British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

History of Rockhead anomalies in the London Basin

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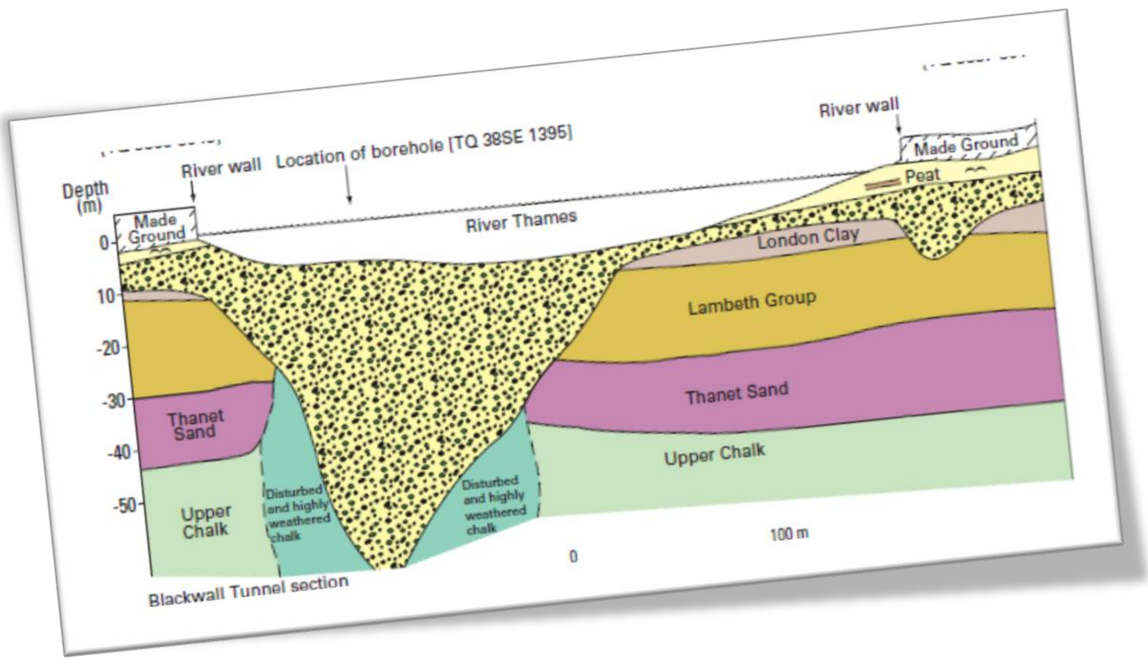
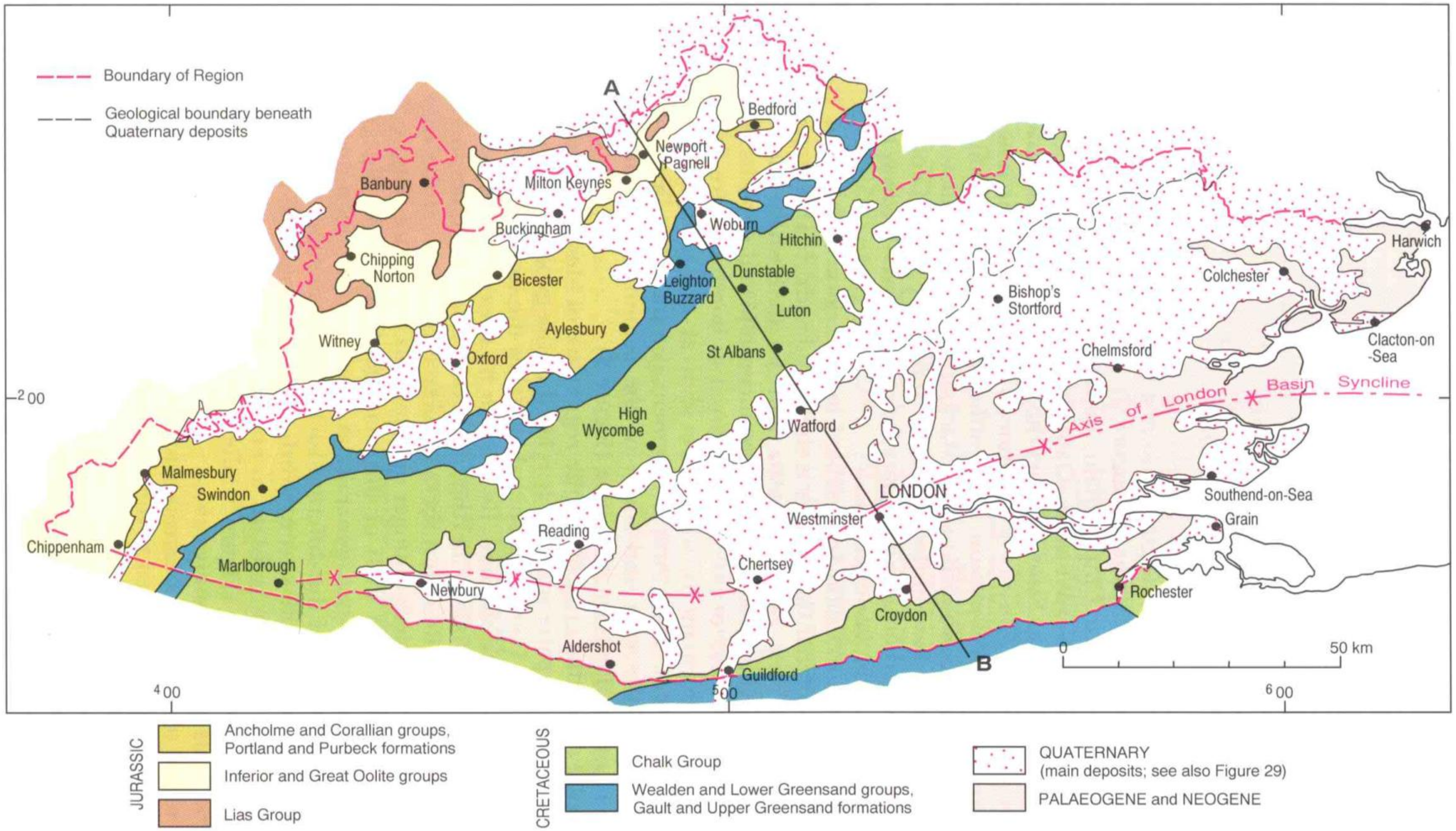
Content

