ENVIRONMENTAL PROBLEMS CAUSED BY GYPSUM AND SALT KARST IN THE UNITED KINGDOM.

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ABSTRACT

In Great Britain gypsum karst is widespread in the late Permian (Zechstein) gypsum of north-eastern England. Here and offshore, a well-developed palaeokarst with large breccia pipes was formed by dissolution of the underlying Permian gypsum. Further south around Ripon, the same rocks continue to dissolve forming an actively evolving phreatic gypsum maze cave system. This is indicated by the presence of numerous active subsidence hollows and sulphate-rich springs. In the English Midlands, gypsum karst is locally developed in the Triassic deposits south of Derby and Nottingham. Where gypsum is present, its fast rate of dissolution and the collapse of the overlying strata lead to difficult civil engineering and construction conditions; these can be further aggravated by water abstraction. Salt (halite) occurs within the British Permian and Triassic strata, and has a long history of exploitation. The main salt fields are in central England and the coastal areas of north-west and north-east England. In central England, saline springs indicate that rapid, active dissolution occurs that can cause subsidence problems. In the past, the subsidence was aggravated by shallow mining and the uncontrolled extraction of vast amounts of brine. This has now almost stopped, but there is a legacy of unstable buried salt karst formed by both natural and induced dissolution. The buried salt karst occurs at a depth of between about 40 and 130m, above this the overlying strata is foundered and brecciated. In the salt areas, development is hampered by both abandoned mines and natural or induced brine runs with their associated unstable ground.

1. 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 (Cooper and Saunders, 1999) (Figure 1). Compared with the British limestone karst, it occurs in relatively small areas. However, rapid dissolution of gypsum produces local subsidence and collapse problems, that are particularly well displayed around Ripon, North Yorkshire. Gypsum palaeokarst features also occur, especially along the coast of north-east England and in the Firth of Forth off eastern Scotland. Salt (halite) karst is well developed in the Permian and Triassic strata of the UK, mainly in Cheshire, the Midlands and the Lancashire coastal areas (Figure 1). Halite is much more soluble and dissolves more quickly than gypsum, consequently, subsidence can progress very quickly, especially if salt mining or brine abstraction occur at the same time.

2. GYPSUM KARST GEOHAZARDS

2.1 Permian gypsum karst of north-east England

Gypsum karst and related subsidence problems occur extensively in the Permian rocks of north-east England, running in a belt 3-4km wide from the coast near Hartlepool, past Darlington, through Ripon to just north of Doncaster (Figure 1). In this belt, up to 40m thickness of gypsum is present in the Edlington Formation and 10m in the Roxby Formation. Both gypsum sequences are overlain by calcareous mudstone units and both rest on dolomite aquifers. This Permian evaporitic sequence is overlain by the Triassic Sherwood Sandstone Group a major regional aquifer. The carbonate aquifers have dip slopes, which form catchment areas that feed water down-dip from the west into the overlying gypsiferous sequences. Gypsum is very soluble and dissolves rapidly, as a result cavities, collapse and breccia pipes have developed perforating the sequence. This has enhanced the water circulation and, locally, broken the mudstone aquitards allowing additional water into the sequence from the overlying Sherwood Sandstone Group aquifer present to the west.

