Challenging today.
Reinventing tomorrow.

Relict periglacial hazards in the UK

Engineering guidance for hazard mitigation

Geological Society, West Midlands Group

14 January 2020

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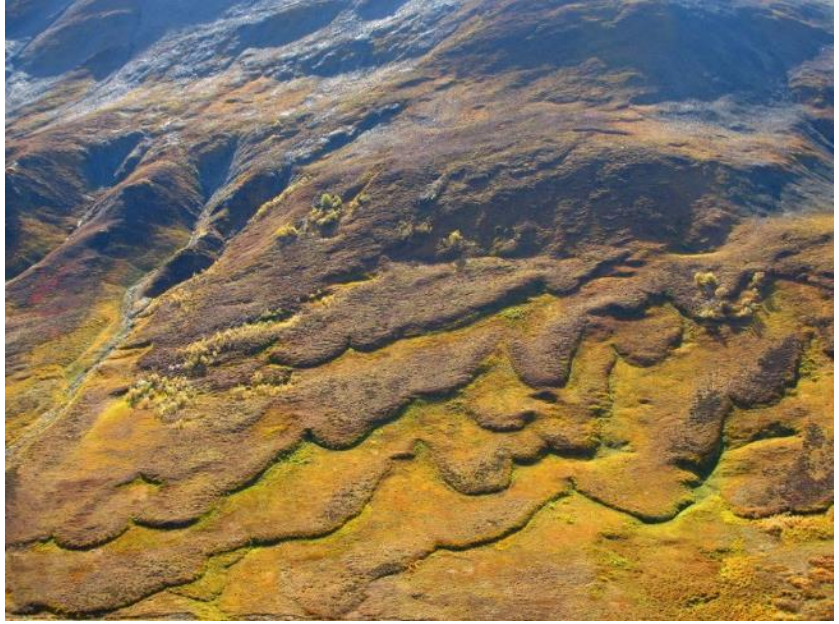
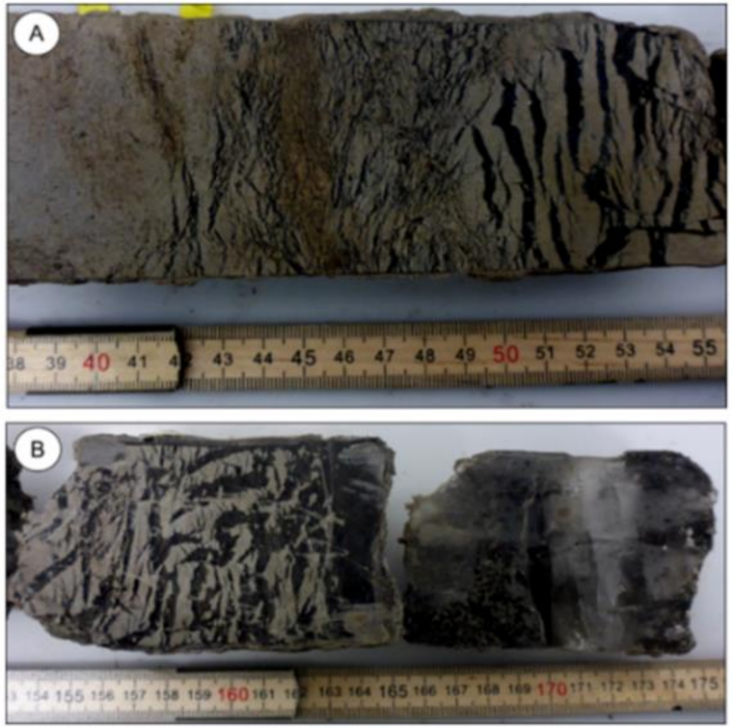
1. The Quaternary Period
2. Relict periglacial geohazards
3. Geotechnical geohazards
4. Managing ground risk
5. Implications for engineering
6. Project examples
7. Collaboration



Solifluction lobes, Arctic Canada



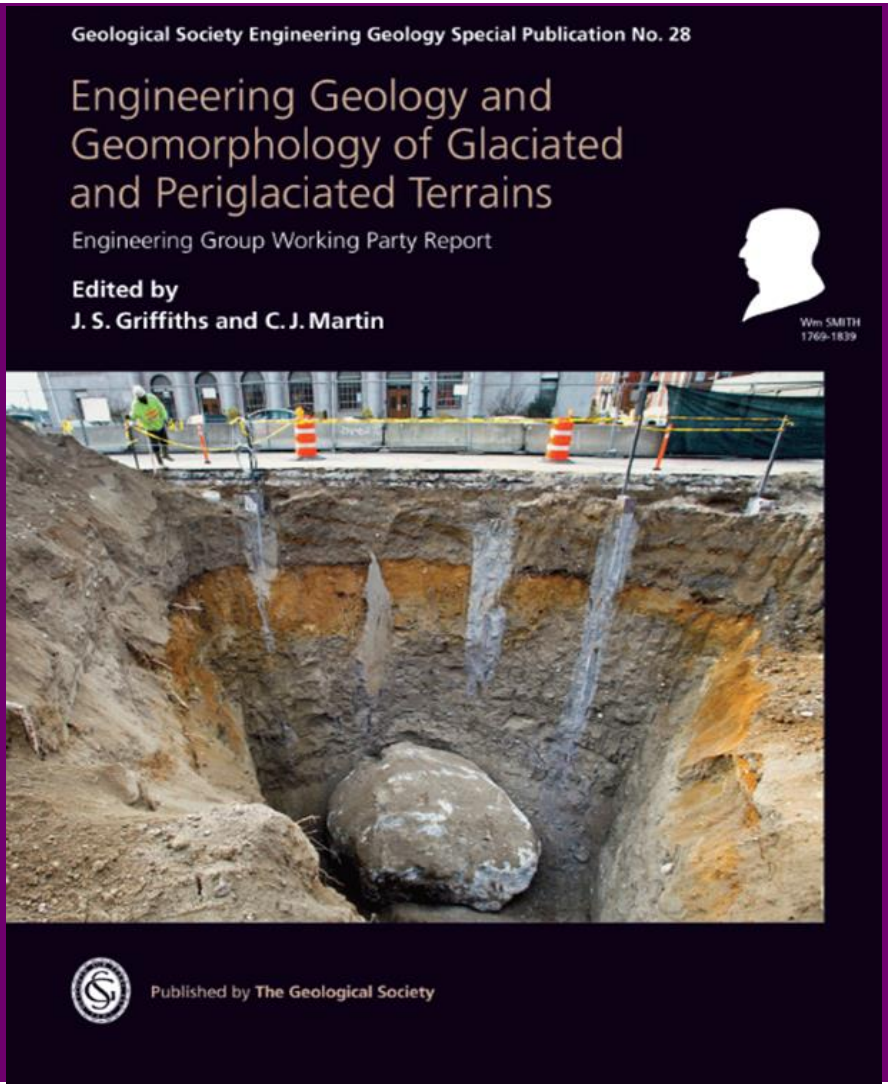
Segregated ice lenses grading downwards to massive-ice in icy sandy-silt, valley fill sediments, Adventdalen, Svalbard. Photo credit: Simon Price

Ice wedge, Arctic Canada

Ice wedge polygons, Alaska

Context

- Griffiths, J. S. & Martin, C. J. (eds) 2017. Engineering Geology and Geomorphology of Glaciated and Periglaciated Terrains – Engineering Group Working Party Report. Geological Society, London, Engineering Geology Special Publications, 28, 501–597.
- Giles, D. P., and Griffiths, J. S., (Eds), (2020) Geological Hazards in the UK : their Occurrence, Monitoring and Mitigation. Engineering Group of the Geological Society Working Party. Geological Society, London. In print.
  - **Periglacial hazards**, landslides, debris flows, karst etc.



Important concepts in Quaternary Science

1. Quaternary Period covers the last 2.6Ma. of the
   1. Holocene (current interglacial, last 11.5ka)
   2. Pleistocene (all past glacial and interglacial periods)

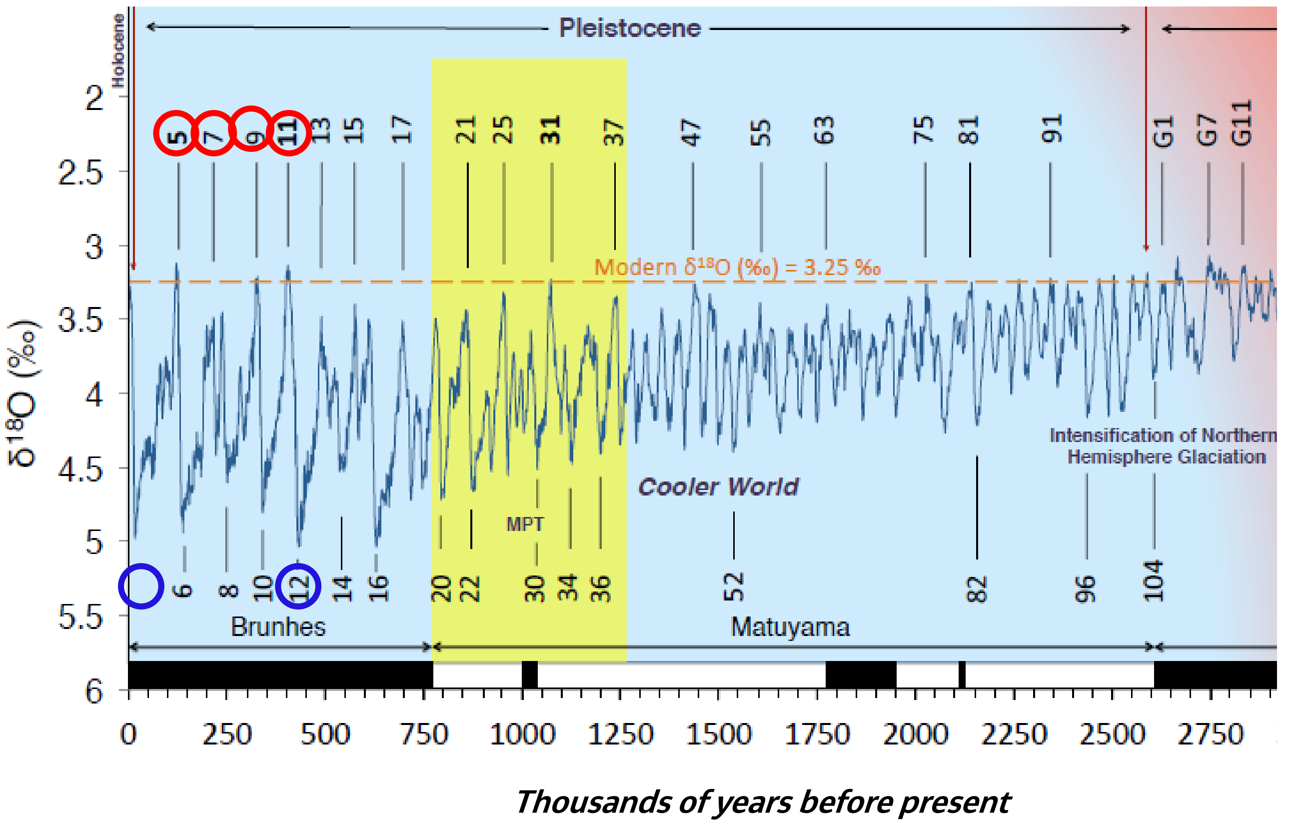
2. Early 20th C Alpine studies suggested four glacial phases with intervening warm periods. No dating, so ages uncertain. Big problems recognising these events beyond the Alps.

3. Study of marine cores (1970s) showed over 50 cycles between cold glacial and warm interglacial periods.

4. These are known as Marine Isotope Stages (MIS). Even numbers are glacial, odd numbers are interglacial. **<u>The cores show over 50 cold periods</u>**.

