The provision of digital spatial data for engineering geologists

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Abstract

Until recently most spatial geological information was in analogue (mainly paper) form, which made it expensive to store and often difficult to use because of its increasing fragility. However, with the rapid advances in information technology in the last twenty years, not only has it become relatively easy to digitise or digitally scan historical information but, increasingly, data suppliers are, themselves, producing the raw data in digital form. This brings with it a host of new problems for the acquisition, management and dissemination of the information. These issues include data collection (what, where, how and by whom), data management and security (metadata, validation, backup, access), data access (how, where and at what price) and the provision of value added products based on the data tailored to the needs of specific users. For engineering geologists, the historical acquisition of geological data in various forms is on the verge of delivering a whole range of new products that should alter the way in which site investigation is carried out.

Introduction

The importance of geology to civil (and, indeed, military) engineering has long been recognised (Fookes, De Freitas and Culshaw 2005; West and Rose 2005). In the United Kingdom (UK) William Smith, who in 1799 produced a geological map (of Bath) that is recognisable as such to 21st century geologists, is often regarded as the father of engineering geology because he demonstrated the value of the application of geology to mining, canal building and land drainage. In the late 19th century, the predecessor of the British Geological Survey (BGS) published a memoir on the soils and subsoils ofgreater London that provided non-geologists and geologists, alike, with information on the near-surface ground conditions for building, water supply and even the location of cemeteries (Woodward 1897; Culshaw 2004). There were relatively rapid advances in engineering geology in the first half of the 20th century but it was not until after the 2nd World War that engineering geologists and geotechnical engineers began to develop comprehensive standards, classifications and codes of working practice for site investigation (see below). However, the value of existing information was long recognised and site investigation practitioners were encouraged to seek out existing geological information, particularly geological maps.

As a result, engineering geologists and geotechnical engineers are both avid users and copious providers of information about the shallow subsurface. Modern working practices for site investigation stress the importance of the ‘desk study’ (Site Investigation Steering Group, 1993), in which existing information about the ground is accessed and interpreted to maximise the efficiency of the ground investigation by, for example, optimising the siting of borehole and the locations of geophysical traverse lines. However, accessing the existing information often has been difficult because the information may be dispersed, relatively inaccessible (geographically), poorly catalogued, or all three and, until recently, the information has existed almost entirely in analogue form only. The development of computer hardware and software that facilitate both the collection of raw data in digital form and the rapid, accurate and economic digitisation of most old analogue records is transforming both the way in which information is stored and the ability of data management organisations to make the information available to users.

Geological surveys were set up to both collect new geological information and to store it for future use. For much of their existence, the information was used mostly by geologists and other geo-professionals. However, other professionals and the general public have shown an interest in accessing geological information, particularly in relation to the potential effect that geological processes may have on buildings. For example, in southern Britain a period of unusually dry weather in the period 1989-91 caused a large amount of damage to houses founded on shrinkable Mesozoic and Tertiary clay formations. As a result, geohazard information systems were set up by the BGS, by the successor to the Soil Survey of England and Wales and by at least one UK-based insurance company (Culshaw and Kelk 1994; Jones et al. 1995). These systems were used by the insurance companies to determine risk and set insurance premiums. It is interesting to note that no such systems were set up following the previous very dry period in 1976. The last ten years have seen an increase in demand for information on geological, and other, natural hazards in the UK. The housing transaction market has mainly generated the demand as solicitors wish to demonstrate that the legal searches that they make are comprehensive (and hence they avoid potential legal action if a property is subsequently damaged by a geohazard). This increasing demand has been further demonstrated by the establishment and expansion of commercial companies specifically set up to act as ‘warehouses’ for environmental information. The information itself is usually obtained from public bodies, such as geological surveys, each enquiry generating a small financial return for the originator of the information.

Because there are over a million housing transactions every year in Britain, the information supplied to data warehouses (or ‘value-added resellers’ as they are also known) has to cover the whole of the country, be up to date and be in digital form. Awareness of the public demand and the rapid improvements in information technology have driven a number of geological surveys to digitise their data holdings and to improve their systems for its management and delivery to users.

