From External Sources to External Users:

A Review of Geological Modeling Development within National Geological Surveys

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Introduction

- Background
- Geological Modeling Process
- Interactions with the Users
- 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

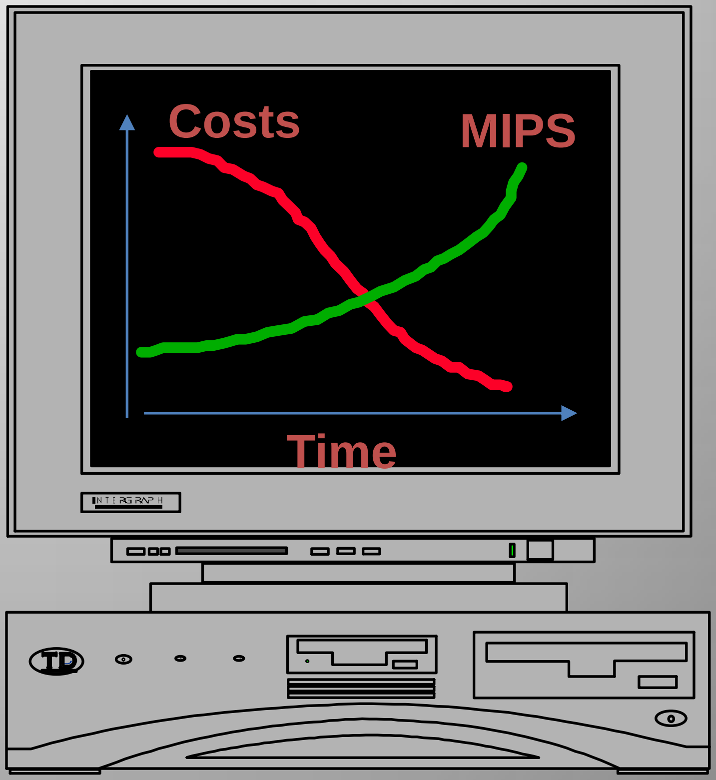
Importance of This Topic …

- 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

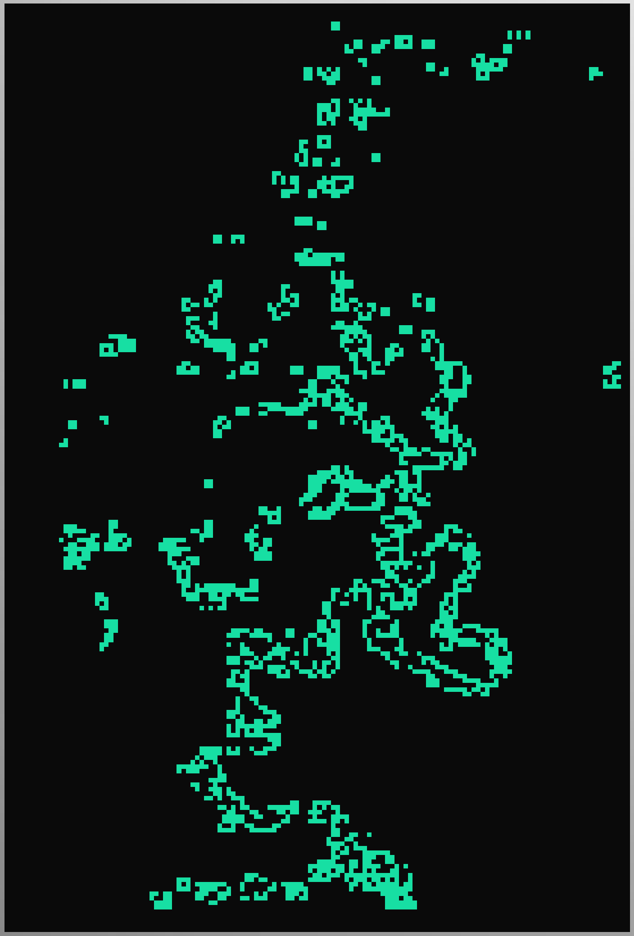


Problems in Subsurface Investigation are Unique...

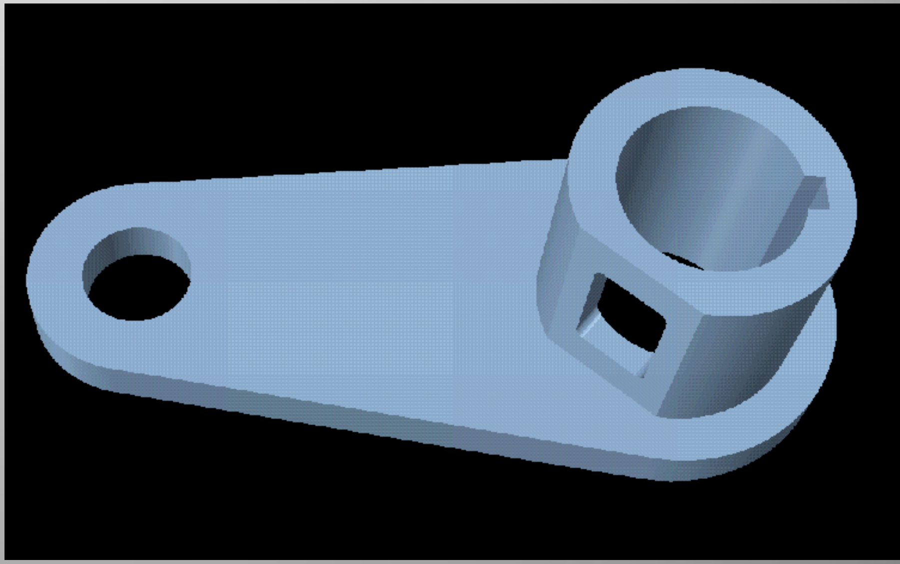
- Subsurface information is often incomplete and conflicting;
- The subsurface is naturally complex and heterogeneous;
- Sampling is most often insufficient to resolve all uncertainties; and
- Scale effects on rock , fluid, and other properties are usually unknown.