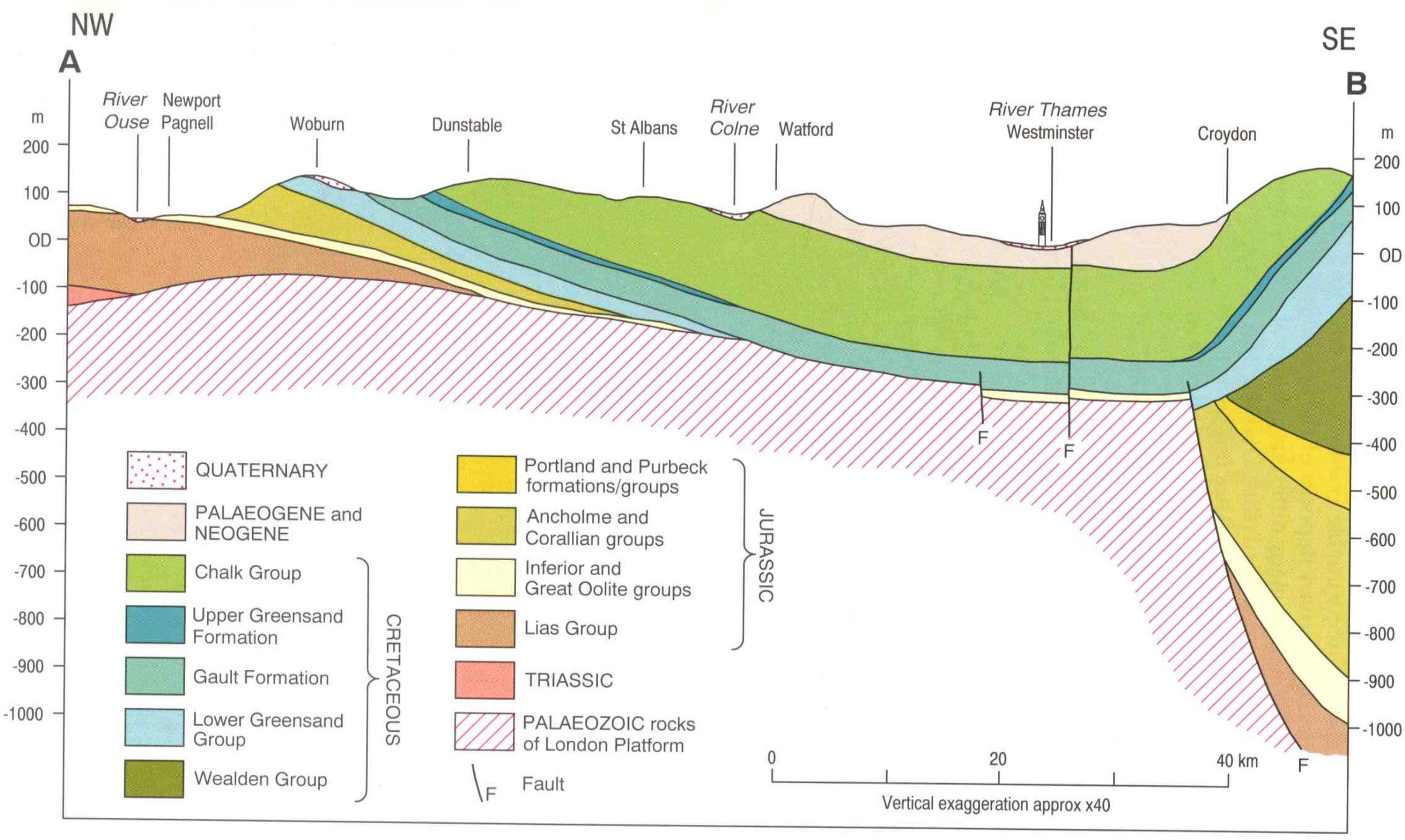
- Overview of rock head anomalies in the London Basin
    - What they look like
    - Where they are
    - Current theories on how they were formed



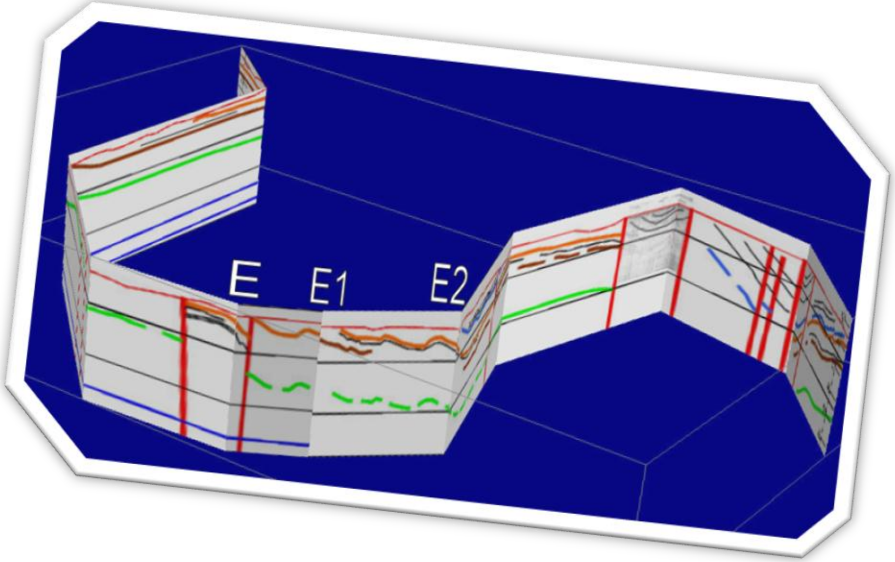
London Basin : Regional Setting



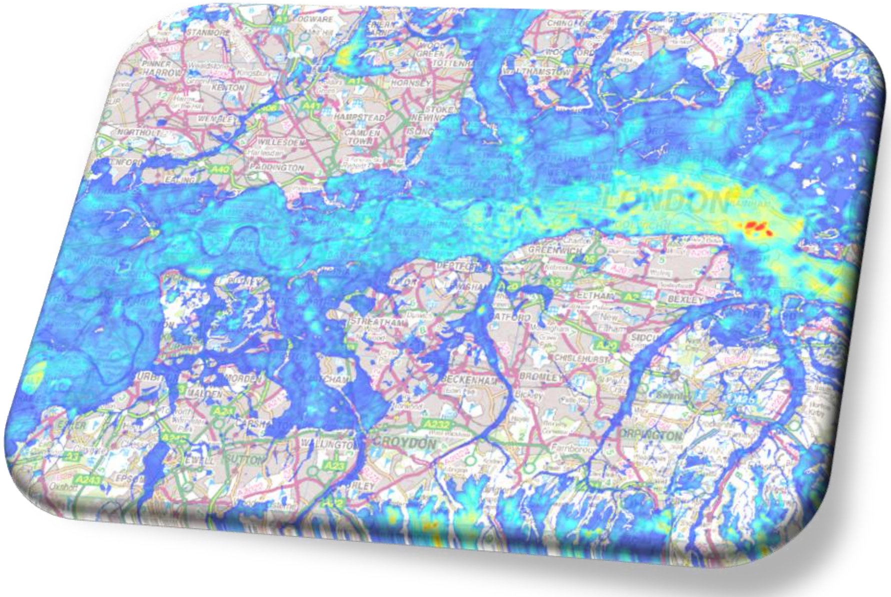
London Basin : Regional Cross Section



How well do we understand the geology in London?



