British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Applied geoscience for our changing Earth

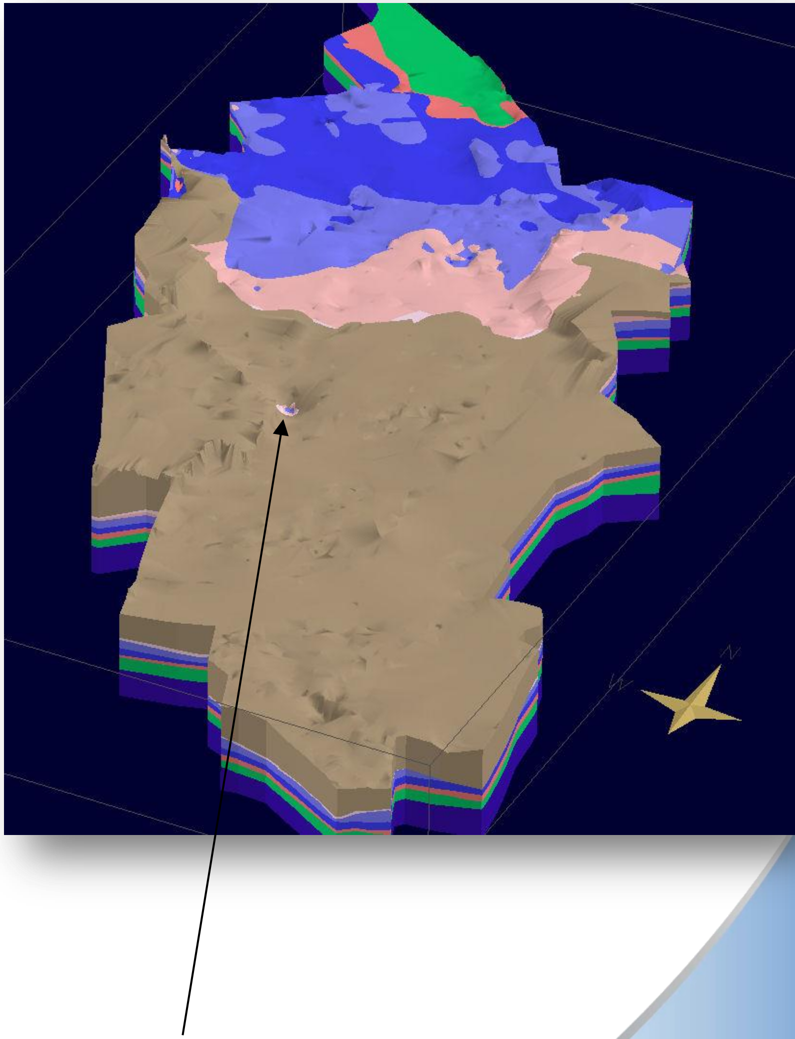
BGS contributions to the mapping and modelling of anomalous buried hollows in London

Presented by Dr Vanessa J Banks on behalf of many BGS colleagues

September 2016

Key characteristics of the anomalous buried hollows

- Funnel shaped irregularities in the rock head surface: London Clay, Lambeth Group and the Chalk
- 5-15+ m deep (33 m, Battersea; 60 m Blackwall); 90 -475 m wide
- Majority underlie Kempton Park Gravel (between Battersea and Greenwich)
- Steep-sided, with slopes < 20 degrees
- Sediment fill
- Diapirism
- Root zone (for many, but not all)



Why study them?

Engineering implications

1. Unexpected distribution of deposits
2. Unpredictable engineering properties
3. Unexpected occurrences of perched groundwater
4. Potential contaminant pathways

Quaternary research interest

1. Process
2. Climate
3. Date

1930

Survey

BGS contributions

2016

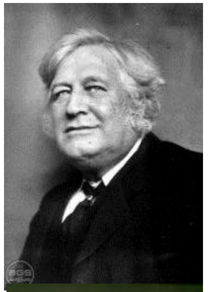
Model

Aims of the presentation

- Edmunds 1931
- Berry
- Hutchinson
- Ellison, Sumbler et al. 1996
- Pharaoh et al. 1996
- Royse Faults
- Ford et al., 2008
- Aldiss and Lee, 2011
- Terrington 3D
- Haslam Faults
- Bricker Susceptibility layer
- Collins collaboration Ashford Hill and geophysics
- Busby et al thermal properties
- Banks et al. 2015 faults and thermokarst
- Lee et al. Quaternary heterogeneity layer

Who are we?

- A Government Organisation founded in 1835 by Henry De la Beche
- To carry out scientific research to understand the structure, properties and processes of the solid earth system
- History of eminent geologists
- The world's first Geological Survey
- Originally part of the Ordnance Survey: Ordnance Geological Survey
- Became IGS in 1964
- Became the British Geological Survey in 1984
- Currently operates under NERC (c 50% funded from NERC)

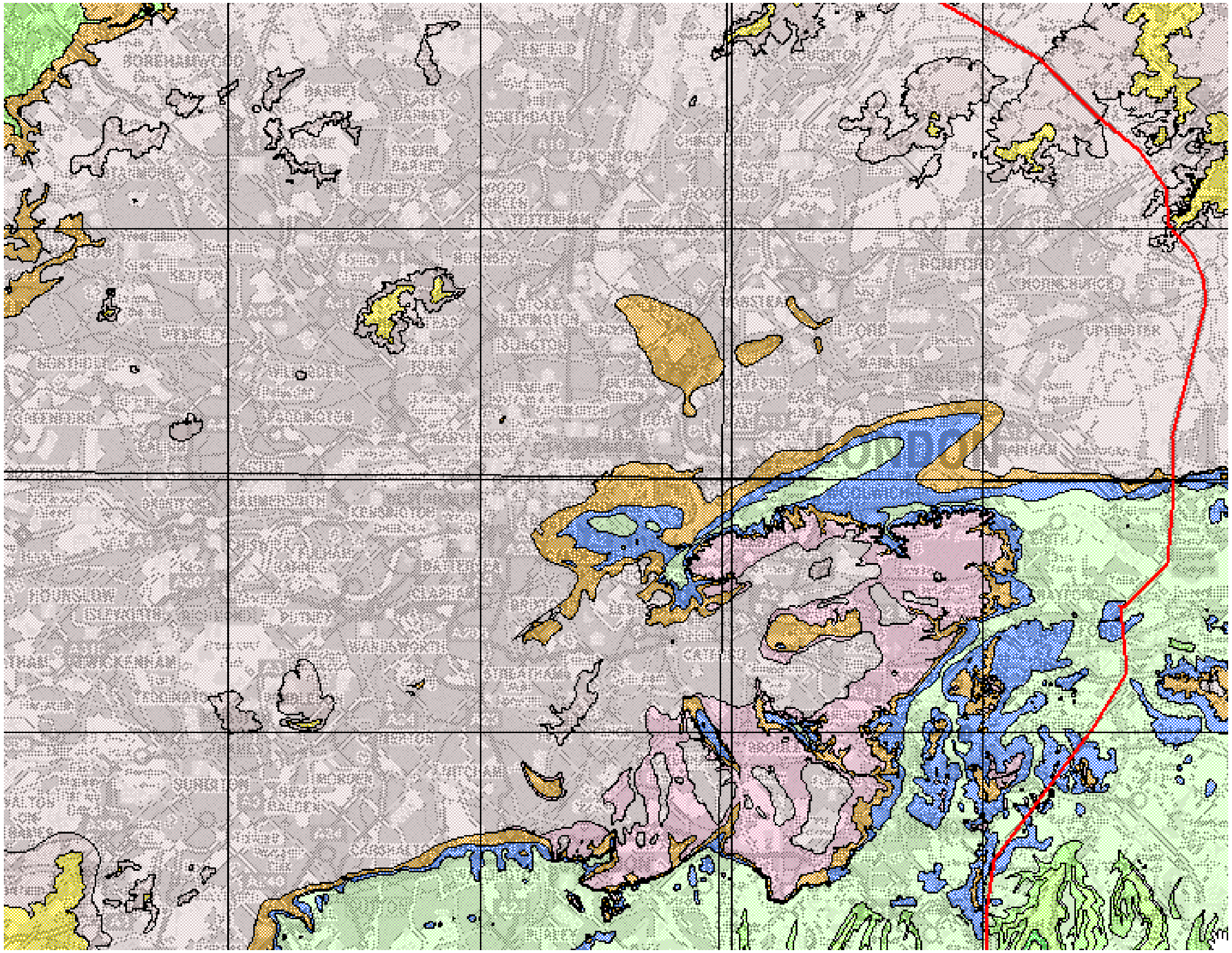





Geology

Age	Group	Principal succession
Quaternary		Alluvium
		River Terraces
Palaeogene	Thames	London Clay Formation
		Harwich Formation
	Lambeth	Reading Formation
		Woolwich Formation
		Upnor Formation
	Montrose	Thanet Formation
Cretaceous	Chalk	Newhaven Chalk Formation
		Seaford Chalk Formation
		Lewes Chalk Formation