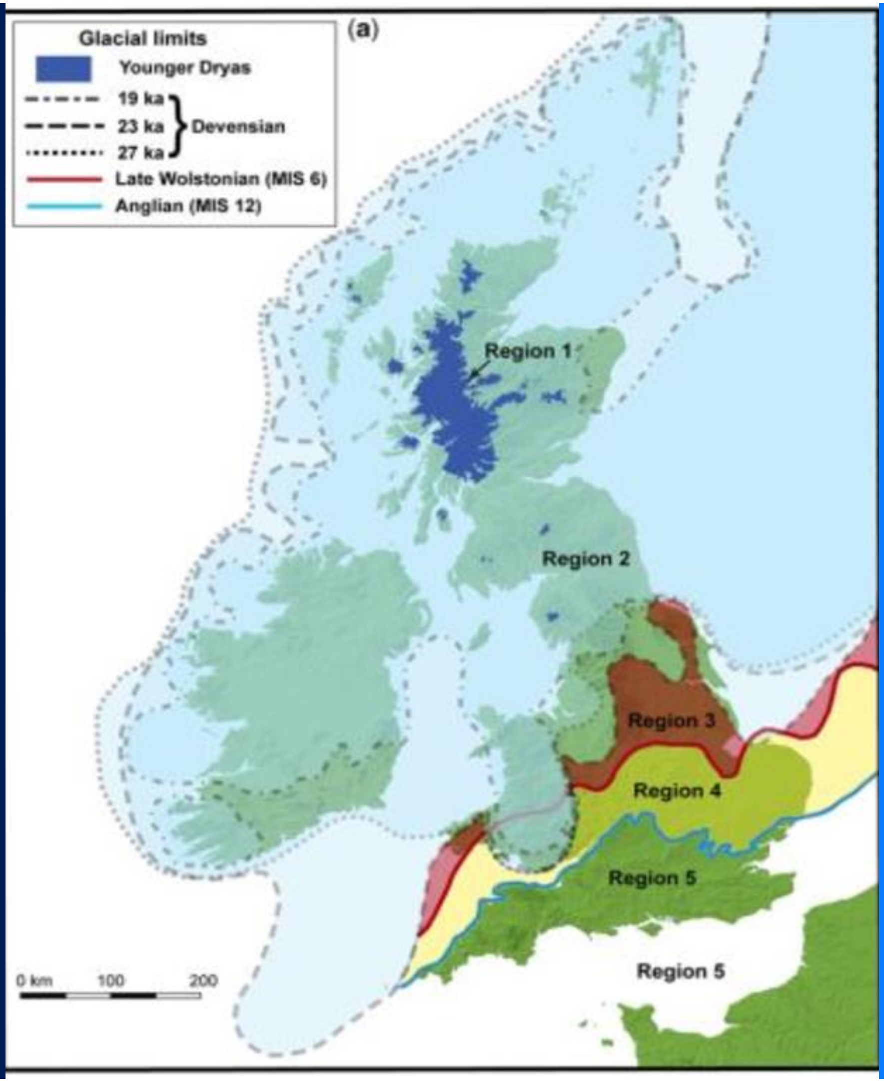
5. Correlating the MIS record with terrestrial sediments and landforms is tricky.

6. In the UK cold periods involved glacial and periglacial processes.



<u>In the UK</u>, glaciations have occurred in:
MIS 12 ('Anglian', c. 450ka BP)
MIS 2 ('Devensian', c. 20ka BP)
Debates over MIS 6, 8 and 10…

Relict periglacial geohazards



- UK wide issue
- Significantly different geohazards depending on location and terrain
- Substantial technical and commercial risk for many civil engineering projects
- Our job as engineering geologists is to describe the "so what?" of periglacial environments, processes and deposits

< Periglacial regions of the UK and Ireland superimposed on a digital elevation model. Figure credit: Murton and Ballantyne (2017)

Landsystems – Murton and Ballantyne (2017)

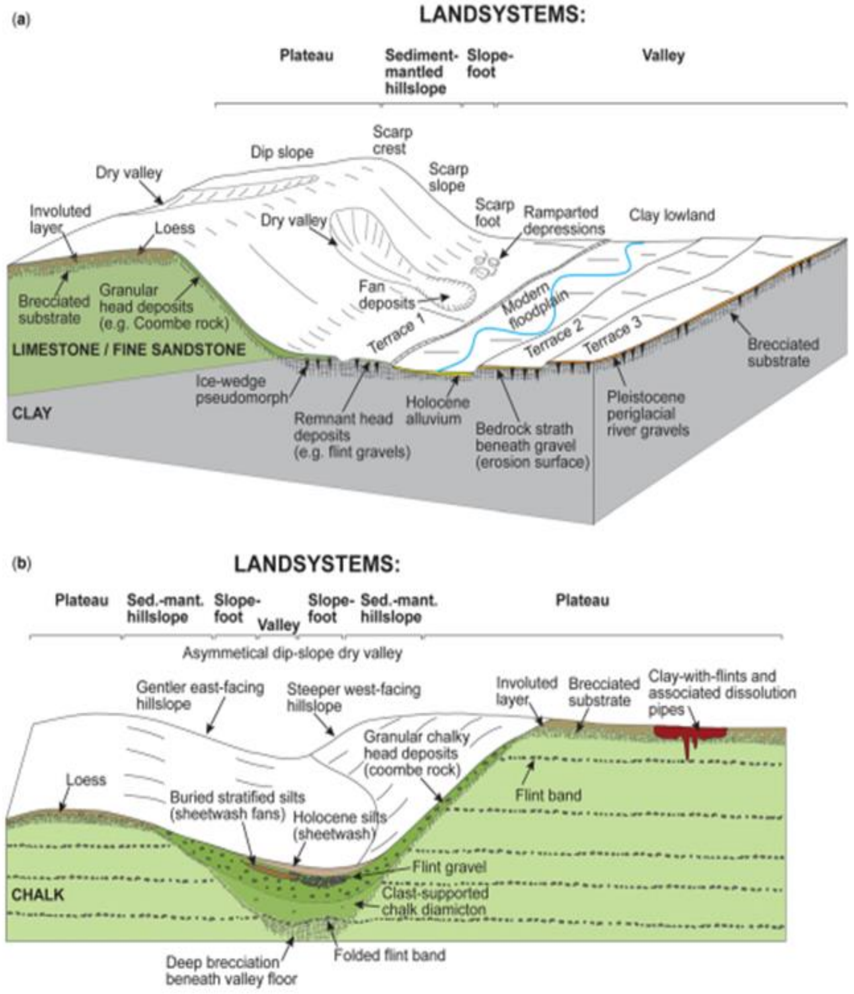


Fig. 5.28. (a) Ground model of limestone plateau-clay vale. (b) Landsystems in the chalklands, where a dry valley is incised into a plateau. Note the greater depth of brecciation beneath the valley floor compared to the plateau. (b) Modified from Mortimore (2014, fig. 6.65).

- A proposed conceptual framework for periglacial landsystems by Murton and Ballantyne (2017)
- Distinguished according to topography, relief and sediment:

Lowland	Upland
Plateau	
Sediment mantled hillslope	
Rock slope	
Foot slope	
Valley	-
Buried	-

Uplands focus for research
Lowland focus for engineering

- Submerged landsystems

< Example landsystems. Figure credit: Murton and Ballantyne (2017)

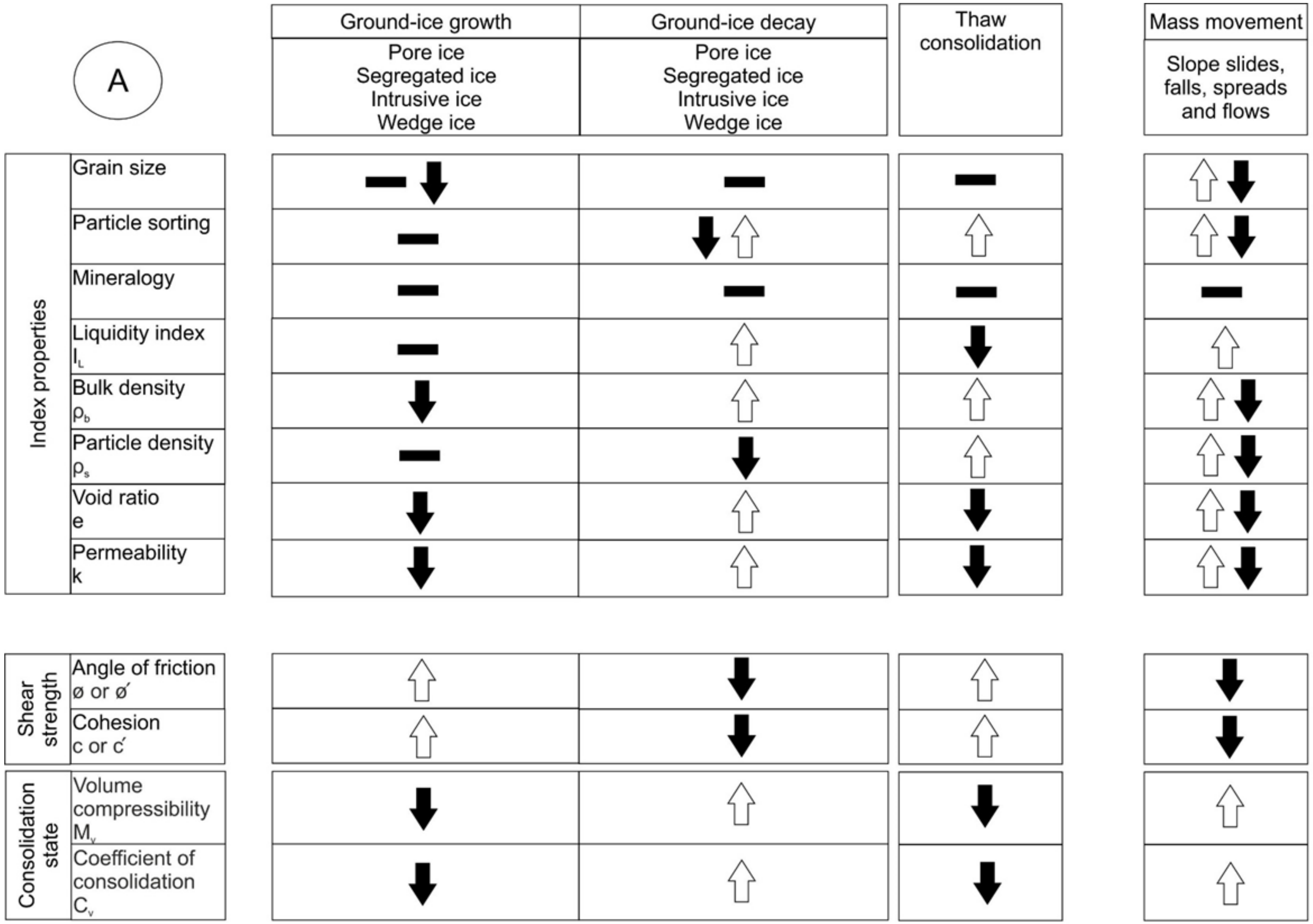
Relict periglacial geohazards

- The most significant relict periglacial features in the UK, in terms of their geotechnical significance, likelihood of being encountered and impact, include:
- - Deep weathering
- - Shallow slope movements
- - Cambering and superficial valley disturbances
- - Rock head anomalies and
- - Cryogenic wedges
- Subsidiary relict periglacial features include: loess, carbonate dissolution, buried valleys and submerged terrains

< Solifluction shears in Oxford Clay, Stoke Hammond. Picture credit: Tom Berry

Geotechnical consequences

- Periglacial geohazards stem from the impact of growth and decay of ground ice on material properties
- Materials must be characterised to understand the nature and extent of changes in parameters
- We can often identify “weathering” in the first few metres but the impact of periglacial process could be deeper and unclear in cores.



