geological Models into MINECRAFT

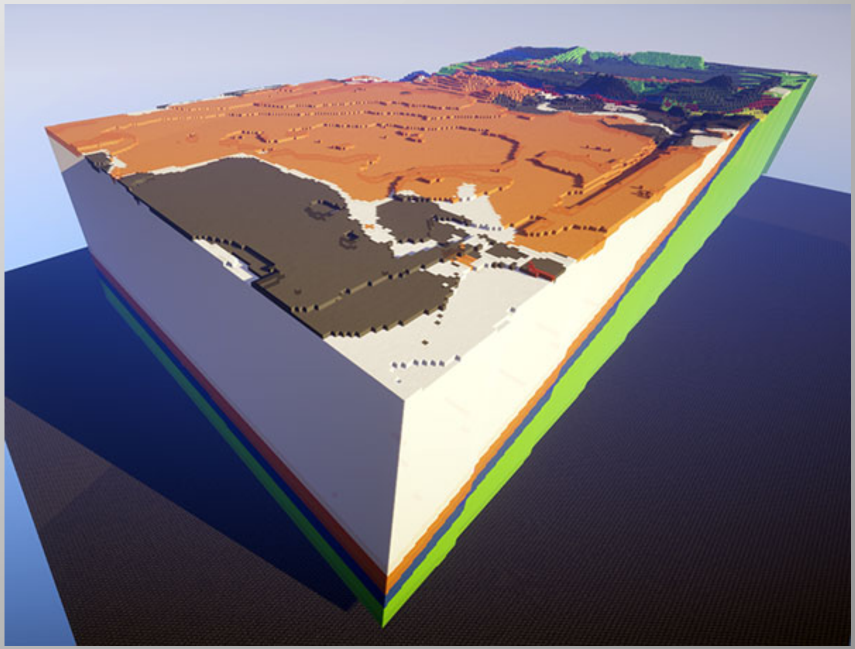
- Exploring Educational Applications of 3D geology models
- MINECRAFT familiar to children
- First built a simple model of all of UK
- Just released three 3D regional models illustrating different geological conditions
- Models available for:
  - West Thurrock (east London - urban landscape)
  - York (NE England - glacial deposits, sandstone aquifer))
  - Ingleborough (North England - Hills, Sed. Rocks, Faults)

BGS MINECRAFT 3D Geology Model
West Thurrock (Eastern London)

Topography and Geology



Geology Only

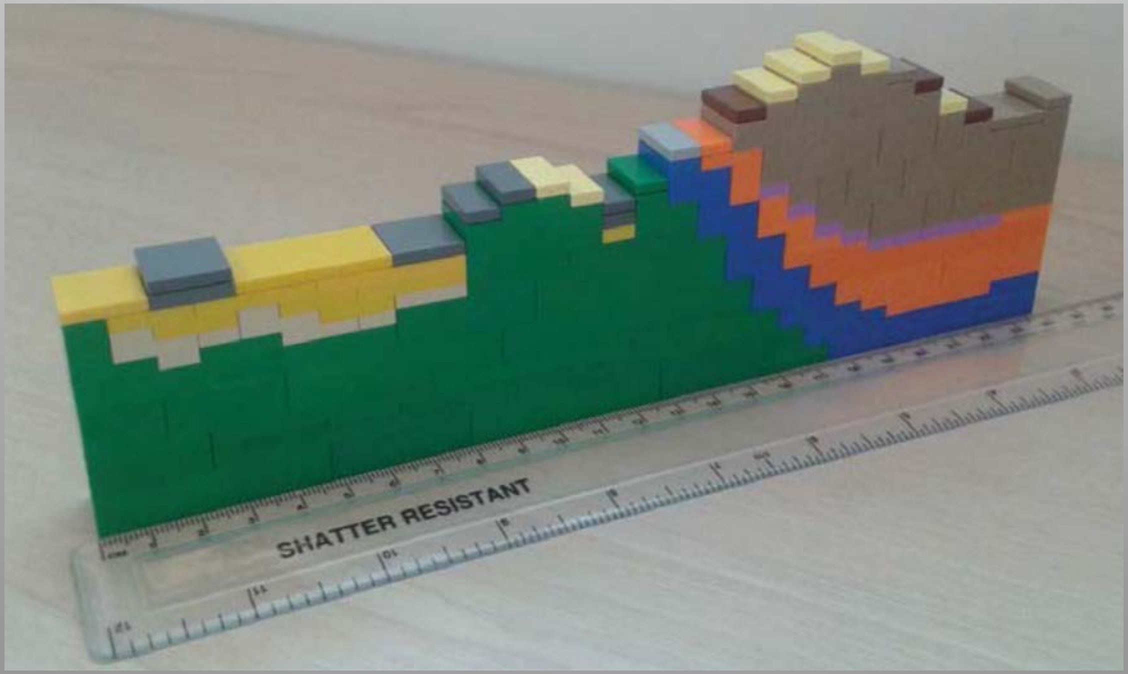


BGS Also Experimenting with LEGO Models

Procedure:

- Convert scientific 3D geology model to voxels corresponding to LEGO bricks
- Select brick colors and sizes from LEGO catalog
- Order bricks, assemble model

EXAMPLE CROSS-SECTION



Final Thoughts

3D geological modeling has evolved over time:

1. **<u>Phase 1: 1985-1995</u>**

   "Can we do it?" – Initial fundamental research, early software and hardware limitations.

2. **<u>Phase 2: 1995-2005</u>**

   "How do we do it?" – Implementation of workflows, databases, software maturity.

3. **<u>Phase 3: 2005-2015</u>**

   "Why are we doing it?" – Operational within geological surveys, models now becoming accepted by users.

The 3D modeling process has become increasingly demand-side driven.