This demand for geohazard information by the public has made information and its management a very much higher priority for geological surveys. In turn, this has had benefits for geo-professionals, such as engineering geologists, who need regular access to geological information. In the UK, site investigation reports are increasingly being provided by the originators in digital form (see below). In addition, the BGS has digitally scanned more than a million analogue borehole logs have been digitally scanned and a digital database of geotechnical properties has been set up that contains parameter values obtained from more than 250 000 samples. In addition, a multi-element geochemical database and landslide and karst features databases have been set up and are being populated. This information can be all related spatially to the geology, as all the 1:50 000 scale maps have been digitised (Jackson and Green 2004), and to a high-resolution digital terrain model, as well as to a topographic map base. Increasingly, access to this information is via the web, with small charges being levied for access to cover storage and management costs.

Provision of data by geological surveys

There are three factors that, collectively, distinguish geological surveys from universities or commercial businesses. They can be summarized by the words: *long-term, strategic* and *national*. Arguably, the major contributor to these strengths is the data and information resource they hold. For too long this asset, in large part a legacy which may represent as much as 170 years of science, has been given low or no priority – the lion's share of funds having gone to support new mapping and research. However, times are changing and a number of geological surveys, including the BGS, have recognised the issue and are starting to place the management and delivery of information at the heart of their organisations. They have realised that to thrive (or maybe just survive!), effective strategies for information management and delivery are essential.

So what are the key strategies that these surveys are adopting for their information resources? There are a number of trends and they can best be summed up in the word '*maturity*'. This maturity is characterised by the following activities:

- Managing data responsibly as a corporate and long-term asset and not as a disposable and low priority part of an individual research project.
- Recognising that the data already held in the survey archives is just as important as the new mapping and research.
- Being consistent and developing, agreeing and using organisational /national/international standards.
- Converting as much paper data as possible to digital format (see below).
- Working routinely in three dimensions as opposed to two.
- Developing end-to-end digital workflows.

and last but certainly not least,

- Acknowledging that if you are a national survey then you should be aspiring to produce national datasets and not just a collection of diverse (or anarchic, to be provocative) project databases.

Tacitly, at least, a number of geological surveys appear to be agreeing that they can no longer be idiosyncratic, introspective and amateur about their data. They recognise that they have to reach out and engage their user community. Surveys have to provide their customers with the data and information they need, in the form they need it, when they need it. Surveys have to meet national and international legal requirements for data and information accessibility. They have to improve the quality and consistency of their data and meet agreed standards, and be transparent about the quality. They must improve the interoperability of data, so it can be integrated with other, non-geological data – from climate measurements to financial and insurance information. And last but not least, they must manage and protect their intellectual property rights, for without this they will have few assets to exploit.

In the BGS the strategy is being translated into a number of specific objectives:

- An operational integrated 3D digital workflow from field to user.
- A corporate architecture and system to model, manage and visualise 3/4D data.
- A digital geological map database of all of Great Britain at scales from 1:625 000 to 1:10 000.
- Digital ground instability data for urban areas at 1:10 000 scale (enhancing and upgrading the existing 1:50 000 scale digital datasets)
- Systematic national digital cover for borehole data
- Generation of 1:50 000 scale derived datasets (for example, mining, groundwater flooding, contaminated land, erosion, corrosion, offshore and near-shore datasets)
- Knowledge transfer by electronic dissemination of information including user friendly e-commerce and web-services (dynamic direct access)
- Increased interoperability, through improved metadata and data architectures and use of extensible mark-up languages (xml)

To deliver these objectives and continue to provide long-term secure data storage and effective access to the increasing volumes of data, information and knowledge, will require BGS to exploit fully advances in information technology.