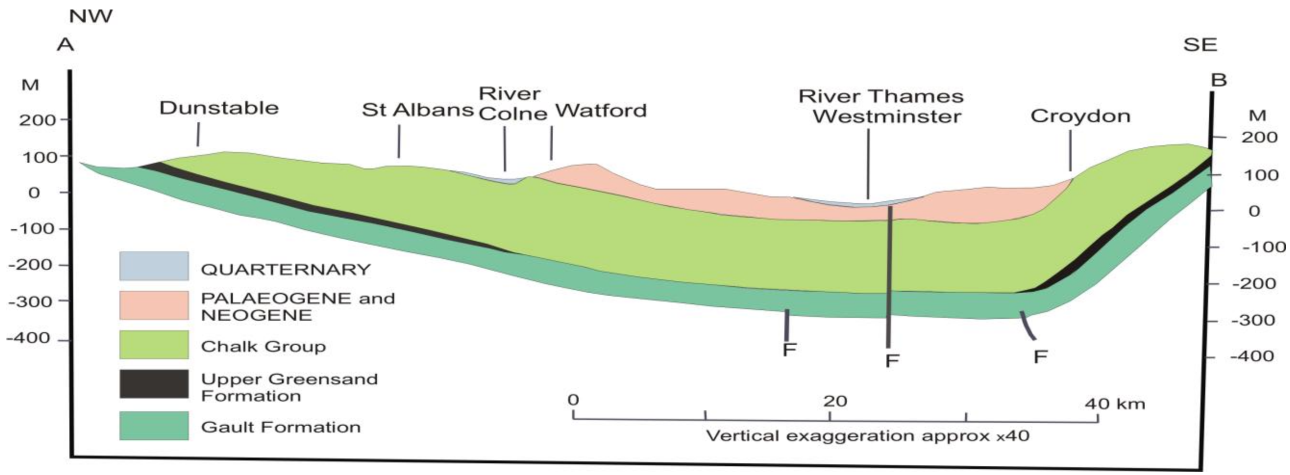
Recent engineering projects (CTRL, CrossRail, Tideway, and DLR) suggest that the structure under London does **not fit the simple layer cake model**



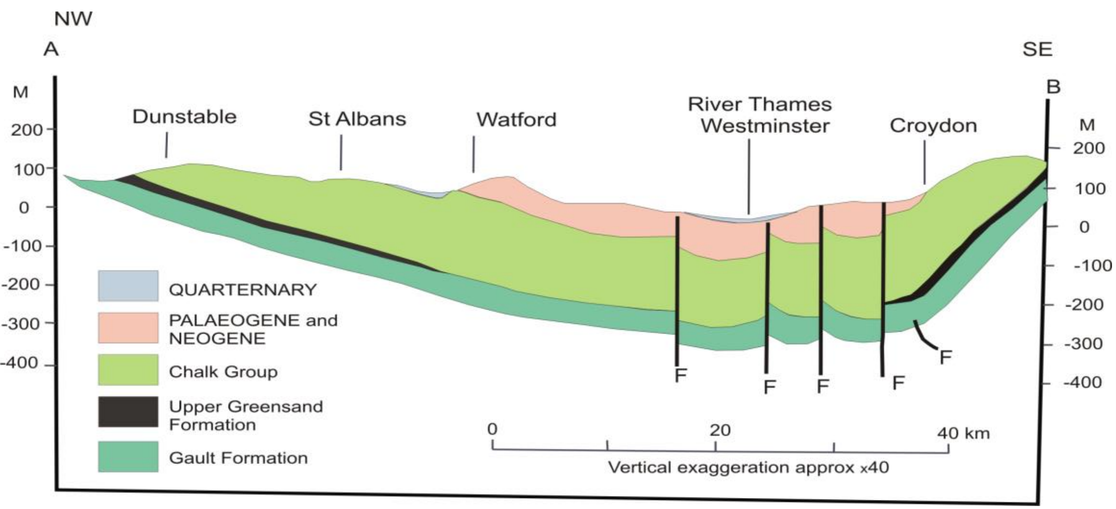
BGS has over 80,000 borehole records for Central London

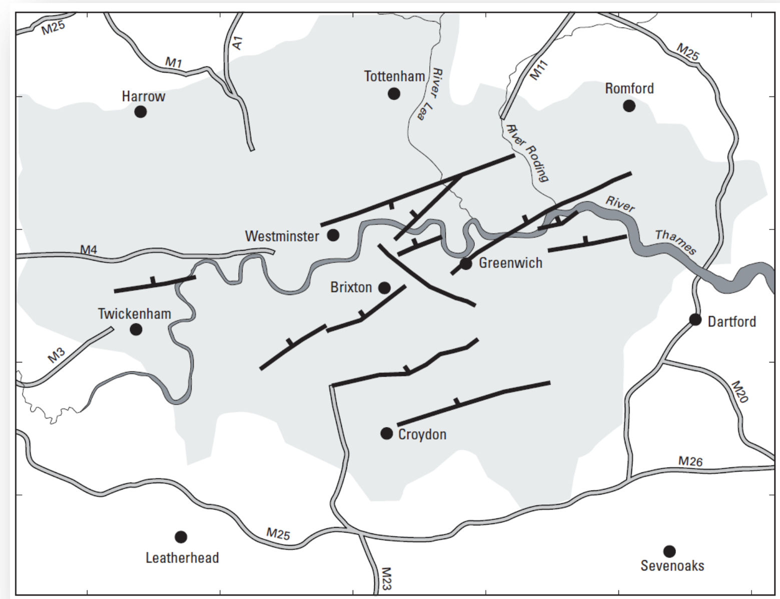
The **solid geology** is largely **unexposed** and covered by either the **built environment** or **superficial deposits**

Are there faults in London ?