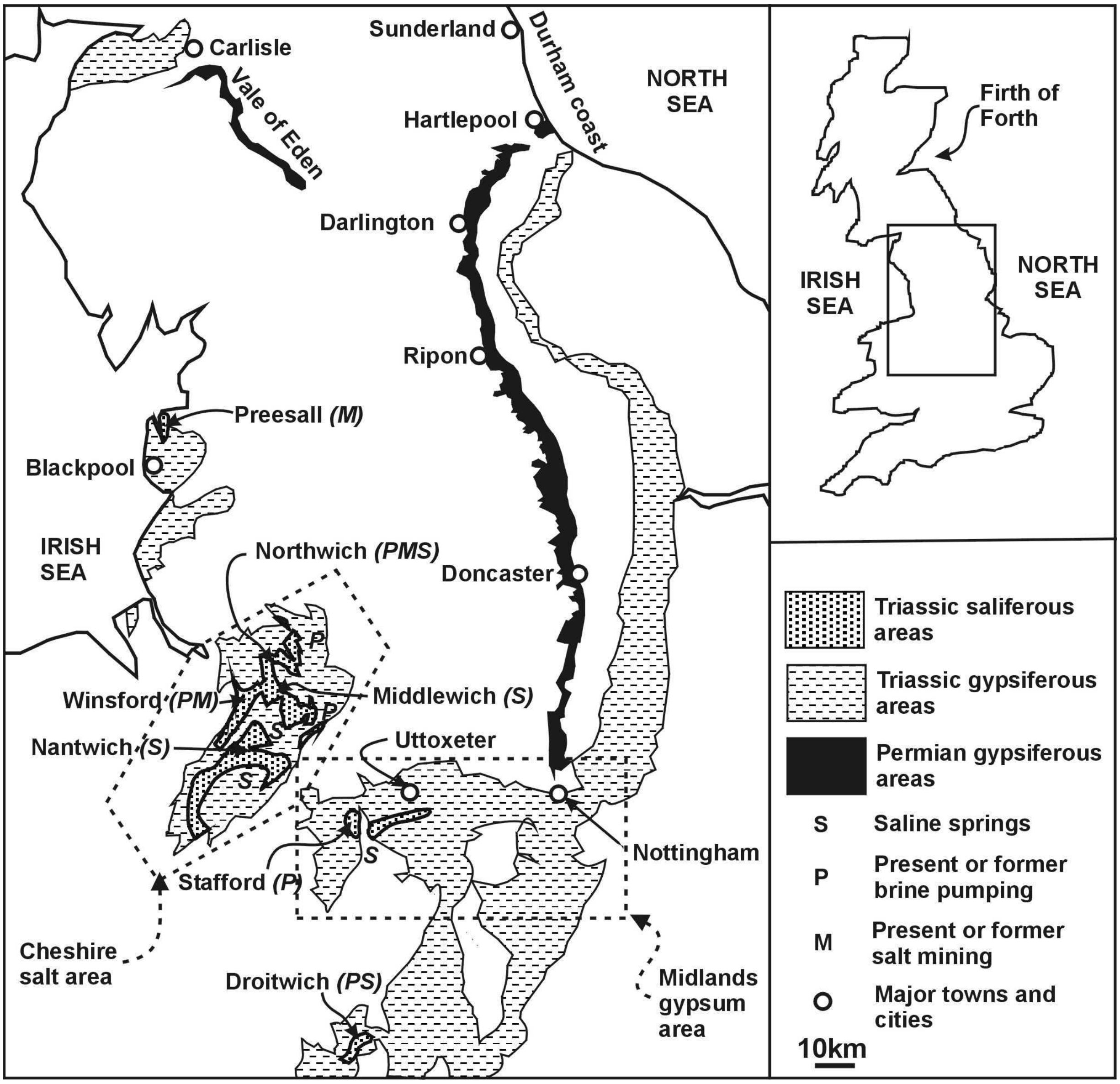

Figure 1
The distribution of gypsiferous and saliferous strata in central and northern England.

Water passes through the gypsum and 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 Wharfe near Brotherton (50km SSE of Ripon). Complex cave systems have developed in the gypsum, and artesian sulphate-rich springs are present locally (Lamont-Black et.al., 1999). Large dissolutional voids can develop in the thick gypsum and at Ripon surface collapses occur locally about once a year. These collapses range up to 30m across and 20m deep, but most are smaller (Cooper, 1995). The subsidence occurs in a grid-like pattern related to the jointing in the underlying rock (Cooper, 1986, 1989).

Most subsidence activity occurs along the river valley margins, where the groundwater escapes from the gypsum into the Quaternary valley fill and alluvial deposits. In many places along the gypsum belt, gypsum dissolution and collapse of the overlying strata have produced a monoclinal fold over the gypsum dissolution front. Large quantities of gypsum are removed by groundwater dissolution yielding high sulphate (0.8-2.0g/l) springs. Calculations by Cooper (1986) suggested that the volume of gypsum being dissolved each year at Ripon was about $120m^3/km^2$. This situation can be aggravated by the abstraction of sulphate-rich groundwater. Cooper (1988) suggested that annually at Ripon $200m^3$ of gypsum were removed each year by boreholes abstracting 212,000m^3 of water. Much of this dissolution may cause joint enlargement, but near the boreholes severe cavernous dissolution of the gypsum beds may occur. Water abstraction may also lower the water table and cause the ingress of Quaternary deposits down into the gypsum karst, and the collapse of the cover deposits, resulting in subsidence (Cooper, 1995).