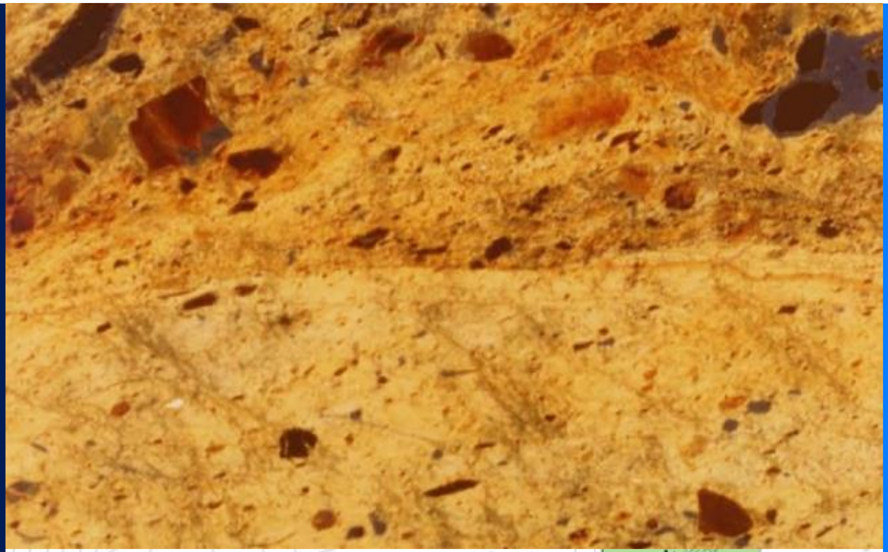
Summary table of some of the geotechnical consequences of the growth and decay of ground ice on geotechnical parameters. Image credit: Simon Price PhD Thesis 2019

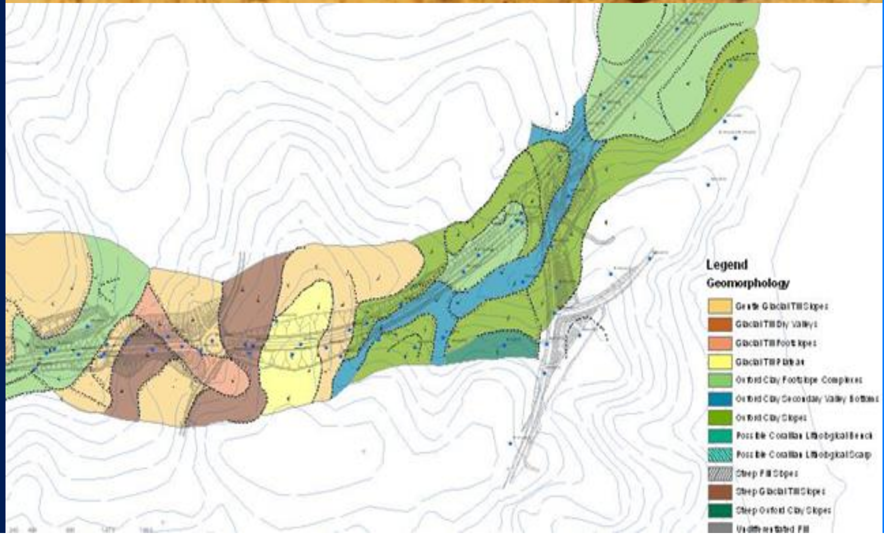
Managing ground risks - Investigations

- Consistent approach as with all engineering projects
- Depth and breadth of investigation tailored to suit the size and complexity of the project and the ground conditions
- Desk study (including LiDAR and Google Earth)
- Walkover survey / geomorphological assessment
- Phased ground investigations
  - Geophysics
  - Intrusive GI(s)
  - Monitoring
- Assessment, analysis and reporting

< Block sampling across a shear surface. Head, near Reading, Berkshire. Photo credit: Tom Berry

Implications for engineering – Detail vs 'lumping'





- We need to understand the detail of periglacial environments, processes and deposits but…
- We must distil the significance to the proposed engineering into broad units for engineering design
- Understand the significance of the geohazard and its impact in the context of:
  - Our ability to make an efficient design change
  - Manage geohazards in design, during operation or during scheduled maintenance
  - Risk / reward balance

Top - Shear surfaces at Walton Wood. Picture credit: Early and Skempton (used without permission)

Bottom - Terrain assessment and example of "Lumping". Picture credit: Tom Berry

Implications for engineering – multiple landsystems

Thames terraces – Drift filled hollows

London Clay – Shallow slope instability, cryogenic wedges

Chalk – Weathering and dissolution

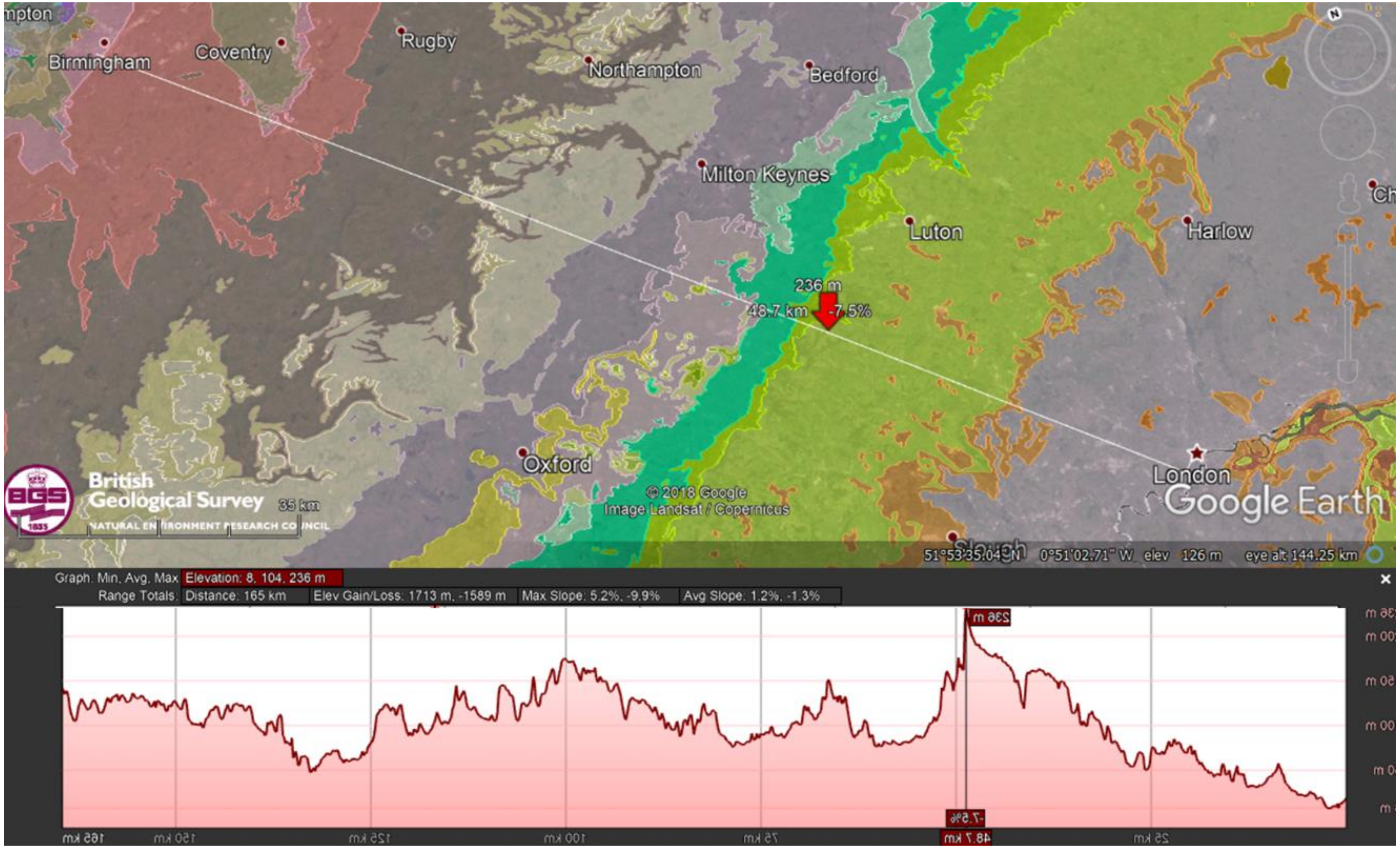
Gault - Shallow slope instability, cryogenic wedges

Upper Jurassic clays - Shallow slope instability,

Great Oolite – Cambering and bulging, shallow slope instability

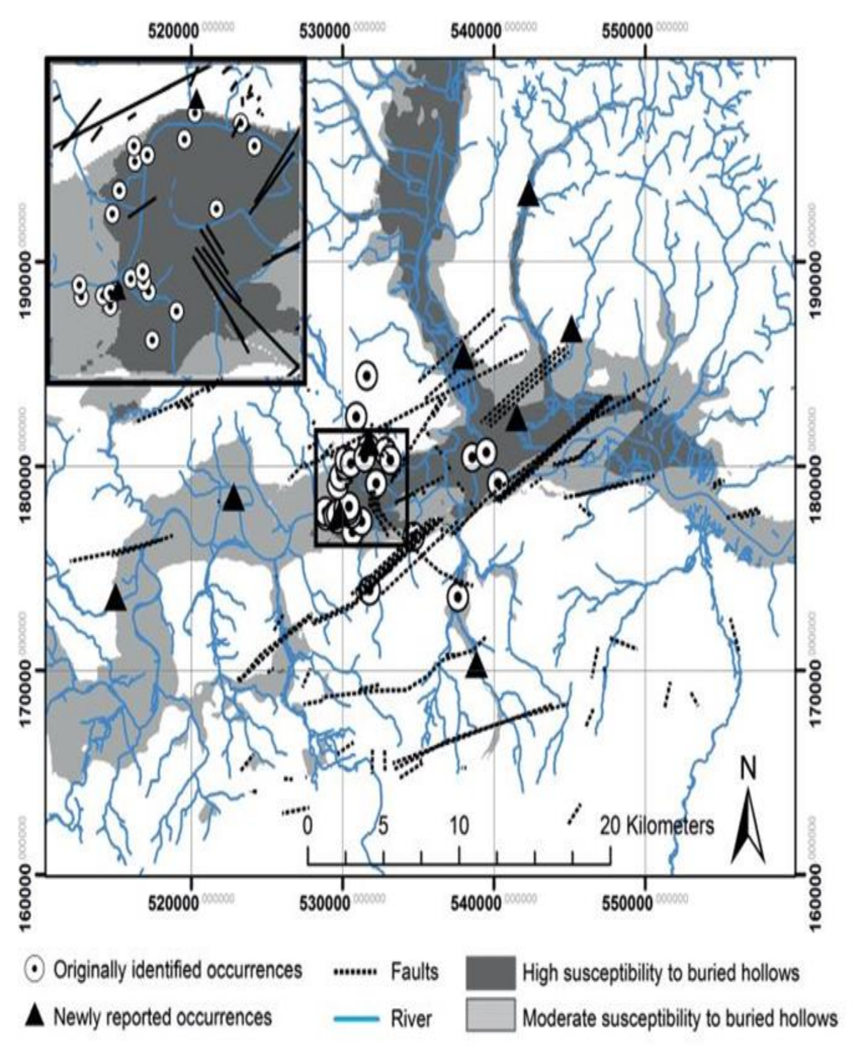
Lower Jurassic Mudstones – shallow slope instability

Mercia Mudstone - shallow slope instability



Variable terrain, geology and periglacial environments and therefore variable geohazards between London and Birmingham.
Picture credit: Reproduced with the permission of the British Geological Survey ©UKRI. All rights Reserved, and Google Earth

Implications for engineering – scale (and time)

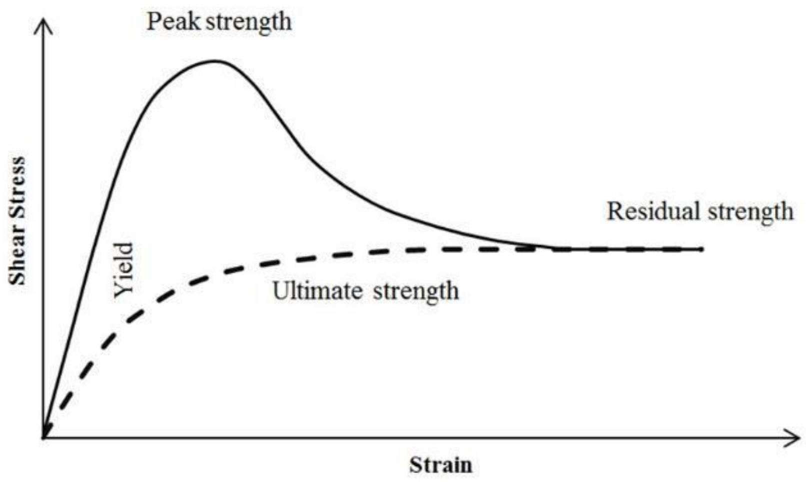


- The previous slide shows a large project but there can be significant changes due to periglacial processes and climates on smaller projects too
- Small building projects can also be significantly impacted by cryogenic wedges, gulls, rock head anomalies, dissolution…
- Future proofing - Changes in precipitation patterns could lead to more water in a system in a steady state leading to reactivation of periglacial shallow slope instability

< Zoned hazard susceptibility map showing rock head anomolies (and faults). Picture credit: Fig. 5. from Banks et al., (2015) BGS©NERC. Contains OS Open data ©Crown Copyright and database rights 2014. Lost rivers of London reproduced from Barton (1992). Reproduced with permission.

Shallow slope movements

- Relict shears can be found on slopes as low as 3 degrees. Can be reactivated if cut or loaded…
- Cryoturbation and frost heave first disturbs the ground reducing clays to residual strength. Season ground ice melting elevates pore-water pressures and leads to detachment.
- Significantly lower shear strength parameters, (cohesion and friction), such that the soils will likely be softer and more compressible than its in situ undisturbed.



