GEOLOGISTS' ASSOCIATION FESTIVAL OF GEOLOGY 2021: CLIMATE CHANGE

A trail through time on the Green Chain Walk

In 2016 The London Geodiversity Partnership (LGP) teamed up with the Green Chain Walk to create audio snapshots to highlight 12 chosen points of geological interest on the Green Chain Walk. Transport for London has taken over the Green Chain Walk and the *Trails through Time* audio have been transferred to the LGP website. We have chosen stops on the Trail through Time to illustrate various changes in climate in the London area that go back more than 65 million years ago. Thus we are going back into Deep Time with a look at anticipated changes in the future.

Click on the image to listen to the audio and the title to take you to the Climate Change pages.

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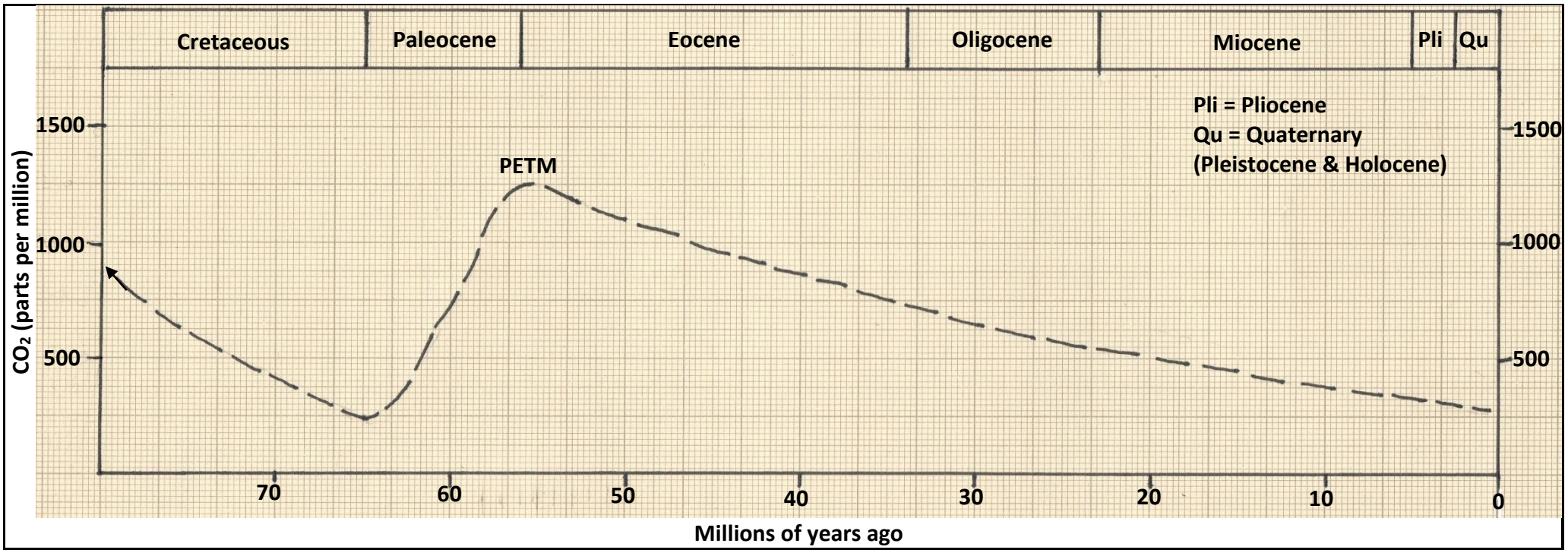
Climate change through the eras: from the Palaeozoic to the future

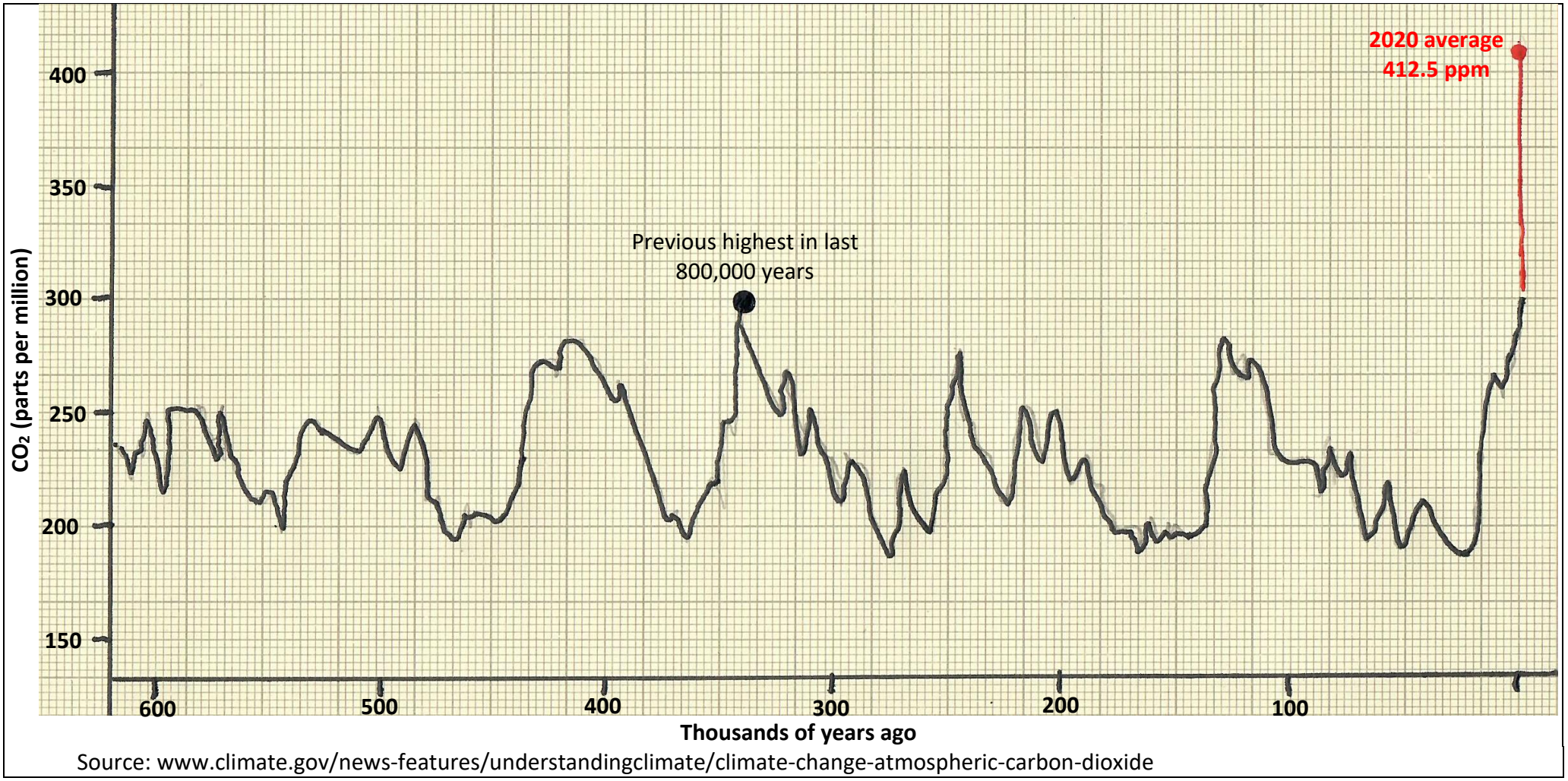
Currently, CO_2 is about 413 ppm (parts per million) read at Mauna Loa, Hawaii. Pre-industrial levels were 280 ppm and the safe level is considered to be 350ppm. CO_2 levels have fluctuated many times throughout the geological past with high points during the Devonian and the Triassic at 2000 ppm. They reached 1200ppm during the 'hot greenhouse' period of the Cretaceous period. At the end of Cretaceous they had fallen to below 300 ppm after which most of the rocks in London were laid down.