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

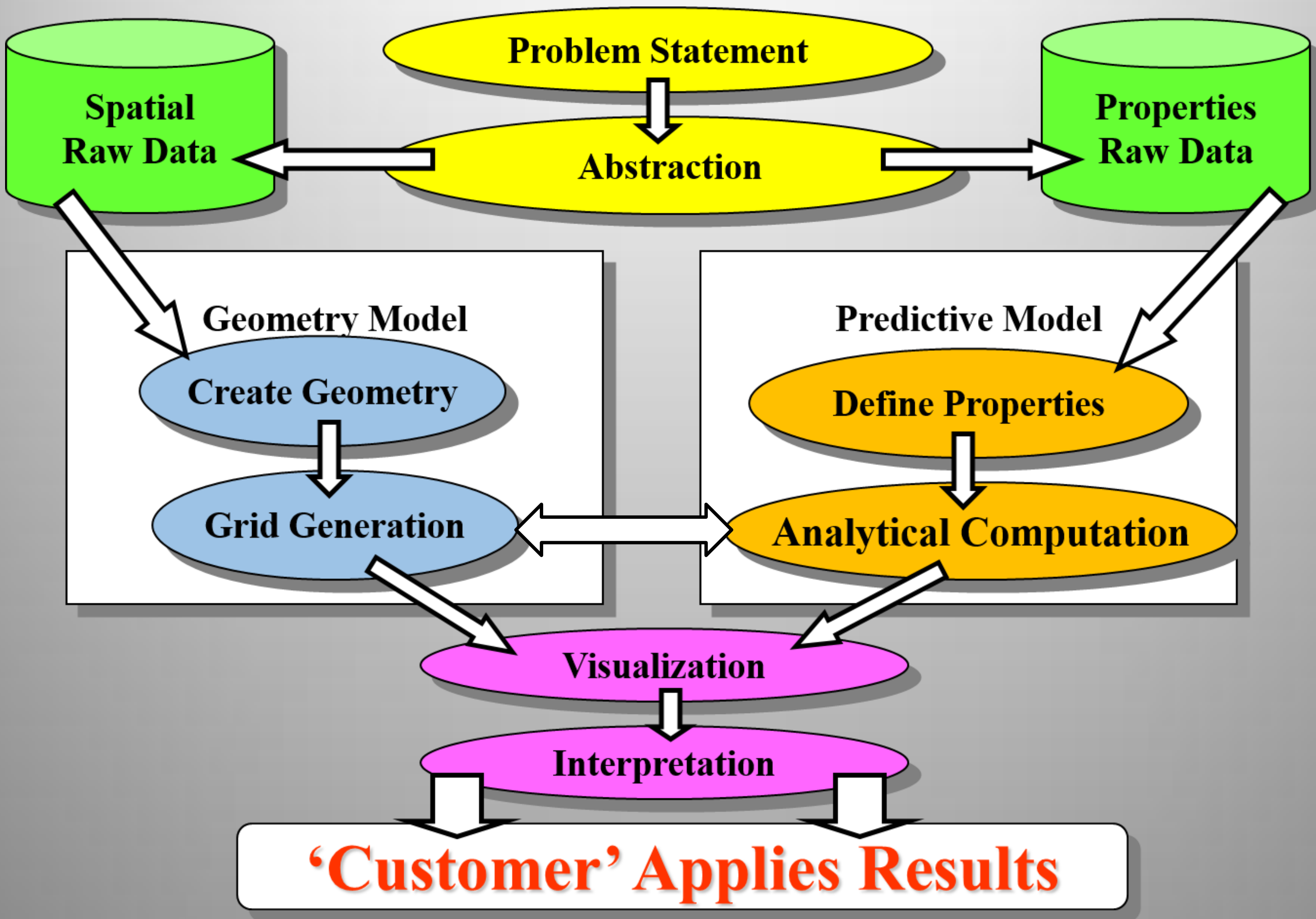
GEO-OBJECT



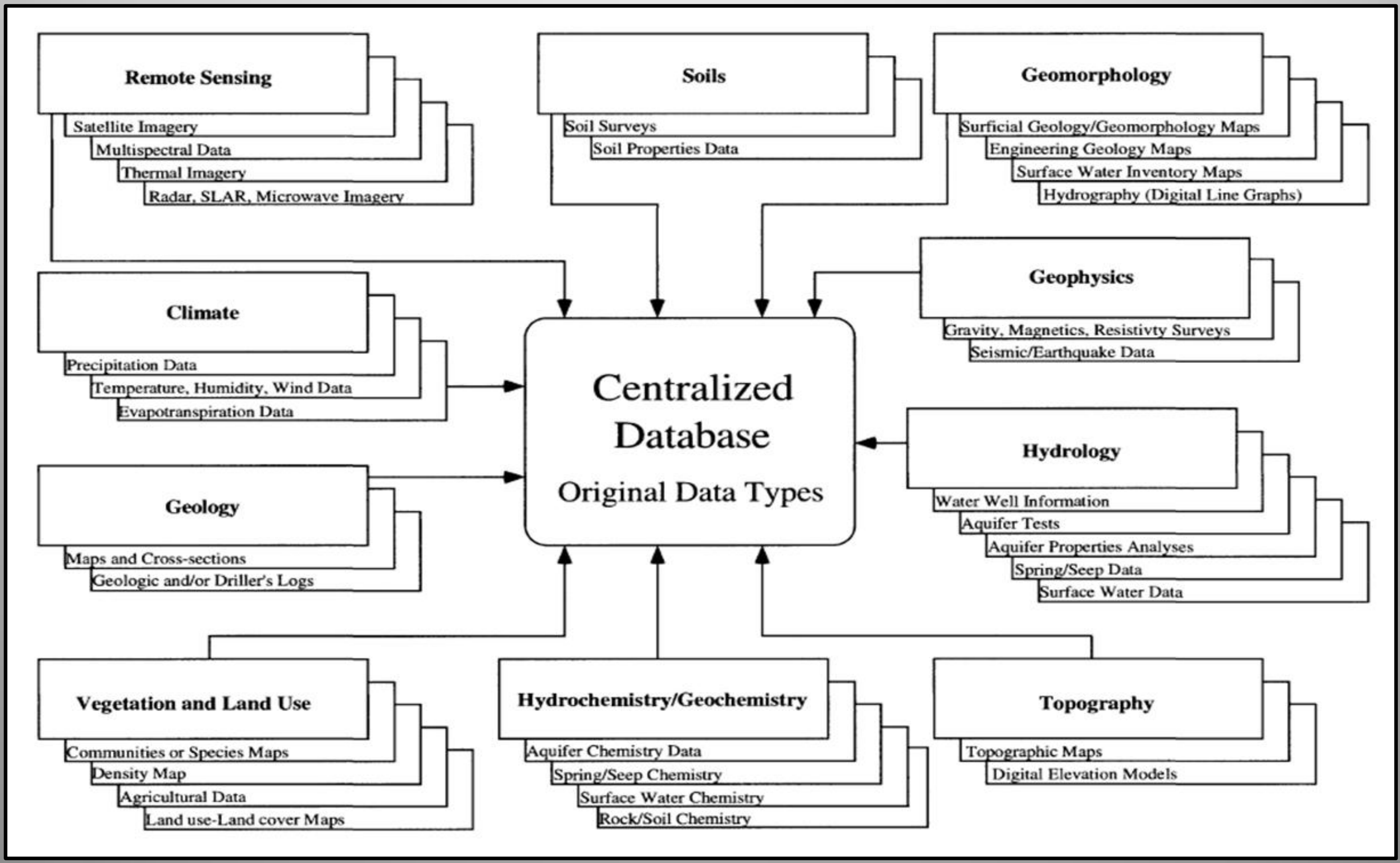
ENGINEERING OBJECT



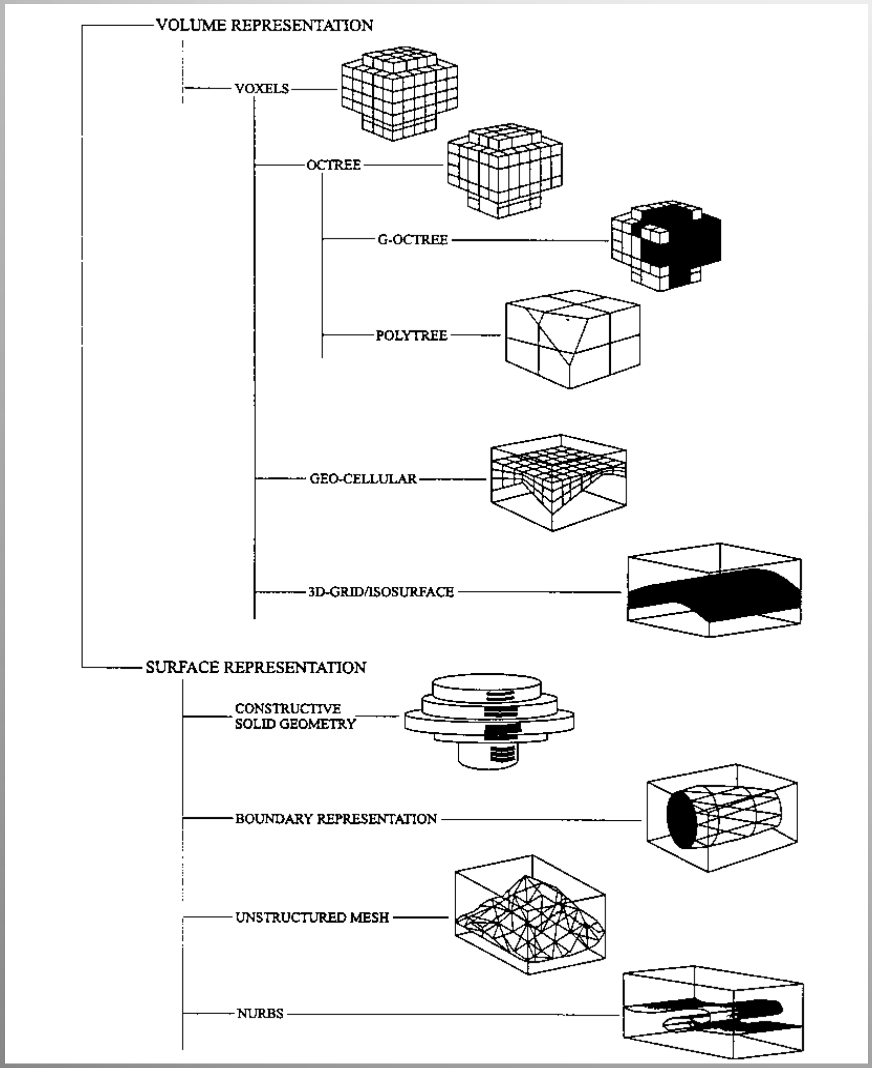
Overview of the Geological Modeling Process



Data Sources & Interactions
Yucca Mountain Project 3D Model (1993)



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)

Creating a 3-D Model Involves Two Stages

Framework Definition

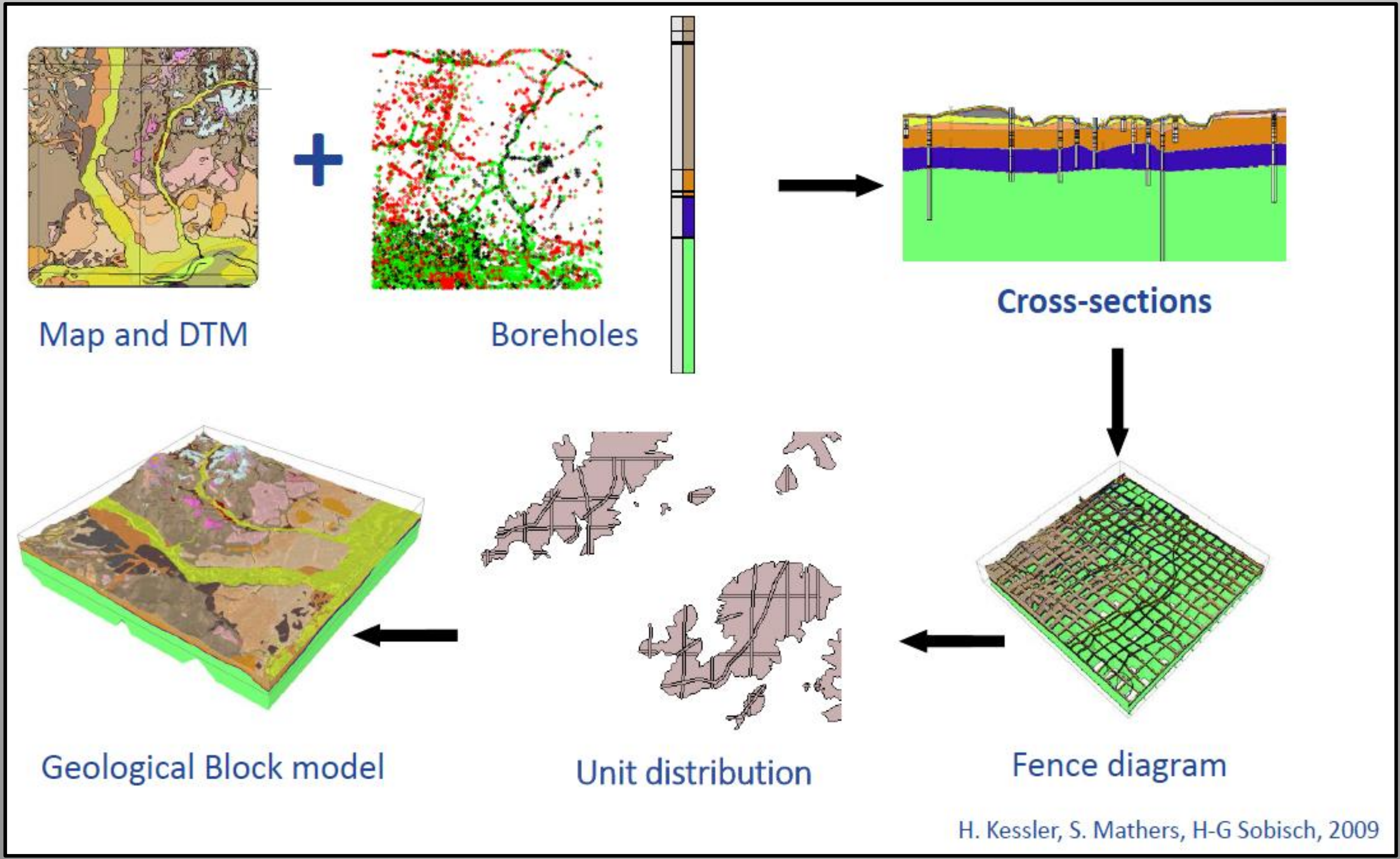
- Borehole and isolated sample data
- Triangulated surfaces
- 2-D grids and meshes
- Iso-volumetric models
  - from triangulated surfaces
  - from cross-sections
  - from grids and meshes
  - parametric (NURBS, etc)
  - Boundary Representations

Discretisation and Property Distribution

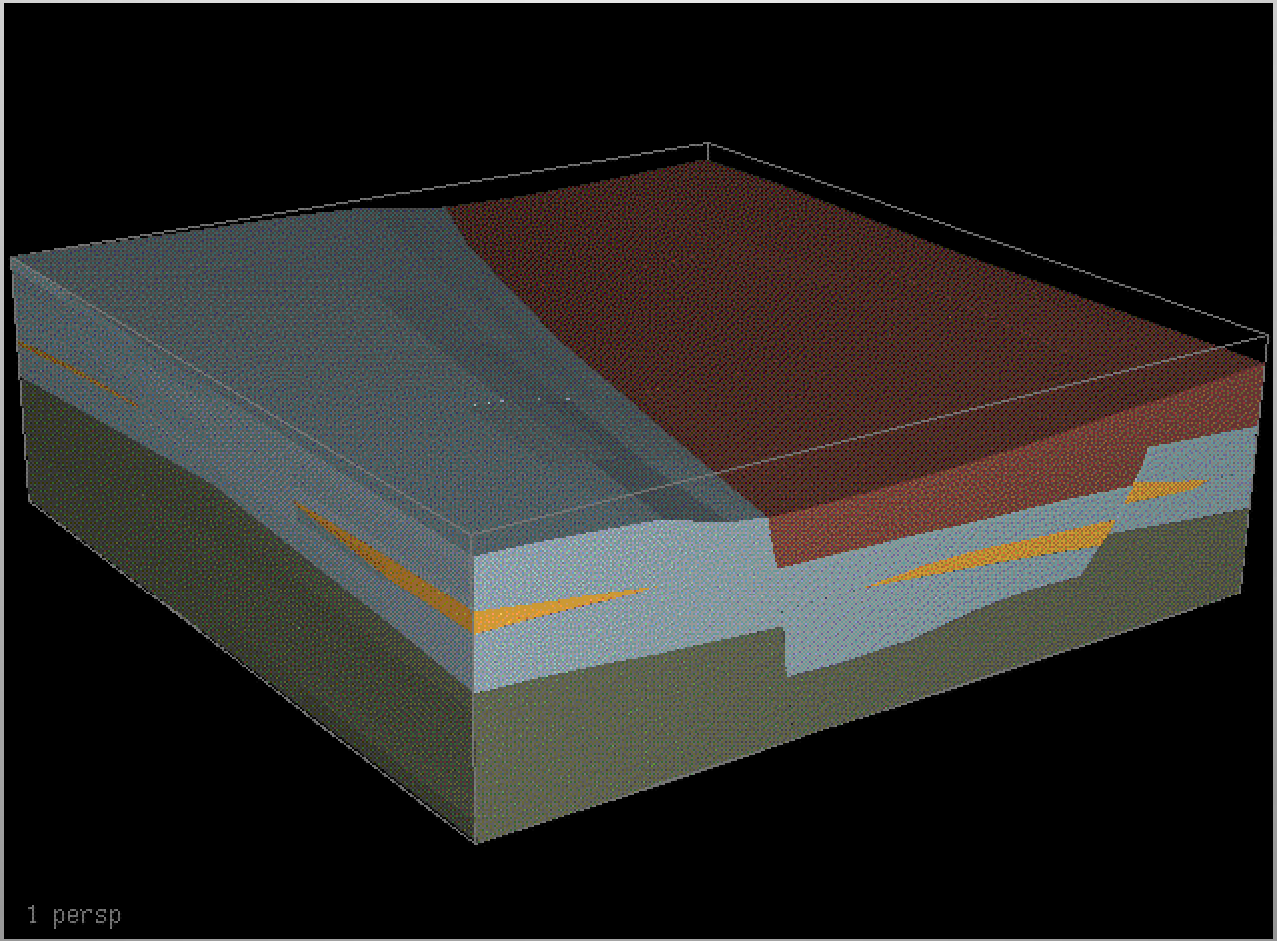
- 3-D grids and meshes
  - regular hexahedral
  - octree variable
  - geocellular
  - tetrahedral unstructured meshes

