British
Geological Survey
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Accuracy of BGS legacy digital geological map data

Information Programme

Open Report OR/09/064

BRITISH GEOLOGICAL SURVEY

INFORMATION PROGRAMME

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Accuracy of BGS legacy digital geological map data

Alan Smith

Keywords

Accuracy, confidence, uncertainty, reliability, digital; geological map; data..

Front cover

Cover picture details, delete if no cover picture.

Bibliographical reference

SMITH, A. 2009. Accuracy of BGS legacy digital geological map data. *British Geological Survey Open Report*, OR/09/064. 24pp.

Keyworth, Nottingham British Geological Survey 2009

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British Geological Survey offices

BGS Central Enquiries Desk
Tel 0115 936 3143 Fax 0115 936 3276
email enquiries@bgs.ac.uk

Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG
Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA
Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD
Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE
Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB
Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF
Tel 028 9038 8462 Fax 028 9038 8461
www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU
Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

Foreword

The British Geological Survey's **DiGMapGB** project **(Digital Geological Map of Great Britain)** is responsible for providing nationwide geological maps in a digital format.

This report, which forms part of the output, has been written especially for GIS users of these maps when supplied under licence as 'tiles' of vector digital data. They will require a basic appreciation of geological terminology in order to understand some of the principles outlined here but need not be specialists.

Acknowledgements

The author would like to thank the many individuals in BGS including geologists and GIS experts in Cartographic Services who have offered their advice and comments on this report at various stages in its preparation, including:
Dr John A Aspden
Dr Robert Addison
Mr Stephen J Booth
Mr Richard A Ellison
Dr Brian S P Moorlock
Mr Poul Strange
Ms Jennifer C Walsby

and in particular those who reviewed the drafts:
Dr Don Aldiss
Dr Christopher A Green
Dr Andrew S Howard
Mr Ian Jackson
Dr John H Powell

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Summary

This report forms part of the output from the British Geological Survey's **Digital Geological Map of Great Britain** (**DiGMapGB**) project which is responsible for providing nationwide digital geological map data at a range of scales. It summarises various aspects of map-making, including traditional geological surveying and digitisation which combine together with other factors to determine the 'accuracy' of digital geological data.

The report is intended primarily for GIS users of the data, especially nongeologists.

First, it describes what a geological map and a digital geological map are. The particular meanings of 'accuracy' and 'legacy' used in the context of this report are then explained. The 'accuracy statement' first issued for digital map data in 2001, is provided. As this covers only the spatial and cartographical aspects the need for a fuller explanation of the many factors that contribute to the overall accuracy of the geological linework is noted.

Second, the report provides basic information about the DiGMapGB datasets, notes the many users and illustrates the need to understand data accuracy for correct analysis.

Third, there is background information on making geological maps, some principles of their survey and compilation, the different types of geological boundary, the selection and generalisation process, and comments on the reliability of geological interpretations.

For those seeking a greater level of technical detail the accuracy of Ordnance Survey topographical base maps is then described in cartographical and positional terms and related to GPS accuracy. This is followed by a similar discussion of the positional accuracy of BGS geological maps at different scales including specifications for the accuracy of digitisation.

Final concluding remarks compare the significance of the various factors that control the accuracy of digital geological map data allowing users to assess their relative importance.

1 Introduction

1.1 WHAT IS A GEOLOGICAL MAP?

Geological maps show the distribution of the various bedrock units, which may be millions or hundreds of millions of years old, at or near to the Earth's surface. The British Geological Survey's maps may also show the more recent, comparatively thin and often discontinuous, cover of superficial deposits, commonly comprising loose or unconsolidated sediments. These maps are interpretations of the geology, made using information available at the time of compilation.

The maps range from detailed large-scale maps of small areas, to simplified medium-scale maps of regions, to generalised small-scale maps of entire countries or even larger areas.

Paper geological maps are usually printed with different colours representing the different rock units. These units are typically labelled with a symbol which is explained in a key that gives the name of the unit, its lithology (composition in terms of rock-type), and its geological age.

The geology is typically compiled on a standard topographical base. In BGS, this is usually from the Ordnance Survey (OS) in the UK, and is used by permission. The topographical base is commonly shown as black colour screened to 50 per cent, so that it appears as a subdued grey when printed, which does not obscure the geological overprinting. Geology and topography are closely related with topographical features often determined or influenced by the nature of the underlying rocks; so in recording the geology it is usual to fit it to the topography as shown on the base map. Geological lines are therefore commonly positioned relative to corresponding topographical details rather than to 'absolute' grid references or co-ordinates.

