# Applying 3D Geological Modeling to Infrastructure Design

**Alan Keith Turner**

**Emeritus Professor of Geology & Geological Engineering CSM**

**Visiting Research Associate - British Geological Survey**

**February 10, 2016**

# SUMMARY

- **Review of 3D Geological Modeling**
- **Two Recent United Kingdom Infrastucture Applications**
- **The Future of 3D Models for Urban Infrastructure Planning**
  - **Sustainable Cities**
  - **Geotech-BIM Concepts**

# 3D Geological Modeling Research Began over 3 Decades Ago

**Evolution of 3D geological modeling:**

**1985-1995 "Can we do it?"**

**– Initial fundamental research, early software and hardware limitations.**

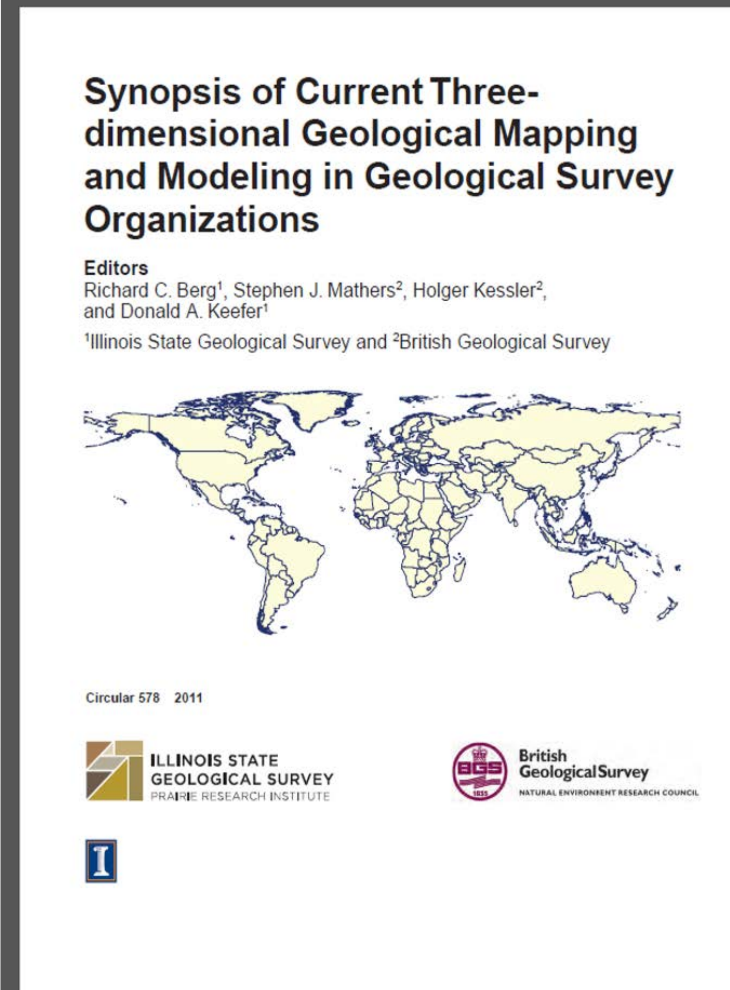
**1995-2005 "How do we do it?"**

**– Implementation of workflows, databases, software matures.**

**2005-2015 "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.**


Synopsis of Current Three-dimensional Geological Mapping and Modeling in Geological Survey Organizations

Editors
Richard C. Berg[1], Stephen J. Mathers[2], Holger Kessler[2], and Donald A. Keefer[1]
[1]Illinois State Geological Survey and [2]British Geological Survey

Circular 578 2011

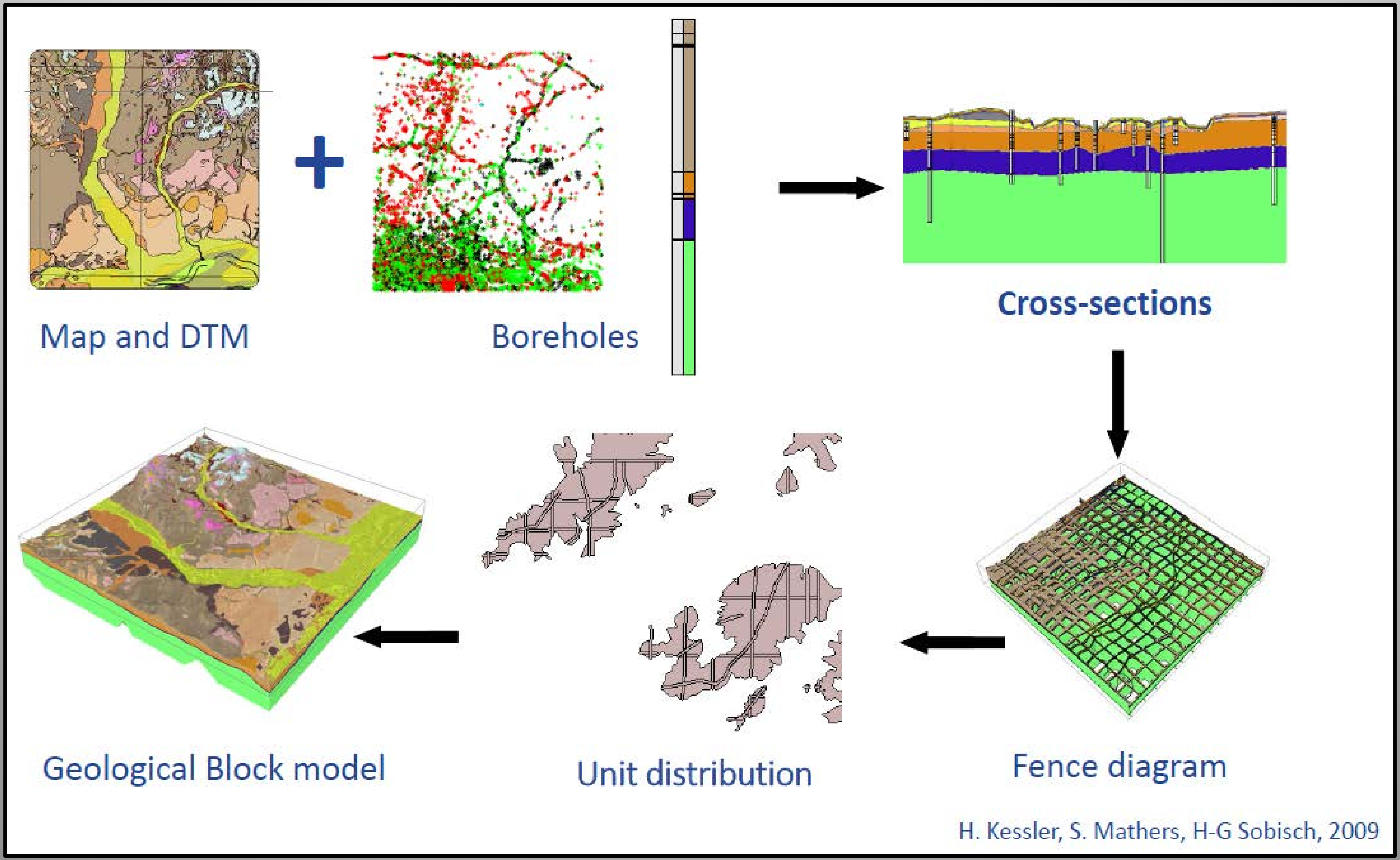
ILLINOIS STATE GEOLOGICAL SURVEY
PRAIRIE RESEARCH INSTITUTE

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

http://library.isgs.illinois.edu/Pubs/pdfs/circulars/c578.pdf

# Typical 3D Model Creation Workflow

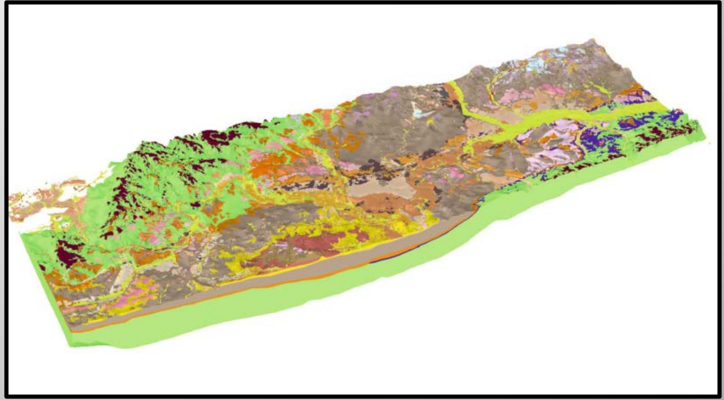
## - This is GSI3D Workflow at BGS -



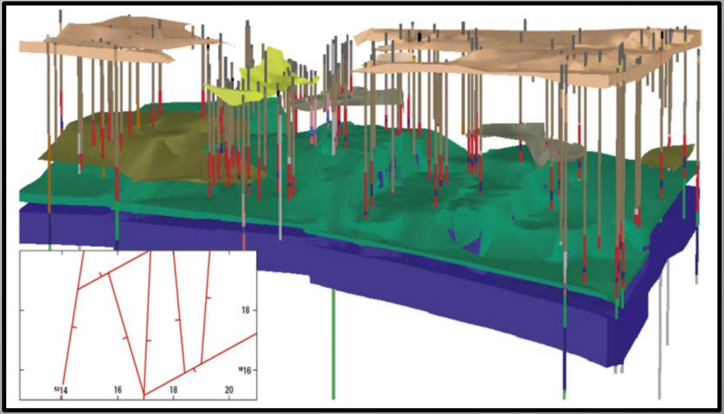
# BGS Model Applications at Many Scales

## National 3D UK Model

## Regional 3D Model (London)



## Site 3D Model (Farringdon Station)

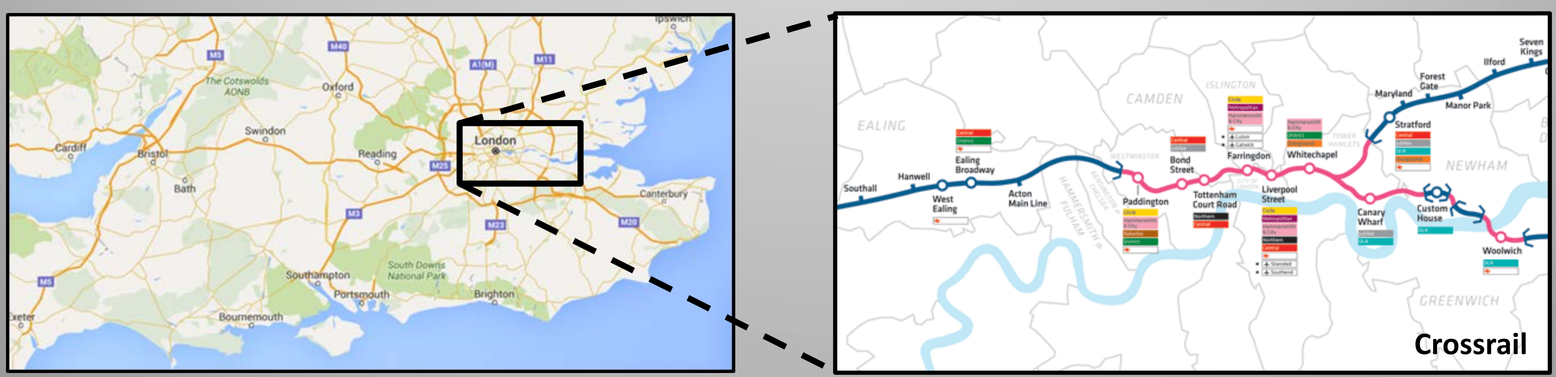


# Two Recent UK Infrastucture Applications

1. Farringdon Station for London CrossRail Project (2009-2015)
2. Planning for Electrification of Railway between Leeds and York (2015)