This is what the geological maps would suggest

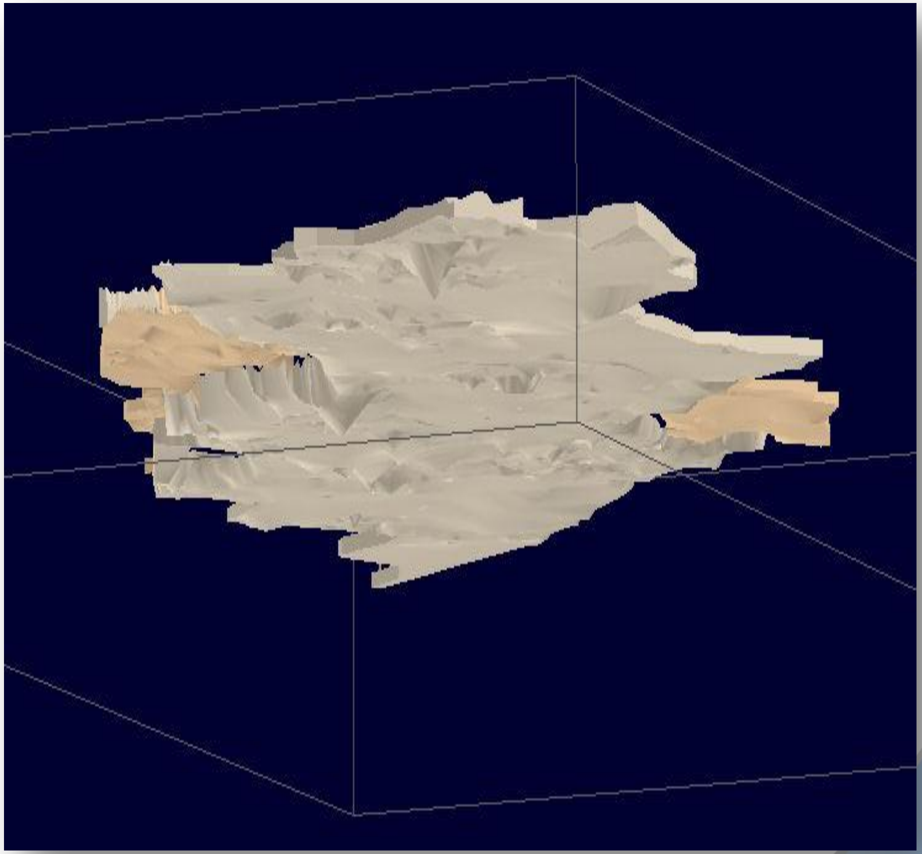




This is closer to reality

Descriptions from the Literature

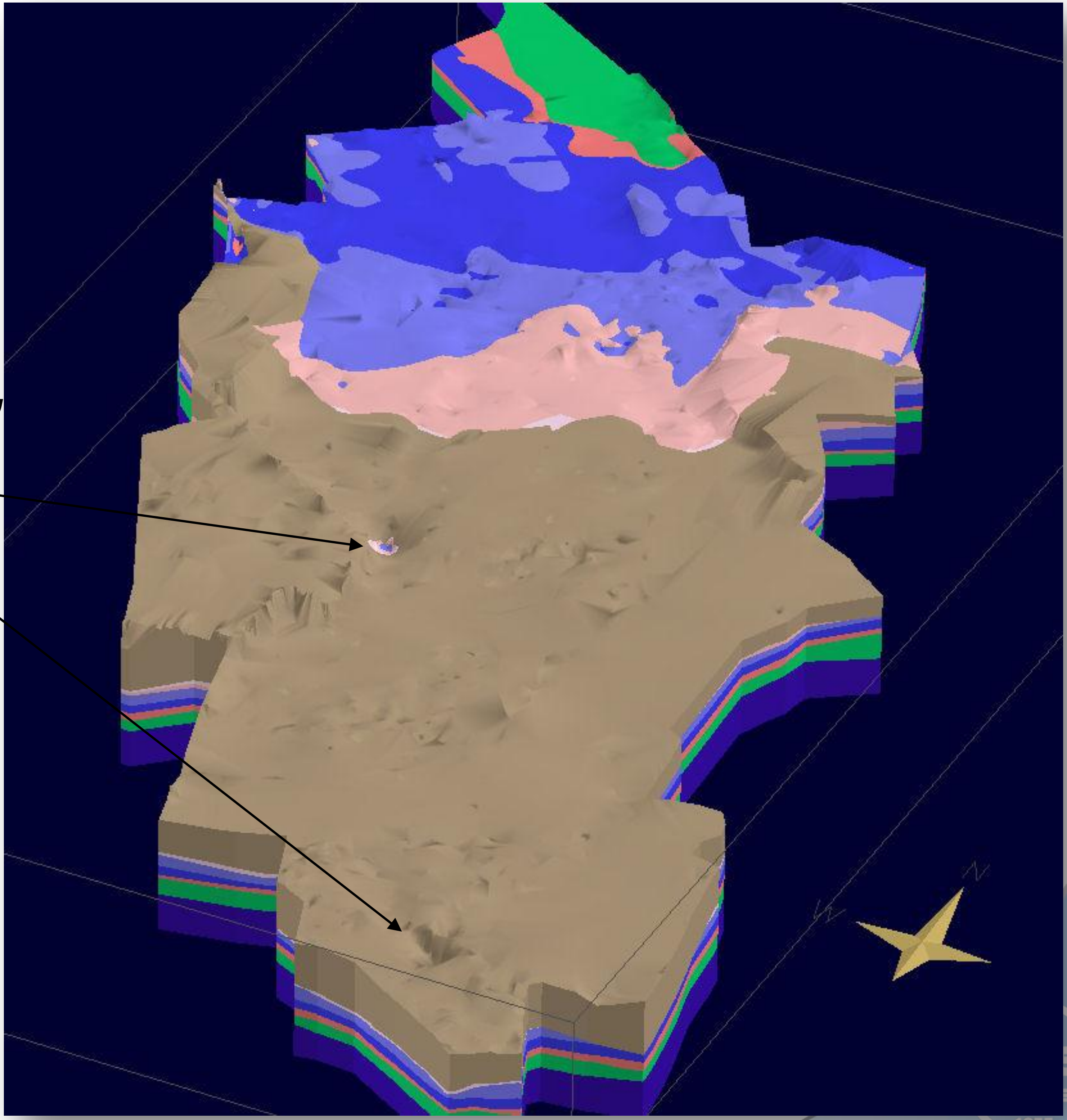
- Irregularities in the rock head surface
- In London they have been encountered beneath the Kempton Park Gravel (between Battersea and Greenwich, Berry, 1979)
- Eroded into the London Clay, Lambeth Group and the Chalk



Lower Lea Valley:

basal 'scours'

could we predict their occurrence?



