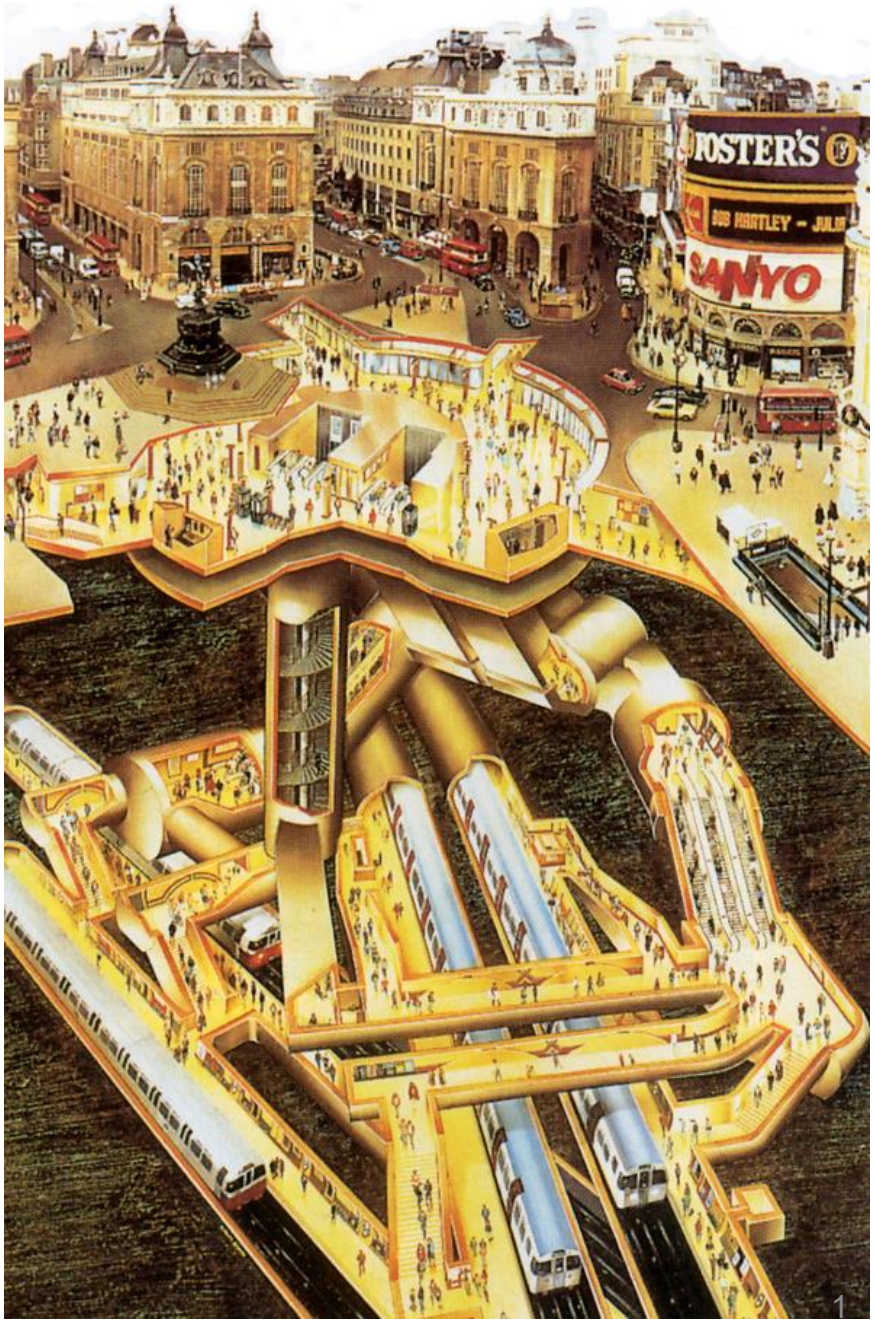
Engineering the Underground

(Session 1)

Presented by:
Nathan Darroch, MA, MIAM,
at the University of Aberdeen,
30 October 2019.



Source: London Transport Museum, undated. *Piccadilly Circus - Gavin Dunn* (1989). [online] London Transport Museum. Available at: http://www.ltmuseumshop.co.uk/posters/london-transport-poster-archive/gallery/gallery-product/poster/piccadilly-circus-gavin-dunn-1989/posterid/32/1062-32.html [Accessed: 28 January 2016].

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- The origins of underground railways
- Transport in the metropolis
- London Underground’s railways
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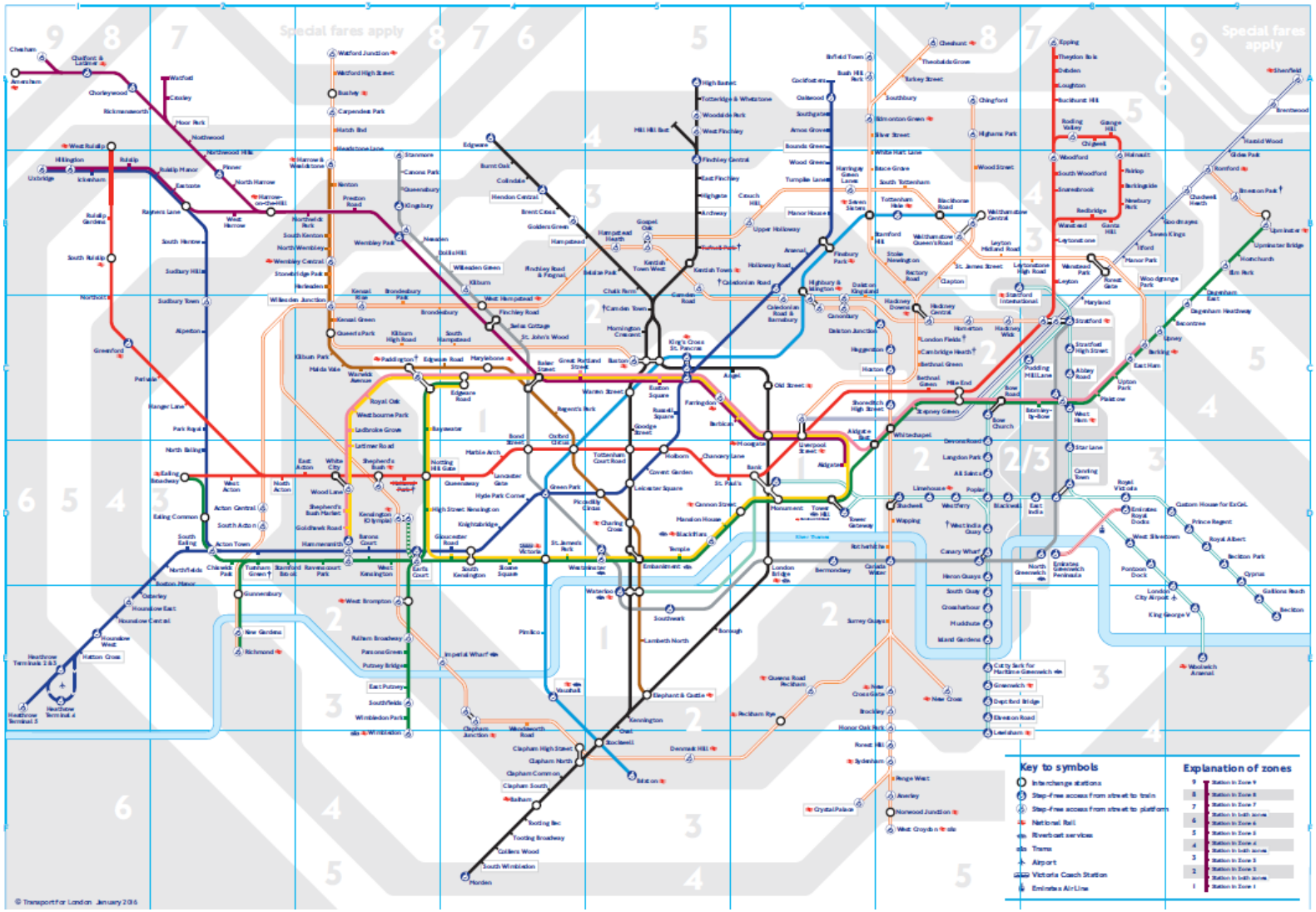
- Summary, session 1

Introduction to London’s underground railways:

What is London Underground?

- London Underground is a rapid transit metro system;
- It uses trains, rails, bridges, earth works and tunnels to carry passengers above and below ground;
- It was the first such system in the world;
- It led and still leads development in changes to technology to improve passenger transit, working with other metro systems globally;
- It affects and is affected by its environment;
- Its operation requires engineering, legal, financial, people, and many other skills, to be effective...;

...it has 11 lines covering 402km (TfL)...

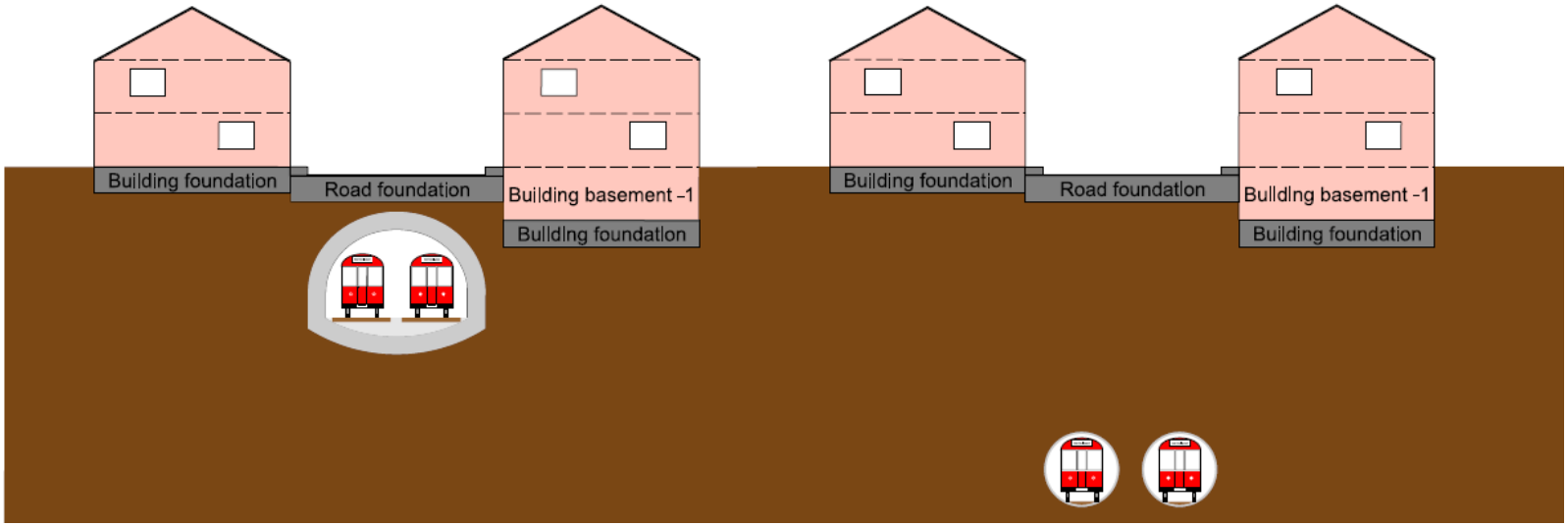


Source: TfL, 2016. Tube Map. [online] Transport for London. Available at: <https://tfl.gov.uk/maps/track/tube> [accessed: 2 February 2016].

...serving 270 Stations (TfL)...

Source: Author's collection

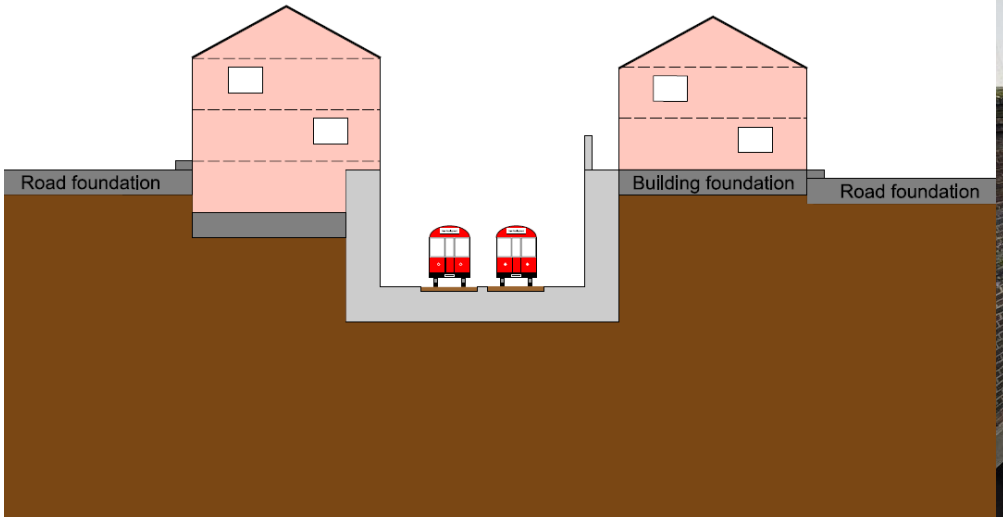
...only 45% of the network is actually in tunnel; most, but not all, are in the central zone...



Sub-surface tunnel below highway
with buildings either side
(0.2m to 7m below ground level)

Tube tunnels below highway
with buildings either side
(2m to 30m below ground level)

...some of the earlier sections in the central zone are also in cutting...



