Smart Geotechnics for Smart Societies – Zhussupbekov, Sarsembayeva & Kaliakin (Eds)

Assumptions and reality in ground models – the case of drift-filled hollows and associated subsurface features in London, United Kingdom

A.L. Flynn
Robert Bird Group, London, UK

P.E.F. Collins
Department of Civil and Environmental Engineering, Brunel University London, UK

ABSTRACT: The subsurface of London is often assumed to be relatively simple, with Late Cretaceous and Palaeogene strata sitting within and forming a synclinal structure (the London Basin). The surface has been modified by mostly fluvial processes during the Quaternary.

More recently, a picture of more complex conditions has begun to be developed, largely driven by the need for deeper foundations, groundwater control and tunnelling. One group of significant features are referred to as 'drift-filled hollows' (DFH). These are commonly closed depressions in the surface of the bedrock (typically the London Clay Formation), that are infilled by later deposits. Adjacent and underlying strata is sometimes disturbed

A new database shows that DFH are more widespread than previously thought, but also highlights issues in how they are classified. It also raises questions about the validity of the 'simple' geological model of London and highlights the danger of using assumptions when planning development, and for reconstructing past events.

1 INTRODUCTION

Understanding subsurface conditions is essential for infrastructure development and is integral to design codes such as Eurocode, where structures must "sustain all actions and influences likely to occur during execution and use" (BSI 2010, p26). Frequently, this understanding is expressed as a ground model that incorporates a range of site geological, hydrogeological and geotechnical information. Importantly, as proposed in the current draft of Eurocode 7 (under review, BSI 2022), the degree of ground variability and uncertainty must be acknowledged. This paper explores how ground variability and uncertainty can be affected by assumptions, particularly in contexts such as the London region in southern England where there is a long history of ground investigation and ground conditions are sometimes *believed* to be predictable. To aid this, a new compilation and assessment of data is presented.

2 STUDY AREA

2.1 *The assumed regional geological model*

The geological model that forms the start point of many ground investigations in the London region was first developed in the 19th Century (e.g. Reynolds 1849), and subsequently added to by many authors (e.g. Wooldridge and Linton 1939; Sumbler 1996; Royse et al. 2012).

DOI: 10.1201/9781003299127-121

This was originally based on surface exposures, small quarries and water wells. More recently, boreholes have been drilled for water and increasingly as part of site investigations, with around 80,000 records now available within the London area.

The generally-followed regional model is of a Palaeozoic basement, unconformably overlain by Cretaceous clays, sands and permeable Chalk. Overlying these is a suite of Palaeogene and Neogene strata, the most widely known of which is the London Clay. The Cretaceous and Palaeogene/Neogene strata form a syncline-like structure, with Chalk hills to the north, south and west, while the Chalk generally occurs at depth in the central London area. The current geological structure is traditionally interpreted as being the result of fairly gentle compression and folding between the later Cretaceous and the Miocene.

During the later Neogene, and particularly during the Quaternary, denudation formed the valley of the river Thames and its tributaries. The northern margin of the area was glaciated approximately 0.45 Ma before present but the area has experienced a periglacial climate for much of the past million years or so. River deposits, principally sand and gravel, are widespread as a series of terrace units (Gibbard 1985, Bridgland 1994). During warmer periods, a range of finer alluvial soils and peat was deposited. These occur locally within the river terrace deposits and beneath the modern floodplain. The modern surface is often characterized by human modification and is often referred to as 'made ground'.

2.2 *Recent modifications to the geological model*

Progressive improvement in ground investigation methods, and the availability of evidence, has permitted additional, principally local, detail to be added to the general geological model. For example, a significant number of high-quality borehole, tunnel and groundwater records have been collected as part of the Crossrail project (see e.g. Davis 2016). This has particularly improved understanding of the stratigraphy, showing that the Palaeogene strata under central London are spatially and vertically complex (e.g. Edgar et al. 2022).

The new attention paid to the detail of borehole and other data has also shown that there is, at least locally, structural complexity (e.g. Newman 2022) with a variety of faults that affect ground properties and drainage.

