THE DEVELOPMENT OF A NATIONAL GEOGRAPHIC INFORMATION SYSTEM (GIS) FOR BRITISH KARST GEOHAZARDS AND RISK ASSESSMENT.

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ABSTRACT

Britain has four main types of karstic rocks, limestone, chalk, gypsum and salt, each with a different character and associated problems. Subsidence problems, difficult engineering and foundation conditions are widespread on these rocks. The triggering of subsidence by water abstraction and the enhancement of dissolution processes are relevant to some areas. Aquifer vulnerability and pollution tracing are concerns in most areas, especially the chalk, which is the major aquifer in southern Britain.

The British Geological Survey has embarked on a comprehensive digitisation scheme of the base 1:50,000 scale geological map information. In conjunction with this, the recording and assessment of geological hazards, including karst problems, are being undertaken to provide complementary digital information that enhances the basic map data. Digital map capture has been established at 1:10,000 scale using a customised interface with the ArcView GIS application. For the karst geohazards, this application is being extended to allow the digitisation of the karst features and the population of the associated Oracle database tables. For each type of karst feature, polygon or point attributes will be defined with suitable dictionaries for the appropriate morphological, stratigraphical or lithological entities. Linked features and databases for springs, stream sinks, dye tracing are being developed, tied to the existing hydrochemistry tables where appropriate. Cave survey and plan data derived from published sources may also be incorporated. From the factual data, hazard areas will be derived.

When the GIS is fully established and populated, the system will highlight the presence of karst features to non-specialists and allow the rapid interpretation of potentially hazardous karst areas by geological, hydrogeological and engineering geologists. With suitable links to polygon feature descriptions, basic geological reports derived semi-automatically are also feasible. The GIS will act as a desktop data capture facility with the intention that it can, ultimately, be extended to the capture in the field of information when suitable portable, robust computers become available.

INTRODUCTION

In Britain, many aspects of controlling the use of geologically unstable land, including karstic areas, have been written into Government planning policy. The main method of control is by the publication and implementation of planning policy guidance notes, the main one being "Planning policy guidance note 14: Development on unstable land" (Department of the Environment, 1990). This guidance information is currently being extended, and the extension (Annex 2; Department of the Environment, Transport and the Regions, 2000) is in the public domain for consultation. This guidance and the proposed additions put the emphasis on the developer to prove land is suitable for development, but the local authorities are also required to be aware of the problems in their areas and where possible to inform interested parties. The developers and the local government can only operate effectively if they know about the hazards that affect them and have access to suitable geological information. The British Geological Survey (BGS) is the main supplier geological and geohazard data.

The BGS has embarked on a major programme of map digitisation and modelling to provide 2D and 3D digital geological information for Britain. In tandem with this it has started a programme of capturing geological hazard information and the assessment of the level of the hazard present. Karst geological hazards in Britain are being considered as part of this geohazard programme. Traditionally, geological information for the solid and superficial rocks has been available as paper maps. The whole of the British 1:50,000-scale map set has been unified and is currently being digitised<http://www.bgs.ac.uk/products/digitalmaps/digmapgb.html>.

The stratigraphical descriptions and coded for the digitised geological units are defined in the British stratigraphical lexicon served via the internet <http://www.bgs.ac.uk/lexicon/lexicon_intro.html>. Similarly, the attribution of lithology is also indexed by tables available over the internet <http://www.bgs.ac.uk/bgsrcs/home.html>. The digitised map data is thus linked to database tables held in a standard way on Oracle servers. Views of index information and some geological information is currently available free over the internet from the BGS Geological Data Index (GDI) <http://www.bgs.ac.uk/geoindex/home.html>. These publicly available, datasets include views of solid and superficial geology at 1:625,000 scale (10-miles to one inch), borehole sites, geochemical and geophysical information. At the same time as these developments a Geographic Information System (GIS) interface utilising ArcView has been developed to allow the digitisation of geological mapping information directly by geologists. This system is constrained by live links to the Oracle lexicon tables that hold the definitions of all the approved polygon and data descriptors. This system is being extended to form the interface for the hazards data capture and the digitisation of karst hazard data.

The geological hazard information for Britain has never been produced as maps and most of the data exists as disparate sources including published papers, field maps, internal reports and some Government-sponsored studies, some with associated databases (Symonds Travers Morgan 1996; Applied Geology Ltd, 1993). Only a few specialists know their way around the information and if they are unavailable, or retire, the information can become difficult to retrieve and interpret. The philosophy of the British Geological Survey is to gather all relevant information and present it in a form that is usable by everyone. The system is currently being constructed around an ArcView interface linked to Oracle tables. This system forms the foundation for the eventual provision of data and interpretations on demand via the world-wide-web. Ultimately, the hazard layers can be linked to database tables and paragraphs of descriptive text to allow automated report generation. The BGS has started to build the system interfaces and databases that record and support the karst hazard information. This paper describes the structure and content of that programme as it relates to karst geohazards.

KARST GEOHAZARD AREAS AND TYPES IN BRITAIN

The karst areas of Britain include four major types and a few additional minor ones, their distribution is shown in figure 1. The areas include limestones, chalk, gypsum and salt, each with different manifestations of the hazards related to them.