Typical 3D Model Creation Workflow

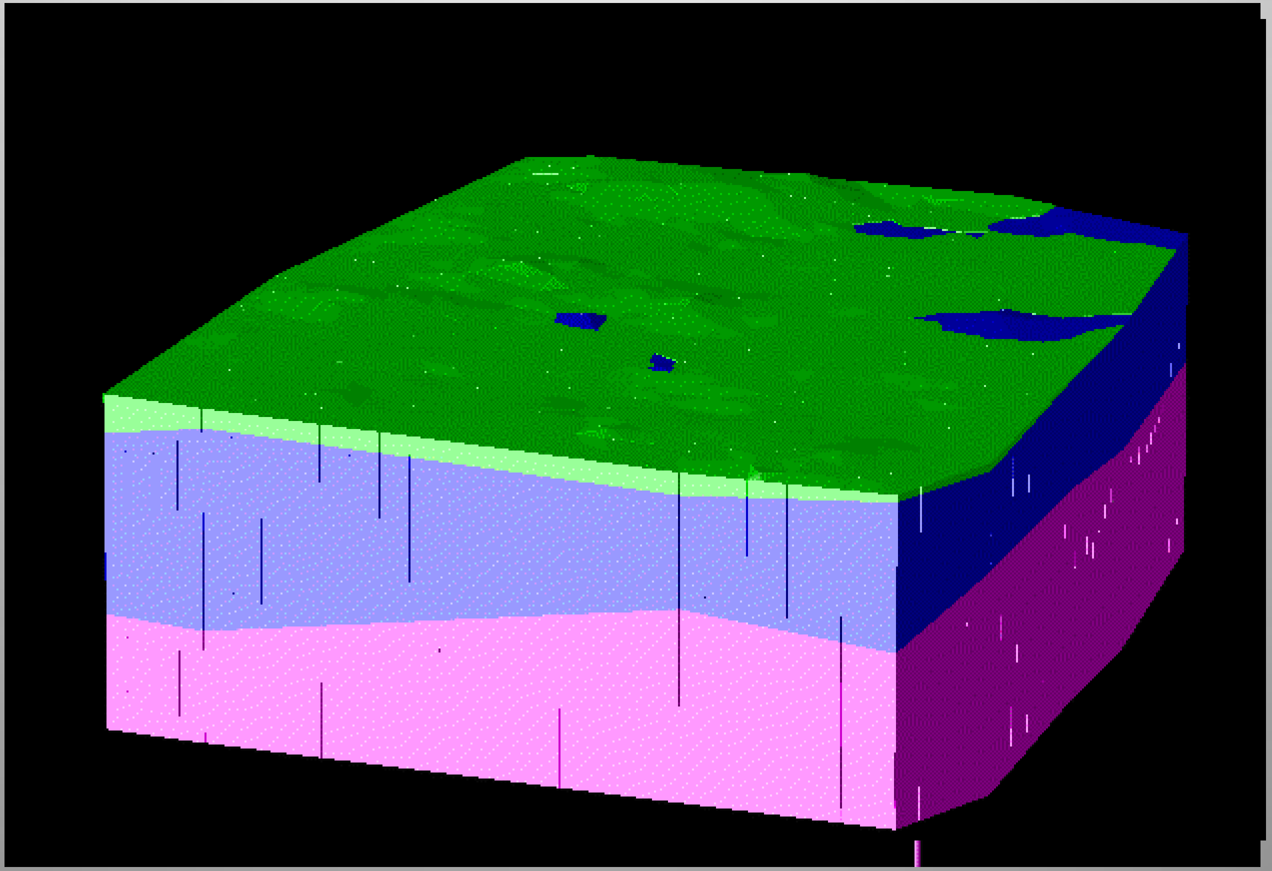
- This is GSI3D Workflow at BGS -



Geometry Models can be Constructed Using Cross-Sections

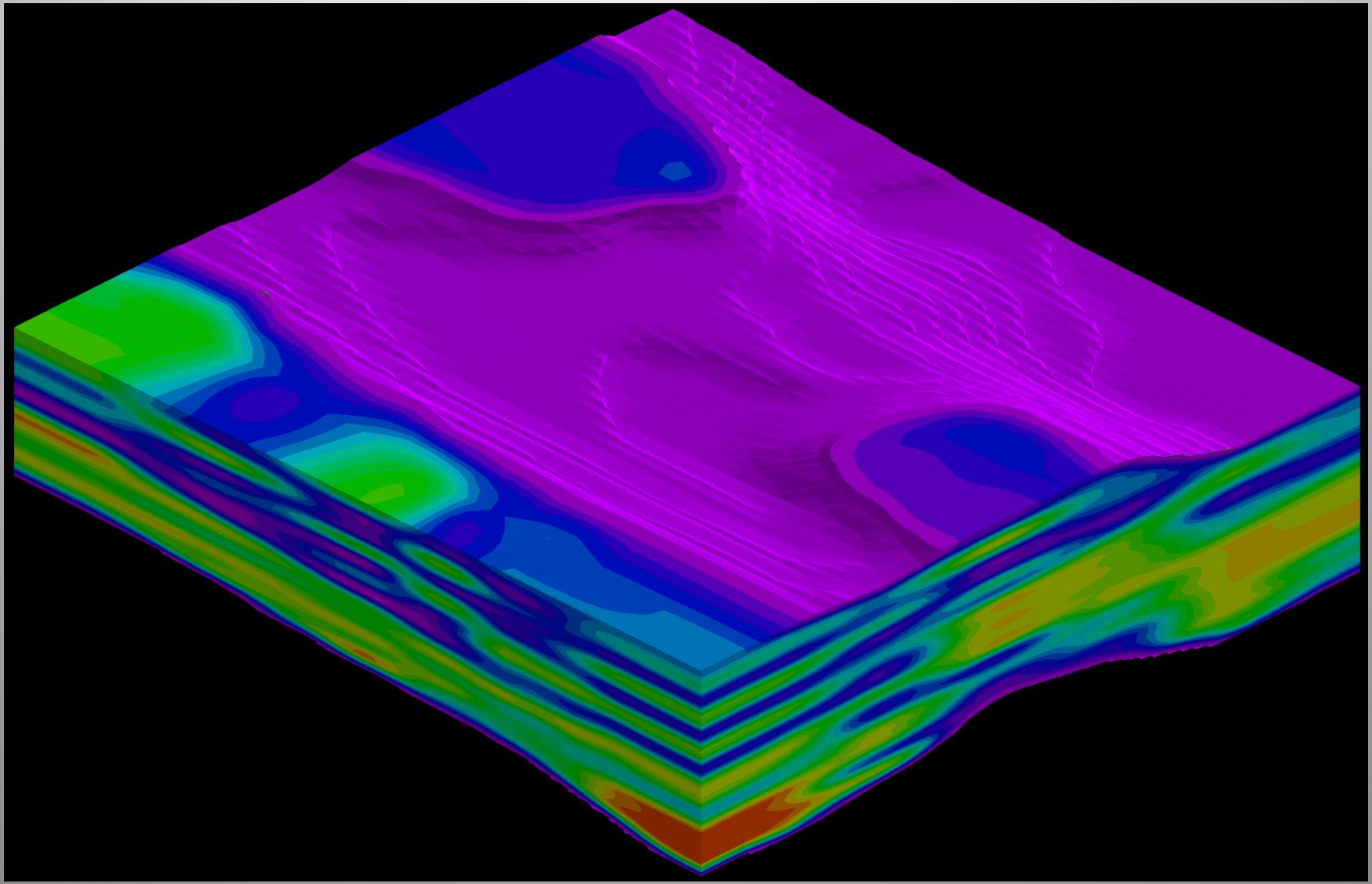


3-D Solid Models can be developed from Multiple Surfaces

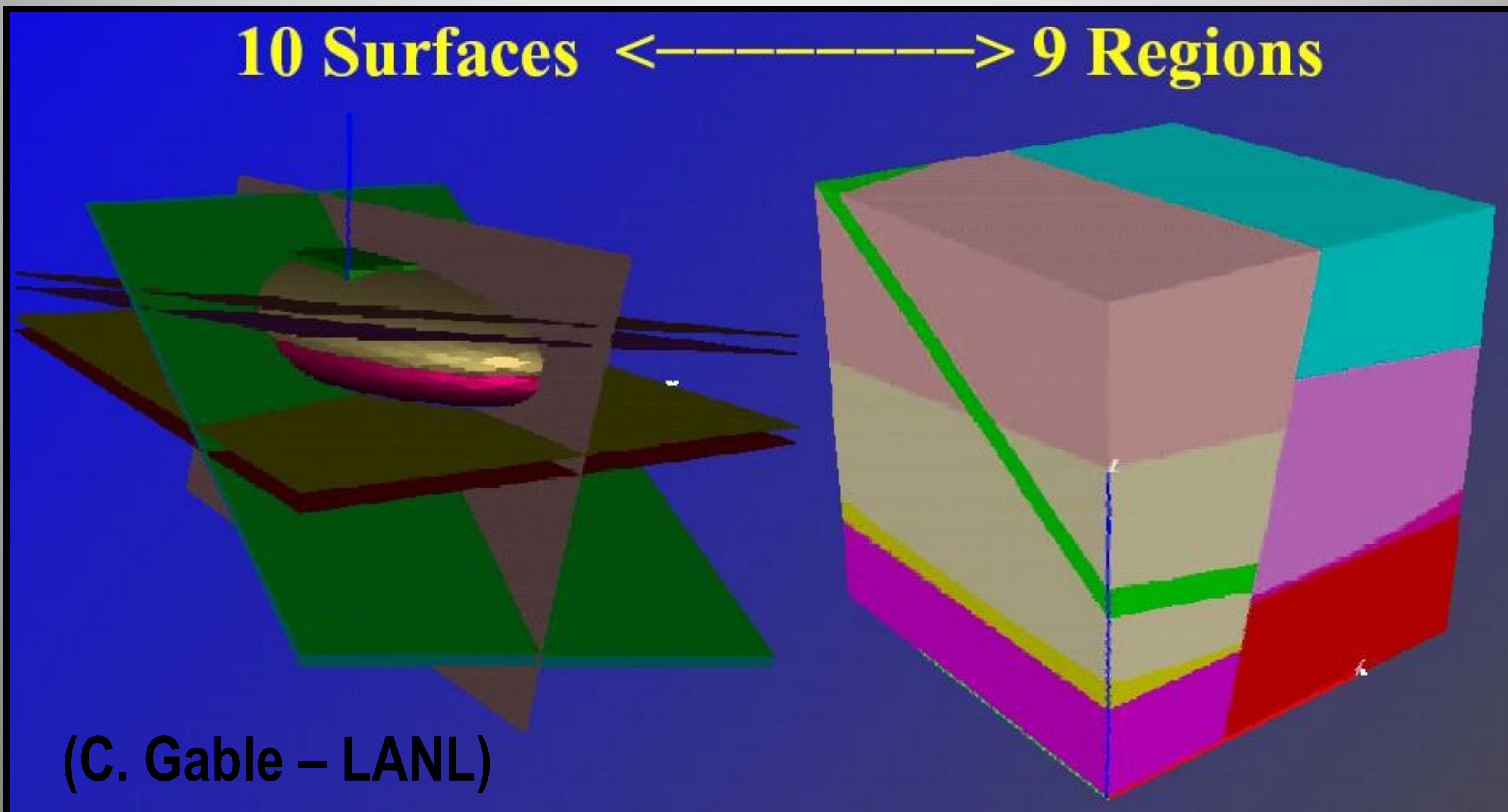


Layered Models may involve many surfaces

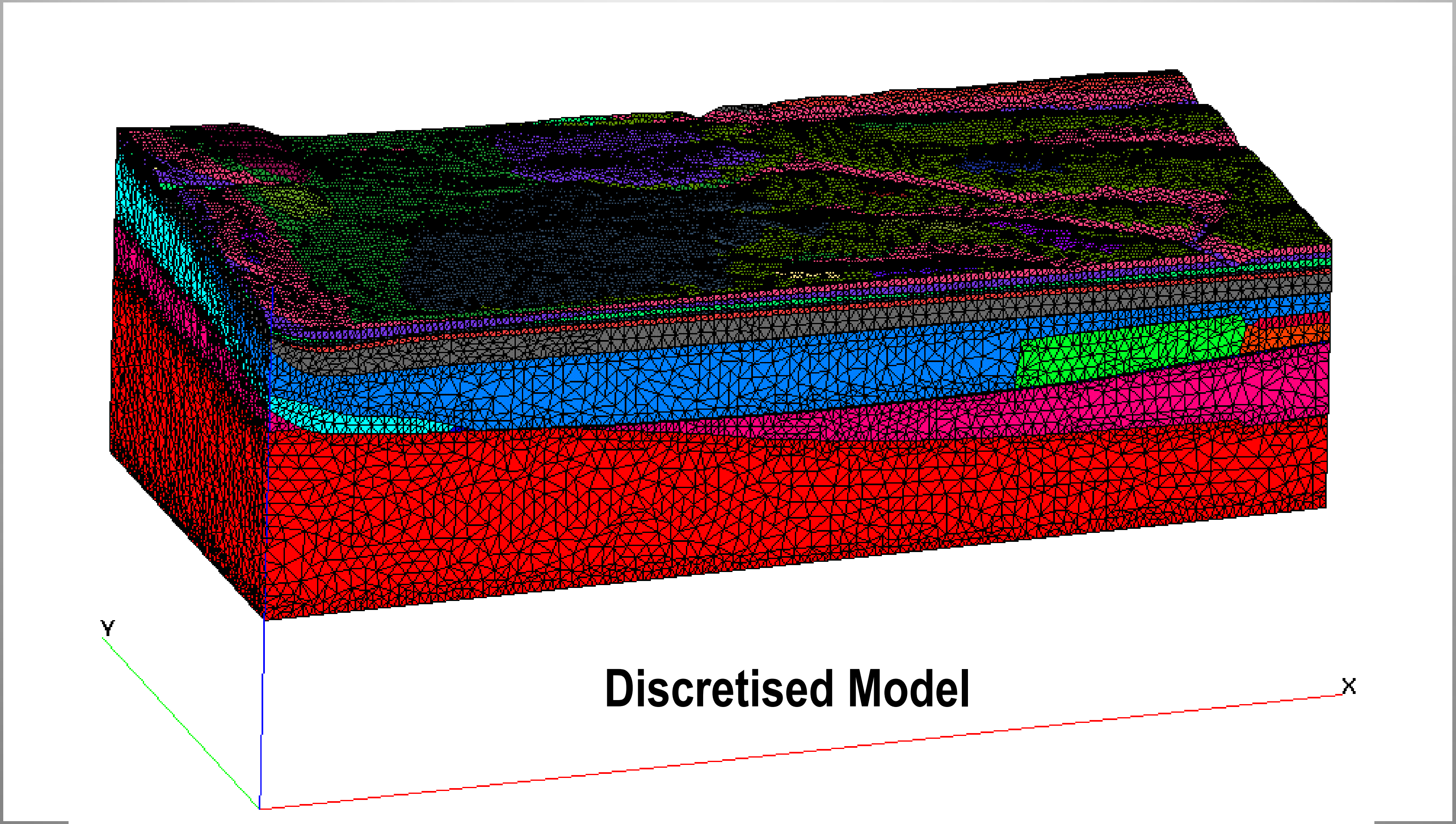
Complex channels and “pinch-outs” add complexity to model



