Sinkholes, the media and the British Geological Survey

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Abstract: The unusually wet winter of 2014 generated a rash of new sinkholes in England, many in karst terrains, but also many over old mines. So many ground failures attracted undue attention in the media, and a host of individual enquiries to the Shallow Geohazards and Risks team at the BGS.

A presentation on sinkholes could not have started without mention of Dr Tony Waltham in the year that he was the recipient of the 16th Glossop Medal of the Geological Society of London, particularly given that his well-received lecture was titled *Control the Drainage: the Gospel Accorded to Sinkholes* (Waltham, 2016). Contrast can be drawn between his tour of the world's range of impressive sinkholes and a recent media request to BGS for interviews on what amounted to little more than a rut in a street in Warwickshire that was underlain by non-soluble rocks. Yet, the BGS work strongly identifies with his key message regarding the need to control drainage as the key component in the mitigation of sinkhole problems.

What are sinkholes?

This is probably the most common enquiry for the karst project team at the British Geological Survey. For a karst specialist sinkholes comprise naturally occurring openings into natural cavities in soluble rock. They may be triggered by downward dissolution, by downward suffosion due to rainwater infiltration through a sediment cover (Fig. 1), or by upward propagating collapse of rock spanning underlying cavities (Fig. 2). Sinkholes can form gradually or instantaneously. However, the term is commonly conflated with collapse subsidences over anthropogenic voids, where the triggering processes may be either natural or anthropogenic, as in the collapse of the cap on a mine shaft. This is not surprising, because if a void opens suddenly, particularly in an urban environment, it may not be clear whether it is or is not a natural feature, and interpretation is reliant on geological understanding (Fig. 3).

Along with caves and springs, natural sinkholes (dolines) are components of the drainage systems that characterizes karst aquifers. It is the perceived suddenness of collapse, and the unpredictability of the locations of new sinkholes, that appear to capture the imagination of the media and therefore of people everywhere. More specifically, the loss of Mr J. Bush to a sinkhole that opened beneath his Florida home in February 2015 had a marked impact across the world.

Figure 2. *Collapse subsidence within Ordovician limestone, exposed at the Cummingsville Quarry, Minnesota, USA.*

Figure 1. *Buried karst at Carsington Pasture, Derbyshire, with soil draped over an irregular rockhead and infilling fissures by suffosion.*

***Figure 3**. Potential difficulty in discriminating between natural sinkholes and mine collapses.*
A: a natural subsidence doline in soil cover on Carboniferous limestone near Inchnadamph, Assynt, Scotland.
B: anthropogenic collapse subsidence due to brine mining at Carrickfergus, Northern Ireland.