Examples of engineering issues – shallow landsliding

"Local" variable geohazards associated with linear infrastructure. West Walton/Ampthill/Kimmeridge Formations, Swinford, Oxfordshire. Picture credit: Google Earth

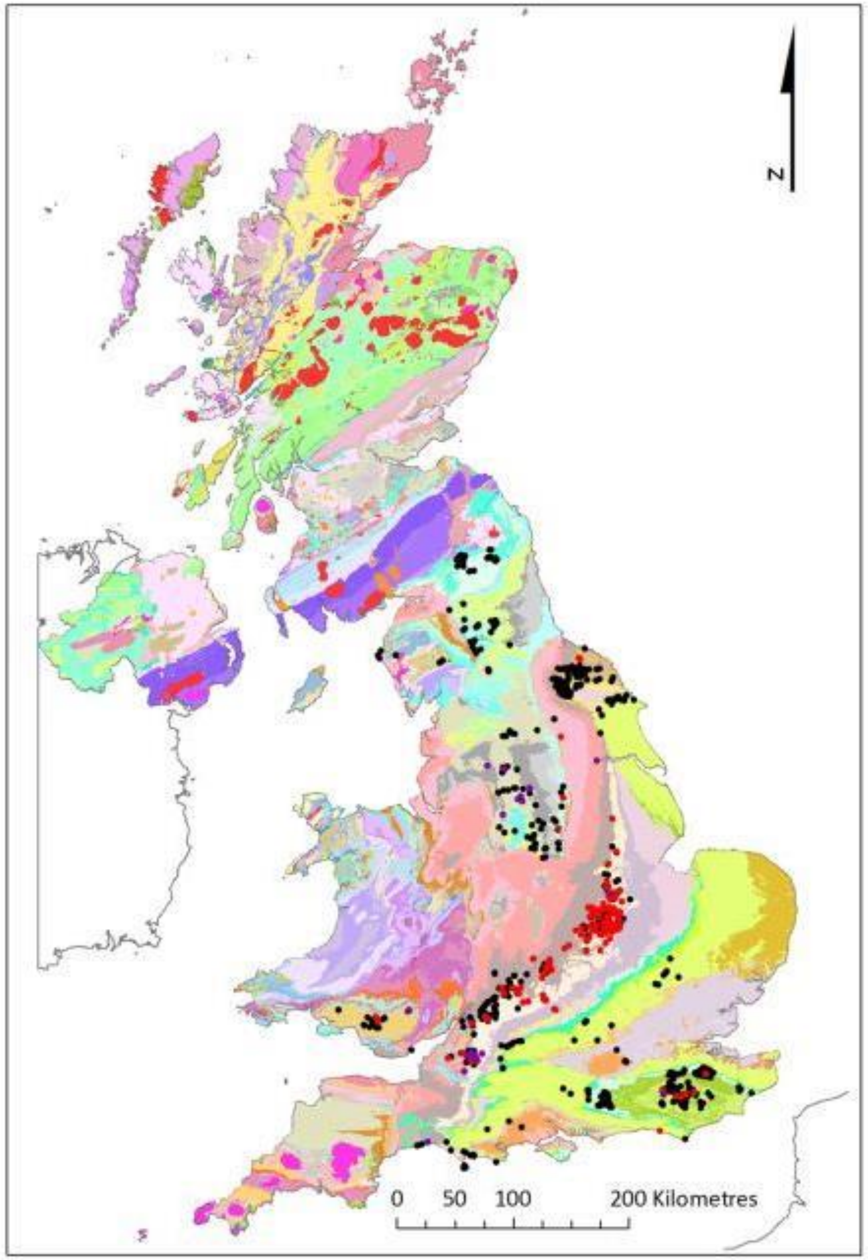
Deeper ground movements: Cambering and superficial valley disturbance

- Extension and down slope movement of large ‘brittle’ blocks and often associated with, compression, upward ‘bulging’ of ‘plastic’ argillaceous rock, in valley bottoms
- Large areas effected – typical of Jurassic limestone over mudstone/clay sequences
- Gulls in valley crests - can occur up to 1km back from the crest of valleys
- Gulls may fill with a breccia known as ‘gull rock’
- Shearing and deep, (62m), disturbance ‘bulging’ of valley bottoms

Google Earth Pro / BGS

Cambering and valley bulging

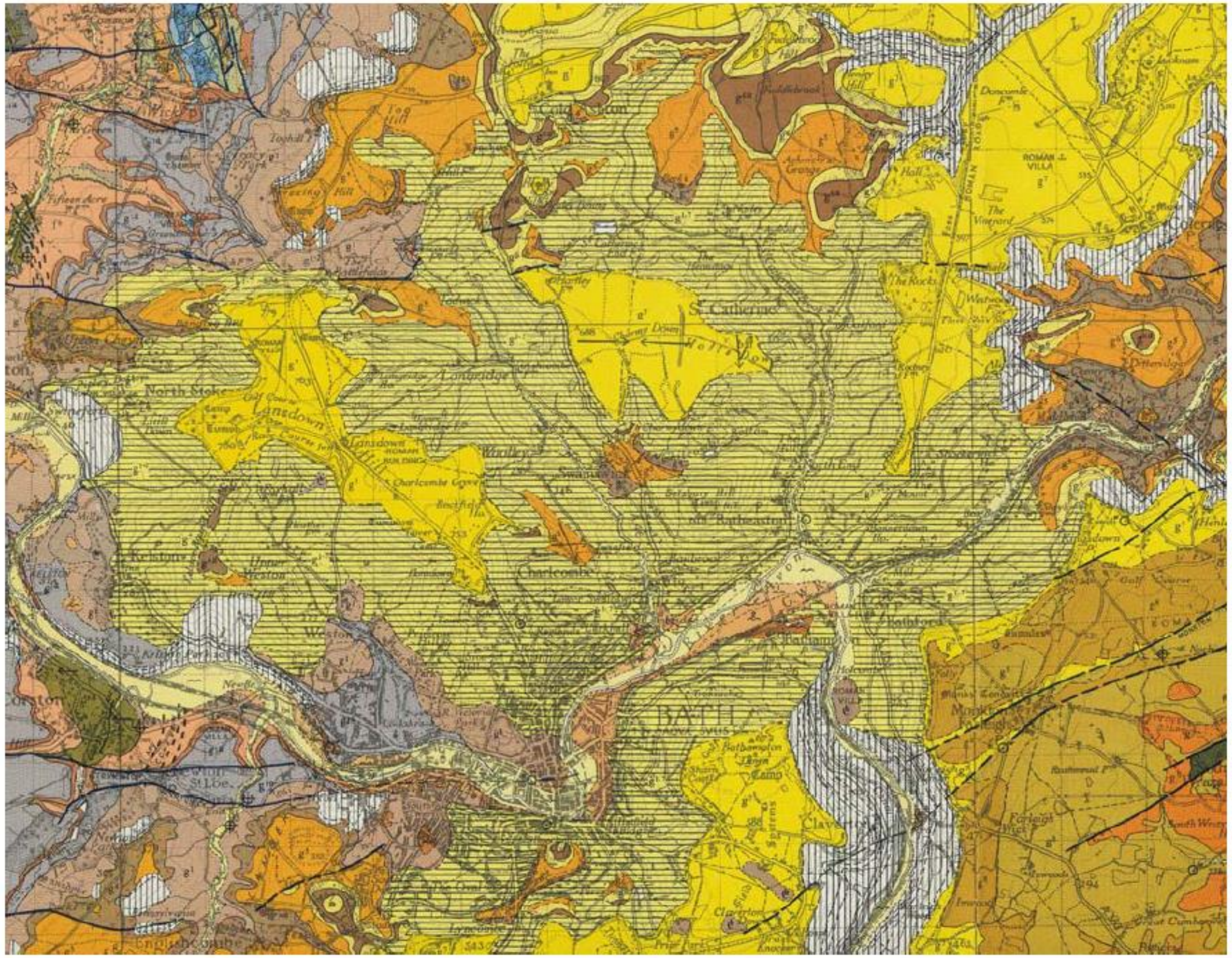
- Rocks susceptible to cambering and superficial valley disturbances are widespread in the UK
- Features commonly associated with the Jurassic strata of Northamptonshire and Rutland, but are also recorded in Carboniferous, Permo-Triassic, and Cretaceous rocks where there is competent/incompetent stratigraphy
- Historical BGS maps use the term ‘foundered strata’ to describe areas of extensive landsliding and cambering. Recent maps same term used to describe areas of natural or manmade collapsed ground unrelated to cambering or valley bulging.



Culshaw et al. (2017)

‘Foundered strata’ around Bath

- ‘Foundered strata’ in green with horizontal hatching
- Landslides in white with vertical hatching

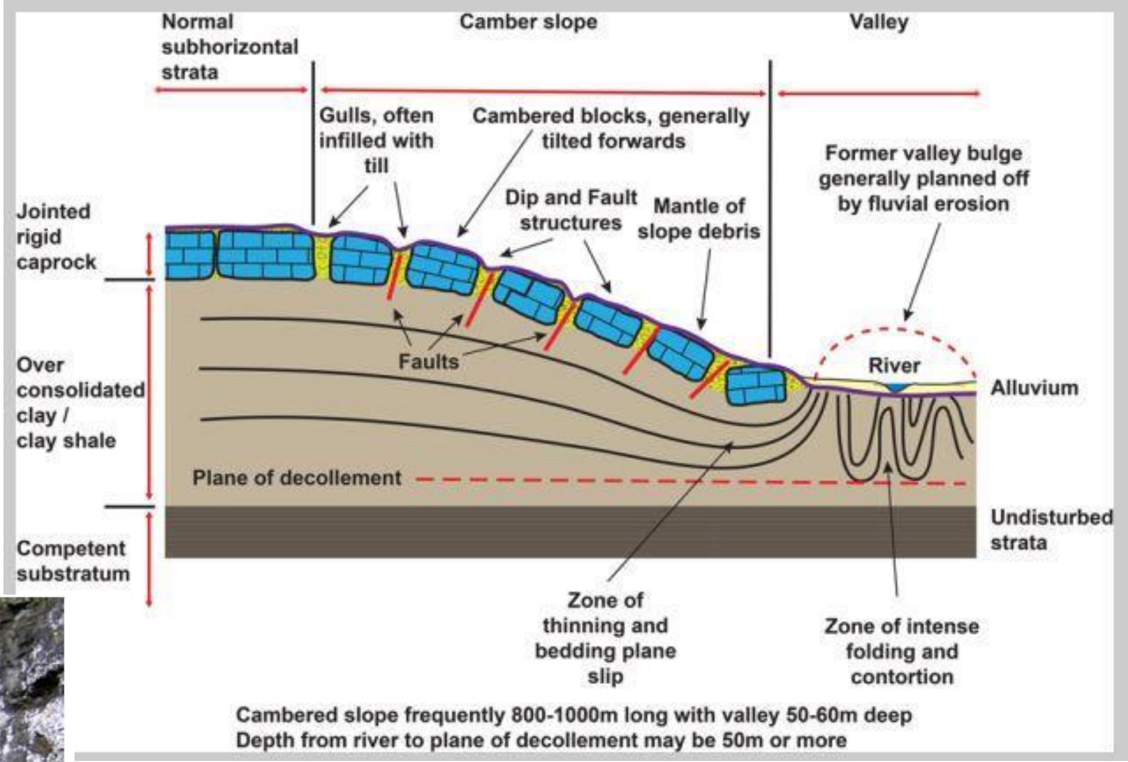


After Hobbs 2008, BGS report

Cambering and superficial valley disturbance

Griffiths and Giles (2017)

- Cambering and superficial valley disturbance most efficient in periglacial environments:
  - rapid valley erosion from seasonal melt
  - release of lateral stress in valley sides
  - seasonal cryogenic disturbance and weakening of mudstones or clays in the valley bottoms
  - concentration of ground ice in the mudstones or clays.
- e.g. A419 Cirencester cuttings through oolitic limestone.
- Big problem for constructions in Bath.