Geology of London - bedrock



Bagshot Fm

London Clay Fm

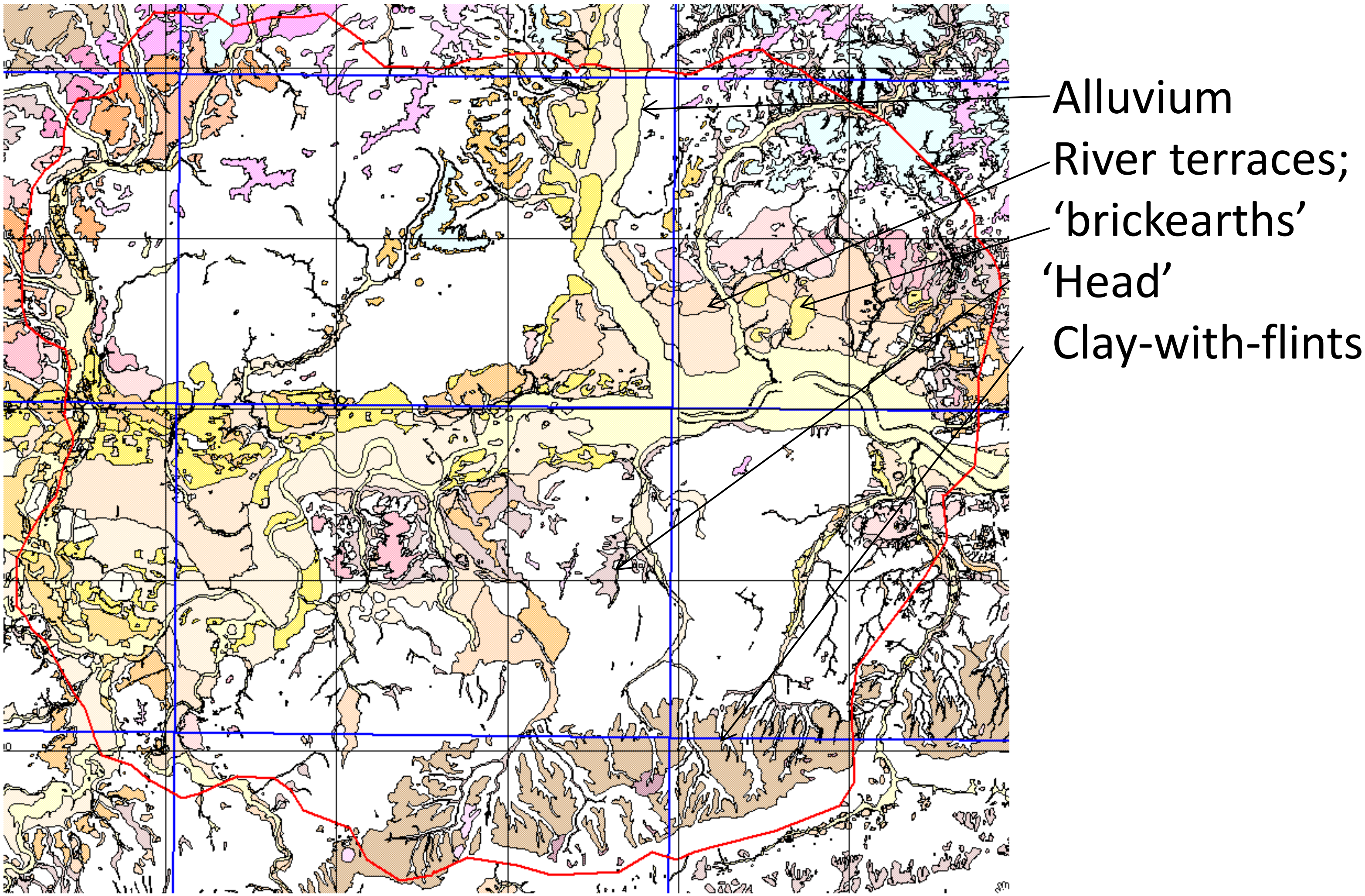
Harwich Fm

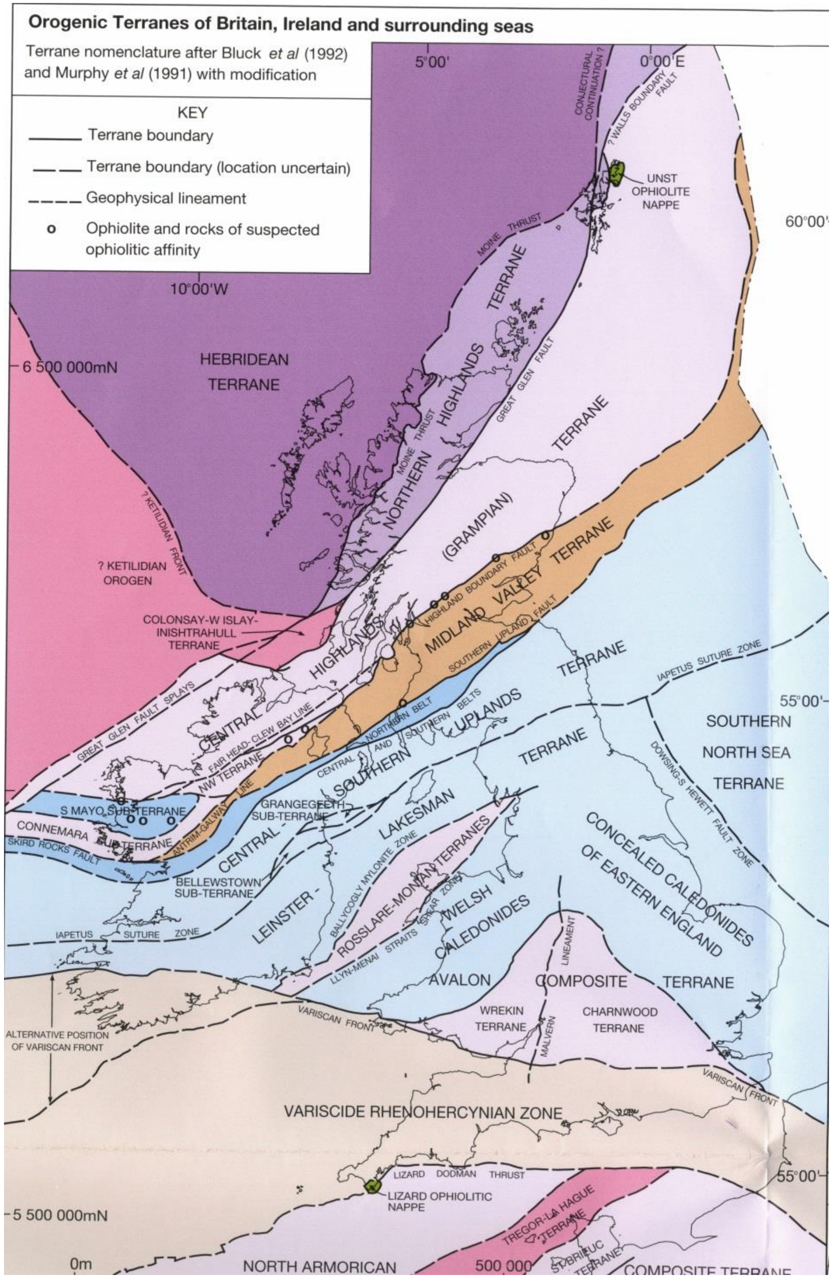
Lambeth Group

Thanet Sand Fm

Chalk Group

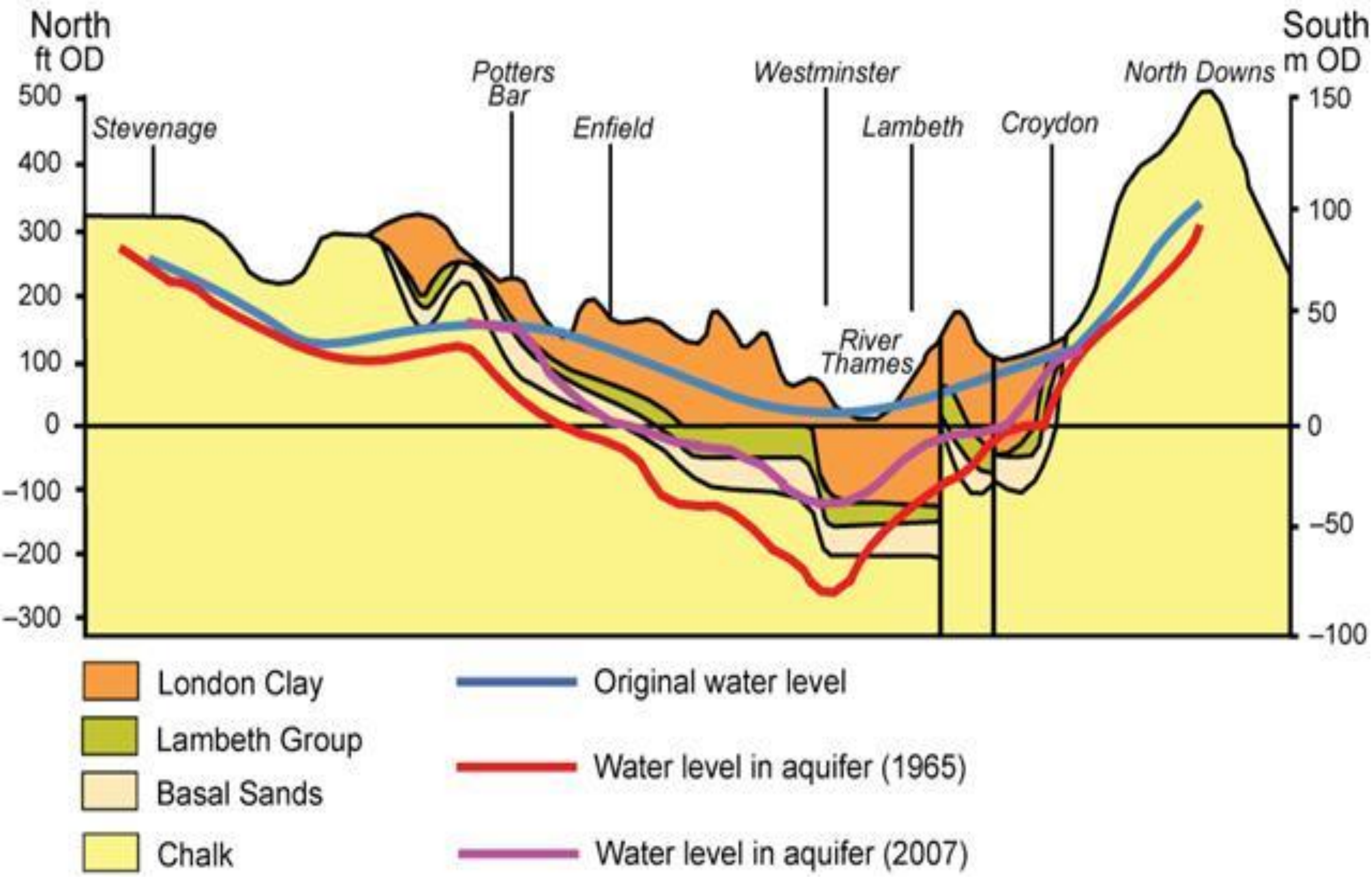
Geology of London : Superficial deposits





Orogenic Terranes Modified after Bluck et al. (1992)

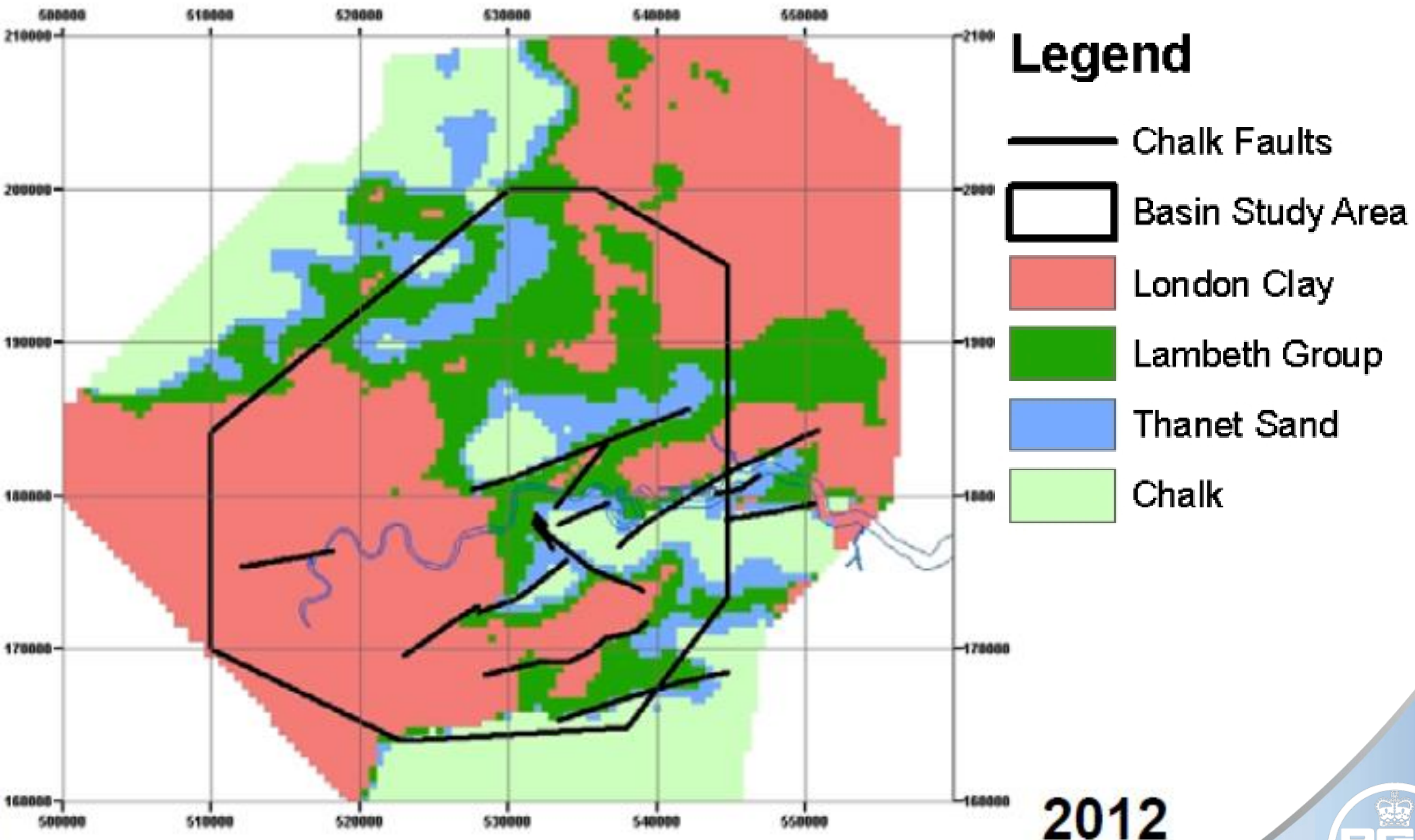
Schematic representation of the London Basin and Chalk aquifer groundwater levels



From the Groundwater Forum Web-page: Thames Water, 2007

Drift Filled Hollows – Pathways to deep groundwater

Watertable Geology

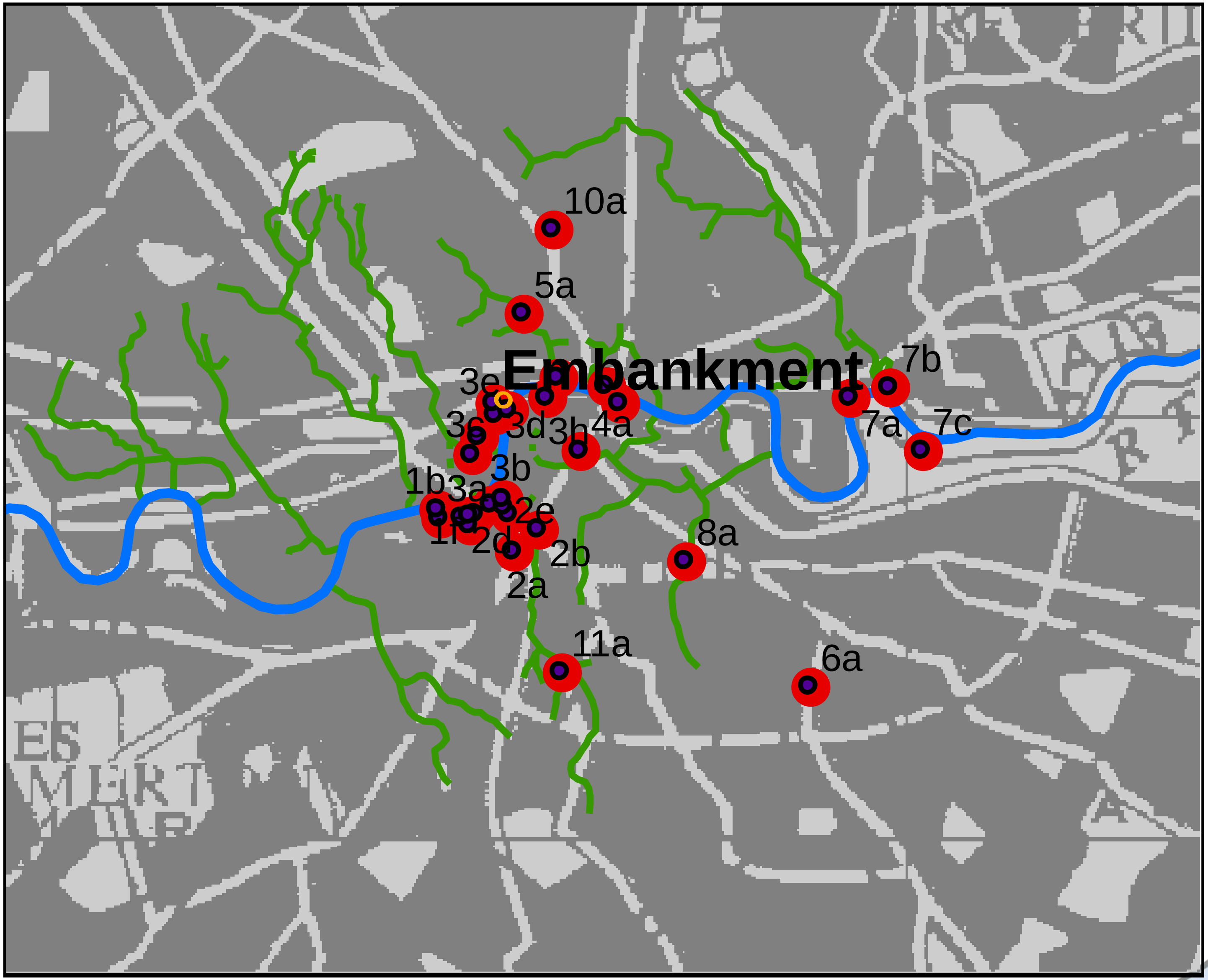


Environment Agency - Management of the London Basin Chalk Aquifer, Status report 2012

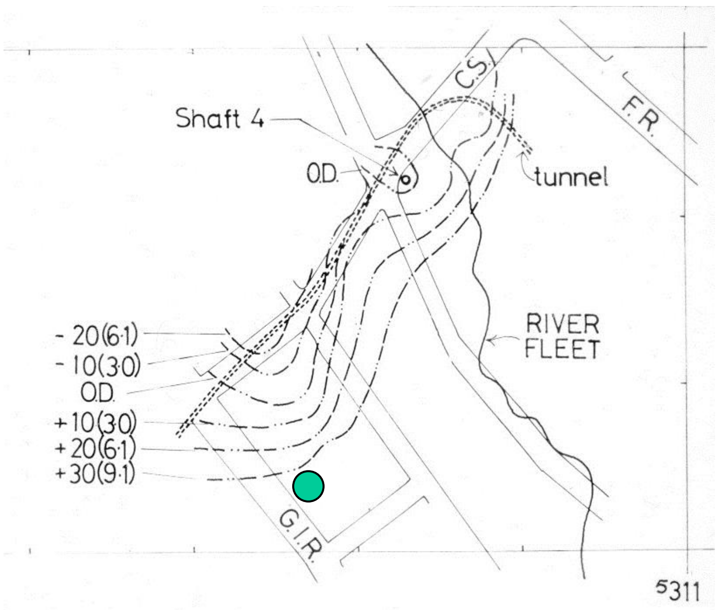
Berry, (BGS 1966 - IGS 1972-1984): Late Quaternary scour-hollows and related features in Central London. QJEG 1979. 12, 9-29.

- 26 drift filled hollows or rock-head depressions
- Two thirds identified during line surveys for tunnels or surface works for large structures
- Beneath Lower Floodplain deposits of Ipswichian to recent age
- Related to shallow buried channels
- Most in the South Lambeth –Battersea-Westminster - Southwark area
- Formed in the surface of the London Clay
- Coincidence with stream junctions
- Diapirism associated with some

Berry: Tracts



Grays Inn Road, London (Berry, 1979)



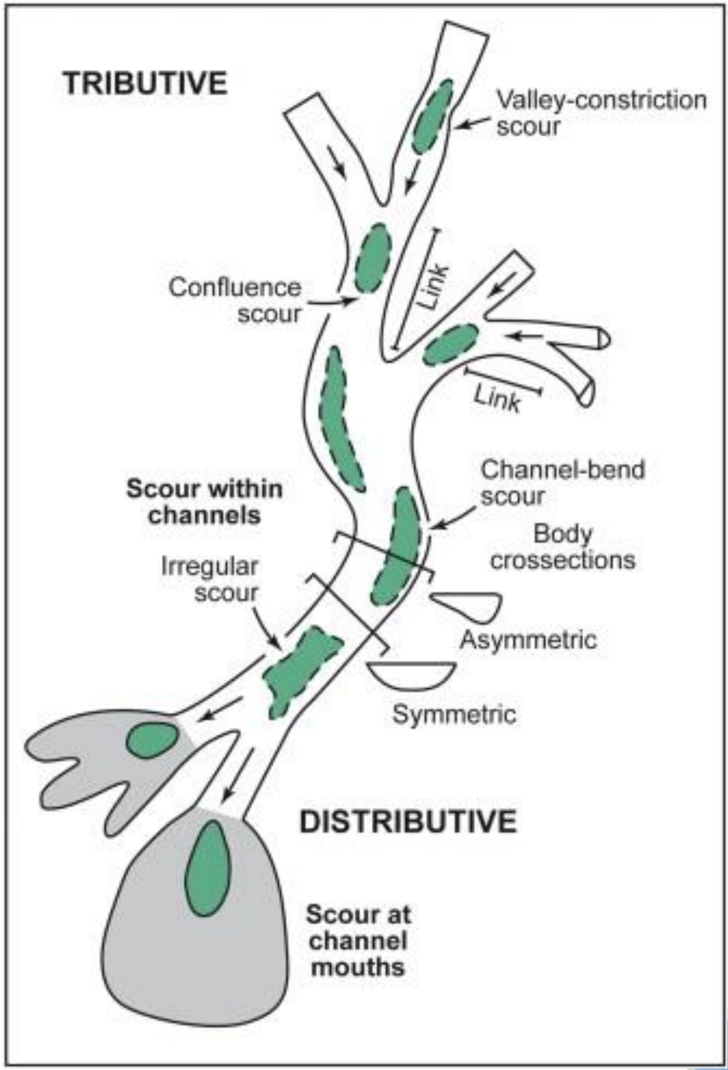
- Fine-grained alluvial sequences with fossils with silts and clays reworked from London Clay
- Densely packed gravels
- Over-consolidated reworked London Clay
- Scour feature infilled with channel deposits, over-bank sediments or lacustrine sediments?