Descriptions from the literature

- 5-15 m deep, locally up to 33 m (Battersea), 60 m (Blackwall) and 90 to 475 m wide (Berry, 1979)
- Steep-sided, with slopes < 20 degrees.
- Sediment fill, comprising of flint gravel and a ‘bedrock melange’ . The bedrock strata are commonly elevated above the elevation of the surrounding bedrock boundary.
- Associated bulging of the underlying strata has been observed in some
- Chalk blocks have been encountered up to 15 m above chalk rockhead (Blackwall).
- Not only the overlying, but also the immediate underlying, strata may be disrupted

Characteristics of some documented hollows

National Grid Reference	Strata affected/ Characteristics of the disturbance	Level (m OD) of base of hollow/ disturbance and basal strata.	Plan dimensions and orientation of long axis	Classification	Reference
28880 77761	River Terrace Deposits extending down into the London Clay.	-14.9; London Clay		Scour hollow	(Berry, 1979)
29761 77642	Drift deposits comprise gravel with subordinate sand, clay and clay bound pebbles. Boundary between London Clay and Lambeth Group elevated by 6.1 m	-29.6 m or deeper; Lambeth Group. In a second hole -27.7 or -31.7.		Scour hollow .	Mieux Brewery of (Berry, 1979)
30214 80285	Well stratified basal gravel overlain by soft fine-grained alluvium capped by black mud, black clay or dark-coloured clay.	-12 m; London Clay	Minimum 46 m. Limits not fully known	Scour hollow	Whitehall Place, Board of Agriculture Building of Berry (1979).
30547 80119	Gravel with interbedded sands.	-27.1; London Clay.	160 x 130 NE-SW.	Scour hollow	Bakerloo Line, Hungerford Bridge of Berry (1979).
34715 76541	Slumped fill	Below -11 m; Thanet Sand Formation.	Influenced by faulting (Berry, 1979)	Scour hollow	Peckham hollow
041 779	Lambeth Group uplifted by approximately 12 m.			Scour hollow	Three Valleys Water Tunnel, Thorney (Simpson et al., 1989).

Anomalous geological succession in the Lea Valley

- Made ground – down to 6.6 m *below* ground level at about – 3.6 m OD

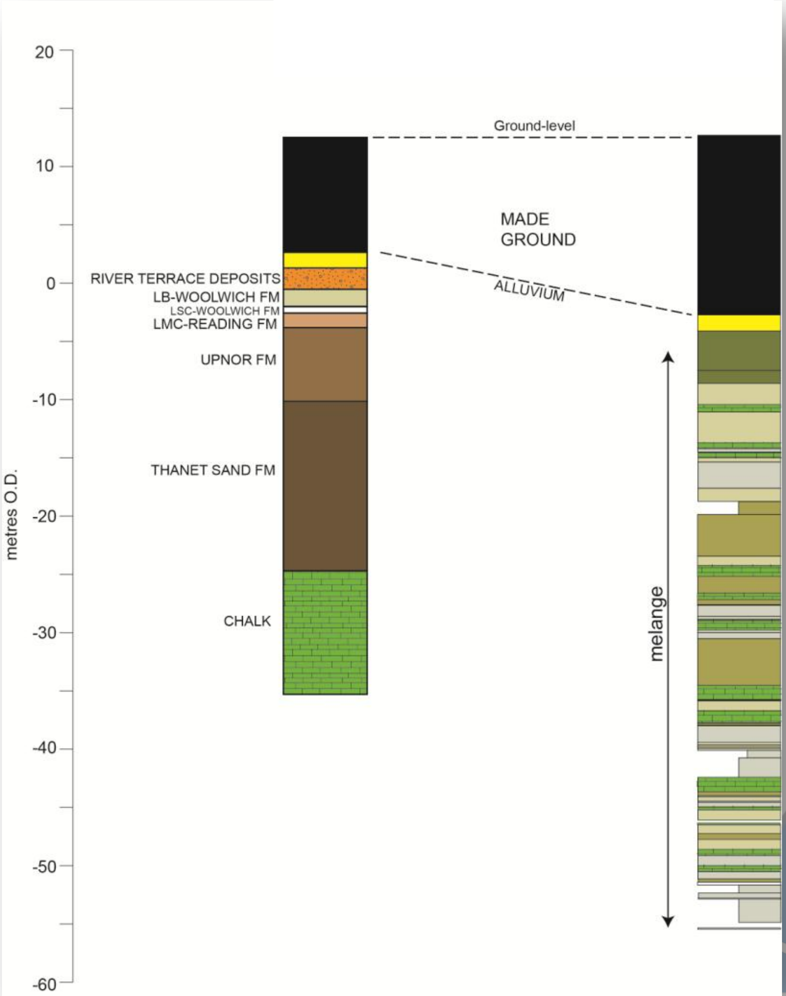
- Anomalous alluvium – CLAY, sandy, and SAND, silty, clayey; 5 crude fining-upwards sequences;

  CHALK fragments in places 4.2 m thick

  no cryoturbation

- Mélange – SAND and SILT, some clayey, mixed with CHALK and FLINT fragments traces of flint gravel

- local derivation
- proportions vary at random
- upwards and downwards movement
- Base not touched at about 59 m below GL



LEE, J R AND ALDISS, D T. 2011

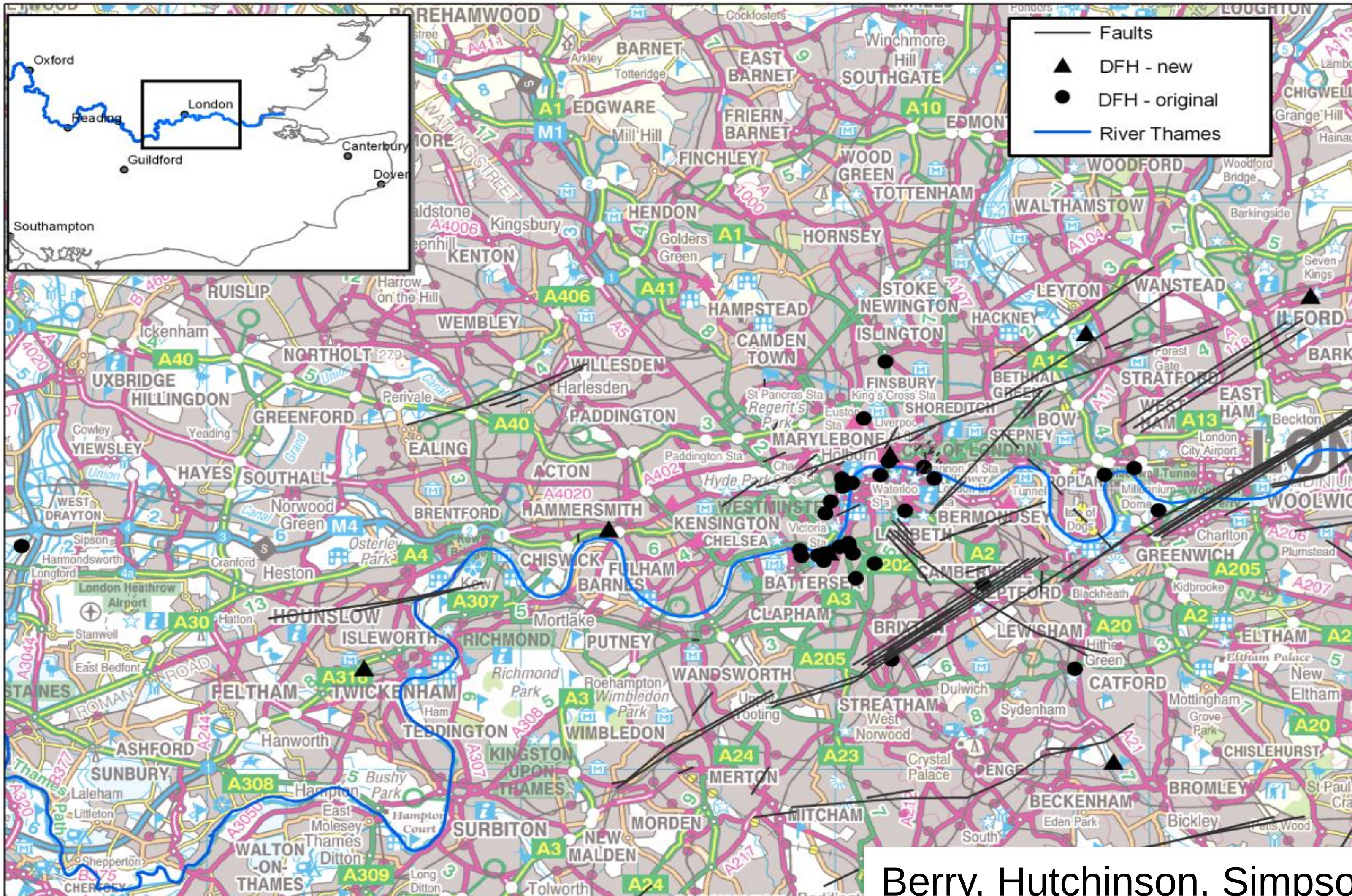
22 m – mélange; silty fine sand with chalk and flint

