Chapter II.3

GYPSUM KARST OF GREAT BRITAIN

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Abstract

In Great Britain the most spectacular gypsum karst development is in the Zechstein gypsum (late Permian) mainly in north-eastern England. The Midlands of England also has some karst developed in the Triassic gypsum in the vicinity of Nottingham. Along the north-east coast, south of Sunderland, well-developed palaeokarst, with magnificent breccia pipes, was produced by dissolution of Permian gypsum. In north-west England a small gypsum cave system of phreatic origin has been surveyed and recorded. A large actively evolving phreatic gypsum cave system has been postulated beneath the Ripon area on the basis of studies of subsidence and boreholes. The rate of gypsum dissolution here, and the associated collapse lead to difficult civil engineering and construction conditions, which can also be aggravated by water abstraction.

Introduction

Gypsum karst in Great Britain is developed mainly in the Permian gypsum of northern England and, less extensively, in the Triassic gypsum of central England (Fig. 1). Compared with limestone karst it is present in fairly small areas, but rapid dissolution of gypsum produces local subsidence and collapse problems, particularly well displayed around Ripon, North Yorkshire. In addition to the active gypsum karst, gypsum palaeokarst features occur, especially along the coast of north-east England and in the Firth of Forth off eastern Scotland.

1. The active karst in the Permian gypsum of Yorkshire and Durham

Gypsum karst and related subsidence problems occur extensively in the Permian sequence of north eastern England. The belt of gypsum karst is 3-4km wide and extends from just north of Doncaster, through Ripon to Darlington and Hartlepool (Fig. 1). Up to 40m of gypsum is present in the Edlington Formation and 10m in the Roxby Formation (Table). Both these gypsum sequences rest on dolomite aquifers and are capped by marl sequences. However, in the subsidence-prone areas dissolution and collapse are so great that the marls are perforated by subsidence pipes and form very ineffective aquicludes. The Permian sequence is overlain by the Sherwood Sandstone Group a major regional aquifer which is mainly of Triassic age.

The two gypsum sequences of the Edlington and Roxby formations rest on the carbonate aquifers of the Cadeby (or Ford/Raisby in the north) and Brotherton (or Seaham in the north) formations respectively. The carbonate dip slopes act as catchment areas and water is fed down-dip into the gypsiferous sequences. The water escapes into buried valleys, along the River Ure at Ripon (Cooper & Burgess, 1993) and, to a lesser extent, the River Tees near Darlington and the River