During the first part of the Paleogene, CO_2 levels and sea levels rose to the beginning of the Eocene when CO_2 reached over 1000 ppm. This PETM (Paleocene-Eocene Thermal Maximum) is the last time they reached such high levels. Since then there have been fluctuations with the ice ages and inter-glacials.

The first graph below was adapted from the Geological Society (Lear, 2020), who concluded that CO_2 changes drive climate change. It shows the fluctuations from the middle of the Cretaceous up to the present.



The second graph shows in more detail the fluctuations that have occurred for the last 600,000 years to the present day. This is adapted from work by the National Oceanic and Atmospheric Administration in the United States (Lindsey, 2021)



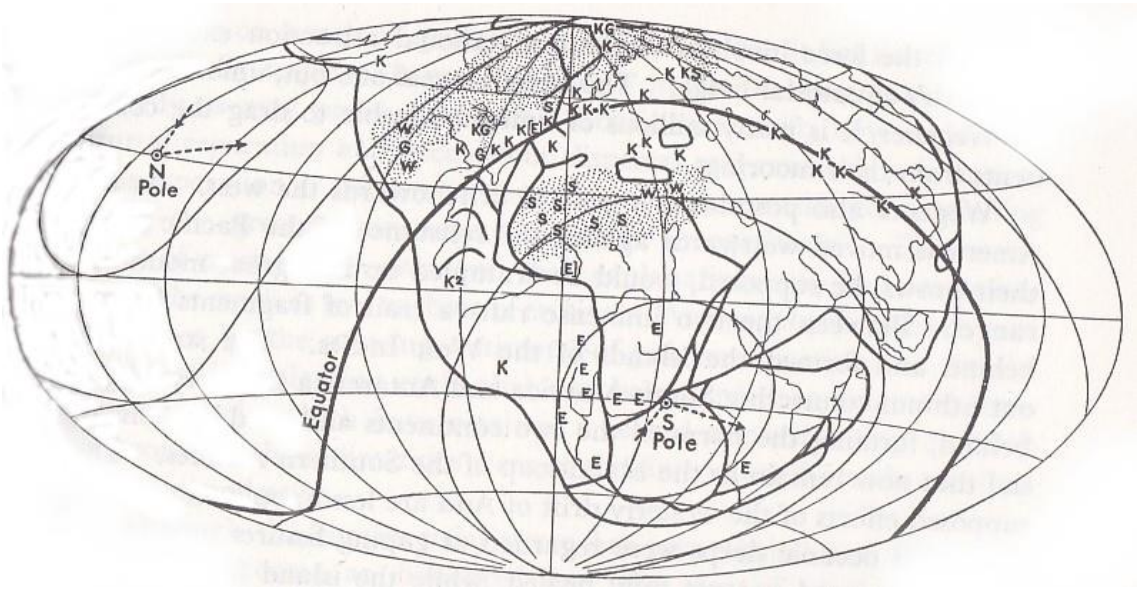
Source: www.climate.gov/news-features/understandingclimate/climate-change-atmospheric-carbon-dioxide

1. Geological Strata and beasties at Crystal Palace Park

Britain at the Equator and Climate change as a cause of extinctions

Audio: Geological Strata

Crystal Palace Park features a montage of Carboniferous strata including faulted coal seams, as detailed in the Green Chain Walk audio. At this time, some 300 million years ago, Britain was situated near the equator with similar conditions of warm, wet climate that exist today in the great equatorial forests of South America, Africa and the Far East. Alfred Wegener, in 1913, proposed his theory of Continental Drift that saw Pangaea break up with the opening up of the Atlantic and the shift northwards of Britain.