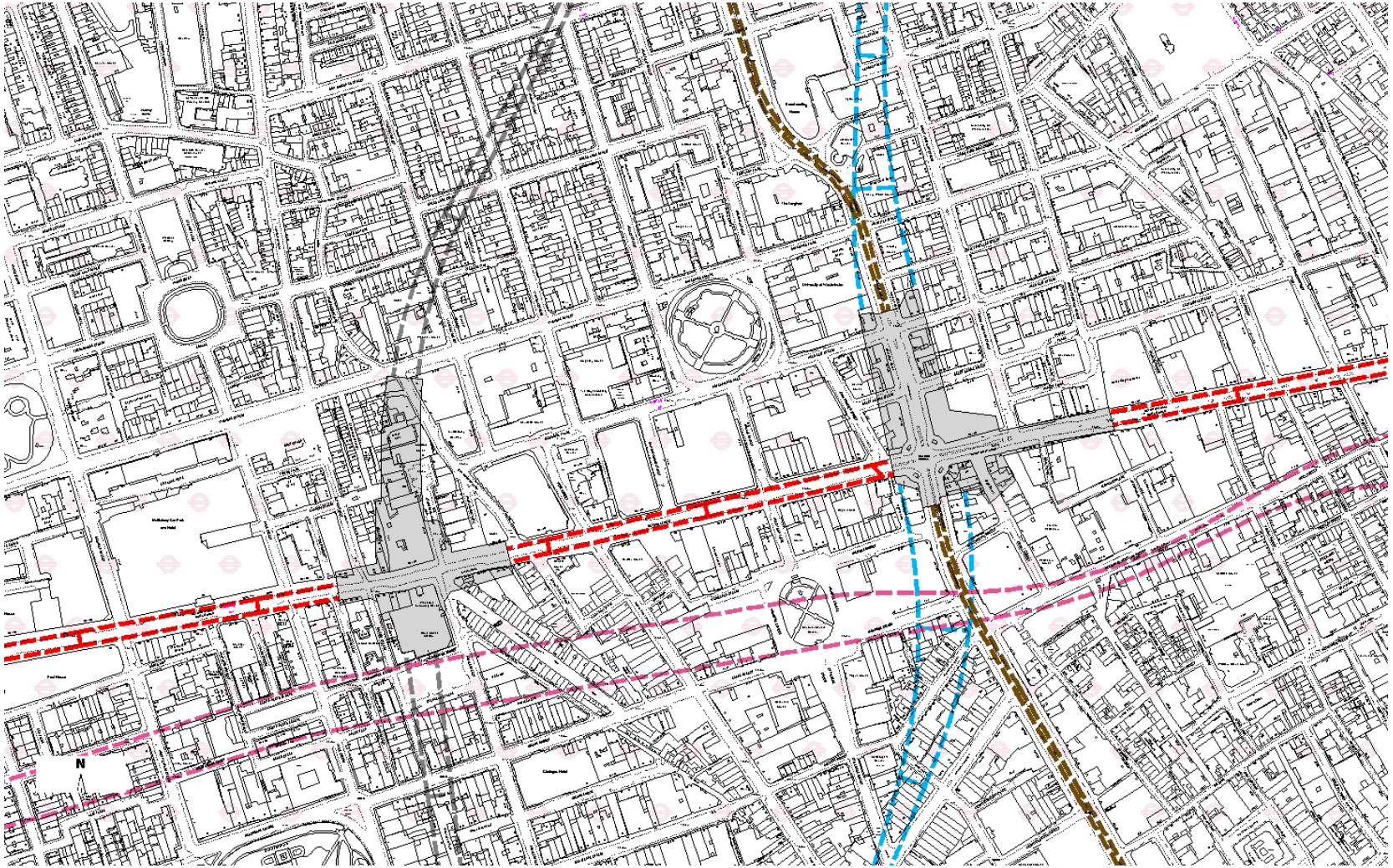
Typical cutting with building over cutting retaining wall, and building offset from top of retaining wall

Image showing railway cutting to the rear of Leinster Gardens, Bayswater

...the remainder is on, just below, or above the surface...

Source: Author's collection.

...there are hundreds of thousands of interfaces between the railway and its neighbours...



Source: London Underground, 2016. 1:1250 plan at A4 showing the Central, Jubilee, Bakerloo, and Victoria lines, dashed red, grey, brown and blue respectively. Shaded areas represent underground infrastructure.

...on 4 December 2015: 4.821 million passengers carried in one day (TfL).

Source: Alarmy, undated. *Rush hour at Oxford Circus station entrance*. [photograph] Available at: <http://www.theguardian.com/uk-news/davehillblog/2013/nov/15/tomorrow-tube-london-underground-stations-commercial-development> [accessed: 2 February 2016].
Source: REX, undated. Commuters at Earls Court tube station. [photograph] Available at: <http://www.express.co.uk/news/uk/472986/Millions-of-commuters-face-delays-on-London-Underground-as-tube-strike-cripples-London> [accessed: 2 February 2016].

But why is it relevant to us as students at the University of Aberdeen?

"*if you're going underground,…why bother with geography?*"
Henry (Harry) Beck, the designer of the world famous tube map,
quoted in Ackroyd, P., 2012. pp.131-132.

Populations are urbanizing and cities are densifying, globally.

Sau Paulo, Brazil

New York, US

Paris, France

London, UK

Underground metro systems are a beneficial means of mass transportation within such environments.

“Metros are the backbone of public transportation systems in cities of different sizes around the world. 148 cities have a metro system and there are close to 540 lines in total. Together, they carry over 150 million passengers per day.

Two-thirds of the world’s metro systems are located in Asia and Europe (50 and 45 respectively). There are 16 systems in Eurasia, 16 in Latin America, 15 in North America and 6 in the Middle East and North Africa (MENA) region.”

Source: Union Internationale des Transports Publics (UITP) (International Association of Public Transport), October 2014. *Statistics Brief World Metro Figures.* [.pdf] Brussels: UITP. Available at: <http://www.uitp.org/sites/default/files/cck-focus-papers-files/Metro%20report%20Stat%20brief-web_oct2014.pdf> [Accessed: 18 February 2016].

They *have* shaped; they *do* shape; and they *will* continue to shape their environments in the future, through *past*, *current* and *future* technology.

Sao Paulo, Brazil ***New York, US***

Paris, France ***London, UK***

So why is today's talk relevant to us as students at the University of Aberdeen?

"*Historical geography is a sub-discipline of human geography concerned with the geographies of the past and with the influence of the past in shaping the geographies of the present and the future*".

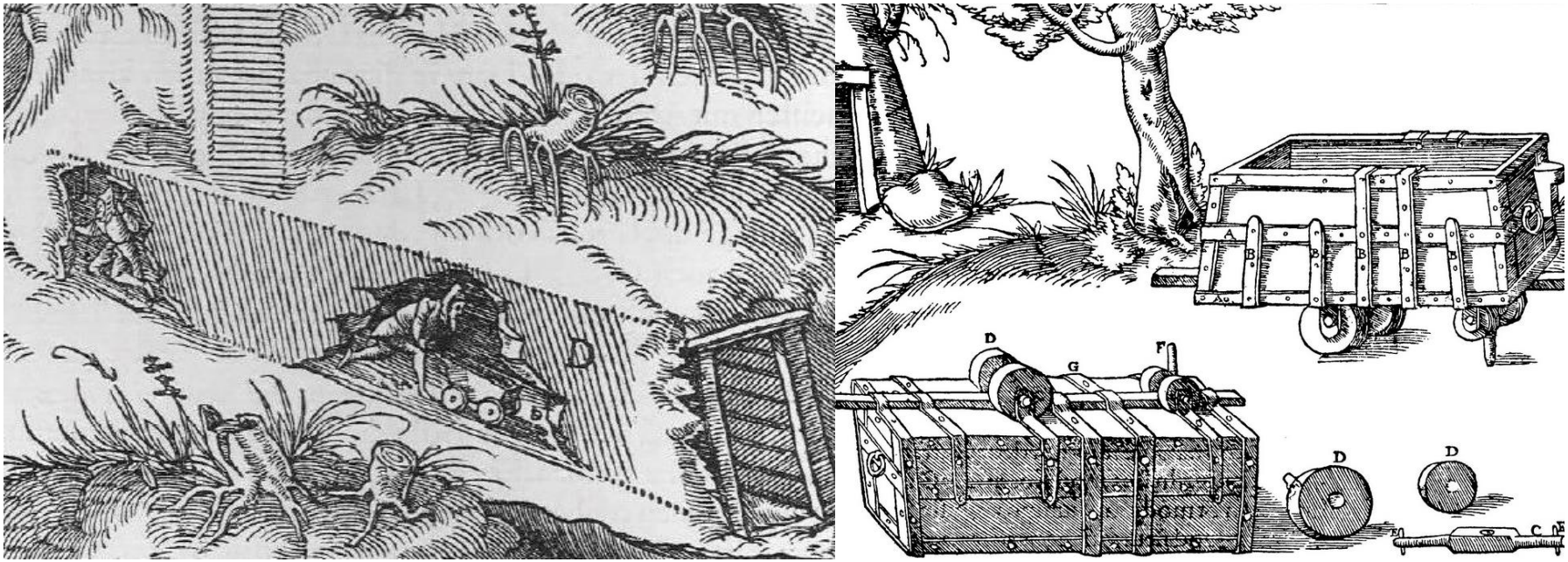
Heffernan, M., 2008.

"*If historical geography is about understanding how the '*past shapes the geographies of the present and the future*', it must be used to advise and guide those managing and planning the urban environment, and its transport infrastructure, now and in the future*".

Darroch, N., 2018.

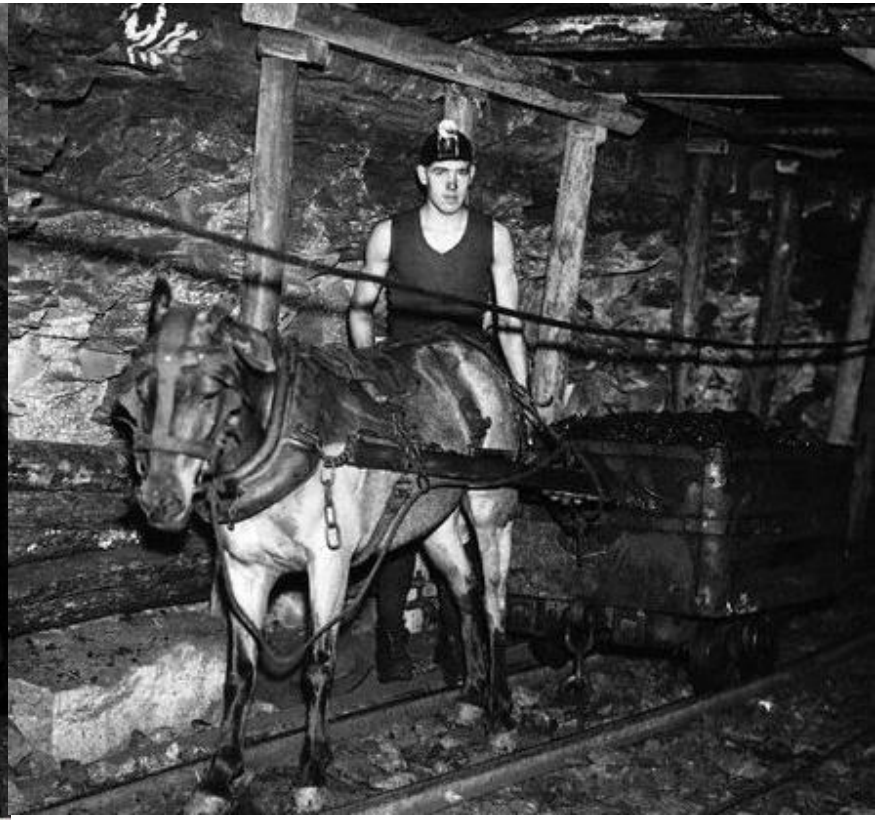
The origins of underground railways

Underground railways have their origins in mining…



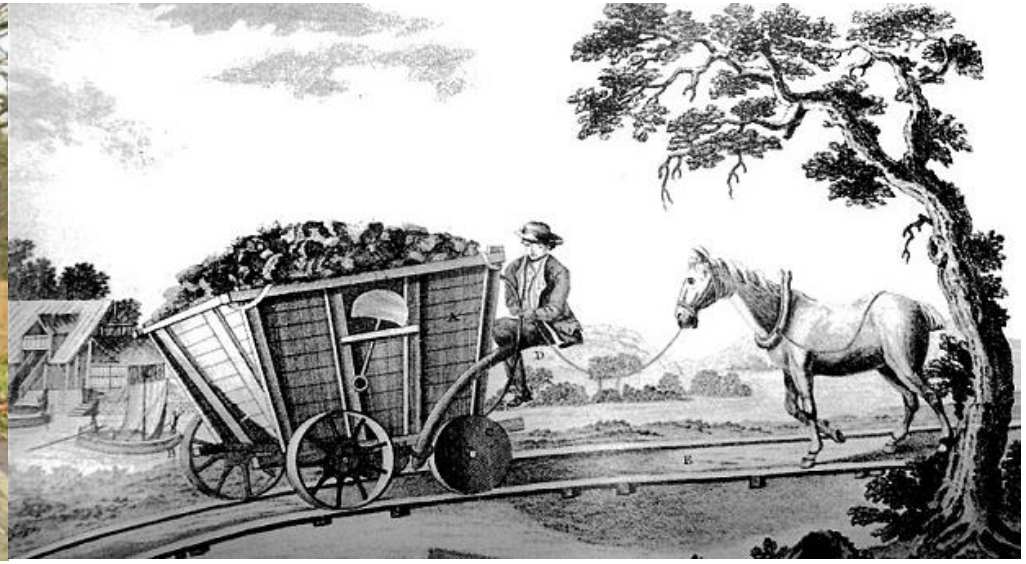
Source: Agricola, G., 1556. *Untitled* [electronic prints] Available at: <http://www.gutenberg.org/files/38015/38015-h/38015-h.htm> [accessed: 2 February 2016].

…motive power for the movement of the wagons, was by, people or animals.



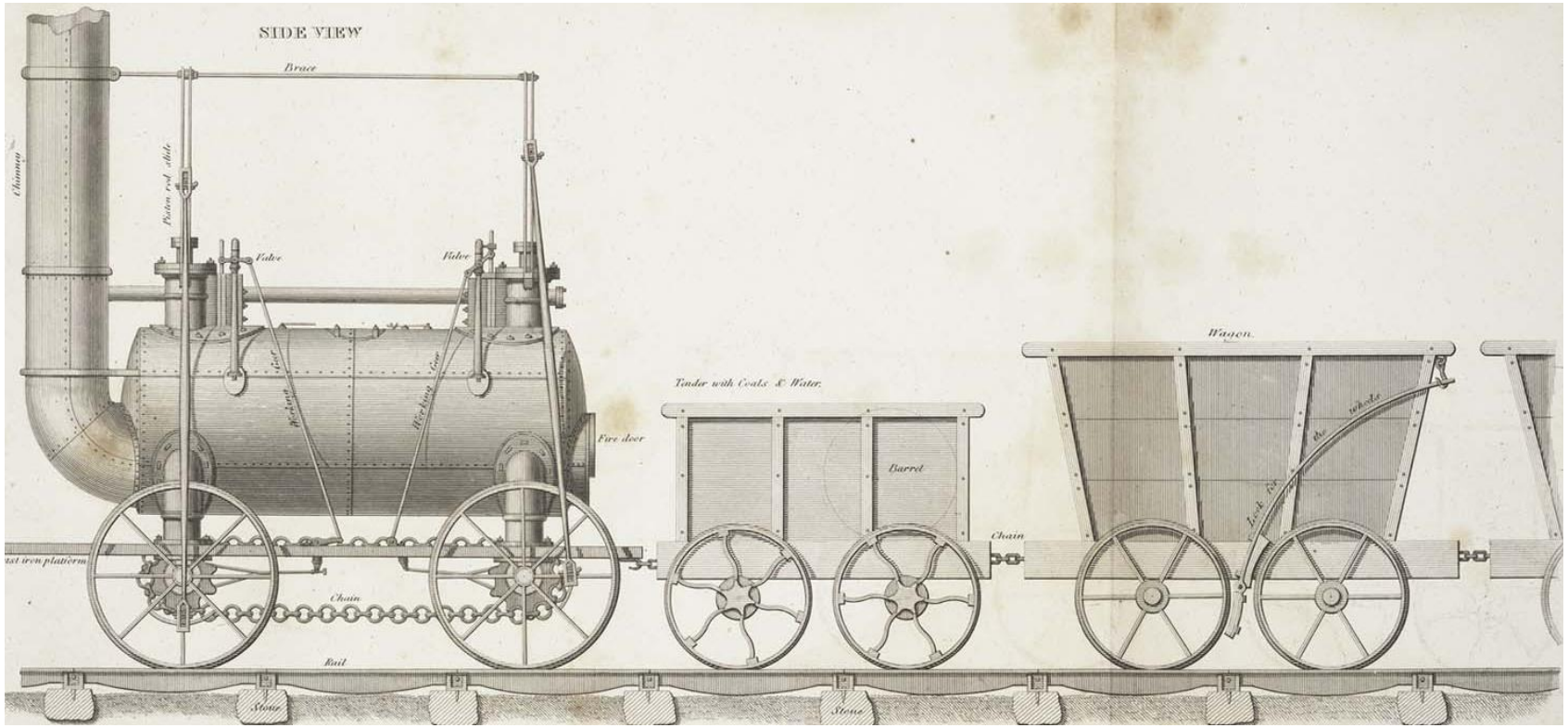
Source: *Bromley Pit - Pensford, Somerset, England*. [photograph] Available at: <http://www.miningartifacts.org/English-Mines.html> [accessed: 2 February 2016].
Source: *Pit pony & miner - Durham, England*. [photograph] Available at: <http://www.miningartifacts.org/English-Mines.html> [accessed: 2 February 2016].