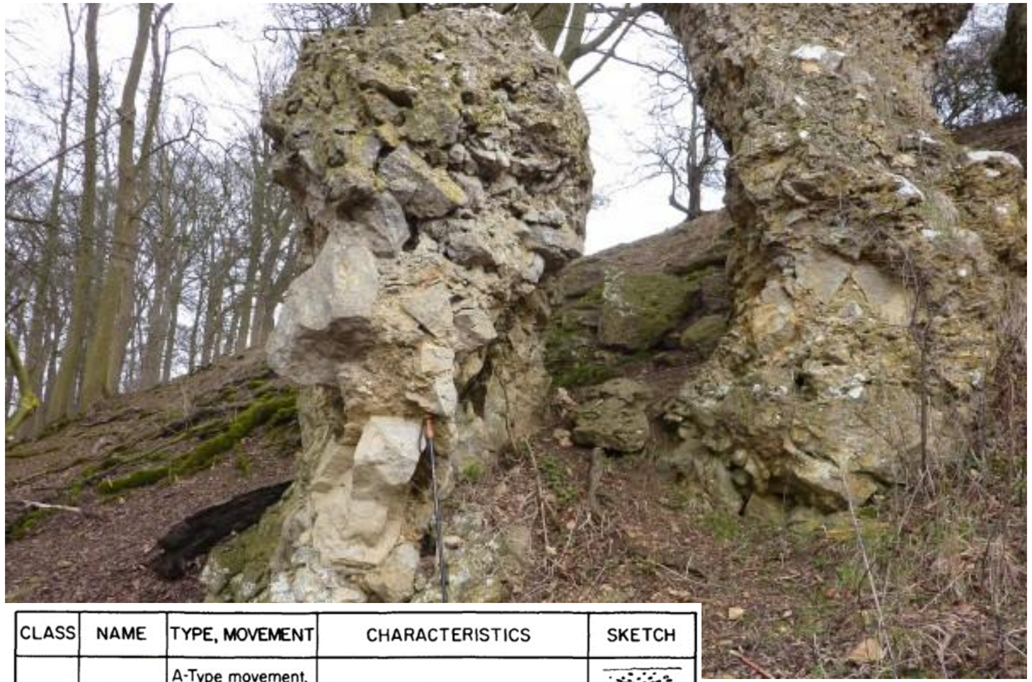


Hobbs (2008)

Blocks can back-rotate, forwards rotate or drape the slope

Cambering and superficial valley disturbance - gulls

- Potential voids/areas of weak fill
- Pathways for water or contamination
- Atypically strong - gull rock cemented with tufa



Tufa-breccia gull rock. Bredon Hill, Worcs.

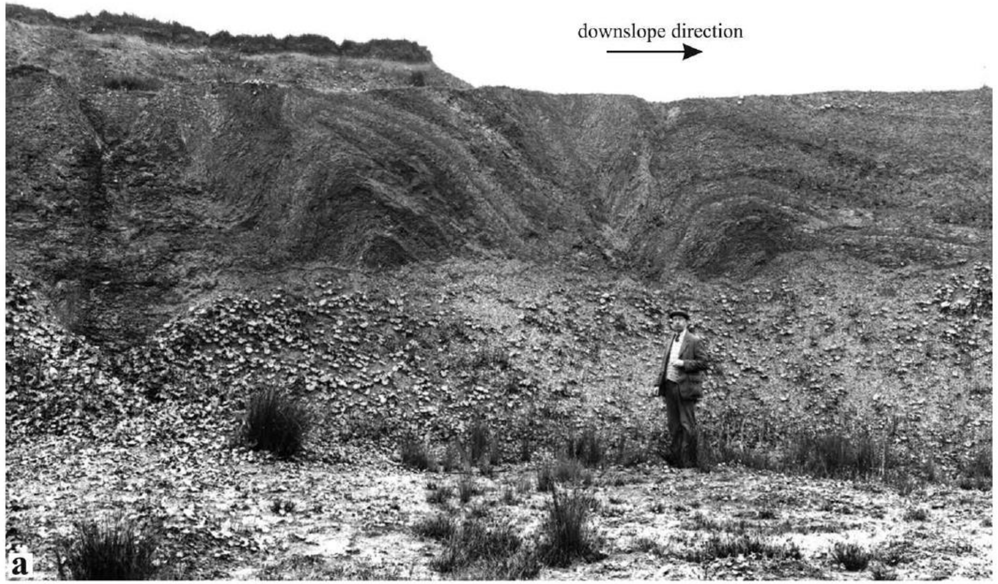
Infilled gull. Magnesian Limestone, near Doncaster, Yorkshire. Picture credit: Tom Berry

CLASS	NAME	TYPE, MOVEMENT	CHARACTERISTICS	SKETCH
I	Infilled	A-Type movement, small to large displacement	Head sags into gull	
IIa	Open	B-Type movement, small displacement	Head not affected. Medium to large voids at depth	
IIb	Open	B-Type movement, large displacement	No Head. Many tilted blocks. Large voids at depth	
III	Mixed	B-Type movement, large displacement	Head sags into gull. Large voids at depth	
IVa	Intact Roofed	C-Type movement, medium to large displacement	Level limestone roof. If present, Head is undisturbed. Large voids and cavity at depth	
IVb	Collapsed Roofed	C-Type movement, (+ B-Type at top), large displacement	Roof of fallen blocks wedged in the top of a large cavity. If present, Head may sag a little	

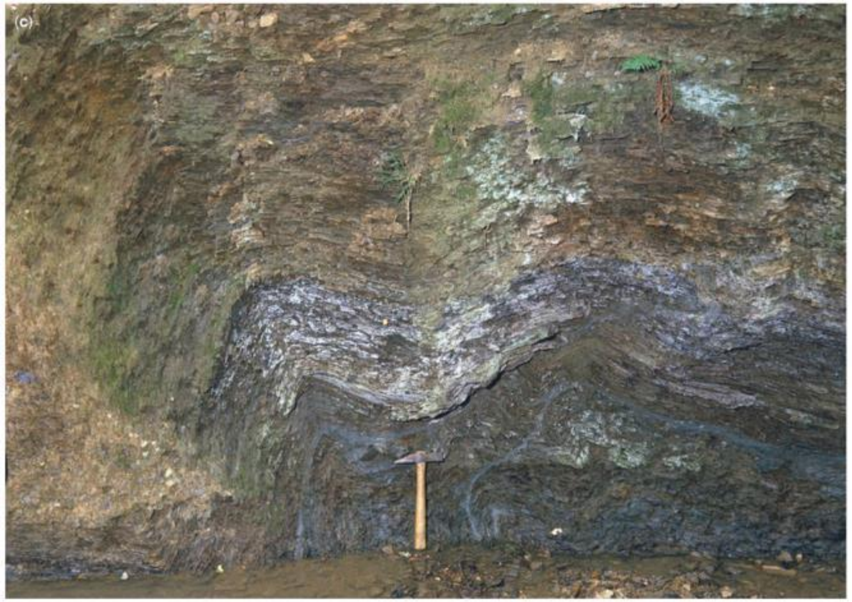
Classification after Hawkins and Privett 1981).

Superficial valley disturbance

- Bulge - Significantly lower shear strength parameters, likely be softer and more compressible than in situ undisturbed form.
- BH data could be misinterpreted inf ground model not anticipated.
- Exposed in temporary cuttings in river valleys.
- Good example on the Dorset coast near Charmouth.



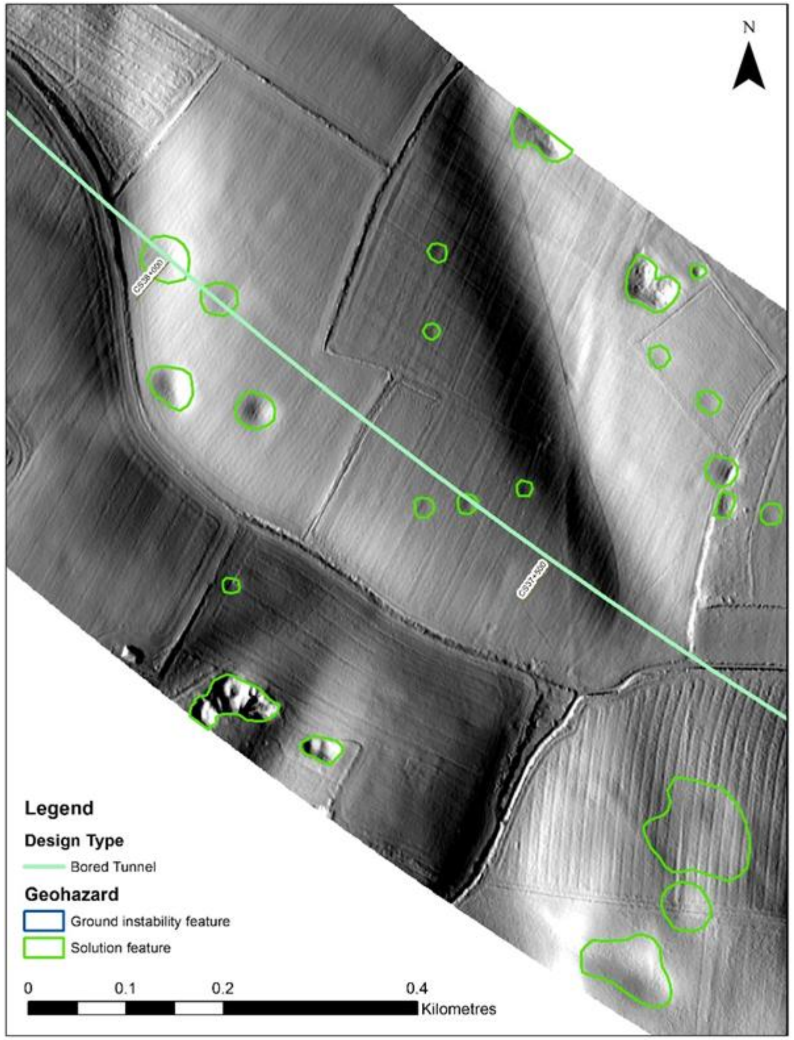
Weald Clay, Horsham (1931). After Gallois, 2010

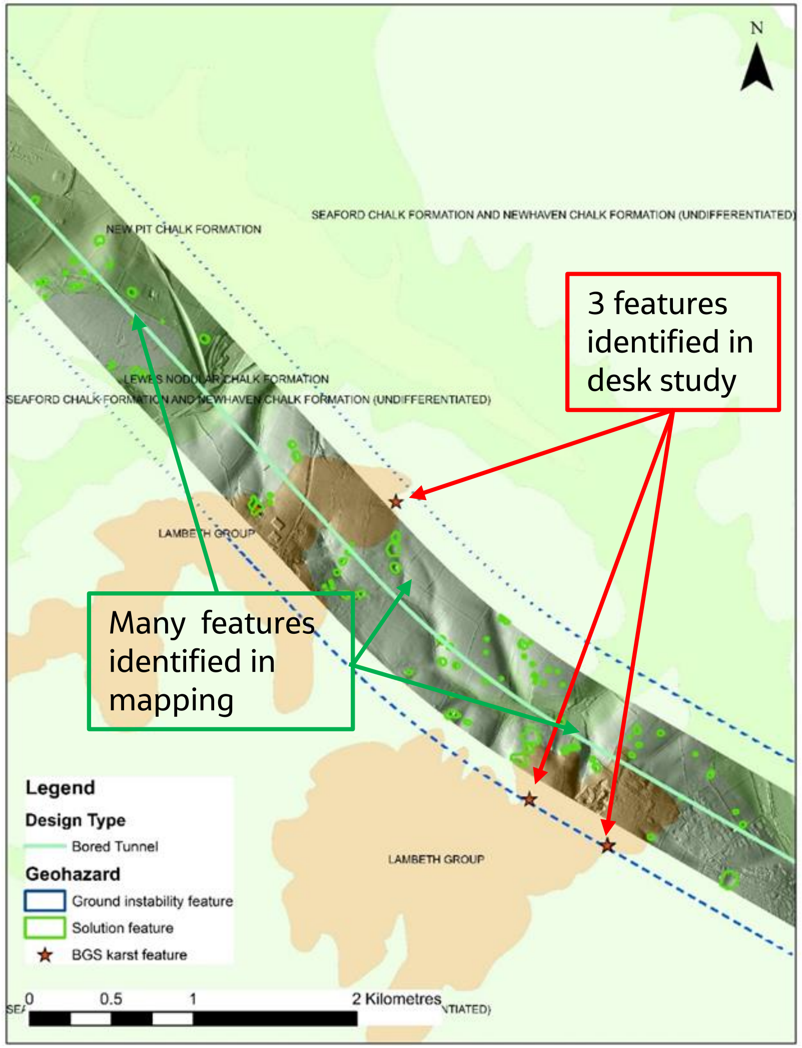


SP28 Murton and Ballantyne Figure 5.20c

Solution

- Karst is not typically considered 'periglacial'.
- But, dissolution process accelerated by cold water characteristic of a periglacial environment.
- Recent encounter of >25m deep, c. 10m wide sand and gravel-filled pipe in chalk.