1.2 WHAT IS A DIGITAL GEOLOGICAL MAP?

Published BGS geological maps are now prepared using digital techniques. The various elements of the geological map are captured digitally to create the DiGMapGB digital datasets for use in GIS applications. The same digital information is also used by BGS Publications as the foundation for the preparation of printing instructions in the production of the printed paper geological map.

The data are in vector models in which three types of spatial feature, represented by polygons, lines or points, are located by reference to X and Y co-ordinates according to the OS British National Grid:

- **polygons** are closed areas such as the outcrop of a body of rock or the area covered by a superficial deposit
- **lines** represent linear features such as geological boundaries, faults, fold axes and glacial channel margins
- points are used for information on specific point locations such as dip arrow data, fault downthrow details, or sample sites.

In cases where digital datasets have been created from older paper maps the opportunity has been taken, where possible, to update the nomenclature of the rock units and correct errors. Limited changes may be made to the geological lines to create a better fit between adjacent maps. The digital map or tile (the map face with no marginalia) may therefore differ from the paper map on which they were based. For example a paper map may refer to 'Bunter Sandstone' and 'Keuper Marl' but the corresponding digital data will refer to the more recent, nationally approved terms 'Sherwood Sandstone Group' and 'Mercia Mudstone Group'.

1.3 MEANING OF 'ACCURACY'

Four main factors determine the overall positional 'accuracy' or reliability of digital map data in general and geological map data in particular:

- Quantifiable aspects of 'precision' which indicate how precisely the data have been created in a technical or absolute sense. For example, is the digital data a faithful copy of the detail shown on the printed map, or have errors been introduced during the digitisation process; if so, of what sort and on what scale are these differences? 'Precision' factors also apply to the Ordnance Survey topographical base map, and may relate for example to the scale and type of surveying.
- Cartographic aspects of map-making, which include the selections, representations and generalisations made in producing maps at progressively smaller scales with decreasing detail.
- In the UK there is commonly a lack of surface exposure. Geological maps here are therefore often interpretations based on a limited amount of direct observation combined with other available data.
- Definitions of geological units; and differences in their understanding and recognition. Geological units are defined in various ways. Some are closely constrained but others less so, and these definitions may change with time and place. Furthermore, different geologists may have different understandings of what has been mapped previously, what they have mapped, and how the boundaries were recognised in practice.

These interpretations are subject to variable levels of uncertainty, and for most practical purposes their reliability is unknown and unmeasurable.

1.4 MEANING OF 'LEGACY' DATA

'Legacy' data here refers especially to digital data derived from existing paper geological maps on which the geological lines were fitted to a contemporary topographical base. Many of the maps were originally in paper form only and were digitised for DiGMapGB. For about the last ten years all geological maps have been produced digitally at BGS. However, until about 2005 the initial geological surveying, was conducted in a traditional manner. They may all, whether paper or digital, be referred to as legacy maps as they are compiled on to OS topographical bases with similar traditional controls on quality.

It is possible that future surveys could adopt a more rigorous and quantifiable approach to positional accuracy combined with statements of confidence on the various types of mapped geological lines and data. Some lines and data may be located by GPS rather than by reference to topographical features. These data will then progressively supplant the legacy data; although this is likely to be a prolonged process.

1.5 DiGMapGB ACCURACY STATEMENT, 2001

The following statement and explanation was issued in 2001 following the first release of the 1:50 000 scale dataset by the Digital Geological Map of Great Britain (**DiGMapGB**) project:

> ***The supplied digital geological lines from DiGMapGB-50 (Version 1) have a spatial cartographical accuracy equivalent to +/- 50 m on the ground.***
>
> *Two sources of error have been considered*
>
> *1. The compilation of geological maps onto 1:50 000 scale maps can lead to an error of +/- 50 m on the ground; ±1.0 mm either side of a line on the map. This is partly as a result of the generalisation of the geological lines mapped at a scale of 1:10 000 (or 1:10 560), to fit the 1:50 000 (or earlier 1:63 360) topographical maps. It is partly because of the errors in conversion from the projection systems used on the earlier County Series maps to the British National Grid.*
>
> *2. The specification for the digitisation of the analogue geological linework required that the digital lines did not deviate from the centre of the mapped line by more than 0.2 mm. This is equivalent to 10 m on the ground at a scale of 1:50 000.*

The first comment above assumes that geological lines are located accurately on the original 1:10 000 large-scale maps, and that relatively minor spatial differences may be introduced in the compilation on to smaller-scale 1:50 000 maps by generalisation and refitting.