On the surface wooden waggonways were introduced to move *coal*, to staithes on rivers for shipping.



Source: The Pont Valley Networks, undated. *Untitled.* [photograph] Available at: <http://www.pontvalleynet.co.uk/uploads/8/3/0/4/8304582/5234728.jpg?408> [accessed: 2 February 2016].
Source: Mail Online, undated. *Untitled.* [electronic print]. Available at: <http://i.dailymail.co.uk/i/pix/2013/07/26/article-2379064-1B02C5F0000005DC-887_624x368.jpg>[accessed: 2 February 2016].

By the early 19th century, changes in *technology* enabled a change in *motive power* allowing more *coal* to be moved, faster...



Source: The History Blog, undated. Untitled. [electronic print] Available at:<http://www.thehistoryblog.com/wp-content/uploads/2013/07/stephenson-locomotive-engine.jpg> [accessed: 2 February 2016].

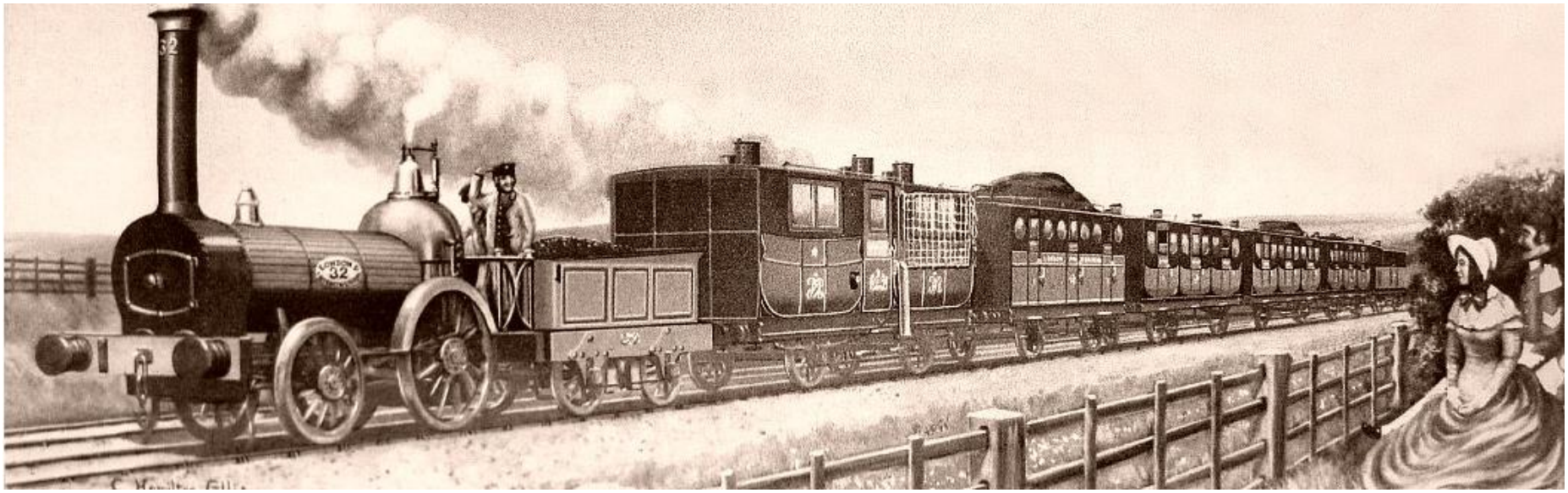
...but this required a change from wooden rails to metal, which was better able to carry the heavier, faster trains.

Source: Paul Jarman, 2014. *Laying oak rails onto hardwood sleepers.* [photograph] Available at: <http://beamishtransportonline.co.uk/2014/11/ten-years-at-beamish-a-reflection/> [Accessed: 18 February 2016].
Source: internetretailing.net, 2016. Untitled. [photograph] Available at: < http://odishasuntimes.com/2015/11/18/centres-nod-for-doubling-of-three-rail-tracks/ > [Accessed: 18 February 2016].

At this time *people* movement nationally was slow and uncomfortable...

Source: *The Quicksilver Devonport-London Royal Mail stagecoach painted as it was about to travel with four new horses in the harnesses*. [electronic print] Available at: <http://www.dailymail.co.uk/news/article-3333750/Last-surviving-Royal-Mail-coach-goes-sale-70-000.html> [accessed: 2 February 2016].

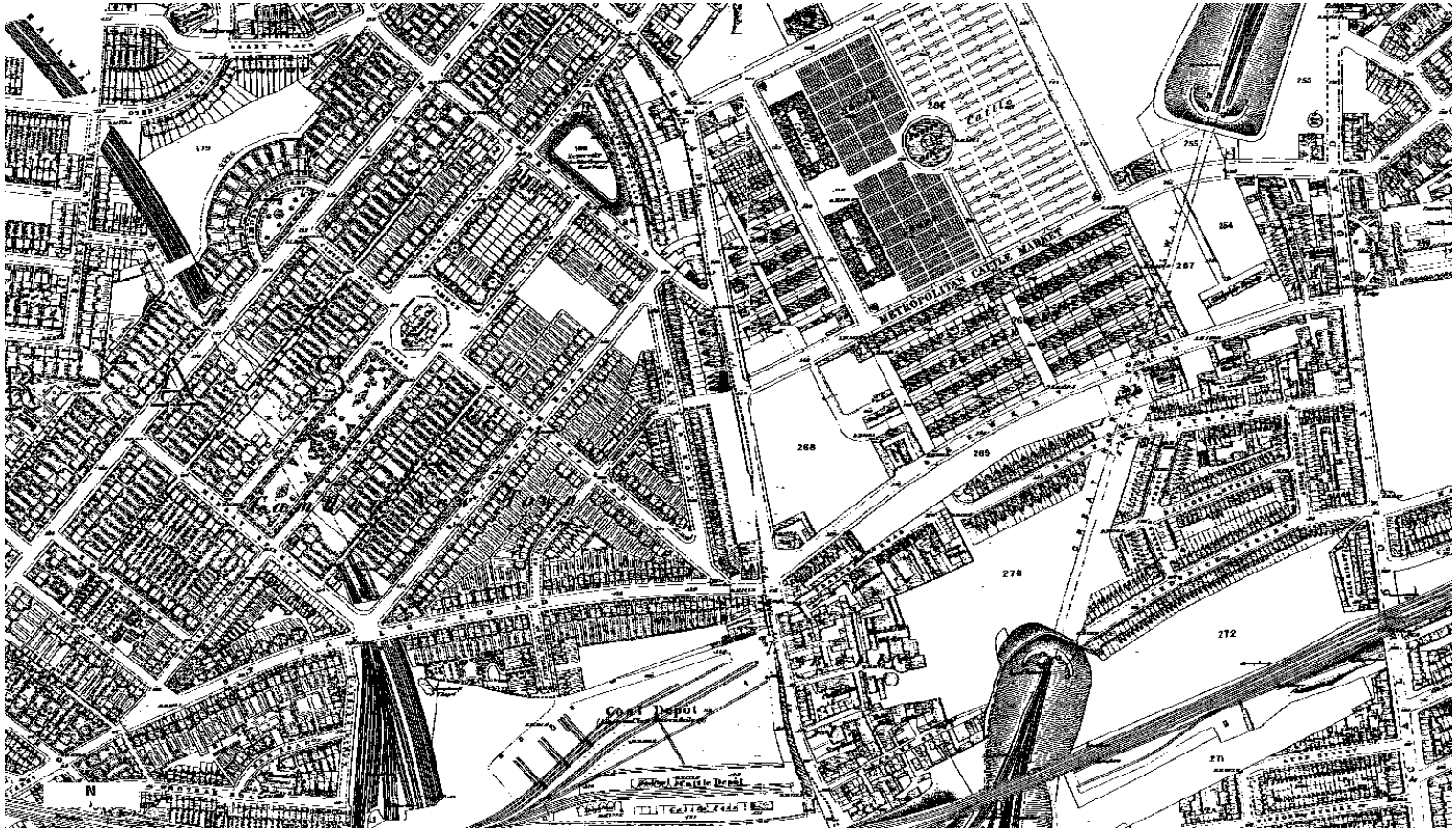
...application of *steam* and *rail* technology enabled faster, more economical movements of *goods* and *people* in one movement, nationally and locally.



Source: *London & Birmingham Railway Bury 2-2-0 passenger locomotive No. 32 heading a mixed train*. [electronic print] Available at: <http://gerald-massey.org.uk/Railway_local/index.htm> [accessed: 2 February 2016].

Transport in the metropolis

By 1863, and the opening of the world's first urban underground railway, tunnels for railways in cities were not uncommon…



Source: London Underground, 2016. Historic Ordnance Survey mapping, c.1862-1895, showing the areas north of Kings Cross and St Pancras main line stations.

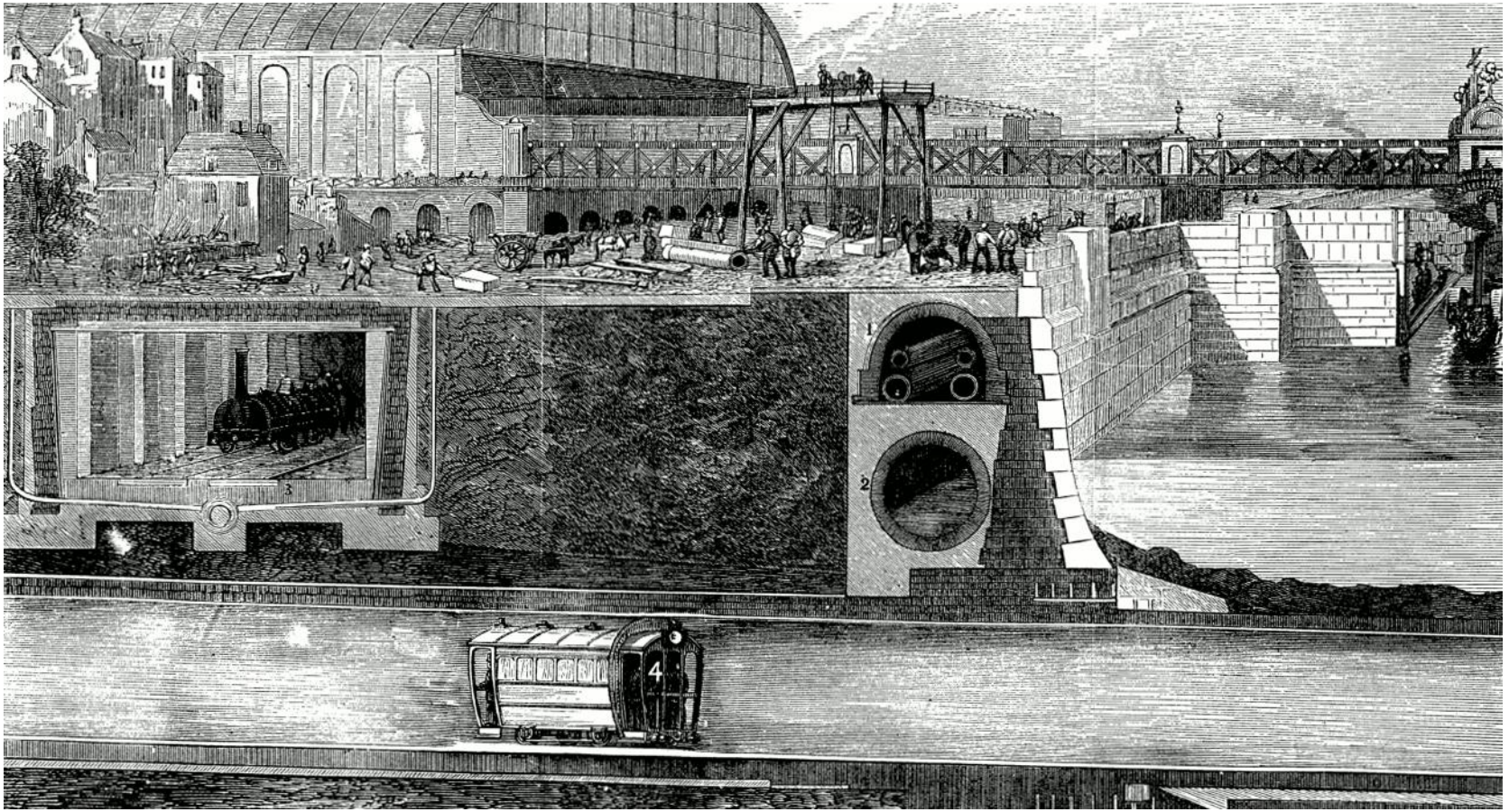
…nor was traffic congestion.

Source: London Stereoscopic and Photographic Company, 1897. *View of Ludgate Hill and Ludgate Circus*. [photograph] Available at: <https://s-media-cache-ak0.pinimg.com/564x/7e/cf/56/7ecf561ded55bb93bf1f914d5fdaf917.jpg> [accessed: 2 February 2016].
Source: *Financial heart: Cheapside, with Bow Church in the background, was one of the most consistently busy areas of London, attracting street-sellers in droves.* [photograph] Available at: <http://i.dailymail.co.uk/i/pix/2012/07/28/article-2180284-143F139F000005DC-332_634x398.jpg> accessed: 2 February 2016].

