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Land Use Planning for High Pressure Pipelines – Ground Hazards from Dissolution of Soluble Rocks

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Land Use Planning for High Pressure Pipelines – Ground Hazards from Dissolution of Soluble Rocks

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Key words

Report; pipeline; karst; limestone; chalk; gypsum; salt; subsidence; hazard; doline; sinkhole;

Front cover

Subsidence hollow (doline) formed in 1997 and caused by gypsum dissolution beneath Ure Bank Terrace, Ripon. The local gas supply had to be re-routed around it.

Bibliographical reference

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Foreword

Several rock types in Great Britain are susceptible to the effects of dissolution by rain, surface and groundwater. This can cause localised damage to built structures including buried pipelines. Detailed investigation is required to establish the true nature and risk of dissolution at a site but this is a costly and time-consuming process that is unnecessary in many instances. The occurrence of ground failures resulting from dissolution is strongly controlled by local geological, geomorphological, hydrogeological and environmental conditions. Thus, it is possible, by assessing existing records and experience, to gain some indication of the susceptibility to dissolution-related failures of the ground at any particular location.

In order to assess, on a national scale, the hazard to the high-pressure gas pipeline network from the dissolution of soluble rocks, Advantica Technologies commissioned the British Geological Survey (BGS) to collate available information regarding dissolution of soluble rocks hazards across Great Britain and present them in a way meaningful to the pipeline operators. The results of this research are presented in this report and accompanying data cd.

Acknowledgements

This study has made use of information gathered using the British Geological Survey Geoscience Spatial Model software running on ArcView. Keith Adlam is thanked for establishing and supporting that software interface. The work has also incorporated data gathered for the British Geological Survey GeoHazarD project managed by Jenny Walsby. Tony Myers in Cartographic Services is thanked for undertaking much of the GIS manipulation of the datasets.

Fiona Harding, Kamil Sahin (Advantica Technologies) and David McHugh and Neil Jackson (Transco) are thanked for their assistance in collating data and detailed advice on project specification and comments during report preparation.

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Summary

This report is a product of a study by the British Geological Survey (BGS) for Advantica on behalf of Transco. It is written to accompany and explain the GIS layer provided as part of a research contract agreed as BGS Commissioned Research Project E1449R83.

Britain has five types of soluble (or karstic) rocks: limestone, dolomite, chalk, gypsum and salt, each with a different character and associated problems. Subsidence, often triggered by anthropogenic disturbance such as water or brine abstraction occurs widely, especially where karstic rocks are overlain by a thin superficial cover. These situations can cause significant engineering and foundation problems that may affect pipelines and their infrastructure.

On instruction from Advantica, research was carried out to determine the susceptibility to ground movement resulting from the dissolution of soluble rocks within a 500 m wide buffer zone centred upon the 18 000 km long high-pressure gas transmission pipeline network.

Available data were compiled and checked using ARCGIS Geographical Information System software. This report describes the manner in which the data have been manipulated and compared with linework provided by Advantica of the national gas pipeline network to identify areas that may be at risk from ground movements. However, the process was not entirely automated and was assessed by BGS staff experienced in the identification, classification and mitigation of karstic soluble rock (karstic) hazards. Susceptibility to ground movement resulting from the dissolution of soluble rocks within the buffered zone is indicated by the classification of the zone into one of five different classes of hazard, 1-5. For each of the hazard classes, general management recommendations are given as to possible measures which may be undertaken to minimise hazard. It is not the purpose of this report to detail actual management policies or make detailed recommendations for pipeline management. Summaries of areas within the buffer zone are presented in Table 1.

1 Introduction

1.1 PROJECT BACKGROUND

The UK Health and Safety Executive (HSE) has introduced a risk-based approach for proposed development near gas transmission pipelines based on a simple decision matrix which considers individual risk and the nature of proposed developments.

Whilst Transco supports the use of hazard, rather than consequence, as the basis for making decisions on land use near its transmission pipelines, The HSE's current risk methodology for ground movement failures may be considered to be conservative and may sterilise land near pipelines unnecessarily. The HSE is aware of the conservative nature of its methodology, and has participated in meetings between Transco, Advantica and the British Geological Survey (BGS) with the objective of developing a more refined approach. This project supports the development of a more refined approach to the assessment of ground movement risk for land use planning and also supports the safe operation of Transco's transmission system, for example by identifying pipeline locations which may be at increased risk from the consequences of dissolution of bedrock.

To achieve the goal of developing a more refined approach to hazard assessment, the BGS, as the primary holder of national geological hazard data for Great Britain, was commissioned to produce datasets which would indicate to Transco, as the pipeline authority, those sections of pipeline which were susceptible to ground movement from natural causes.