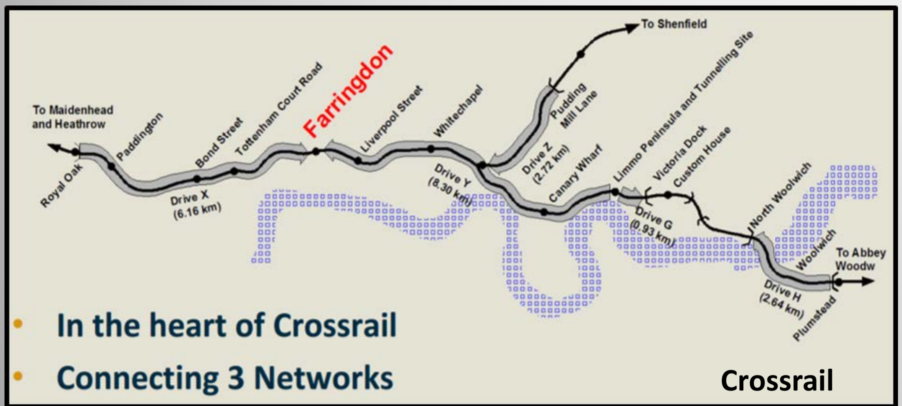
# London CrossRail Project (2009-2015)

- Crossrail will link Reading and Heathrow in the west with Shenfield and Abbey Wood in the east via 21 km (13 miles) of twin-bore tunnels under central London
- Connects with key London rail stations and London Tube network
- Passes around and beneath existing Tube tunnels at depths up to 30 m (100 ft) – thus encountering some problematic geological conditions




- 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




- Two 300 m (985 ft) platform tunnels plus multiple access tunnels
- 30 m (100 ft) below the surface

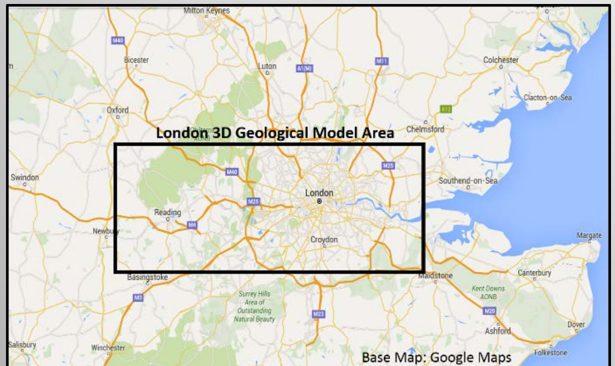
Architect's Impression of Farringdon Platform


**PRIOR INVESTIGATIONS IDENTIFIED ADVERSE GROUND CONDITIONS:**

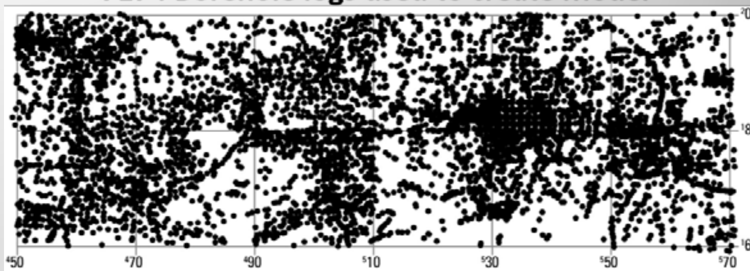
- Multiple faults,
- Buried valley of Fleet River
- Water-bearing sands within the tunneling medium (Lambeth Group)
- Potential surface settlement on old buildings and surface railway

# Existing 3D Subsurface Information

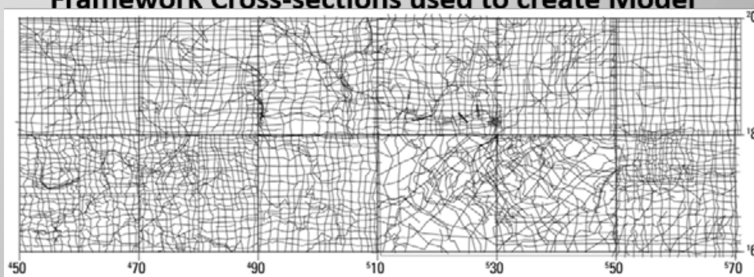
## BGS Regional 3D London Model



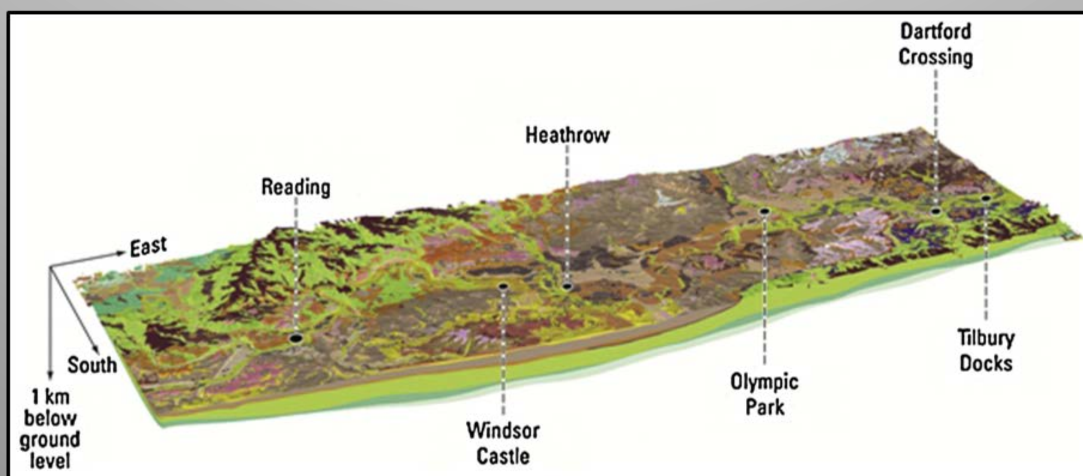

7174 Borehole logs used to create Model




Framework Cross-sections used to create Model



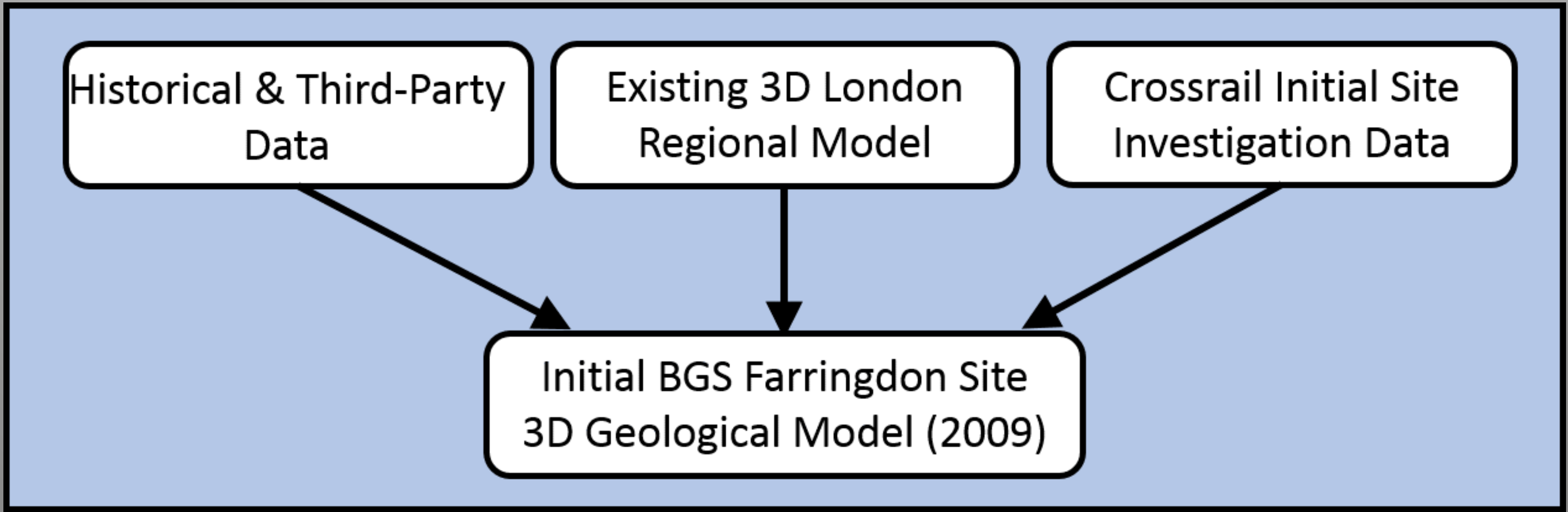

Oblique View of Completed London Model




(From Mathers et al., 2014)