2.2 The Permian gypsum karst of north-west England

Permian gypsum occurs in the faulted half-graben of the Vale of Eden, south-east of Carlise, Cumbria (Figure 1). Four main gypsum sequences occur interbedded with mudstone and siltstone of the Eden Shales (Arthurton & Wadge, 1981). The "B" bed gypsum is the most widespread (4.9-6.6m thick) and is present throughout the Vale, extending to Carlisle. It has long been exploited and karst features were noted in many gypsum mines and quarries. These include caves in Houtsay Quarry about 30km SSE of Carlisle (Ryder and Cooper, 1993). Here there is a downdip transition of karst style from west to east. It goes from complete dissolution, through buried gypsum karst with gypsum pinnacles to gypsum karst with caves, then into massive gypsum and, finally, massive anhydrite. The gypsum occurs between low permeability mudstones and forms a gypsum karst belt 200-400m wide. The gypsum is overlain by a variable sequence of up to 8m of glacial till and sand and gravel with later deposits suggesting a possible pre- or sub-glacial origin for the karst. When explored, the caves were dry, but this may be due to mining and local de-watering. Quarrying has now destroyed the Houtsay Quarry caves, but approximately 200m of passages were recorded. The caves comprised mainly circular to irregular phreatic conduits with frequent changes of size and direction following the joint pattern in the rock. There were several circular roof pockets and avens plus a cavity migrating upwards through the overlying Eden Shales. Rogers (1994) briefly described caves in the Vale of Eden entered from 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. The presence of caves in the gypsum and cavities in the overlying strata are important both for mining and development over the gypsum areas to the south-east of Carlisle.

2.3 The Permian gypsum palaeokarst of northern Britain

In the north-east of England, gypsum palaeokarst is visible along the Durham coast from Hartlepool northwards to Sunderland. The rocks here are similar to those at Ripon (Figure 1), but with additional limestone formations in the middle of the sequence. Here, just off shore, the Hartlepool Anhydrite Formation is up to 130m thick; it is equivalent to the sulphate in the Edlington Formation to the south and also rests on dolomite. In the onshore areas the Hartlepool Anhydrite has been almost completely dissolved. Consequently, the overlying limestones are foundered and perforated by large breccia pipes (Smith, 1994) up to about 30m in diameter extending upwards for many tens of metres. Complete dissolution of the gypsum and anhydrite extends along the coast and offshore for 3-5km (Smith, 1994, figure 42) passing eastwards into a zone of gypsum karst. The overlying rocks have collapsed and produced a monocline and associated synclinal structure between the old reef front in the west against which the sulphate was deposited, 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; Smith, 1994) 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 mineral-rich clays such as the Hartlepool Anhydrite residue and the Seaham Residue (Smith 1994). About 90km to the east of Edinburgh, beneath the Firth of Forth and North Sea, the late Permian sequence crops out beneath 10-20m of Quaternary deposits. 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 proved a gypsum karst surface with pinnacles of gypsum and anhydrite surrounded by foundered rock. The belt of foundered strata and sulphate karst is 10 to 20km wide and like its onshore equivalent, the overlying Triassic sandstones are affected. In the west, anhydrite and gypsum have been proved, but in the east, a dissolution residue was tentatively recognised (Thomson, 1978). The age of this karst is not known, but may be similar to the offshore sulphate karst of Durham.

2.4. Triassic gypsum karst of the Midlands

In the Midlands near Nottingham (Figure 1), gypsum has been exploited from two main levels, the Tutbury and Newark gypsum beds, of the Triassic Mercia Mudstone Group. In the Tutbury Gypsum (up to 8m thick) mined at Fauld (40km WSW of Nottingham), Wynne (1906) recorded areas of dissolution and collapse including a probable phreatic tube about 6m wide and 2m high. Nearby at Chellaston (Smith, 1918) described features typical of gypsum karst including swallowholes adjacent to pillars of gypsum, breccias and the pinnacled upper surface of the gypsum. Gypsum is also present throughout 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 road cuttings show that the Tutbury Gypsum of the Aston upon Trent area (20km SW of Nottingham) caps the hills, where it has been extensively mined. It 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 (Cooper and Saunders, 1999).