Although there are many types of ground movement which can affect a pipeline route and infrastructure, it was felt that hazards posed by the dissolution of soluble rocks and by landslide hazards were the most relevant. To this end the BGS was commissioned to produce two national datasets to assess the hazards posed to the transmission pipeline network. This report describes the procedure followed and the results of the research that determine hazard resulting from the dissolution of soluble rocks.

2 Dissolution Hazards in Great Britain

2.1 DISTRIBUTION OF DISSOLUTION HAZARDS FROM SOLUBLE ROCKS IN GREAT BRITAIN

Britain has four types of soluble (or karstic) rocks: limestone, chalk, gypsum and salt, each with a different character and associated problems (Figure 1) (Cooper et. al., 2001). Subsidence, often triggered by anthropogenic disturbances such as water or brine abstraction, occurs widely, especially where karstic rocks are overlain by a thin superficial cover. These situations can cause significant engineering and foundation problems that may affect pipelines and their infrastructure.

The limited occurrence of rocks susceptible to dissolution means that it is convenient to discuss each rock type individually.

2.1.1 Limestone

The Carboniferous Limestone hosts the best-developed karst landscapes and the longest cave systems in the country. Although karst features are widespread, the best-developed karst occurs in the Yorkshire Dales, the Peak District, the Mendip Hills and around the margins of the South Wales coalfield (Waltham, et al., 1997). Cambrian and Devonian Limestones, together with some Jurassic limestones locally also display karstic characteristics. The major problems associated with these karst areas are water supply protection, geological conservation and engineering problems. Subsidence associated with subsidence hollow (doline) formation does occur, but is generally not severe enough to affect pipelines.

2.1.2 Chalk

The Chalk is the most widespread carbonate rock in the country and of immense importance for water supply. It forms Great Britain's most important aquifer. In places it has solutionally enlarged fissures and conduits, notably sediment-filled dissolution pipes. Chalk dissolution also generates subsidence hazards and difficult engineering conditions associated with the development of clay filled pipes and fissures. Other problems also include irregular rockhead, localised subsidence, increased mass compressibility and diminished rock mass quality. It is not generally considered to be problematical to pipelines.

2.1.3 Dolomite

Dolomite is less soluble than limestone and produces fewer karst features. The caves in dolomite tend to be small and of limited extent while surface features are scarce. The main areas of dolomite are in the Permian sequence of north-east England and the rock has a low hazard rating.

2.1.4 Gypsum

Gypsum karst is present mainly in a belt 3km wide and about 100km long in the Permian rocks of eastern and north-eastern England (Figure 1) (Cooper, 1986, 1998). It also locally occurs in the Triassic strata, but the effects of it are much less severe than those in the Permian rocks. The difference is mainly caused by the thickness of gypsum in the Permian sequence and the fact that it has interbedded dolomite aquifers. In contrast the Triassic gypsum is present mainly in weakly permeable mudstone sequences. The gypsum karst has formed phreatic cave systems, but the high solubility rate of the gypsum means that the karst is evolving on a human time scale. Active subsidence occurs in many places, especially around the town of Ripon. The active nature of the dissolution and the continuing development of subsidence features cause concern for pipelines crossing the area.

2.1.5 Salt

Salt in Great Britain occurs mainly in the Permian and Triassic strata of central and north-eastern England (Figure 1). Many towns on the Triassic strata have "wich" or "wych" in their names indicating that they are sited on former salt springs emanating from actively dissolving salt karst (Cooper 2002). These places became the focus for shallow mining and near-surface "wild" brine extraction, a technique that exacerbated the salt karstification. In some of these areas subsidence is still occurring. Most extraction of natural brine has ceased and modern exploitation is mainly in dry mines or by deep, controlled brine extraction leaving brine-filled cavities. Since the cessation of natural brine pumping, the saline ground water levels have returned towards their pre-pumping state. Brine springs are becoming re-established and natural karstification and subsidence may be expected to occur. The exact nature of the brine flow is not fully understood, but the subsidence caused by them may be severe enough to cause concern for pipeline structures.

