Geotechnical Observations

The Influence of Geology on London's Underground Railways

Jonathan R A Gammon

Former Non-Executive Director / Advisor

Geotechnical Observations Limited

London Petrophysical Society

at Geological Society, Burlington House on 6 November 2025

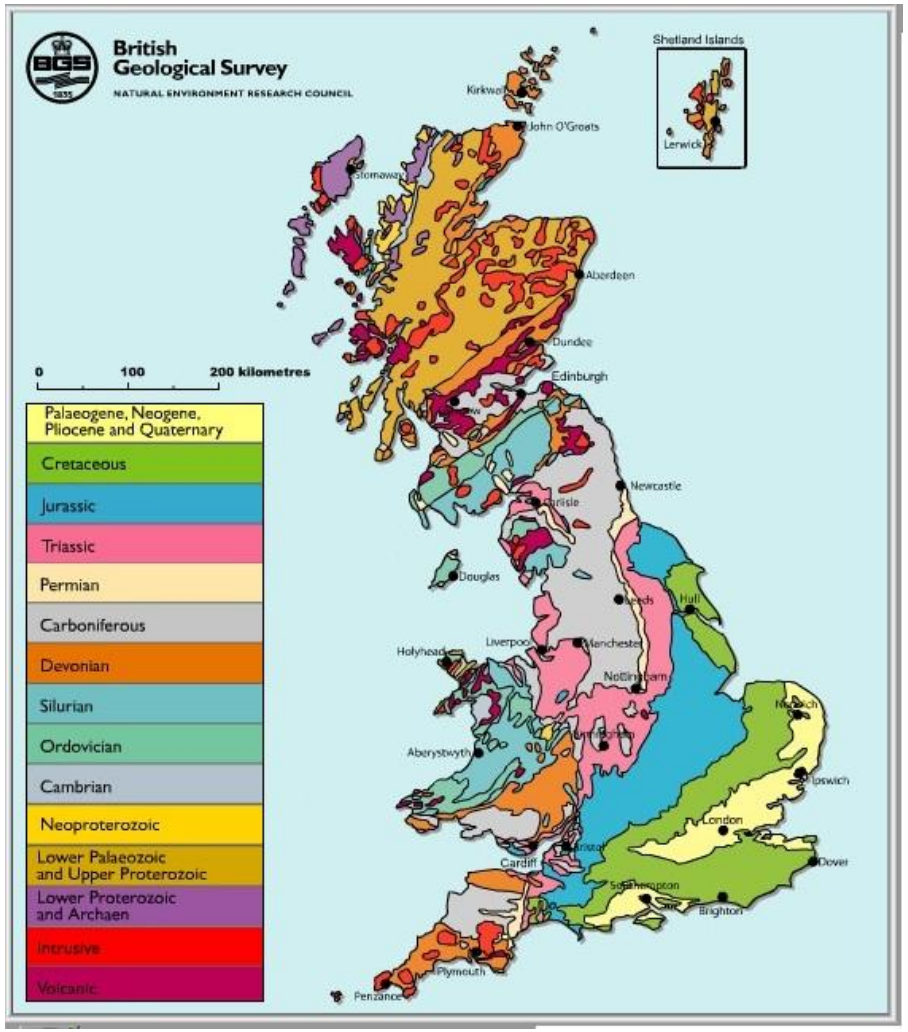
Oil and Gas Background

- Foundation design for offshore oil production platforms, North Sea, UK 1970s
- Dammam to Jubail Port Infrastructure Studies, Saudi Arabia 1978
- Container Terminal, Bandar Mahshahr Port, Iran 1978
- Kawerau to Gisborne Gas Pipeline, New Zealand 1984
- Tender Design Appraisal and Client Representative for Contractor's Detailed Design, Ras Laffan Port, Qatar 1992
- Um Said (Mesaieed) Jetty, Qatar 1993
- Gas Pipeline Replacement, River Humber, UK 2016

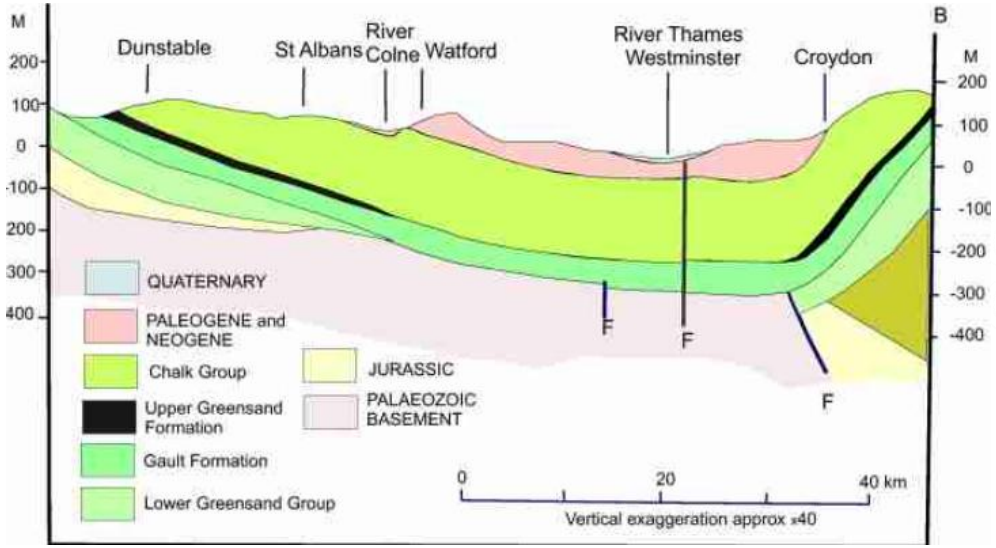
Contents

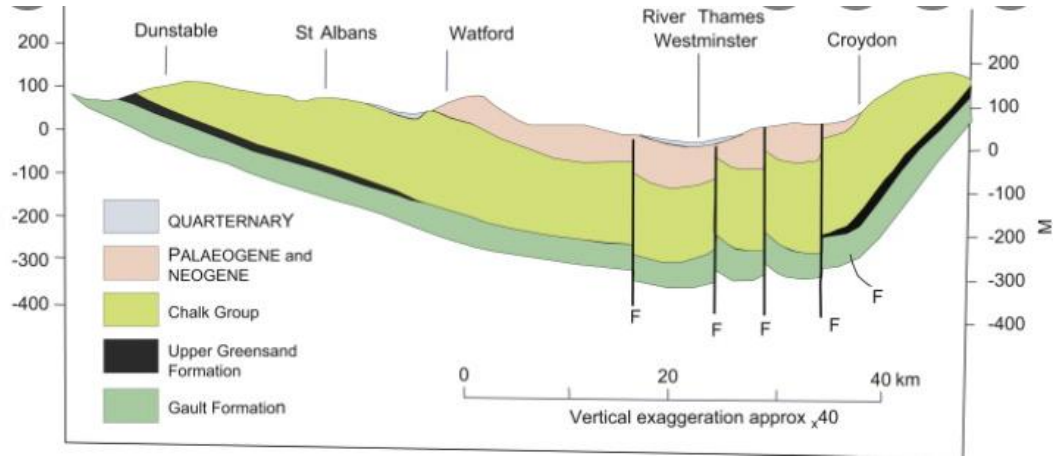
- Geology of London
- Early days of the Underground railway
- Brunels' Rotherhithe Tunnel
- Increasing extent of the Underground railway
- Tunnelling techniques
- Jubilee Line Extension; Crossrail; Northern Line Extension
- The Future

Geology of Great Britain



Cross-sections through the London Basin

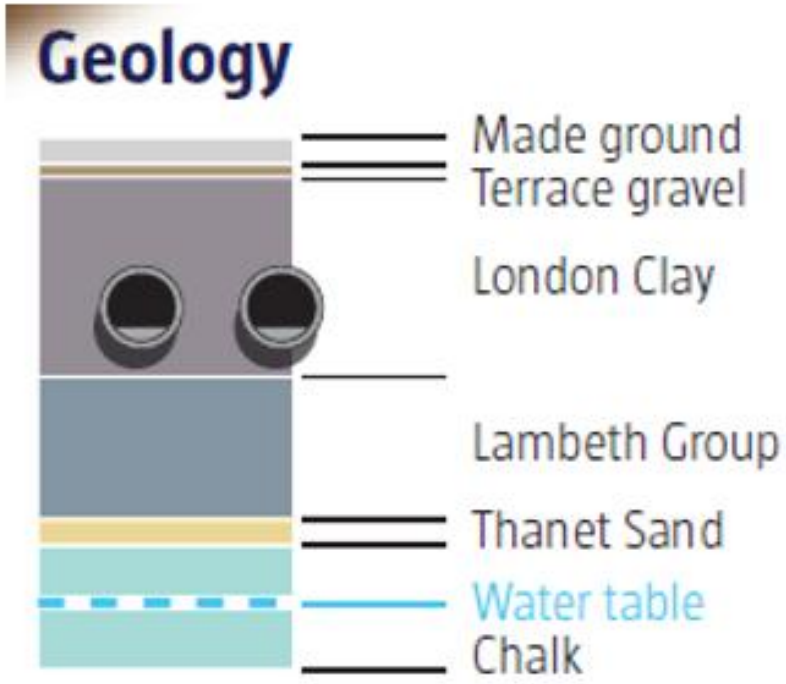




The above, most-recently produced, cross-section illustrates the greater frequency of faulting within the Chalk and overlying formations than was previously interpreted.

Key Geological Deposits/Formations

- Made Ground / Alluvium / River Terrace Deposits
- London Clay
- Lambeth Group (previously Woolwich & Reading Beds)
- Thanet Sand
- Chalk



Note the position of the groundwater table on this illustration. The groundwater regime in London is complex, mainly because of the relatively very low permeability of the London Clay, acting as an “aquiclude, and the consequences of water abstraction from the Chalk formation. Not shown is the upper, “perched”, water table within the permeable Superficial Deposits which can be influenced by proximity to the River Thames and the tidal fluctuations in the River’s water level.