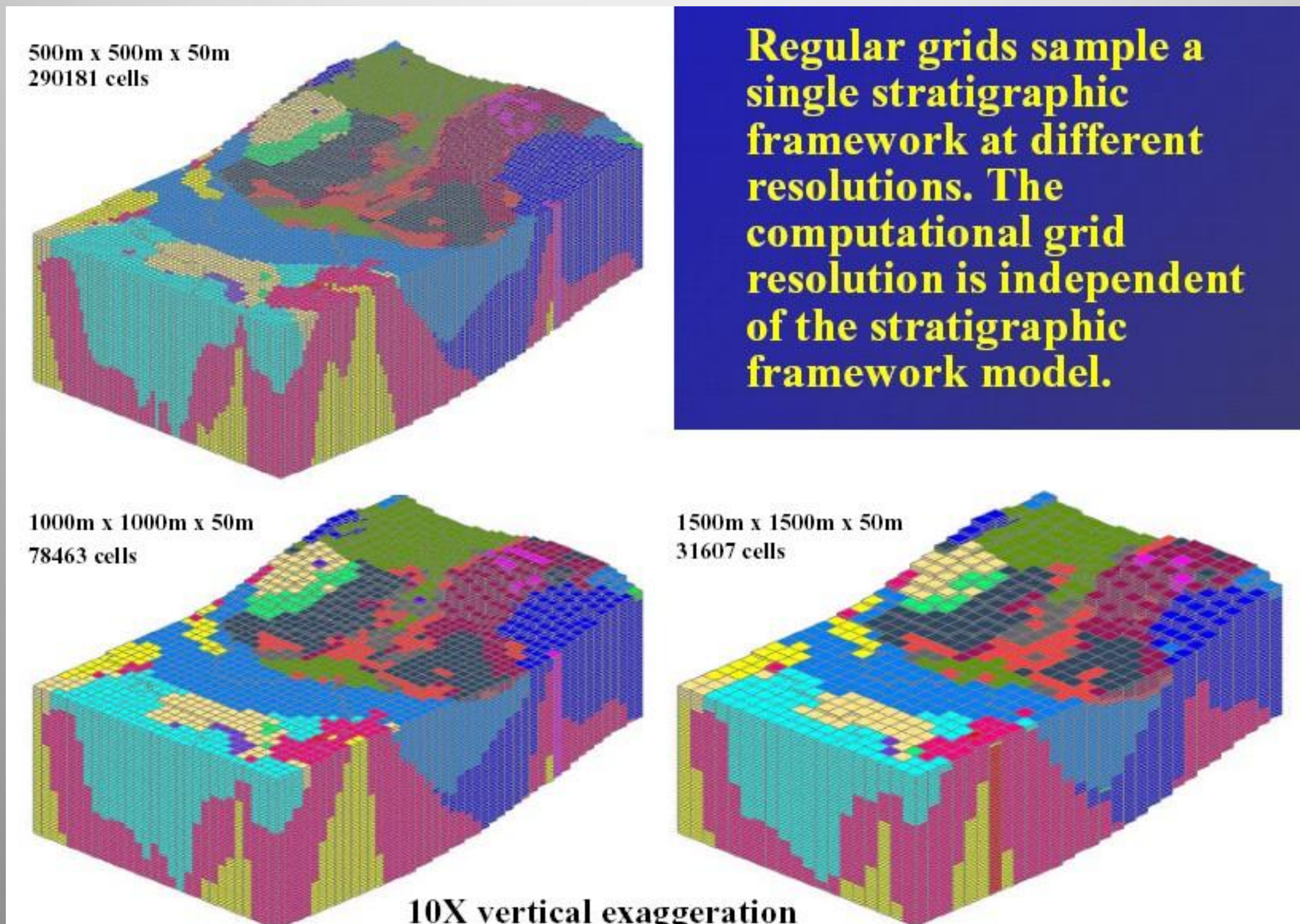
Regional (Volumetric) Subdivision Feasible for Non-stratigraphic Cases



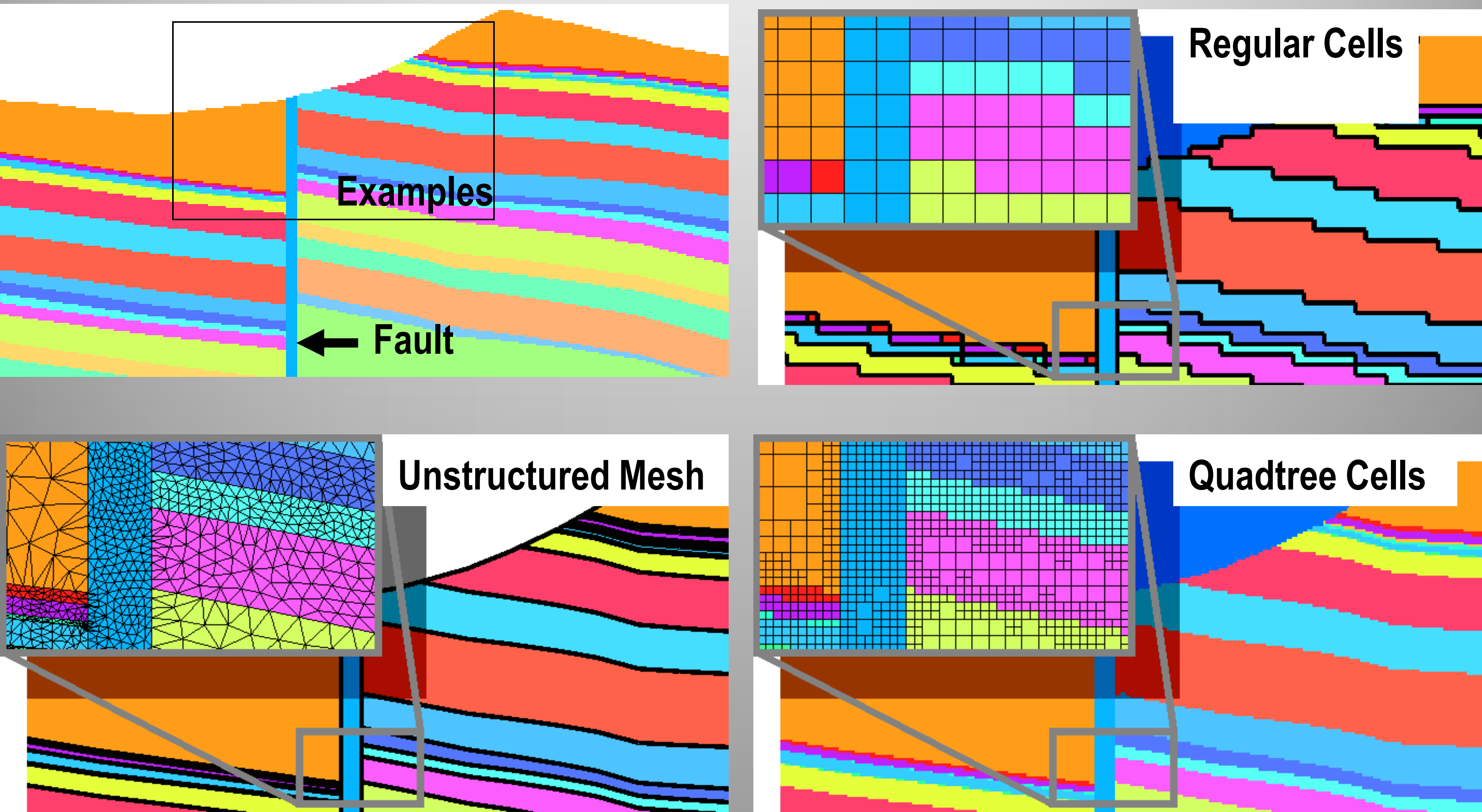
Framework Models require Grids or Meshes to assign Property Distributions



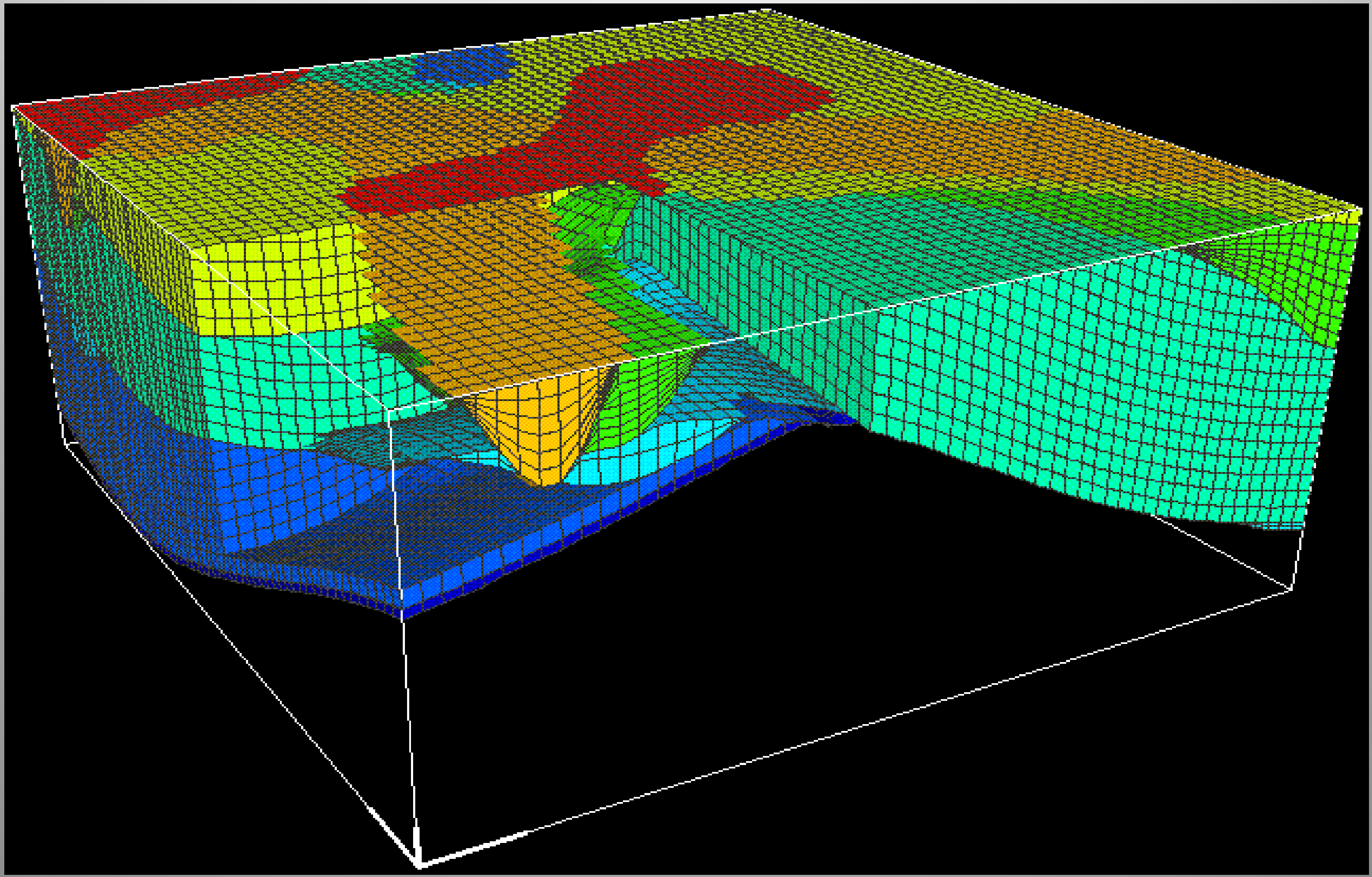
Geological Framework Defined First – then Grid Resolution