Times Building excavations (New Printing House Square)

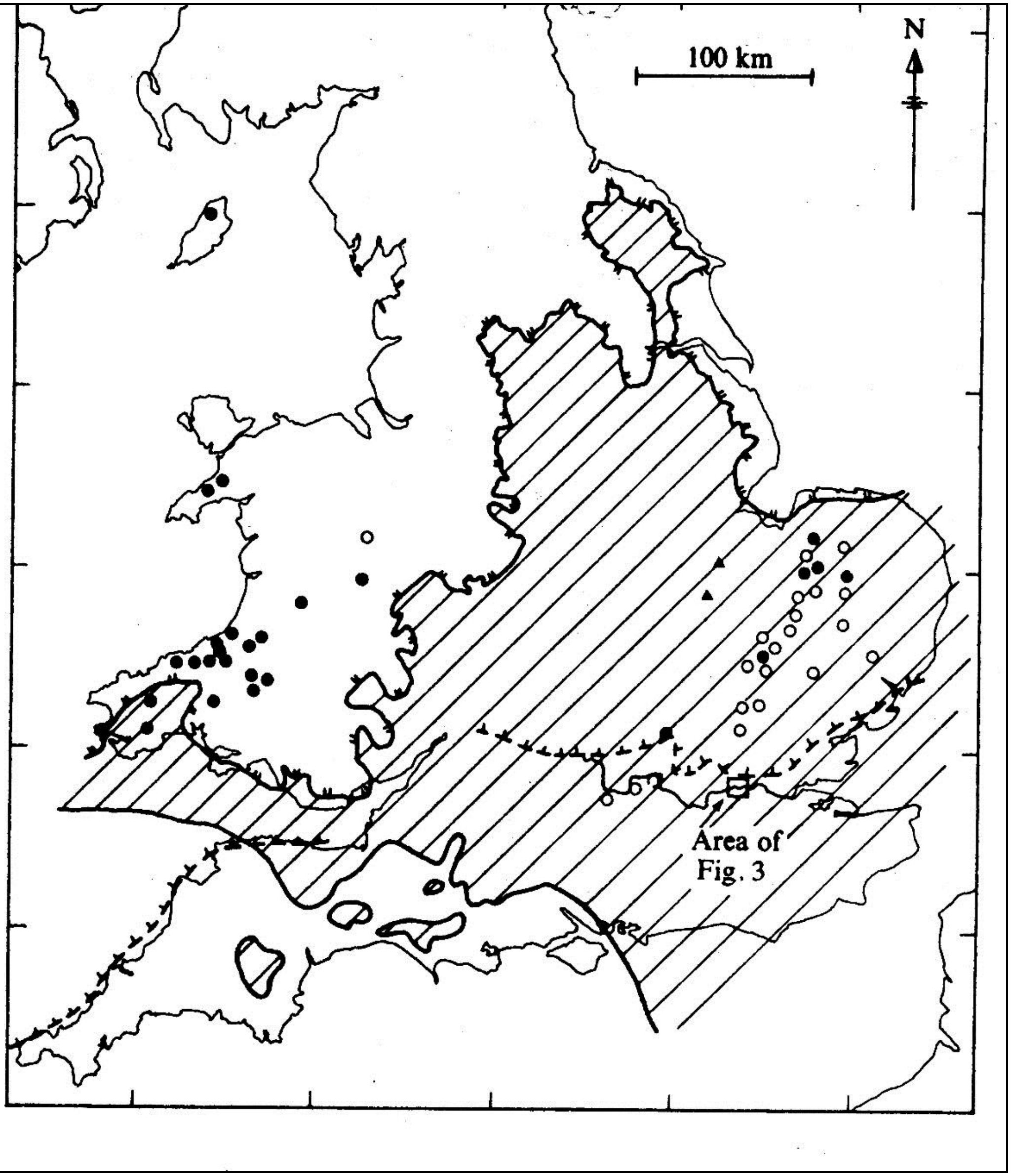
Photographs by Frank Berry

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 (Kjerfve et al 1979; Rice et al., 2008)
- Scour depth increases at higher discharge angles
- Discontinuous gully formation (Rose et al., 1980)



Hutchinson Possible pingo remnants (1980, 1991)



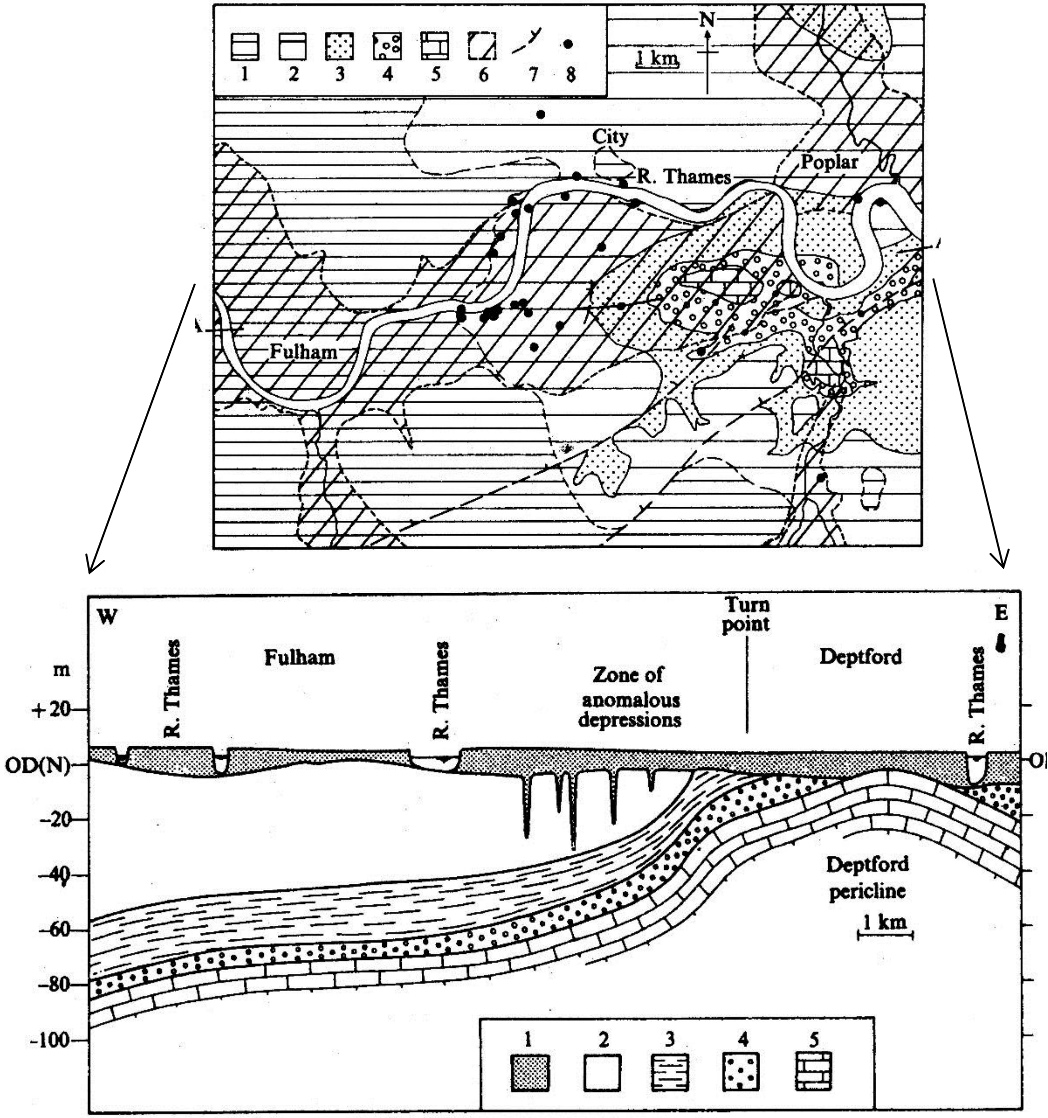
Key:

- ● suspected open pingo
- ○ suspected remnants
- ▲ possible closed system

Pingos

- A mound of earth-covered ice
- Regions of continuous or discontinuous Permafrost (Canada, Alaska and Siberia)
- Reach 70 m in height; 600 m in diameter.
- Core of solid ice
- Segregation ice
- Upward growth
- When the ice melts the dome collapses into a volcano shape hill
- Closed or hydrostatic
- Open or hydraulic

Hutchinson 1980, 1991

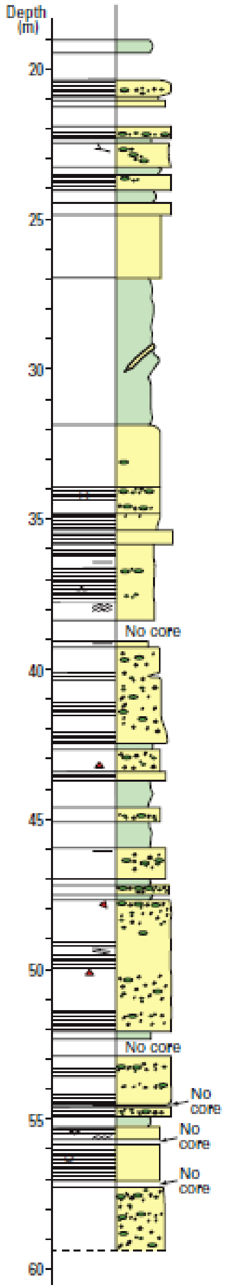


1. Context: valleys, near the valley floor;

2. Association with feather-edge of the London Clay;

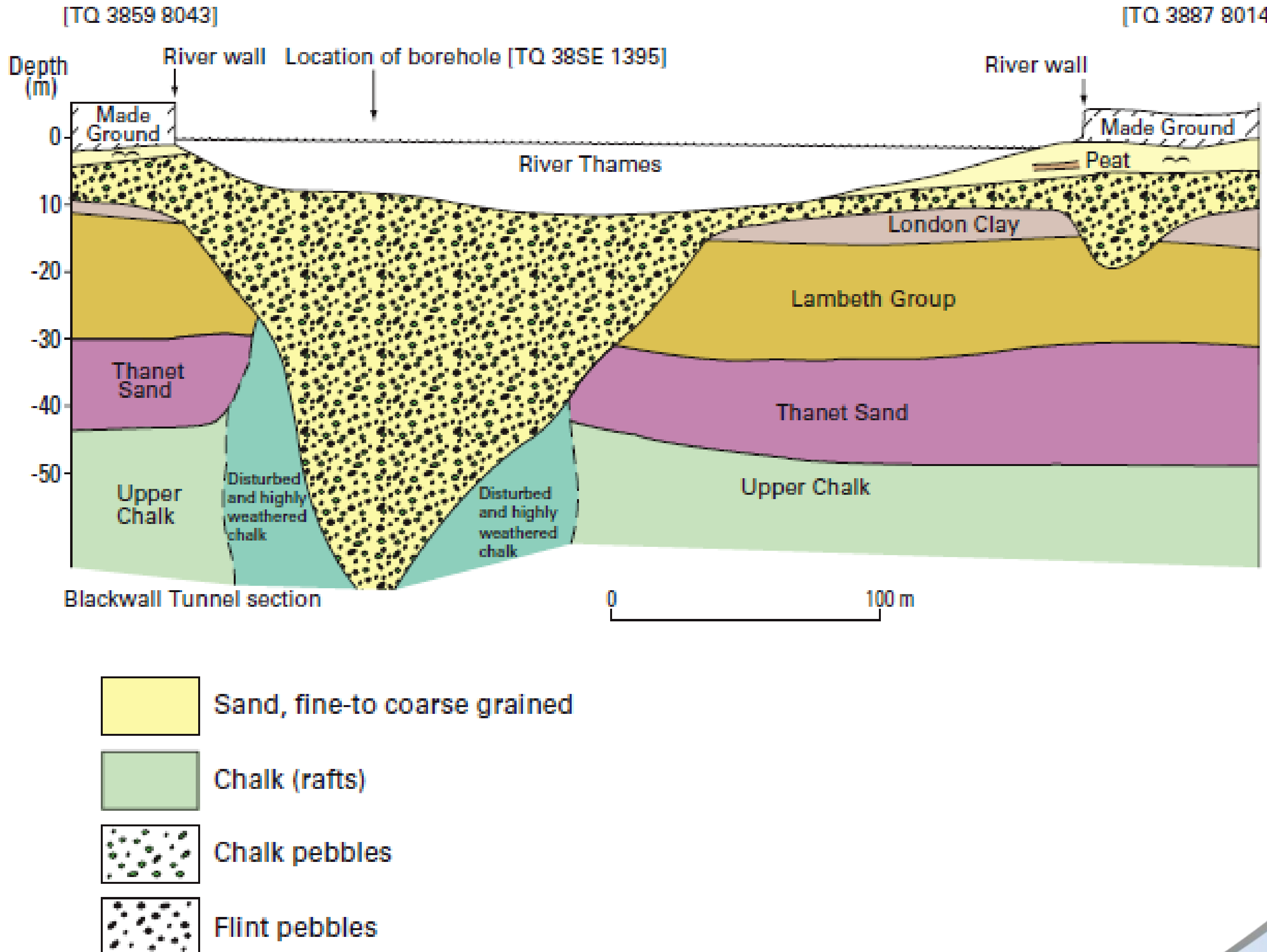
3. Zone of former artesian groundwater conditions, and