30.9 m – mélange; silty fine sand with chalk and flint

33.6 m - mélange: fractured chalk

43.3 m mélange: cluster of flint pebbles

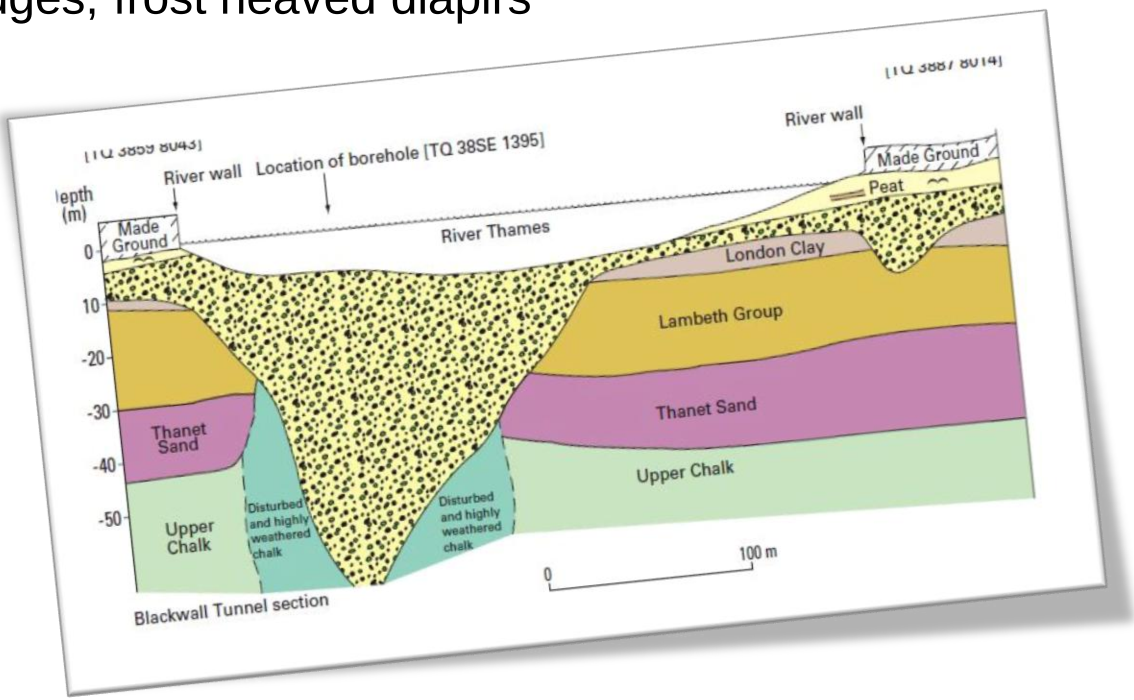
Location of anomalies in London



Berry, Hutchinson, Simpson and from the boreholes database

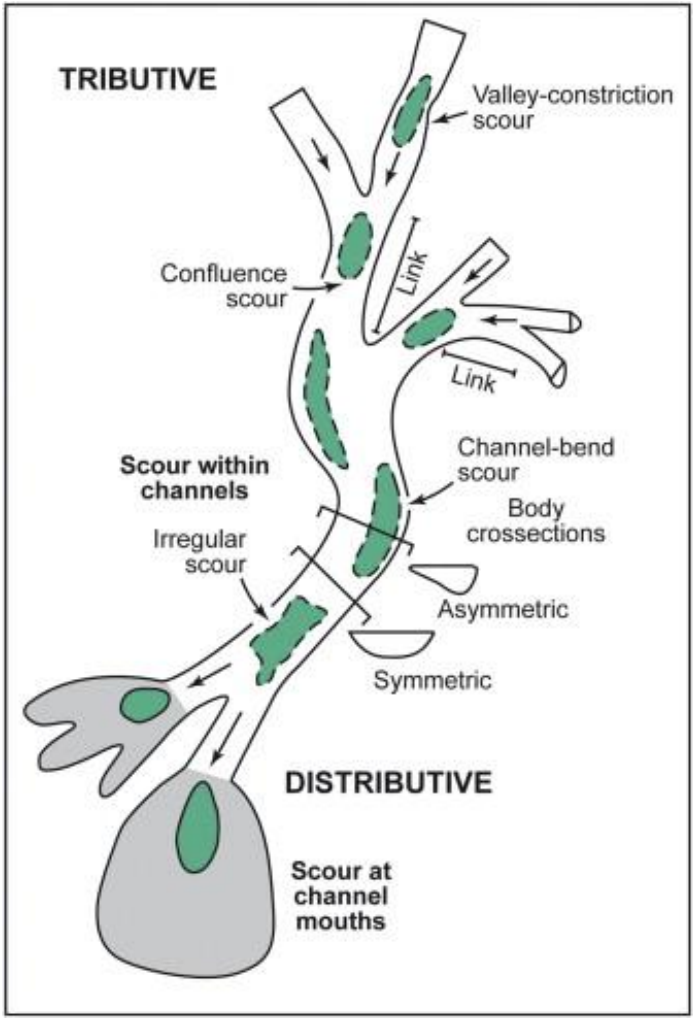
what are they ?