2.3 *Anomalous near surface features – drift-filled hollows*

Variability in the thickness of superficial deposits resting unconformably on Palaeogene strata in and beyond central London is well known (Berry 1979; Hutchinson 1980, 1991). There have been several investigations of individual features where an apparently closed depression in the basal Quaternary unconformity is infilled by an anomalously thick sequence of superficial deposits (e.g. Hawkins 1952; Collins et al. 1996; Lee and Aldiss 2012; Davis et al. 2018). Some, but not all of these features include significance disturbance of the Cretaceous and Palaeogene strata that they overlie, including diapiric structures, or are close to faulting. Some are known to penetrate through some or all of the Palaeogene strata to reach the Cretaceous Chalk. The term 'drift-filled hollows' (DFH) is generally used when this type of feature is encountered in London.

Potential risks associated with drift-filled hollows are due to significant horizontal and vertical variability in ground properties, including permeability and bearing capacity. There is also uncertainty over whether the features are all the result of past processes, or whether some are still actively developing, or could be reactivated in the future. As exploitation of deeper geology increases for deep foundations, excavations, tunnelling, and geothermal energy, it is important that the current uncertainty around these features is addressed.

Although many drift-filled hollows have been reported, detailed studies have been typically based on individual features, with different researchers dealing with apparently unique features. There is a need to consider them more holistically to see if there are common patterns.

Berry (1979) identified several drift-filled hollows in central London and attributed them to river scour. A similar scour hypothesis was proposed by Rose et al. (1980). In contrast, Hutchinson (1980, 1991) proposed a more complex suite of processes including artesian pressure, valley bulging and particularly ground ice growth and decay (i.e. pingos). In a study to the west of London, Collins et al. (1996) considered a series of drift-filled hollows underlying the modern floodplain and valley-side river terrace deposits, and concluded that localized subsidence, possibly linked to passive (and possibly active) tectonic control was the dominant process. The robustness of evidence for massive ground ice in the hollows in central London was questioned by Collins (2013; also Banks et al 2015) as typical and unambiguous diagnostic features had not been found.

The review by Banks et al. (2015) of drift-filled hollows in central London identified some geographical clustering which supported Hutchinson's (1980) identification of areas most likely to have a drift filled hollow present i.e. areas where impermeable strata are thinner, and a confined/artesian aquifer.

New evidence continues to add to understanding, with the most recent compilation first reported in Flynn et al. (2020) and completed by Flynn (2022).

3 APPROACH

In the most recent work (Flynn 2022), a rigorous re-evaluation of existing evidence was completed with a deliberately non-genetic methodology that minimized the risk of interpretive bias. The bulk of the data was retrieved from the British Geological Survey's GeoIndex database (BGS 2020), with supplementary evidence provided through new site research, industry collaboration and a limited number of published studies e.g. Davis et al. (2018) who provided tunnel face logs.

Data quality was variable and required critical assessment and, where appropriate and possible, confirmation with other evidence. Records that did not meet strict quality criteria were excluded. A new database was established to manage the data and analysed using the ArcGIS 10.5.1 software. Features identified through this new analysis were named using a numbering system to a) maintain interpretative distance from previous work and b) retain confidentiality for sites where required.

4 RESULTS

Collation of the results confirm that the near surface stratigraphy of London is complex. Around 90 features that meet one or more of the commonly-used criteria used to identify a DFH were identified. The detail of the validated evidence collated has allowed the frequency of particular structures often associated with DFH to be assessed (Table 1).

Table 1. Number of features identified with the given characteristic (total of 87 features).

	Present	Absent	Unknown
Diapir	13 (15%)	14 (16%)	60 (69%)
Faulting	18 (21%)	6 (7%)	63 (72%)
Hollow penetrates through Palaeogene strata	25 (29%)	51 (59%)	11 (12%)
Full depth of feature known	34 (39%)	29 (33%)	24 (28%)

What is clear is that, even with higher than normal levels of site investigation evidence, potentially significant information is frequently absent in the assessment of ground conditions for development.

Where DFH depth can be reasonably reliably established, most appear to occur a continuum between a few metres to around 30 m depth. A number are noticeably deeper, with the deepest being in excess of 70 m.