Britain near the Equator at the end of the Carboniferous when our coal seams were being laid down. K indicates where Coal occurs.

After A.W. Koppen and A. Wegener 1924 and reproduced in A, Holmes, 1965.

Restored Iguanodon sculptures, lived 139.8–124 million years ago.

Photo: L. Baker, March 2020

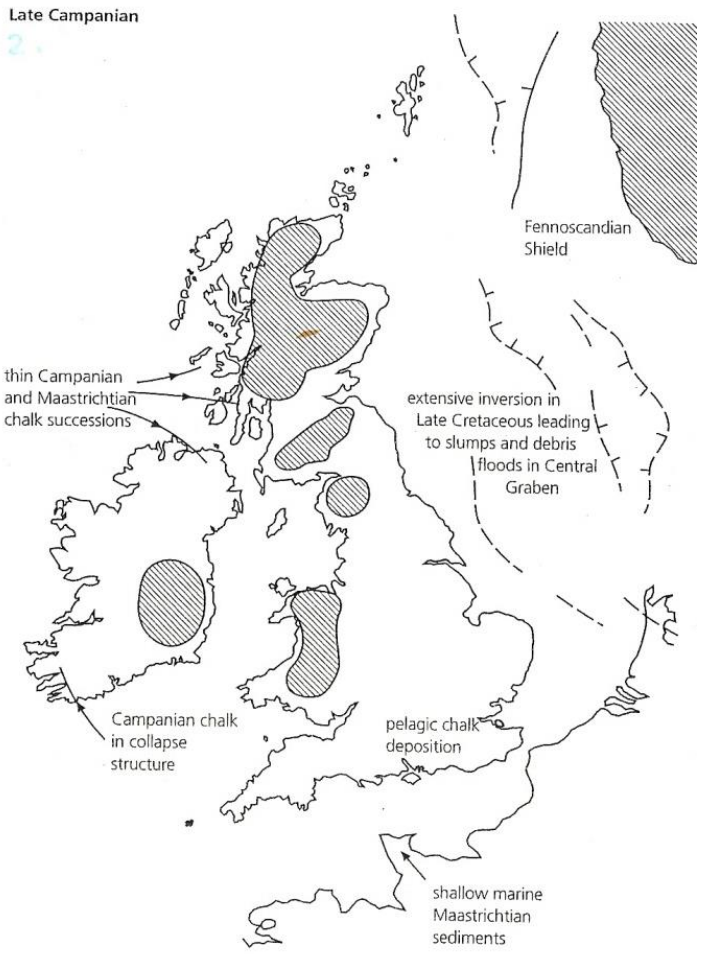
Crystal Palace is more famous for its dinosaurs, but actually it tells a tale of evolution from early mammal-like reptiles on the first of the islands, to the marine reptiles, pterodactyl and dinosaurs of the 'Secondary' Mesozoic Island to the Tertiary and Quaternary Mammals of the 'mainland', after the dinosaurs, and other animals featured on the Secondary Island had become extinct. The evolutionary process was often driven by climate change and in the case of the dinosaurs is thought to relate to an abrupt cooling relating to dust in the atmosphere from volcanic eruptions of the Deccan Trapps (India) and the impact of a large meteorite on the Yucatan peninsula (Mexico).

Further information with more recent pictures can be found on the website of the Friends of Crystal Palace Dinosaurs: www.cpdinosaurs.org.

2. Chalk Caves, Chislehurst

CO_2 levels during the Late Cretaceous

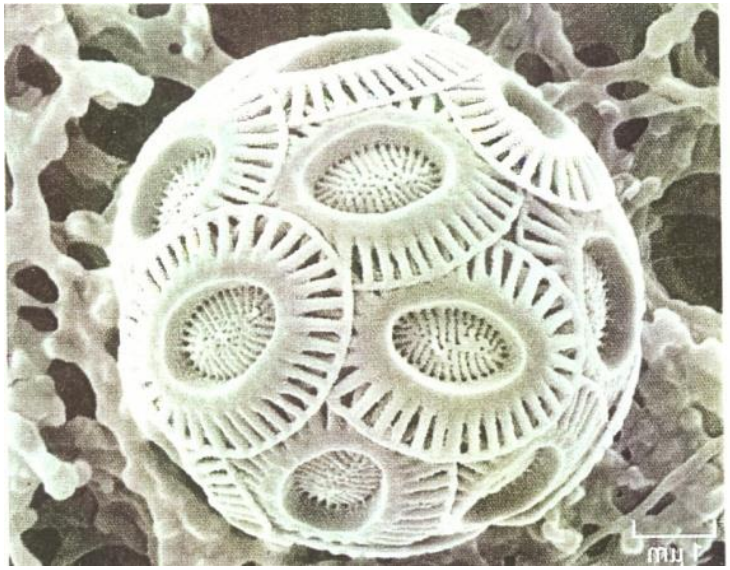
Audio: Chalk Caves

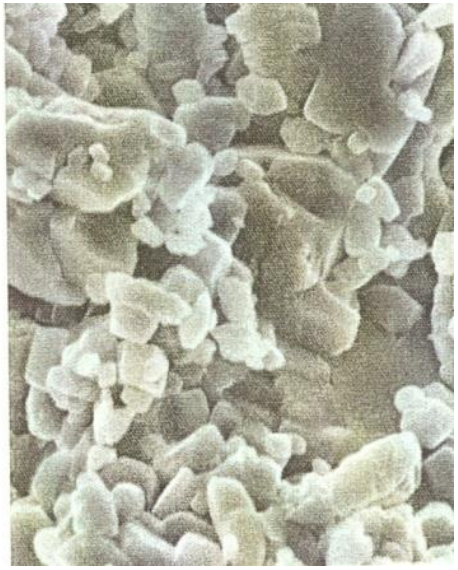


Palaeogeography of Britain towards the end of the Cretaceous showing only very small land masses.
From Woodcock & Strachan, 2000

Chislehurst Caves were mined for their chalk which lies close to the surface in the valley above. During the Cretaceous period when the Chalk was being deposited beneath the sea 85 to 95 million years ago, there was a large amount of sea-floor spreading as the supercontinent of Pangaea continued to break up with the Atlantic continuing to 'unzip' to the north. The volcanic activity resulted in large quantities of CO_2 entering the atmosphere to be about 1000 ppm and the displacement of sea water by the production of vast volumes of oceanic crust, with a consequent rise in sea levels to over 200 metres higher than today. This in turn submerged much low-lying land so that about two-thirds of our present landmass was under water. In Britain it is thought that only the mountains in Wales, the Lake District and Scotland rose above the waves.