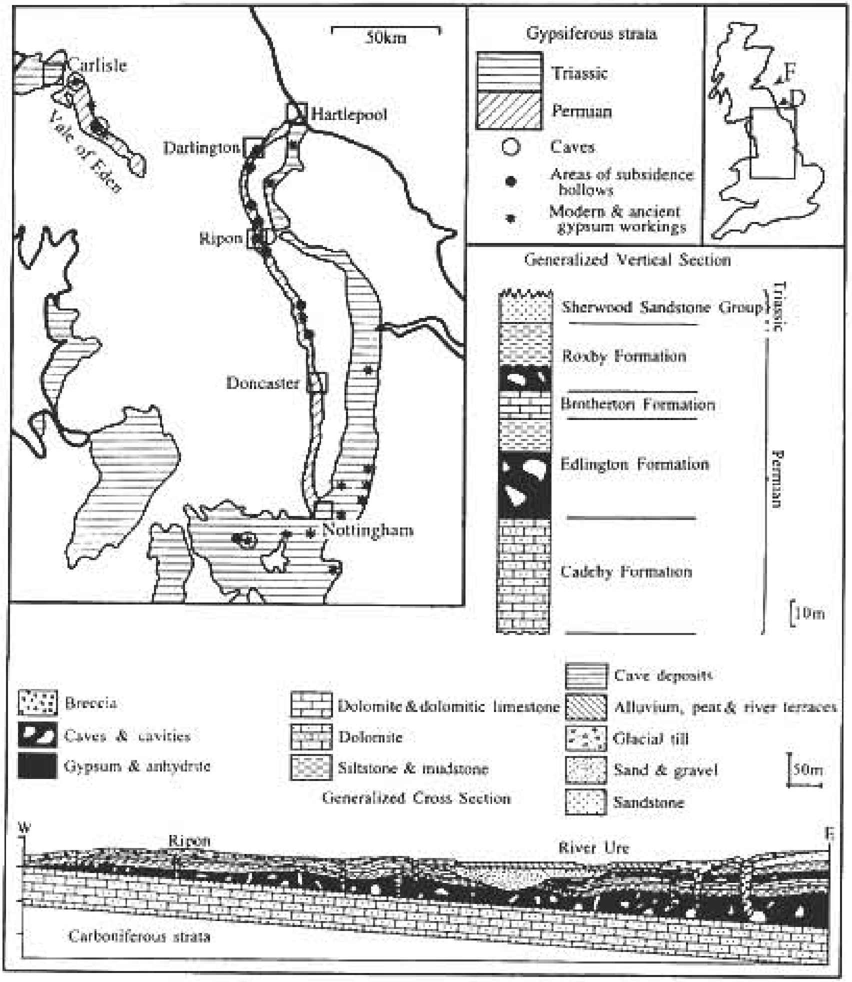

Fig. 1. The distribution of gypsiferous strata in the north of England and the Permian stratigraphical sequence present in Yorkshire. The sketch geological cross-section illustrates the geology in the vicinity of Ripon. The cross-section shows the development of caves in the gypsum sequences and their upward propagation as breccia pipes. Numerous ages of breccia pipes are depicted, some filled in with glacial deposits and others only recently breaking the surface. Other regions mentioned in the text are shown on the inset map of the UK: D - Durham coast area gypsum palaeokarst in Permian sequence; F - Firth of Forth gypsum palaeokarst in the Permian sequence.

Wharfe near Brotherton (50 km SSE of Ripon). Complex cave systems are developed in the gypsum, and artesian sulphate-rich springs are present locally. Because of the thickness of gypsum present the dissolutional voids can be large. At Ripon the dissolution causes surface collapses which occur locally at a rate of about one a year. These collapses can be up to 30m across

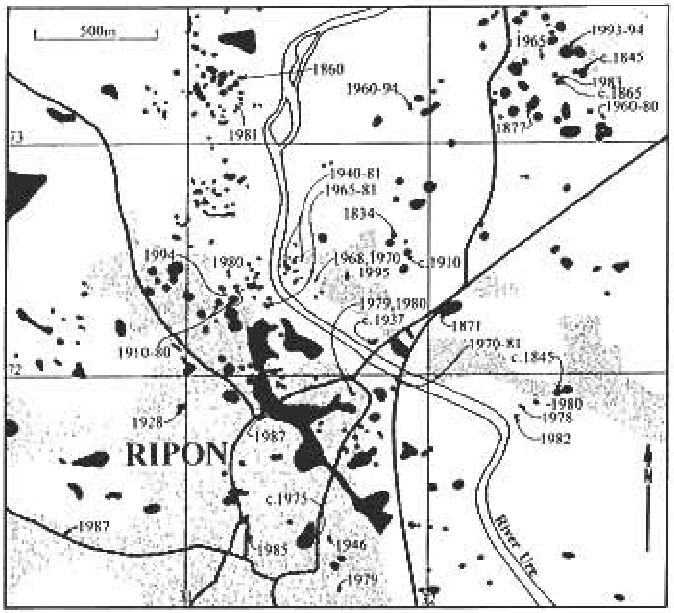

Fig. 2. The distribution and ages of subsidence hollows recorded in the visinity of Ripon, North Yorkshire, UK. The built up areas are shaded and the subsidence hollows and roads are shown in black. The cross-sections in Fig.1 runs approximately SW-NE across this area. The kilometre grig is the National Grig, used with acknowledgement to the Ordonance Survey.

and 20m deep, though most are smaller (Cooper, 1995). The subsidence here is not random, but occurs in a reticulate pattern related to the jointing in the underlying strata (Cooper, 1986, 1989). The distribution of subsidence hollows, and concentration of active subsidence events, show that some zones of subsidence are more active than others. The most active zones are along the margins of the river valley where the groundwater escapes from the gypsum into the Quaternary valley fill and alluvial deposits (Fig.2).

In the east of England the climate is temperate with a strong Atlantic influence and an annual rainfall that ranges from 50 to 75cm. The degree of water infiltration is variable, from very high on bare limestone dip slopes, to low in areas blanketed with thick Quaternary till deposits. Natural dissolution is removing large quantities of gypsum so that the groundwater and many springs are high in sulphate (0.8-2.0g/l). Calculations suggest that the volume of gypsum being dissolved each year at Ripon is about 120m3/km2. The abstraction of groundwater high in sulphates can also remove large volumes of gypsum. Cooper (1988) suggested that at Ripon 200m3 of gypsum was removed each year by boreholes abstracting 212,000m3 of water annually. Much of this dissolution probably represents enlargement of joints, but around the boreholes severe dissolution of the gypsum beds is likely. In addition to dissolution, water abstraction can lower the water table and trigger off both the ingress of Quaternary deposits into the gypsum karst, and the collapse of the cover deposits, resulting in subsidence. Similar problems are suspected of causing subsidence in the Darlington area (Cooper, 1995).

Table

The sequence of the Permian and Triassic rocks in north-eastern England (from Darlington southwards) and their main lithological and hydrological properties.