The majority of the DFH occur beneath the floodplain and later Pleistocene river terraces, with the majority of the infilling materials including river gravels and alluvium, sometimes featuring disturbance since deposition. Known DFH hollows are spatially clustered mainly in central London, with a second group in eastern London and fewer in West London (Figure 1).

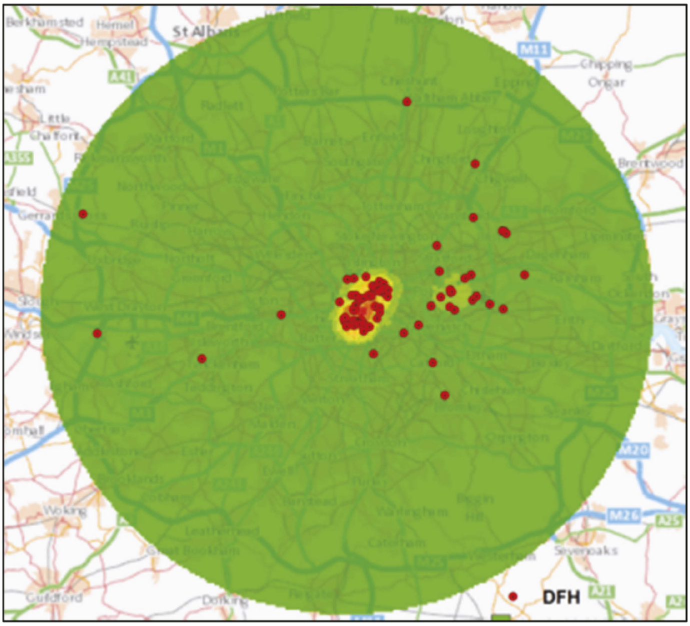

Figure 1. Heat map showing the distribution of known Drift Filled Hollows. The map is centered on central London.

5 CONCLUSIONS

The new, extended dataset confirms that Drift-filled Hollows are a common feature of near-surface geology in London. Sampling bias, due to the overall distribution of data points may mean that areas which show low frequency of features may simply reflect a paucity of data. This is most likely to be the case in the outer parts of the circle shown in Figure 1, where development has been less intense, but is probably a less significant factor for much of the mapped area.

There is some indication that the features are clustered, suggesting one or more spatial controls. Single climate influences, such as hypothesized permafrost and ground ice, or controls such as scour at river confluences might be expected to create a more uniform distribution, particularly along the valley floor. Similarly, simple geological controls such as the thickness of the impermeable London Clay might be expected to produce linear strips of DFHs.

A more likely explanation is that the distribution of DFH is, in part, controlled by linear geological structures, such as faults. Detailed investigations, often related to tunnelling e.g. Linde-Arias et al. (2018) and Morgan et al. (2021), show that such structures are more common than previously thought. These may have interacted with factors such as ground ice, localized erosion and geological material characteristics to allow, in an active or passive fashion, for hollow formation.

The identification of large number of drift-filled hollows, particularly in geographical clusters, provides a useful step forward in helping site developers and engineers assess likely hazards and risk in London. More work is required on the nature and origin of the features to better understand their impact on urban infrastructure and how they generate and influence the "actions and influences" which must be addressed under the Eurocode system.

The presence of such a large number of hard-to-predict ground features in an area such as London, with it's substantial volume of ground data has implications for other regions globally where current assumptions of ground predictability may be masking the true nature of risk.

REFERENCES

Banks, V.J., Bricker, S.H., Royse, K.R. and Collins, P. 2015. Anomalous buried hollows in London: development of a hazard susceptibility map. *Quarterly Journal of Engineering Geology and Hydrogeology*, 48, 55–70, doi: 10.1144/qjegh2014-037.

Berry, F.G. 1979. Late Quaternary scour-hollows and related features in central London. *Quarterly Journal of Engineering Geology and Hydrogeology*, 12, 9–29, doi: 10.1144/GSL.QJEG.1979.012.01.03.