Limestones

The limestone karst of Britain was reviewed by Waltham et al (1997). The Carboniferous Limestone karst areas form much of the English Pennines and parts of Scotland, south-western England and South Wales. Areas of Jurassic limestones are also widespread in the east, centre and south of England. Small areas of Devonian limestones occur in Devon and Cambro-Ordovician limestone occurs in Scotland. The Carboniferous limestones of the UK host the largest and most extensive cave systems in the country. The major problems associated with the limestone karst areas relate mainly to water supply protection and some engineering conditions. The collapse of dolines occurs, but most of the limestone areas are in rural situations and the effects on property and infrastructure are slight. Dolines commonly form places where farm and other refuse or waste is illegally tipped, when this occurs it can cause rapid contamination of the karst groundwater and local drinking supplies fed from it. Items that are important for the GIS recording of the limestone areas include cave locations, stream sinks, springs, dolines and pollution sources.

Chalk

Chalk underlies much of eastern and southern Britain (Figure 1), it is the most widespread carbonate rock in the country and of immense importance for water supply. It is porous and includes less permeable calcareous mudstone beds and flints as nodules and beds. The rock is commonly strongly jointed with networks of microfractures that are karstified on a small, but extensive scale. Many of the karstic conduits are controlled by the positions of the flint and mudstone horizons, but the size of the conduits developed rarely exceeds one metre in diameter. The rock has traditionally been modelled as a large porous medium, but recent understanding is highlighting the karstic nature of the rock. It is therefore important to record the karstic features in the GIS including dolines, stream sinks, permanent and seasonal springs, and pollution sources. The seasonal streams are locally called winter-bournes (Waltham, et al., 1997) and the word bourne is commonly included in the place names of settlements on the Chalk. In addition to water supply, the Chalk also generates subsidence hazards and difficult conditions for construction and engineering projects (Edmonds, 1983). Surface and near-surface karstification of the rock, especially beneath and adjacent to superficial deposits, produces subsidence dolines, clay-filled pipes or fissures and uneven bedrock.

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. 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. In places where the major rivers have cut through the Permian sequence, the gypsum karst has formed phreatic cave systems. The rapid solubility rate of the gypsum means that the karst is evolving on a human time scale and active subsidence occurs in many places, especially around the town of Ripon (Cooper 1986, 1989, 1998). The active nature of the dissolution and the ongoing subsidence features, cause difficult conditions for planning and development (Symonds Travers Morgan, 1996; Paukstys et al., 1997; Cooper ,1998). The GIS entries for the gypsum karst include subsidence dolines (many with a known date of subsidence), sulphate-rich springs, stream sinks and the extent of the gypsum belt.

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. These places became the focus for shallow mining and near-surface “wild” brine extraction, a technique that exacerbated the salt karstification (Arup Geotechnics, 1991; Calvert, 1915; Collins, 1971). 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 and how it might interact with mined and brined areas has yet to be studied. To understand these mechanisms it is important to collate the information and integrate it with data about the amount of salt in spring and river water. The BGS has a national geochemical database, which includes river water analyses for most of the saline areas. The generation of a karst hazards GIS will allow the rapid integration and analysis of the various datasets. The GIS data for the salt areas will include saline springs, subsidence dolines and areas of more widespread subsidence. Because the salt karst is strongly influenced by brine pumping and mining, there will also be entries into a similar mining database.

KARST HAZARDS DATABASE AND GIS

There is a wide range of karstified rock types in Britain, but they have many common characteristics including springs, sinks, subsidence features and distinctive groundwater chemistries. These are all features relevant to a British karst hazards database. In the past 20 years, attempts have been made to collate such karst information in Britain. An early study was of the Chalk (Edmonds, 1983) and this formed the starting point for the "Natural Underground Cavities" study for the then Department of the Environment (Applied Geology Ltd, 1993). This study produced a large complicated database of information held in Dbase4 architecture. However, it also included much information (such as geological map and formation data) that is now available as layers in a geographic information system (GIS). The practicalities of this database have been assessed to help define the BGS karst database structure; some data fields have been accepted, but the slightly populated or potentially GIS-derived data fields have been abandoned. Another study of karst hazards utilising GIS was done by Wadge et al (1993) using the data sets of Cooper (1986 and 1989). This study produced a prototype expert GIS system for the city of Ripon using ArcInfo running on Sun workstations. Later studies at Ripon have extended the karst hazard information and presented it in a suitable way for planning (Symonds Travers Morgan, 1996; Paukstys et al., 1997). It is now appropriate to extend these assessments beyond the small study areas to a national dataset. There is a need for good accessible geological information to allow the proper implementation of the planning guidance policy for unstable land (Department of the Environment 1990, Department of the Environment, Transport and the Regions, 2000). The BGS karst geohazards project and complementary projects on landslips and mining help BGS to supply these needs.