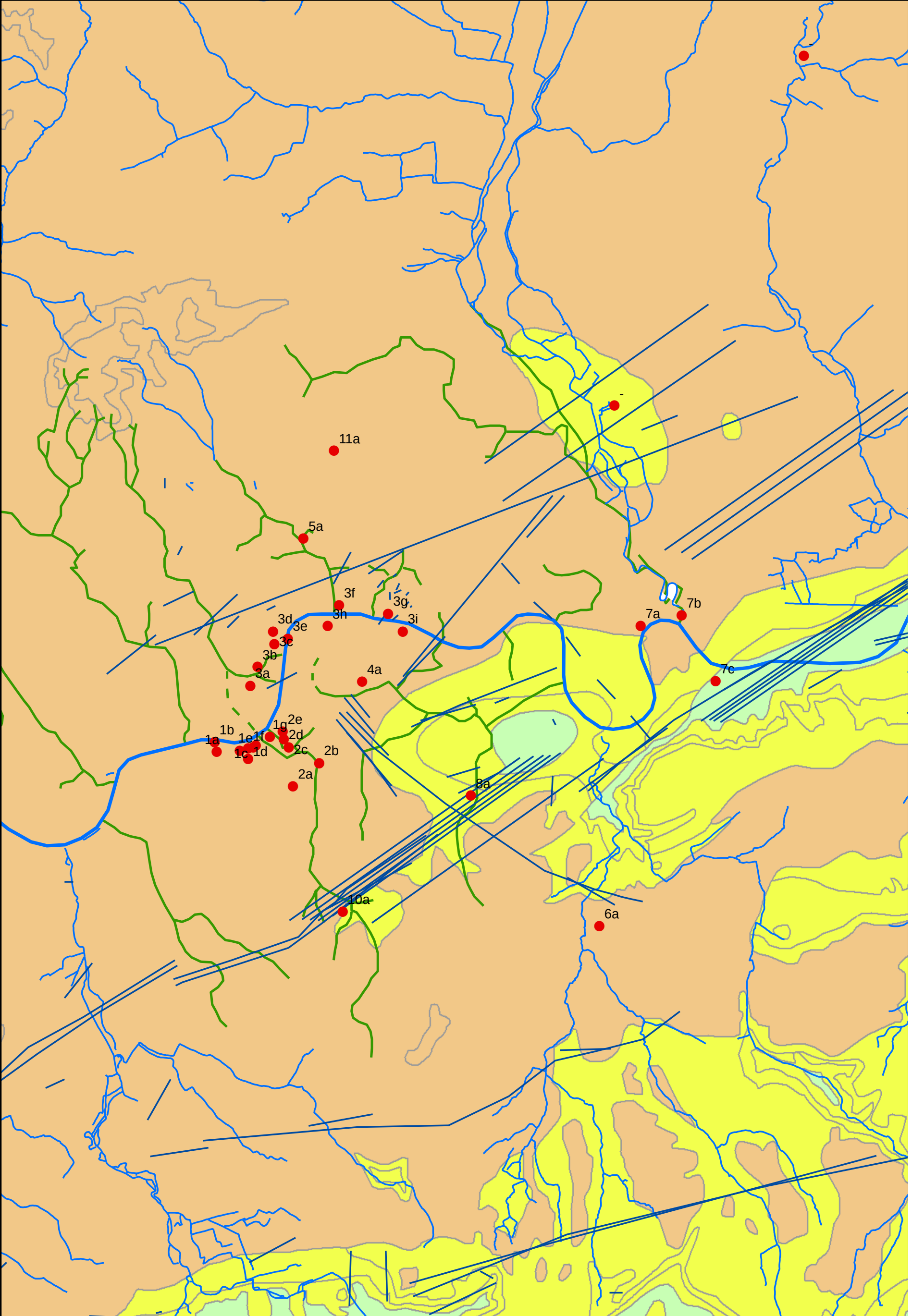
4. Potential for unloading due to scour



Richard Ellison et al., 1996, 2004:

BGS
1972-2014

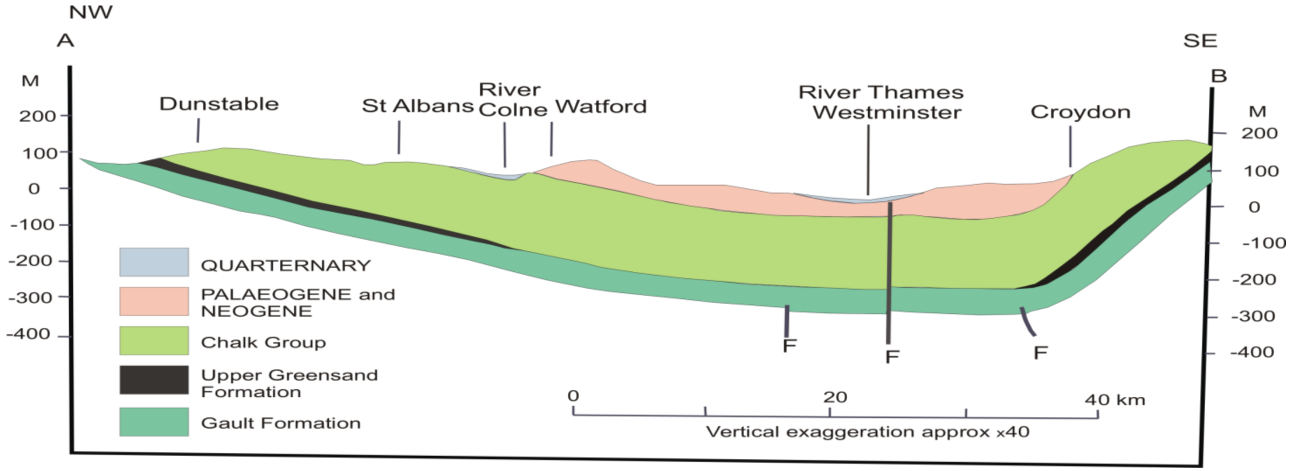




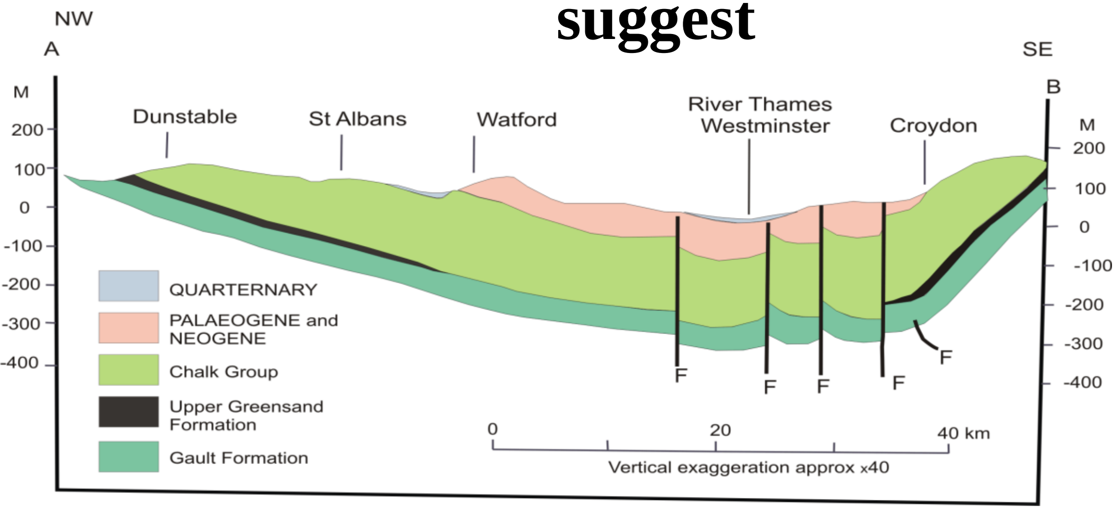
Dr Kate Royse Chalk fault mapping

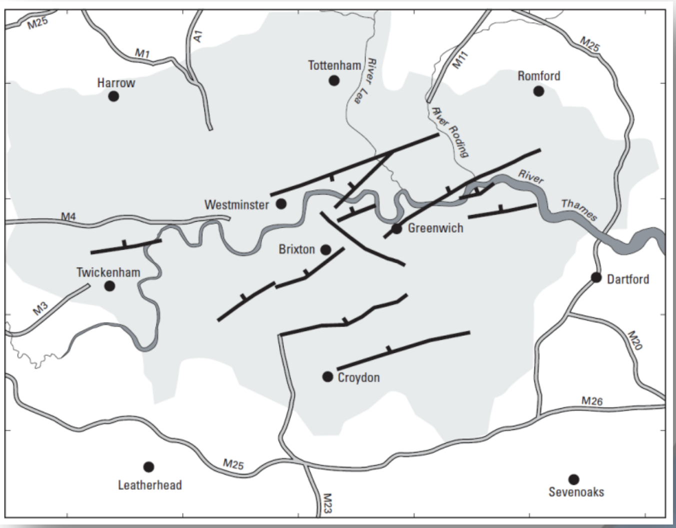
BGS
2001 -

Chalk faults



This is what the geological maps would suggest



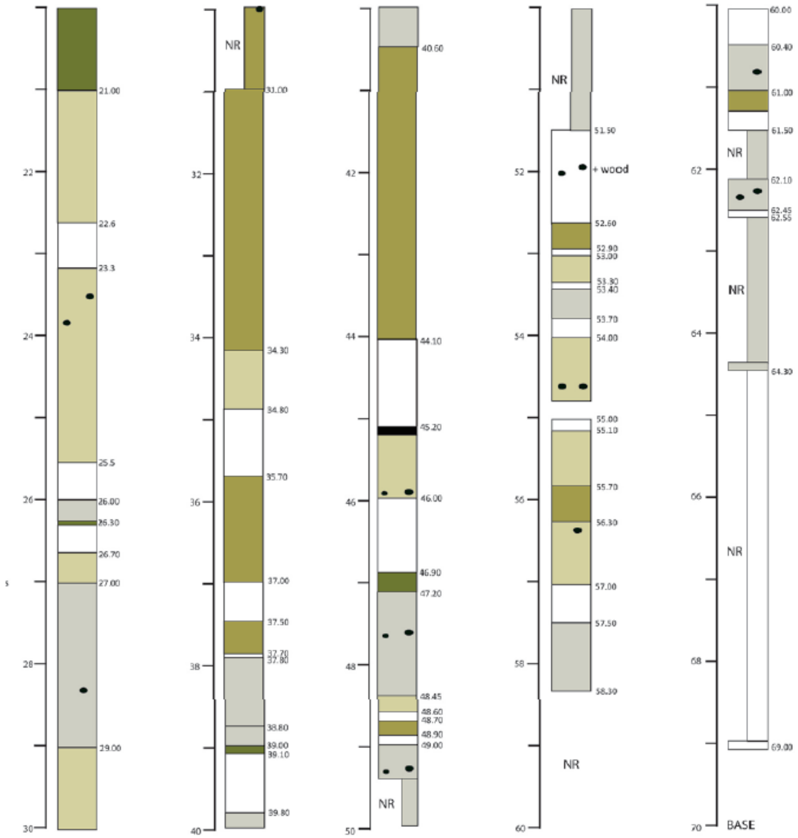


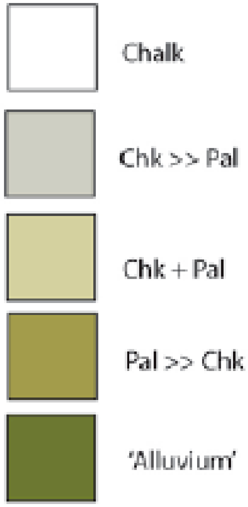
This is closer to reality

Lower Lea Valley Aldiss and Lee

Aldiss et al., (2012)

BH TQ38NE 1366





BGS
1978 - 2014

Core sub-samples

BH159: 22 m below GL – mélange; silty fine sand with chalk and flint

BH159: 30.9 m GL – mélange; silty fine sand with chalk and flint

BH159: 33.6 m below GL - mélange: fractured chalk

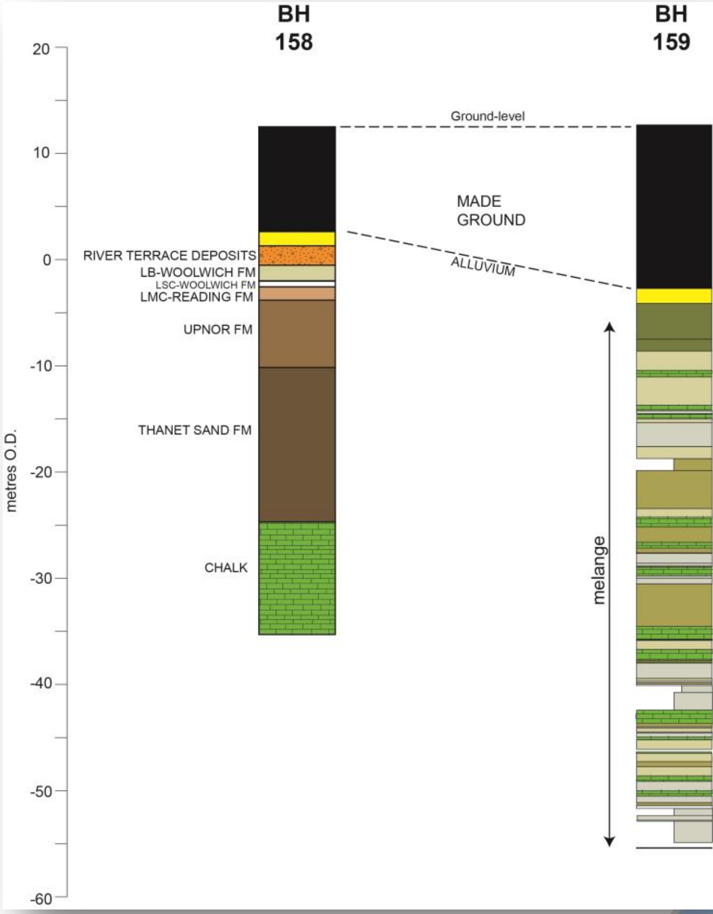
BH159: 43.3 m GL mélange: cluster of flint pebbles

Anomalous geological succession in the Lower lea Valley: summary

- Made ground – down to 6.6 m *below* original 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 depth



Aldiss and Faults (2013)

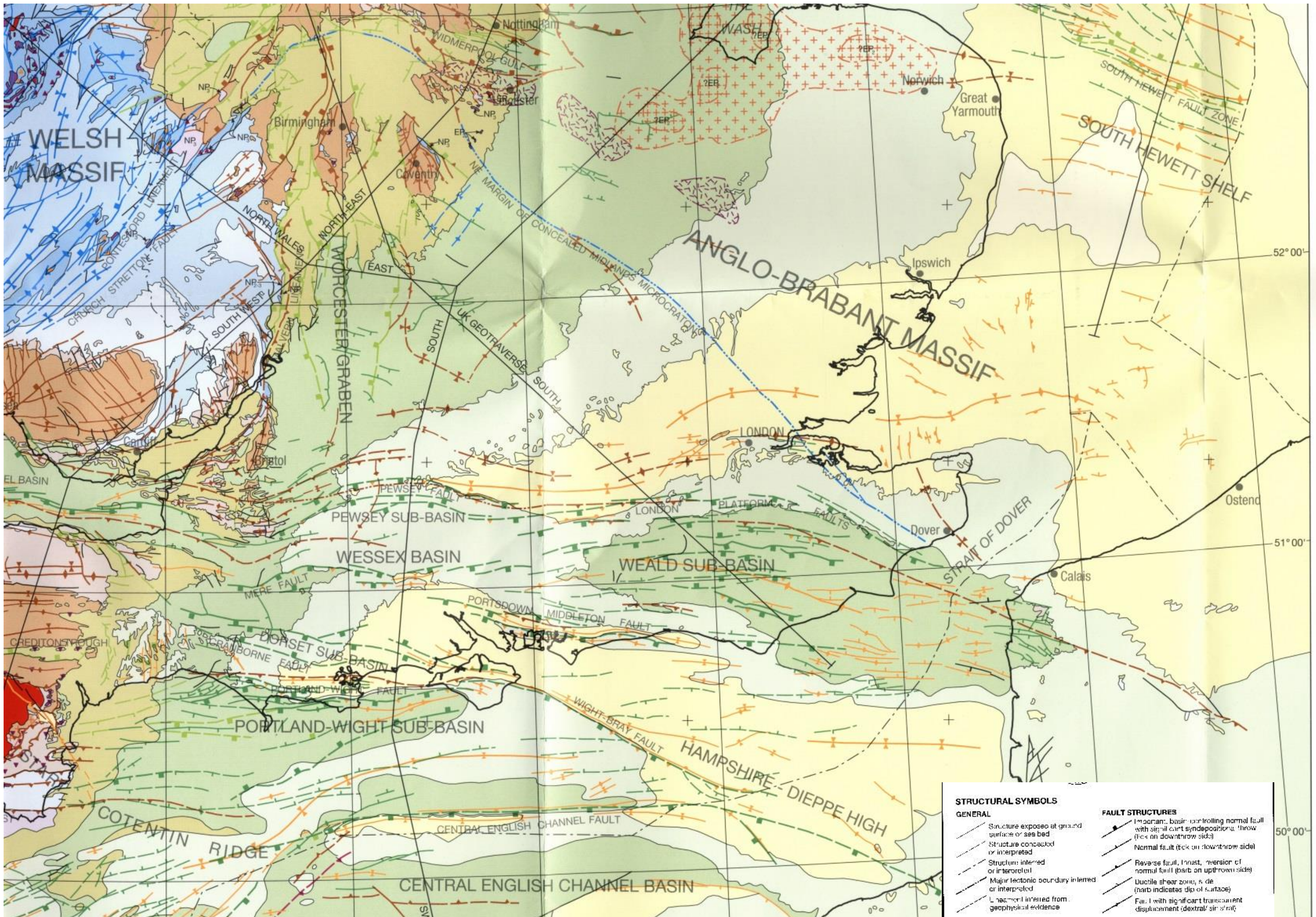
- Past mapping methods
- Relative uniformity of extensive bedrock units such as the London Clay Formation and the Chalk Group
- Widespread presence of Quaternary and anthropogenic deposits, and
- Urban development