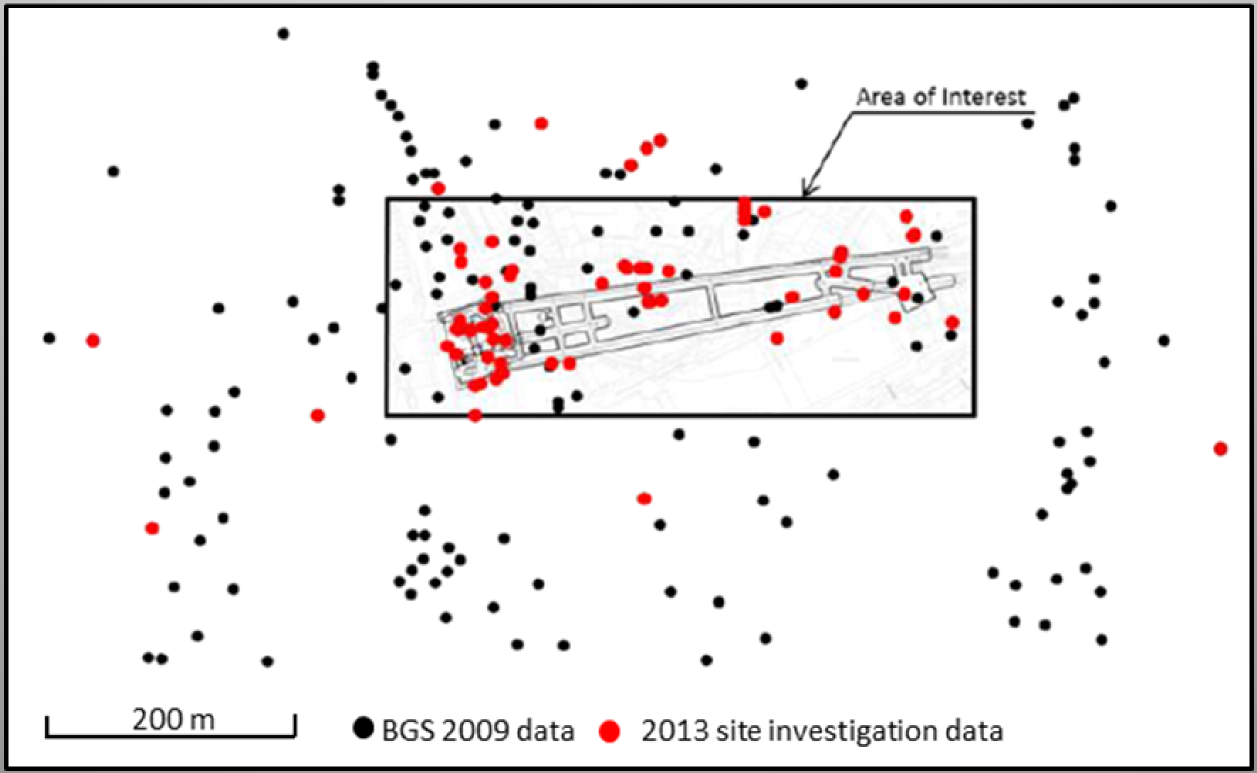
# Initial 3D Geological Model of Farringdon Station Site

- **By 2008 Crossrail had completed initial ground investigations, at least on fault has been identified but little confidence in the ground model.**
- **In 2009 Crossrail commissioned BGS to develop a 3D geological site model to guide future investigations**
- **Model constructed using existing London regional model, historical & third-party data, and available Crossrail data**



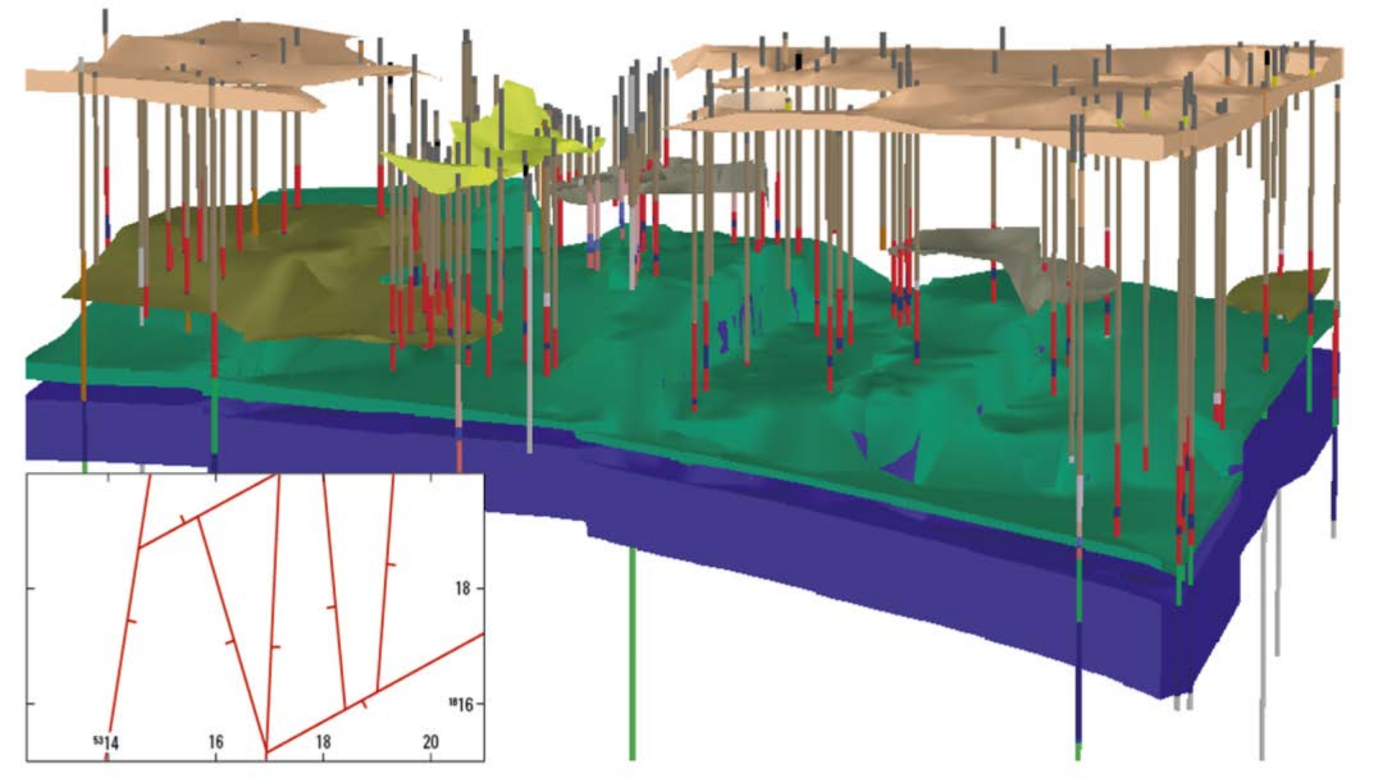
# Farringdon Station Design Modeling (2009-2013)

**Initial 2009 BGS 3D geological model of Farringdon station was progressively updated as new Crossrail exploration data received**



# Farringdon Station 3D Model

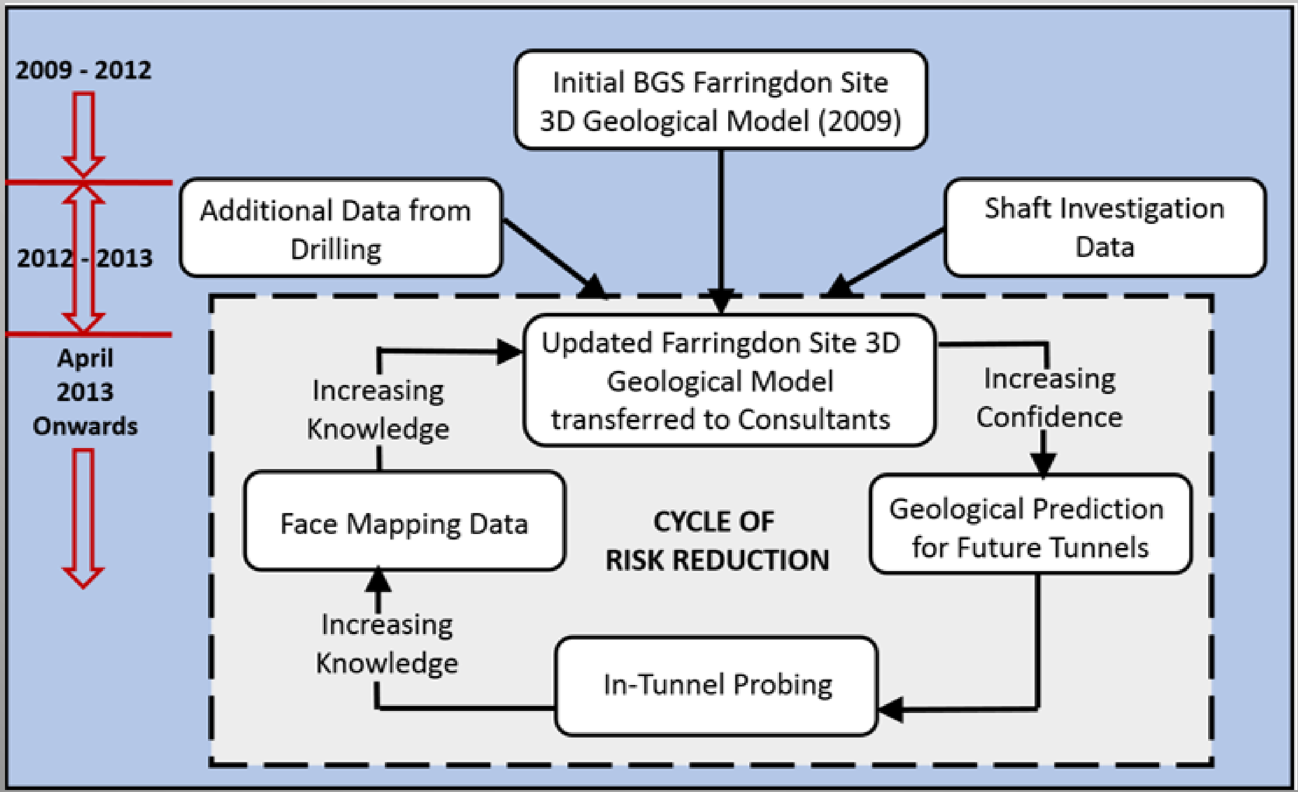
**3D model display of sand and gravel (water-bearing) units and faults**




(Aldiss et al., 2012)

# Farringdon Station 3D Model Integrated into Site Supervision Workflow (2013-2015)

**In 2013, this model was handed over to the contractor and integrated into the site supervision workflow**




(Modified from Cabrero & Gakis, 2014)

# Model updated on daily basis as station excavated
# - Faces mapped as excavation advanced -

**Geotechnical Record - Face Mapping**

Document Number: 222E5-Face Map 012-TH9-2013-05-07.xlsx

www.dr-sauer.com | BFK Bam | Ferrovial | Kier

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Logger: | Rafael Marin Bellido | Date: 06/05/2013 | Time: 00:15 | Shift: Night - 23:00 to 07:30 | Document Number: 222E5-Face Map 012-TH9-2013-05-07.xlsx | | |
| Location: | Early Western | Tunnel: STW2-PL1 | Sequence: Pilot TH | Advance no: 9 | Tunnel Meters: 5.7 to 6.7 | Chainage (km): | (EB) 6+969.7 to 6+970.7 |

**Unit Description:**

(UMB) stiff grey-blue, mottled CLAY

(LTB) stiff to very stiff, grey, sandy CLAY interlaminated with light blue clayey SILT

(LSB) stiff, dark grey silty CLAY with white shell (fragments)