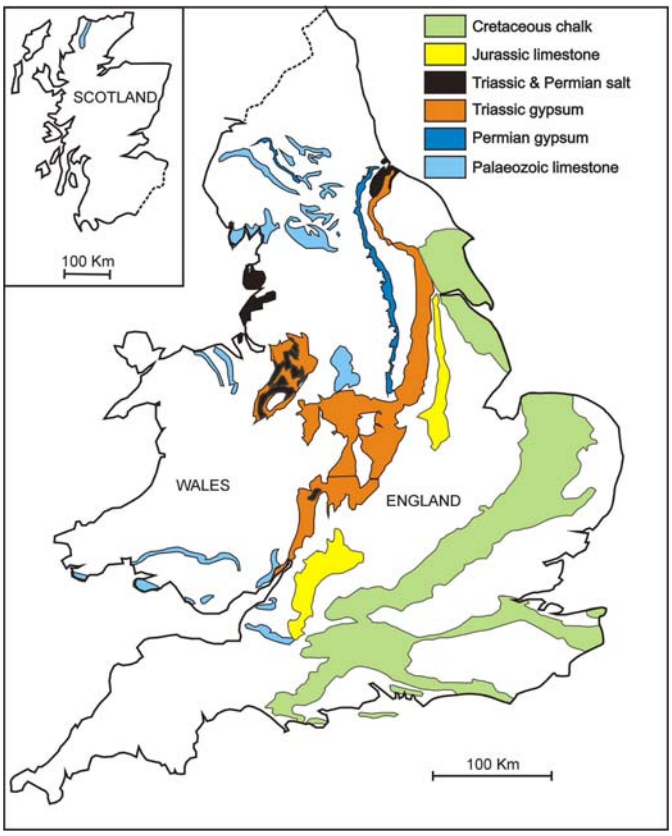

Figure 1 The distribution of the main soluble rocks in Great Britain (excluding Permian dolomite)

3 Dissolution Hazards to Buried Pipelines in Great Britain

3.1 SUBSIDENCE AND COLLAPSE

3.1.1 Carboniferous and Devonian limestone:

Collapse dolines commonly form in the cover strata in areas of interstratal karst such as the Llangattock Plateau in South Wales. The rocks here comprise insoluble sandstones over karstified Carboniferous Limestones. The collapses here are rare and infrequent, but they have the potential to create very large collapses or areas of subsidence, with differential settlement.

Suffosion dolines are quite common in areas with a thin superficial cover such as till, river terrace and head deposits. Subsidence occurs where superficial deposits are gradually washed into fissures in the underlying karstic rocks, creating metastable cavities in the unconsolidated cover materials which subsequently collapse. This is probably the most common form of subsidence in karstic areas, and dolines can be quite large in size. These may also undergo repeated collapse, especially if infilled. In addition to major dolines, flushing out of sediment from infilled cavities or joints can be aggravated by the alteration or impediment of drainage. However, this is unlikely to cause major collapses. Very irregular rockhead is also typical of limestone karst areas.

In areas of bare karstic limestone, the collapse of near-surface cave systems crossed by a pipeline would be extremely rare, but if it did happen, it could create a significant collapse.

3.1.2 Triassic and Permian gypsum

Gypsum dissolution areas are prone to the formation of voids that can migrate upwards as breccia pipes through considerable thicknesses of the adjacent soft strata (Cooper, 1986, 1988, 1989, 1998). In the majority of the Triassic gypsum areas the gypsum is fairly thin and interbedded with moderately impervious strata, these areas are not very hazardous (Cooper and Saunders, 1999). In some of the Permian gypsum areas, there are very thick sequences of the rock. These are mainly interstratal karst, interbedded with aquifers making the adjacent gypsum very prone to dissolution. The thicknesses of gypsum present are considerable and the sizes of the subsurface voids are large. In these areas, appreciable voids can develop and break though to the surface causing significant subsidence features that in some places may reach 30 m or more across and many metres deep. These occur on a human rather than a geological time scale (Cooper, 1998) and may constitute hazards to pipelines or their infrastructure.

Figure 2. Subsidence crater (doline) caused by the dissolution of Permian gypsum beneath the village of Sutton Howgrave, North Yorkshire [SE 3146 7928]. The hole started to collapse in December 2000, the photograph was taken on 14th February 2001 when the hole was 5-6m in diameter and 11m deep with water at a depth of 8m. The crater is about 400m from the gas pipeline. Photo A.H.Cooper © NERC.

3.1.3 Triassic salt

Salt is the most soluble of the commonly present soluble rocks. Its solubility means that it is never seen at the surface in Great Britain and it generally occurs in areas with considerable thicknesses of superficial deposits. It is prone to natural dissolution and salt springs are commonly present where it occurs (Cooper, 2000, 2002). It is also a valuable mineral resource that has been exploited by shallow mining and brine extraction. Where near-surface brine has been exploited, or is being exploited at the moment, linear brine runs with their associated subsidence radiate from the extraction points. These runs can be a hundred metres or more in width and up to several kilometres in length. Even after brine extraction has ceased, these brine runs may continue to be active and become conduits for natural dissolution. In some of the salt areas, crater subsidence has also been reported.