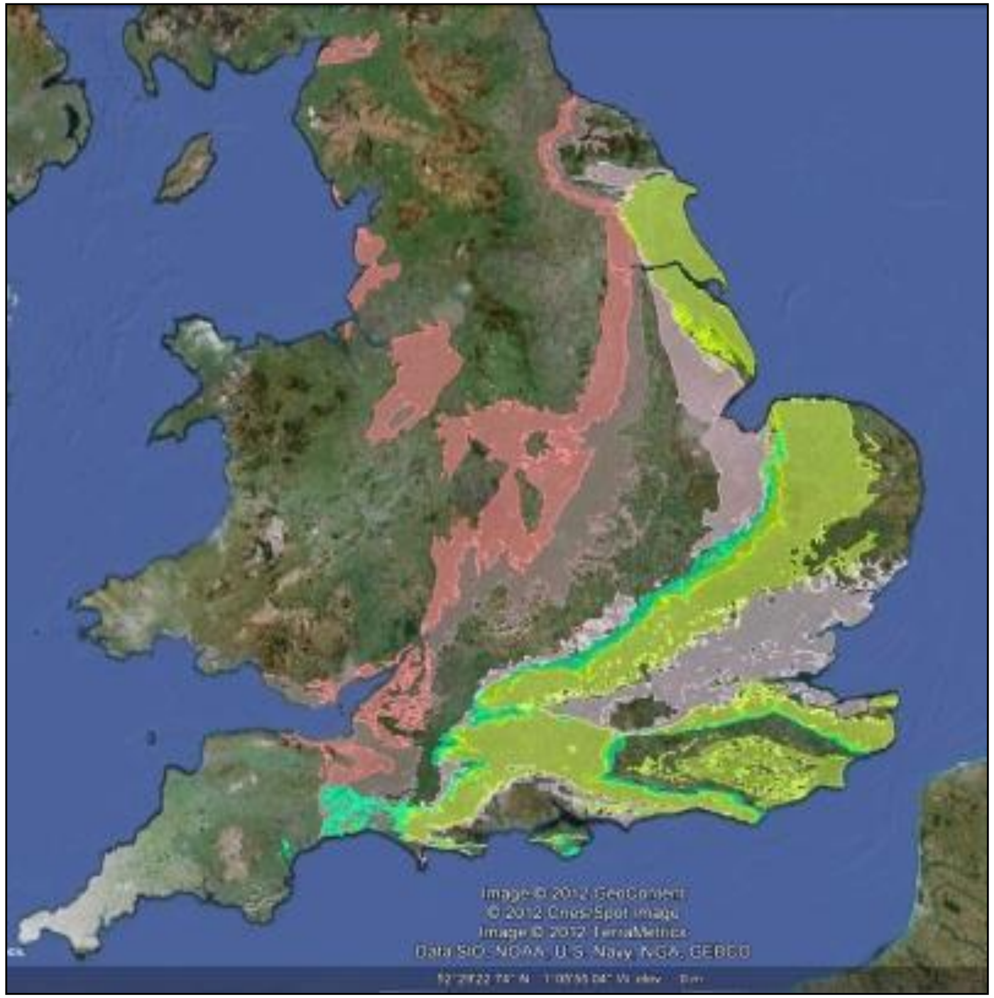




Picture credit: Jacobs, includes BGS data used with permission

Irregular rock head and deep weathering

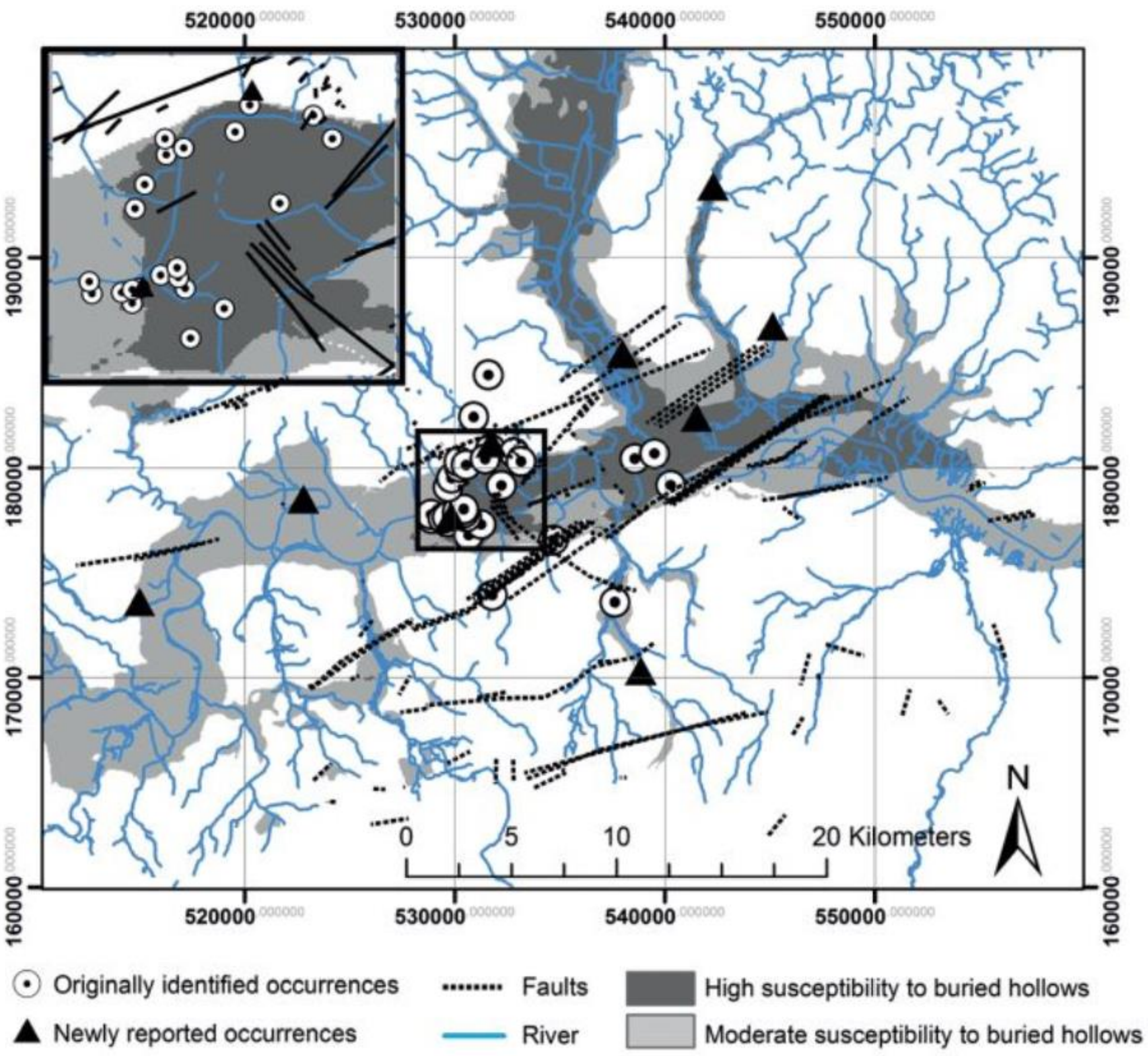
- The mechanical breakdown of rock through the presence of water in discontinuities and intergranular pore spaces
- 'Frost susceptibility' of a material determined by the presence of pore spaces large enough allow capillary action, but not large enough to break capillary link.
  - Silty sands most susceptible
  - Clays, pure sand and gravel not susceptible
- Chalk and weak silty sand mudrocks are particularly susceptible - weathering depths in excess of 10m
- Problems of ground model development, reduced bearing capacity, increased settlement, increased permeability, karst



Google Earth Pro / BGS

Rockhead anomalies

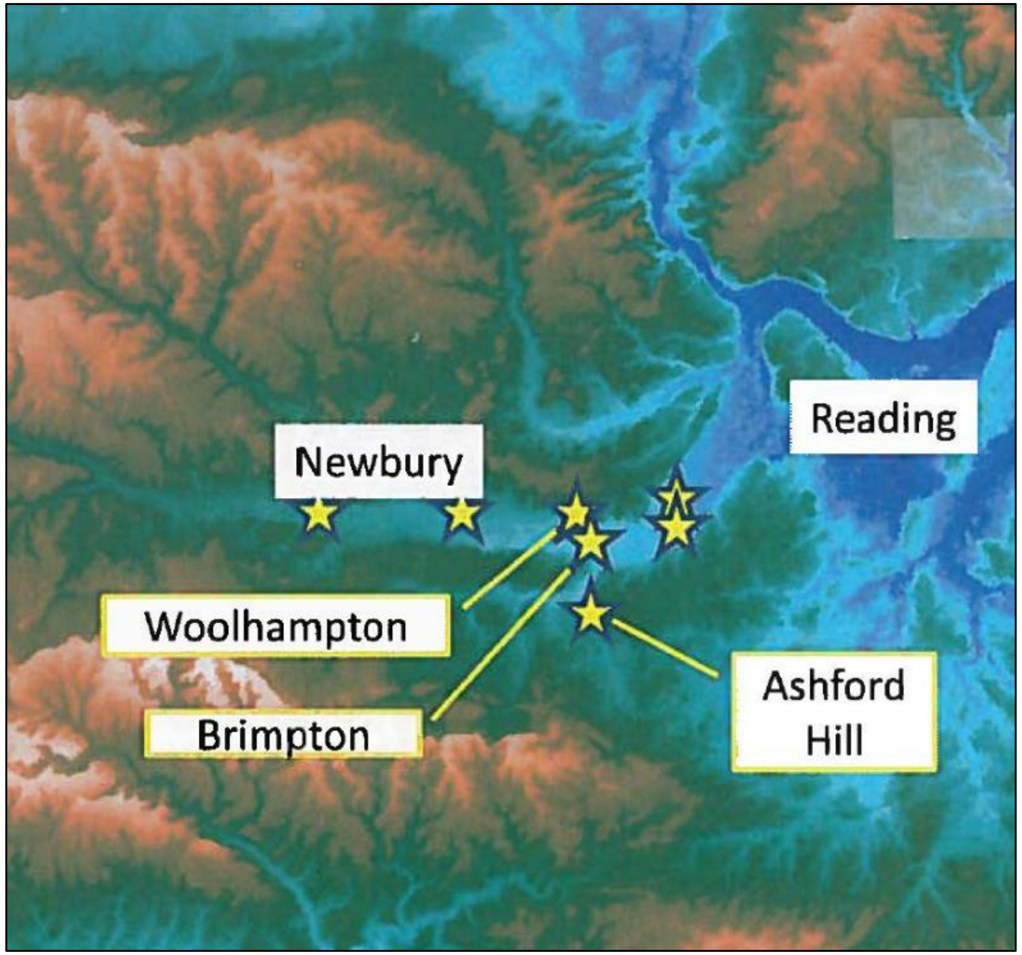
- Atypical ground conditions described in the lower Thames Valley – below Pleistocene terrace gravels. Formation by: scour (Berry, 1979), pingos (Hutchinson, 1980), scour and pressure release (Hutchinson 1991), chalk dissolution (Gibbard, 1985), faults (Banks et al. 2015).
- Hutchinson concluded composite in origin, confirmed by Banks et al:
  - periglacial weathering and diapirism,
  - groundwater close to ground surface (artesian pressures),
  - related to river terrace deposits (bedrock scour and pore water pressure release),
  - where LC is thin.
- 100s of m across, up to 30m deep. Isolated or clustered.