Chalk itself is mostly composed of billions of the calcite skeletons of tiny coccoliths (calcareous nannoplankton), raining down to the sea floor from the shallow seas above.

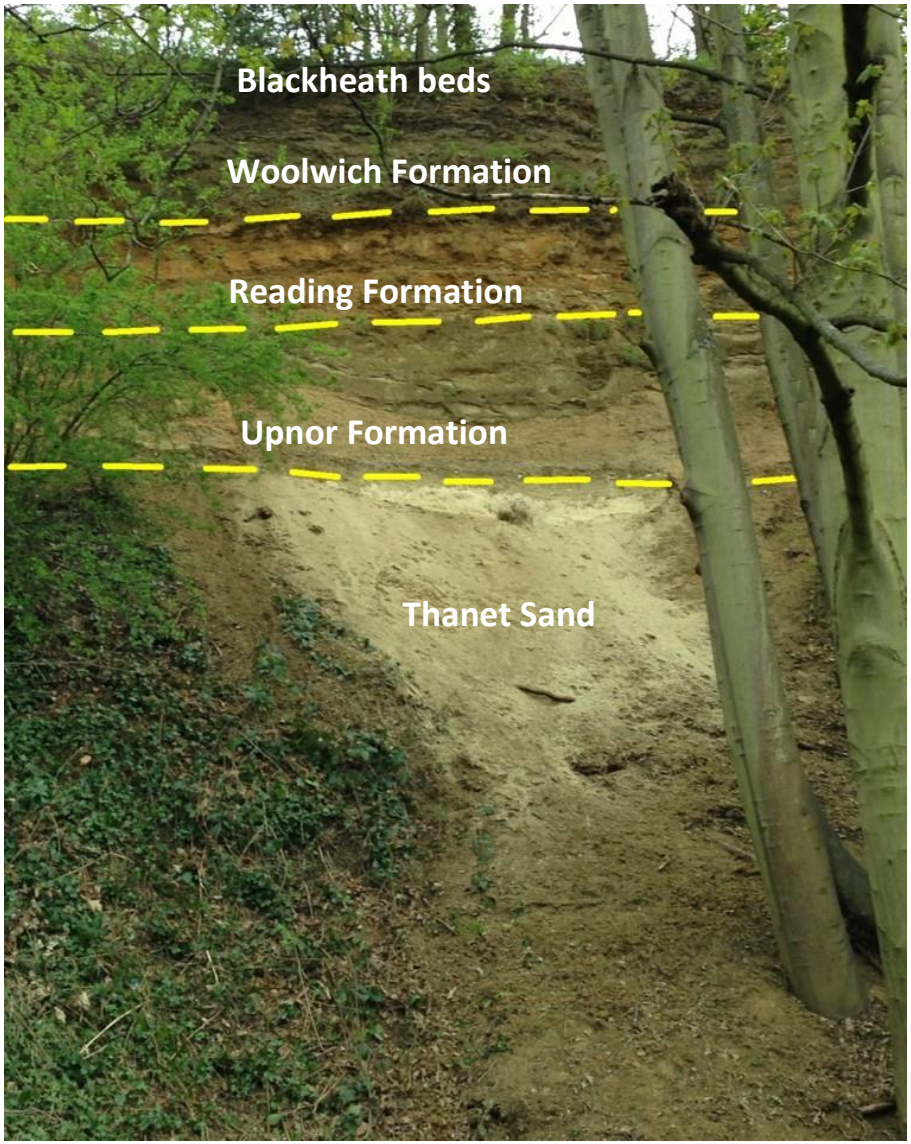




3. Sand Quarry, Gilbert's Pit, Charlton

The boundary between Palaeocene and Eocene was a Thermal Maximum (PETM).
Seen at Gilbert's Pit, it is used as a proxy to understand Climate Change