	Formation/Group	Thickness metres	Description	Hydrological Properties
TRIAS-SIC	Sherwood Sandstone Group	300	Red sandstone with subordinate mudstone beds, especially near base	Major regional aquifer TDS 0.15-0.3g/l mainly as carbonate
P E R M I A N	Roxby Formation	up to 26	Red-brown calcareous mudstone (marl) with up to 10m of gypsum (Billingham Anhydrite Formation) at base	Very leaky aquiclude with gypsum karst aquifer at base; sulphate-rich
	Brotherton Formation (Seaham Formation in north)	8-14	Calcitic dolomite, mainly in thin beds	Aquifer TDS~0.5g/l mainly as carbonate; sulphate-rich in places
	Edlington Formation	up to 50	Red-brown calcareous mudstone (marl) with up to 30-40m of gypsum (Hartlepool Anhydrite Formation) at base	Very leaky aquiclude with gypsum karst aquifer at base TDS 0.8-2.0g/l mainly as sulphate
	Cadeby Formation Ford and Raisby formations in north)	up to 65	Dolomitic limestone, commonly massive, but porous and locally leached	Major local aquifer TDS 0.2-0.5g/l as carbonate

2. The karst in the Permian gypsum of Cumbria

In the northwest of England, gypsum of Permian age is well-developed in the faulted half-graben of the Vale of Eden, Cumbria (Figure 1). Four main gypsum sequences are present, named from the bottom upwards as the "A", "B", "C" and "D" beds (Arthurton & Wadge, 1981). The gypsum beds are sandwiched between the mudstone and siltstone aquicludes of the Eden Shales (60-180m thick), except for the basal "A" bed, which rests on the Penrith Sandstone, a local aquifer. The "A" bed is thickest (10m), but is restricted to the south of the Vale of Eden. The "B" bed is the most widespread (4.9-6.6m thick) and present throughout the Vale, extending to Carlisle. The "C" bed (1.2-3.1m thick) and "D" bed (1.2-3.7m thick) occur mainly in the south.

The "B" bed has been widely exploited as a mineral deposit. Gypsum karst features have been noted in many mines and quarries, such as Houtsay Quarry about 30km SSE of Carlisle, where caves were recorded by Ryder and Cooper (1993). Here they noted a downdip transition from west to east from complete dissolution, through buried gypsum karst with gypsum pinnacles to gypsum karst with caves, then into massive gypsum and, in turn, massive anhydrite. The gypsum is sandwiched between low permeability mudstones and the gypsum karst area is around 200-400m wide. A variable sequence, up to 8m thick, of glacial till and sand and gravel with later deposits overlies the gypsum. These deposits conceal and partly fill the buried gypsum karst, suggesting that some of the karst features date from pre- or en-glacial times; the exact climatic conditions that occurred during their formation are unknown. The caves may have partly formed as a sub-glacial phenomenon under increased hydrostatic head. The caves were dry when explored, but this may relate to mining and local de-watering.

The caves at Houtsay Quarry have now been destroyed by quarrying, but approximately 200m of passages were present. In the north there was a single main passage, about 2m in diameter, following an overall south-east to north-west line with frequent changes of size and direction that followed the joint pattern in the rock. In several places there were circular roof pockets and one large aven. At the south of the quarry the caves included two straight tubular phreatic conduits, 1.2-2m in diameter, one with a vertical dissolutional aven that extended through to the top of the gypsum. In all the caves the rock faces were covered by small-scale scalloping. Minor vadose grooves were also present. There were no speleothems, but the gypsum walls commonly had a powdery efflorescence. The cave floors were covered with deposits of ochre-coloured clay, and in the larger caves these were interlayered with peat and broken up by polygonal desiccation cracks. The only other records of caves in the gypsum hereabouts have been given by Rogers (1994) who briefly described caves encountered in the gypsum mines. He noted dry and water-filled avens up to 9m high and 6m in diameter and horizontal passages that ran for more than 18m.

3. The paleokarst in the Permian gypsum of Durham and the Firth of Forth

In the north-east of England, gypsum palaeokarst is well displayed along the Durham coast from Hartlepool northwards to Sunderland. The Permian geological sequence is similar to that in the Ripon area (Figure 2), but with some additional limestone formations in the middle of the sequence. Here the Hartlepool Anhydrite Formation is up to 130m thick and equivalent to the sulphate in the Edlington Formation to the south; it rests on the dolomite of the Ford Formation. In most of the onshore areas the Hartlepool Anhydrite has been completely dissolved, so that the overlying limestones are foundered and perforated by large breccia pipes (Smith, 1994 and numerous references therein). In the coastal cliffs these breccia pipes reach about 30m in diameter and extend upwards for many tens of metres. The area of complete dissolution extends along the coast and eastwards offshore for 3-5km (Smith, 1994, figure 42) passing eastwards into a zone of gypsum karst. The overlying rocks have collapsed and produced a synclinal structure between the old reef front in the west and the dissolution front of the sulphate sequence in the east. The age of the karstification that caused this structure is unknown. Many of the foundered sequences show both massive de-dolomitised collapse breccia and later, more open structured, breccia-filled pipes. Smith (1994) considers that some of the dissolution was initiated during Mesozoic earth movements and uplift. The intrusion of an igneous dyke (dated at around 58 million years) into collapse breccia at Whitburn suggests that uplift and dissolution had commenced by the mid-Paleocene. In many places the only relics of the gypsum and anhydrite sequences are dissolution residues of heavy mineralrich clays.