Full advantage is being taken of e-Science initiatives (and in particular GRID technologies); BGS systems will become more collaborative in nature, using the strengths of client-server architecture and migrating to advanced web-based networks providing shared processing and data resources (for example, digital geological map data). For major commercial clients, government departments and agencies and scientific collaborators on major projects, a ‘web-services’ approach, providing secure and flexible access through customised web portals to data and systems, is seen to be the most appropriate way to deliver information in the future (for example, Alker et al. 2002). These web-services will facilitate greater interaction and cross-disciplinary work and government and commercial clients will have access to the latest BGS digital information in the way they want it, without the need for local storage and management of BGS data. The Digital Energy Atlas and Library (DEAL) Data Registry, developed and managed by BGS and funded by the UK Offshore Operators Association, gives a glimpse of one way to deliver data in the future (Figure 1). A second example is the GeoReports system, a full e-commerce web-enabled GIS, which generates bespoke plain English language reports on the geology, hydrogeology or instability of an area (Figure 2). This system is also an example of another strand in the BGS strategy, which is, to ensure that geological information is comprehensible to those who are not degree-qualified geoscientists: effective outreach is regarded as crucial.

Digital capture of data in the field and advanced 3D and 4D processing, modelling and visualisation systems will provide tools for unified workflow management and spatial modelling, maximising the value of the geoscience knowledge held by geological surveys. In this and other areas, manipulation of remotely sensed data (such as LIDAR and InSAR) is envisaged as playing an increasing role. A Geoscience Visualisation Centres are being developed (for example, at the BGS and at the University of Durham, UK) to enable complex multi-themed information to be presented as interactive and dynamic models using advanced Virtual Reality/Augmented Reality technologies. This is another development that will help data providers to reach out and improve the appreciation of the relevance geological knowledge.

While the focus is on developing improved delivery of digital data, there still will be a continuing demand for hard-copy output. Thus, work on developing (digital) publication services will continue, with new systems providing flexible access to customised print-on-demand maps and books, (incorporating, for example, site-centred mapping and thematic selection facilities).

All of these developments will depend on unglamorous but fundamental data management protocols (and the underpinning quality and security systems). Further, while cost recovery is becoming a key part of the business model of many geological surveys, effective intellectual property rights control will also be critical. Last, but not least, an enhanced programmes to enhance public understanding of science will improve links to schools and raise the profile of geoscience with the general public by providing improved access to more exciting new material, both in print and on the web. Geological surveys must continue to communicate their science, not only to government, industry and commerce, but also to the public, and to children to ensure the development of the next generation of earth scientists!

Data management

Engineering geologists and geotechnical engineers generate a wealth of spatially referenced geoscientific data, which traditionally has been documented in site investigation (SI) reports. A large number of these reports now exist, estimated at in excess of a million for the UK, which represent a valuable national resource that can be ‘harvested’ to produce a range of new knowledge. However, these legacy data need to be managed carefully to ensure that the information they contain remains of value. A range of issues potentially limits their usefulness including the format, evolving standards, and scattered nature of the reports.

The resource

The majority of engineering geology data comprise paper-based SI reports of one form or another. A small, but increasing percentage of data is digitally captured and communicated to end-users in electronic transfer formats, such as the Association of Geotechnical and Geoenvironmental Specialists (AGS) transfer format (Anon. 1999a). The paper-based records have a number of advantages and a range of disadvantages. The principle advantages are:

- The familiar format of a bound report is still user-friendly and has more *gravitas* than a purely digital report.
- Paper reports are seen to have a higher preservation potential than purely digital records, which are perceived of as part of the transient short-term

computing culture. This is an important consideration when subsequent legal disputes between parties may hinge on the veracity and integrity of the original report.

- Evidential status of digital documents has only recently become clear and requires the investment in and maintenance of an electronic records management system.

The principal disadvantages of the paper-based reports are:

- Cost of long-term storage of paper records means that there is pressure to reduce costs by disposal of records as soon as possible, or to store them in unsatisfactory conditions in which the records deteriorate rapidly.
- The difficultly of reusing the data held on the printed pages within the report.