While public transport enabled movement over greater distances, the vehicles were small and relatively slow…

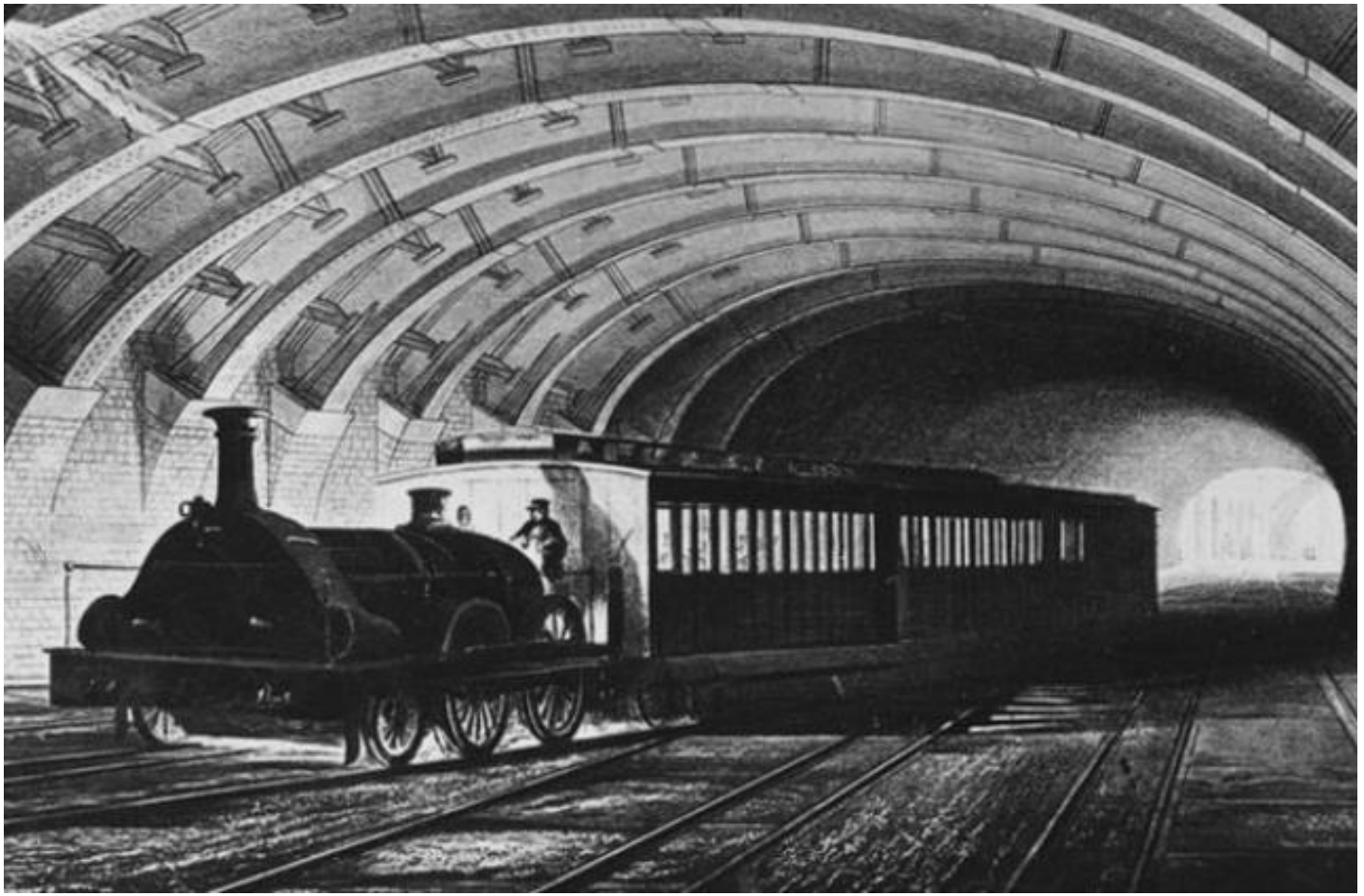
Source: London Stereoscopic Company/Getty Images, undated. *This is a 'knifeboard' omnibus, which carried some of the passengers sitting outside the bus. The bench on the roof was known as the knifeboard. The vehicles were launched in the early 1850s and this picture was taken of passengers in their top hats in 1865, travelling on the route between Bank and the Strand in London.* [photograph] Available at: <http://www.telegraph.co.uk/expat/expatpicturegalleries/10886175/In-pictures-London-buses-in-black-and-white.html?frame=2935509> [accessed: 2 February 2016].
Source: *Illustration of the opening of the first London tramway at Marble Arch.* [electronic print] Available at: <http://www.bbc.co.uk/news/in-pictures-15990563> [accessed: 2 February 2016].

…therefore going underground was considered the most beneficial solution...



Source: Illustrated London News, undated. *Section of the pneumatic tube under the Thames River, London.* [electronic print] Available at: <www.ianvisits.co.uk> [accessed: 2 February 2016].

…application of steam traction on metal rails enabling faster smoother journeys with longer and more connected vehicles.



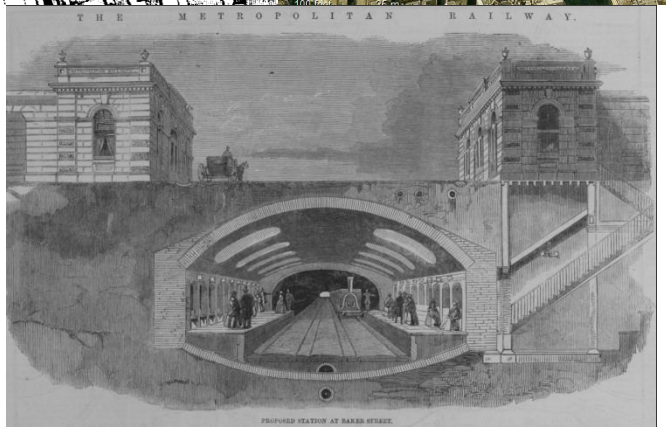
Source: Mirror, 2013. Journey: The first Metropolitan train on the underground line passing through Praed Street. [electronic print] Available at: <http://www.mirror.co.uk/news/uk-news/going-underground-a-metro-spective-to-celebrate-150-1522223> [accessed: 24 October 2016].

The sub-surface railways

Built between 1859 and 1884, the sub-surface railways carved their way around central London…

Source: The Illustrated London News , 1861. *Construction of the Metropolitan Railway close to King's Cross station in 1861*. [photograph] Available at: <https://upload.wikimedia.org/wikipedia/commons/c/c8/Constructing_the_Metropolitan_Railway.png> [accessed: 2 February 2016].
Source: Google Maps, 2016. Google Streetview. Available at: [online] Available at: <https://www.google.co.uk/maps/@51.5304273,-0.1210157,3a,75y,313.51h,86.97t/data=!3m6!1e1!3m4!1szKKMbfnR_WQQgP5ZLiAKPQ!2e0!7i13312!8i6656> [2 February 2016].

…passing under the public highway...

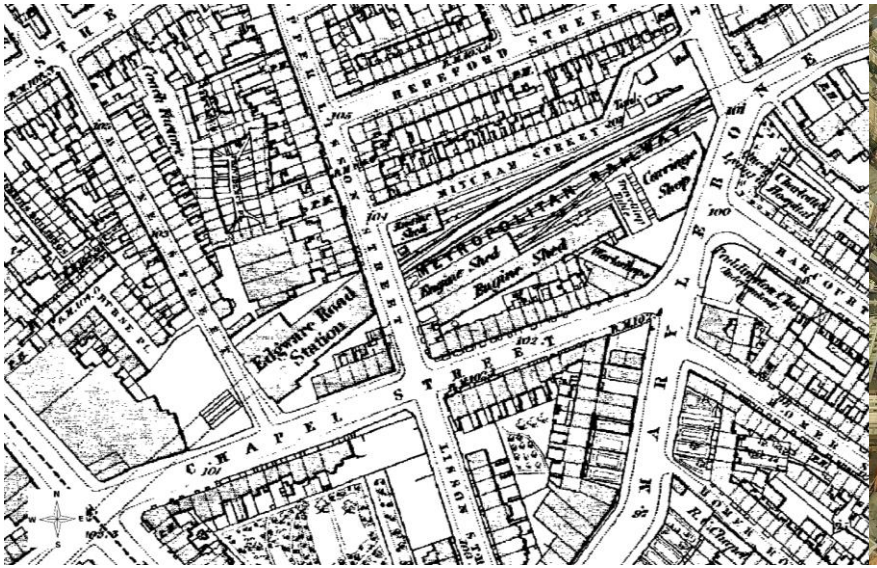


Source: London Underground, 2016. Historic Ordnance Survey mapping, c.1862-1895, showing Baker Street Metropolitan Railway station and the Metropolitan line (dashed purple).

Source: Ian Visits, undated. *Proposed Station at Baker Street.* [online] Available at: <http://www.ianvisits.co.uk/blog/2012/12/28/how-the-worlds-first-underground-railway-was-built/ >[accessed: 2 February 2016].

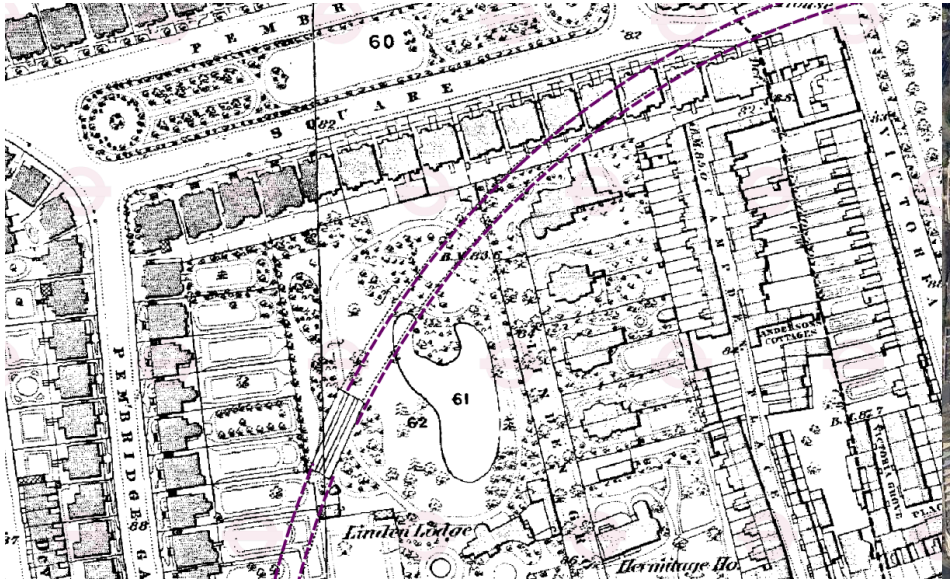
Source: Bing Maps, 2016. Baker Street Metropolitan line station and environs. [online] Available at: <http://www.bing.com/maps/ > [accessed: 2 February 2016].

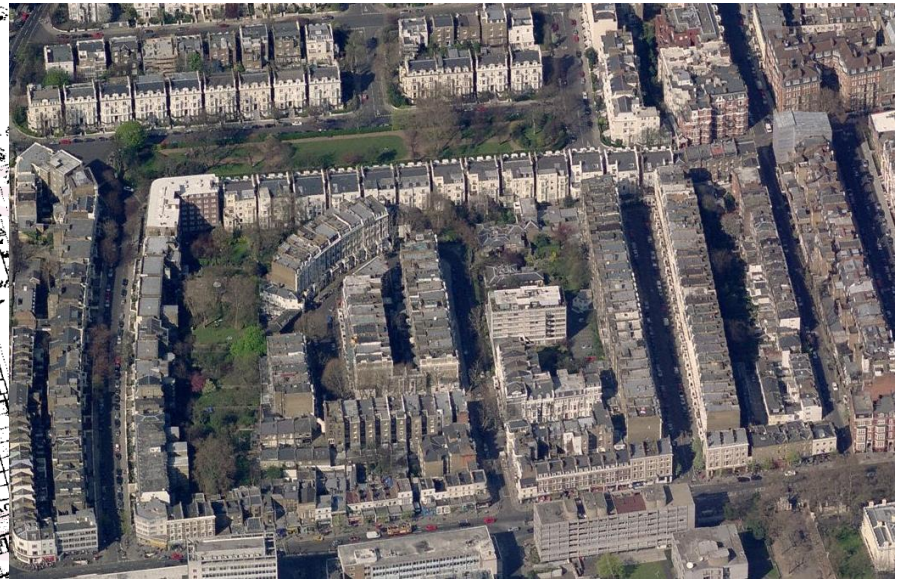
…also causing the demolition of property, its presence obvious within its environment today…



Source: London Underground, 2016. Historic Ordnance Survey mapping, c.1862-1895, showing Edgware Circle and District line station.
Source: Bing Maps, 2016. Edgware Road LU Station and environs. [online] Available at: <http://www.bing.com/maps/ > [acessed: 2 February 2016].

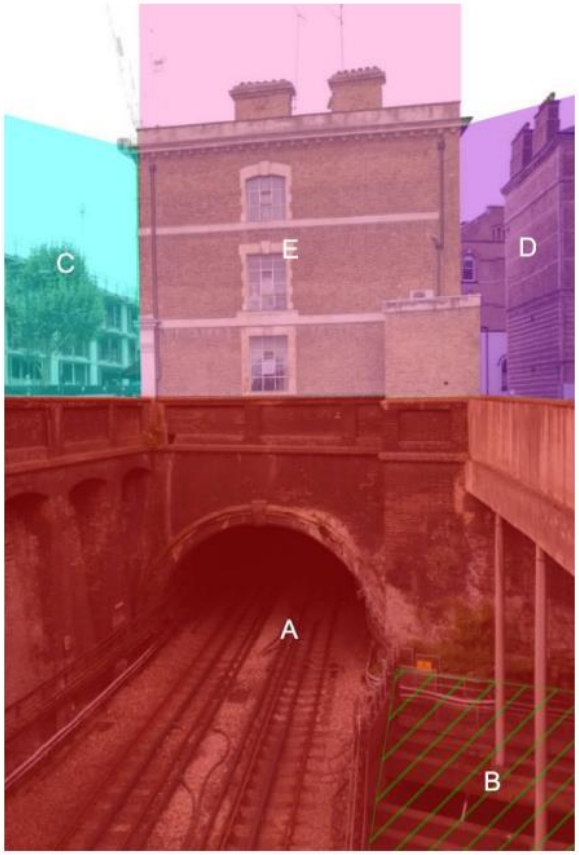
...it also passed under existing property, with much less obvious effect, but still having a direct effect on its environment today.





Source: London Underground, 2016. Historic Ordnance Survey mapping, c.1862-1895, showing the Metropolitan line (dashed purple) near Pembroke Square, London.
Source: Bing Maps, 2016. Pembroke Square and environs, showing the effect of the presence of the Metropolitan line. [online] Available at: <http://www.bing.com/maps/> [accessed: 2 February 2016].

The presence of the sub-surface railway created and creates complicated relationships with its neighbours...



A = London Underground land and airspace
B = Network Rail land and airspace (below)
C = TfL Streets highway
D = Local authority highway
E = Building owner

Source: Nathan Darroch.

...the construction of the railway not just affecting buildings, but rivers, sewers and roads.