Plan of London’s Geology (BGS mapping)

1:625 000 scale geology

Bedrock geology

- NEOGENE ROCKS (UNDIFFERENTIATED) - GRAVEL, SAND, SILT AND CLAY
- BRACKLESHAM GROUP AND BARTON GROUP (UNDIFFERENTIATED) - SAND, SILT AND CLAY
- THAMES GROUP - CLAY, SILT, SAND AND GRAVEL including London Clay
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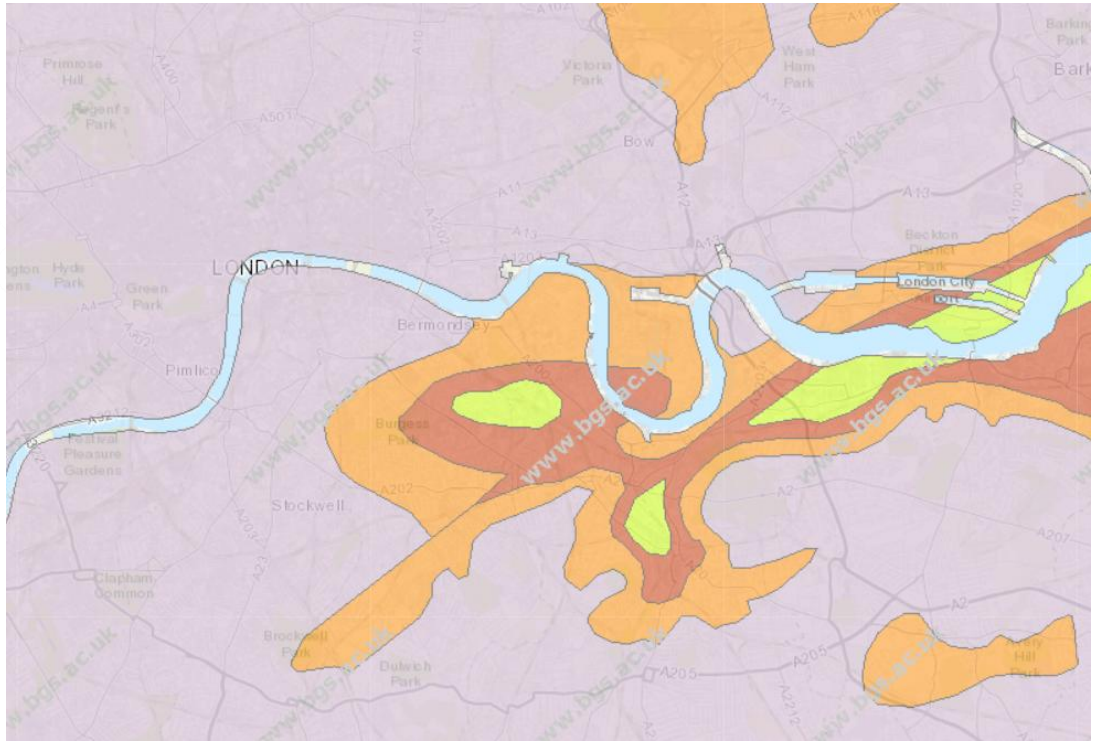
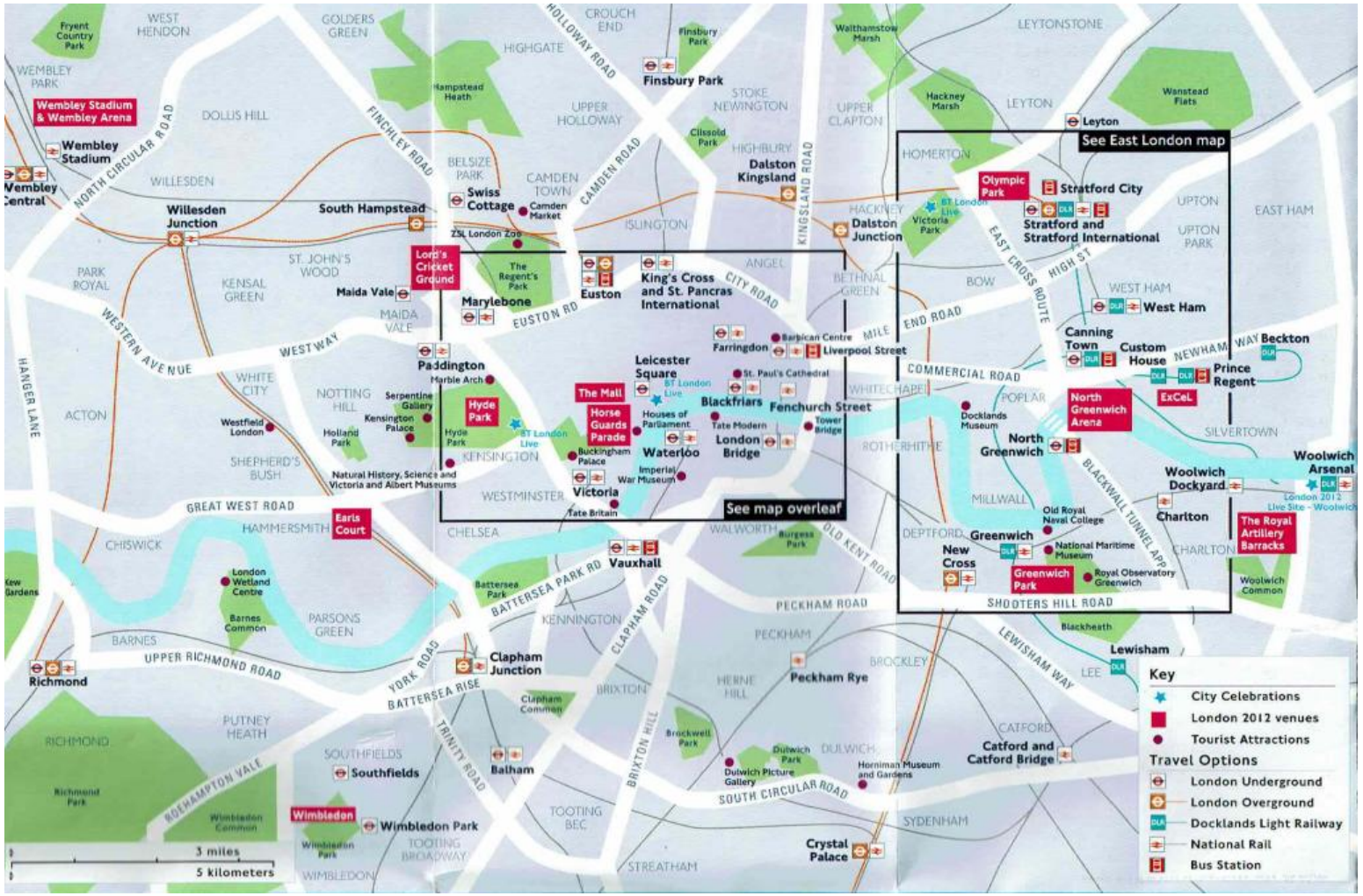
- GREY CHALK SUBGROUP - CHALK
- WHITE CHALK SUBGROUP - CHALK
- GAULT FORMATION AND UPPER GREENSAND FORMATION (UNDIFFERENTIATED) - MUDSTONE, SANDSTONE AND LIMESTONE
- LOWER GREENSAND GROUP - SANDSTONE



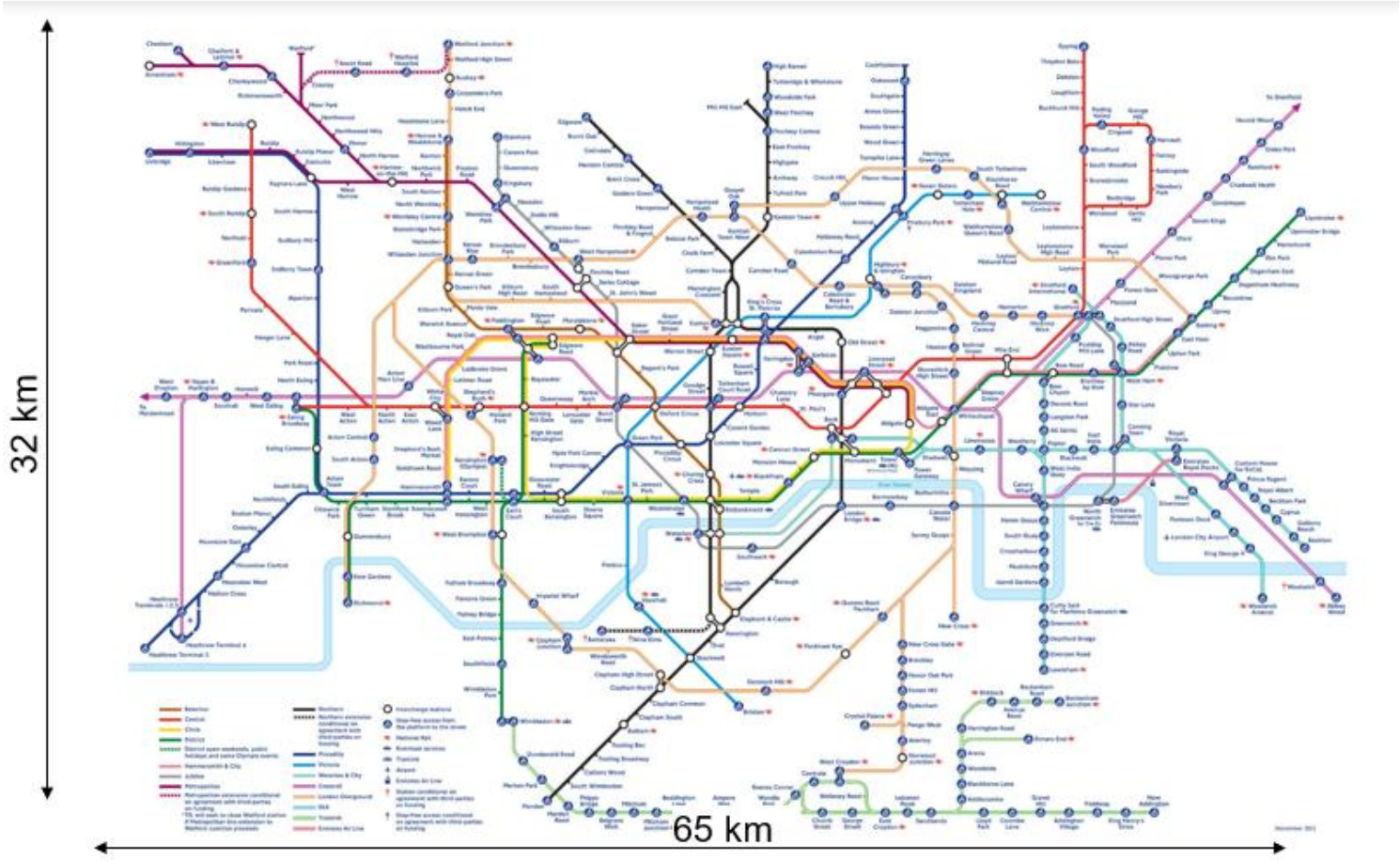
Map of London



London's Main Stations, with opening dates

- London Bridge, opened 1836
- Euston, 1837
- Paddington, 1838
- Fenchurch Street, 1841
- Waterloo, 1848
- King's Cross, 1852
- Victoria, 1860
- Charing Cross, 1864
- Cannon Street, 1866
- St Pancras, 1866
- Liverpool Street, 1875
- Blackfriars 1886
- Marylebone 1899