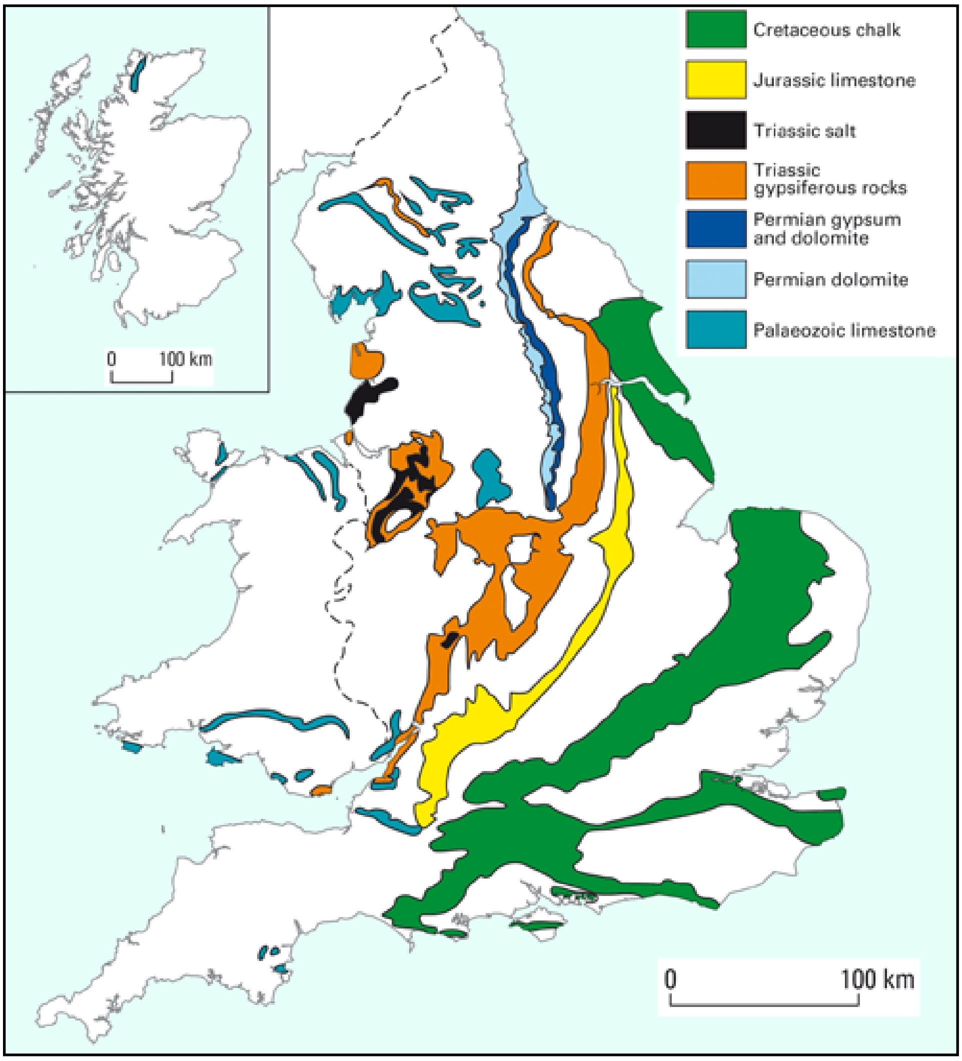

***Figure 4**. Distribution of soluble rocks in Britain, with dissolution rates increasing in the sequence from limestone to chalk to gypsum to salt (map by BGS).*

How do sinkholes form?

This is probably the second most common enquiry, in part because they can form in a number of ways. Essentially, they require a cavity over which a surface opening develops. For natural sinkholes forming where insoluble sediments overlie the soluble rocks, the surface opening may develop by suffosion, whereby unconsolidated sediments are washed down into underlying voids. Alternatively, consolidated rocks will collapse once the void developing beneath the cap exceeds the spanning capacity of the bridging rock mass. Where soluble rocks crop out, or lie beneath a cover of soil or drift sediments, dolines form as a result of the natural dissolution of soluble rocks such as salt, gypsum and limestone, including chalk (Fig. 4).

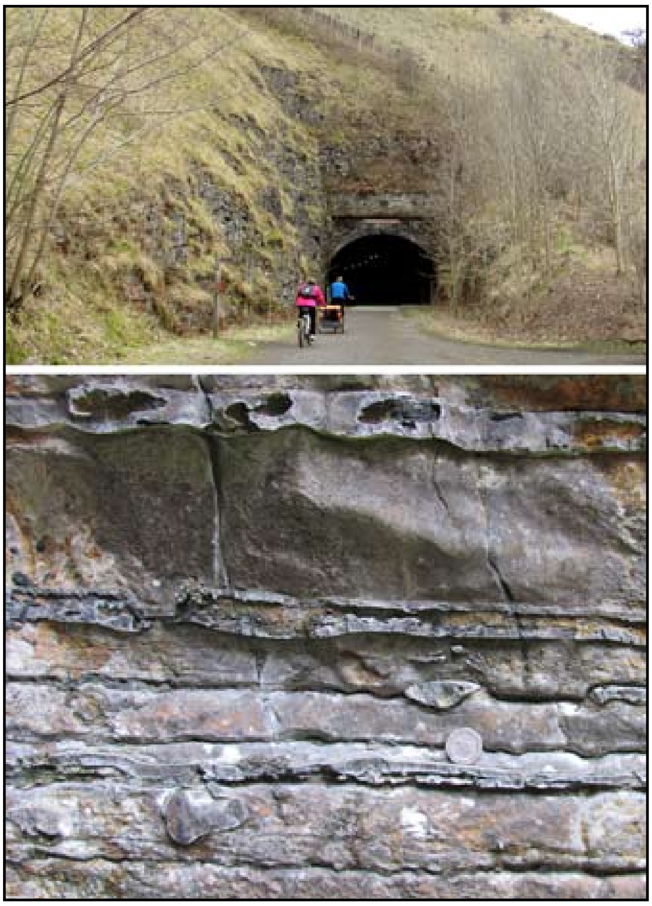

Figure 5*. Rock cutting at the approach to Cressbrook Tunnel on the Monsal Dale Trail, with a close-up view of the differential face retreat on chert and limestone.*

While laboratory-determined rates of dissolution can be found in the literature they are not necessarily representative of field conditions. The opening of the Monsal Dale Trail provided access to a dated cutting in interbedded limestone and chert, which shows clear evidence of differential face retreat (Fig. 5). Systematic measurement of the differentially weathered surfaces on both sides of the cutting indicated recent dissolution rates of 31 mm per 1000 years (Banks & Jones, 2014). This value is lower than the rates of up to 100 mm/ka widely recognized for surface dissolution of Carboniferous limestone in the Pennines (Ford, 1977; Trudgill, 1985), and probably reflects the verticality of the measured face beside the tunnel.