Standards and best practice change with time. For example, the current British Standard Code of Practice for Site Investigation was published in 1999 (Anon. 1999b). However, it was originally issued in 1950 and was extensively revised in 1957 and 1981 (Anon. 1950; 1957; 1981a). These standards are supported by best practice guidance from professional associations (particularly the Geological Society and the Institution of Civil Engineers), which provide further advice and clarification (for example, Anon. 1970; 1972; 1977; 1981b; 1981c; 1995). Over the time that site investigation has been undertaken, the accuracy and ease of measurement has also increased, making it possible to include a larger number of more accurate tests within reports as time passed. The result is that the way SI reports are created has changed over time and should not be assumed to be stable.

SI reports, though numerous, are rarely centrally managed. They are normally held in offices of site investigation companies, geotechnical engineers, other professionals, local authorities and clients for a short period after completion of the work before they are moved on to some other form of storage. A few far-sighted companies had policies of microfilming reports but many created warehouses containing numerous filing cabinets, or used contract storage companies to hold the documents. Some organisations have attempted to systematically donate data to the geological survey organisation in their country, as is the case with the UK Highways Agency, which donates to the British Geological Survey's National Geoscience Data Centre.

The general picture is of a resource, which is largely on paper, conforming to progressively evolving standards, held in a distributed manner over a wide geographical area and with no single authoritative source that provides an overview of information that is available.

Managing the resource

The management of this paper legacy, and its digital derivatives, itself is subject to records management standards (principally Anon. 2001). The management falls into two main activities: the creation of metadata and the physical management of the records themselves.

Metadata is essentially data about data. It is a method of describing a data item, dataset or group of related datasets so that a potential user can determine if they are fit for the intended use. Metadata is often described as the 'who, what, why, where, when and how of data'. It is a powerful tool for understanding data and its complexities and subtleties. It is particularly appropriate for describing legacy engineering geology data where there is a range of issues that need to be documented.

As discussed above, there is inherent variability within site investigation information relating to the evolving standards and developing best practice. This variability needs to be documented by the metadata so that those reusing the data clearly understand its limitations and constraints. This will enable them to use the data with confidence.

Metadata is itself subject to national and international standards (for example, Anon. 2003). This and associated standards define how any spatially located information should be documented in metadata. This comprehensive standard covers many eventualities that need not be used for a given knowledge domain, such as site investigation. This is recognised by the development of individual 'profiles,' which are effectively a subset of Anon. (2003) relevant to a specific knowledge domain. These are currently being defined, such as the UK GEMINI profile being jointly developed by the UK Association of Geographic Information (AGI) and the Cabinet Office's e-Government Unit, which is focused on Discovery Metadata. A profile for geotechnical data would provide clarity and improve communication.

All records created by any organisation have a life cycle. Typically when a record is first created it is consulted frequently. As the information in a record grows older it becomes less useful and is consulted less frequently. Eventually it will cease to be consulted for the purpose for which it was originally collected. The National Archive in England and Wales uses the terms “current”, “semi-current” and “archive” to describe these three phases in the life of a record. Best practice in records management requires that records be reviewed regularly – a process known as records appraisal. Its purpose is to plan the stages of the life cycle of a record and develop appropriate policies for each of these phases. The plan is known as a retention schedule in which the time periods at each phase of the life is estimated and provision is made to store the records in the most appropriate and cost-effective environment during each phase of its life. All good retention schedules are accompanied by a disposal schedule, which declares the policies under which a record is disposed of and what will happen to it.

A typical SI report will have a short “current” phase during the planning of a development, a longer “semi-current” phase while the development is constructed and a long “archive” period while the record is retained as evidence of good practice. At the end of the archive period there are normally two options. The first is the destruction of a record, typically by shredding or incineration. The second is transfer of the SI report to a third-party who wishes to re-use the record for another purpose.

In Britain, the BGS’s National Geoscience Data Centre actively seeks SI reports to support the geological mapping and other research projects. It also provides a service supplying non-confidential borehole records to organisations conducting desk studies. Other countries have similar schemes to reuse a range of legacy borehole information for a range of purposes, for example, a project in Manitoba to build 3D geological models using legacy boreholes (Thorleifson and Pyne 2003).