3.1.4 Chalk

Flushing out of sediment from infilled dissolution pipes in the Chalk is quite likely to occur where drainage is altered or impeded, but probably unlikely to cause very large collapses. However the density of areas of subsidence in certain areas may be enough to create problems. Very irregular rockhead, causing differential settlement, many be a problem. Caves are rare and cavern collapse will only create very minor subsidence if any.

3.1.5 Jurassic Limestones

There is a possibility of solutionally enlarged sediment filled joints becoming washed out. However, these are unlikely to create cavities large enough to cause problems.

3.2 LATERAL MOVEMENT

Lateral movement is not generally associated with the subsidence caused by underground dissolution where subsidence hollows or dolines form at the surface. It is unlikely in most of the limestone areas, the Chalk and the gypsum areas. In areas of salt subsidence where there is thick superficial cover and where linear subsidence features form, lateral movement has been observed. This has been noted on the Crewe to Manchester railway line (Figure 3).

Figure 3. Lateral and vertical movements of the Crewe to Manchester railway line over an area of active salt dissolution and subsidence. Note the pylon bases with vertical adjustment and the lateral movement of the railway line. Photo A.H.Cooper © NERC.

4 Derivation of dissolution hazard ratings: BGS Methodology

4.1 LINEAR ROUTE HAZARD ASSESSMENT

To assess the hazards to the gas pipeline network, the digitised lines supplied to the BGS were buffered at 250m (500m corridor) and cut against the enhanced BGS GHASP (formerly **G**eo-**HA**zard **S**usceptibility **P**ackage, dataset) to produce a GIS layer indicating the areas where there may be high hazard ratings for the pipeline.

4.1.1 The GHASP dataset

The GHASP dataset was initially designed for assessment of geological hazards causing building damage. Some geological hazard areas included in it are not hazardous to pipelines, but are very hazardous to shallow foundations of buildings. In some areas hazards are of limited extent and although they are not emphasised in GHASP they could constitute a pipeline hazard. Consequently, additional factors have been added to the GHASP dataset to make the new dataset constructed for this project.

GHASP was originally developed using a code system in which district geologists (experts in the geology of a particular region), supported by engineering geologists, identified geological hazards within their district. By this method, the susceptibility to landslide, dissolution of soluble rocks, running sand, shrink-swell, compressible soils and mining-induced subsidence was determined for each postcode sector.

Dissolution susceptibility was determined by the professional judgement of each district geologist. Assessments of hazards in each district were based upon knowledge of known incidents of subsidence resulting from ground dissolution, known characteristics of bedrock karstic behaviour, broad geotechnical character of each postcode sector, thickness of superficial cover and observations of geomorphology made by the geologist and his/her mapping team. Where required, engineering geologists who in addition to their own professional knowledge and expertise had access to a considerable library of geotechnical data across Great Britain, advised district geologists on geotechnical and geomorphological parameters.

Although the system is essentially based upon empirical data and judgement, it has proved to be a practical method of collating and interpreting a great deal of complex and experiential information that would otherwise have been very difficult to use. It has proven to be an effective tool for assessing hazards at a national and regional (1:50 000) scale and is still widely used by many BGS clients including engineering companies and members of the insurance industry.

4.1.2 The modified GHASP dataset

The GHASP dataset has been modified to create more detailed geohazard polygons, in particular, areas deemed to be at greatest risk from karst geohazards. These are notably the areas where the Carboniferous Limestone and Chalk occur next to impermeable strata. They are also areas of interstratal karst in both limestone and gypsum. In addition, areas underlain by salt have been added to the dataset, including many not shown on the published geological maps. The delineated areas have been incorporated into the GIS and each given a hazard rating on a scale of one to five.

The modified dataset benefited from the detailed karst database being constructed by BGS (Cooper, et al., 2001) and from information contained within the Natural Cavities Database constructed for the Department of the Environment (now DETR) by Applied Geology Limited (1993). These detailed datasets were used to constrain the information in the modified GHASP dataset and to provide local information relative to the pipeline routes. The BGS dataset is not yet complete, but it details dolines (subsidence features also called sinkholes or subsidence hollows), springs, stream sinks, caves and building damage. These data are held in a GIS environment allowing them to be consulted in conjunction with the pipeline route buffers. The detailed BGS datasets are still being populated and it is possible that in the future more information will come to light that will require some of the areas in this report to be reassessed.

4.2 EXPLANATION OF HAZARD RATINGS

This operational dataset for use by pipeline managers contains five hazard zones.

1. Low: areas where soluble rocks are present, but very unlikely to cause any significant problems.
2. Low to moderate: areas where soluble rocks are present and unlikely to cause any significant problems.
3. Moderate: areas where soluble rocks are present in considerable amounts, but problems are unlikely except in very adverse and unusual conditions.
4. Moderate to high: areas where soluble rocks are present in considerable amounts and where some surface subsidence has occurred; possibly hazardous in adverse conditions such as enhanced surface or sub-surface water movement.