COMPLEMENTARY APPROACHES:

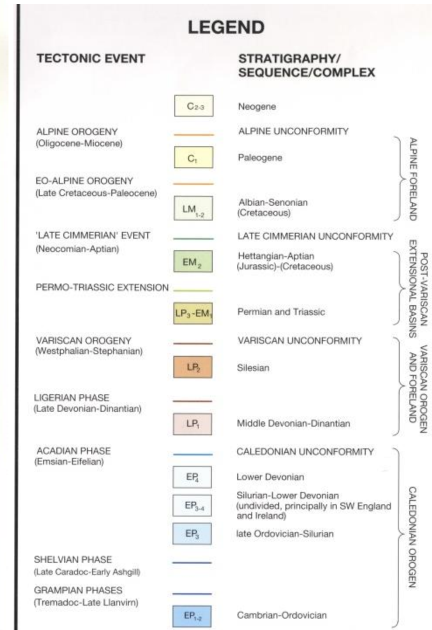
- Geophysical data
- Satellite-based radar interferometry
- Geological modelling

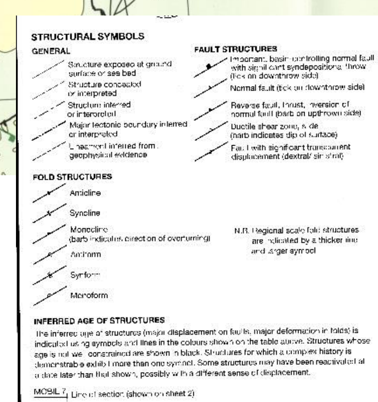
LATE QUATERNARY DISPLACEMENT

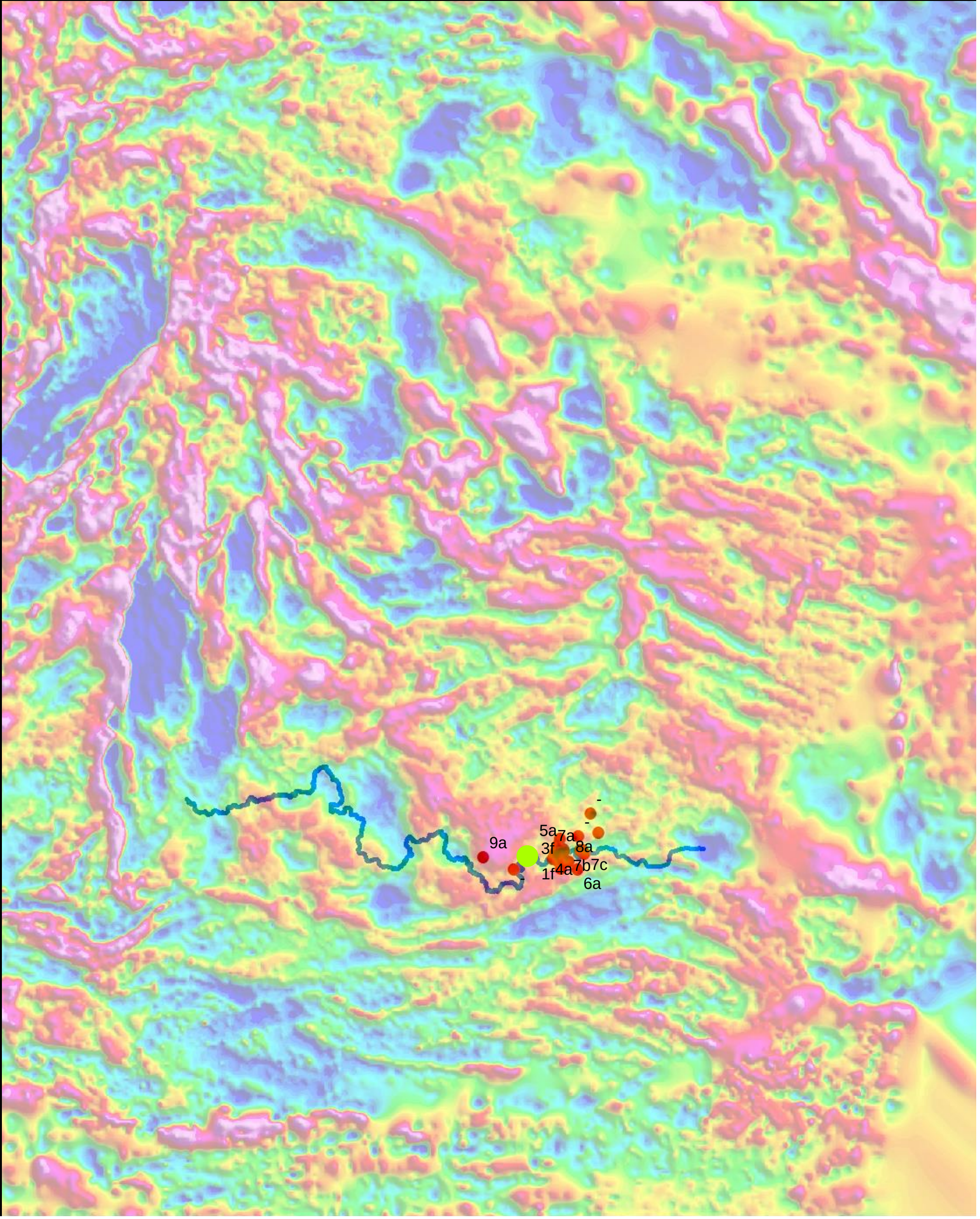
Tectonic Map (Dr Tim Pharaoh et al., 1996)



BGS
1983-



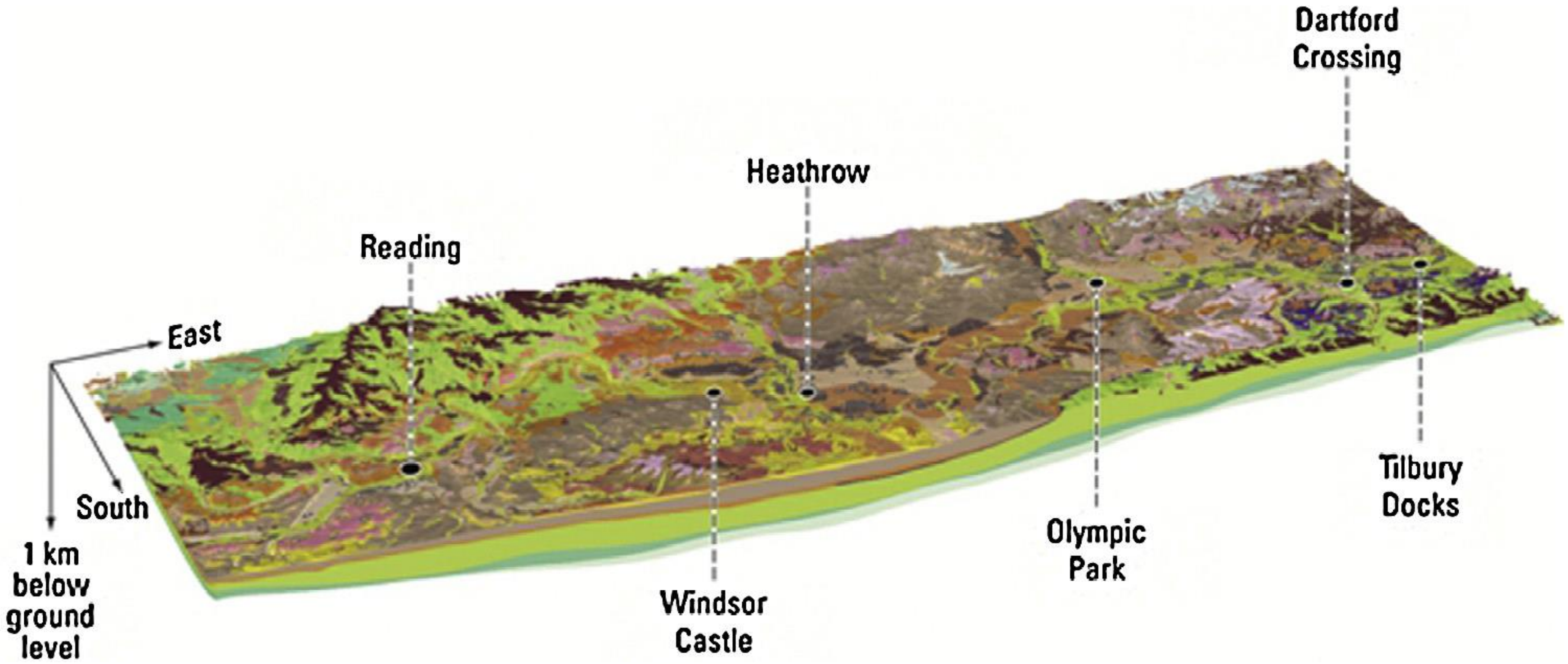




Dr D Beamish
Gravity data

BGS
1978-2014

3D modelling



- 6700 km of cross sections
- Equivalence to 1: 50 000 scale mapping

Bricker susceptibility layer

BGS
2008 -

Provide a map with the potential location of difficult ground conditions associated with the buried hollows:

- ⇨ Reduce the potential for unforeseen ground conditions
- ⇨ More effective site investigation design.
- ⇨ Reduce risk of project over-run and additional costs
- ⇨ Contribute to understanding potential contaminant pathways

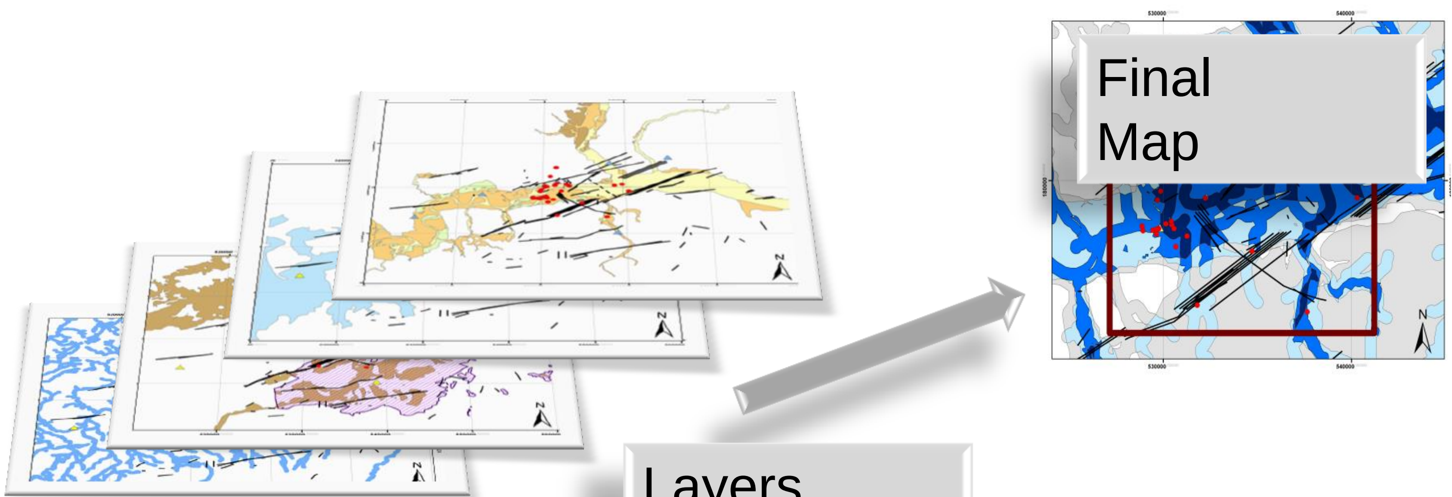
Susceptibility layer development

1 Criteria definition

1. Situated in valleys, close to the valley floor.
2. Associated with the feather edge of the London Clay
3. Artesian groundwater conditions (Simpson et al., 1989).

   Actual uplift pressures required to generate uplift of the higher than the Historic Maximum Value.

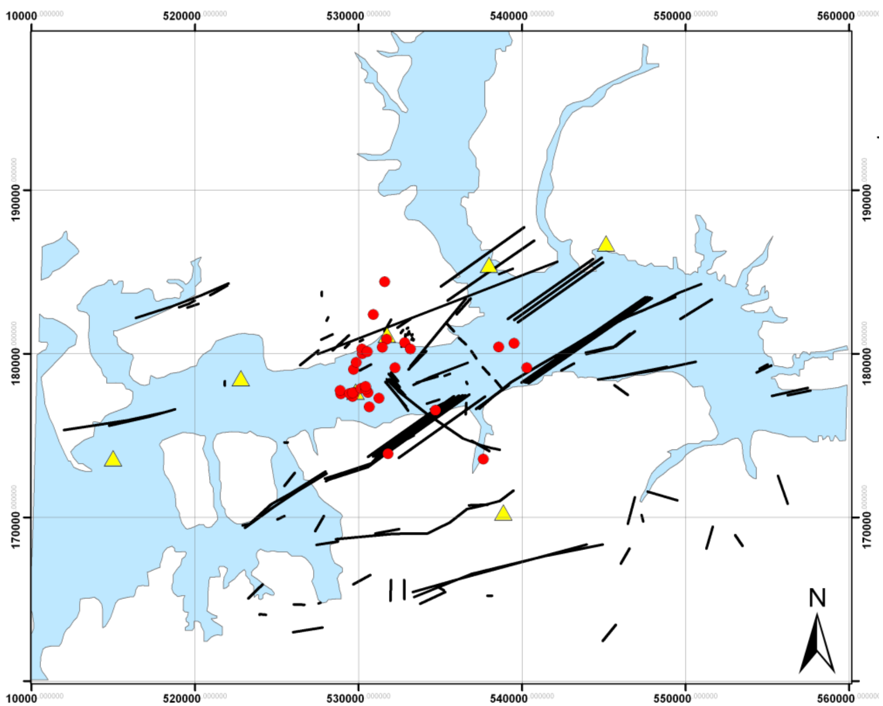
1. Unloading of the overburden material (by scouring) may have facilitated pore water pressure breaching of the London Clay.