1. The process understanding (how these things were formed) is unclear
2. Historically (Berry, 1979) referred to these as ‘Scours’
3. Recently (Hutchinson 1980 and 1991) ‘Pingos’
4. Alternative explanations: Chalk Dissolution; thermokast features, ice wedges, frost heaved diapirs



Scours

- Form as a consequence of fluvial or glacio-fluvial processes
- Can occur in a number of settings :
  - Confluence of river channels
  - Flooding
  - Meanders
- Scour depth is between 3 to 5 times the depth of the confluent channel
- Scour depth increases at higher discharge angles



Scour occurrence in natural systems
Feldman et al 1995

Pingos

- A mound of earth-covered ice
- Found in regions of continuous Permafrost (Canada, Alaska and Siberia)
- Can reach up to 70 m in height and 600 m in diameter.
- Their core is made of solid ice
- As the water seeps into the spaces in the ground it freezes and creates ‘lenses’ of ice which gradually grow in size as more and more water seeps in
- As they grow larger the ground above them is pushed upwards into huge domes
- When the ice melts the dome collapses into a volcano shape hill

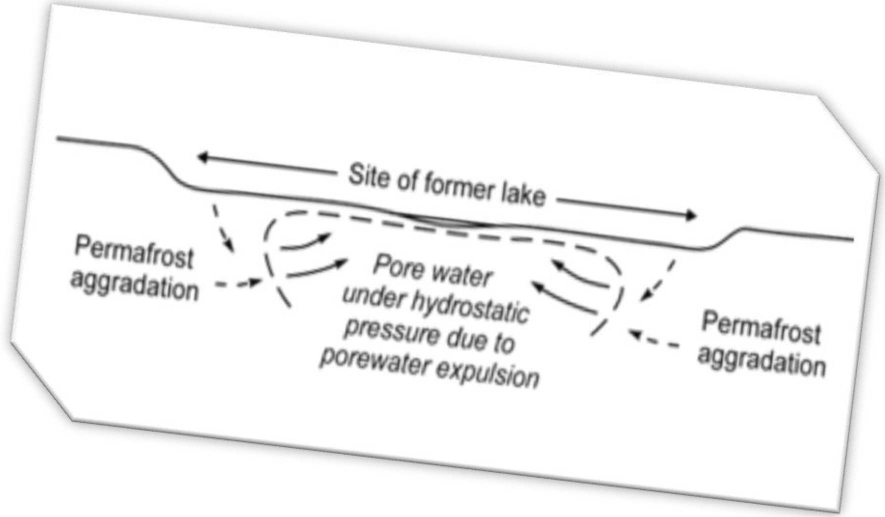
Hebert PDN, ed. *Canada's Polar Environments* [Internet]. CyberNatural Software, University of Guelph. Revised 2002. <www.polarenvironments.ca>

Pingo Classification

Based on how water is supplied to the growing ice core

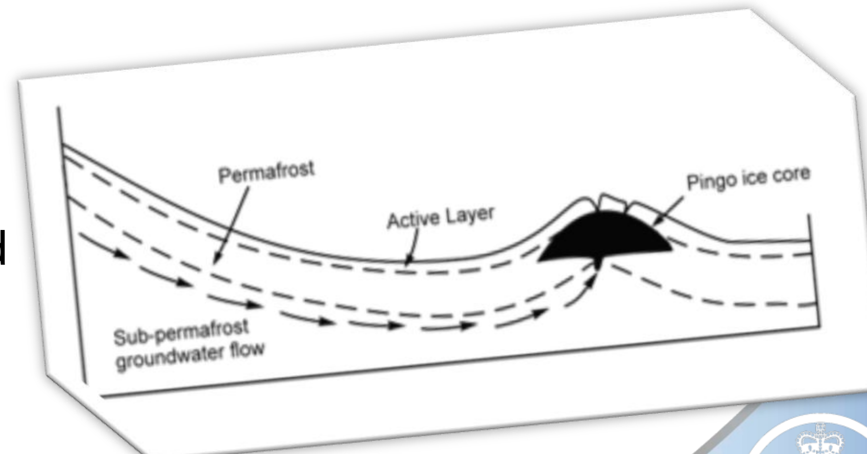
Closed System or Hydrostatic

- Result of hydrostratic pressure on water from permafrost
- Drained lakes or river channels
- Shape depends on the body of water they originated from



Open System or Hydraulic

- Groundwater flow from an outside source
- Often found at the base of slopes and where permafrost isn't permanent
- Shape oval or oblong
- Usually found in unglaciated terrains



Ross et al 2007

Identification of decayed Pingos

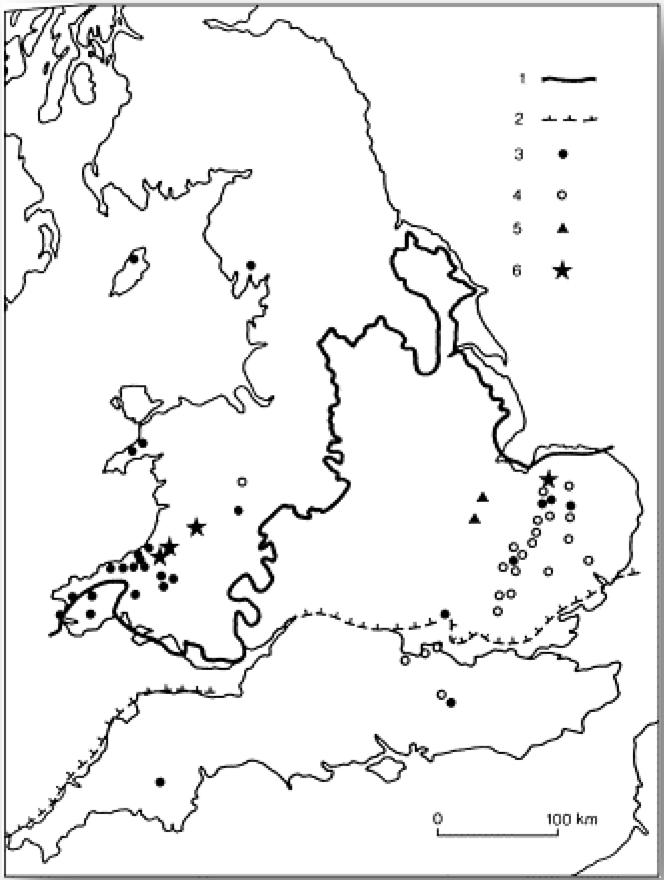
Pingos decay from the top down, leaving a circular, or oval rampart often containing a pond, or marshy area (Mackay, 1988)

The oldest reported pingo like remnants are 400 million years old

Diagnostic Criteria for Pingo Scars (De Gans, 1988 and Mackay's 1988) :

- Minimum depth of depression 1.5 m and diameter 25 m
- At least part of the rampart is present, and contains sediment derived from the depression, often as outward dipping strata
- Bottom of depression lies below the level of the surrounding ground and is floored by sediment that is sufficiently permeable to allow migration of groundwater.
- The volume of the rampart should approx that of the depression
- Presence of peripheral deposits associated with mass wasting, stream deposition and debris flow
- Accompanied by other permafrost phenomena.