5. High: areas where considerable thicknesses of soluble rocks are present and where significant surface subsidence has been observed either due to natural or induced dissolution. A high possibility that surface subsidence may occur and that some of it may be severe enough to affect pipelines and their infrastructure.

Only hazard zone 5 presents areas that **may** include areas that constitute a significant hazard to pipelines in the vicinity. In any other areas outside these five zones, dissolution problems are not thought to occur.

5 Distribution of Hazard Zones within the Pipeline Buffer

5.1 AREAS WITHIN ZONES OF HIGH HAZARD (ZONE 5)

5.1.1 Chalk and carboniferous limestone

There are no areas of Chalk or Carboniferous Limestone within zones of High Hazard.

5.1.2 Triassic salt

There are numerous areas that are rated as a high hazard in the parts of the country underlain by salt. These include parts of Cheshire and around Droitwich where there is salt at rockhead and where there has been, or is currently, salt extraction.

Areas of concern include the whole of the Cheshire saltfield where salt is at rockhead. Notable areas are between Crewe, Sandbach and Middlewich. Here a pipeline runs close to Elton Flashes (SJ 7217 5940) and the distressed railway shown in Figure 3. The ponds called "Flashes" are the result of brine abstraction. Although salt extraction of the wild brine has ceased in this area, natural groundwater and brine movement continue to cause subsidence in the vicinity. There is another "Flash" near the pipeline a little to the north of here at Crabmill Flash (SJ 7180 6073).

To the south of Crewe, a pipeline runs close to Wynbunbury Moss (SE 6970 5032). This and many of the named mosses in the area are natural salt subsidence features. Salt subsidence has been recorded in the vicinity (De Rance, 1891) who also recorded subsidence in the vicinity of Crewe Hall and Weston.

West of Nantwich the pipeline crosses some more areas that may be prone to salt subsidence and where salt springs have been recorded. No details of any subsidence have been found for this area.

Around Northwich and Winsford down to Middlewich, there are numerous pipelines crossing the subsidence-prone area of salt at rockhead. Near Marston, there are still brine wells (SJ6757 7565) that are extracting salt from near surface. In the vicinity there has been subsidence of the canal (SJ 6688 7573) and there are numerous "Flashes" in the area. There are also a number of enclosed ponds near the pipeline hereabouts and these too may have been formed by salt dissolution and extraction. South of Winsford a pipeline crosses the River Weaver about 400m upstream of Top Flash. The River Weaver with both the Top and Bottom Flashes all lie on the a zone of salt dissolution and subsidence, it is possible that salt subsidence could occur in the vicinity of the pipeline, but no up-to-date information is available to the BGS.

At Thornton near Blackpool and Preesall, a pipeline crosses the southern mapped limit of the salt deposits that have been extracted near Preesall. The geological mapping at the southern end of the salt area is not based on many boreholes and there is no recorded subsidence. However, immediately to the north-east across the River Wyre there is active subsidence associated with brine extraction. The pipeline south of the river may not be in a very hazardous place, but it and the surrounding area should be examined.

Droitwich has a long history of salt extraction with Roman brine springs recorded near the river in the middle of town. These springs relate to an elongate brine run that starts in the south near a pipeline (SO 8926 6050) near to which there is a subsidence lake (SO 8927 6052). The subsidence lake, about 200m long, formed in the past 60 or so years and was probably related to salt extraction in Droitwich and at Stoke Prior. Another pipeline crosses this brine run to the north-east of Droitwich at (SO 9129 6508) and brine springs have been recorded at Brine Pits Farm about 700m to the north-east of here.

Between Stafford and Burton upon Trent, salt deposits have been recorded mainly at depth. These come near surface beneath superficial deposits around the margins of an area underlain by Triassic gypsum. Salt subsidence features are present along this subcrop and some salt springs have been recorded in the vicinity. The east end of Chartley Moss (SK 0306 2819), the adjacent low area along Stony Brook (SK 0299 2841) and the area west of Amerton (SJ 9879 2748) are all subsidence features related to salt dissolution. In addition, salt springs and minor seismic events at Chartley Moss suggest active salt dissolution and subsidence is still occurring hereabouts. (Cooper 2002).