Map of the London Underground



	London Underground
Year of opening:	1863
Current Length of System:	402km
Number of Stations:	270
Average No. of Passengers per day:	3.4 million
Cost of maintenance per annum:	£700 million

55% of the Underground runs on the surface

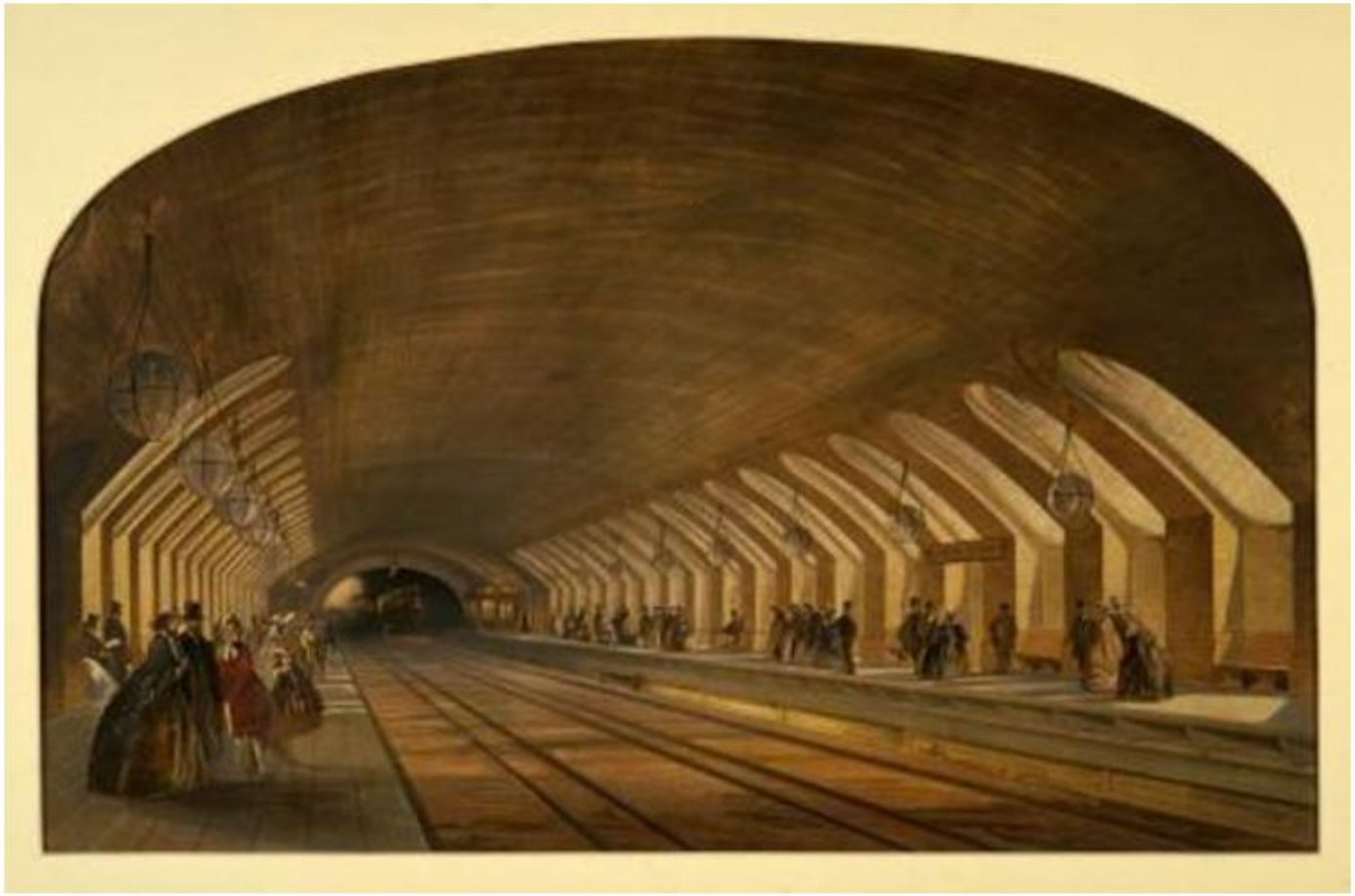
London Underground’s key dates and events

- The world's first underground railway **opened in January 1863** between Paddington and Farringdon using gas-lit wooden carriages hauled by steam locomotives. It carried 38,000 passengers on the opening day.
- The Metropolitan District Railway (commonly known as the District Railway) opened in December 1868 from South Kensington to Westminster as part of a plan for an underground "inner circle" connecting London's main-line stations.
- The Metropolitan and District railways completed the Circle Line in 1884, built using the cut and cover method.
- The technology for the safe tunnelling of tubes deeper below London had been developed by 1870, but the first successful tube railway was not practical until electric power and safe lifts were perfected in the late 1880s.
- On 18 December, 1890, The City and South London Railway opens the world's first deep-level electric railway. It runs from King William Street in the City of London, under the River Thames, to Stockwell.

Cut-and-Cover Tunnels and Stations

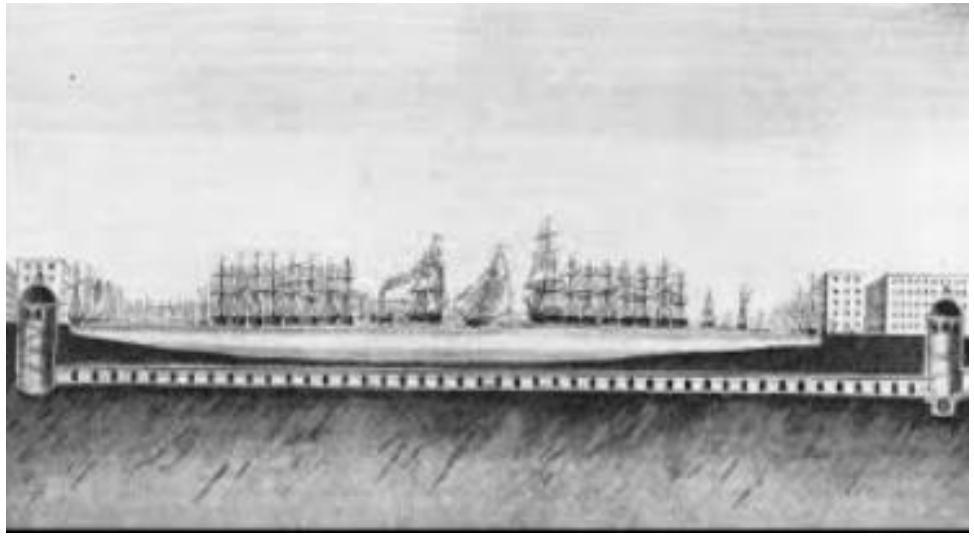
32 kilometres (20 miles) of cut-and-cover tunnels

Shallow depth stations and tunnels



Print; Baker Street Station on the Metropolitan Railway, 1863 - 1869

Bored Tunnels: Brunels' Thames Tunnel



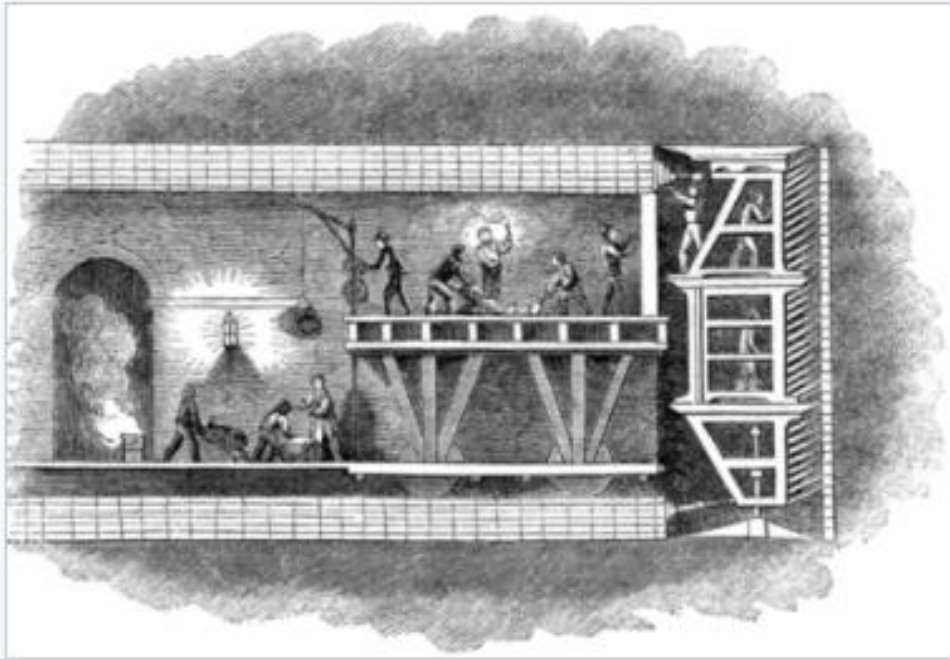
The Thames Tunnel excavation as it was probably around 1840

- First tunnel in the World beneath a river.
- Started in 1825* and finished in 1843.
- Length: 366 metres (1200 feet); Height: 7 metres (23 feet); Width: 11 metres (36 feet).
- Depth below high watermark: 23 metres (75 feet).
- Depth to top of tunnel beneath the bed of the River Thames: About 5m (16 feet).
- To transport goods across the Thames due to London Bridge and Blackfriars Bridge congestion.
- Integrated into the Underground first in 1869 and then in 2010 as part of the London Overground system.