Source: London Underground, 2012. PC100, carrying the King's Scholars Pond Sewer, through the roof of tunnel TL53, west of Baker Street. [photograph] London Underground survey.
Source: Bing Maps, 2016. Brittania Street and environs, Kings Cross, London. [online] Available at: <http://www.bing.com/maps/ > [accessed: 2 February 2016].

From their opening in 1863 trains were powered by steam, until they were replaced by electric trains from 1904.

Source: Getty Images, 2012. *Shortly after 1pm on January 9 in 1863 the inaugural train pulled out of Paddington station to begin a 3.5mile journey under the capital's streets and into the history books.* [photograph] Available at: http://www.dailymail.co.uk/news/article-2249372/Steam-train-returns-London-Underground-time-century-mark-150-years-Tube-opened.html#ixzz40WHt3WlU [Accessed: 18 February 2016].
Source: Jeltex, 2015. U*ntitled*. [photograph] Available at: <http://jelltex.blogspot.co.uk/2015/01/thursday-22nd-january-2015.html >[accessed: 18 February 2016].

Summary, session 1:

- Underground railways have their origin in 16th century mining
- The guidance and weight distribution system was applied to surface transportation of coal
- Technological advances saw steam powered rail vehicles used for passenger transit nationally
- Combining tunnels and rail transit was a beneficial means to avoid surface congestion within the city
- Mid 19th century technology for tunnelling affected and still affects surface development
- An alternative technology was required for tunnelling and the powering of trains...

Engineering the Underground

(Session 2)

Presented by:
Nathan Darroch, MA, MIAM,
at the University of Aberdeen,
30 October 2019.

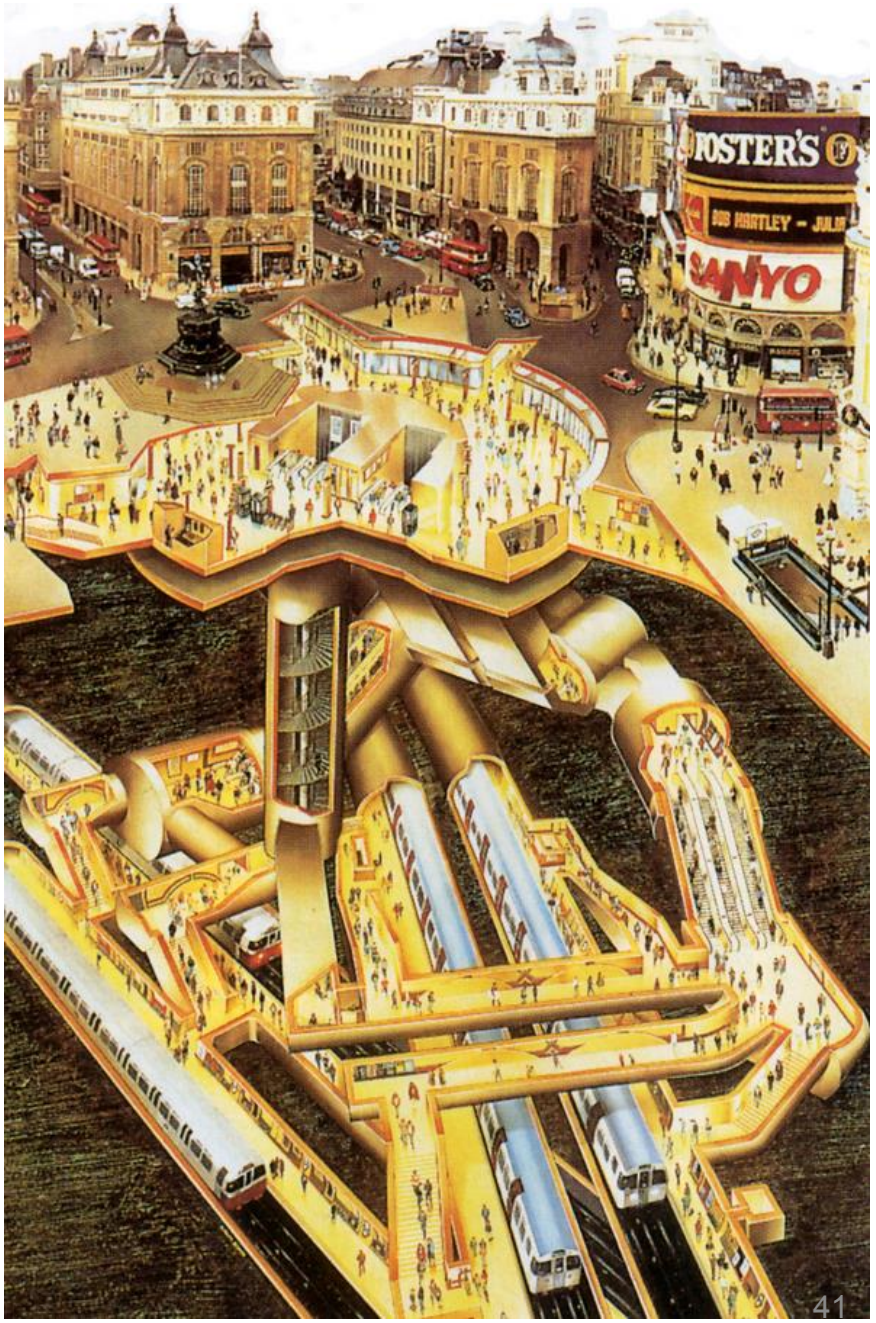


Image source: London Transport Museum, undated. *Piccadilly Circus - Gavin Dunn* (1989). [online] London Transport Museum. Available at: http://www.ltmuseumshop.co.uk/posters/london-transport-poster-archive/gallery/gallery-product/poster/piccadilly-circus-gavin-dunn-1989/posterid/32/1062-32.html [Accessed: 28 January 2016].

Session 1, summary:

- Underground railways have their origin in 16th century mining
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Contents, session 2:

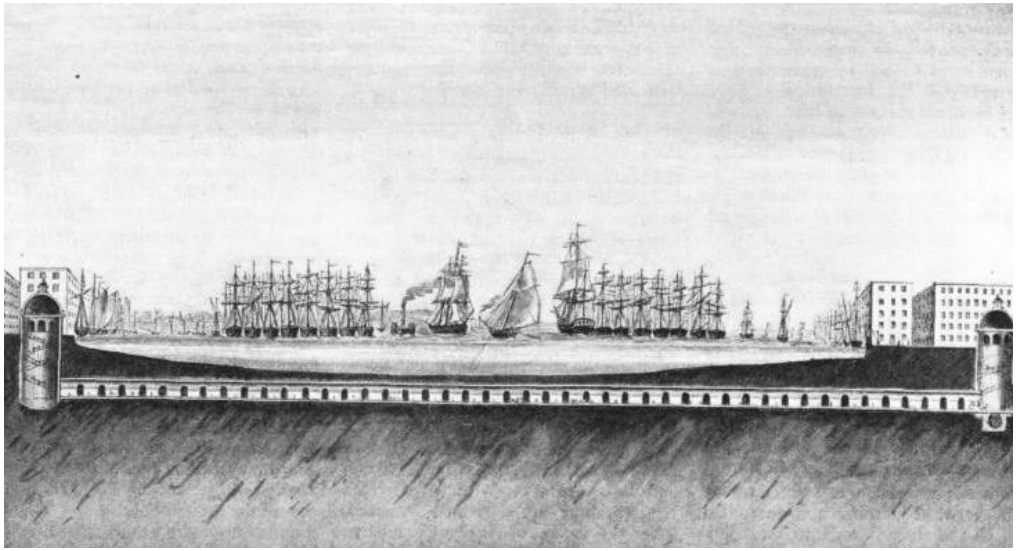
- Summary of session 1
- London Underground’s railways
  - The tube railways
  - The suburban railways
  - The future
- Summary
- References

The tube railways

The River Thames has been a hindrance to north-south travel for millennia.

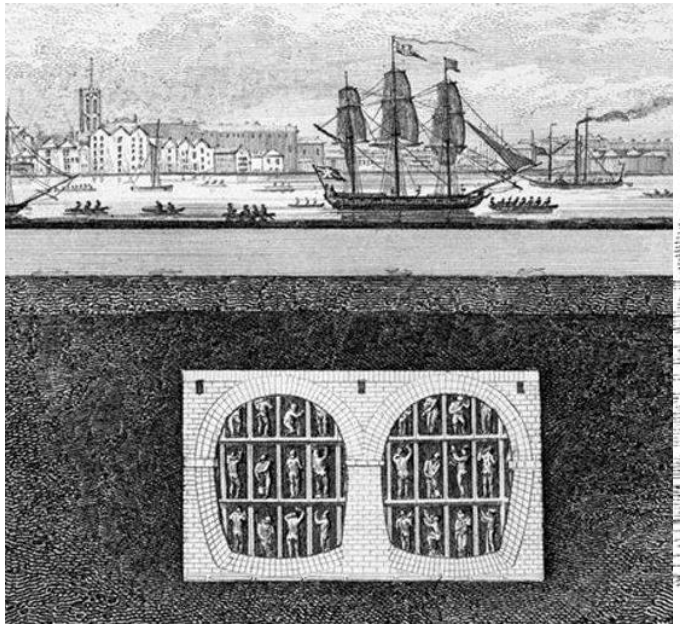
Source: The Victorian Web, undated. *Old London Bridge. From a model by John Thorp in the London Museum. From London past and Present In the section Before the Great Fire, 1666.* [electronic print] Available at: <http://www.victorianweb.org/technology/bridges/36.html> accessed: 2 February 2016].
Source: Victorian London - Thames - Bridges - London Bridge , undated. *London Bridge, Looking North-west.* [photograph] Available at: <http://www.victorianlondon.org/thames/londonbridge.htm> [accessed: 2 February 2016].

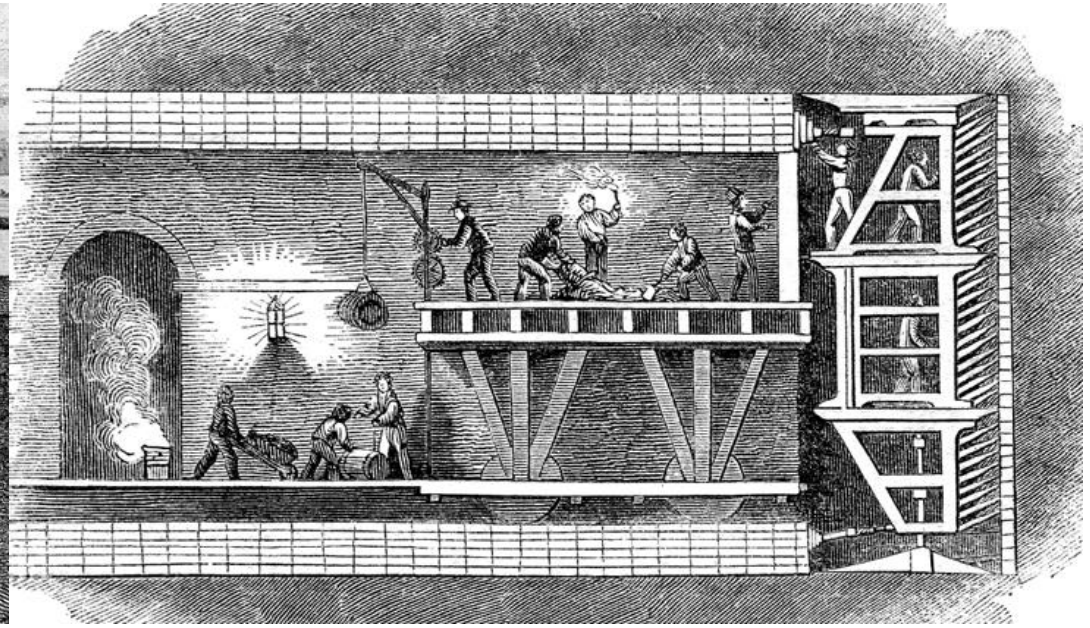
In 1843, the world's first *modern* tunnel under navigable water was opened in London, to ease some of the pressure on the bridges.



Source: Mike's Engineering Wonders, 2011. *Sectional Diagram Of The Thames Tunnel.* [electronic print] *Available at:* <http://www.engwonders.byethost9.com/e027.html> [accessed: 2 February 2016].
Source: BBC News, 2010. *People enjoying the tunnel in 1835* [sic]. [electronic print] Available at: <http://www.victorianlondon.org/thames/londonbridge.htm> [accessed: 2 February 2016].

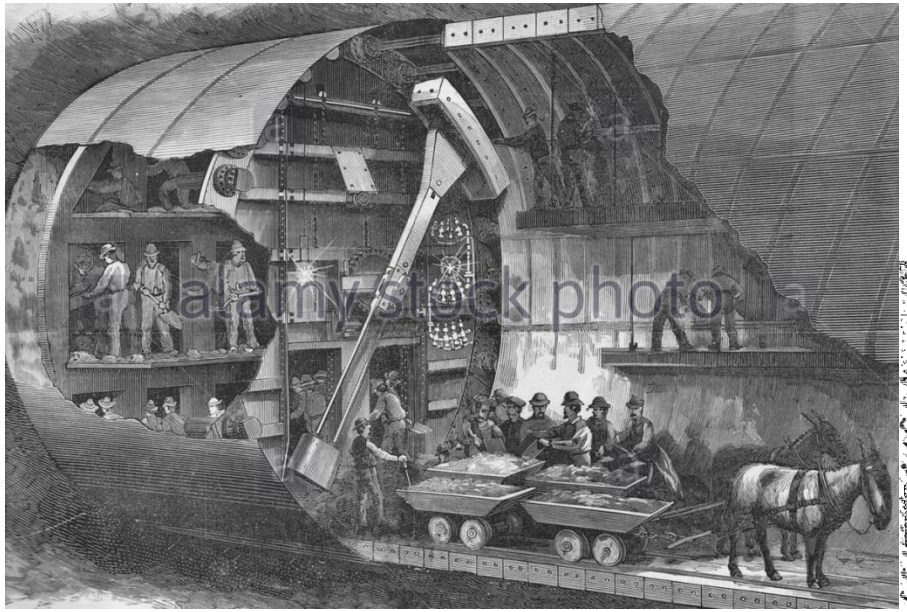
It was constructed using a “tunnelling shield”.