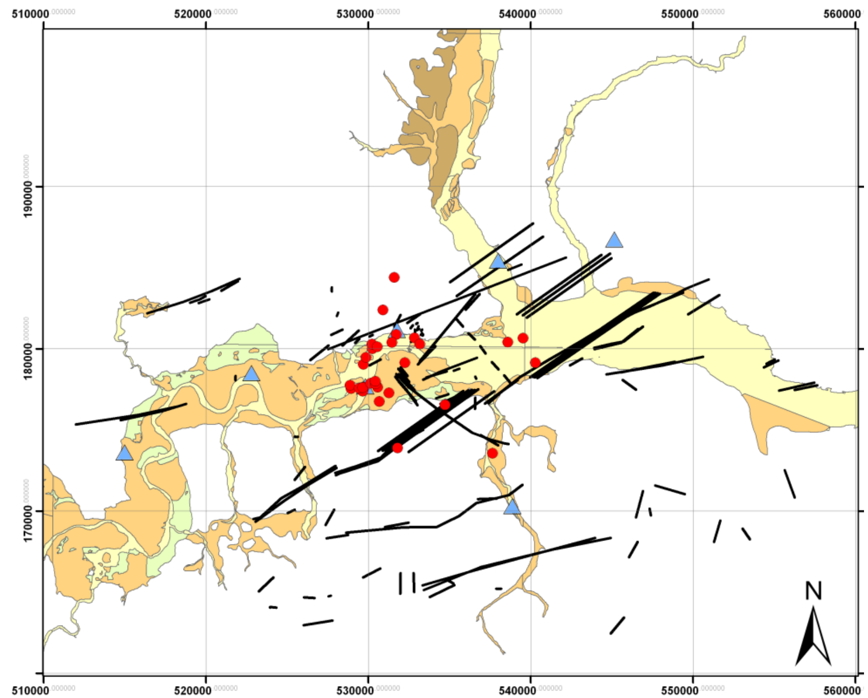
Susceptibility layer development

2 Development of GIS layers

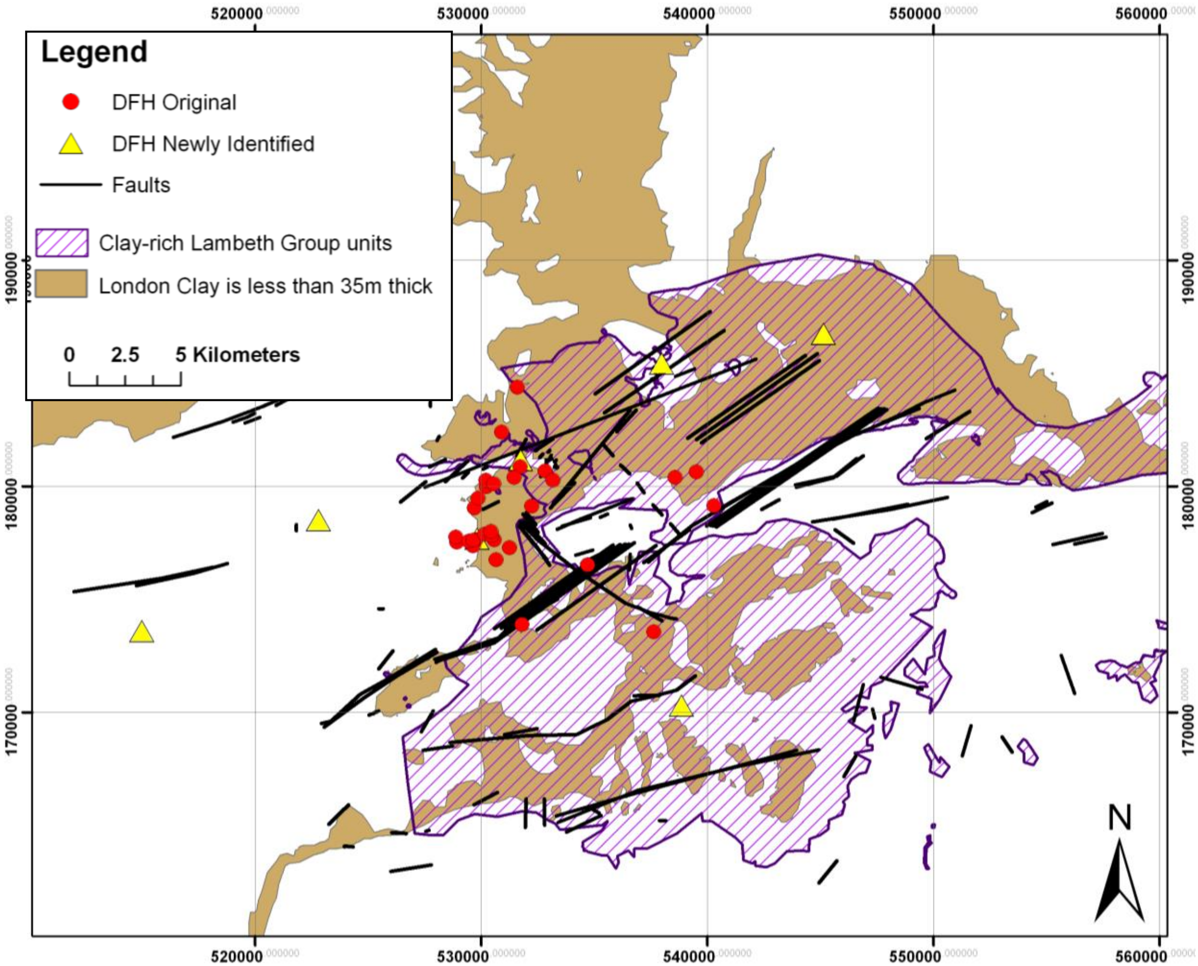
Artesian zone



Kempton Park



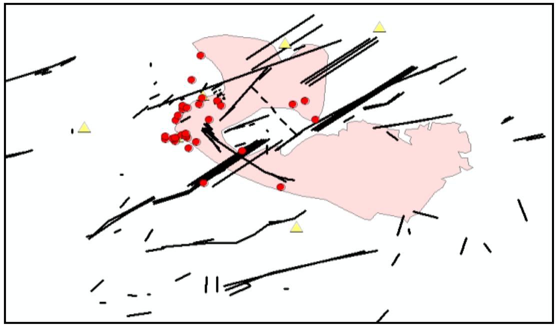
Confining layer



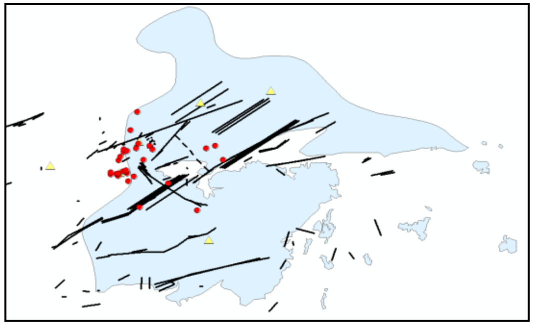
- Combined the Lambeth Group clay-units with areas where the London Clay is <35 m thick
- Not accounted for thickness of Lambeth Group units…but unlikely to exceed 35 m
- May be areas where the thickness of the Lambeth Group units is insufficient to confined the groundwater pressure

Lambeth Group contribution to the confining layer

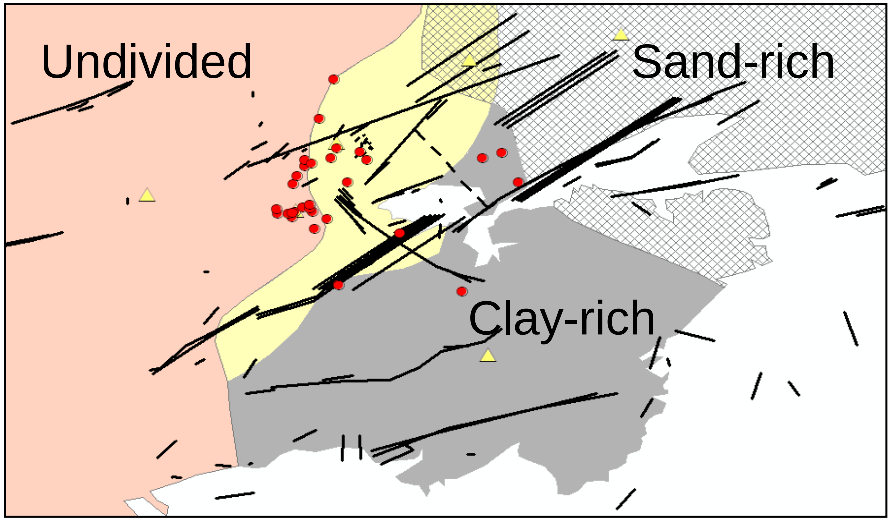
- Lambeth Group sub-divisions include in the London memoir and refined as part of another BGS project:
- Mainly interested in the East where the London Clay is <35 m or absent



Laminated beds



Lower Shelly Clay

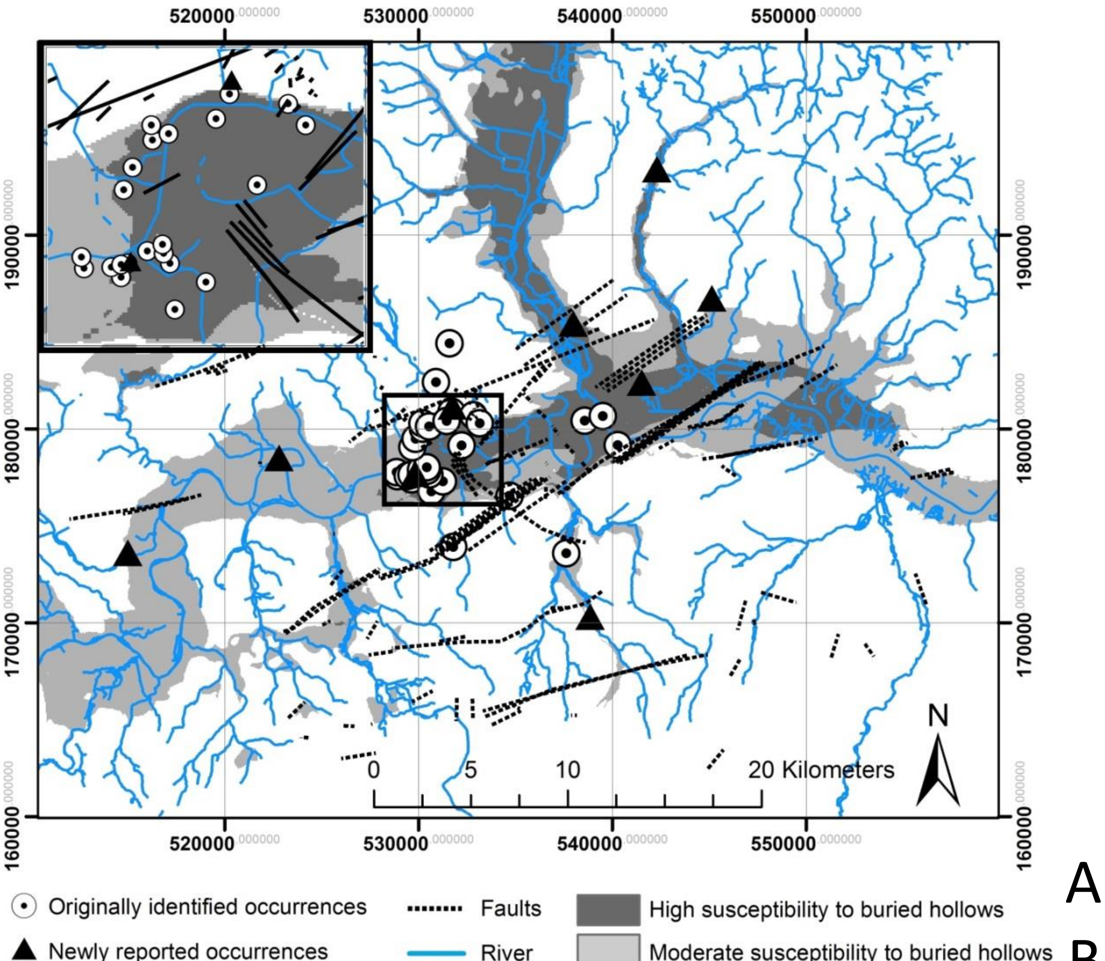


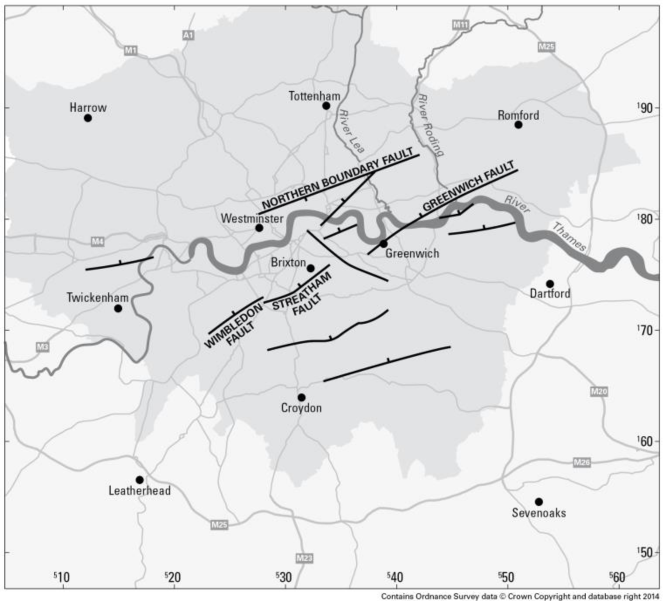
Mottled beds

Susceptibility layer development

3 Combining the GIS layers

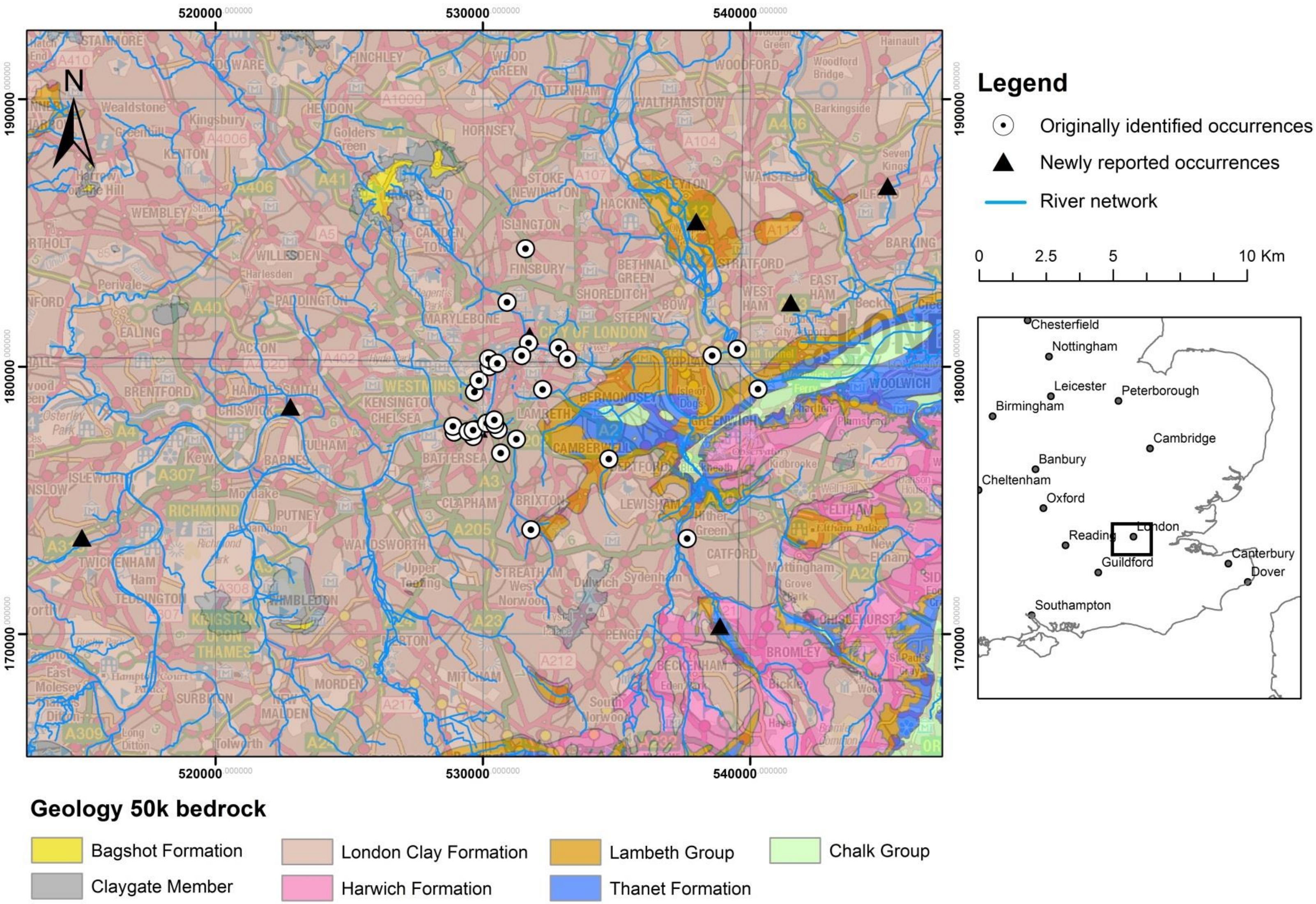
Of the 31 buried hollows:
65% zone A
19% zone B





Susceptibility layer development

4 Validation



Limitations of the approach

1. Process of formation remains equivocal; susceptibility to different processes is not considered in the layer BUT absence of proven connection through the London Clay is not proof of absence of connection

2. The majority of occurrences are in a small area between Battersea and Charing Cross, an area of 30 km^2. Clustering imposes a common hydrogeological setting. BUT…hollows within zone A beyond the cluster suggests the criteria may be applied over the wider area

3. Finds associated with development, which may bias the association with the Kempton Park Gravel.

4. Potential **overlap/double accounting** with current contributory factors: Kempton Park Gravel and artesian conditions

5. Only covers **Central London**

6. Quantitative assessment of **faults** has not been included.

7. .