UK examples of Relic Pingos



Walton Common Norfolk, ramparted depressions, open system pingo scars?

Ballantyne and Harris (1993)

Pingo’s association with Faults

Golmud to Lhasa rail route (Wu et al. 2004)

27 active faults in 8 active seismic zones encountered along the route.

The northern part of the area has permafrost and active faults provide favourable conduits for groundwater flow, which results in linear zones of springs in May to October and **en echelon pingos in November to April of each year. Large range in the size of the pingos (metres to tens of metres in height).**

suspected that ice melting at depth from geothermal heat, produces thermal springs along most of the active faults, this provides the source of the water.

Seasonality of pingo growth and position along the fault zones results in an apparent migration of the pingos.

Other Theories

Discontinuous gully formation: (Rose et al., 1980)

- whereby permafrost provides cohesion for bed sediments, which are seasonally eroded along a channel
- forms at times of peak discharge without a proportionate increase in sediment supply.
- Would result in more elongate (in the order of 2 km in length), possibly open ended hollows.

Chalk dissolution (Gibbard, 1985)

- More than one process may have been in operation, the upward displacement of bedrock boundaries in the vicinity of a number of hollows would preclude chalk dissolution as the triggering process.
- Locally can trigger ground disturbance but associated with the feather edge of cover deposits

Seasonal Frost Mounds

- **lithalsas** (**mineral) or organic palsas**
  (Calmels et al., 2008; Worsley et al., 1995)
- leave similar remnant features (up to 100 m long and 40 m deep)
- probably form a continuum with pingos
- The key difference between **mineral (lithalsas)** and **organic palsas** is the nature of the host soil
- They are associated with discontinuous permafrost, in contrast with pingos
- Mineral palsas and palsas also differ from pingos in forming mounds of segregation ice by cryosuction
- Both pingos and palsas commonly form in clusters though palsas commonly form a higher density and commonly coalesce.

Despite the range of formational processes associated with different types of cryogenic mound the morphology of the remnant features are comparable, rendering process discrimination from relict scars difficult.

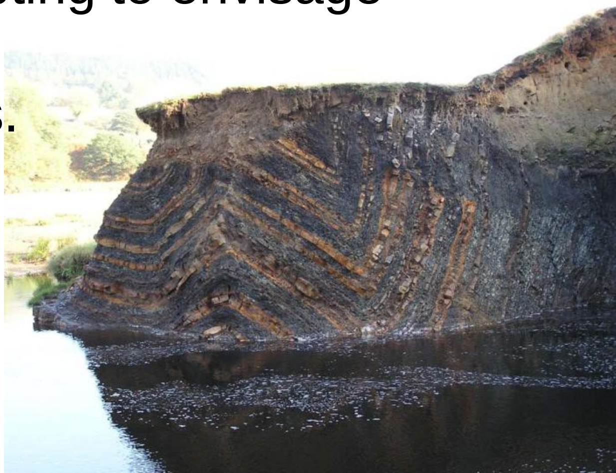
Bulging

Bulging is most closely associated with valley settings where rapid incision of valleys through competent into underlying, less competent argillaceous strata.

This releases horizontal stresses and initiates lateral displacement of the argillaceous strata towards the valley.

Descriptions of some of the *hollows* do include reference to local bulging of the bedrock strata

Where this is associated with the hollows it is tempting to envisage a comparable process in operation, guided by remnant permafrost and excess pore pressures.



Clay Diapirism

- Berry (1979) identified diapiric structures occurring at the base of depressions within the London Clay
- Henriet et al. (1982) used this as evidence of land based diapiric structures in the London Clay
- Hutchinson (1991) suggested that the diapiric rises were likely due to artesian pressure in strata underlying the London Clay facilitated by unloading produced by scouring.
- It should be noted that diapiric structures in hollows are not confined to London Clay, but may also include all bedrock formations down to Chalk.

Frost heave and Ice wedges

- It is possible that the bulging of the bedrock strata is attributable, at least in part, to frost heaved diapirs.
- Bedrock heave can occur in frozen ground.
- This is characterised by the uplift of frost-wedged blocks with uplift being facilitated by the pressure generated by free water freezing in joints (Dionne, 1983).

Thermokarst processes

- Thermokarst features might account for deformation of the drift in the hollows and the bedrock diapirs.
- More specifically, thermokarst involutions in glacial deposits form by loading and buoyancy or by water escape during the degredation of ice-rich permafrost and bedrock diapirism can result from the melting of segregation ice

Dual Processes

Scour and pore pressure release (Hutchinson, 1991)

In currently identified hollows some are not associated with diapirs and less commonly some diapirs are not associated with scour features

Scouring might be penecontemporaneous, as a consequence of the increased discharge associated with the improving climatic conditions.

Alternatively, sediment that is already disturbed by diapirism might naturally form a focus for subsequent scouring.

Segregation ice appears to be paramount in terms of soft sediment deformation and diapirism, whilst the influence of artesian pore water pressure is implicit in the depth to which the disturbances occur and the potential for sediment injection.

Could diapiric intrusion of the underlying Lambeth Group into the London Clay beneath the basins reflected zones of high artesian pressure and possible weakening of the London Clay and the Woolwich and Reading Beds by freezing and thawing?

Permafrost wasting

- Release of pore pressures, possibly via faults or dominant joints such that they formed groundwater discharge points as permafrost melting occurred.
- Associated with neotectonic movement on faults or dominant joints as permafrost wasting took place (de Freitas, 2009).
- This hypothesis would also be in keeping with the apparent focus of artesian pressures on the bedrock high in the chalk.
- Differential wasting of ground ice could be important ; results due to differences in the thermal conductivity and diffusivity of the chalk and overlying clays.
- The chalk thermal conductivity and diffusivity is likely to be higher than that of the clays.
- This might facilitate earlier more rapid wasting in the recharge zone (North Downs) than in the basin, thereby increasing the artesian groundwater pressures.

Implications on Engineering

1. Unexpected distribution of deposits
2. Disturbance of materials : strength reduction and greater variability
3. unexpected occurrences of perched groundwater

Higginbottom and Fookes (1971) presented an excellent overview of engineering aspects of periglacial features.

examples from the literature of active pingos:

Golmud to Lhasa rail route in the Tibetan Plateau, China, where seasonality and anthropogenic influences result in the added complexity of apparent pingos migration, almost all are associated with faults (Wu et al., 2005).

Alaskan Pipeline Project, routes were selected in order to avoid active pingos (Trans Canada-ExonMobil, 2011).

Wu et al., 2005

Rockhead anomalies in the London Basin

1. They have been known about for a long time

2. They probably occur throughout the basin but mostly found in London due to engineering works

3. Nobody knows for sure what they are or how they were formed but there are lots of theories

4. It is very likely that they are not all formed by the same processes