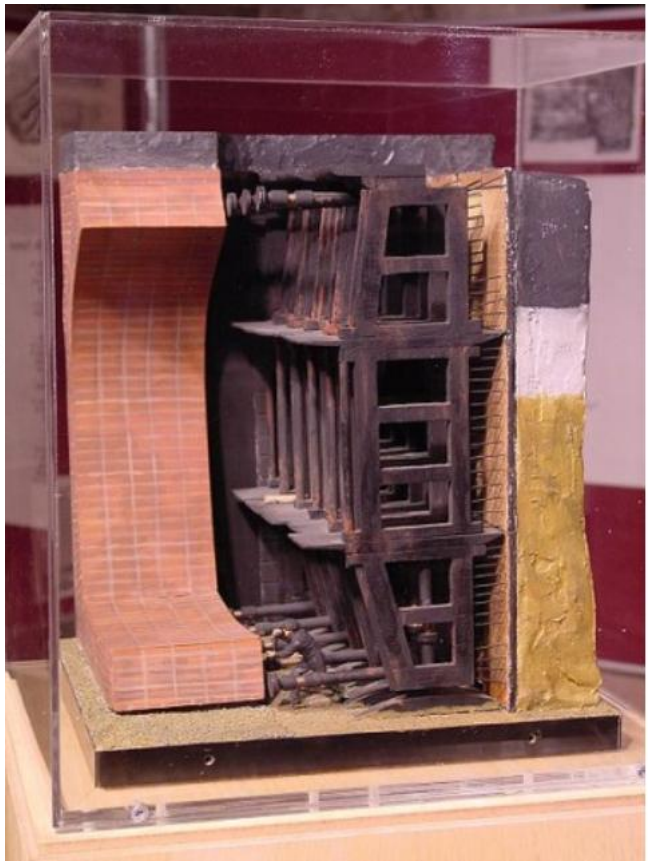
*The same year the first passenger railway between Stockton and Darlington commenced operation

Inside the Thames Tunnel in the mid-19th century

Brunel's Shield

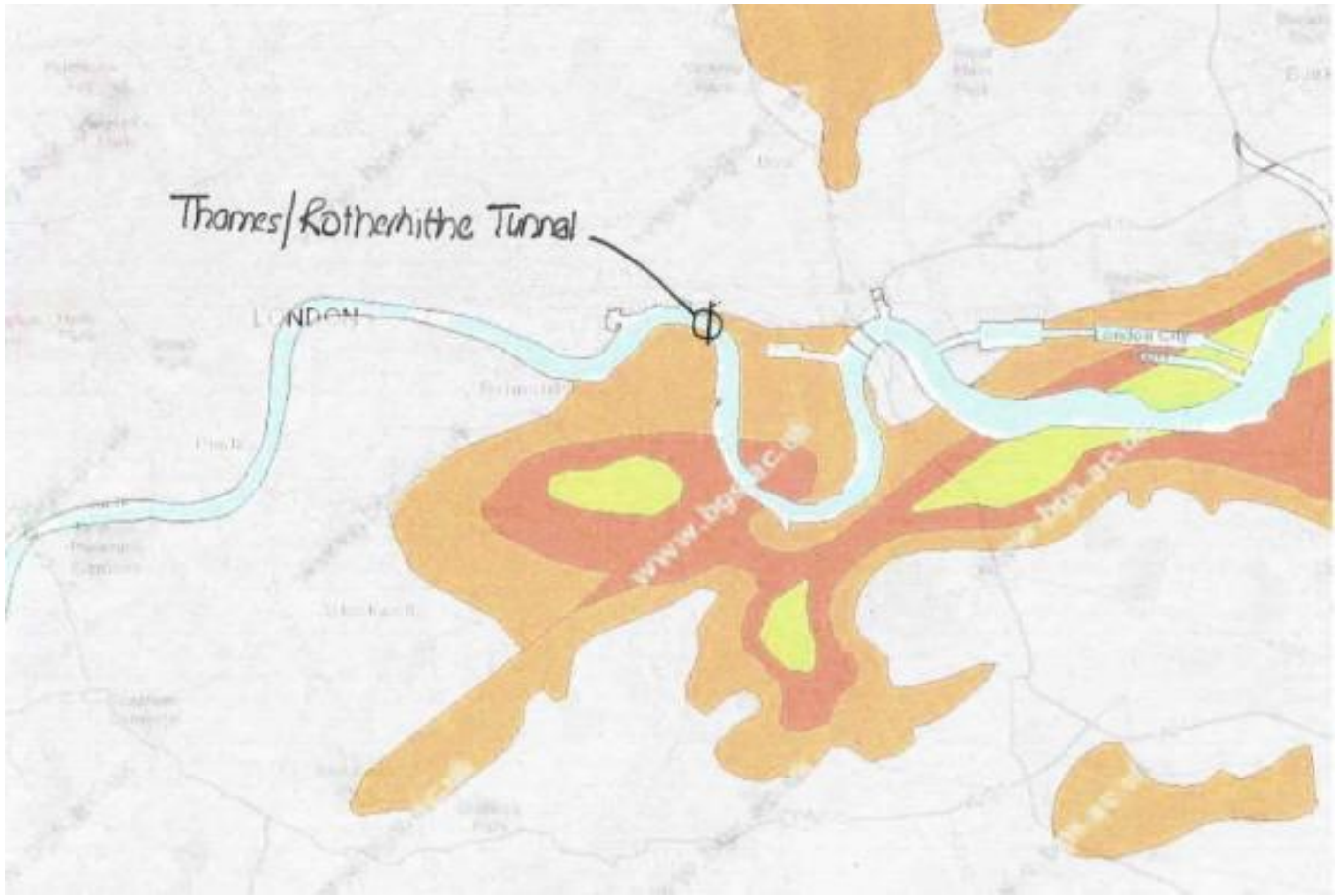


Side view of the tunnelling shield (far right) used to construct the Thames Tunnel; the permanent brick supporting structure is built immediately behind it.

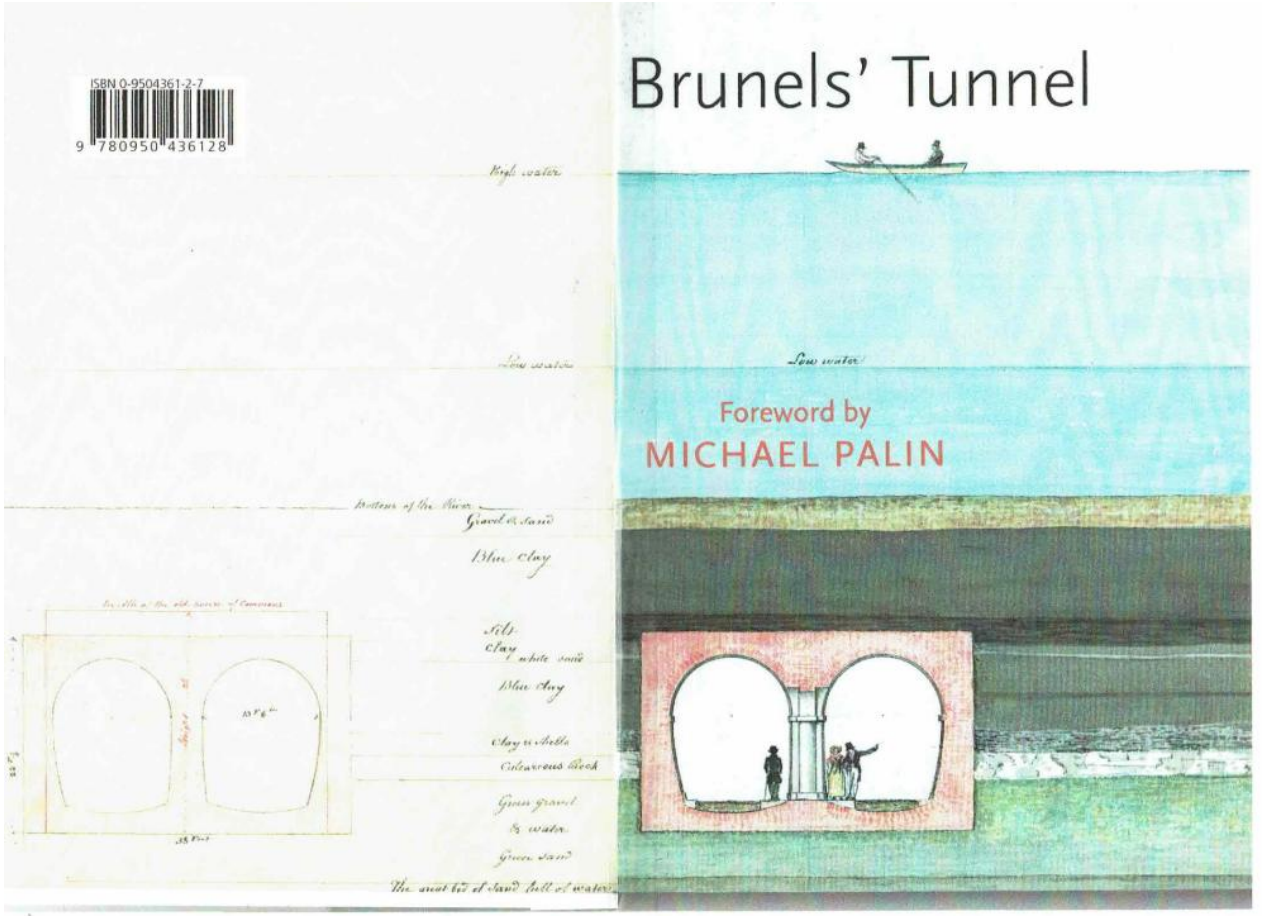


Rate of progress: 3m to 4m (10 feet to 13 feet) a week

Location of the Brunels' Tunnel: Geology



Cross-Section and ground conditions



The development of Tunnel Shields

Key dates:

1818 Marc Brunel and Lord Cochrane patent a rectangular shield.

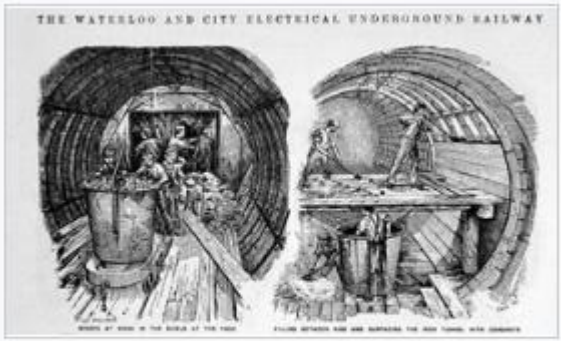
1840 Alfred Ely Beach proposes a circular shield as the way forward.

1864 Peter W Barlow patents a circular shield.

1870 James Henry Greathead secures three patents for a circular shield.

1884 A Greathead Shield is used to form part of the (now) Northern Line with a tunnel diameter of 3.1 metres (10 feet) diameter. First “deep tube”, using circular segmental cast-iron tunnel linings.