Banks et al. (2015) BGS

Rockhead anomalies

- Not just London! Data probably reflects recent focus of work in that city.
- Unexpected and differing ground conditions with poorer soil properties (lower bearing capacity, higher settlements etc).
- Potential for groundwater (and soil) ingress into foundations and tunnels
- Pathways for contamination into the aquifer.
- Can be engineered but costly if not expected

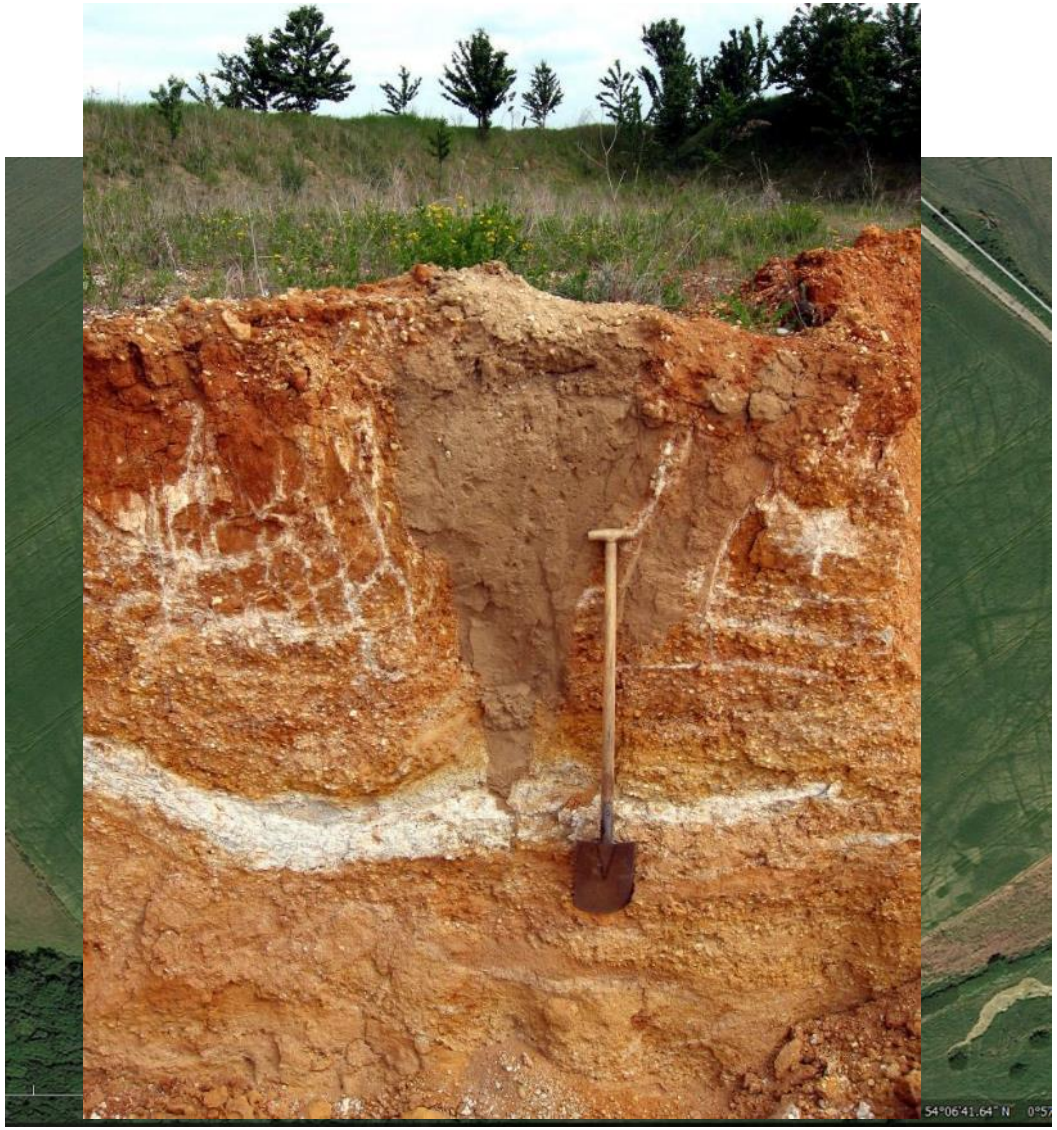


Collins (2013)

Palsas/lithalsas and ice wedges

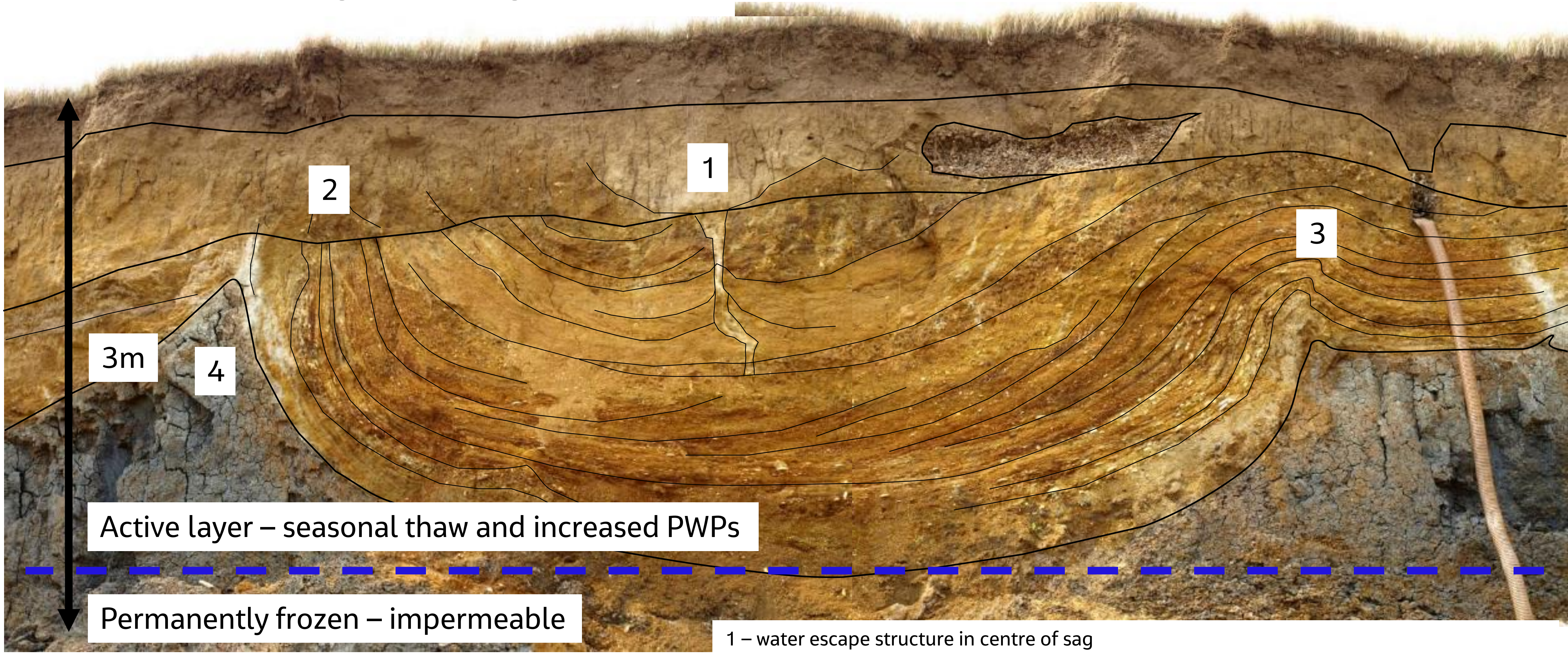
Thompson Common, Norfolk, showing a cluster of relict lithalsa mounds

- Remnant expression of ice or sand wedges active during periglacial periods
- Cracks formed during the winter are subsequently filled with ice and/or sand
- Up to 3m wide and 10m deep
- Weaker soils that transmitted groundwater
- Side support and control of ground water

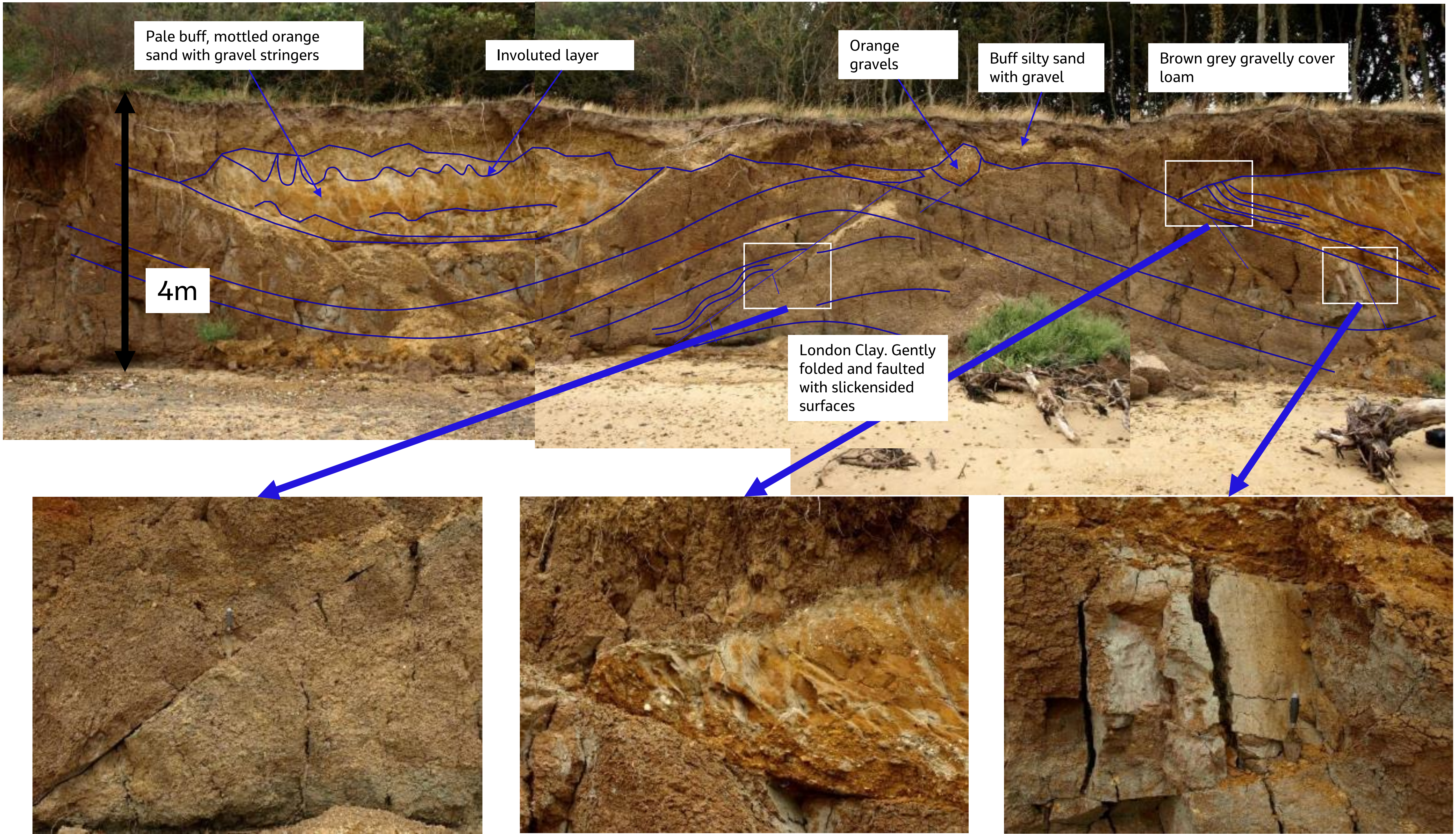


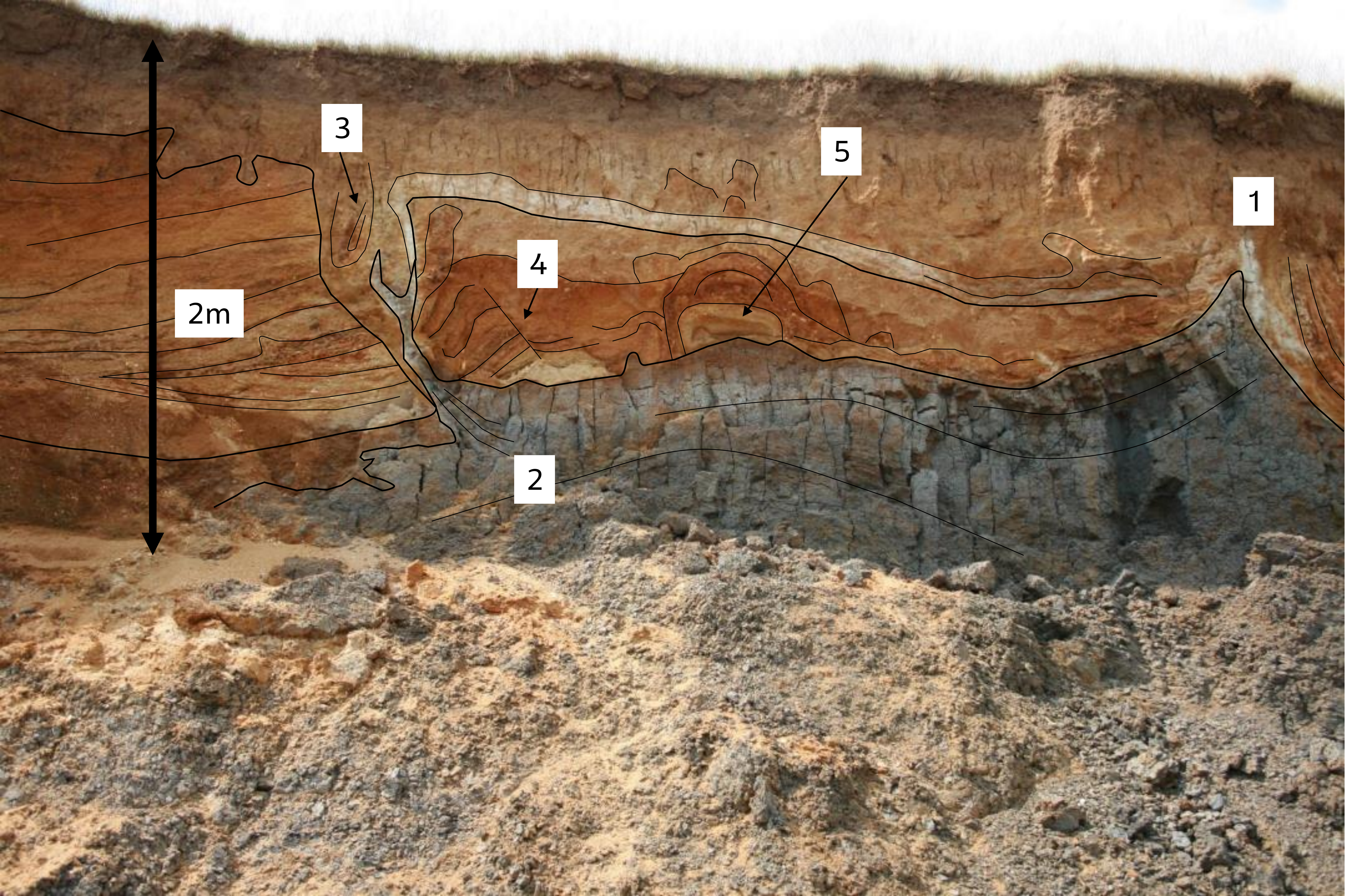
Cryogenic wedges in high plasticity clays. Lias Mudstone, Bulmer, North Yorkshire. Picture credit: Google Earth