The winter storm events of 2014

For much of Britain the period between December 2013 and February 2014 was the core of its wettest winter since 1910, and it was also the stormiest winter in the last 20 years. Guided by the jet stream, the easterly tracking weather systems took a more southerly route than that of typical winters, generating prolonged wet weather that caused extensive disruption to infrastructure in southern England. As well as the flooding, particularly of the Somerset Levels, and landslides that affected the railway infrastructure, there were reports of unusual numbers of ‘sinkholes. across the country.

Among the first of the 2014 ‘sinkholes’ that were reported to BGS was one on 10 February that was the collapse of the capping of a denehole in the central reservation of the M2 motorway, near the village of Erriottwood in Kent. This was one of a number of denehole shafts that collapsed during this period. Another occurred in the grounds of the Rainham Mark Grammar School at Gillingham, Kent (Fig. 6). Deneholes are medieval chalk mines; typically they comprise a narrow shaft with a bell-shaped base that may incorporate a number of short galleries and small chambers radiating from it. The chalk was either burnt to form lime or applied directly to the fields for agricultural improvement.

As the wave of ‘sinkhole’ events unfolded, it became apparent that there was also a common association of shaft collapses with former brickworks; a car was engulfed by a shaft collapse at Walter’s Ash, Buckinghamshire, and houses had to be evacuated adjacent to a collapsing shaft at Oakridge Gardens, Hemel Hempstead. This association is attributed to the historic practice of using locally-won, wash-mill, ground chalk as an additive of up to 15% in brick making; this improved the firing process and gave a yellow hue to the bricks.

Natural sinkhole events included suffosion in a number of buried karst features, particularly in areas where there is a thin covering of granular material over the chalk. Sites like Croxley Green, where glacial deposits overlie the chalk, and Gillingham, Kent, where the feather-edge of the Palaeocene Thanet Sand lies on the chalk, are typical of situations where new sinkholes are more likely to occur in southeast England (Edmonds, 1983). There is also a greater potential for dissolution of the chalk bedrock where pyrite in the granular cover weathers to increase the acidity of water migrating through the capping materials.

Farther north, two sinkhole events were associated with gypsum dissolution. One was a natural collapse subsidence in Ripon, where sinkholes are attributed to

Figure 6*. Denehole exposed by a new surface collapse in February 2014,at Rainham Mark Grammar School, Gillingham, Kent.*

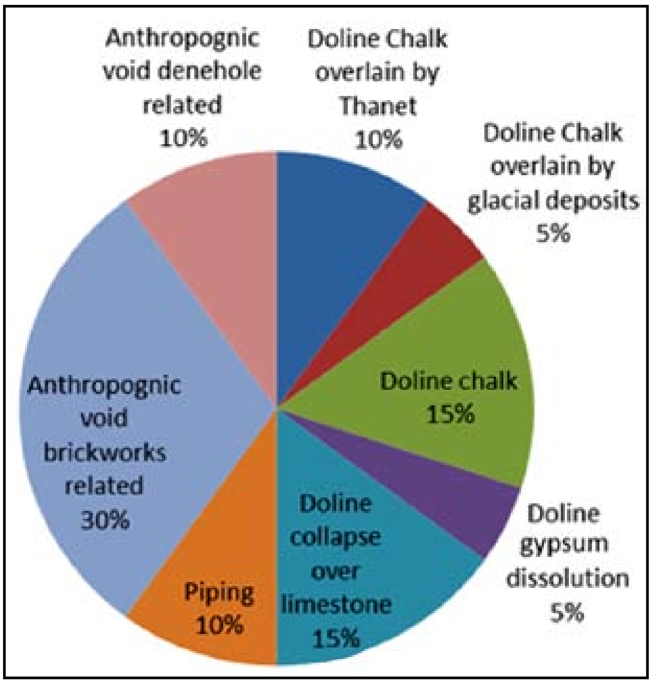

***Figure** 7. Breakdown of the types of 'sinkhole' events reported to the BGS during February 2014 (from Banks et al., 2015).*

dissolution of thick beds of gypsum within the Permian sequence. The other was related to abandoned mine workings in the Vale of Eden.