Audio: A Sand Quarry



South face at Gilbert's Pit showing the different strata and PETM

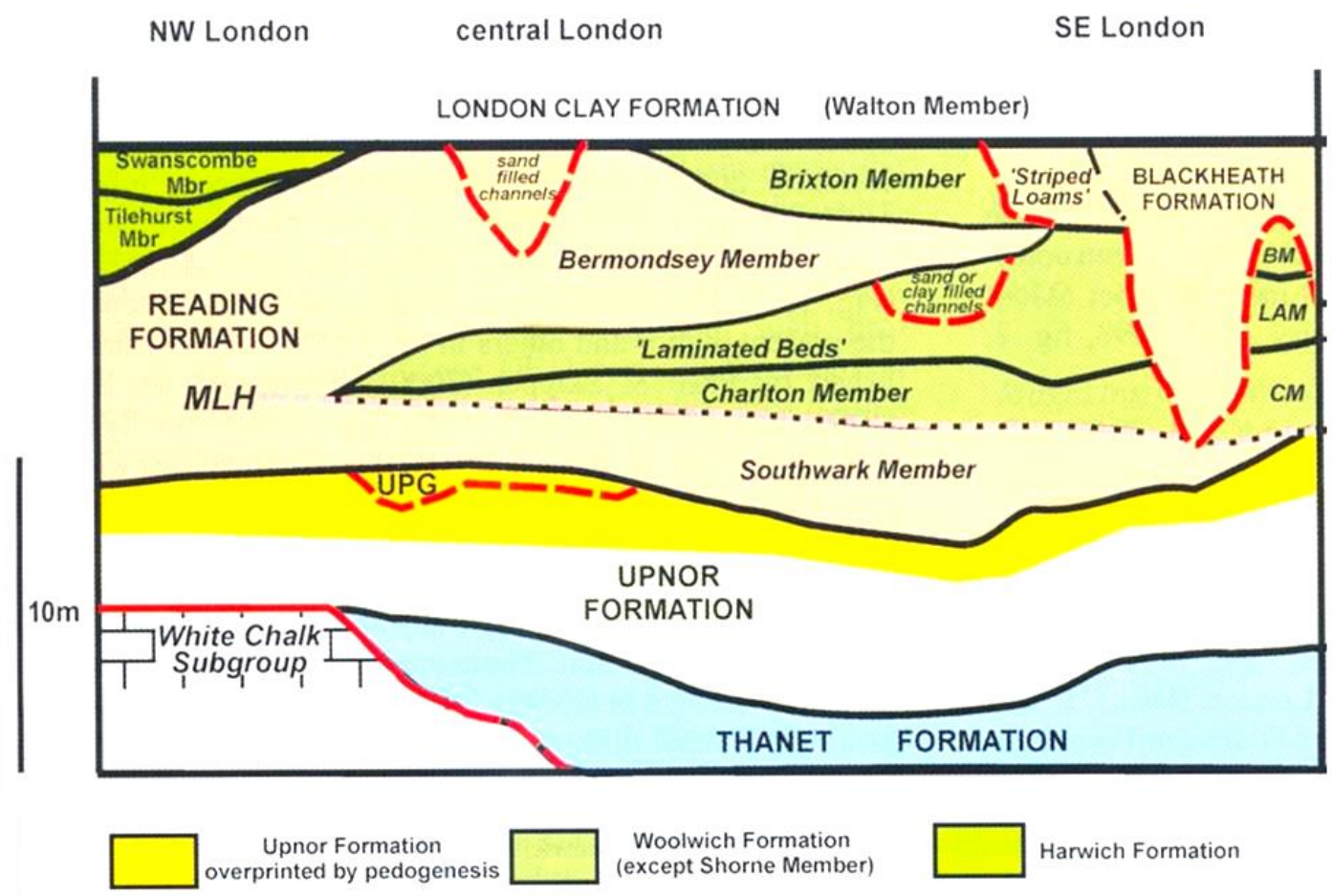
Gilbert's Pit in Charlton was quarried primarily for Thanet Sand but more recently it has been awarded a Site of Special Scientific Interest status (SSSI) for the overlying Lambeth Group, particularly the Woolwich Shell Bed, which was renamed the Charlton Member of the Woolwich Formation by Chris King in 2016.

PETM

The Lambeth Group consists of three separate formations. At the base is the Upnor Formation – a marine sand which can still be seen on the south face of the pit. The Woolwich Formation is above that, with a grey appearance near the top of the south face when seen from below. This was formed in estuarine/lagoonal conditions and the low diversity of fossils is typical of those found in similar environments today. Between these two the Reading Formation has been recognised at Gilbert's Pit and appears as orangey/brown clay on the south face. At the top of the mottled clays of the Reading beds in this pit an abrupt change is noted before the onset of the Woolwich Formation and it has been recognised that the temperature at this point was abnormally high. It is referred to as the Paleocene-Eocene Thermal Maximum, or PETM for short, and occurred about 55.5 million years ago. The relative thicknesses of these three formations vary considerably across London and cause considerable headaches for engineers. It is for this reason that the steps at Gilbert's Pit have been installed so that these critical horizons can be examined in detail, and is particularly useful for engineers who are planning tunnelling through London.

Typical tropical weathering gave rise to the mottled appearance of the Reading clay; the red colour is due to oxidisation with the green mottling formed by reduction by the roots of swamp vegetation. At Charlton the green has weathered to an orangey-brown. During wet periods water enters cracks in the clays which is then evaporated during intensive dry periods. In Hertfordshire, pebbles at the top of the Upnor Formation have been

cemented by silica to form Hertfordshire Pudding Stone (HPS) during this period. Elsewhere sand has been silicified to form sarsen stones. At Gilbert's Pit there are neither but the grey colouration at the base of the Woolwich Formation is very marked.



The Lambeth Group through Central London. MLH (Mid-Lambeth High equates to PETM

After, King, C. 2016. Revised Correlation of Tertiary Rocks. Geological Society Special Report No. 27

Much energy has been expended on the PETM in recent years to find out why the temperature reached such heights and it is being used as a proxy of what might happen now if global temperatures continue to rise. During this period Britain was at latitude 40° N with sea temperatures of about 17°. The temperature was probably increased by considerable volcanic activity arising from the Mid-Atlantic Ridge related to the opening of the Atlantic and a possible major reorganisation of ocean circulation. Ash resulting from volcanoes in the northwest of Scotland is found intermittently in the sediments dating between about 56 - 50 million years ago. There were no icecaps at this time and Britain experienced a sub-tropical environment. Evidence from elsewhere suggests the elevated temperature caused a run-away knock-on effect of releasing trapped methane (CH_4) from beneath the surface of marine sediments that contributed (by oxidation) to the atmospheric CO_2, which further heated the temperature of the oceans in a positive feed-back loop. This is one of the tipping points that scientists are worried about today.