3. HALITE KARST GEOHAZARDS

In Britain, halite, or rock salt, occurs mainly within Permian and Triassic strata and has a long history of exploitation (Sherlock, 1921; Notholt and Highley, 1973). Subsidence, mainly induced by mining, has affected all the main Triassic salt fields including Cheshire (Calvert, 1915), Staffordshire (Arup Geotechnics, 1990), Worcestershire (Poole and Williams, 1981), Preesall (Wilson and Evans, 1990) and Northern Ireland (Griffith, 1991). Beneath coastal Yorkshire and Teeside, Permian salt has been won from the Zechstein Group south and south-east of Hartlepool and some ancient subsidence has occurred along the banks of the Tees. The high solubility of halite means that it can dissolve rapidly and cause severe subsidence problems induced either by mining or natural causes (Waltham, 1989). The depth of the dissolution zone varies from around 40-130m, above this the overlying strata is foundered and brecciated. British salt from underground rock salt deposits has been exploited since at least early Roman times. Place names ending in “wich” or “wych” indicate natural brine springs, and it is around such springs that the towns of Droitwich (Poole and Williams, 1981), Nantwich (Earp and Taylor, 1986), Northwich and Middlewich developed in the West Midlands and Cheshire (Calvert, 1915). Coincident with these near-surface salt deposits, areas of natural subsidence occur. These include places such as Chantley Moss in the Staffordshire salt field 10km SW of Uttoxeter and 5km NE of the saline spring of Shirleywich (A. Brandon, pers comm. 2000).

In the late 19th and early 20th Centuries the salt deposits were worked by two main methods: traditional mining and wild brine solution mining. Most of the conventional mining was in shallow “pillar and stall” mines with networks of tunnels commonly separated by insubstantial salt pillars. “Wild”, “bastard” or uncontrolled, brine solution mining involved sinking boreholes and shafts down to the wet rock salt surface and pumping the brine out. This wild brine method induced the flow of brine towards the extraction boreholes and linear subsidence belts spread out from the boreholes. In some situations, mine owners even pumped the brine from flooded pillar and stall mines (Calvert, 1915; Griffith, 1991). Around Northwich and Middlewich, the resulting subsidence was catastrophic and widespread. New lakes (called “meres” or “flashes”) appeared almost daily, many were hundreds of metres across. The subsidence in Cheshire was so severe that an Act of Parliament was passed placing a levy on all local salt extraction. This levy, which funded building reconstruction and compensation payments, is still made at a lower rate by the “Cheshire Brine Subsidence Compensation Board” to reflect the reduced risk from modern extraction (Collins, 1971). Modern salt extraction takes place mainly in deep dry pillar and stall mines, or by controlled brine extraction leaving large, deep, underground chambers that are left flooded and filled with saturated brine.

Current planning procedures ensure that the modern exploitation lies largely outside urban areas so that risks are considerably reduced. However, there is still a legacy of problems related to the salt deposits. These include old salt mines that have not collapsed, and compressible or unstable collapsed ground over former salt mines. In addition, natural salt dissolution at the rockhead interface, between the salt deposits and the overlying superficial deposits, can cause ground engineering problems and aggressive saline groundwater. Near-surface mining and brine extraction has largely ceased and the hydrological system has, or is in the process of, rebalancing itself. It may be expected that natural groundwater flow will re-establish itself through the disrupted saltfield. This may induce further subsidence problems. The accurate mapping of the rock salt and associated deposits, plus an understanding of their dissolution and collapse characteristics, will help to guide development and planning in these subsidence-sensitive areas.

4. PLANNING FOR SOLUBLE ROCK GEOHAZARDS

Subsidence is the most common environmental problem caused by gypsum and salt karst in the UK. At Ripon, subsidence, which can be sudden and catastrophic, occurs almost yearly and has caused about $1,500,000 of damage in the last 10 years. In Cheshire, abandoned salt mines combined with natural or induced groundwater flow have left a legacy of damaged ground. These problems can be reduced by careful planning and construction. A recent study of the Ripon problem has recommended a formal approach to planning for gypsum geohazards (Thomson *et al.*, 1996; Paukstys, *et al.*, 1999). This involves recognising the subsidence-prone areas and having guidelines for site investigation, design and construction. For each land use 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 problem 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; Lamont-Black, 1999). Integral with the planning process, careful consideration should be given to the restriction of water abstraction in gypsum karst areas and near-surface brine extraction in salt karst. These measures would reduce both the amount of dissolution and prevent drawdown of the water table, which can trigger subsidence. Sulphate-rich groundwater and sulphate attacks on concrete are also problems in the gypsum karst areas (Forster et.al., 1995). Site investigation for construction 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 (Cooper and Saunders, 1999). 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 (Cooper and Saunders, 1999).

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