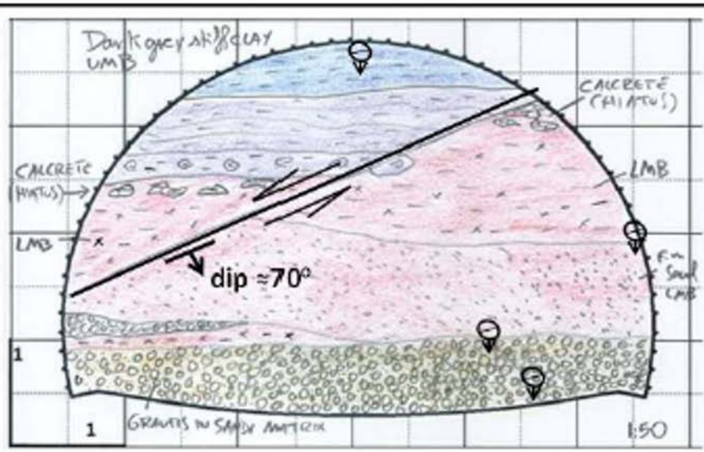
(LMB) stiff to very stiff, multi-coloured, mottled, partly silty sandy CLAY

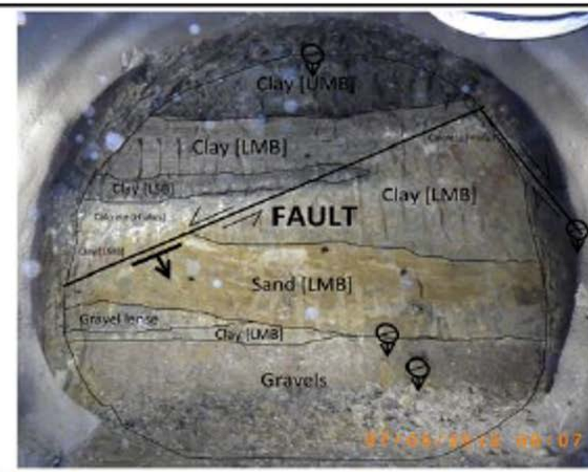
Notes:

**Discontinuitues:**

| Set | Length | Apperture | Shape | Fill | Weathering | Water Flux |
|---|---|---|---|---|---|---|
| 1 | 3-10m | Tight | V Rough | Intact | Dry | Dry |

Notes: Some water dripping on right sidewall through discontinuitie line




**Water Inflow**

Seepage was noted in the topmost probe hole, the gravels of LMB and the RHS sidewall.

**Excavation Stability**

Face was in general stable with minor instabilities occuring in the areas where seepage occurred.

**Obstructions / Voids**

No obstructions were encountered during the excavation of the current advance.

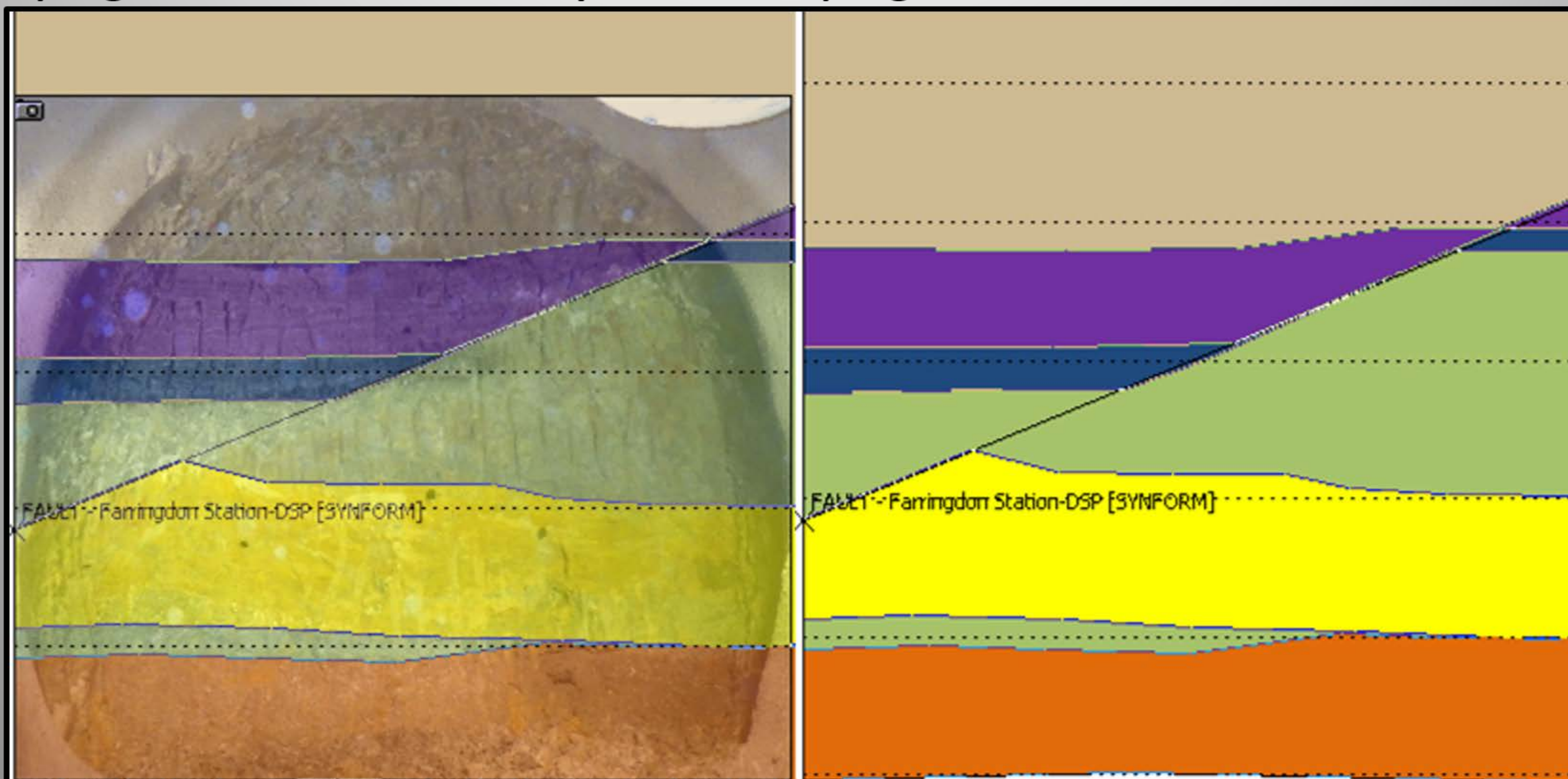
**Notes**

Farringdon Fault was encountered.

(Modified from Cabrero & Gakis, 2014)

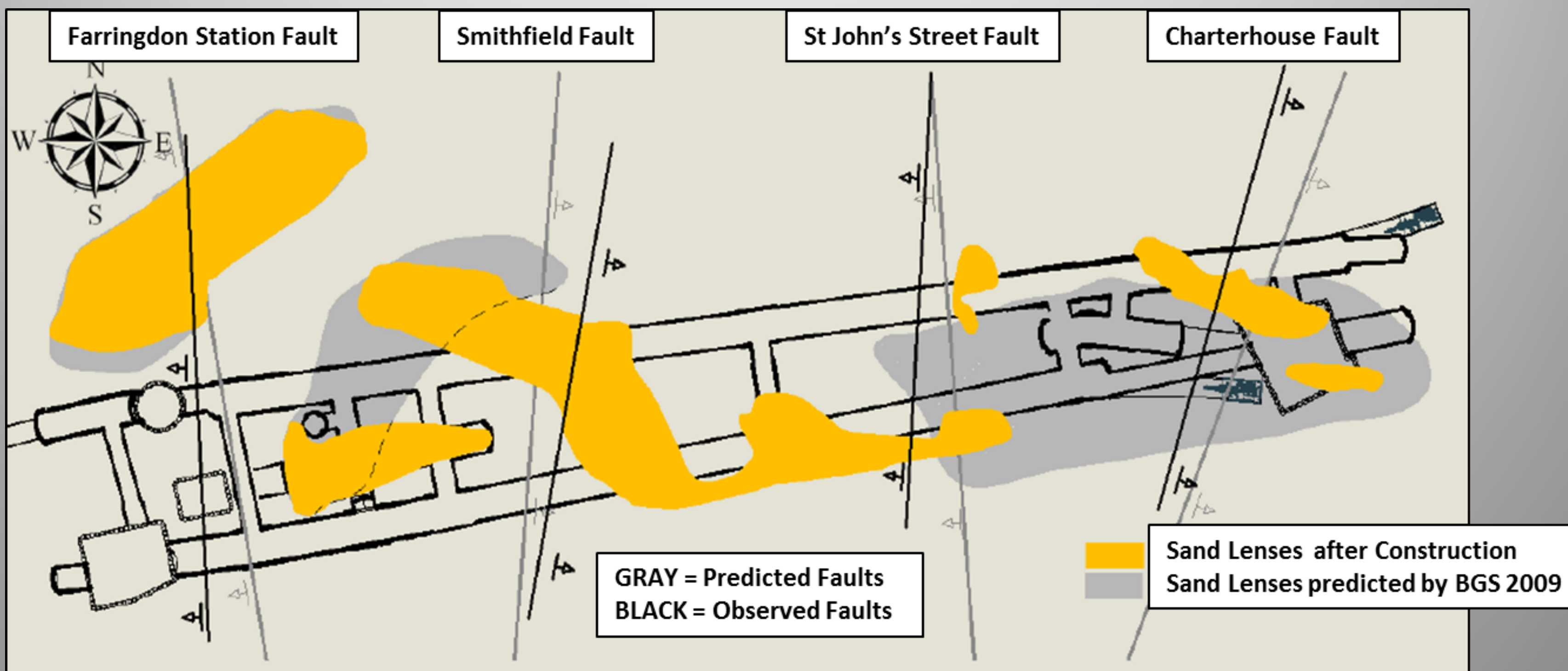
# Model updated on daily basis as station excavated
# - Digital face maps updated 3D model -

**A) Digital Version of Face Map** **B) Digital Cross-section within 3D Model**




(Modified from Cabrero & Gakis, 2014)