5.1.3 Permian gypsum

There are a few areas underlain by Permian gypsum that are considered to be in a high hazard zone. One is situated to the north of Ripon where a pipeline crosses the Permian gypsum sequence. A small subsidence (Figure 2) occurred about 400m from the pipeline in 2001. This collapse might have been triggered by water abstraction in the area. On the line of the pipeline there are several very much larger collapse areas, including one about 100m across that reputedly formed only 50m from the pipeline centreline in 1873 (located at NGR SE 3170 7845). Another subsidence hollow, active within the last 40 years and within the pipeline buffer, is 20m across and 107m from the centreline of the pipeline (NGR SE 3120

7651). To the south of the River Ure the pipeline traverses gypsum very near the surface and crosses a belt with numerous subsidence features. The Ripon area is a very active area of gypsum dissolution and its associated subsidence (see cover picture). Many of the holes are small, but collapses of 20-30m in diameter are common and much larger holes are present in the area. How much the larger holes owe to their initial collapse and how much relates to the funnelling in of the material is not certain.

Near Brotherton at Burton Salmon, a pipeline crosses another area underlain by Permian gypsum. This area has suffered subsidence at the Punch Bowl (SE 4852 2820) which is a local doline with the pipeline running very close to it. The pipeline passes 10m from a subsidence 50m in diameter and about 20m from one 30m in diameter. Just to the south of here at Byram Park (SE 4947 2632), the pipeline passes within 35m of a subsidence feature 60m across.

5.2 AREAS WITHIN ZONES OF MODERATE TO HIGH HAZARD (ZONE 4)

5.2.1 Carboniferous Limestone

In South Wales and the Bristol – Mendips - Forest of Dean area, there are several small areas of moderate to high hazard associated with the Carboniferous Limestone. These areas occur where impermeable strata either abut or overlie the Carboniferous Limestone, allowing drainage from outside the limestone area to drain onto it enhancing the local water infiltration. In these areas, the density of karst features, such as stream sinks and cave systems are likely to be higher. Shallow cave systems may be present and voids may be encountered during construction. Anthropogenic disturbance and extreme climatic events may trigger subsidence and collapse but these are generally quite rare.

5.2.2 Permian gypsum

In the Darlington area, a pipeline crosses a zone 4 area underlain by gypsum. The subsidence in this area has been slight in broad depressions. No catastrophic collapses have been recorded and the area has a thick covering of superficial deposits which help to blanket the effects. There are also zone 4 areas underlain by gypsum to the southeast of Catterick and southeast of Tadcaster. There is not much information about the subsidence in these places, but water abstraction at Tadcaster may aggravate the subsidence situation near the River Wharfe.

5.2.3 Triassic salt

Areas of zone 4 underlain by salt occur in the vicinity of Droitwich and Stafford. They exist as concentric areas to the main brine run for Droitwich (detailed above in zone 5) and to the north of the main salt subsidence-prone area of Stafford.

5.3 AREAS WITHIN ZONES OF MODERATE HAZARD (ZONE 3)

Many segments of the pipeline network are within zones of Moderate Hazard. These are generally areas where the Carboniferous Limestone is known to contain significant cavities at depth, but is capped by non-karstic rocks such as the Millstone Grit or Mercia Mudstone. This situation is common along the northern margin of the South Wales Coalfield and also in parts of the Bristol region. Although the cover rocks may not be karstic, major collapses within the Carboniferous Limestone have been known to propagate through the cover, creating collapse dolines at the surface. In South Wales, collapses can propagate over 50 m up into the overlying Millstone Grit, creating spectacular collapse dolines, although none have been recorded in living memory. Good examples of these are well developed close to pipelines crossing Mynydd Llangattock, near Abergavenny (e.g. Grid square SO 19 14). A good example of a collapse void in the Millstone Grit which has yet to reach surface is Ogof Siambre Ddu, a large chamber over 40 m in diameter in Millstone Grit near Abergavenny (SO 252 115), (Waltham et al, 1997)

Zones of Moderate Hazard also occur where impermeable strata, typically Palaeogene sands and clays, either abut or overlie the Upper Cretaceous White Chalk. This situation is common on the Chilterns north of London, Kent, Dorset and the Newbury area and in places along the South Downs. In these areas, water from the impermeable rocks drains onto the Chalk, creating dissolution pipes, stream sinks and cavities. Dissolution pipes up to 20 m deep and 10 m wide can form in extreme cases, but most are less than 5 m deep and 2 m across. Typically they are metastable and filled with sediment. However, anthropogenic disturbance or extreme climatic events may flush out the sediment creating open voids. In active stream sinks, these voids can develop and refill with sediment rapidly over a period of several years. Good examples of such stream sinks can be seen at Water End near Potters Bar near where a pipeline crosses the Mimmshall Brook. The sinks (Grid square TL 23 04, Waltham et al, 1997) are very well developed and new sinkholes appear after flood events. Some sinkholes are known further up the valley close to the line of the pipeline. Spectacular sediment filled dissolution pipes up to 12 m deep and 5 m wide could also be seen in the Castle Limeworks quarry (TL 228 027), 200 m from a pipeline. Similar sinkholes and pipes are common around the Palaeogene margin.