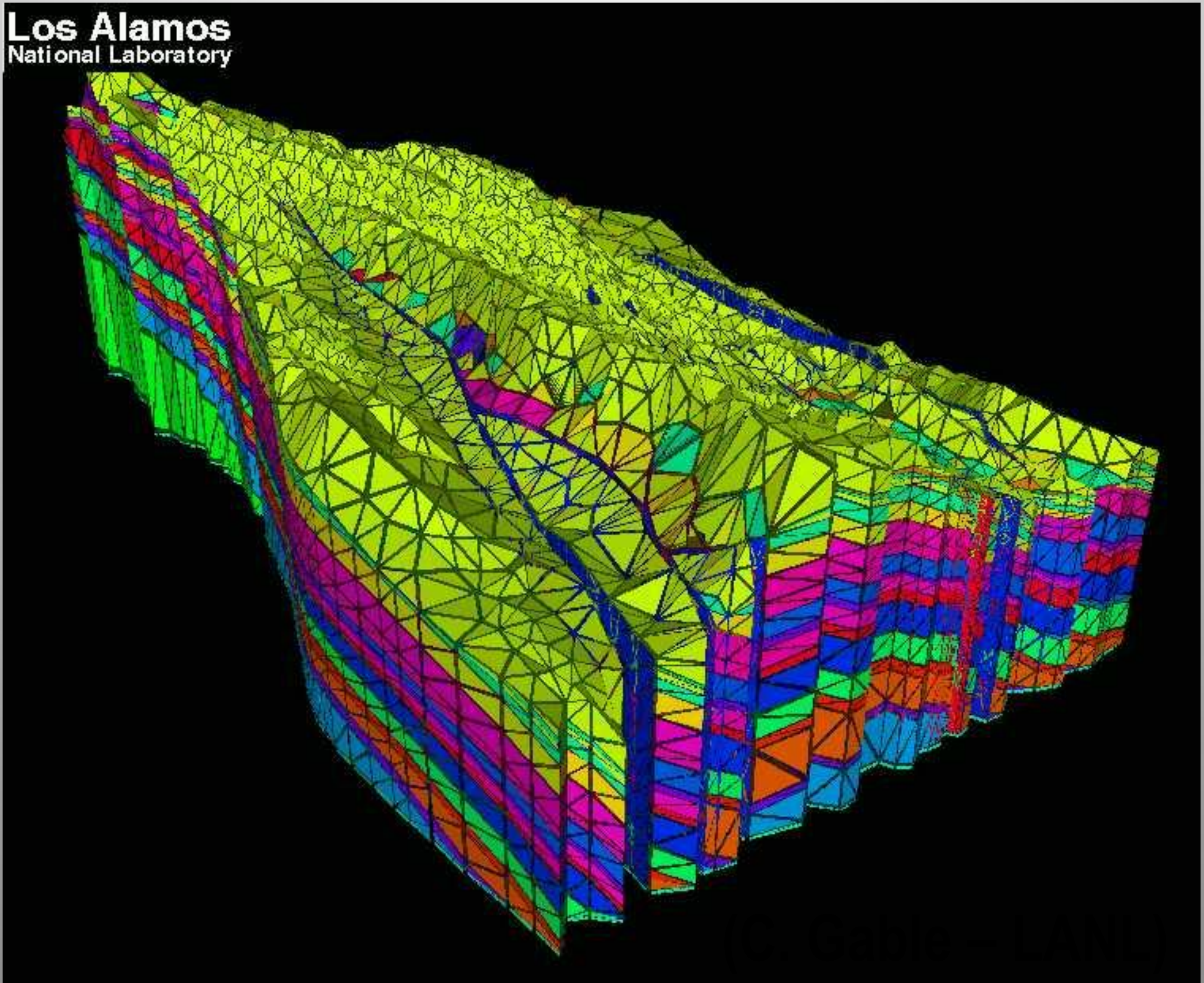
Discretisation may involve "structured" and "unstructured" meshes



“Geocellular” Volumetric Model



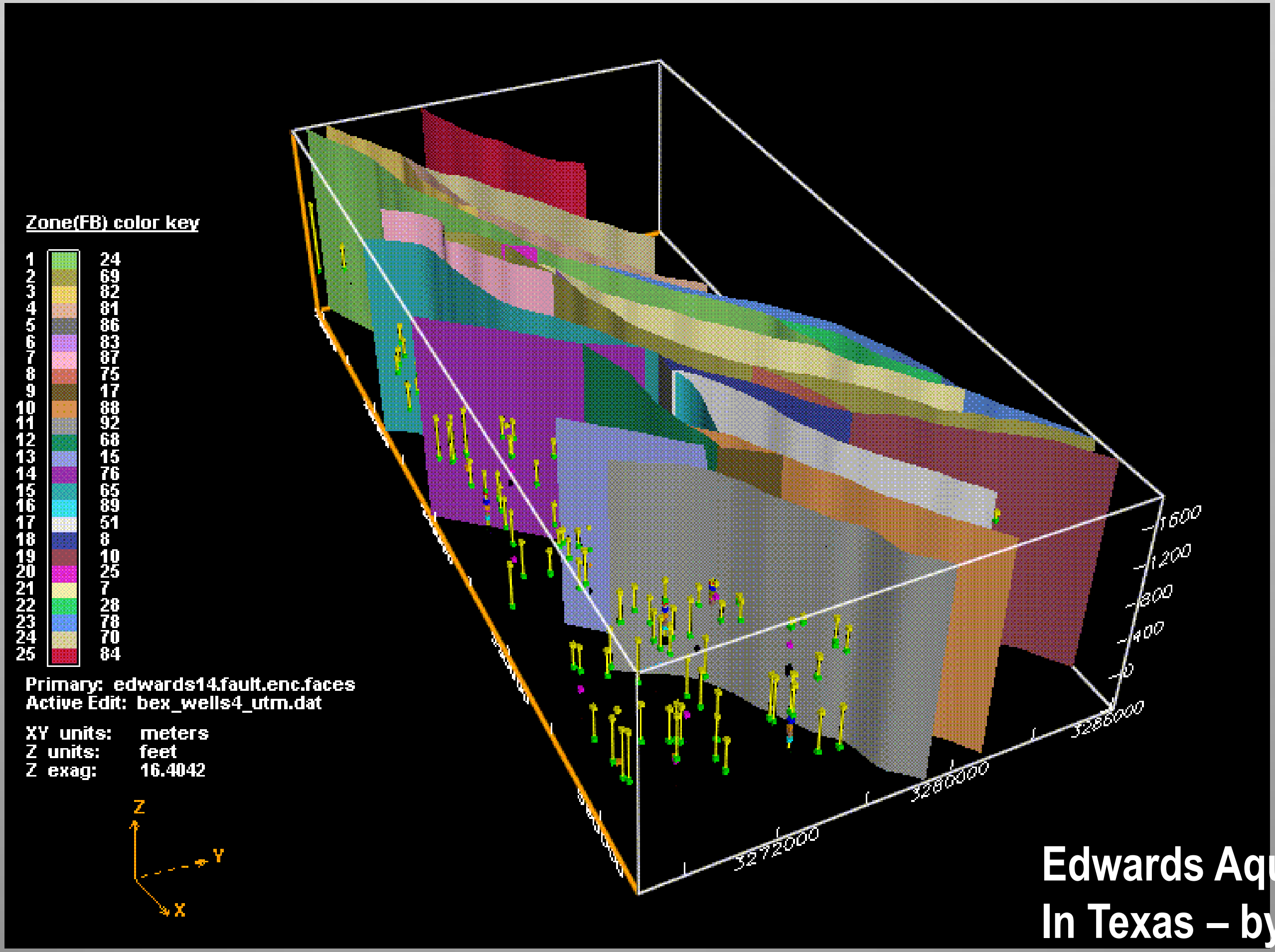
Yucca Mountain Represented by a Tetrahedral Mesh Model



(C. Gable – LANL)

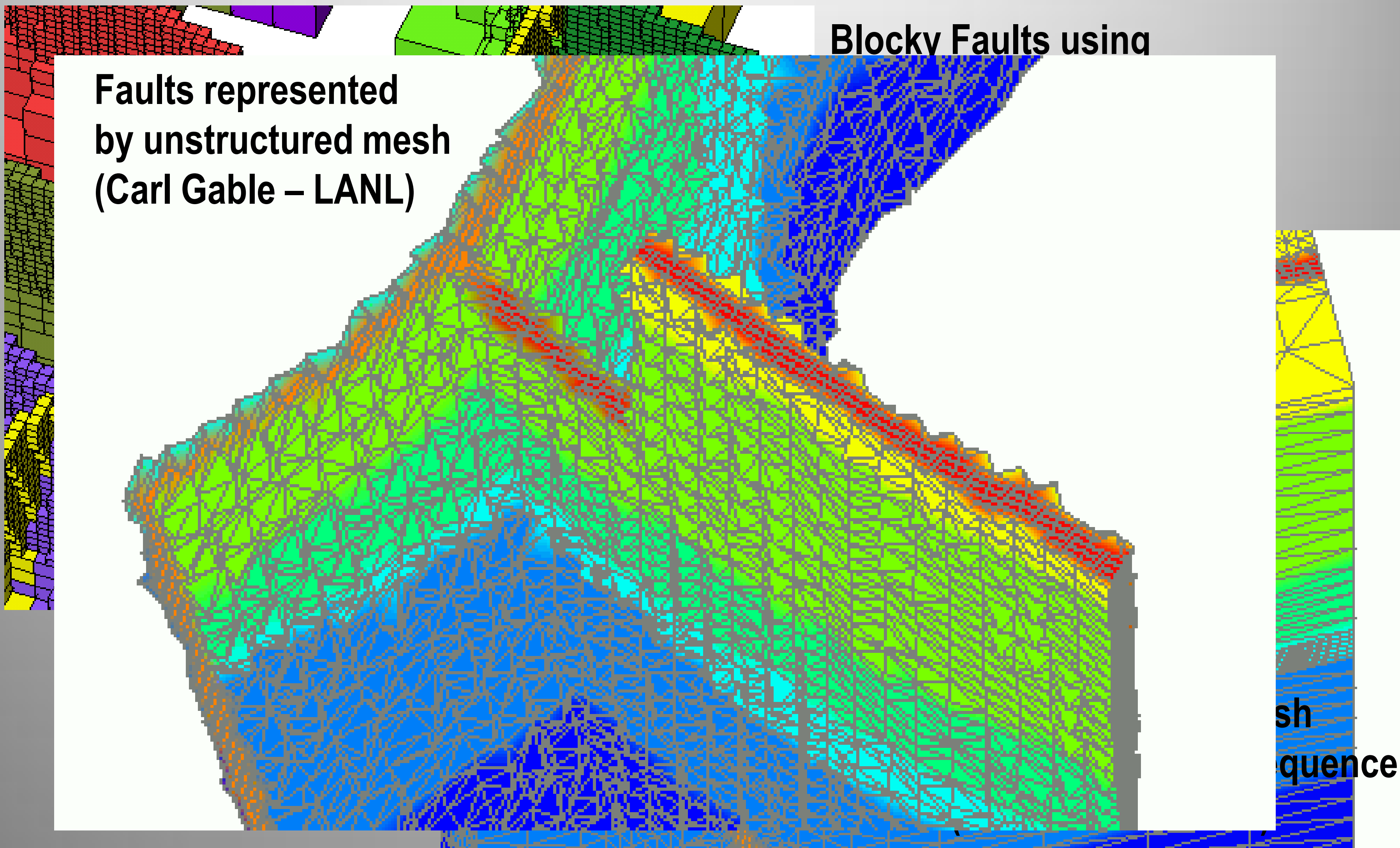
Accurately Modeling Faults is a Challenge