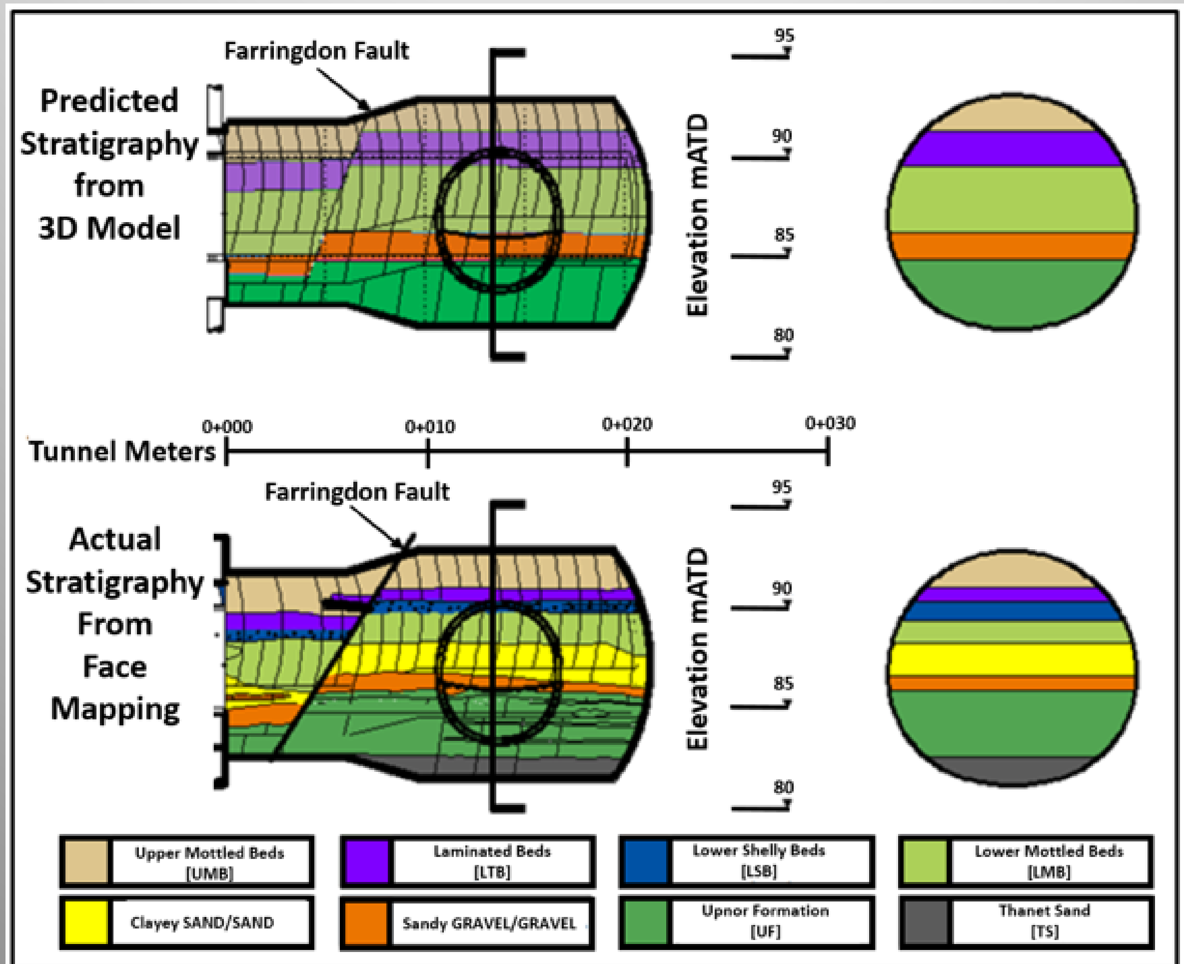
# Farringdon Station
## Predicted vs Observed locations of sand lenses and faults




(Gakis, 2014)

# Farringdon Station
## Success in Predicting Geological Conditions

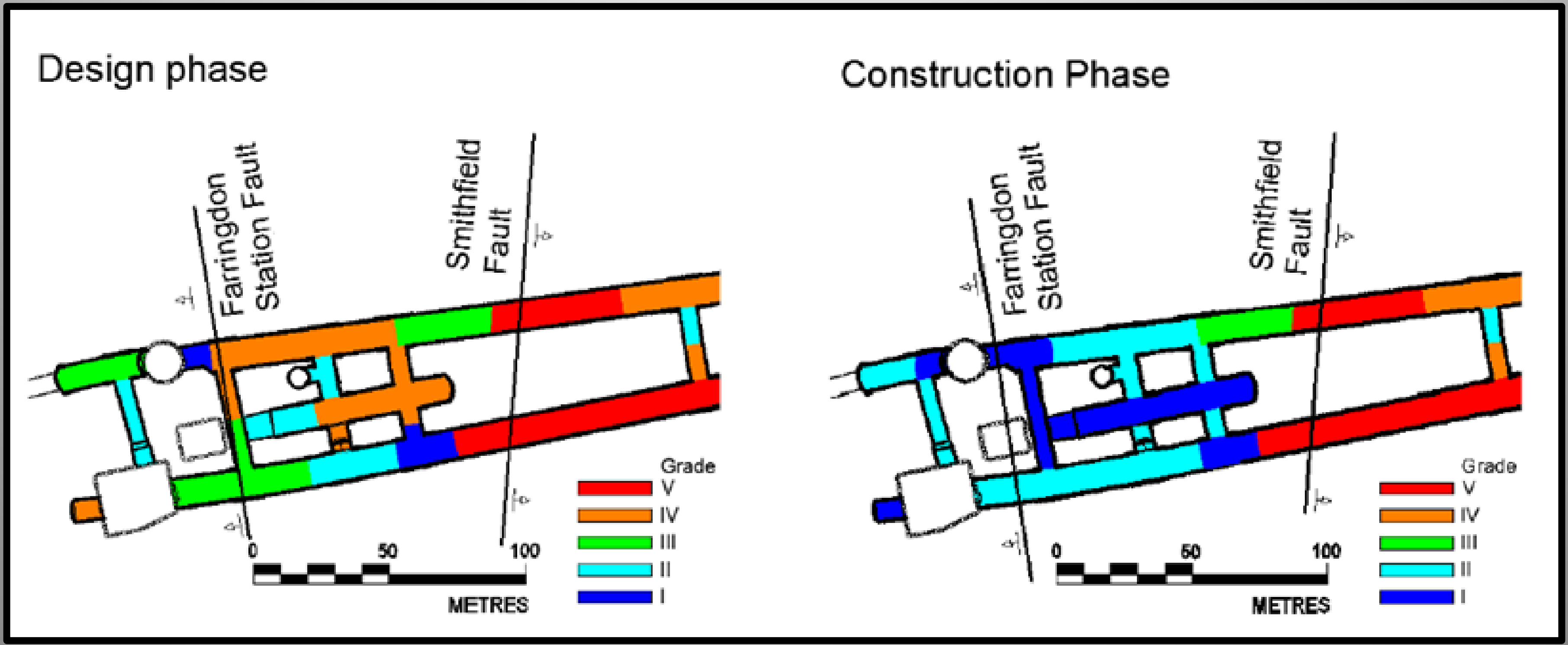
**Geological predictions at one section of Farringdon station**




(Gakis, 2014)

# Farringdon Station

## Comparison of Estimated Risks to SCL Tunneling from Water-Charged Sand Units




(Gakis et al., 2014)

# Consequences of Employing Farringdon Station 3D Model

**Because the Ground Model was updated daily as station excavated:**

- **Enabled geological predictions ahead of excavation**
- **Provided a geological database to collate and store all acquired data**
- **Confidence increased as tunneling progressed**
- **Key Element in reducing Geotechnical Risk**
- **70% reduction of in-tunnel probing compared to original plan**
- **Efficient SCL design and installation**
- **Station excavation completed 3 months early!**

# 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

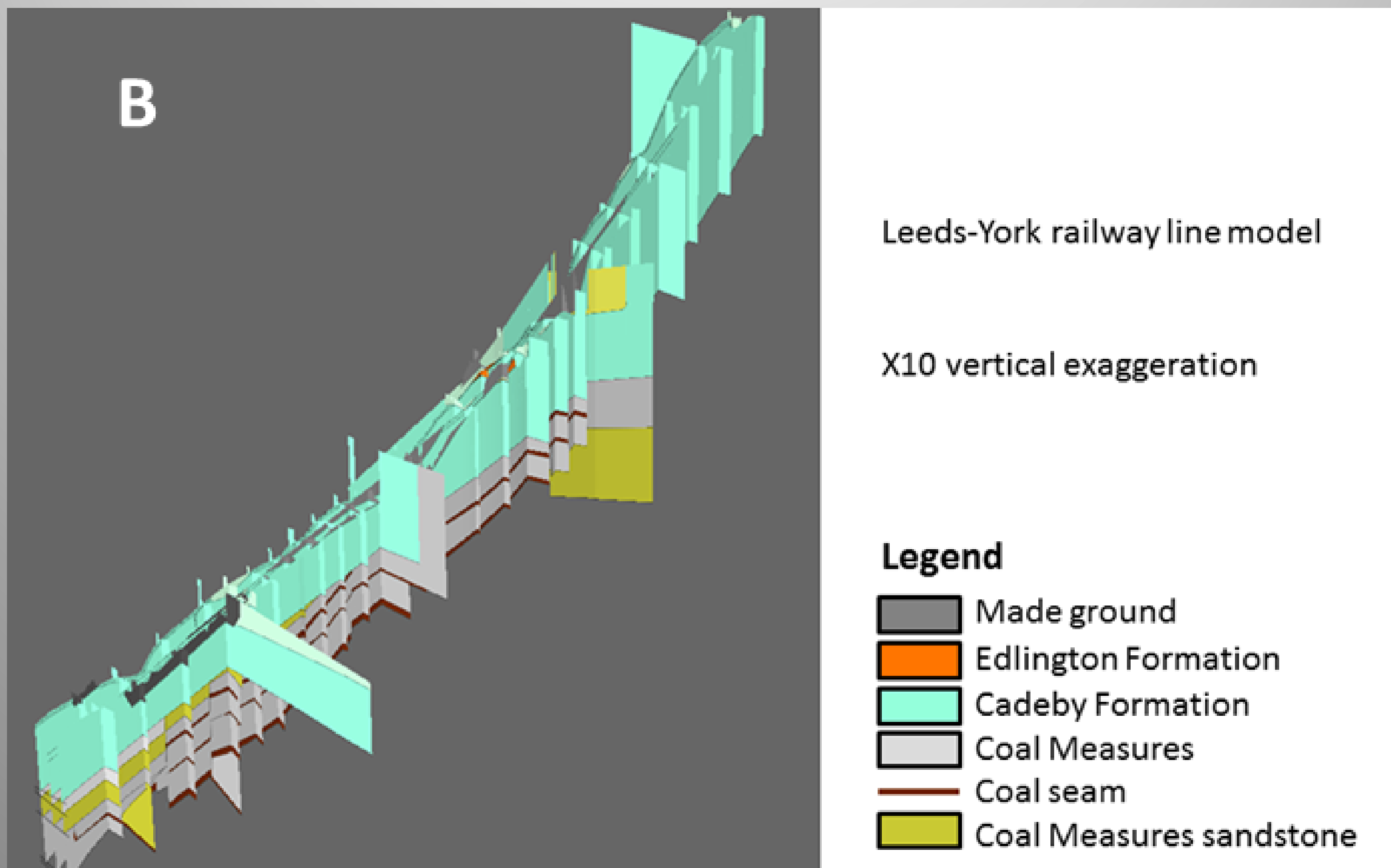
# Planning for Electrification of Railway between Leeds and York (2015)