1886 A Greathead Shield is used to form Bank Station with a diameter of 7 metres (23 feet).

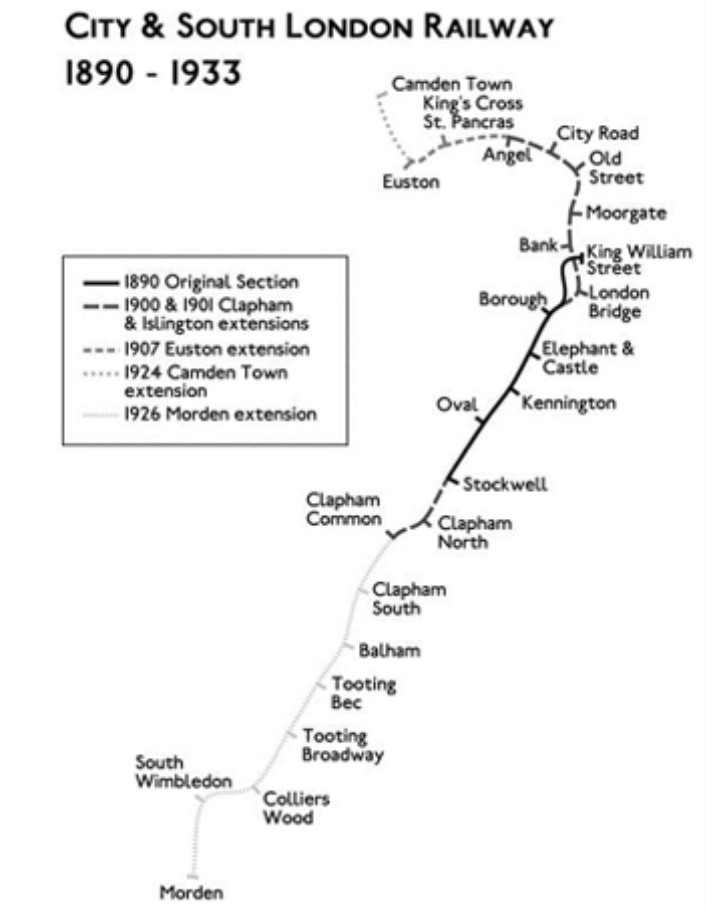


The Greathead tunnelling shield in use on the Waterloo & City Railway

Tunnel Shields essentially restricted to forming tunnels in London Clay

Greathead Shield

City & South London Railway [Northern Line]



Northern Line (Bank branch)

James Greathead's Paper about the C&SLR

19 November, 1895.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

(Paper No. 2873.)

"The City and South London Railway; with some Remarks upon Subaqueous Tunnelling by Shield and Compressed Air."

By JAMES HENRY GREATHEAD, M. Inst. C.E.

London Underground 1932/33
Actual alignment and Harry Beck's first map

Plan of London’s Geology (BGS mapping)

1:625 000 scale geology

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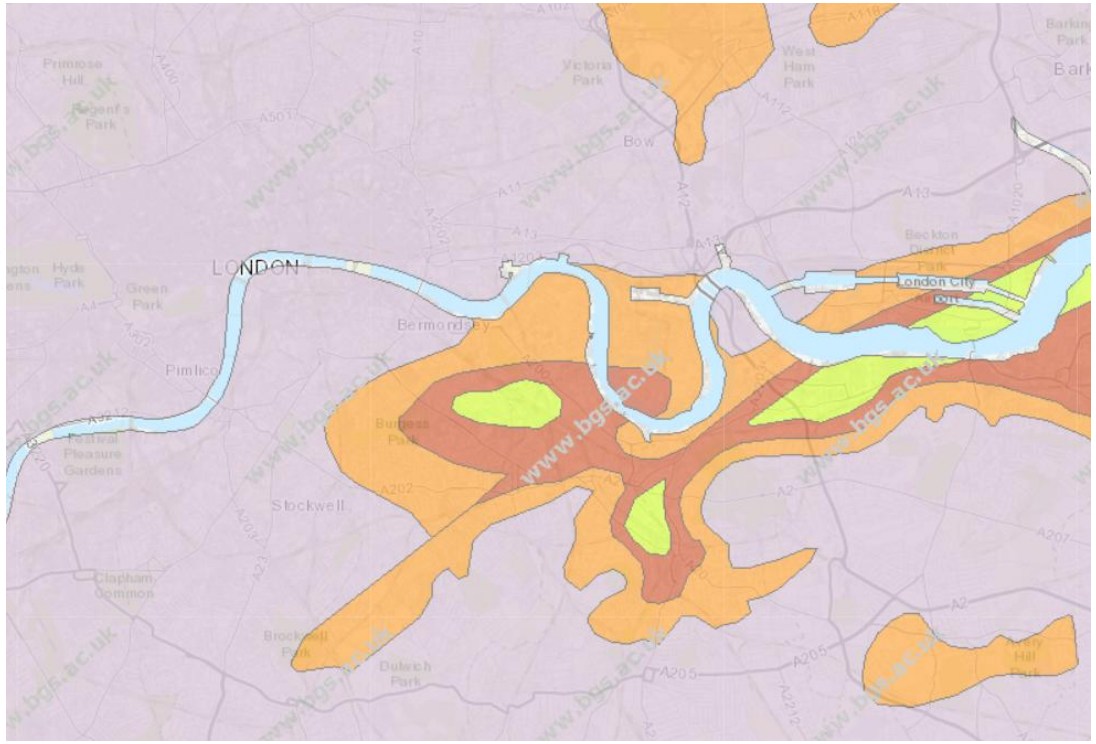


Tunnel Boring Machines: Rotating Cutter Heads

- The first TBM that tunnelled a substantial distance was invented in 1863 and improved in 1875 by British Army officer Major Frederick Edward Blackett Beaumont (1833–1895)
- In 1883, this TBM was used to bore a railway ventilation tunnel - 7 feet (2.1 m) in diameter and 6,750 feet (2 km) long - between Birkenhead and Liverpool, England, through sandstone under the Mersey River.
- Modern TBMs typically consist of the rotating cutting wheel, called a cutter head, followed by a main bearing, a thrust system and trailing support mechanisms. The type of machine used depends on the geology of the project, the amount of ground water present and other factors.

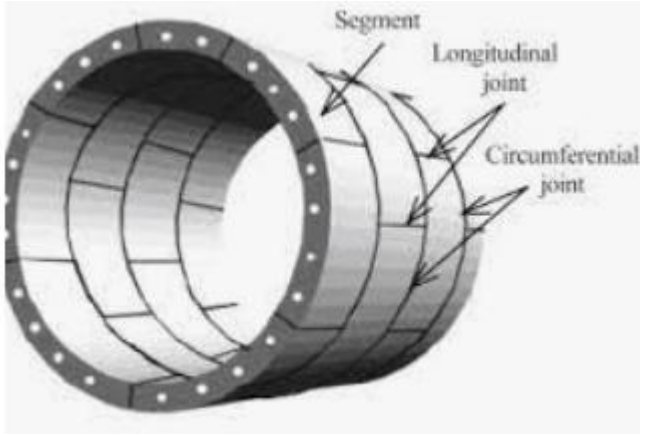
Rates:
Slurry Tunnel Boring Machine: cost more than £16,000,000 each
Earth Pressure Balance Tunnel Boring Machine: cost more than £18,000,000 each

Tunnel Boring Machines

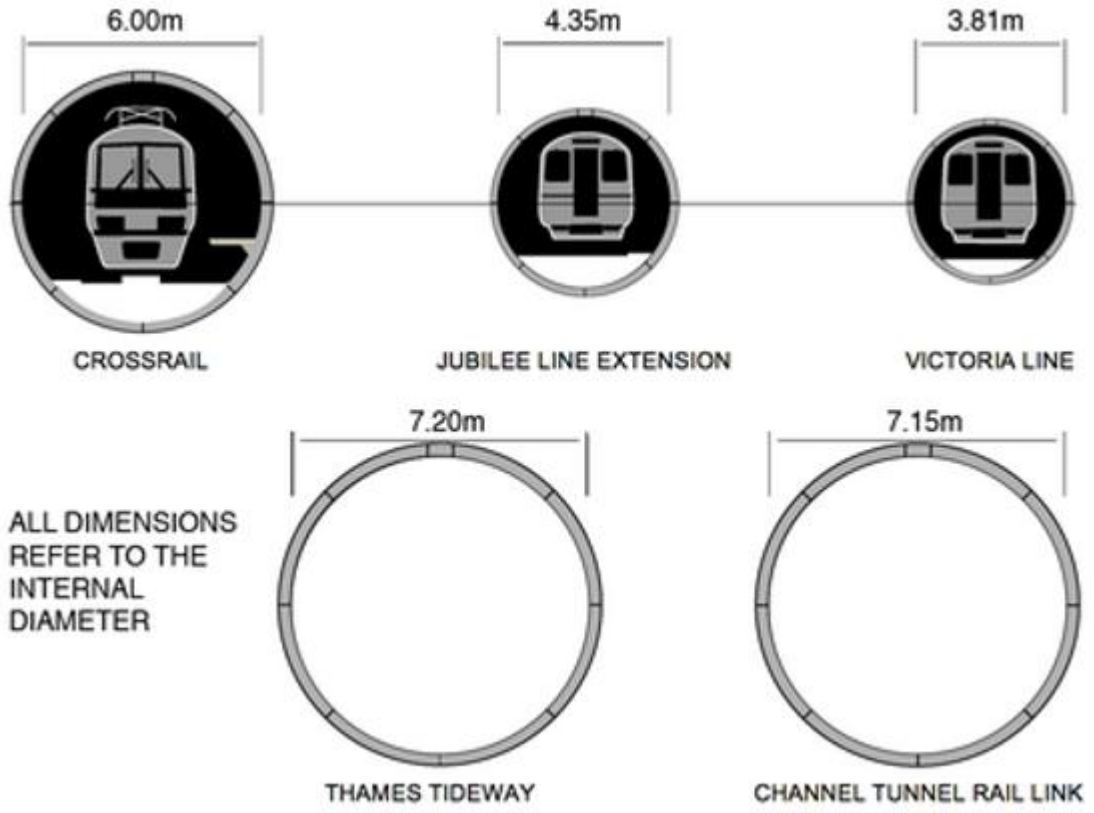
Tunnel Boring Machines (TBMs)

- Substantial items of equipment: up to 2000 tonnes including a cutter head assembly of 1000 tonnes
- Over 200m (almost 700 feet) long.
- Able to operate in a wide range of ground conditions
- Able to operate in water-bearing ground (silts and sands)
- Include integrated tunnel lining placement systems
- Tunnel arisings disposed of on wagons or on conveyor belts