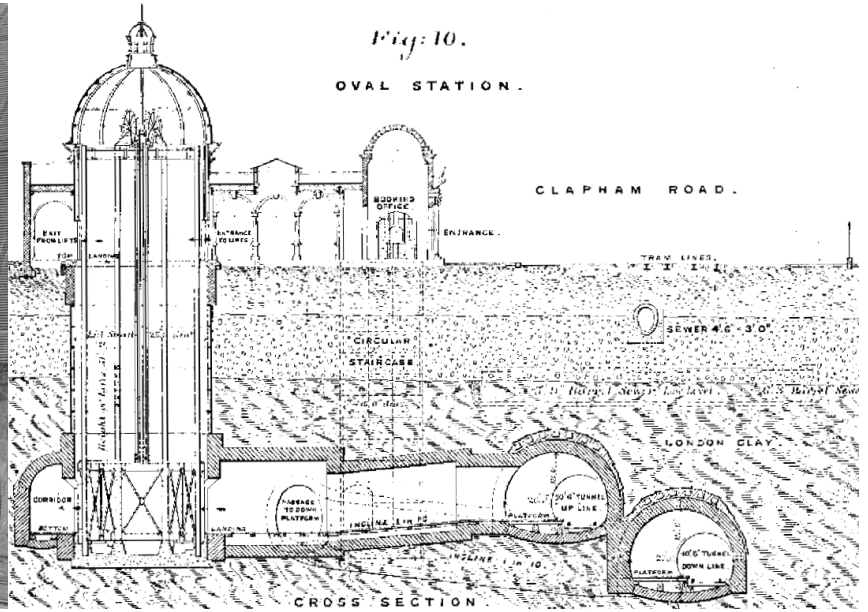




Source: BBC, 2016. *Untitled.* [electronic print] Available at:<http://www.bbc.co.uk/learning/schoolradio/subjects/history/victorians/brunel/thames_tunnel > [accessed: 2 February 2016].
Source: Wikipedia, .2015 *Diagram of the tunnelling shield used to construct the Thames Tunnel*. [electronic print] Available at: < https://en.wikipedia.org/wiki/Thames_Tunnel > [accessed: 2 February 2016].

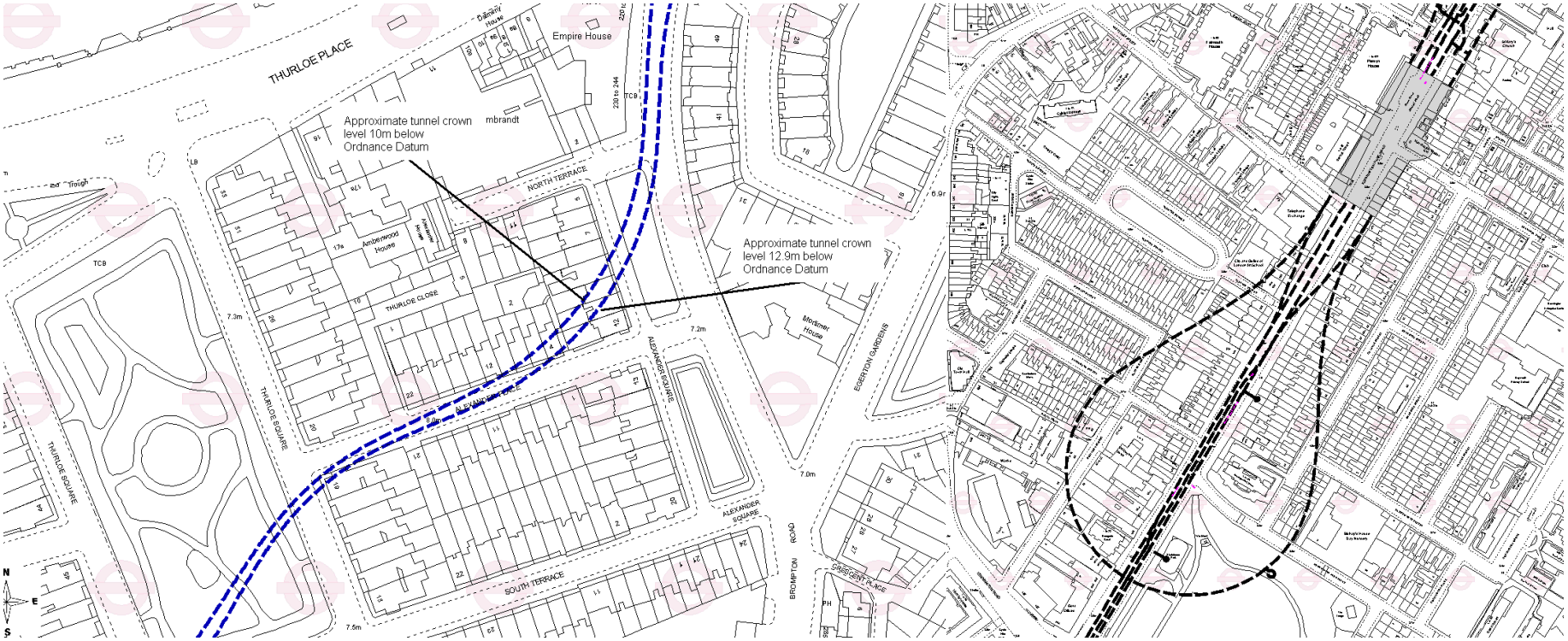
From 1886, shield technology, developed from the Thames Tunnel shield principle, enabled construction of tunnels deeper under ground than cut and cover methods…





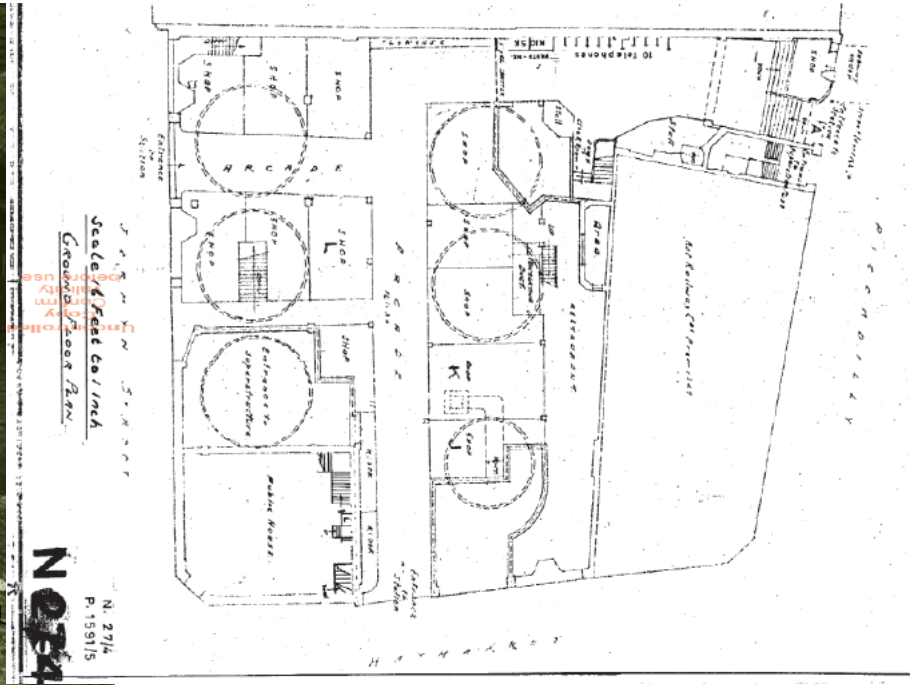
Source: Alamy, undated. *The Beach Hydraulic Tunnelling Shield at work.* [electronic print] Available at: <http://c8.alamy.com/comp/D027HT/the-beach-hydraulic-tunneling-shield-at-work-in-the-great-railway-D027HT.jpg>[Accessed: 18 February 2016].
Source: Greathead, J., H., 1893. The City and South London Railway. *Proceedings of the Institution of Civil Engineers,* 112(1893), pp.39-73.

...tunnelling deeper enabled the railway to pass under 19th century and early 20th century property without adversely affecting it. *Physically*.



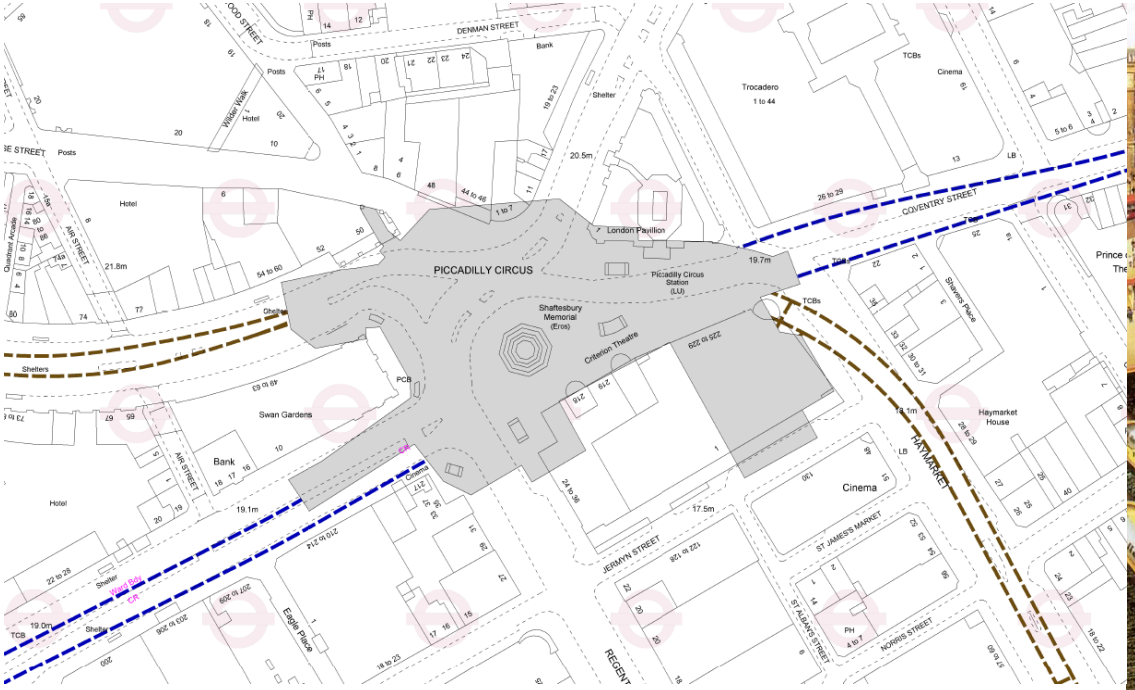
Source: London Underground, 2016. Modern Ordnance Survey mapping, c.2014, showing the Piccadilly line (dashed blue) near Alexander Place, London.
Source: London Underground, 2016. Modern Ordnance Survey mapping, c.2014, showing the Northern line (dashed black) at Kennington Station, London. Shaded areas represent underground station infrastructure.

Due to their depth these railways had to be operated by electricity. Water powered lifts were used to take people to and from the trains within stations.



Source: London Transport Museum, undated. *A train at Borough Junction on the City and South London Railway.* [photograph] Available at: <http://www.ltmcollection.org/resources/index.html?IXglossary=Underground%20lines> [accessed: 18 February 2016].
Source: Nathan Darroch, 2012. *Drawing showing the Ground Floor plan of the original Piccadilly Circus Station, Undated. LUL Electronic Archive No.: P063 15372.* [diagram] Available at: <http://etheses.whiterose.ac.uk/3905/> [accessed: 18 February 2016].

Increasing traffic saw the need for the application of new technology within stations, causing a change in the design of stations.



Source: London Underground, 2016. Modern Ordnance Survey mapping, c.2014, showing Piccadilly Circus station and the Piccadilly and Bakerloo lines (dashed blue and brown respectively).

Source: London Transport Museum, undated. *Piccadilly Circus - Gavin Dunn* (1989). [online] London Transport Museum. Available at: http://www.ltmuseumshop.co.uk/posters/london-transport-poster-archive/gallery/gallery-product/poster/piccadilly-circus-gavin-dunn-1989/posterid/32/1062-32.html [Accessed: 28 January 2016].

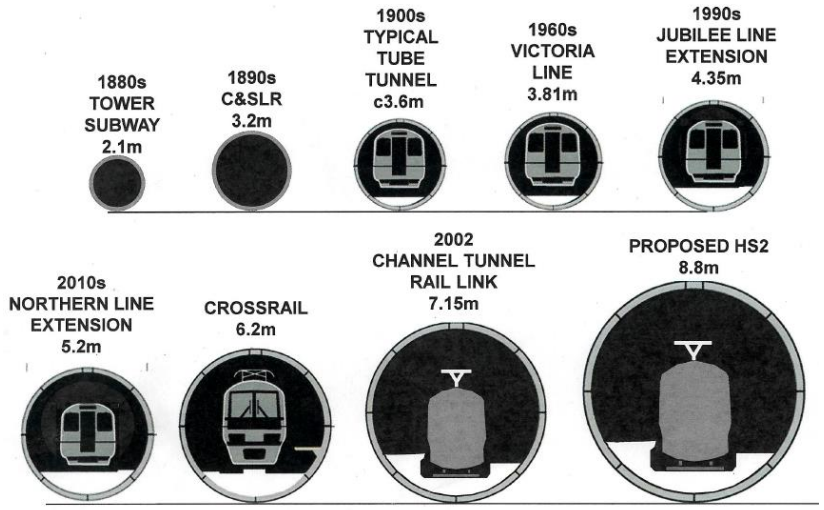
The conversion from surface buildings, with lifts, to under highway ticket halls, with escalators, created alternative uses for surface land and buildings.

Source: TimeOut, 2015. Tube Stations: then and now. [online] Time Out Magazine. Available at <http://www.timeout.com/london/things-to-do/tube-stations-then-and-now >[Accessed: 2 February 2016].
Source: Google Maps, 2016. Haymarket and environs, London. [online] Available at: <https://www.google.co.uk/maps/@51.509746,-0.1329224,3a,75y,292.82h,100.89t/data=!3m6!1e1!3m4!1scPHfKlF7uf6SdkjaRrzh8w!2e0!7i13312!8i6656> [Accessed: 2 February 2016].

But the tunnels were originally of small diameters (4-5m), station tunnels (7.5m) easily became, and still become congested.

Source: PA Wire, 2015. *Untitled*. [photograph] ITV.com. Available at http://www.itv.com/news/london/topic/tube/?page=2 [Accessed: 17 February 2016].
Source: Dominic Lenton, 2013. *Keeping the subterranean tunnels cool in summer is notoriously difficult, but air-conditioned trains are being introduced. [photograph]* Engineering and Technology Magazine. <http://eandt.theiet.org/magazine/2013/01/photoessay.cfm> [accessed: 17 February 2016].

Whilst further technological development has allowed automation of tunnel construction, and larger diameter tunnels (7-8m)...

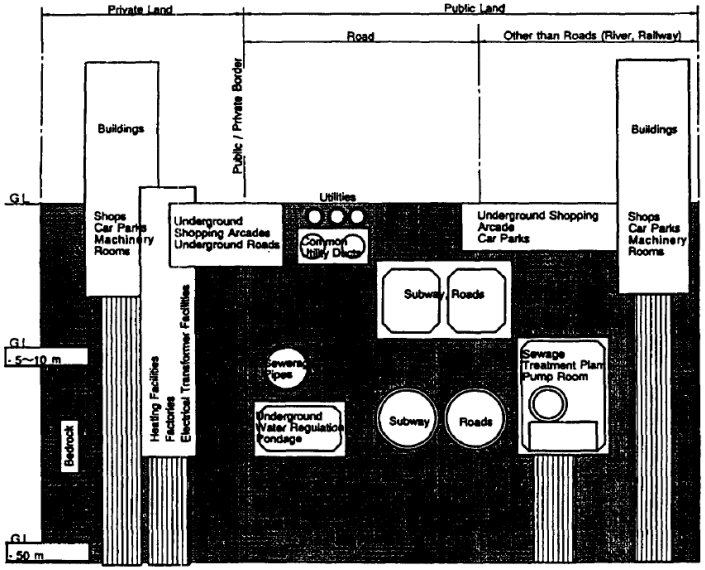


Source: London Reconnections, 2011. *The TBM from the side*. [photograph] Available at: <http://www.londonreconnections.com/2011/in-pictures-the-crossrail-tbms/>[accessed: 2 February 2016].