The fields that have been defined initially for the new British karst hazards database are shown in Tables 1-5, these will be reviewed in the early stages of database population. In designing this system numerous problematical areas have been found. The main problems are how to keep the system simple and how to record temporal information. Problems include how to link data sets such as tracer tests to sinks and springs where multiple links may exist and numerous dye tracer tests may have been undertaken. The definition of the way subsidence event dates are recorded is also difficult since some features may occur instantaneously, while others may have occurred over an extended time, or have only vague subsidence dates associated with them. As many of the geologists who will have to use the system may not be karst experts, it is important to keep the number of data fields to the essential minimum; options for more details will be held on secondary screens if the study requires them. It is envisaged that the proforma sheets required to record the karst data will eventually be displayed in the field on a portable computer, or hand-held data capture device, to facilitate direct database entry during fieldwork. In common with the BGS data architecture, each database entry will include the user code for the geologist responsible for its input, the National Grid Reference, the ground elevation and the observation date. These will either input manually or via a Global Positioning System during field data capture.

Item	Details/Type	Links
Dolines, subsidence hollows and pipes; point or polygon data Information such as stream sinks are linked to the sinkholes via the GIS	Size at surface	
	Shape (plan)	
	Shape (profile)	
	Type (if known)	
	Reliability of information	
	Date of subsidence	
	Fill deposits	Linked to the stratigraphical and lithological lexicons
	Property damage	Links to secondary field, recorded using the NCB scale of property damage 1-5 (NCB, 1975)
	Evidence of quarrying	
	Stream sink?	Links to stream sinks database
	Pollution	Linked to "lithological" lexicon defining waste types
	Source of information	
	Other data	

Table 1. The main database fields for sinkholes and subsidence features in the karst geohazards database

Item	Details/Type	Links
Stream sinks, point data Linked to the sinkholes via the GIS	Name of stream sink	
	Size of stream sink under average conditions	
	Seasonality	
	Type of sink	
	Reliability of data	
	Hydrochemistry data	If yes, link to hydrochemistry database and secondary data entry field
	Proven tracer tests	If yes link to hydrological links database
	Source of information	
	Other data	

Table 2. The main database fields for stream sinks in the karst geohazards database

Item	Details/Type	Links
Springs and resurgences; point data	Name of spring	
	Size of spring under average conditions	
	Seasonality	
	Type of spring	If borehole links to borehole database and secondary data entry sheet
	Reliability of data	
	Hydrochemistry data	If yes, link to hydrochemistry database and secondary data entry sheet
	Uses: Public water supply?	
	Proven tracer tests	If yes link to hydrological links database
	Source of information	
	Other data	

Table 3. The main database fields for springs and resurgences in the karst geohazards database

Item	Details/Type	Links
Natural cavities; point, line and scanned data	Name of cave	
	Type of cavity	
	Size	
	Rock units	Link to stratigraphical lexicon
	Links to other caves	
	Hydrologically active	Link to hydrological links database
	Reliability of data	
	Source of information	
	Other data	

Table 4. The main database fields for caves in the karst geohazards database

Item	Details/Type	Links
Hydrological links; attributed line data	Type of test	
	Link determinant	
	Operator	
	Tracer collection	
	Links to other caves	Links in database to other sinkholes and resurgences
	Flow time	
	Reliability of data	
	Source of information	
	Other data	

Table 5. The main database fields for hydrological links in the karst geohazards database

In addition to these databases, national databases already exist for borehole and water abstraction information. A separate exercise is producing national information about rockhead surfaces and the thickness of superficial deposits. These factors are important for the interpretation of mantled karst areas that are particularly prone to subsidence sinkhole formation. Used in conjunction with the karst information within a GIS environment, new interpretations of the relationships between the causes of the data can be readily made.

IMPLEMENTATION OF THE KARST HAZARDS GIS AND DATABASE

The karst hazard database is under construction and test areas are being populated with data to confirm the working practicalities of the system and the data fields. These test areas include Ripon for gypsum and part of Hampshire for the chalk. When the system is fully implemented, it will allow the karst geohazards data to be continuously revised as new information is acquired. Other entities will be derived from the database using GIS to interpret it. These will include the subsidence-prone areas or geohazard domains, which commonly cut across geological boundaries. They can only be defined by synthesis of the karst geohazard information outlined above, allied with geological map information. For example, the belt of subsidence caused by dissolution of the Permian gypsum in Yorkshire affects three formations and the basal part of the overlying group. This area is about 3km wide forming a linear belt through the city of Ripon where special planning constraints are formally enforced (Symonds Travers Morgan, 1996; Paukstys et al., 1997). The karst hazards database and the GIS will allow this belt to be defined for the remainder of the gypsum karst area. Similarly, in the Chalk areas, the GIS synthesis will help with the identification of geohazard domains, which can then be added to the GIS as a layer to help with planning and groundwater protection.

The karst hazard database structure is designed to interact with numerous other databases held by the British Geological Survey. The database has a unified structure constrained by definitions served directly from the Oracle databases to prevent the erroneous entry of incorrect data. The database fields will each have a descriptive definition held in a linked table. This can then be used to produce automated reports of selected items or areas directly from the database. Because the database is served through a GIS interface, it allows the hazards information to be interrogated and linked with the underlying geological information, hydrological and hydrogeological datasets. The system also forms the foundation for gathering the information directly using computer technology in the field.

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