The zone 3 areas of Triassic salt are located where there is significant cover and no wet rockhead/brine near the surface. There is only a moderate possibility of some subsidence occurring. A few areas the Triassic and Permian gypsum are also assigned to this category, but most of the Triassic areas are assigned to a lower category.

5.4 AREAS WITHIN ZONES OF LOW TO MODERATE HAZARD (ZONE 2)

Much of the Carboniferous outcrop is deemed to have a low-moderate hazard. However, the likelihood of intercepting a significant cavity cannot be completely ruled out, especially on the Carboniferous Limestone where unknown relict cave systems may be present. Much of the Triassic gypsum areas fall within this zone and the majority of the Permian dolomite areas. Small cavities may be expected, but large voids significant to a pipeline would be unusual.

5.5 AREAS WITHIN ZONES OF LOW HAZARD (ZONE 1)

Much of the Chalk outcrop and other Jurassic limestone areas are deemed to have a low hazard. Some karst features may be present, especially in areas with a thin superficial deposit cover such as clay-with-flints. However, the likelihood of intercepting a significant cavity is thought to be minimal.

The majority of the Triassic gypsum also has a low susceptibility to subsidence.

6 Recommendations

6.1 MANAGING SOLUTION HAZARD

Although it is outside the scope of this report to make detailed recommendations in the management of pipeline hazard susceptibility, there are a number of general recommendations that can be applied to the management of areas susceptible to dissolution of soluble rocks. These relate to the general consequences of failure in the close proximity of buildings or fixed installations and how best they can be mitigated.

Five hazard zonations have been identified by this study. For the purposes of many pipelines, where a significant hazard is posed by a loss of support over a 15 m span, only those areas in zone 5 are considered to be of a significant hazard, However it should be borne in mind that further investigation of some sites currently in zone 4 may lead to the conclusion that they should be included in the higher hazard zonation (in many cases such assessment may result in the re-classification to a lower hazard zone).

It is generally recommended that where the high hazard ratings have been identified, areas are assessed as appropriate. The results of such investigations may be used as a baseline (if none is already available) against which the results of future routine reconnaissance can be compared.

Detailed assessment should be carried out by appropriately trained and instructed staff. The evolutionary nature of hazards resulting from the dissolution of soluble rocks mean that it is important that a reporting procedure is used and for areas of specific concern a baseline dataset (interpreted photograph/ geomorphological survey) is referred to. It is also important that periodic revisions of these hazard zonations are made to ensure that such hazard classes are based upon the most up to date information available.

6.1.1 Areas within zones of high hazard (Zone 5)

Management policies should, in addition to the general recommendations, consider ground features associated with subsidence such as:

- Formation of new hollows or depressions, especially if circular or oval in shape
- Presence of standing water in locations where it has not previously been observed; again this should be especially noted if the water is seen to filling a rounded depression
- Tilting of trees, walls or buildings
- Open cracks in the ground

6.1.2 Areas within zones of moderate to high hazard (Zone 4)

Management policies should consider verification and where necessary, amendment of Zone 4 status and subsequently to consider assessment of any subsidence features.

6.1.3 Areas within zones of moderate hazard (Zone 3)

The status of Zone 3 areas should be considered for verification Zone 3 status by examination of field and/or remote data and amendment.

6.1.4 Areas within zones of low to moderate hazard (Zone 2)

No action required

6.1.5 Areas within zones of low hazard (Zone 1)

No action required

7 Conclusions

The information held by the British Geological Survey in its GIS databases has allowed the gas pipeline network in Great Britain to be assessed for the potential ground instability caused by the presence of soluble rocks. For the majority of the network and most soluble rock areas, there is little cause for concern. However, areas underlain by Triassic salt where there has been salt extraction, or where it is still taking place, could be problematical. In these areas subsidence events have commonly produced depressions many kilometres long and up to a hundred metres or more across.

There are a few areas underlain by Permian gypsum where subsidence has occurred near to the pipeline network and where future subsidence could occur. In general the historically recorded gypsum subsidences are between 5 and 30m across. However, larger ones do exist and all that can be said of their age is that they post-date the ice-age and thus formed in the past 12,000 years.

The 250 m buffered zone used in this research has a total area of 8403 km^2 (8 402 903 402 m^2). Just over 15 % of the total area covered by the buffer zone is affected by one of the solution hazard classes. The great majority of this (15.2% total buffer area) falls within zones 1, 2, 3 and 4. The remaining 0.6%, a total area of 52 km^2 lies within zones of hazard rating 5 (Figure 4 and Table 1).