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

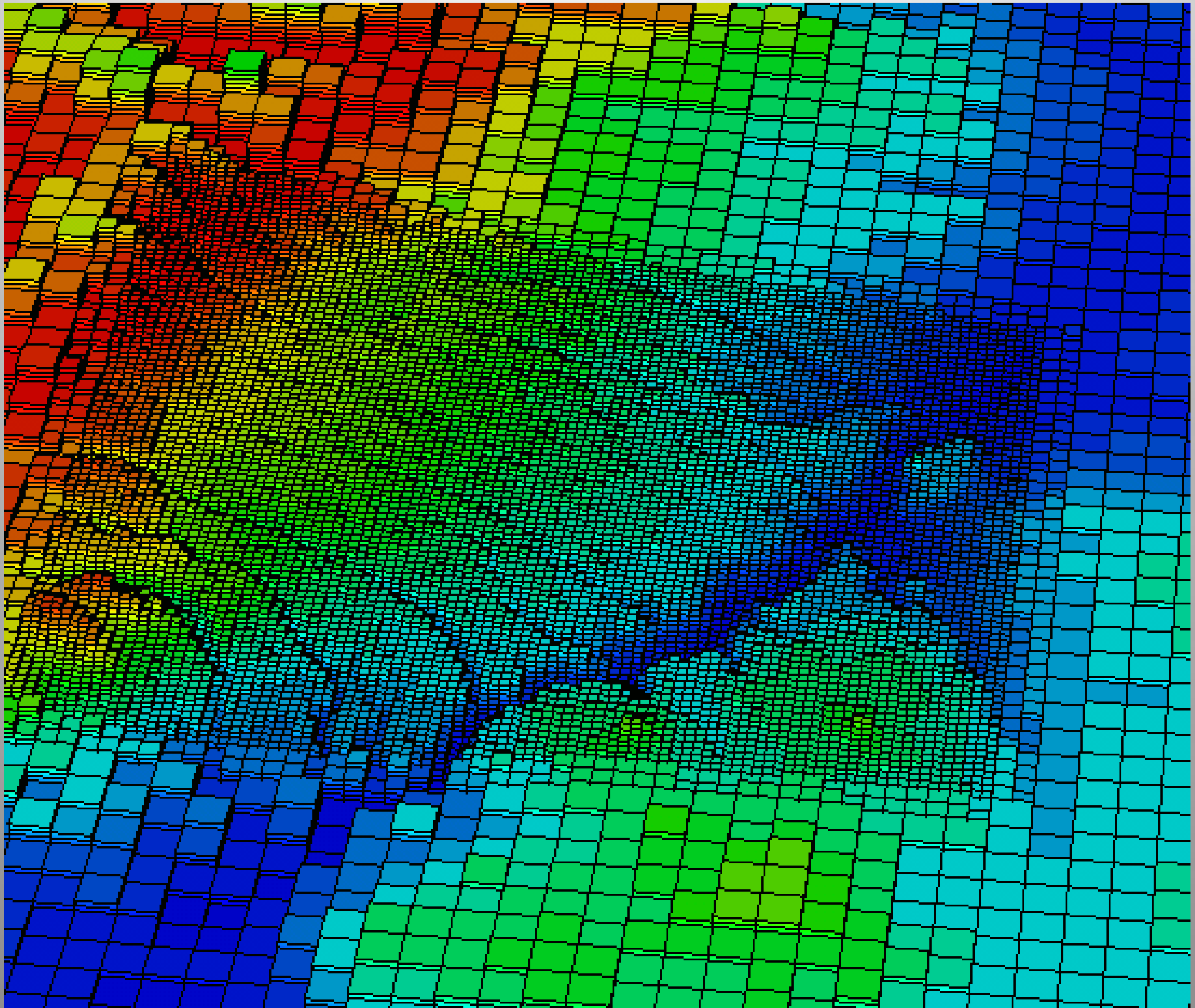


Edwards Aquifer Model
In Texas – by USGS

Advanced Fault Modeling



Models may be "Nested" from Regional to Local Scales

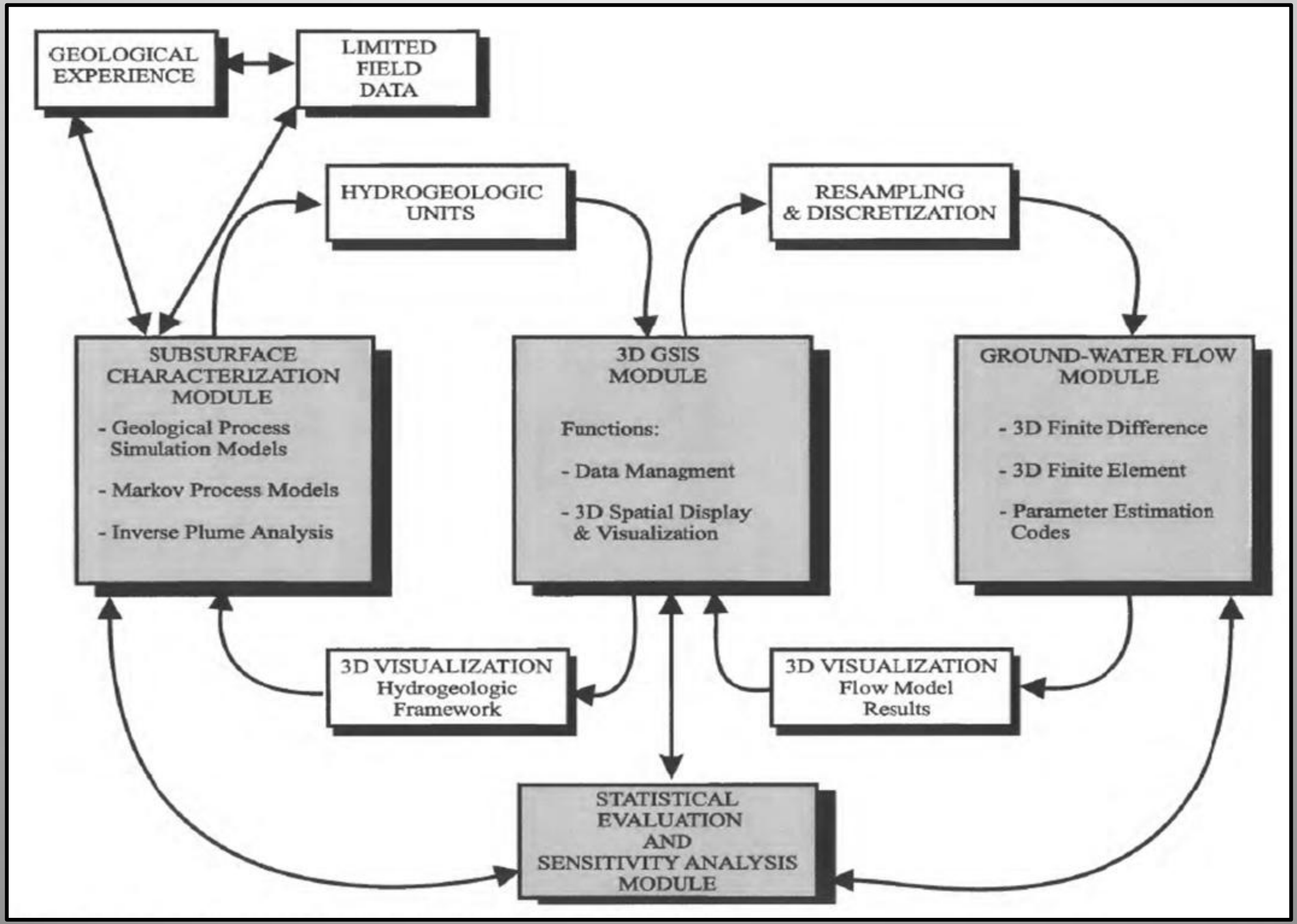


The Ultimate Purpose of 3D Geological Modeling is Prediction…

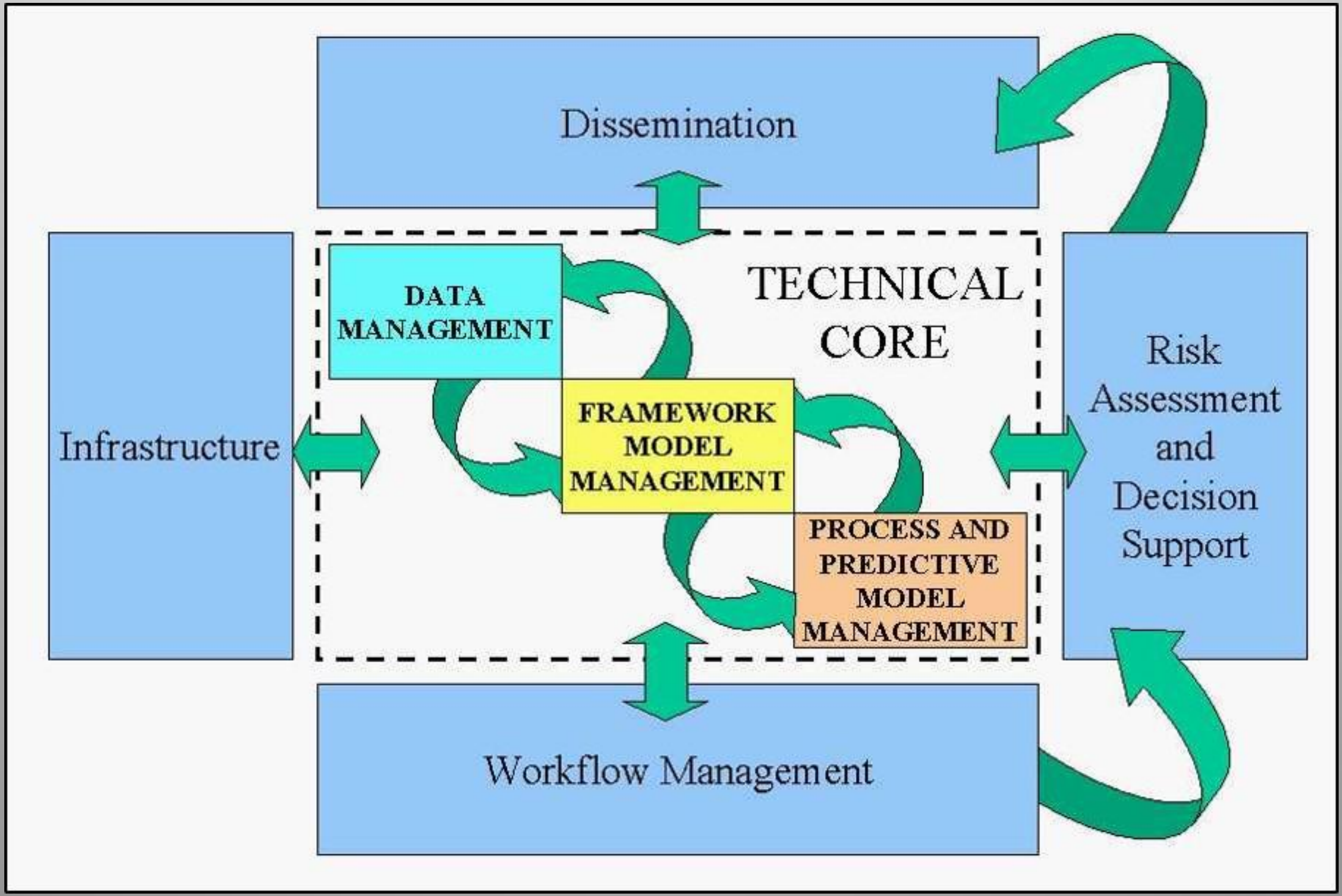
Prediction has an ***extrapolative*** rather than ***interpolative*** character…

- Involves risk
- Leads to Decision-making

3D Modeling Workflow Concept circa 1994

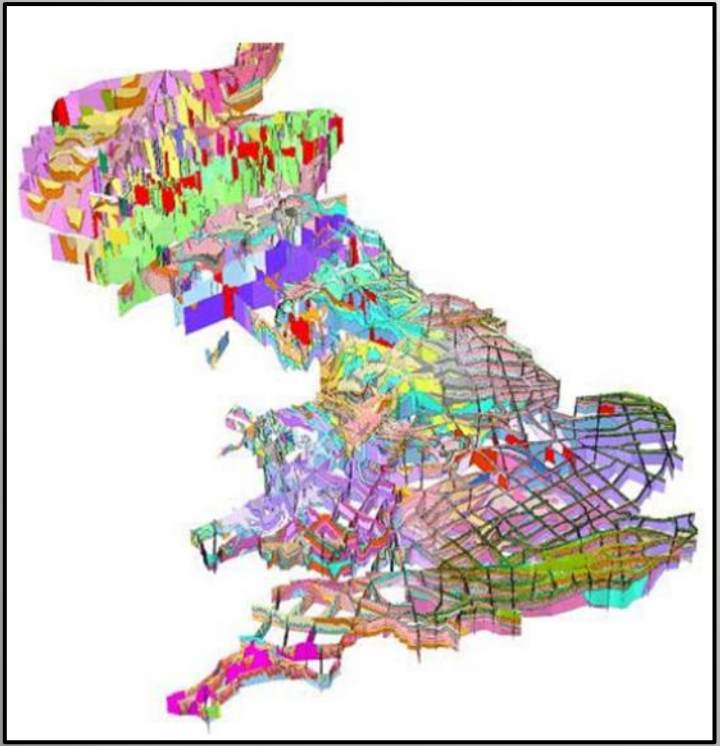


Modeling & Data Management Concept circa 2002

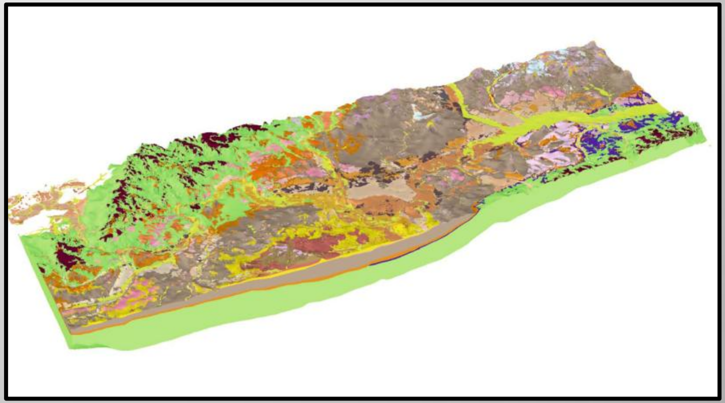


Model Applications at Many Scales

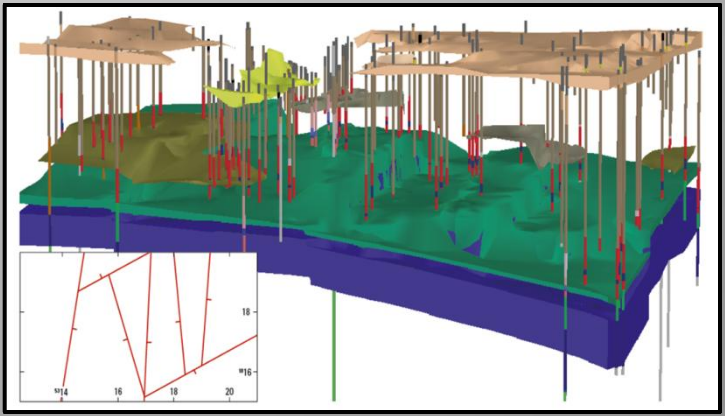
National 3D UK Model



Regional 3D Model (London)



Site 3D Model (Farringdon Station)