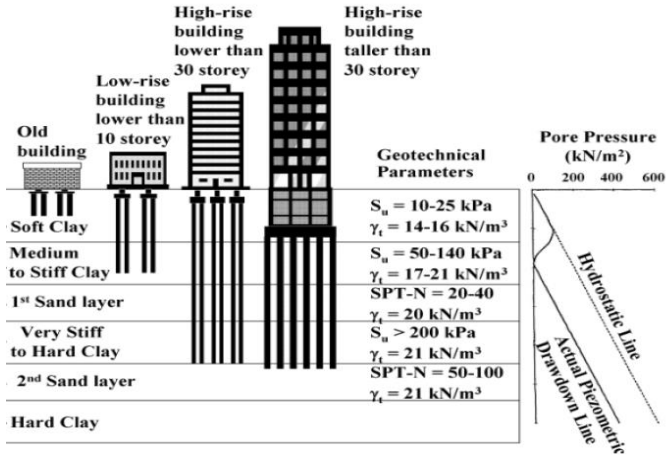
Source: The Docklands and East London Advertiser, 28 January 2015. *Crossrail tunnel…now completed*. [photograph] Available at: <http://www.eastlondonadvertiser.co.uk/news/take_a_walk_through_crossrail_s_tunnel_before_the_trains_start_running_1_3933032> [accessed: 2 February 2016].

... since the 1950s, buildings have become taller and their foundations deeper.

Central China's mega-city Wuhan has started the construction of the country's largest "underground city," as more cities look to underground space as land resources become scarce.
Source: Hubei, 2015

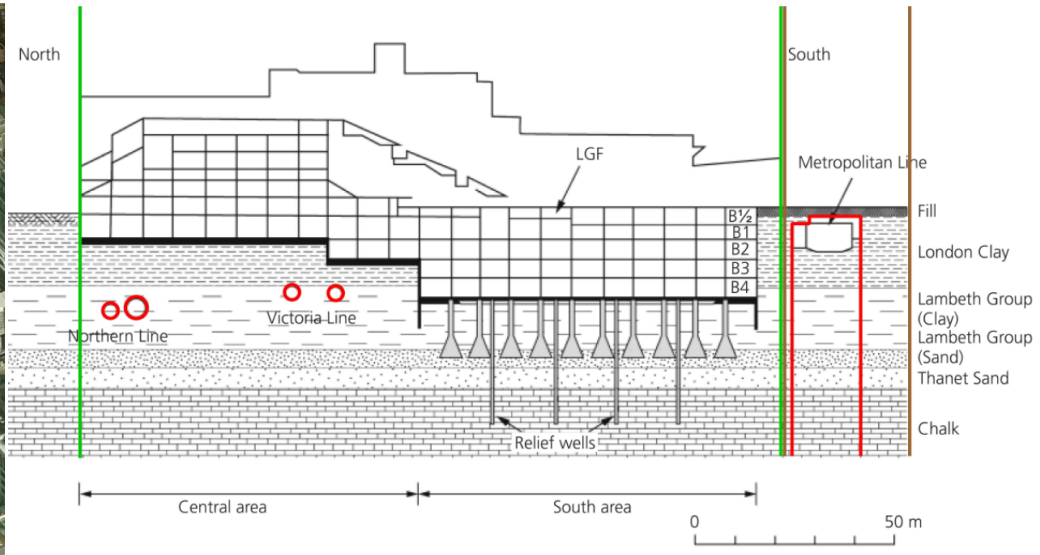


Potential uses for Urban Underground Space in Japan.
Source: International Tunnelling Association, 2000



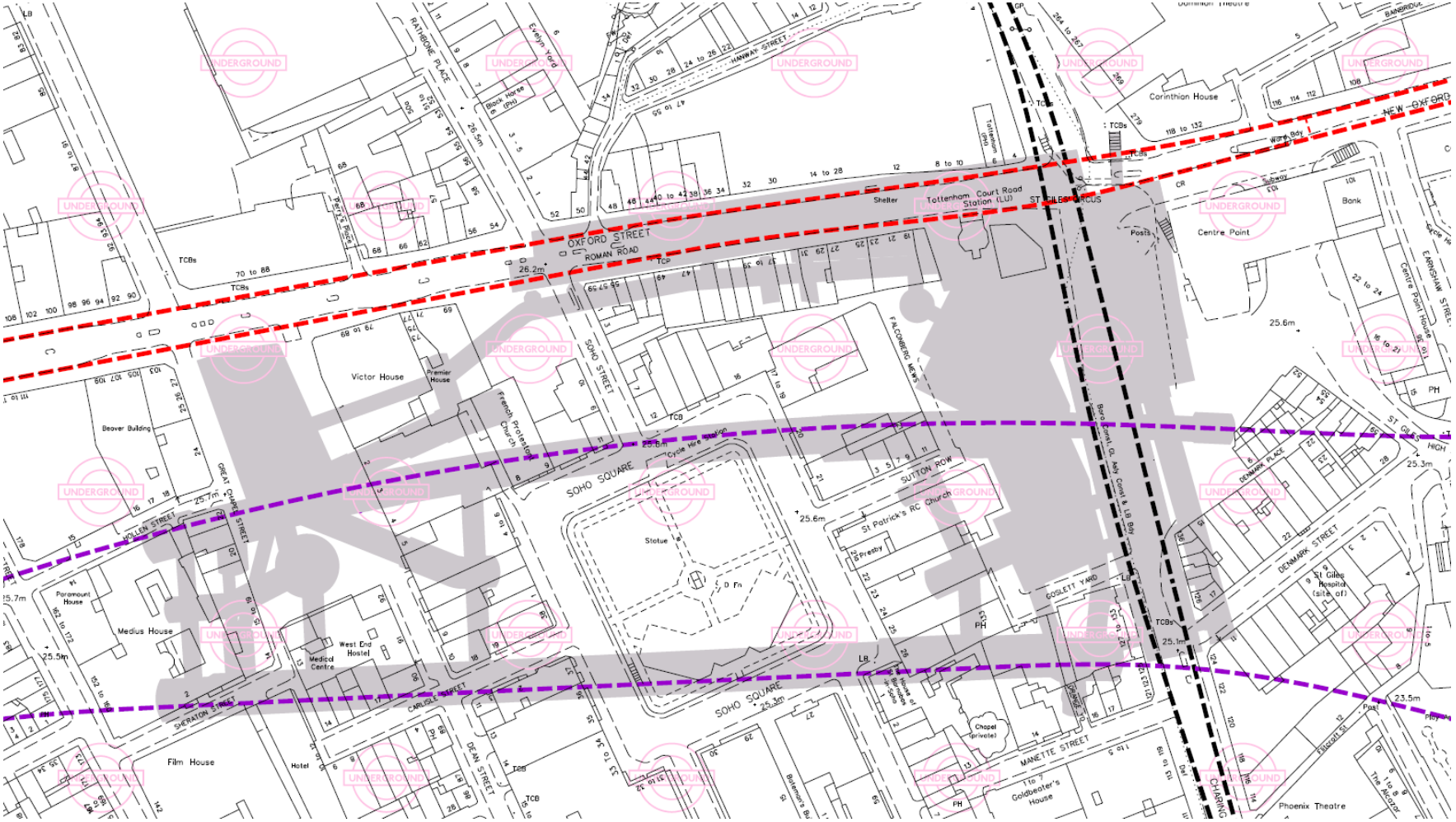
Typical design of superstructure using Piled Foundation concept in Bangkok subsoil.
Source: Cheang, Phien-weij, Almornfa, 2013.

The need for the subsoil for foundations and metro infrastructure, has increased the physical and legal interfaces.



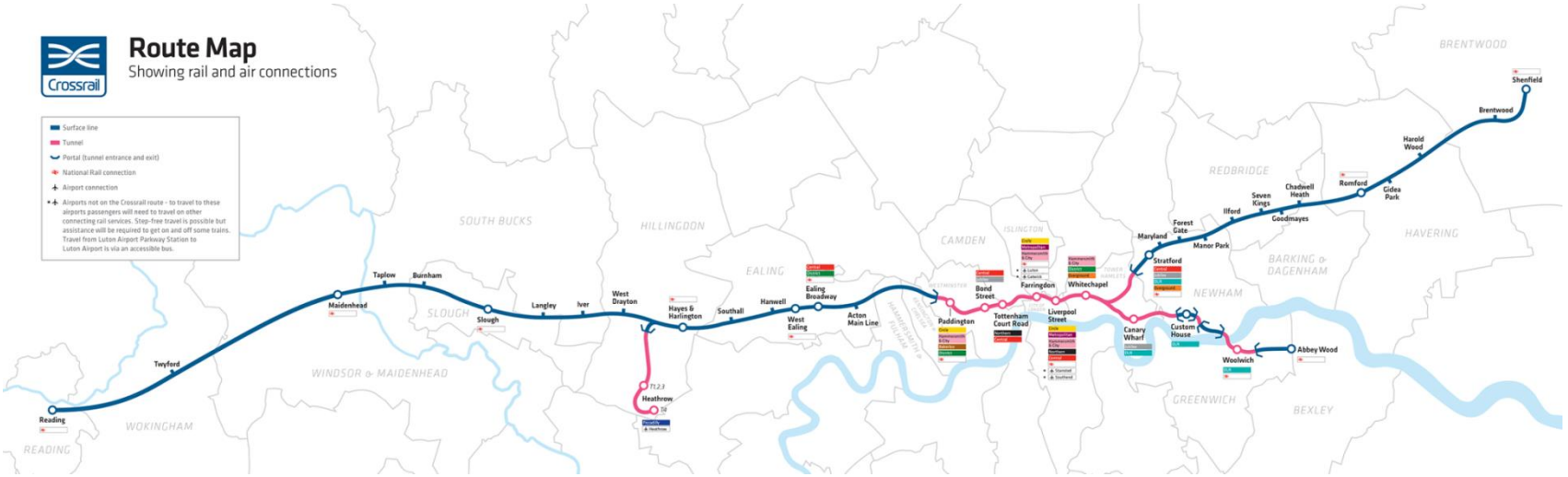
7Source: Bing Maps, 2016. The British Library, London. [online] Available at: <http://www.bing.com/maps/> [accessed 25 October 2017]; Simpson, B., and Vardanega, P.J., 2014. *Results of monitoring at the British Library excavation*. [online] Proceedings of the Institution of Civil Engineers - Geotechnical Engineering. Available at: <https://doi.org/10.1680/geng.13.00037> [Accessed 25 October 2017].

This is the ‘new’ Tottenham Court Road station for Crossrail.



Source: London Underground, 2016. Modern Ordnance Survey mapping, c.2014, showing the Central, Northern and Crossrail lines (dashed red, black and purple respectively) in relation to Tottenham Court Road station and environs, London.

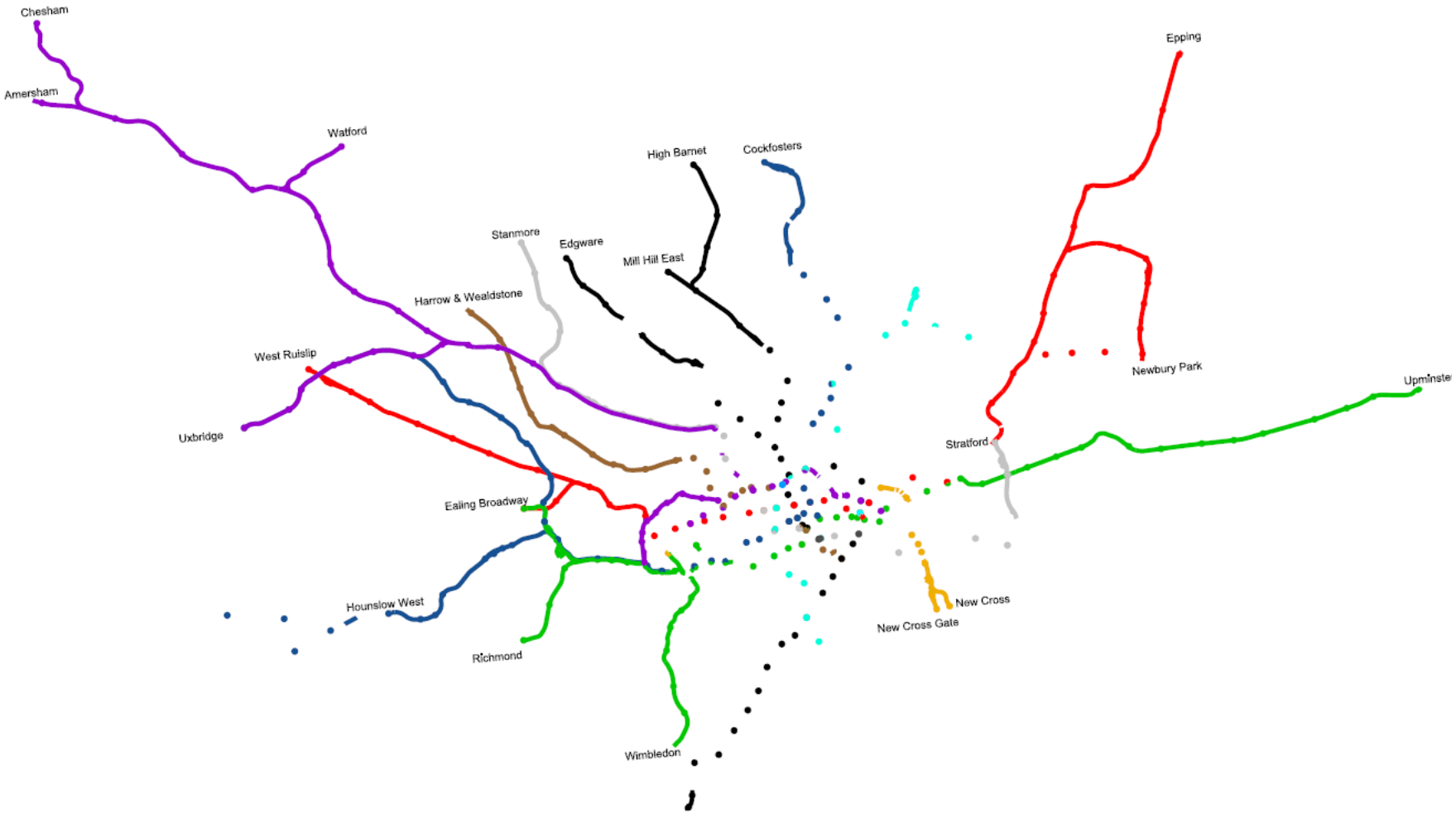
Crossrail will bring people from further afield *directly to the central core of London*, with little or no change of train.