4. Pebble Pit Blackheath, Pebble Conglomerate Dog Rocks Plumstead and Fossil Enclosure Lesnes Abbey Wood

Environment of the Blackheath beds *Audios: Pebble Pit, Pebble Conglomerate and Fossil Enclosure*

The Blackheath Member of the Harwich Formation (or Blackheath Formation of Hooker, 2010) is prominent in southeast London as a plateau running from Blackheath in the west to Erith in the east. The distinctive rounded black pebbles gave Blackheath its name. It can be seen at Eliots Pit, Blackheath and at the top of the Sand Pit at Gilbert's Pit, Charlton. It is also at the Dog Rocks Plumstead where the pebbles have been cemented in exotic shapes and in Beckenham Place Park there are cemented lumps but without the interesting shapes. It is at Lesnes Abbey Wood in the Fossil Enclosure that the Blackheath beds have made a name for themselves. Here a shell bed crops out at the base of the pebbles which very occasionally throws up fragments of bone and teeth of early mammals, dating from near the beginning of the explosion into numerous forms after the extinction of the dinosaurs at the end of the Cretaceous. For this reason the Fossil Enclosure is a Site of Scientific Interest (SSSI).

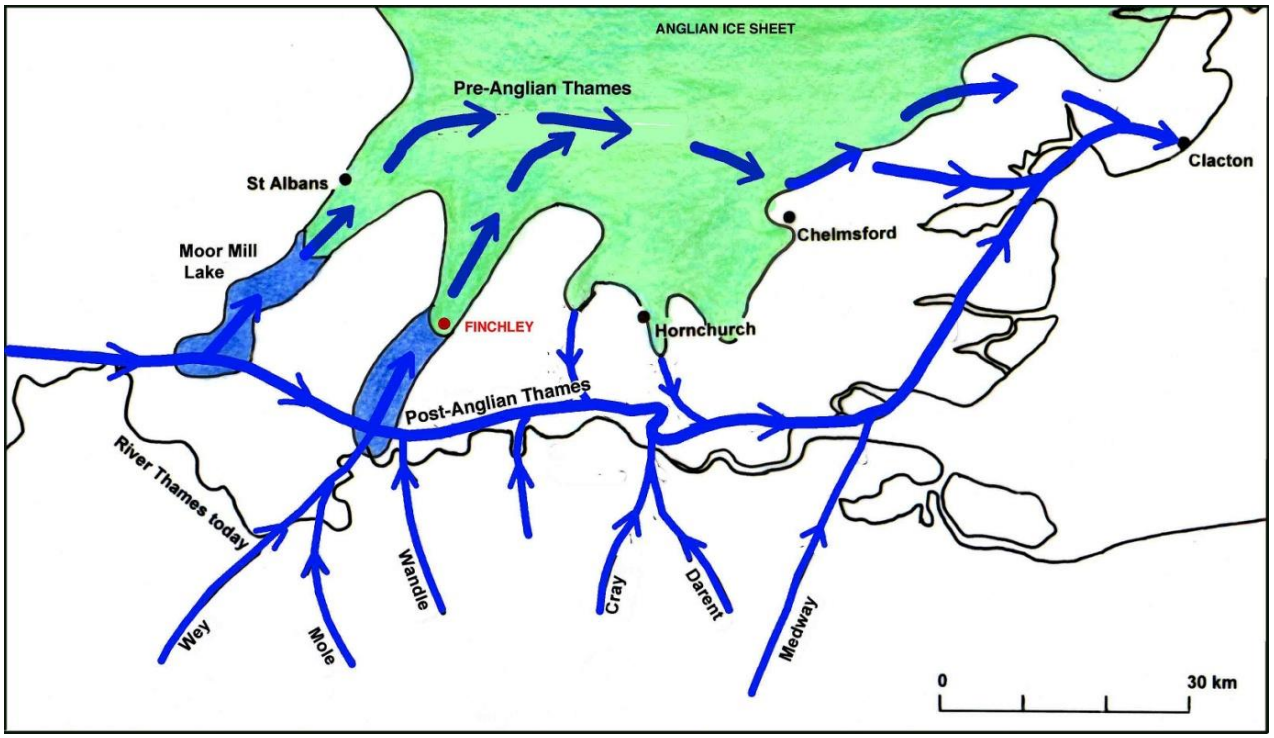
Although the Blackheath beds are only slightly younger than the Lambeth Group discussed at Gilbert's Pit, it is worth looking in more detail at the climate at the time of their deposition, which can be inferred from the fossils found at Abbey Wood as well as those found in the overlying London Clay, particularly where it is best exposed on the foreshore on the Isle of Sheppey, further down the Thames Estuary.

Reconstruction of the environment near Abbey Wood 55 million years ago
From C. Janis Chapter 5 in The Book of Life Ed. S.J. Gould 1993. Random House

Jerry Hooker (Hooker, 2010) has described 46 species of mammal from the Lessness Shell Bed in the enclosure. They include early primates, rodents, horse ancestors as well as more archaic extinct groups such as *Coryphodon,* a sculpture of which is located near the entrance to the pit. The animals were washed into the sea from a nearby river. Some of the associated shells are marine species while others are more brackish as those in the Woolwich Shell Bed, also washed out to sea. Shark teeth are a common and coveted find. But it is the plant material from elsewhere that gives a better indication of the environment of the time. They indicate a sub-tropical environment that can be compared to Malaysia and the Philippines today with *Nipa* palms, mangroves and other tropical flora. However the seeds of magnolia have also been found in the London Clay providing evidence of seasons. Britain was at about the same latitude as Barcelona but the temperature indicated by the Eocene flora imply that it was generally rather hotter than 40° N is today.

