Superficial Hollows and Rockhead anomalies in the Thames Basin, UK: origins, distribution and risk implications for subsurface infra-structure and water resources.

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Abstract:

Recent findings in London show that the subsurface is much more complex than expected, with a number of apparently anomalous features that present a direct hazard to infrastructure development and a risk to groundwater management. Of these features, one of the least understood are the anomalous superficial hollows which occur in the rockhead – in much of the Thames Basin, this is the top of the London Clay Formation – and which are infilled by reworked bedrock and a range of Quaternary deposits, principally alluvial sands and gravels deposited by the River Thames and its tributaries.

The infilled hollows range in size and shape. Several are a few hundred metres across and can be more than 60 m deep. Determining their exact form is problematic as few are subject to thorough site investigation. The sediment infill of the hollows differs substantially from the surrounding ground in terms of strength and drainage, as well as some differences in chemistry. This presents a real hazard to infrastructure as there is a potential for vertical and horizontal movement, flooding, as well as increasing the risk of contamination of the chalk aquifer.

In the paper, the locations and characteristics of known hollows are reviewed and evidence for how they formed is reassessed, considering different hypotheses (scour, ground ice, karst subsidence, seismo-tectonic). From this we consider the implications for continued development of subsurface infrastructure.

Keywords: Quaternary, Deformation, Risk, Infrastructure, Hydrogeology

1 Introduction

Increasingly, infrastructure development in large cities is exploiting the subsurface for key resources and space. Unexpected ground conditions present key risks to projects during construction and operation e.g. due to subsidence (e.g. NCE 1984; Paul, 2009) and groundwater contamination.

In the London area of south east England, a major source of risk is unexpectedly deep sequences of permeable, often unconsolidated Quaternary sediments and soils (sand, gravel, clay, silt, fractured/puttied chalk and peat) which infill anomalous hollows in the rockhead surface. Typically, these occur beneath the floodplain and low terraces of the River Thames and some of its tributaries. Increased interest in these infilled hollows stems from their occurrence in major infrastructure projects e.g. CrossRail and renewed interest in the chalk aquifer water resources of the London Basin. In addition, evaluation of existing and new borehole and exposure data suggests a much greater degree of structural complexity in the geology of the Thames Basin. Several of the known hollows occur at historic water sources and near to newly-identified geological faults.

While the general location of many of the hollows is known, their full geometry is uncertain. A large number of borehole records exist for the London Basin, but these are geographically clustered, often shallow, and often of insufficient quality. As a result, it is probable that several, perhaps many undiscovered hollows remain. It is important to establish both where and why they occur and also to assess if they are potentially active features with respect to sediment accumulation, on-going settlement and hydraulic functioning.

2 Locating and characterising superficial hollows in the Thames Basin

Numerous hollows have been encountered in the London Basin over the past 150 years. These were examined in the 1970s (Berry 1979; Hutchinson 1980), and this catalogue has been updated and digitized by the British Geological Survey as part of the BGS Future Thames project (Figure 1). The digitization of the dataset has enabled the distribution of the hollows to be considered in their geological and geomorphological contexts (Banks et al. in prep). The GIS relates key geographical contexts that are associated with known hollows: proximity to present-day river channels, artesian groundwater conditions, thickness of the confining clay layer, position beneath certain river terraces and proximity to known geological structures. Based on this analysis, a provisional risk evaluation has been produced. This still needs to be refined, not least because knowledge of the location of the known hollows is influenced by a spatially skewed borehole data set. Despite this limitation, this GIS analysis has helped refine some of the major contexts which will have controlled the formation of the hollows.
[insert fig 1 here]

The full characteristics of the superficial hollows and the surrounding strata in the Thames Basin are generally unknown. Those that have a reasonable number of high quality borehole records, including some encountered during the CrossRail project, appear closed with no obvious inlet/outlet. Several are a few hundred metres across and can be up to 60 m deep. Most appear to have elongate forms. Surface sealing precludes access for re-examination. Similar features, however, occur elsewhere in the Thames Basin, most notably in the valley of the River Kennet, a major tributary of the Thames, where several hollows and their surroundings have been studied, both in quarry exposures and using boreholes. These include sites at Woolhampton, Brimpton and Ashford Hill (Figure 2).