Rate of progress: Ideally about 20 metres (66 feet) per day

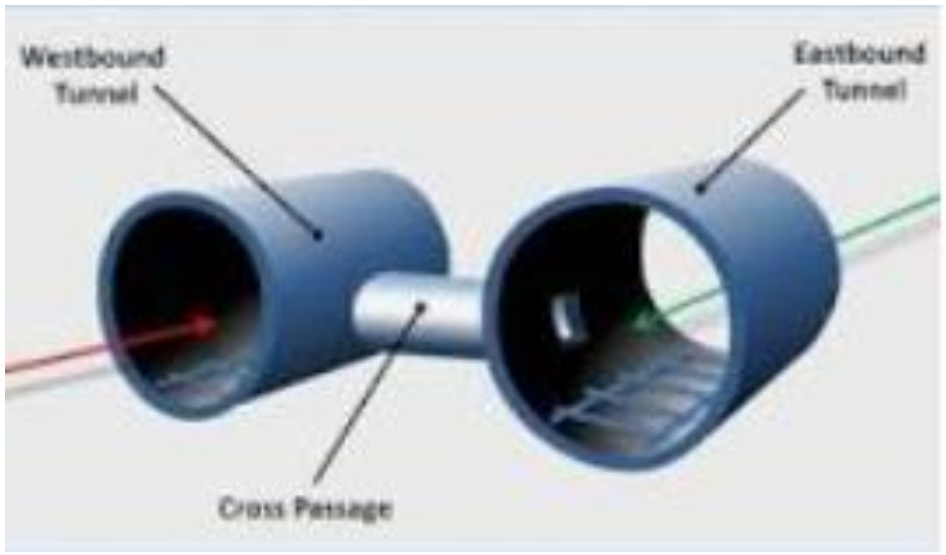


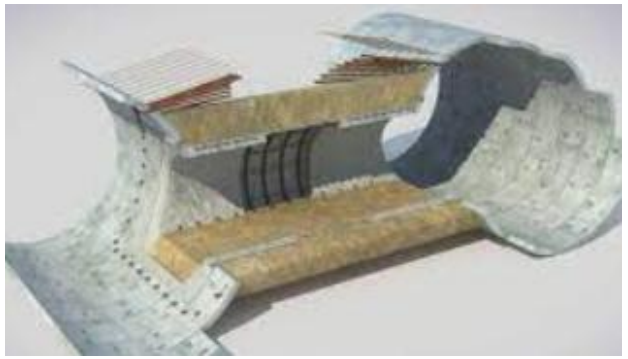
Tunnel diameters



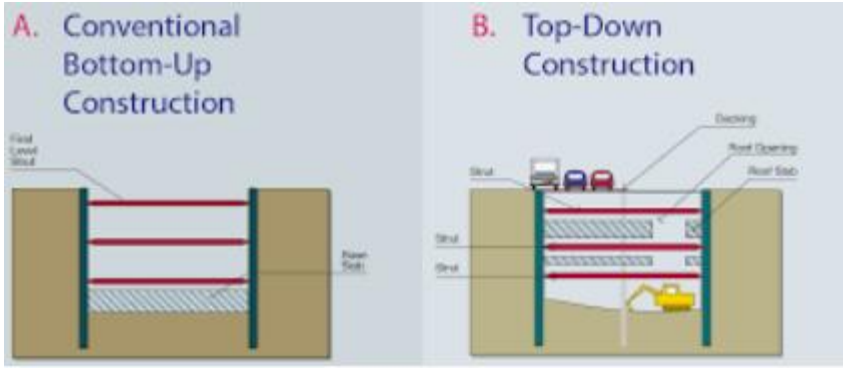
Sprayed Concrete Lining

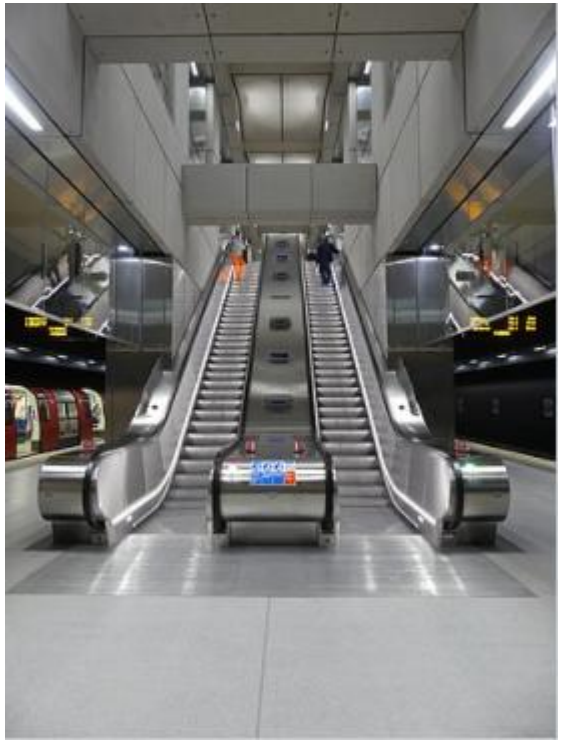
Shafts and Cross-Passages



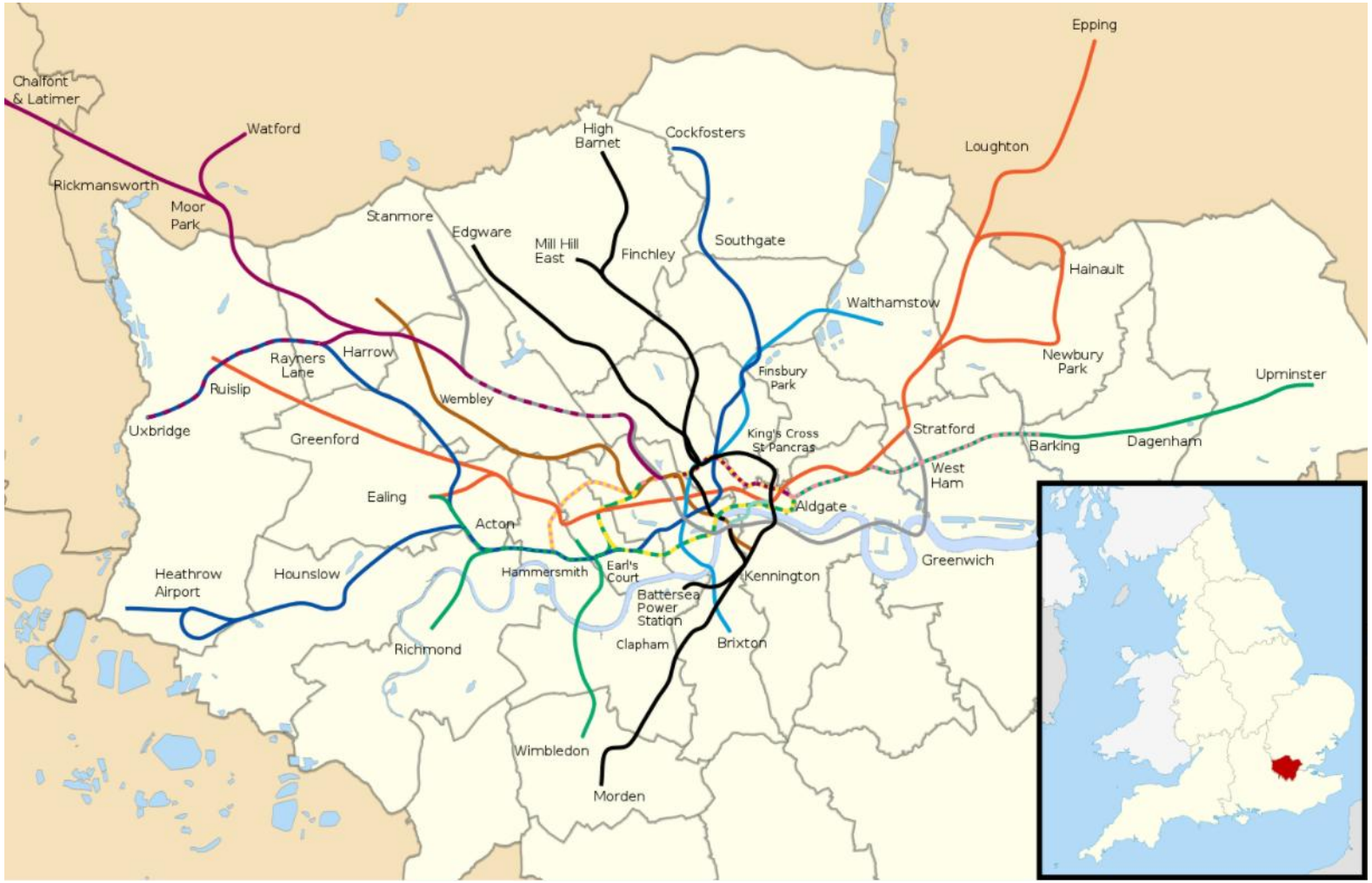


Stations

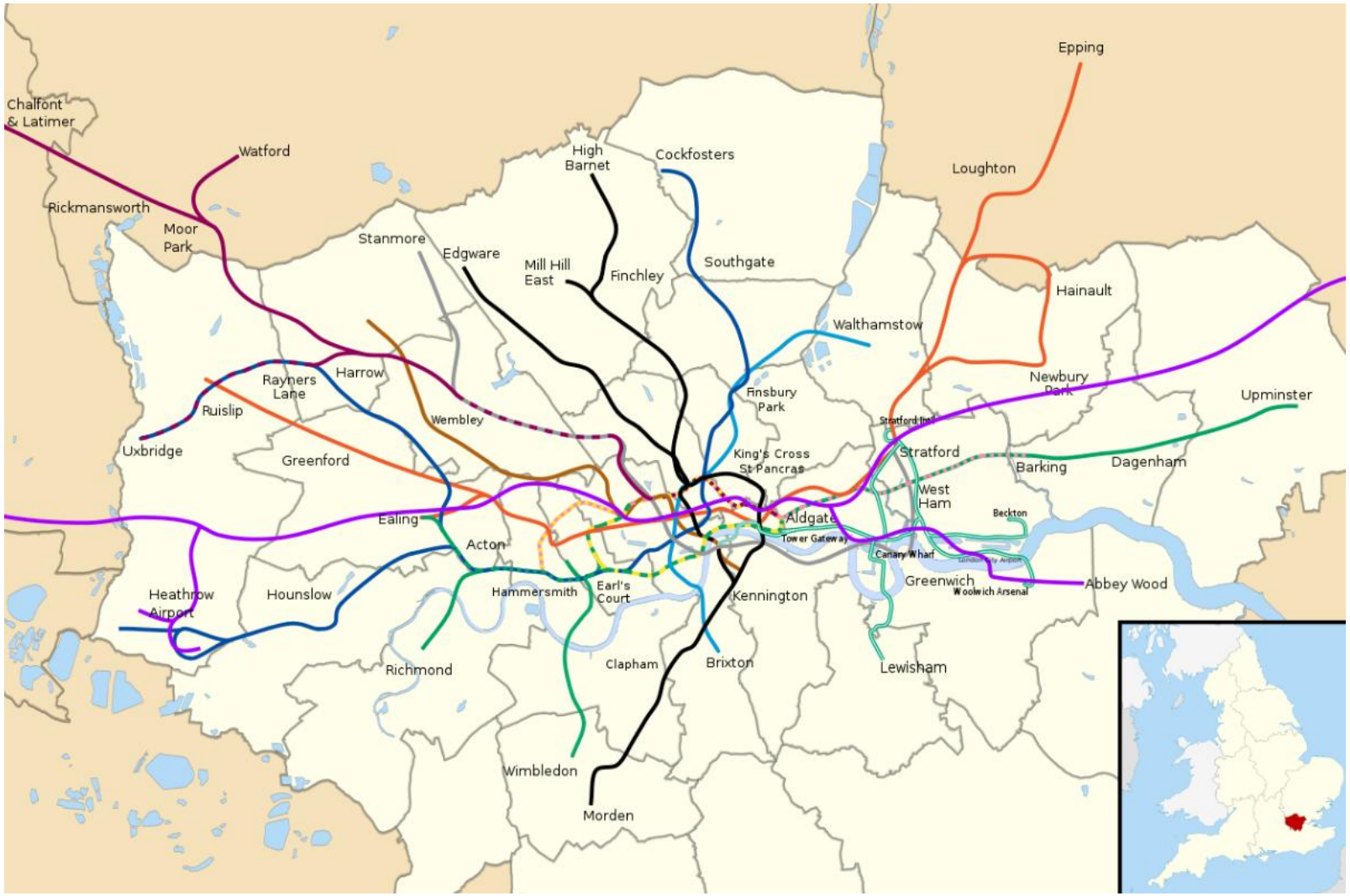

A. Conventional Bottom-Up Construction
B. Top-Down Construction



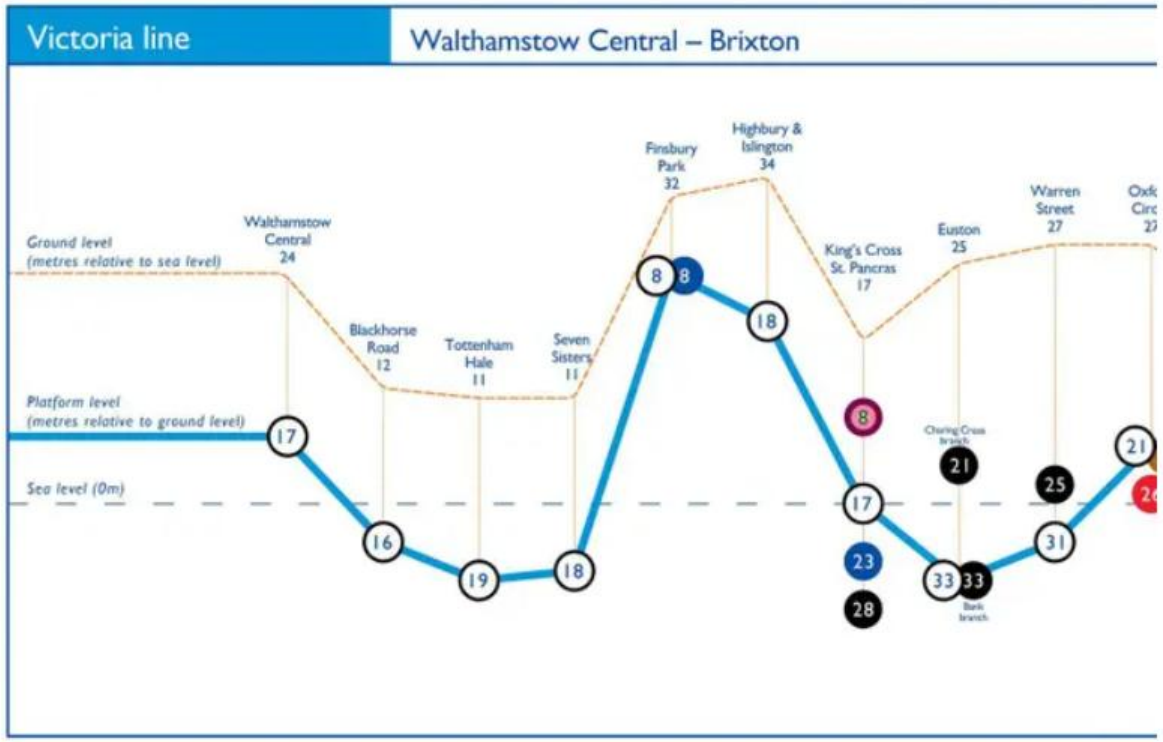
London Underground (LU) Alignments



Current LU Alignments including Elizabeth Line



Example of London Underground depths



The numbers circled on the coloured line equal how many metres below ground level the platforms are / Daniel Silva