BGS 2020. GeoIndex (onshore). Web tool available at https://mapapps2.bgs.ac.uk/geoindex/home.html (last accessed 11- 09-2022)

Bridgland 1994. *Quaternary of the Thames*. Geological Conservation Review Series, Joint Nature Conservation Committee.

Collins P.E.F., Fenwick I.M., Keith-Lucas D.M. and Worsley P. 1996. Late Devensian river and floodplain dynamics and related environmental change in northwest Europe, with particular reference to a site at Woolhampton, Berkshire, United Kingdom. *Journal of Quaternary Science* 11, 357–375. Doi: 10.1002/(SICI)1099-1417(199609/10)11:5%3C357::AID-JQS250%3E3.0.CO;2-U.

Davis J. 2016. A *geology of London for tunnellers and engineers*. https://learninglegacy.crossrail.co.uk/documents/geology-london-tunnellers-engineers/ last accessed 11- 09-2022.

Davis, J., Soler, R., Hill, N. and Stark, A. 2018. Tunnelling out of a drift filled hollow under Moorgate. Crossrail Project. *Infrastructure Design and Construction*, 5, 237–250.

Edgar J., Ghail R.C., Lawrence J., Skipper J, Mason P.J. 2022. *The impact of facies variability within the Harwich Formation on ground engineering in the London area, UK.* Quarterly Journal of Engineering Geology and Hydrogeology 55. doi: 10.1144/qjegh2020-136.

Flynn A.L. 2022. Drift-filled hollows in the London Basin: Characteristics, Origins and Assessment of Risk. PhD thesis, Brunel University London.

Flynn A.L., Collins P.E.F., Skipper J. A., Pickard T., Koor N., Reading P., Davis J. A. 2020. Buried (drift-filled) hollows in London – a review of their location and key characteristics. *Quarterly Journal of Engineering Geology and Hydrogeology* doi: 10.1144/qjegh2019-145.

Gibbard 1985.

Hawkins, H. 1952. A pinnacle of chalk penetrating the Eocene on the floor of a buried river-channel at Ashford Hill, Near Newbury, Berkshire. *Quarterly Journal of the Geological Society*, 108, 223–260, doi:10.1144/GSL.JGS.1952.108.01-04.11.

Lee, J.R. and Aldiss, D.T. 2012. *Possible Late Pleistocene pingo development within the Lea Valley: Evidence from Temple Mills. Stratford, East London*. CR/11/033 N, British Geological Survey. https://nora.nerc.ac.uk/id/eprint/508854/1/CR11033N.pdf

Linde-Arias E, Harris D, Ghail R. Engineering geology and tunnelling in the Limmo Peninsula, East London. *Quarterly Journal of Engineering Geology and Hydrogeology* 51, 23–30 doi: 10.1144/qjegh2016-116.

Morgan T. Ghail R., Lawrence J. 2021. Major faulting in London: evidence for inherited basement faults in the London Basin. *Quarterly Journal of Engineering Geology and Hydrogeology* 54 doi: 10.1144/qjegh2018-193.

Newman T.G. 2022. Construction geological logging of the Thames Tideway Tunnel beneath central London: unearthing the ground truth. *Quarterly Journal of Engineering Geology and Hydrogeology* 55, doi: 10.1144/qjegh2021-154

Reynolds J. 1849. *Splendid new map of London showing the grand improvements of 1847*. Reynolds, Strand.

Rose J., Turner C., Coope G.R. and Bryan M.D. 1980. Channel changes in a lowland river catchment over the last 13,000 years. in Cullingford R.A., Davidson D.A. and Lewin J. (editors) *Timescales in Geomorphology*. John Wiley & Sons, Chichester. 159–175.

Royse, K.R. de Freitas, M. Burgess, W.G. Cosgrove, J. Ghail, R.C. Gibbard, P. King, C, Lawrence, U. Mortimore, R.N. Owen, H. Skipper, J. Geology of London, UK. *Proceedings of the Geologists' Association* 123 (2012) 22–45

Sumbler M.G. 1996. *London and the Thames Valley*. British Geological Survey.

Wooldridge, S.W. & Linton, D.L. (1939), *Structure, Surface and Drainage in South-east England.* Institute of British Geographers, Publication, 10.