- 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

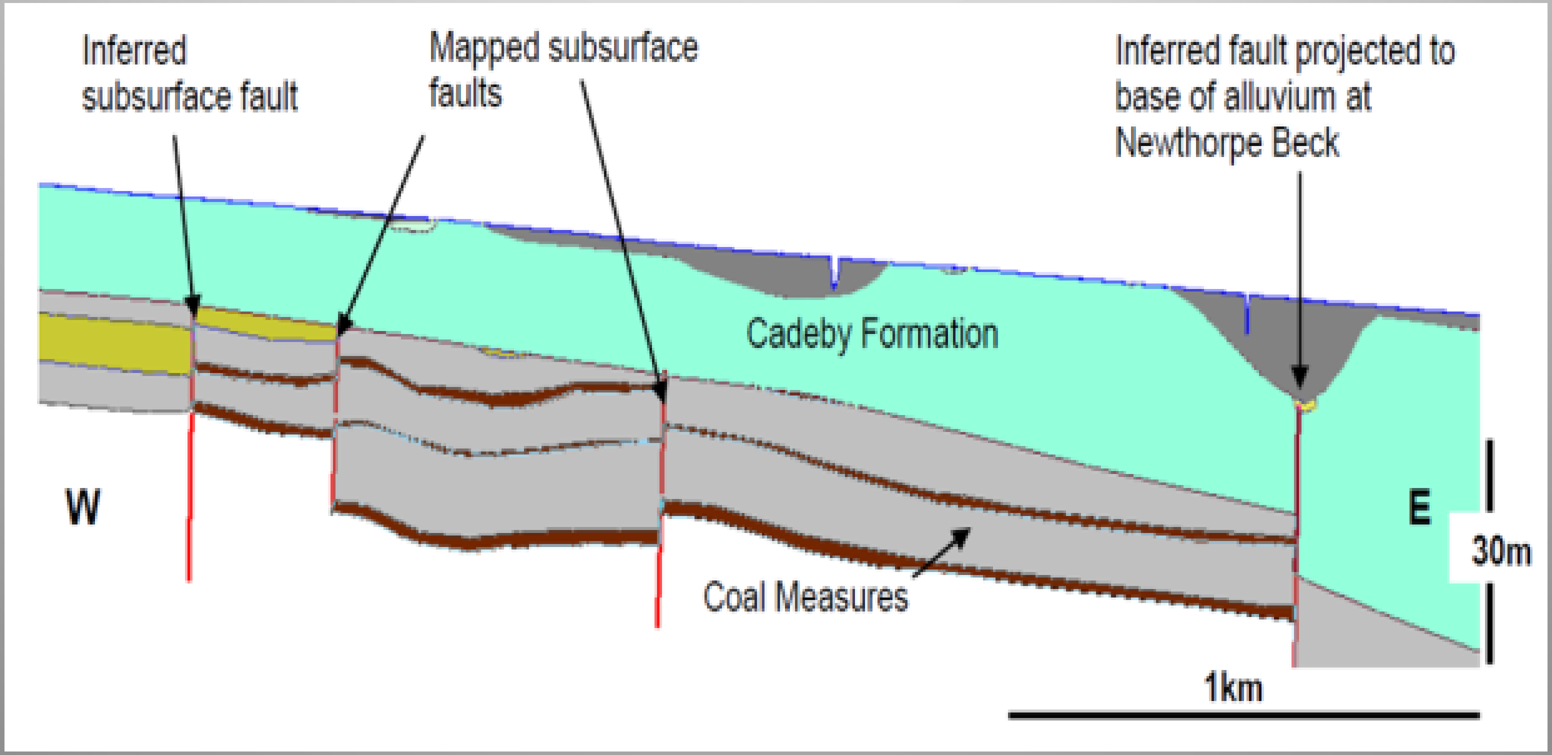
# Planning for Electrification of Railway between Leeds and York (2015)

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



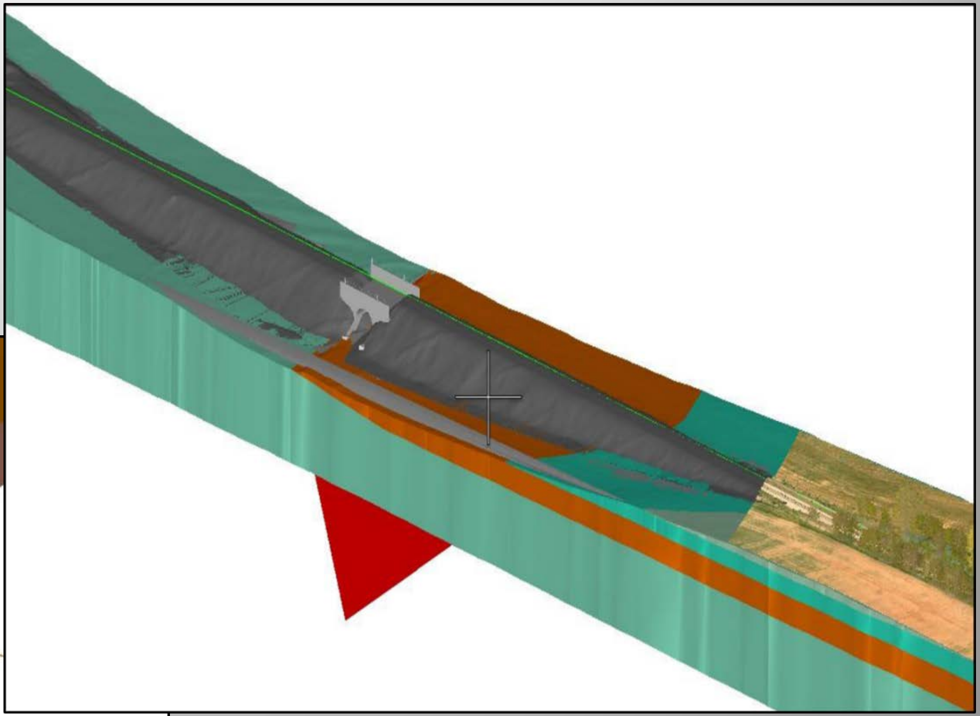
# Planning for Electrification of Railway between Leeds and York (2015)

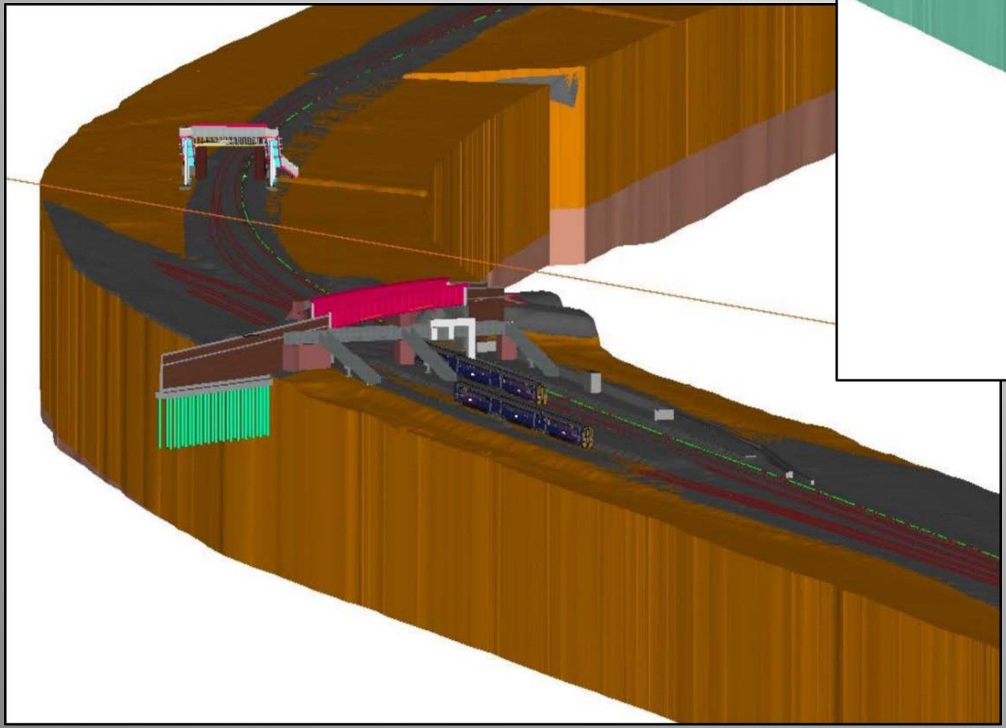
- Center-line Cross-section of 3D model (central 4 km section)
  - showing faults



# How Did Client Use the Model?

**Combined geological model information with CAD infrastructure design files**





**This illustrates the future of 3D model applications**

# The Future of 3D Models for Urban Infrastructure Planning

- Sustainable Cities
- Geotech-BIM Concepts

# 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*

# Britain is investing in major infrastructure projects

- **<u>Energy</u> (power stations, nuclear waste repository, unconventional and re-newable energy, gas-storage, national grid).**
- **<u>Transport</u> (Crossrail tunnels, High Speed Rail, major roads, airports).**
- **<u>Flood Defenses</u> (coastal, rivers and local urban areas).**
- **<u>Housing</u> (new towns, reclamation of brownfield sites)**

**And all of this in light of a growing population and the impacts of climate change**


BBC Sign in News Sport Weather iPlayer TV Radio

NEWS

Home UK World Business Politics Tech Science Health Education Entertai

Business Your Money Market Data Markets Companies Economy

Osborne to launch National Infrastructure Commission

30 October 2015 | Business

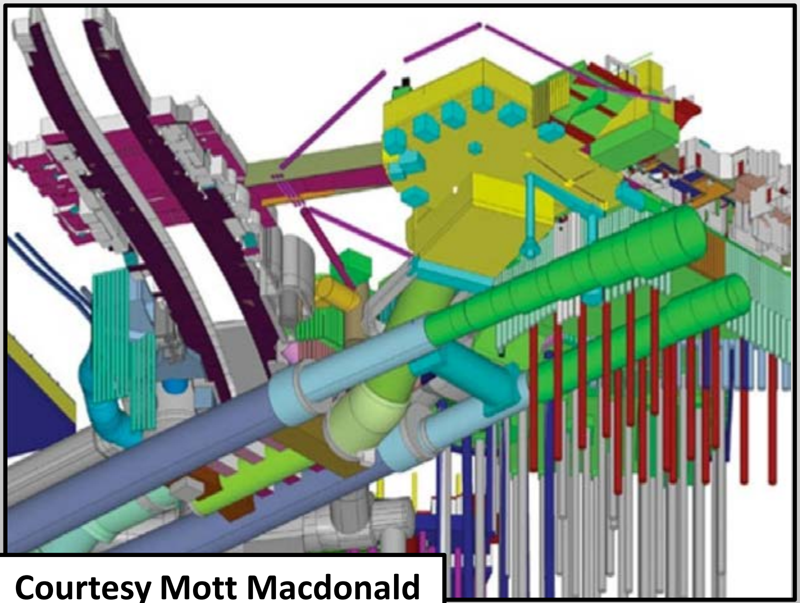


**Chancellor George Osborne will launch the National Infrastructure Commission later to oversee £100bn of spending on infrastructure projects.**

The money, which had already been announced, will be spent by 2020 on "vital projects" such road, rail and flood defence improvements.