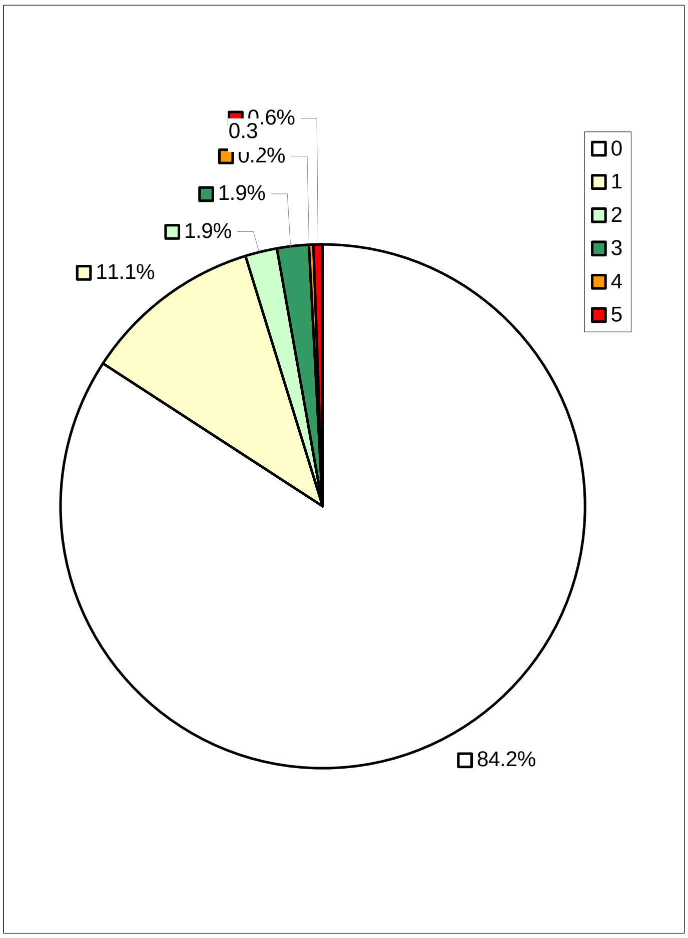

Figure 4. Percentage of Total Buffer Zone affected by Soluble Rocks Hazard Ratings

Table 1. Areas of Total Buffer Zone affected by Soluble Rocks Hazard Ratings

		Area in sq m	Area in sq km	Percentage Area of Buffer
Solution Hazard CLASS	**1**	935 910 154	936	11.1
	2	159 083 780	159	1.9
	3	155 979 073	156	1.9
	4	21 262 753	21	0.3
	5	5 169 7342	52	0.6
	All	1323933102	1324	15.8
Area Unaffected	**0**	7 078 970 30	7079	84.2

Glossary

A**quifer**: A rock that is water-bearing, either in the pores or the joints.

Breccia pipe: A sub-vertical cylindrical pipe-like structure caused by the gravitational collapse of the overlying strata into a cave or cavity.

Brine: A solution of common salt caused by natural or induced dissolution of rocksalt (NaCl).

Chalk: A fine-grained white porous limestone ($CaCO_3$) mainly of Cretaceous age in the UK.

Doline: A basin or funnel-shaped hollow in a soluble rock caused either by surface dissolution or underground dissolution and collapse. Sub-types include solution dolines, collapse dolines and suffosion

Dolomite: The mineral and rock composed of calcium magnesium carbonate, $CaCO_3MgCO_3$.

Gypsum: The rock or mineral composed of the hydrated form of calcium sulphate, $CaSO_4.2H_2O$.

Gypsum karst: A distinctive terrain created by the erosion of gypsum where the topography and landforms are a consequence of efficient underground drainage.

Halite: The rock or mineral composed of common salt NaCl.

Head: deposits of mixed rock types in a matrix of finer material deposited in valley and low areas by down-slope movements.

Interstratal karst: karst developed in a soluble rock beneath a cover of insoluble rock. Collapse events may propagate through the overlying insoluble rock producing collapse dolines.

Karst: A distinctive terrain created by the erosion of soluble rock where the topography and landforms are a consequence of efficient underground drainage. Usually applied without qualification to limestone terranes.

Limestone: the rock composed of calcium carbonate $CaCO_3$

Rockhead: The surface of the rock concealed beneath a cover of later (superficial or drift) deposits.

Rocksalt: the rock composed of common salt NaCl

Salt: see rocksalt and halite

Suffosion: removal of material at depth by dissolution or mechanical erosion with the washing in of the overlying material.

Till: deposits of mixed clay, sand, gravel, cobbles and boulders in variable amounts deposited from a melting ice-sheet. (also commonly referred to as Boulder Clay)

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