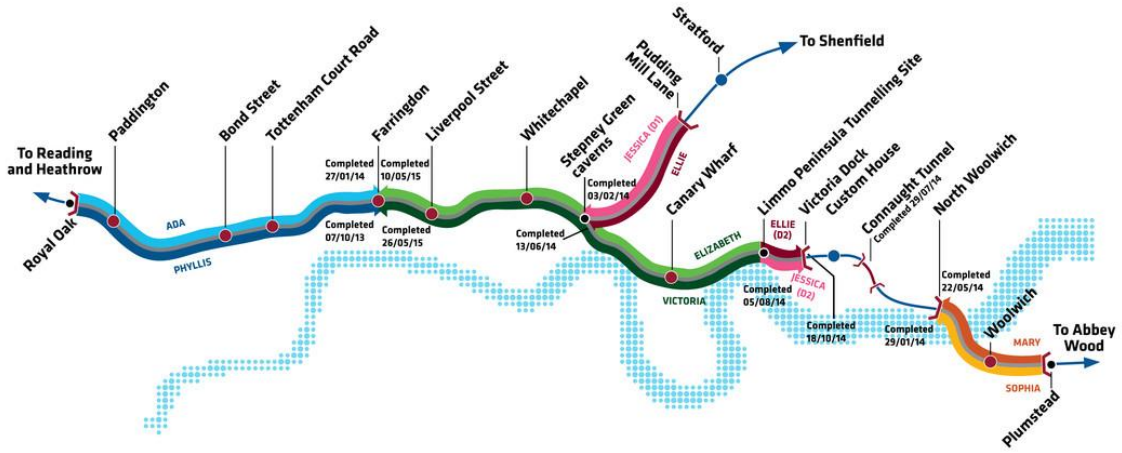
The deepest station is Hampstead on the Northern line, which runs down to 58.5 metres (190 feet).
In Central London the deepest station below street level is also the Northern line. It is the DLR concourse at Bank, which is 41.4 metres (135 feet) below street level.

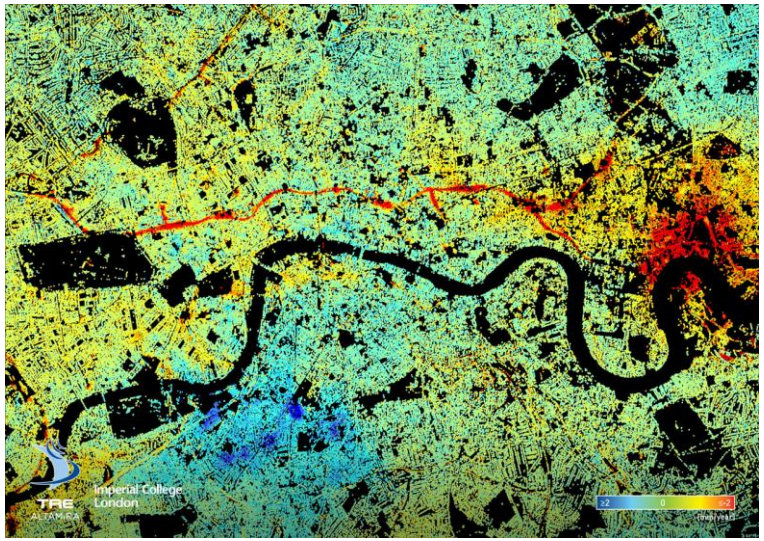
Jubilee Line Extension

Jubilee Line Extension:

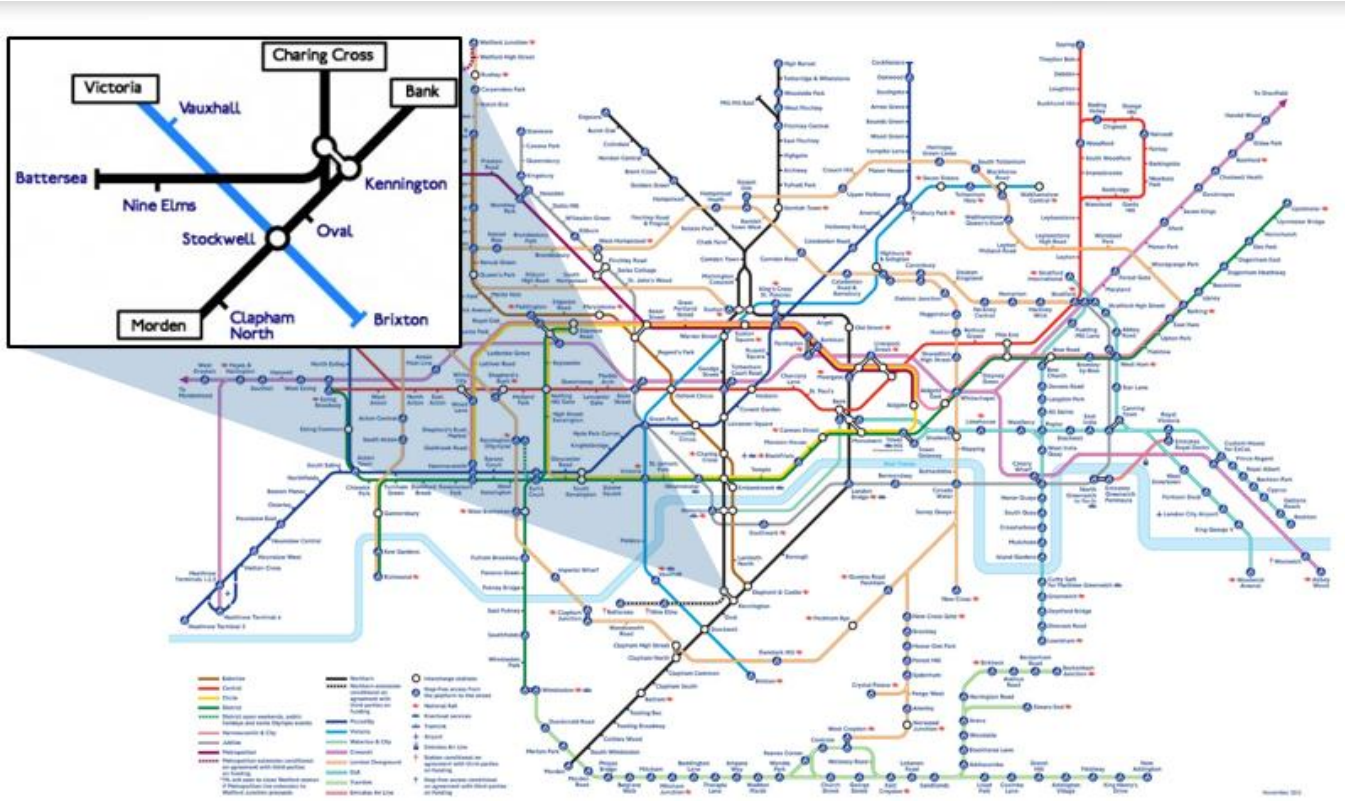
- Started: December 1993
- Stalled in October 1994 because of the Heathrow Tunnel collapse (using the New Austrian Tunnelling Method [NATM], which was subsequently renamed Sprayed Concrete Lining)
- Internal diameter: 4.35m (14 feet)
- Deepest Station: Westminster; 40 metres (130 feet)
- Opened: 22 December 1999