Although further events have followed, a total of 23 'sinkhole' events were reported to BGS in the spring of 2014. Of these, 40% were anthropogenic features, and their principal trigger was the intense rainfall (Fig. 7). The impact of the rainfall was primarily direct, but at some sites there was an indirect trigger created by the focusing of surface water flow on zones of failed drainage, in particular on leaking pipes.

From the BGS perspective these events were associated with a media frenzy that required considerable resources. The first wave of media attention focused on the events themselves. A second wave focused on impact and especially on the insurance aspects for property owners. BGS staff had a responsibility to present accurate information without causing blight to areas. The concerns with respect to insurance relate to the fact that is usual for home insurance to provide cover for buildings rather than for land; consequently, the cost of remediating sinkholes that develop in garden areas and do not affect buildings falls back on the owner. Further to this, there was a significant increase in the number of sinkhole-related enquiries from home owners, which required immediate attention. In February 2014 the BGS fielded more than 120 enquiries about sinkholes, compared with about 5 in a typical month.

Although wide-ranging, the public enquiries could be divided into process-related questions, practical questions regarding whether a given feature was or was not a sinkhole, how to monitor or mitigate a sinkhole, and who is responsible for such actions. There were also academic questions relating to numbers, types and distribution of sinkhole events. This had the advantage that web-page communications could be used to provide guidance and also answers to some of the more common questions. In parallel with these activities, senior BGS staff were required to report to Government through the Science Advisory Group that reports to the Cabinet Office. Further to this, the state of emergency required that BGS provide relevant data, notably on the locations of landslides and karst features, for infrastructure managers and emergency responders during the alert.

Why was the focus of attention on BGS?

As well as the mapping and modelling that forms the core of its product and outputs, BGS maintains databases and delivers a range of national-scale geoscience information. During the winter storms, many of the datasets were available to support the response. The National Karst Database (Farrant & Cooper, 2008) is a GIS-hosted Oracle database that was available for addressing specific enquiries, though full coverage of Britain has still to be achieved. The BGS GeoSure hazard susceptibility layers, include those documenting karst and landslide hazards, proved useful for regional-scale planning and response. Further to this, the public enquiries, which usually relate to individual land holdings, required full use of the database layers for geology, historic maps, field slips, records of mines and quarries, mine plans and mining susceptibility, along with recourse to borehole records.

Within the East Midlands, one enquiry was in regard to the collapse at Foolow in December 2013 (Fig. 8), which was associated with modern fluorspar workings encountering former lead zinc mineral workings (Hunter, 2015) and was easily identified in the mining susceptibility layer and in associated mapping.

As well as the maintaining the data holdings, BGS staff pursue research into a variety of topics related to karst. These include mapping, karst landscape evolution, conceptual and numerical modelling of karst groundwater systems, structural and stratigraphical influences on karst, tufa, groundwater tracing, weakly karstic aquifers, and karst groundwater ecology. Speleothem research is undertaken in a range of contexts, including the dating of gulls associated with cambering in Jurassic limestones (Farrant *et al*., 2015) and the interpretation of the environmental conditions that they record during their formation. Recent work also included studies of the very rapid precipitation from anthropogenic lime waste associated with lime burning in the Peak District near Buxton (Field *et al*., 2014).

An indirect reason for people turning to the BGS to respond to the winter storm events may have been that other organisations that might have contributed found themselves stretched in different directions.

The Environment Agency was responding to flooding-related issues, so passed 'sinkhole' enquiries on to the BGS. Similarly, many enquiries were passed on via the local authorities.

How has BGS responded?

Since winter 2014, the Government Chief Scientist has encouraged BGS to consider how to make its data more relevant and accessible to end users. In response to this, there has been a more focused effort to complete the population of the National Karst Database; however, this is based on comprehensive searches of literature and databases, as well as the examination of maps and aerial photographs, which means that it is time consuming. Within BGS there has been a concerted effort to work more closely with infrastructure owners and managers. Furthermore, the Shallow Geohazards and Risks team has been working with emergency responders to ensure effective communication during response. This focus on data use in the applied context has aligned well with the Natural Environment Research Council funding of research into the environmental risks to infrastructure.

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Figure 8. *The large ground failure over mine workings at Foolow, Derbyshire, in December 2013.*