Source: Crossrail, 2016. *Regional Map*. [online] Available at: <http://www.crossrail.co.uk/route/maps/regional-map#> [accessed: 2 February 2016]

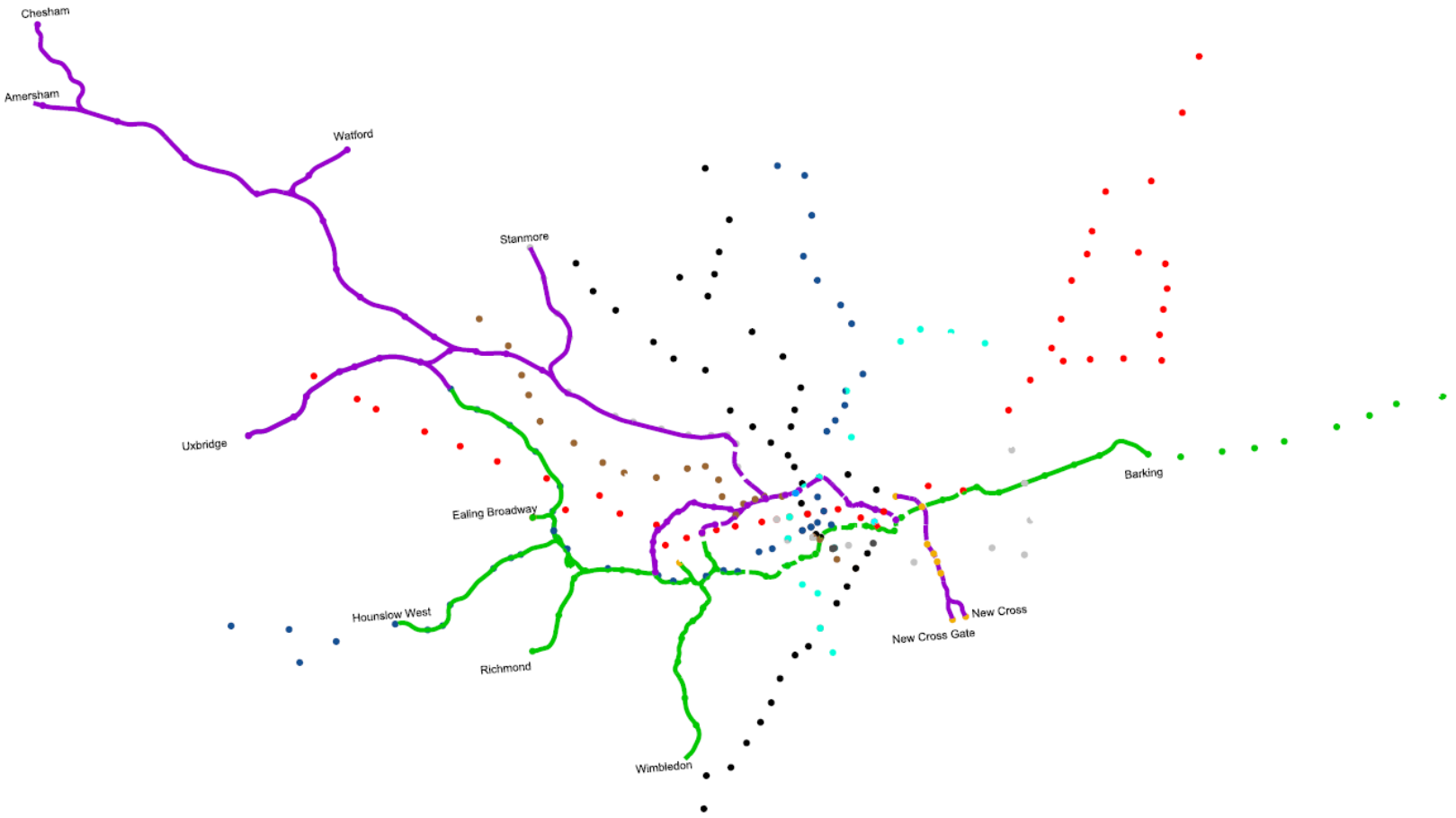
The suburban railways

With only 45% of London Underground's railways actually *under ground*, there is a remaining 55% on, just below or above the surface.



Source: Plan showing the extents of the surface suburban London Underground network.

This 55% was developed to *attract* and *stimulate* passenger traffic and thus extra revenue through suburban development.

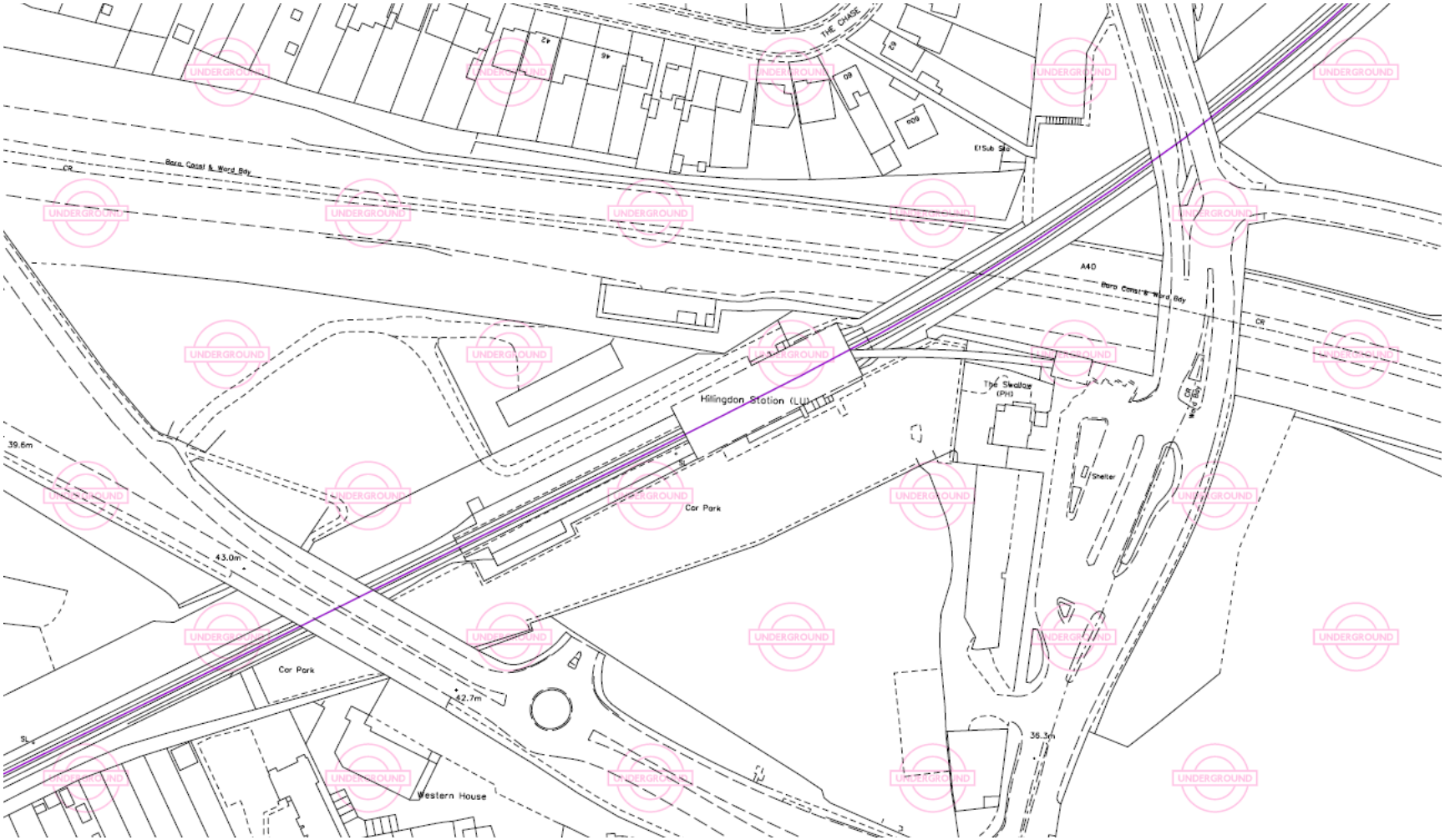


Plan showing the extents of the District and Metropolitan lines, surface railways.

The principle originated with early railways to and from the capital, followed by the sub-surface railways, and the tube railways.

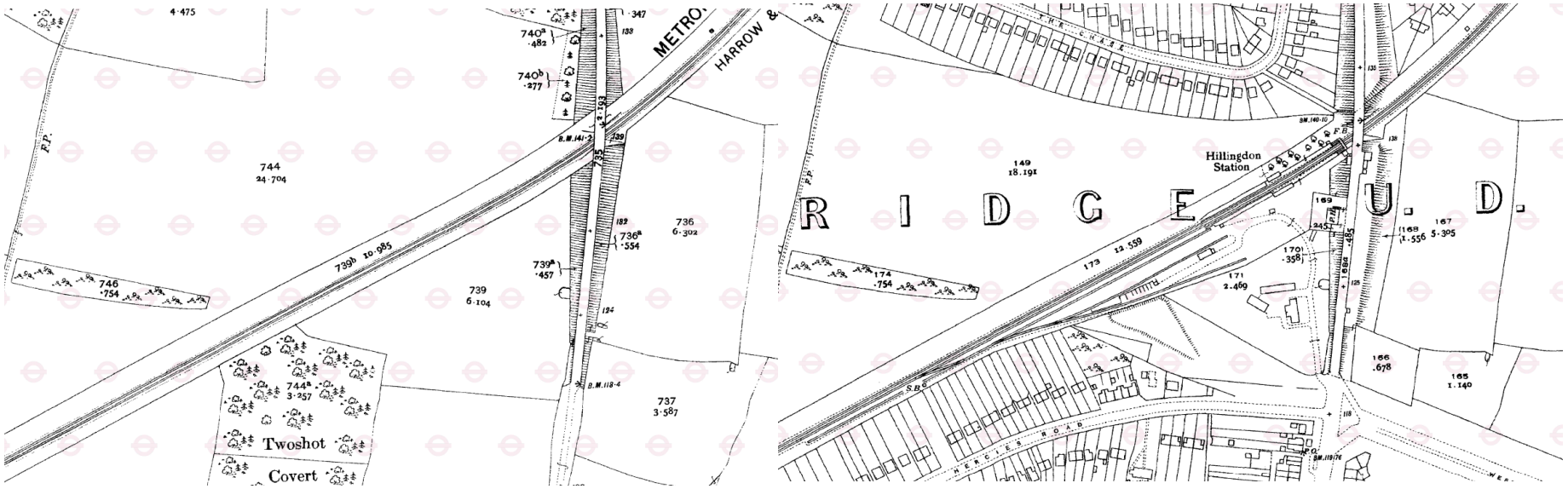
Source: Plan showing the extents of tube railways, suburban extension surface railways..

As with the underground sections, the surface railway has an affect on, and is affected by its environment.



Source: London Underground, 2016. Modern Ordnance Survey mapping, c.2014, showing Hillingdon London Underground station and environs..

Hillingdon station opened in 1923 to serve suburban development. Its opening stimulated further development, 19 years *after* the railway opened.



Source: London Underground, 2016. Historic Ordnance Survey mapping, c.1895 -1912, showing the environs of the Metropolitan line at Hillingdon station, Greater London.
Source: London Underground, 2016. Historic Ordnance Survey mapping, c.1908 - 1925, showing the environs of the Metropolitan line at Hillingdon station, Greater London.

Changes in transport technology (the car) have resulted in the need for improved highway accommodation and relocation of the railway at Hillingdon.

Source: Bing Maps, 2016. *Hillingdon London Underground station and environs*. [online] Available at: <http://www.bing.com/maps/> [accessed 2 February 2016].

The future…

New underground railways are required…

- Crossrail - opening in stages from 2020/2021
  - *Abbey Wood/Shenfield to Reading; "*a high frequency, high capacity service that will make travelling in the capital easier and quicker and will reduce crowding on London's transport network" (Crossrail, 2018).

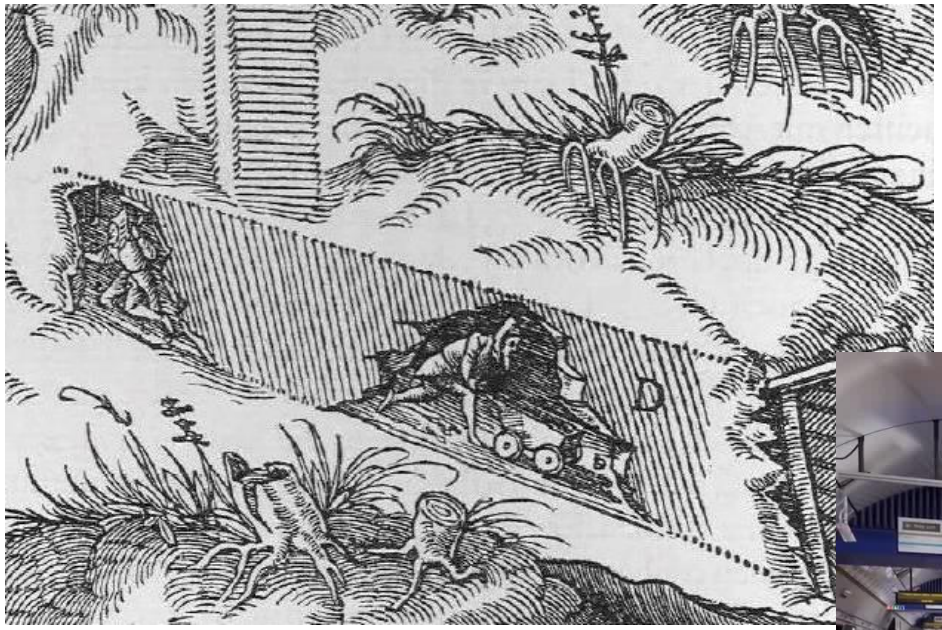
- Northern Line Extension - opening throughout in 2021/2022
  - *Kennington to Battersea; "*supporting 25,000 new jobs; and more than 20,000 new homes" (TfL Undated (b)).

Also in planning are…

- Crossrail 2 - opening date to be confirmed
  - *North East suburbs to South West suburbs, and beyond (Crossrail 2, 2018)*

- Bakerloo line Extension – opening date to be confirmed
  - *Elephant & Caste to Lewisham* (TfL, undated (a))

…all with their origins in a mine in 16th century Germany.



Summary:

- Sixteenth century technological advances led to today's London Underground network
- The technology has been copied, and developed globally
- Metros can and do play an essential part of movement within cities and their growth
- Changes in technology have had an effect on the railways, their design, location and their environment and vice versa
- On one day in 2015, London Underground carried nearly 5 million people
- This will soon be the norm in London, requiring more underground lines to be opened, with connections further afield
- Technological developments have kept London moving and will continue do so in to the future.

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