The physical management of paper-based records can be an expensive operation. A typical volume of a bound A4 size SI report currently costs about £4 (€6) per year to store in filing cabinets in commercial office space. These costs reduce to about £2 (€3) in a records centre on rolling shelving or other compact storage system. Of course, these prices will vary considerably depending upon location but it is clear that storing hundreds of reports in office filing cabinets and thousands in data centres will cost considerable sums. The alternative is to save money on storage costs by using inappropriate storage environments (Figure 3).

Going Digital

Many organisations are now producing digital versions of their SI reports. These take a number of forms:

- The traditional report published in digital format, for example, Portable Document Format (PDF).
- Report data produced in a data transfer format such as the AGS transfer format (see above).
- Scans of legacy SI reports held as image files, for example, jpg2000 or tiff.
- Abstractions of data from the original report, paper or digital, and held in a database (Culshaw 2005).

Publishing reports in a digital format, such as PDF, improves the availability of the report by allowing rapid reproduction, reduces publication costs and reduces storage costs. Some digital formats can be locked at publication so that they are not subsequently changed. However, to ensure legal admissibility of records appropriate quality assured systems must be in place.

The AGS, and similar transfer formats are being increasingly used to pass geotechnical information between organisations. This allows the information to be loaded directly into compliant geotechnical engineering software ready for processing. It reduces the problems and costs associated with entering data from paper-based or locked digital reports. However, the record itself is transferred as CSV (comma separated variable) format (XML format in the future) and can easily be changed without a record of the change having been recorded in the file. It is therefore not acceptable as evidence.

Many organisations, including the British Geological Survey, are currently engaged in programmes to scan borehole and other geotechnical engineering records. The advantages of this are:

- Creating a security copy of key records as part of a disaster recovery strategy.
- Reducing costs of storage.
- Improving accessibility of records.
- Centralised management of records formally held on multiple sites.

Where the data from a SI report is reused for a non-geotechnical engineering purpose, such as geological mapping, the data needs to be abstracted into a database in which it can be manipulated to produce the desired output. This abstraction can be done from paper-based SI reports or can be speeded up by manipulating data in digital transfer formats. Typical outputs of such a database are illustrated in Figures 4 and 5.

Conclusions

Within a few years, the conventional ‘desk study’ that should form an important part of all site investigations will have been revolutionised. The digitisation of much of the information held by geological surveys is enabling easier access to it via the web. This, and the development of web search engines for academic publications, means that, potentially, engineering geologists at their computers will be able to obtain information on relevant past publications, previous site investigations carried out near their location of interest, view 2D geological maps, digital terrain models, borehole logs and geotechnical test results and use attributed 3D models of the shallow subsurface to design their investigation and help interpret its results. However, this new capability, driven by the advances in information technology and the new priority given by geological surveys to their information holdings, brings with it increased responsibilities for data maintenance and management. Also, users will probably need to accept that they will have to pay a modest charge to access this information. Unless taxpayers, through their governments, are willing to pay the increased costs of digitisation and digital data management, the era of public bodies, such as geological surveys, freely providing access to geological information will pass completely. However, once engineering geologists and other users appreciate the benefits of the newly available information in digital form, it is likely that the cultural change will come to be accepted and the ways in which we interpret the ground will be changed significantly.

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Figures

Figure 1. The Digital Energy Atlas and Library (DEAL) Data Registry, funded by the UK Offshore Operators Association (www.ukdeal.co.uk).