Examples of engineering issues – GI data interpretation



1 – water escape structure in centre of sag
2 – truncated bedding, indicting erosion of the upper part of the deformed Crag sequence before or during deposition of the coverloam
3- ductile deformation of Crag bedding by density loading processes
4 – density loading of LC, which rises into the Crag.


Pale buff, mottled orange sand with gravel stringers
Involuted layer
Orange gravels
Buff silty sand with gravel
Brown grey gravelly cover loam
4m
London Clay. Gently folded and faulted with slickensided surfaces



Complex soft sediment deformation, including diapirism of the LC (1) and pressurised water escape ‘flame’ structures.

Water escape structures comprise a ‘flame’ of LC injected upwards into the Red Crag, tight folding (3) and faulting (4) of the Crag and intermixing of LC and Crag.

The LC is gently folded (amplitude c 0.5m, wavelength c. 3m), with the upper hinge point associated with tighter folding in the overlying Crag (5).

White/bleached streak extending right of the flame structure shows false bedding and is assumed to reflect groundwater effects rather than deformation.

Summary of Periglacial geohazards

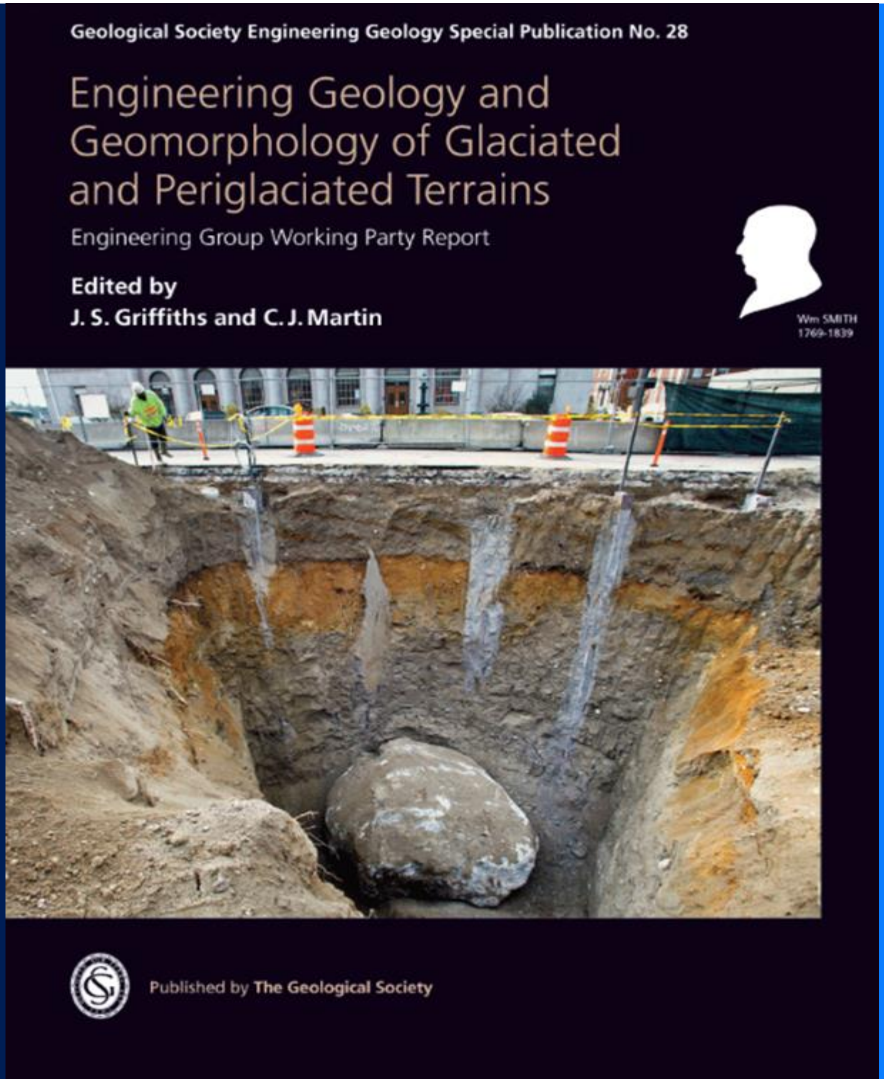
Berry, et al. (2020), Relict Periglacial Geohazards in the UK, in Giles, D. P., and Griffiths, J. S., (Eds), Geological Hazards in the UK. Engineering Group of the Geological Society Working Party. Geological Society, London

- What are the hazards and where can you find them
- Engineering implications
- Monitoring and mitigation
- X-ref to details in Griffiths and Martin (2017)

Key: ** Widespread/likely; * Rare/unlikely; - Not present/not feasible.

Geohazard	Landsystem / occurrence (see legend for explanation)										Engineering implication	Investigation and monitoring (see tables 2 to 5 for more information)	Planning considerations and engineering mitigation
	Lowland						Upland						
	Plateau	Rock slope	Foot slope	Valley	Buried	Submerged	Plateau	Sediment mantled	Rock slope	Foot slope			
Irregular rock head and deep weathering (including tors)	**	*	**	**	**	**	**	**	*	**	Variable or unforeseen ground conditions resulting in rock head being deeper or shallower than expected. Has impact on anticipated groundwater regime.	Preliminary ground model to document processes of weathering and likely depths. Geophysical survey calibrated with logged boreholes and/or trial pits to develop a detailed understanding of the weathering profile.	Ground modelling to understand relationships between topography, materials and engineering rockhead. Ensure engineering manages ground risk i.e. foundations on consistent formation.
Solifluction and active layer detachment slides	-	*	**	**	**	**	-	**	*	*	Shallow slope instability following reactivation of shallow shears (<5m bgl) that may occur on very low angle slopes. Instability may be triggered by engineering works (slope loading or cuts to slope etc.) and changing groundwater levels.	Geomorphological mapping to identify subtle lobes. Interpretation of LiDAR particularly useful. Trial pits to confirm depths of shears. Monitoring of slope movements and groundwater.	Avoid areas of mapped potential instability if possible. Dig and replace sheared soils if possible or consider harder engineering solutions (shear keys, soils nails geotextile etc.) if not.
Cambering and valley superficial valley disturbances	-	**	**	**	*	*	-	-	*	*	Variable or unforeseen ground conditions (<20m bgl). Competent cap rocks at valley margin and on slopes not in situ and blocks may be separated by voids or sediment fills (gulls); dips often represent downslope block	Ground model to define likely affected areas. Geomorphological mapping to identify location of cambered blocks and intervening gulls, and superficial valley disturbances. Geophysics, boreholes and/or trial pits	Design to appropriate support to cambered rock slopes, (stiffened extended foundations, separate structures). Consider variable ground conditions associated with gulls and hydrogeology. Consider on-going stresses from

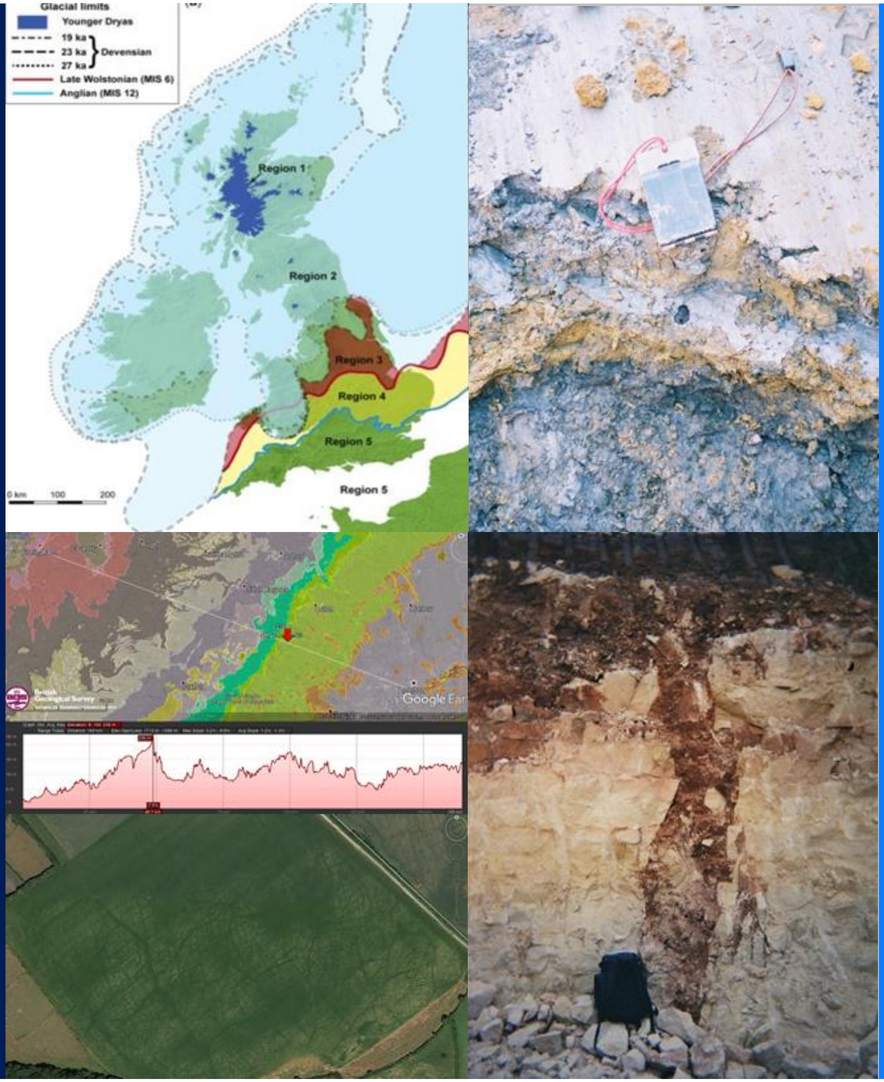
Opportunities for collaboration



- How to best apply valuable academic knowledge to industry, to our mutual benefit?
- Sharing of experience between ICE and GSL.
- Collaborative working group via the QRA or GSL?
- 1 day field meetings for industry?

< SP28. Picture credit: Geological Society London

Summary



- UK wide geohazard
- Substantial technical and commercial risk for many civil engineering projects
- Periglacial geohazards can be investigated, monitored and mitigated against
- Fantastic opportunities in the future to work together to advance science and to deliver effective efficient engineering solutions

< Various. Picture Credits: See Above

Thanks for listening

- My co-authors: Tom berry (Jacobs), Simon Price (Arup) and Neill Hadlow (Jacobs)
- Jacobs: Prof. Roger Moore and Peter Gilbert

Any questions?

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Thank You

Jacobs Challenging today. Reinventing tomorrow.