5. Pebble Conglomerate, Dog Rocks, Plumstead

The audio includes the nearby gorge of the Slade and how repeated periglacial conditions led to its formation *Audio: Pebble Conglomerate*



How the Anglian Ice Sheet forced the Ancestral River Thames to change its route to flow through the London Basin. *After Bridgland & Gibbard, 1997*

Plumstead Common is a continuation of the Blackheath plateau with rounded black pebbles cemented at the Dog Rocks and visible in uncemented form at the nearby Slade. This is an extraordinary feature: a gash in the plateau at right angles to the gorges or coombs that are directed towards the Thames. Probably it originated as a fault but has since been eroded and enlarged so that now it is about 15 metres deep with a lake at the bottom.

The erosion is the result of the Ice Ages, particularly over the last 450,000 years when the Ice Sheets were at their greatest extent, reaching as far as north London. Evidence of glacial till can still be seen in the railway cutting at Hornchurch and, more easily, in freshly-dug graves in Finchley but the tongues of ice never reached as far as south London. In fact, before the ice London did not exist. The route of the Thames was through the Vale of St. Albans reaching the North Sea at Clacton. The ice sheet prevented flow of the Thames with water piling up as pro-glacial lakes. As the ice melted, about 400,000 years ago, vast quantities of water were released pushing the route of the Thames further south, more or less to the present route through what is now London.

South London would have been a periglacial environment and as the frozen ground thawed, similar large quantities of water would have eroded existing weaknesses in the landscape. Since that time, 5 subsequent ice ages have further shaped the landscape as a result of freeze-thaw processes. The most recent of these events only began to end about 20,000 years ago – not long in geological terms. We should be heading for another ice age but will man-made global warming delay the onset?

6. Rock Sculpture, *Walking the Dog*, Dulwich Picture Gallery

When the ice ages reached London, 450,000 years ago

Audio: Rock Sculpture

Glacial erratics dot a field in Yellowstone National Park: it may be ice-free today, but boulders dropped by ancient glaciers indicate that it wasn't always this way.
NPS Photo /J Scmidt from https://www.nps.gov/articles/glaciersandpastclimates.htm

There is a large time gap between the strata with their associated ancient climates detailed in the points of interest along the Green Chain Walk in 1-4 above and those described in 5-10 below. During this time gap great earth movements saw Africa colliding with Europe, throwing up the Alps further south and causing a gentle 'crumple' in the southeast of England.

The story of London begins only about 400,000 years ago when the climate was very different. The world was just coming out of the most intense of the Ice Ages, the Anglian. At its height 450,000 years ago the ice sheet reached north London at Finchley, Hornchurch and elsewhere but it never came as far south as southeast London.

Ice is an extremely powerful source of erosion. As ice-sheets move over the land they pluck rock fragments and transport them within the body of the ice. As they bump along, many become rounded. Some of them can be huge and many of them are as large as the ones used by Peter Randall-Page in his *Walking the Dog* sculpture. We don't find such glacial erratics in southeast London and the boulders chosen come from Finland.

During the Anglian Ice Age, and indeed subsequent ice ages, the water in the North Sea was completely incorporated into the ice sheets and it would have been possible to walk over the area to Europe and Scandinavia. In the fields of Essex boulders of Larvikite, transported from as far away as southern Norway have been picked up. As it is not permitted to take eroded boulders out of the landscape, the boulders selected for these sculptures were collected from aggregate quarries in the Satakunta Region of Southwest Finland.

7. Submerged Forest, Erith

What will happen as sea level rises?

Audio: Submerged Forest

The submerged forest at Erith in 2007. *Photo: J. Sidell*

On both sides of the Thames there are places where it is possible to see the roots of ancient forests. They provide evidence of rising sea levels in the past. The most extensive exposure at low tide is at Erith and is featured in the *Trails through Time.* Here whole trunks can be found along with nuts and seeds which indicate that there are distinct dates of peat accumulation from nearly 6,000 to about 3,000 years ago, with sea levels perhaps as much as 3m lower; the oldest featuring dry land species such as yew and the younger levels wetland species, predominantly alder, with less common willow and poplar, amongst others.

Now London has lost its wide flood plain and the Thames has been channelled into a deeper, faster flowing river. In Central London high embankments were first constructed in the 1860s by Joseph Bazalgette at the same time as creating the Victorian sewers. Since then, the Embankment walls have been heightened on several occasions to stop flooding. Eventually, with rising sea-levels the Embankments will be topped again and the archaeologists of the future will find the remains of buildings rather than forest beneath the waves.

8. Hand-made bricks, Wickham Valley

Brickmaking and the Industrial Revolution

Audio: Hand-made bricks

The audio snapshot on Hand-made bricks discusses the low-technology processes used on site for making bricks, whether from the Quaternary Brickearth found in the Wickham Valley or the clays of the Reading Beds from the Lambeth Group. Apart from Shooters Hill, the 55-50-million-year-old London Clay has been eroded and although the sandy Claygate beds at the top are used extensively in North London, they are not a candidate for bricks in southeast London.

The low-temperature method described in the audio was not as damaging to the environment as the more sophisticated, higher temperature method used in kilns where large quantities of CO_2 were emitted from tall stacks as the picture below of the Wickham Valley brickworks shows. It was the Industrial Revolution that propelled emissions into the current problems we are experiencing today.

Wickham Valley Brickworks. The area is now completely built over.

9. Gravestones, Nunhead Cemetery

The effects of weathering on gravestones

Audio: Gravestones

Nunhead Cemetery was selected for the *Trails through Time* as an urban site where it is possible to study rocks, including weathering. Before London became a smokeless zone the effect of CO_2 and SO_2 on our buildings and monuments was immense. This is particularly noticeable on limestone tombstones, such as those carved out of Portland Stone, where the writing becomes increasingly illegible with time.

Tombstone of the Petley family: a monument to weathering. The lead lettering for Joseph Petley, d.1878 stands so proud of the stone that some of the letters have fallen out. By feeling down the tombstone it is clear that the lettering becomes continuously less proud so that the last name, Mary Petley who died in 1960 lies flush with the limestone.