3D Models for External Users:
Geotechnical Engineering Applications

- 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

37%

of project overruns cite ground problems as a major contributor

National Economic Development Office

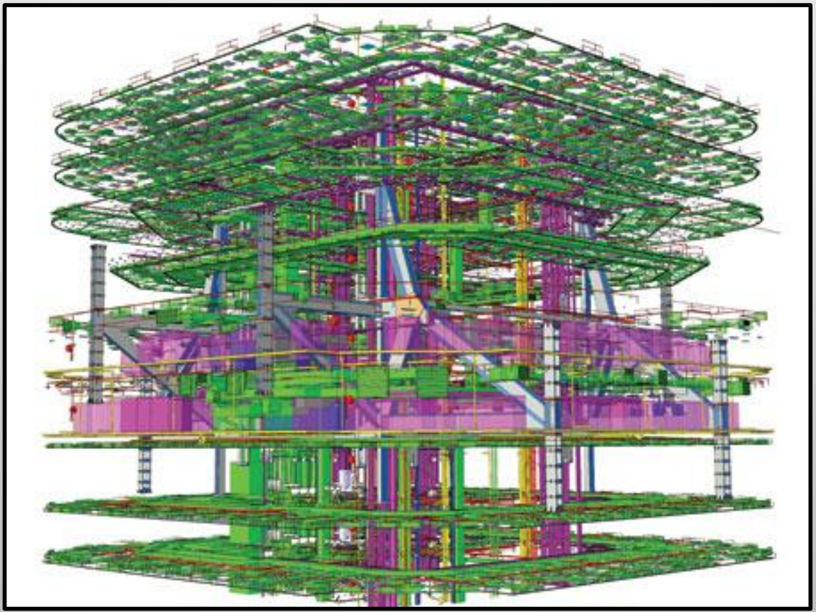
70%

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

National Audit Office

Building Information Modeling (BIM)

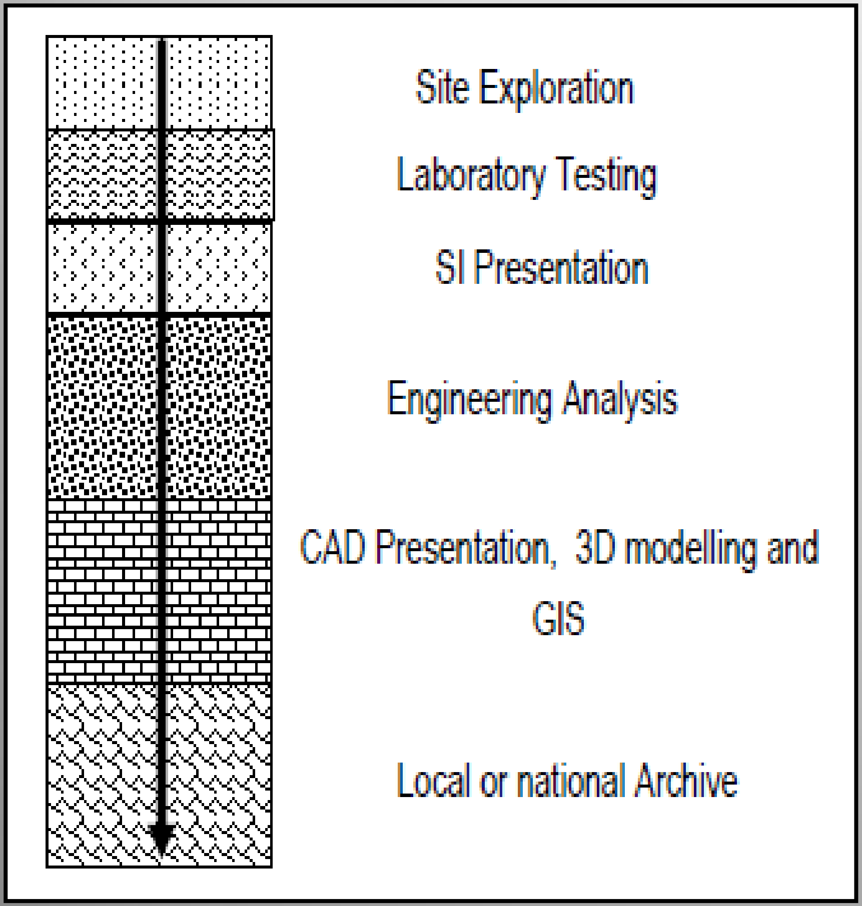
But Where is the Geology?



- 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

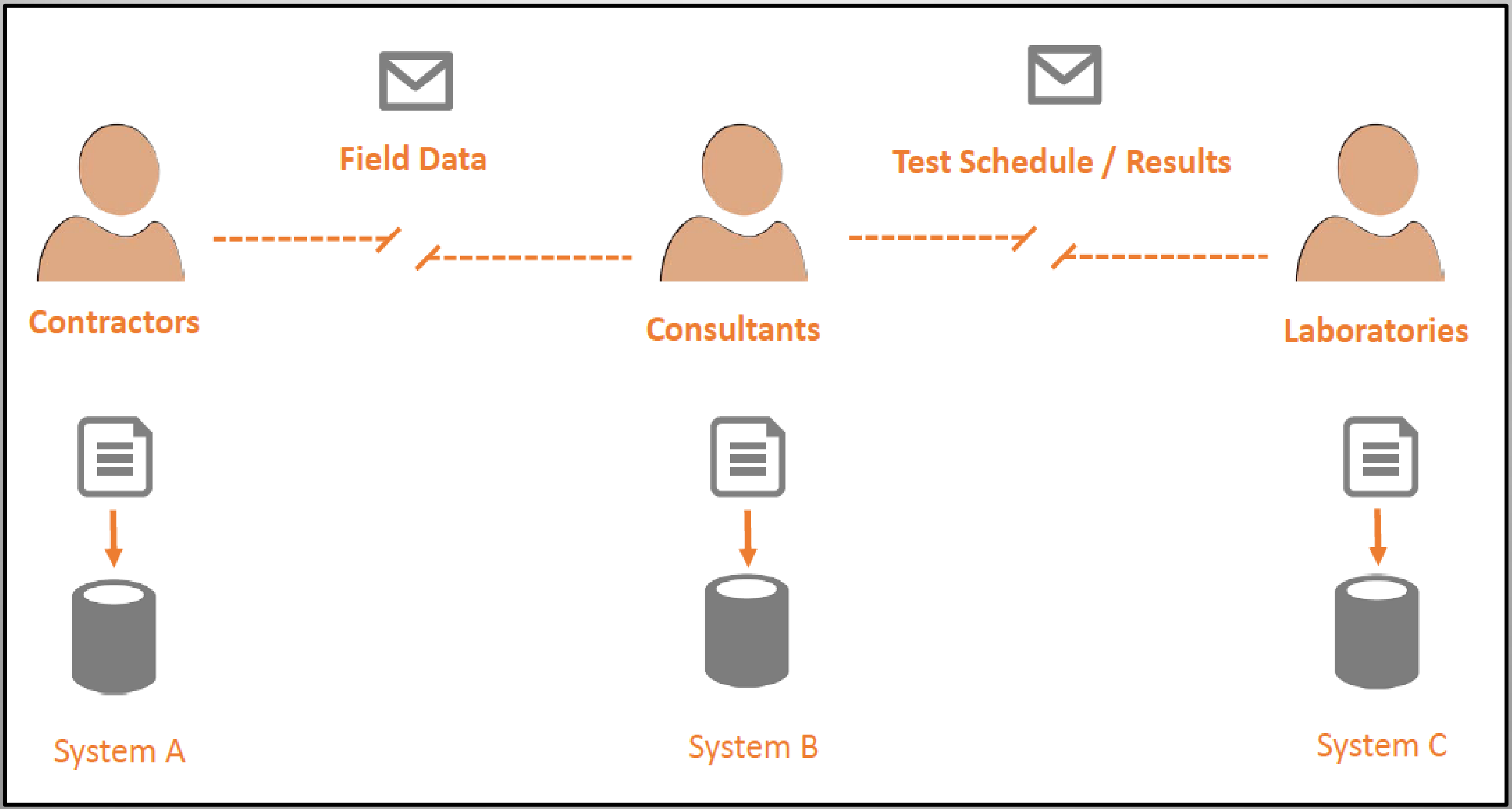
Traditional Geotechnical Data Journey (Chandler & Hutchinson 1998)



- **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

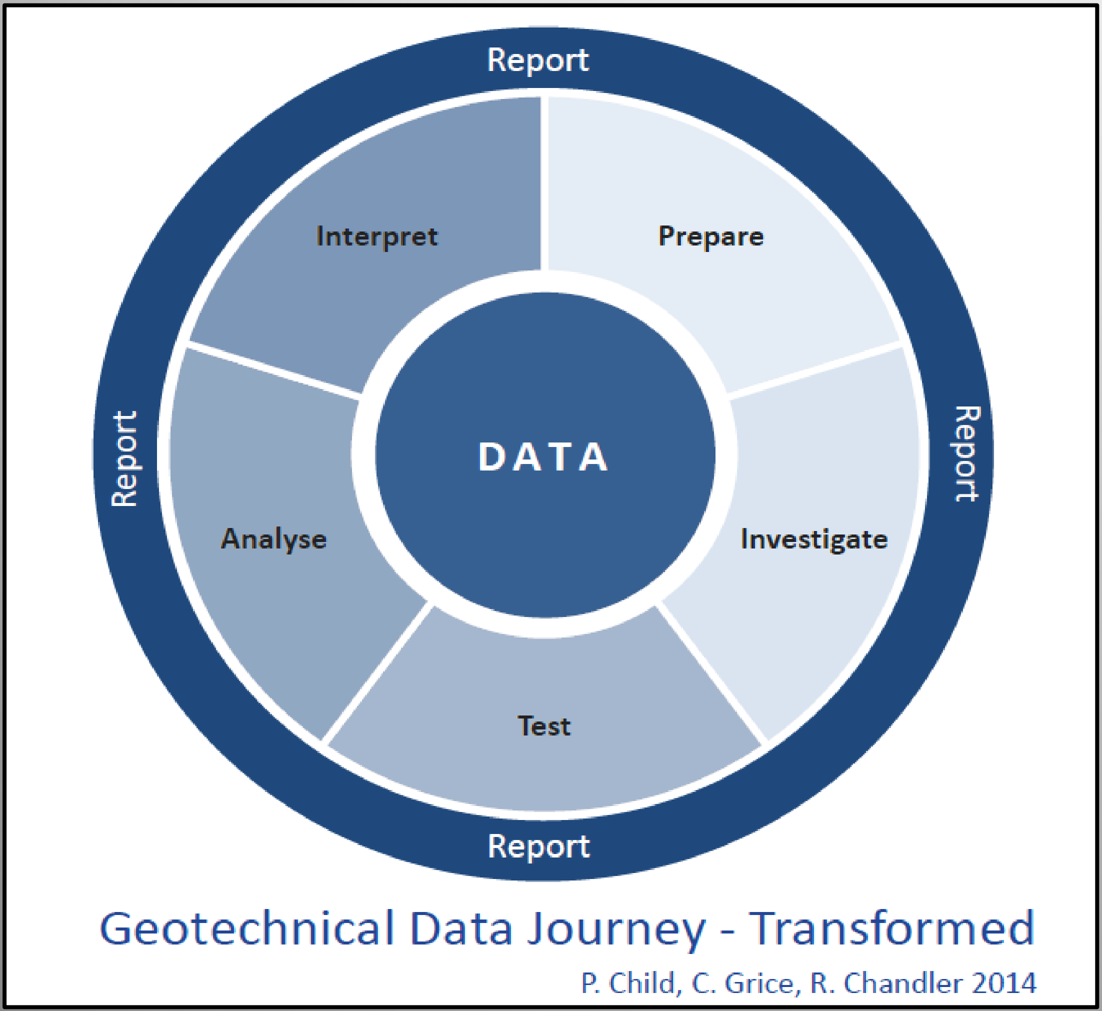
Limited availability of quality geotechnical data