Beneath the seabed of the Firth of Forth and North Sea (about 90km east of Edinburgh) the late Permian sequence crops out beneath Quaternary deposits commonly 10-20m thick. Gypsum and anhydrite have been proved in shallow boreholes and the surface of the rock has been imaged by shallow seismic surveys (Thomson, 1978). These investigations prove a gypsum karst surface with pinnacles of gypsum and anhydrite surrounded by foundered strata. This foundering affects strata including the overlying Triassic sandstones. The belt of foundered strata and sulphate karst is 10 to 20km wide. In the west, anhydrite and gypsum have been proved, but in the east a dissolution residue was tentatively recognised. The age of this karst is not known, but may be similar to the offshore sulphate karst of Durham.

4. The karst in the Triassic gypsum of Central England

Around Nottingham (Figure 1) gypsum has been exploited at two main levels in the siltstones and mudstones of the Triassic Mercia Mudstone Group; these are the Tutbury and Newark gypsum beds. The Tutbury Gypsum is massive, up to 8m thick, and the Newark Gypsum comprises an 18m sequence of mainly nodular and thinly bedded gypsum with mudstone. In the Tutbury Gypsum mined at Fauld (40km WSW of Nottingham), Wynne (1906) recorded areas of dissolution and collapse including a "circular wash hole"; this appears from his description to be a phreatic tube about 6m wide and 2m high. Nearby at Chellaston (Smith, 1918) described the sequence as having numerous swallowholes adjacent to pillars of gypsum; he also described the pinnacled upper surface of the gypsum and gypsum breccias, all features typical of gypsum karst.

In addition to the Tutbury and Newark gypsum, the mineral is also present in much of the associated Triassic sequence. The widespread dissolution of gypsum in these rocks of the Nottingham area was recorded by Elliott (1961), who noted a near-surface zone (0-30m) with cavities and brecciated strata where most of the gypsum had been dissolved. Recent exposures for a new road have shown that the Tutbury Gypsum of the Aston upon Trent area (20km SW of Nottingham) caps the hills, where it has been extensively mined. On the sides of the hills the gypsum passes downdip, towards the water table, into a zone of partial dissolution with collapse areas and cavities. It then passes into an area of severe dissolution with only relict masses of gypsum up to 5m across, and finally into a zone of complete dissolution. In the areas where dissolution has been severe the foundered mudstones are weak and give rise to difficult engineering conditions for road and bridge construction.

5. Environmental problems associated with gypsum karst

Subsidence is the most common environmental problem associated with gypsum karst in the UK. Sudden catastrophic subsidence occurs around Ripon about once a year and has resulted in damage of about $1,500,000 in the last 10 years. In the city of Darlington large areas of housing have also been damaged. Amelioration of the subsidence problems can be approached on two fronts: planning and construction.

A recent study of the Ripon problem has recommended a formal approach to planning for gypsum geohazards (Thomson et al, 1996). This involves recognising the subsidence-prone areas and having guidelines for site investigation, design and construction. For each planning application special proformas have to be signed by a "competent person" who is a qualified geotechnical specialist. The most cost-effective way of developing gypsum karst areas is to avoid the subsidence problems by keeping development away from actively subsiding areas, subsidence hollows and areas between subsidence hollows. If these areas cannot be completely avoided, development might be possible after a full site investigation has been undertaken. Some areas of subsidence have been close to or connected with water abstraction (Cooper, 1988). Integral with the planning, careful consideration should be given to the restriction of water abstraction in gypsum karst areas, both to reduce the amount of gypsum dissolution and prevent drawdown of the water table which can trigger subsidence.

For construction, site investigation can be made more cost-effective by the use of geophysical techniques, especially microgravity (Patterson et al, 1995) and resistivity tomography (Cooper, 1995). Development may then proceed by using reinforced and extended foundation structures for buildings, and geogrid textile materials for the protection of roads (Paukstys et al, in press). At Ripon a specially reinforced bridge has been constructed with sacrificial piers, so that the collapse of any one support will not cause the bridge to collapse; the structure has also been equipped with load monitoring devices to warn of any failure.

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