[insert figure 2 here]

A detailed reconstruction of the London Clay rockhead at Woolhampton reveals a deep closed hollow with steep margins (Collins et al. 1996). Infilling strata showed evidence of post-depositional tilting towards the centre of the hollow that occurred between ~15 to ~11 ka BP. At nearby Brimpton, a similar hollow was infilled between ~100 - ~74 ka BP (Bryant et al 1983; Worsley & Collins 1995), though no evidence of tilting was reported. A feature at Ashford Hill has been described (Hawkins 1953; Hill 1985), based on boreholes, many of which extend below the base of the hollow. These permit a provisional 3 dimensional reconstruction of the subsurface stratigraphy (Figure 4). The hollow is closed, but extends along the valley floor. Sediments in the hollow, indicate local lacustrine, marsh and fluvial conditions as the hollow formed, followed by subsidence of the hollow's centre and mass movements from the over-steepened margins. Deeper boreholes indicate that a mass of brecciated and puttied Cretaceous Chalk, has penetrated upwards through up to 60 m of Tertiary strata.

[insert figure 3 here]

3 Possible origins

Several hypotheses have been proposed to explain the presence of superficial hollows and associated features in the Thames Basin. These largely rely on assumptions of former conditions and limited data. Based on the features from the Kennet valley, hypotheses for the origin of the hollows can be assessed.

a. 'Pingo' (or related ground-ice form). Regional palaeoclimatic reconstructions suggest that permafrost is likely to have existed at various times. The available data show no evidence of the ramparts that surround many relict and active pingos. Work on active pingos (Mackay 1998) suggest a +/- planar base associated with the maximum depth reached by the massive segregated ground ice – this would not be likely to leave a deep hollow on melting. The infilling sediments suggest ongoing subsidence after hollow formation – at Ashford Hill, this may be continuing to present. The apparent upward migration of deeper bedrock deposits observed at some sites would support the upward flow component associated with pingos.
b. River scour. Some hollows may be due to locally deep erosion in the past. The Kennet hollows do not occur at confluence points, where scour is potentially at a maximum. Several of the hollows are also very deep, penetrating beyond the likely maximum depth of scour.
c. Localised consolidation settlement. The depth of the hollows is too great and the underlying strata are already over-consolidated.
d. Karst subsidence. Dissolution-prone puttied Chalk is present beneath the hollow at Ashford Hill. Boreholes penetrating solid Chalk nearby show the presence of cavities at depth. Both may have contributed as micro-faults, tilting and breccias in the hollow infill suggest that both slow and rapid collapse occurred.

The origin of the Ashford Hill Chalk intrusion (similar features are known in central London), is uncertain. Freeze-thaw associated with the development and decay of permafrost may have been involved, though permafrost depth in former cold stages is uncertain. There is also a lack of experimental studies of how freeze-thaw affects heavily loaded Chalk. However fragments of chalk have been mobilized. Loading was almost certainly involved as movement was towards the valley centre – this may have been through creep as the horizontal gradients are shallow. Upwards movement may have been driven by high groundwater pressures (Hutchinson 1980). A confining permafrost layer might have enhanced this, though cold stage regional groundwater tables may have been lower than present. The Ashford Hill valley appears structurally controlled and upwards movement of the Chalk may have exploited a pre-existing fault or joint. Additional loading to drive this might have come through a seismic event, though this is speculative. Flow structures were found in Chalk samples collected in the 1930s and 1980s, but these might have been due to sampling.

4 Conclusions

The infilled superficial hollows and associated deformations remain problematic. The 'pingo' hypothesis, as a single causal mechanism at least, seems unsupported by the available evidence. Hollow formation can be explained by a simple hypothesis involving dissolution-driven subsidence, though uncertainty remains over the extent of areas affected by this, and whether it remains a significant hazard. A more complete understanding of the risk will only come when the nature and extent of these features is better understood and the processes involved are better constrained.