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

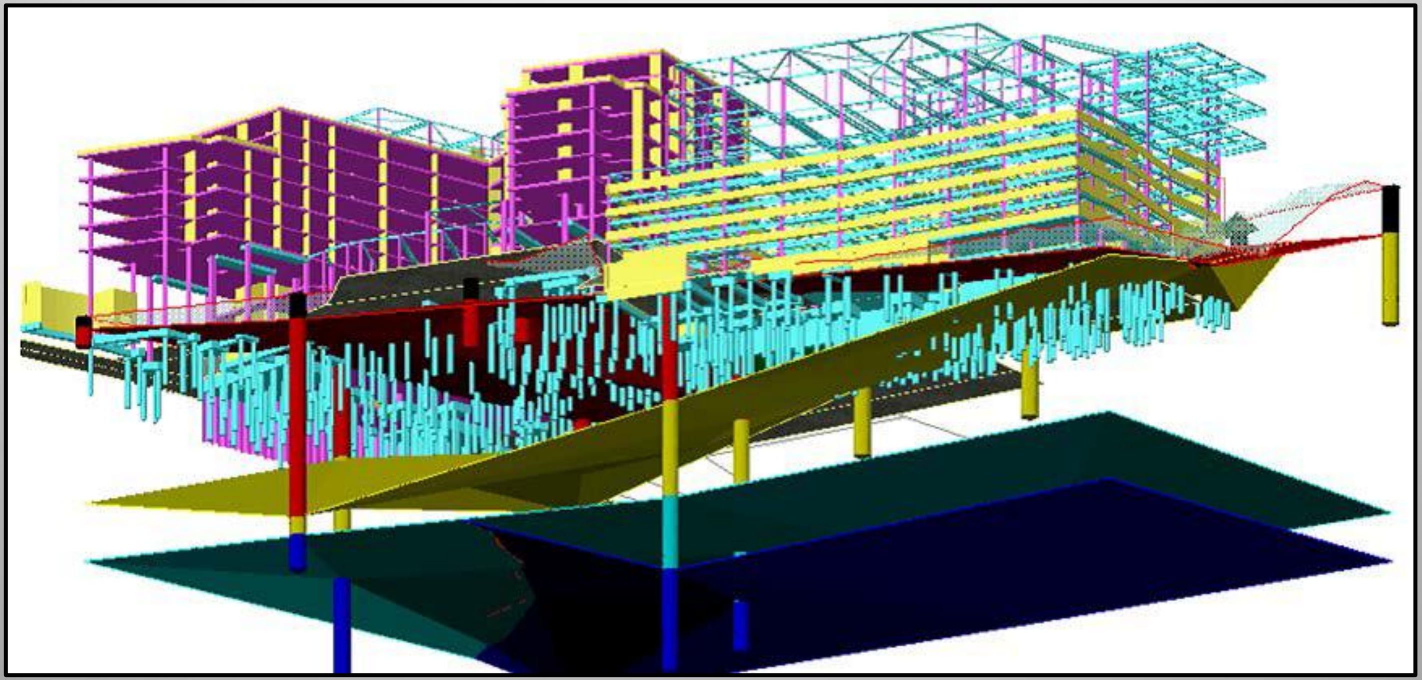
Possible Solution

Apply BIM principles throughout the Geotechnical Data Journey



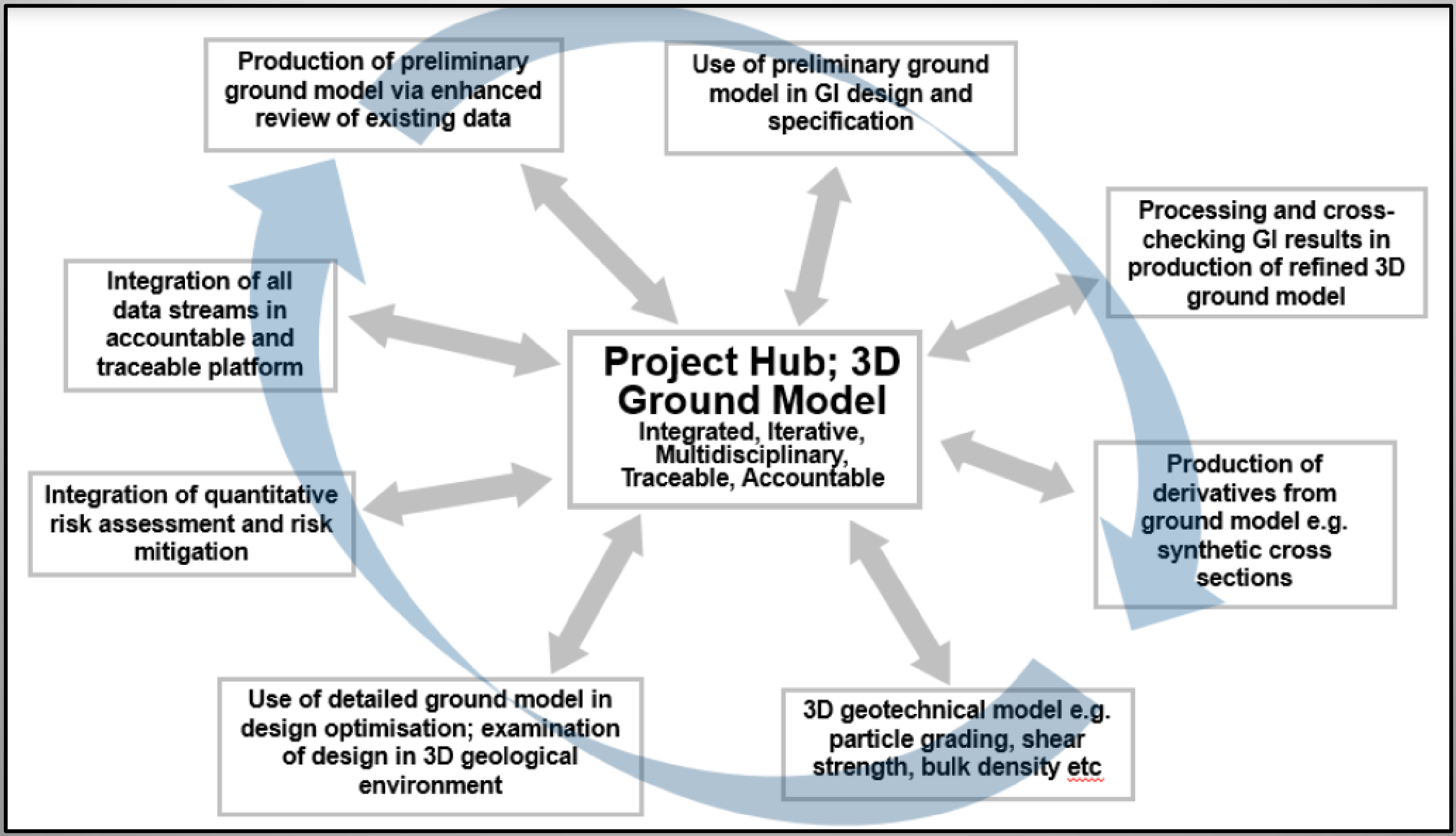
- Geotechnical BIM
- Historic data & 3D models utilised throughout
- Centralised data repositories
- Incremental data delivery and iterative refinement
- Data reuse and collaboration

"Geo-BIM" – BIM and the Subsurface

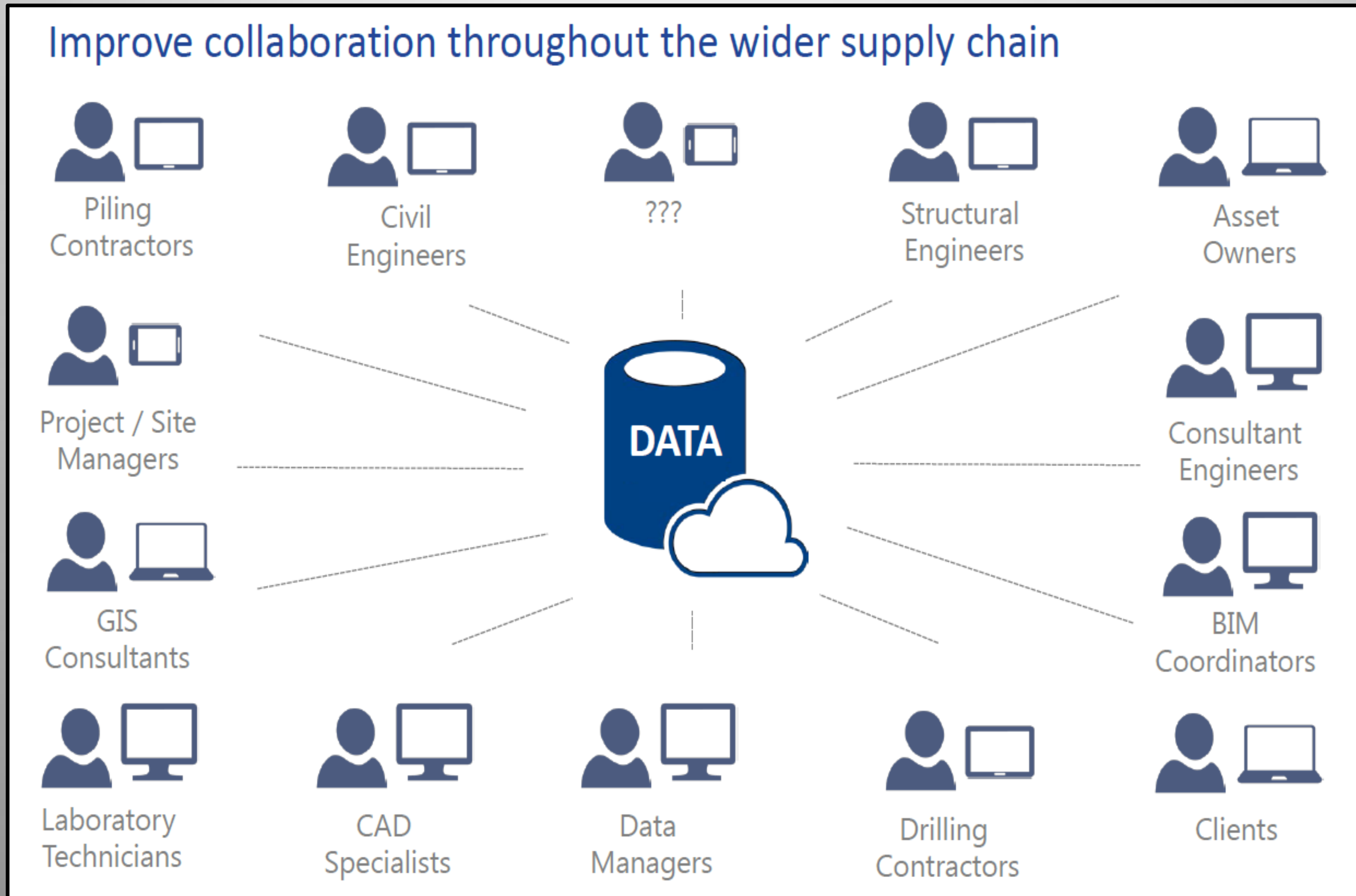


- **Extend/Integrate 3D Geological Modeling techniques to the BIM environment**

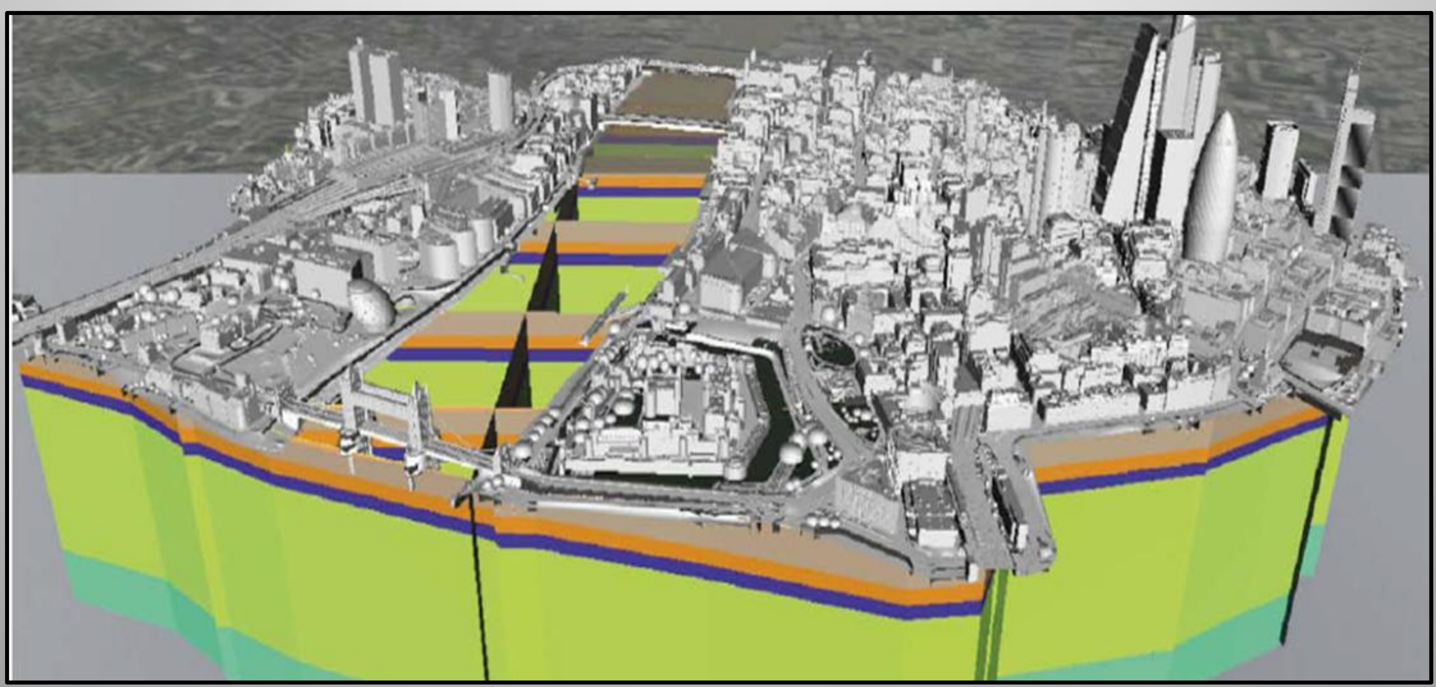
Potential Integrated Geo-BIM Workflow
(source: CH2MHill)



Geo-BIM can support Collaborative Modelling



Current Capability:
City of London on 3D Geology Model



City model courtesy of ARUP

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.

PROPOSED BOOK
TO BE PUBLISHED
BY WILEY

Proposed Book Title

Applied Multidimensional Geological Modelling:
Informing sustainable human interactions with the shallow subsurface

EDITORS: A.K. Turner, H. Kessler, M. van der Meulen

CONTACT: kturner@mines.edu

Applied Multidimensional Geological Modelling:

Informing sustainable human interactions with the shallow subsurface

HOW TO PARTICIPATE:

- **Chapters may be developed by individuals or by teams led by an individual**
- **All contributors will be recognized**
  - **After the chapter title.**
  - **Short Biographies will be included in book**
- **If requested, EDITORS will assist individuals in preparing chapters**
  - **For example: If contributors provide EDITORS with a series of source documents, EDITORS will prepare an initial draft for contributors to review and edit.**

Applied Multidimensional Geological Modelling:

Informing sustainable human interactions with the shallow subsurface

YOUR COMMENTS and SUGGESTIONS ARE WELCOMED!

SEND COMMENTS TO:

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