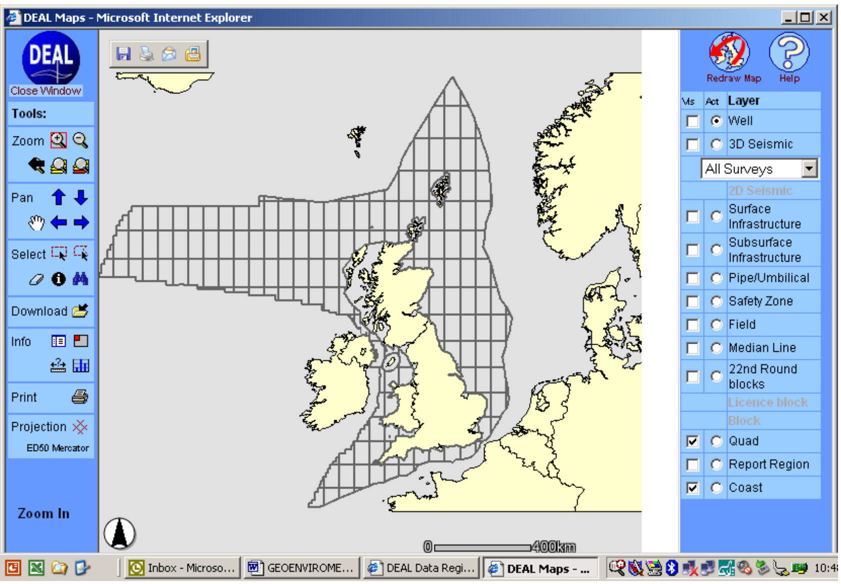

Figure 2. GeoReports (http://www.bgs.ac.uk/georeports/home.cfm) offers a range of site-specific geoscience reports tailored for different user needs.

Figure 3. Site investigation report damaged by mice.