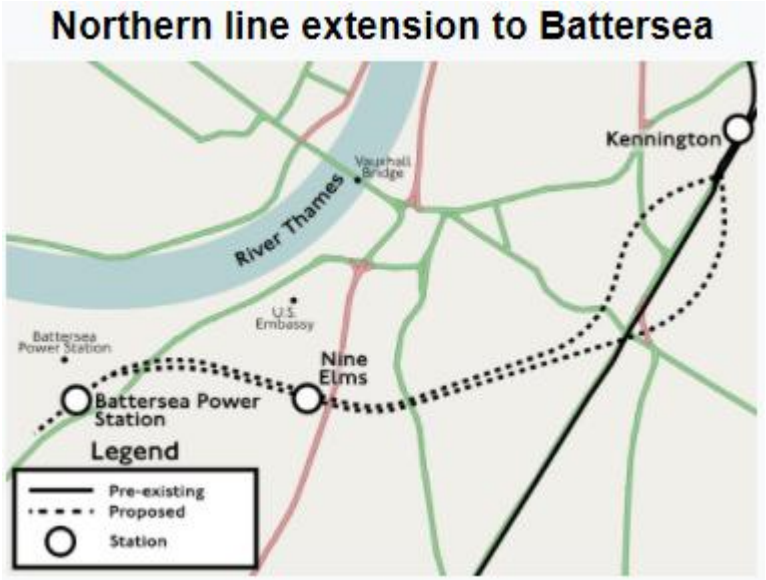
Crossrail: Ground movements monitored by satellite

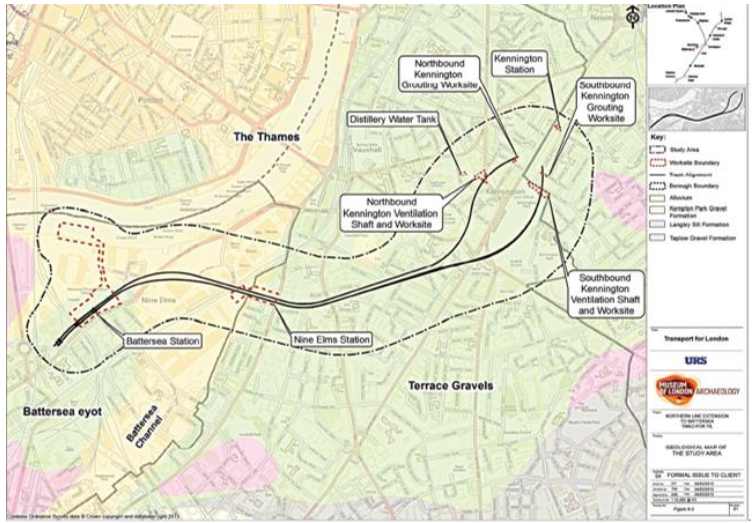




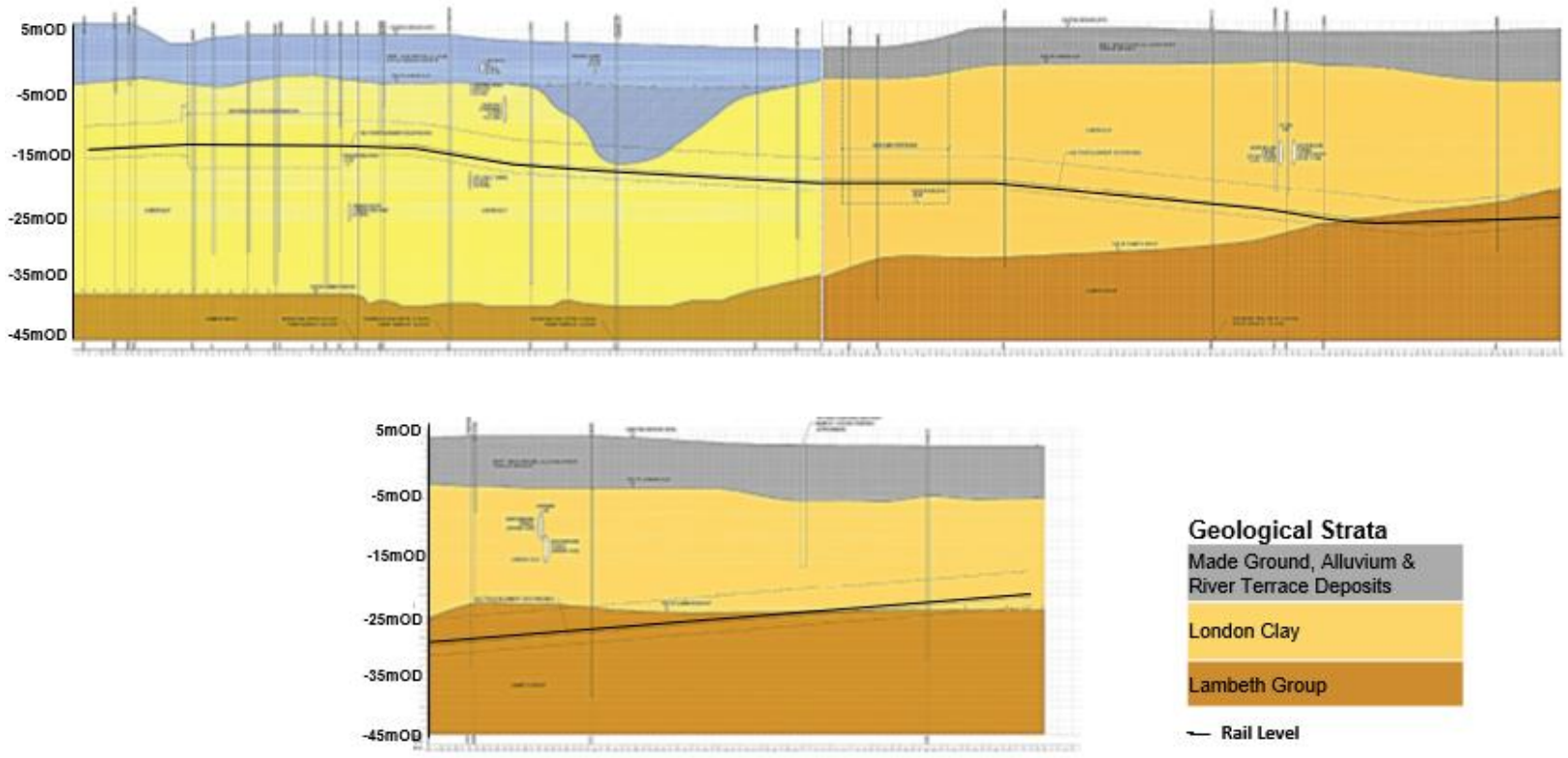
Northern Line Extension





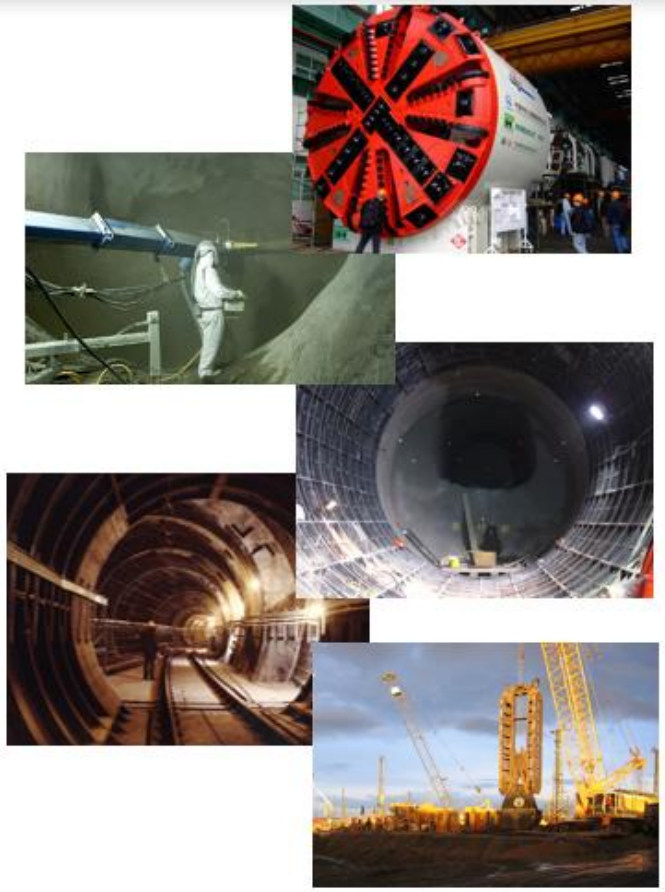


Northern Line Extension: Inferred geological longitudinal section



NLE: Construction techniques

- Tunnel Boring Machine (TBM)
  - Earth Pressure Balance Machine
- Sprayed Concrete Lining
- Spheroidal Graphite Iron
- Step Plate Junction
- Cut and Cover Station Boxes



The future….

- Crossrail 2 (Epsom to North-east London)
- Barking to Riverside extension (Complete)
- West London Orbital
- Bakerloo Line Extension
- ?

Thank you

- Any Questions?