# Building Information Modeling (BIM)

## But Where is the Geology?

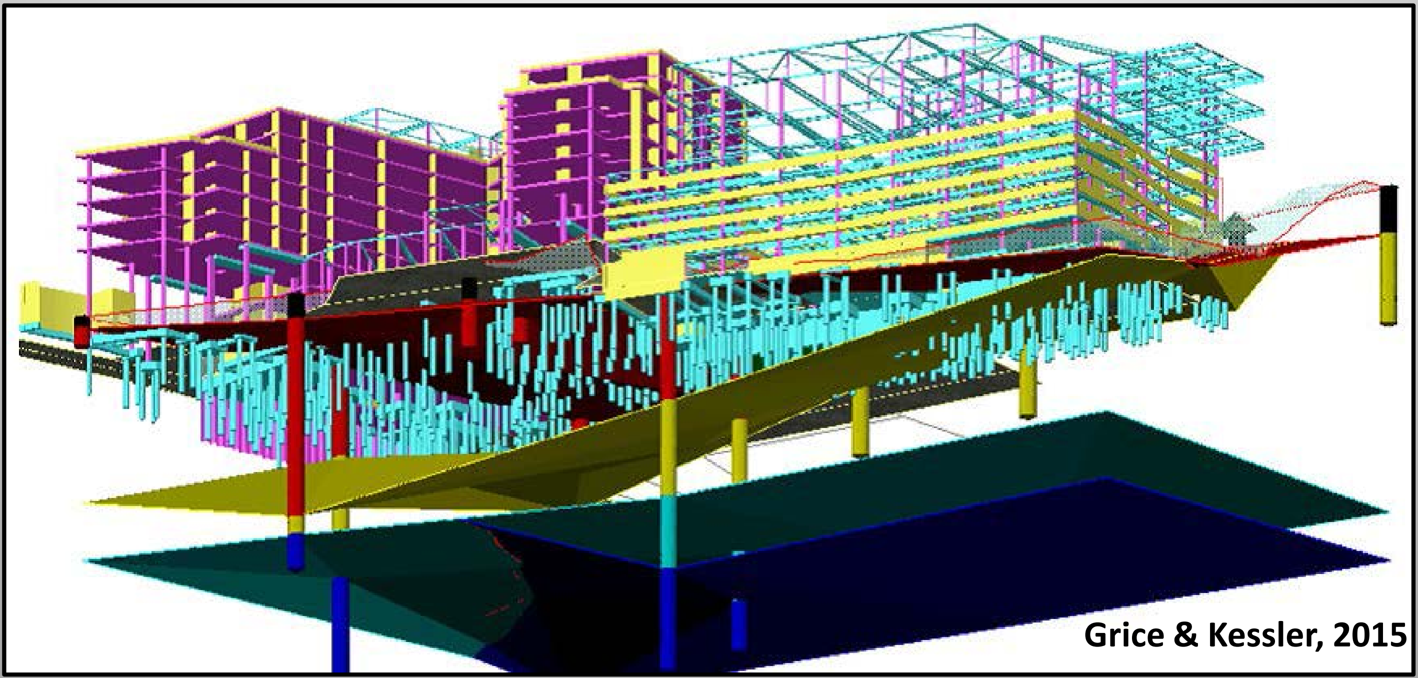


Courtesy Mott Macdonald

- 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.

# "Geotech-BIM"

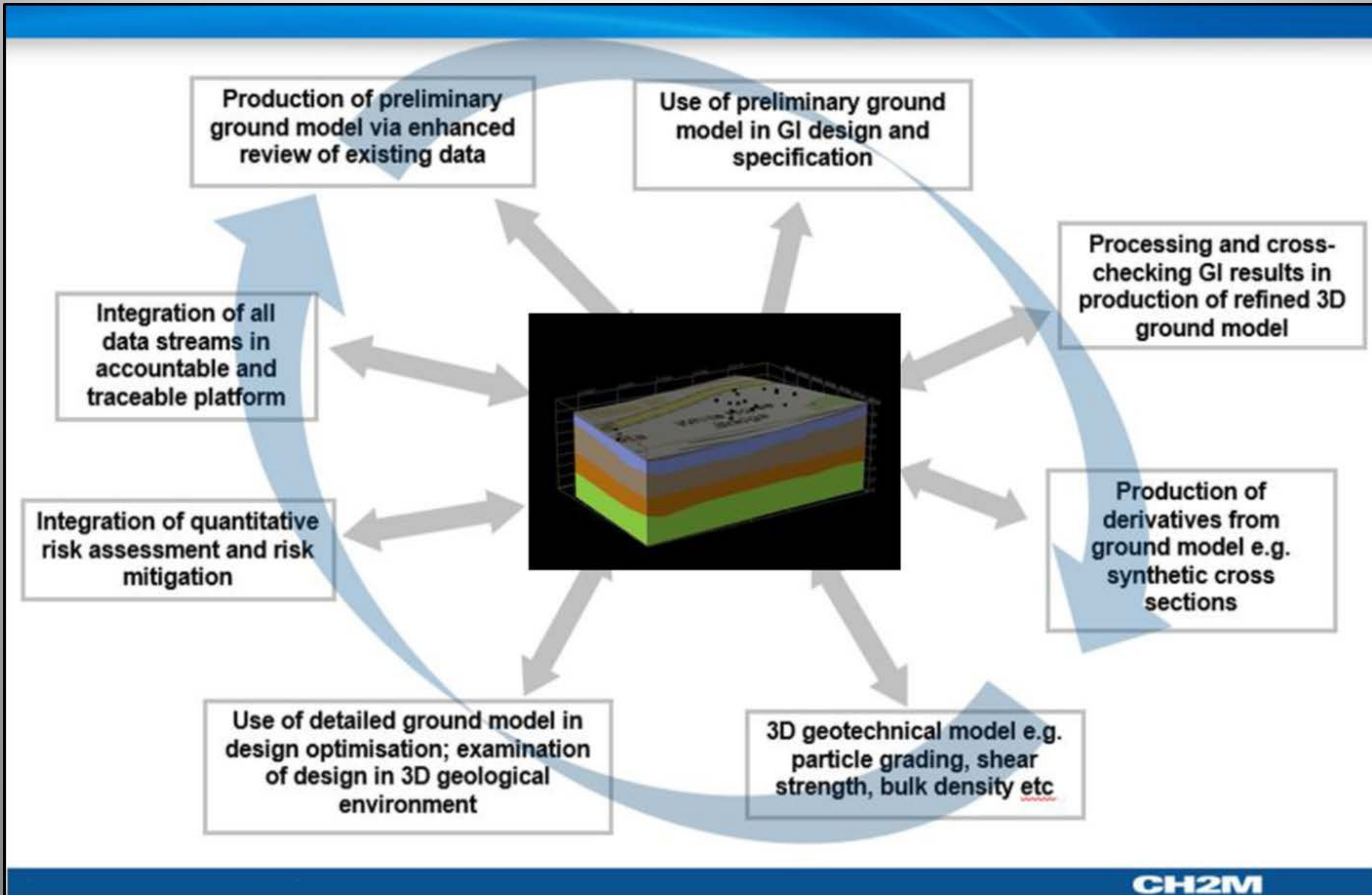
## *BIM and the Subsurface*



Grice & Kessler, 2015

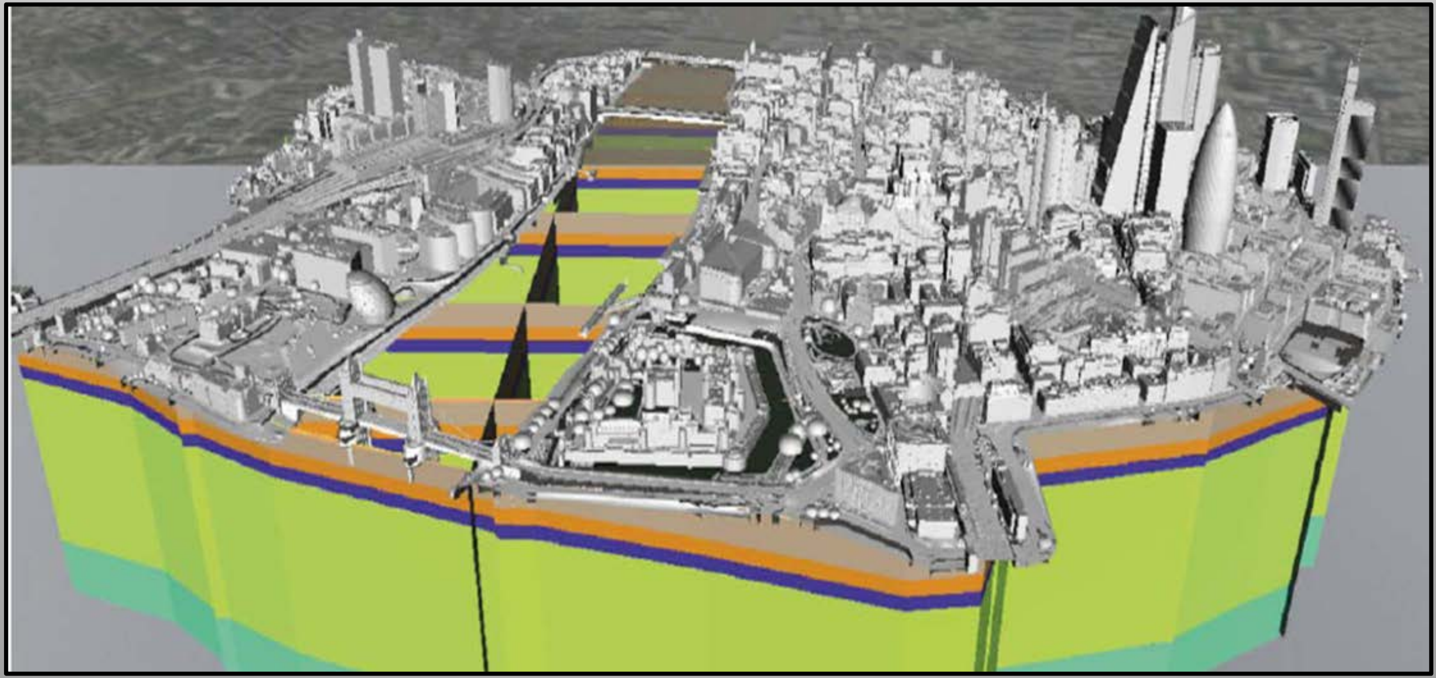
- **Extend/Integrate 3D Geological Modeling techniques to the BIM environment**