Photo D. Clements 2016

Tombstones at Nunhead Cemetery with many rock types to compare weathering.

Photo L. Baker 2016

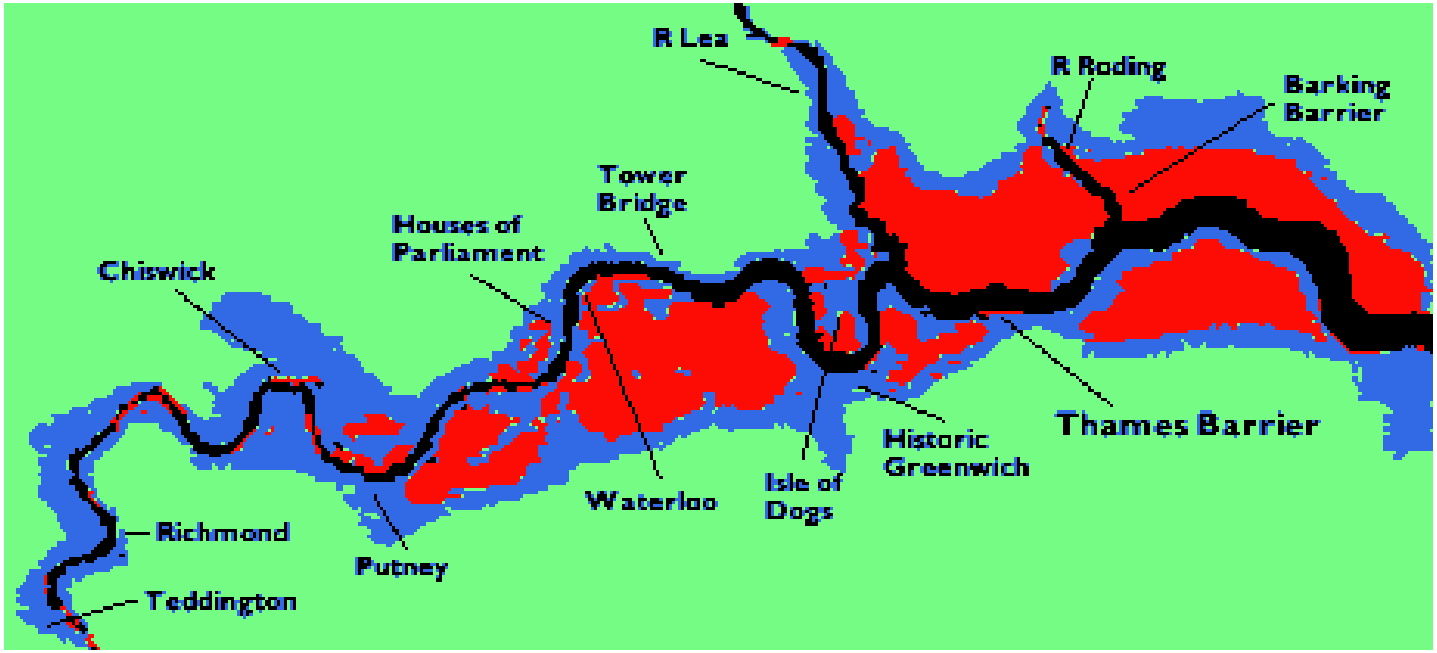
10. Thames Barrier – beginning of Green Chain Walk but not included in Trails through Time

Protecting London from flooding – but for how long?

The biggest flood event in living memory is the 1953 Storm Surge. Canvey Island in the Thames Estuary was severely affected but effectively saved London from very serious damage. The flooding problem has become more acute as sea level has risen in the estuary. This results from polar ice melting and thermal expansion of the sea as average sea temperatures increase. The estuary is also sinking as the Earth readjusts to the melting of the Ice Age. Combined, these effects mean that sea level is rising up to 4mm per year. Clearly something more drastic than raising the Embankments once again will have to be done.

The result was the eventually construction of the Thames Barrier in the 1980s. It became operational in October 1982 and first used in February 1983. The barrier closes when a flood incident is likely, isolating the upstream low-lying land from the high sea level in the estuary. A recent review has confirmed the barrier will be capable of providing protection against rising sea levels until at least 2070. Since 1982 it opened it has closed 199 times (June 2021) and currently it is operated up to 15 times per year, which is expected to increase to 30 times per year by 2030. But what will happen after 2070? Or if the Barrier is breached before then? The flooding that could be caused by a 1953-type flood would directly affect 1.5 million people currently living in the flood-plain of the Thames and its tributaries.

For more information on the Thames Barrier look at: www.gov.uk/guidance/the-thames-barrier



Further Reading

London Geodivesity Partnership Green Chain Geotrail: www.londongeopartnership.org.uk/geotrails
Guide 68 *The Geology of London.* Geologists' Association: www.geologistsassociation.org.uk/guidesales
Digital copies of individual itineraries: Itinerary 6 *Charlton, Plumstead and Abbey Wood*; Itinerary 8 *The 'Geological Illustrations' of Crystal Palace Park*: www.geologistsassociation.org.uk/digital-downloads

British Geological Survey

Map viewer, with access to borehole and other information: https://mapapps.bgs.ac.uk/geologyofbritain/home.html
Map 1:50,000 maps. Available on line:

270 South London https://largeimages.bgs.ac.uk/iip/mapsportal.html?id=1001765
271 Dartford https://largeimages.bgs.ac.uk/iip/mapsportal.html?id=1001766

Geology of London - London Memoir with details of the geology covering both these maps:
Ellison, R.A., Woods, M.A., Allen, D.J., Forster, A., Pharoah, T.C. & King, C. 2004. *Geology of London. Memoir for sheets 256 (N London), 257 (Romford), 270 (S London), 271 (Dartford)*. British Geological Survey, Keyworth, Nottingham.

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