6 References

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Figures

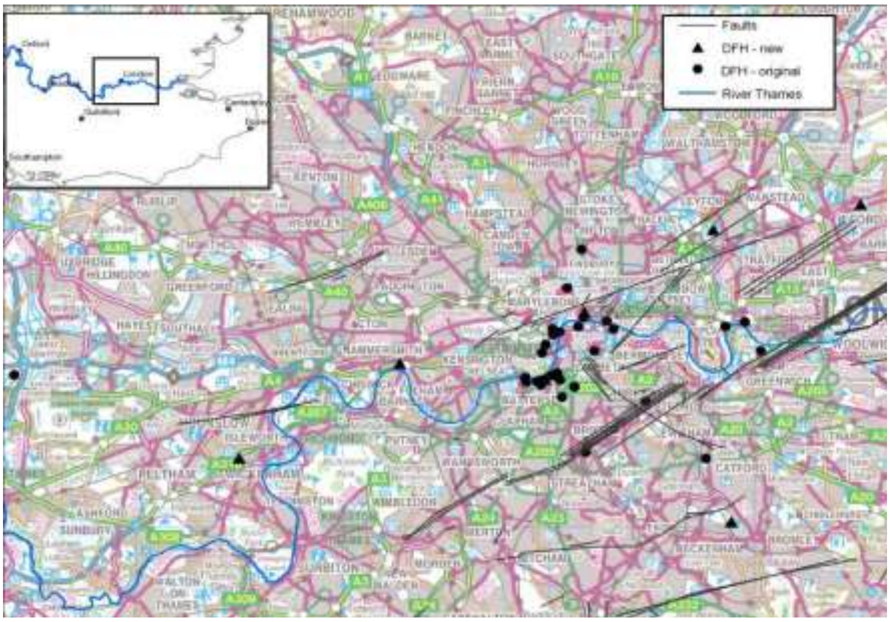

Figure 1. Location of known superficial hollows in London

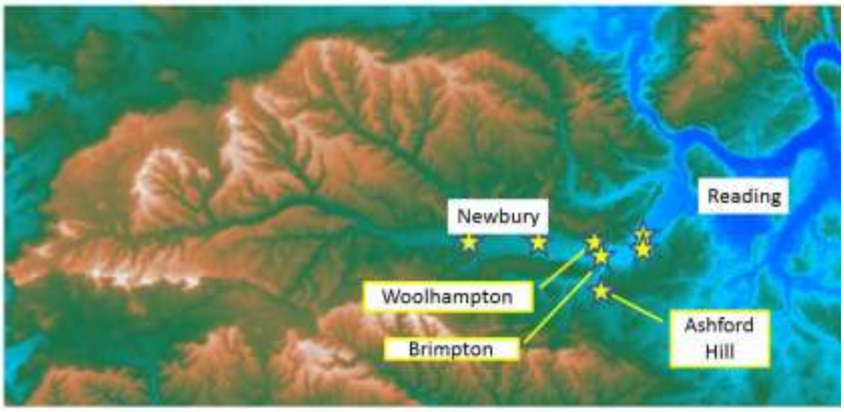

Figure 2. Digital Elevation model of the Kennet valley region, western London Basin (dark blue = low elevation; white = high elevation) showing location of known superficial hollows.

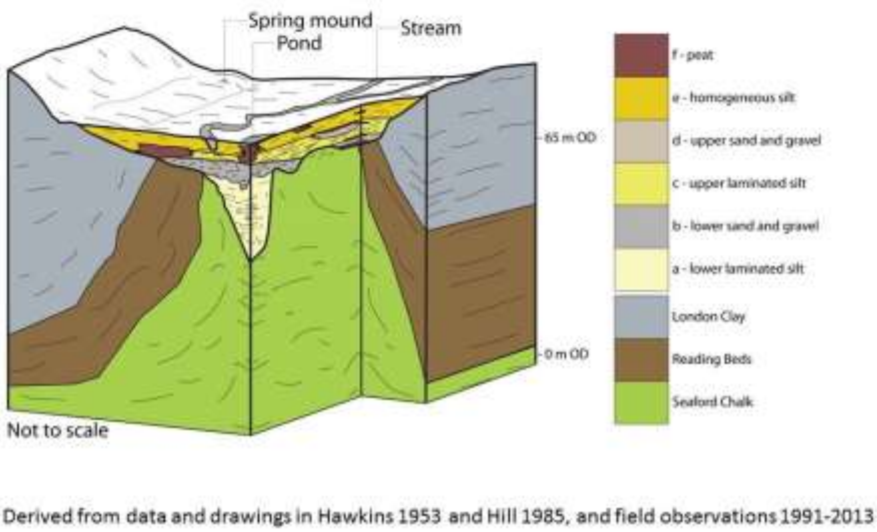

Figure 3. Conceptual ground model for Ashford Hill, showing the superficial hollow and associated deformed strata.