# Potential Geotech-BIM Workflow



# Current Capability:

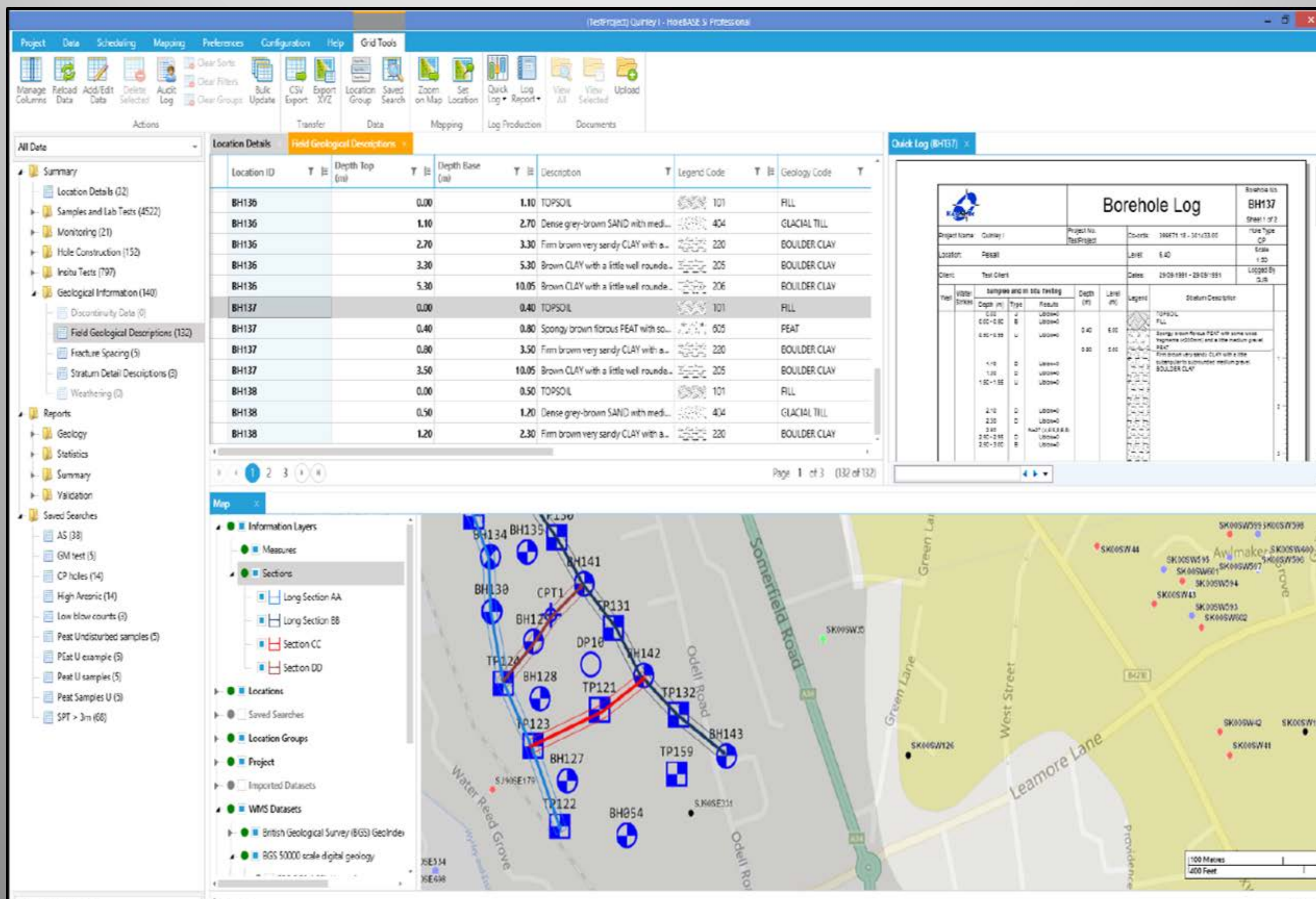
## City of London on 3D Geology Model



City model courtesy of ARUP

# Available Now –

## Direct access to BGS geological maps and boreholes through web map services



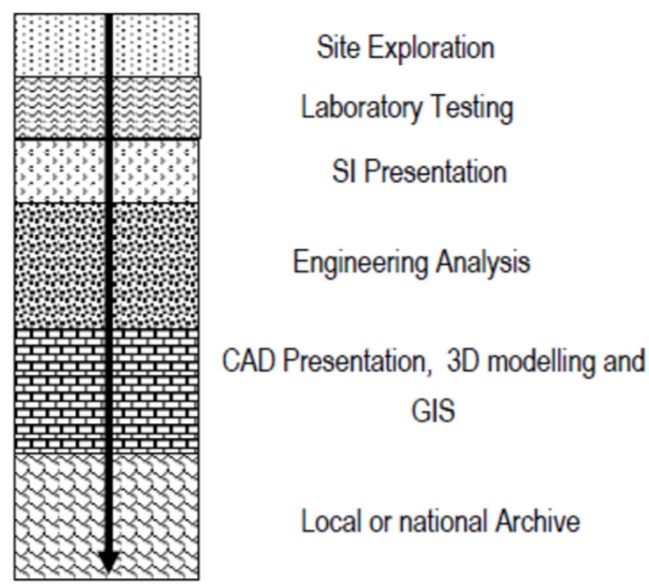
# Current Research –
## Integrating Digital Field Information with 3D Models

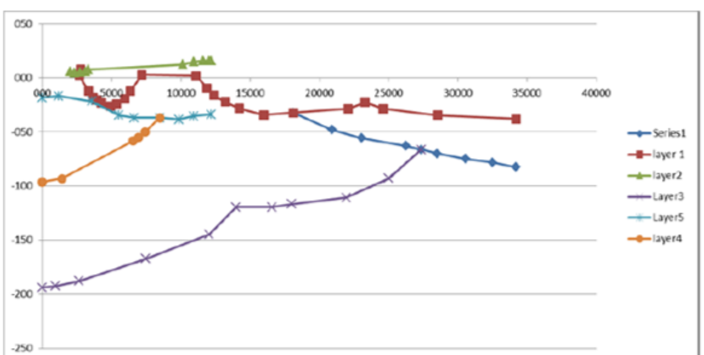
### Working with the AGS
(equivalent too DIGGS in North America)

AGS Association of Geotechnical & Geoenvironmental Specialists

A new initiative to include interpreted data and the concept of layers in the next phase of the AGS data transfer format (AGSi)

Electronic Reporting

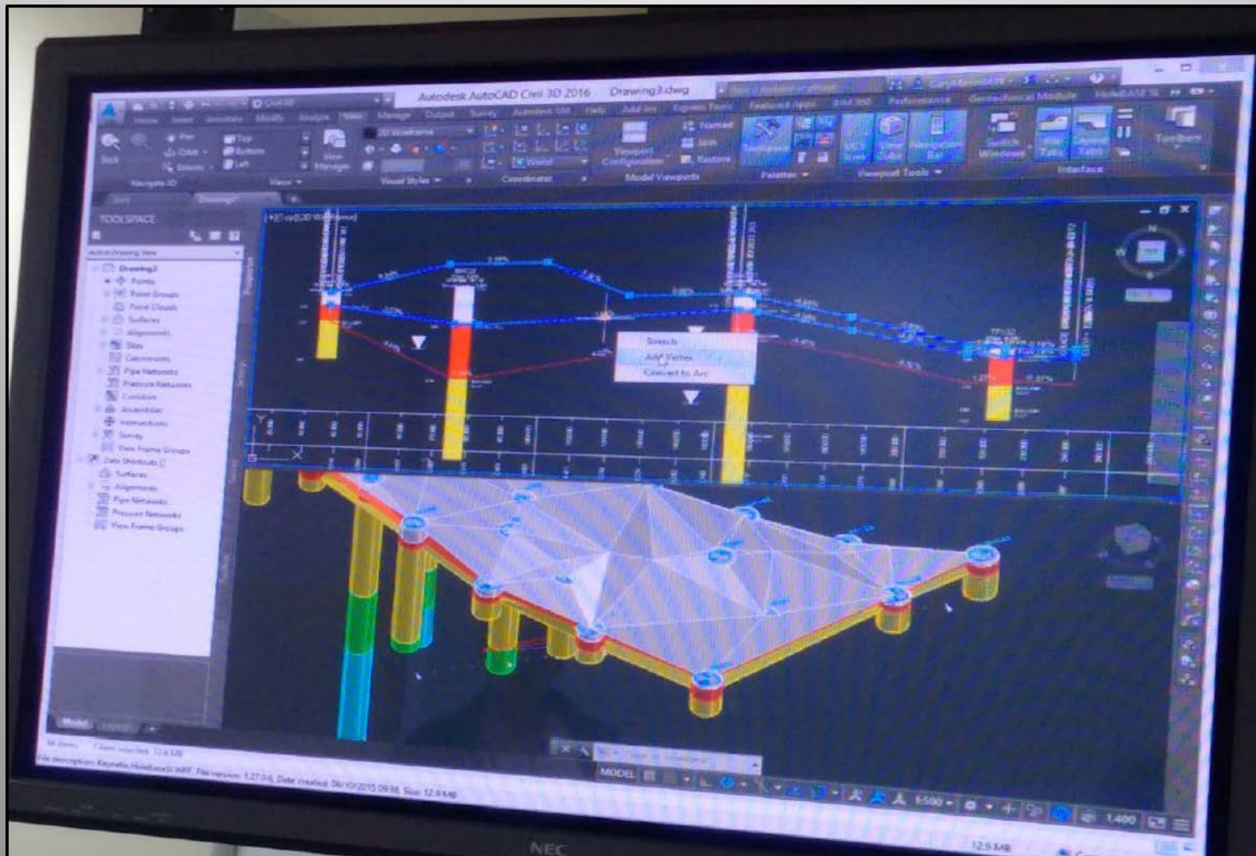



Geological cross-section transmitted via xml and visualised in Excel

# In The Future –

## Ability to edit sections and surfaces and submit them back to the BGS to be incorporated in the national geological model




Early prototype section editor in Autodesk–HoleBase plug-in