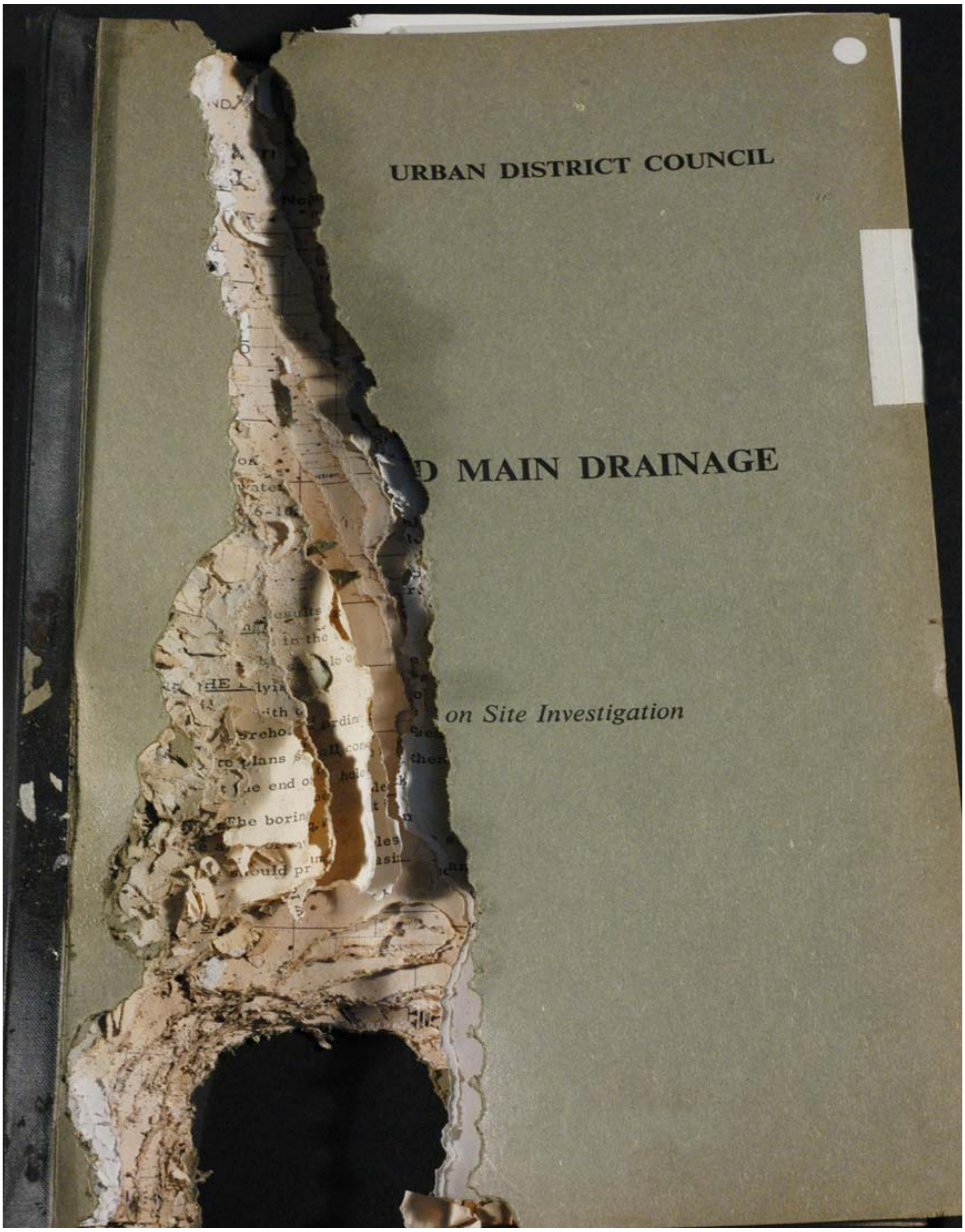

Figure 4. Superficial and artificial deposits draped over a digital terrain model of the Swansea/Port Talbot area of South Wales (blue = till; pink = glaciofluvial sand and gravel; ochre = beach and tidal flats deposits; brown = peat; yellow = alluvium; dark brown = beach and blown sand; red = artificial deposits; glaciolacustrine deposits are present in the model but are hidden by later ones). The arrow points approximately north.

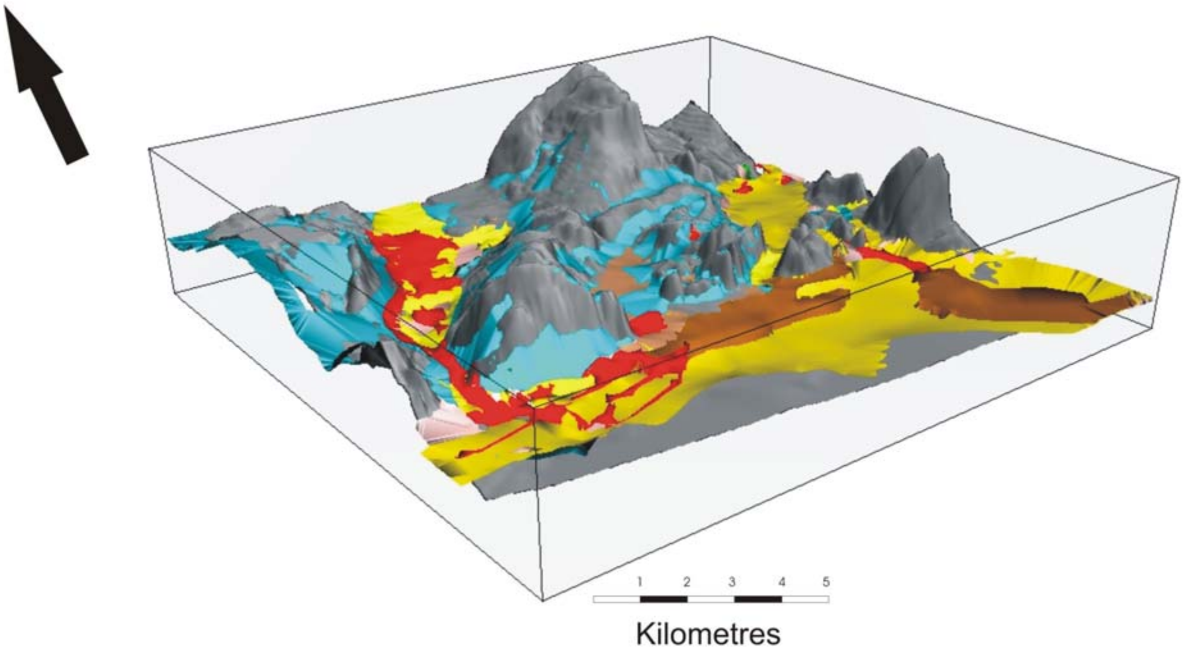

Figure 5. Fence diagram generated from the borehole database.