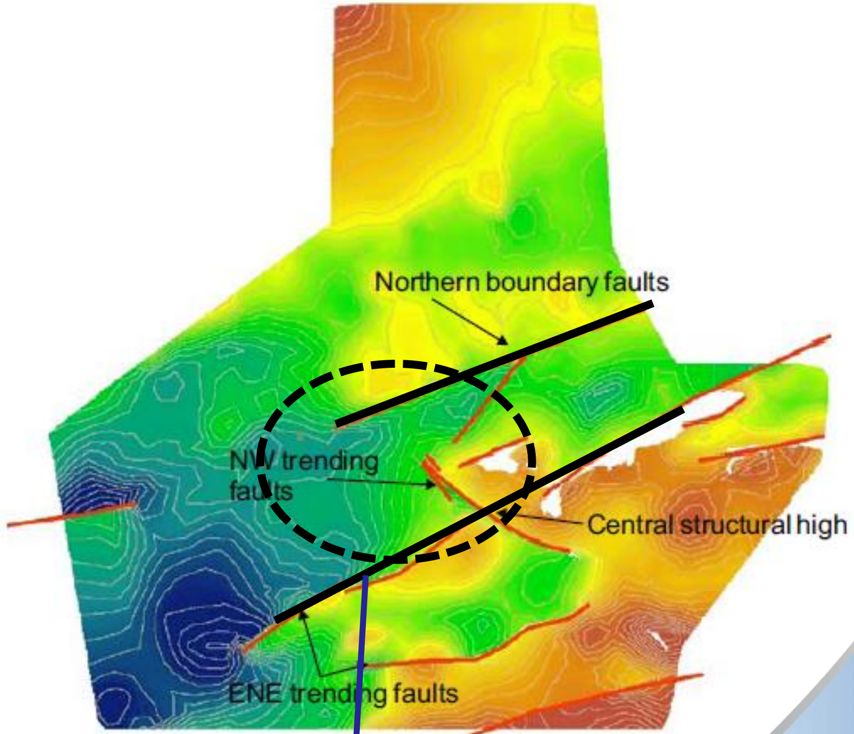
Banks et al. 2015. Anomolous buried hollows

•Presents the susceptibility layer and considers processes

- Asks whether the hollows might be:
    - Scouring
    - Remnant pingos (open and closed)
    - Dissolution features
    - Valley bulging
    - Frost heave and ice wedges
    - Ground ice relics
    - Dual process models
    - Thermokarst processes

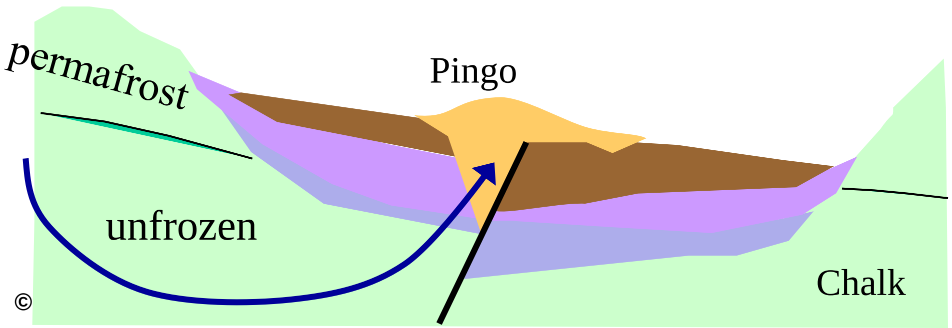
Buried Hollow Association with Faults

- Half of the hollows lie within 1 km of a mapped fault.
- The majority fall between the Northern boundary fault to the north and the Streatham and Greenwich faults to the south



Royse 2010

Fault is barrier to groundwater flow



Dr Jon Busby; Provision of thermal properties data for ground collector loop design.

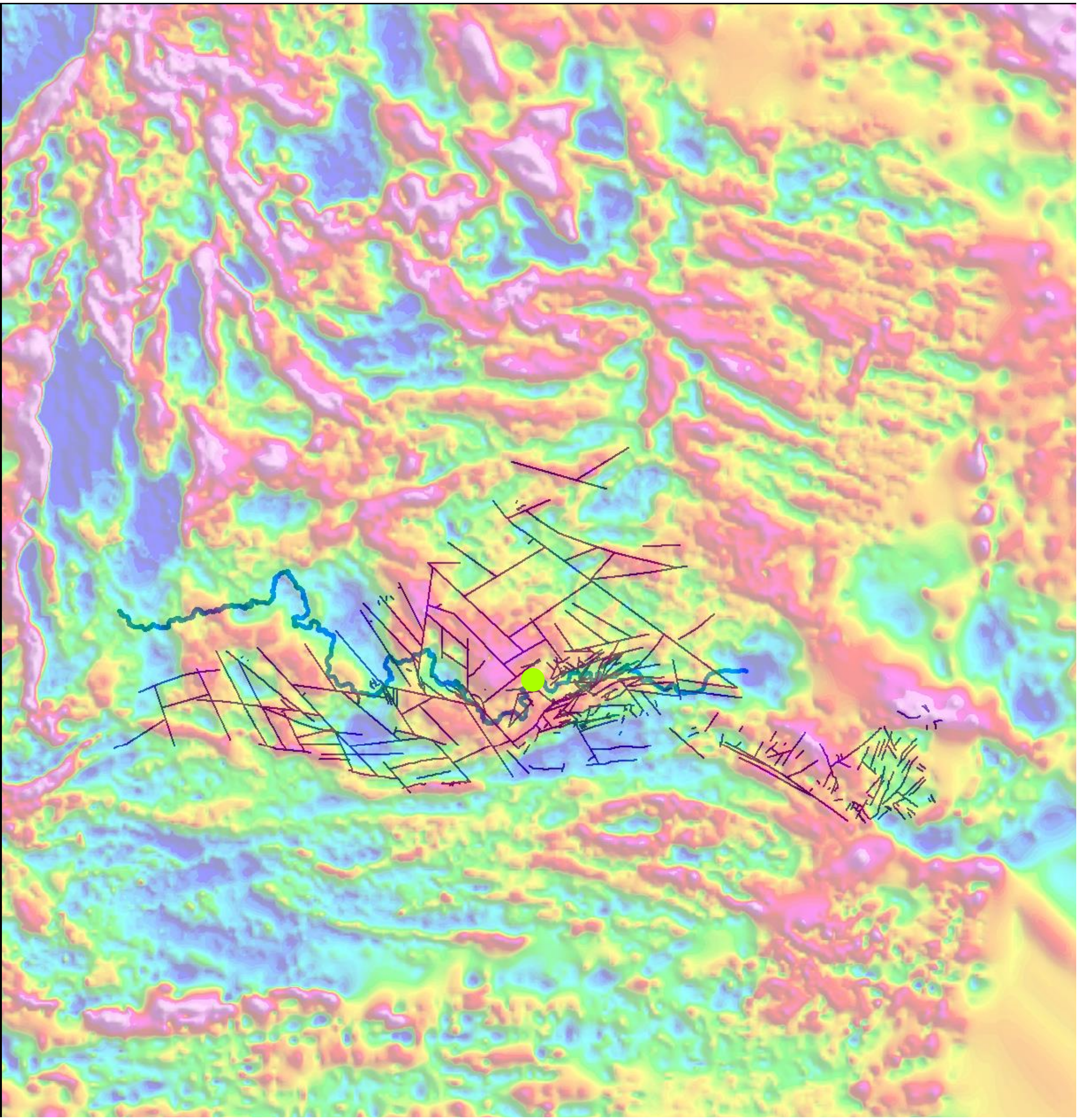
Unit	Thermal conductivity $W\ m^{-1}\ K^{-1}$	Thermal diffusivity $m^2\ day^{-1}$
Alluvium	1.67	0.056
River Terrace Deposits	2.5	0.079
London Clay Formation	1.79	0.0849
Harwich Formation	2.4	0.1206
Lambeth Group	2.2	0.1078
Thanet Sand	2.35	0.1074
Chalk Group	1.67	0.0745

BGS
1983 -

- 4727 laboratory measurements
- Parent material and texture
- UK based tables of thermal conductivity
- Available through GeoReports

Potential for permafrost modelling

- Evidence to support the thermokarst hypothesis – thermal properties of strata, but the situation is moe complex and needs to take account of advection and latent heat effects
- Potential for contemporaneous neotectonic research (de Freitas, 2009)
- And requires modelling of groundwater levels during the Quaternary
- Potential PhD topic?
- BGS host s permafrost modeler Johanna Scheidegger who would be interested to collaborate on this topic

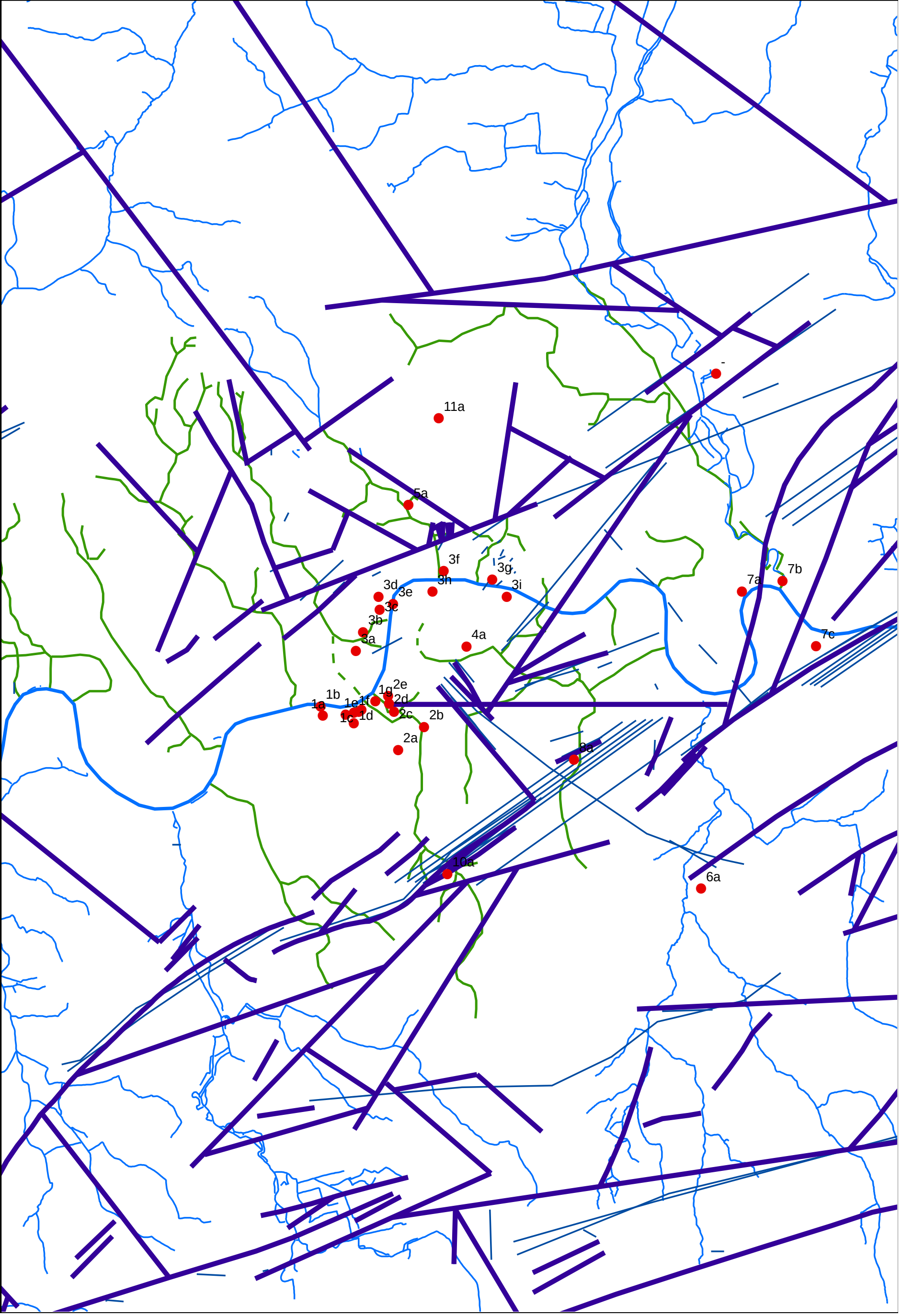


Dr R Haslam Fault mapping

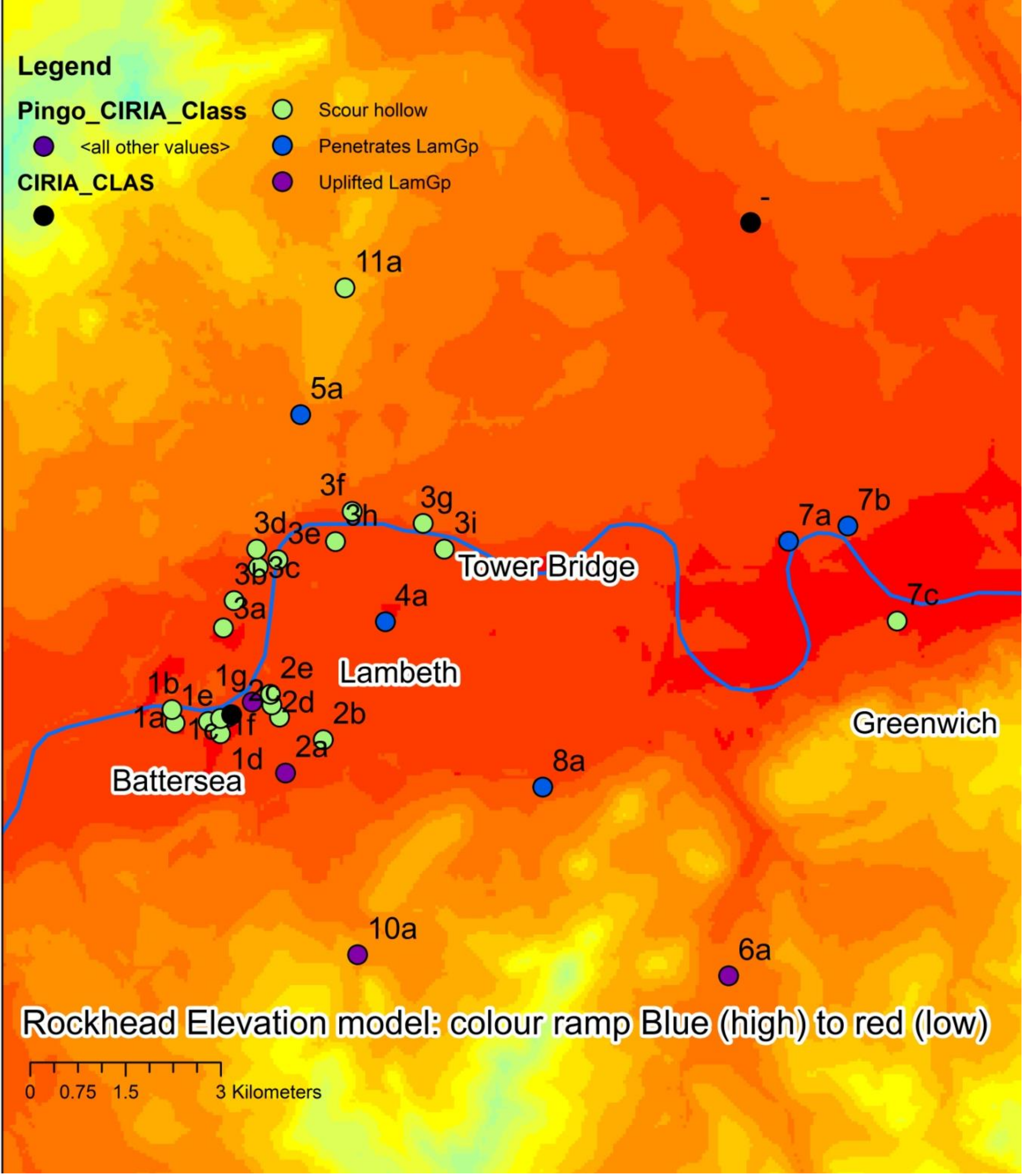
BGS

2012 -

Fault mapping

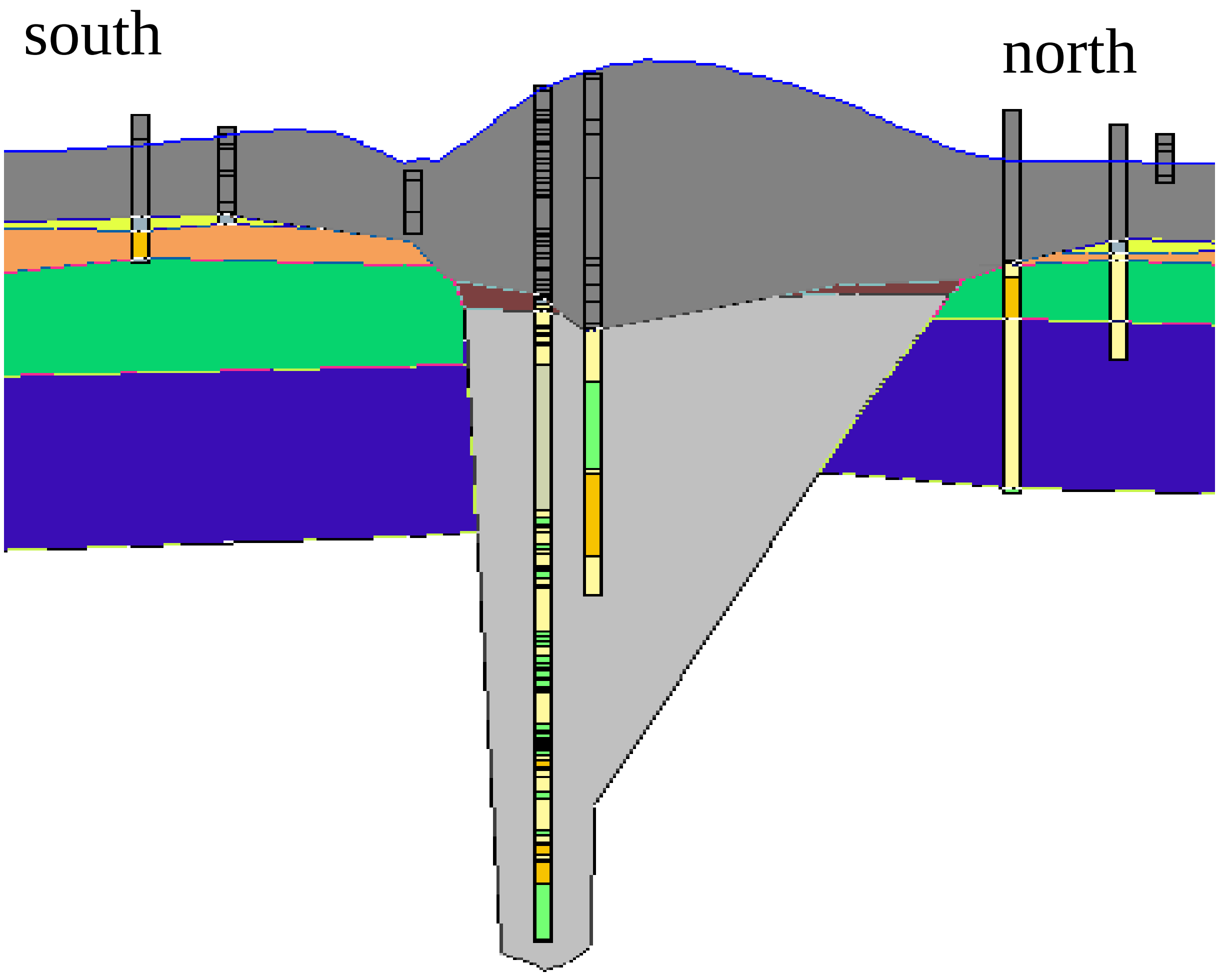


Ricky Terrington Rockhead model



BGS
2001 -

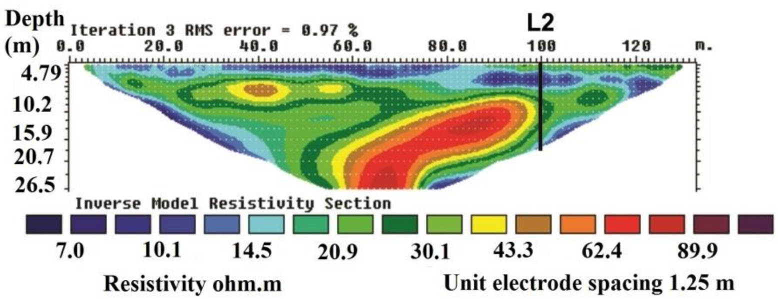
Aldiss 3D modelling with potential follow up by Terrington



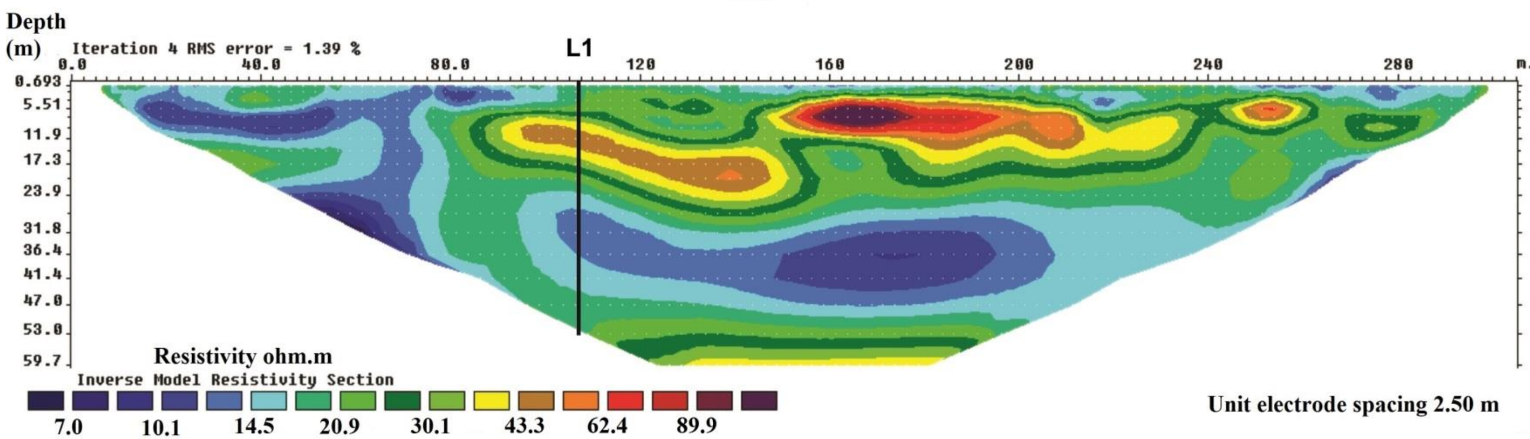
Brunel collaboration – geophysics: Chambers et al., geophysics for detection

BGS
2000 -

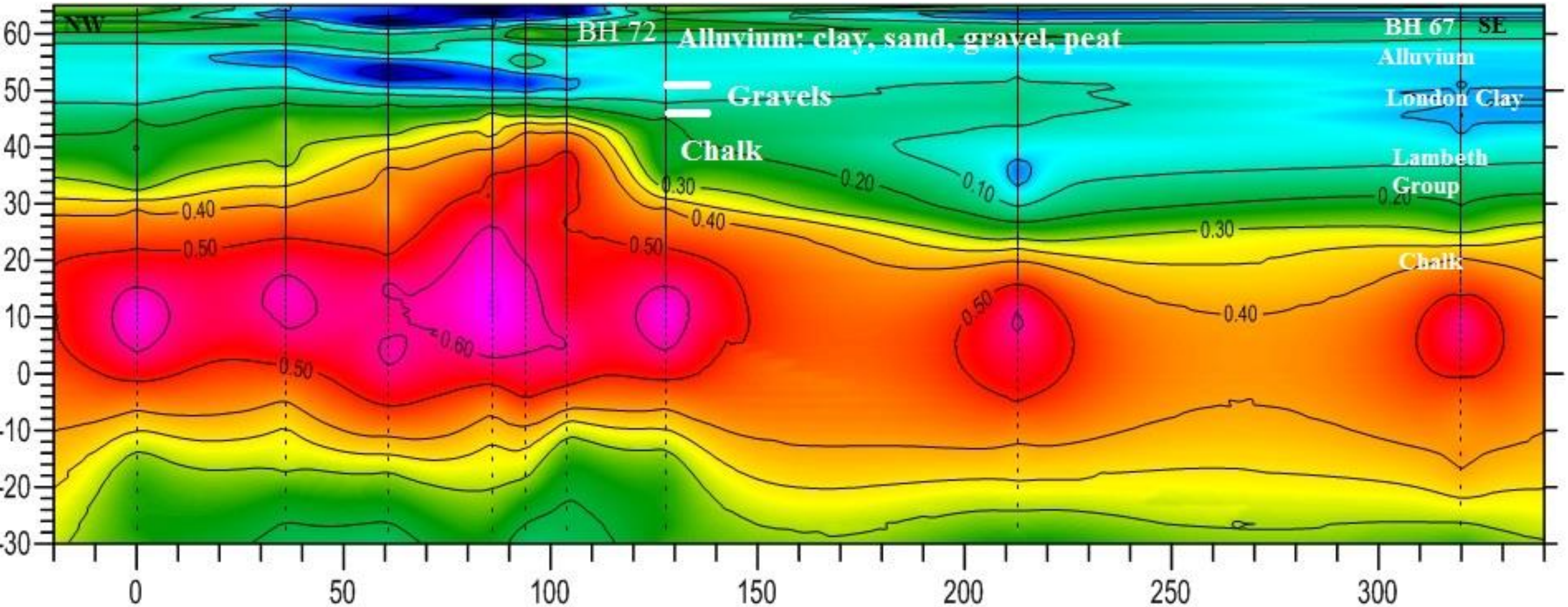
Line 1



Line 2



Application of passive seismic: *Tromino*



Lee et al., Quaternary heterogeneities

BGS
2003 -

- The project aims to develop a series of thematic data sets based upon a range of Quaternary 'features' that may produce geological heterogeneity (distinctly non-uniform properties) in the known properties of the shallow sub-surface.
- Development of a spatial index showing the susceptibility (rather than known occurrence) for specific features to be present based upon a range of geological, topographic and process-based rules.

- National-scale datasets to be developed for:
  - Drift filled hollows
  - Buried valleys
  - Blockfields and frost weathering
  - Deformed glacigenic terrains
  - Regolith (weathered bedrock)

Conclusions

- Two groups of buried hollow: scours and “rooted” hollows.
- There is not always sufficient evidence to discriminate
- BGS has had a prominent role in recording the features
- BGS has ongoing research that potentially feeds in to process understanding
- There are collaborative PhD opportunities

References:

ALDISS, D.T. 2013. Under-representation of faults on geological maps of the London region: reasons, consequences and solutions. Proceedings of the Geologists Association, 124, 6, 929-945.

BANKS, V. J., BRICKER, S. H., ROYSE, K. R., & COLLINS, P. E. F. 2015. Anomalous buried hollows in London: development of a hazard susceptibility map. *Quarterly Journal of Engineering Geology and Hydrogeology* 48, 1, 55-70. *http://doi:10.1144/qjegh2014-037*

BLUCK, B.J., GIBBONS, W. AND INGHAM J.K. 1992. Terranes. In: Cope, J.C.W., Ingham, J.K. and Rawson, P.F. (eds) 1992. *Atlas of Palaeogeography and Lithofacies.* Geological Society, London, Memoir **13**, 1-4.

BUSBY, J., LEWIS, M., REEVES, H. & LAWLEY, R. 2011. Initial geological considerations before installing ground source heat pump systems. *Quarterly Journal of Engineering Geology and Hydrogeology*, **42**, 295–306.http://doi.org/10.1144/1470-9236/10-049

BERRY, F G. 1979. Late Quaternary scour-hollows and related features in central London. *Quarterly Journal of Engineering Geology*, Vol. 12, 9-29

DE FREITAS, M.H., 2009. Geology; its principles, practice and potential for Geotechnics. Quarterly Journal of Engineering Geology and Hydrogeology 42, 397-441.

ELLISON, R.A., WOODS, M.A., ALLEN, D.J., FORSTER, A., PHAROAH, T.C. & KING, C. 2004. *Geology of London. Memoir of the British Geological Survey, Sheets 256 (North London), 257 (Romford), 270 (South London) and 271 (Dartford) (England and Wales)*. British Geological Survey, Keyworth, Nottingham.

ENVIRONMENT AGENCY. 2013. Management of the London Basin Chalk Aquifer, Status Report 2012. Cat. code LIT 7108. http://cdn.environment-agency.gov.uk/LIT7108_d84693.pdf (accessed online 7 April 2014).

FORD, J.R., MATHERS, S.J., ROYSE, K.R., ALDISS, D.T. & MORGAN, D. 2010. Scientific discovery and realisation through 3D geological modelling, with examples from the UK. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften*, **161**, 205–218.

LEE, J R AND ALDISS, D T. 2011. Possible Late Pleistocene pingo development within the Lea Valley: evidence from Temple Mills, Stratford, East London. *British Geological Survey Commercial Report, CR/11/033. 25pp.*.

MACKAY, J.R. 1985. Pingo ice of the Western Arctic Coast. *Canadian Journal of Earth Sciences*, **22**, 1452–1464.

ROSE, J., TURNER, C., COOPE, G.R. & BRYAN, M.D. 1980. Channel changes in a lowland river catchment over the last 13000 years. *In*: Cullingford, R.A.,Davidson, D.A. & Lewin, J. (eds) *Timescales in Geomorphology*. Wiley,Chichester, 159–175.