The second comment specifies the accuracy of the digitisation process and shows that for most purposes the differences introduced here are trivial.

Other factors affecting the overall accuracy of geological lines were not discussed.

1.6 THE NEED FOR A MORE DETAILED EXPLANATION

Although true, the comments above refer only to two cartographical aspects of the accuracy of geological maps. They do not adequately explain the many factors that contribute to the overall accuracy. In particular they do not address the questions: ‘is the geological linework correct? or ‘how accurate are the geological data?’ These relate to the accuracy of the geological interpretation, which requires particular clarification.

As a result, this report has been written especially for GIS users with some geological knowledge but who are not specialists in mapping, to explain how geological maps are made and hence some of the problems involved in trying to assess how much confidence can be placed in their accuracy, in a broad sense. The key factors are summarised in Table 2 in the concluding remarks.

A proper understanding of the accuracy of geological linework and its relevance is needed in order to make appropriate use of digital geological map data in GIS applications.

2 Using digital geological map data

2.1 BGS DiGMapGB DATASETS

The DiGMapGB project provides nationwide digital geological map data at a range of scales. The main DiGMapGB datasets are at 1:10 000, 1:50 000, 1:250 000 and 1:625 000 scales. They are usually supplied with up to four polygon themes: bedrock (or 'solid' geology); superficial (or 'drift' deposits); mass movement (mainly landslides); and artificial (or man-made ground) as well as linear features.

Every polygon of data is labelled, or attributed, with a two-part code that identifies the name of the geological unit represented and its lithology (rock type). For example an area of Mercia Mudstone Group mudstone is coded as MMG-MDST; a sandstone bed within it is MMG-SDST.

Attached to this two-part code are other types of information, including age and hierarchy, supplied with the licensed data. Three of these information fields are of particular relevance here:

- nominal scale of the original source of information used to prepare the digital data
- latest date of OS information on the topographical base of the original printed geological map
- latest date of BGS geological information on the map; this is usually the year of publication of the most up-to-date printed, or released, map sheet.

It is recommended that geological map data should be used at, or about, the same scale as the original source. Larger-scale data (e.g. 1:10 000) may be used at a smaller or less-detailed scale (e.g. 1:50 000) but the converse (e.g. using 1:50 000 data at 1:10 000 scale) is to be avoided. This is discussed in more detail later and illustrated by reference to Figures 1 and 2.

A topographical base is not supplied with the digital data; users will need to obtain their own if one is required on which to drape the geology. OS typically supplies the latest version, and DiGMapGB data may not necessarily fit a modern topography. The age of the OS base used for the printed BGS map is embedded in the DiGMapGB data; the older this is, the more likely that changes in topography have taken place since the compilation of the geological map, especially in urban areas.

The year date of BGS information refers to the age of the most recent geological line-work. This may be particularly relevant for assessing, for example, the artificial ground theme that was only routinely surveyed from the 1980s onwards.

Further information on these and other datasets together with explanatory notes and background information on the DiGMapGB project can be viewed on the BGS web site at: http://www.bgs.ac.uk/products/digitalmaps/home.html

2.2 THE USE OF DIGITAL DATA

BGS digital data is widely used in GIS applications, integrated with other types of data to facilitate analysis, problem solving and decision-making. Many local authorities, for example, are now responsible for providing registers of contaminated land, and for the planning of waste disposal sites. In these cases, geological information combined with information on hydrology, water supply, mineral resources, quarrying, biodiversity, conservation, distribution of population, and transport networks, for example, assist in planning for the optimum sustainable development.

2.3 THE NEED TO UNDERSTAND ACCURACY OF DiGMapGB DATA

The various types of datasets used by licensees in combination with the BGS DiGMapGB data may have a wide range of different origins and each have their own level of accuracy. Source maps may be at different scales, and compiled on different topographic bases. They may be accurately surveyed plans, or rapidly sketched geological interpretations made on aerial photographs. They may include measured readings at specific points or interpolated contours drawn by hand or derived from a modelling package. It is important to understand each dataset, and how each relates to the others, in order to conduct a proper analysis.

Some of the accuracy problems involved may be illustrated by two generalised examples:

- A minerals planning dataset may have been derived from a simplified 1:100 000 scale mineral resource map. If a more accurate 1:50 000 scale geological map is then published for the area both the minerals resource and planning data may need revision if they are to remain in agreement with the latest interpretation of the geology.
- A building control department may have regulations controlling development on an outcrop of clay bedrock that is subject to excessive shrink and swell, and therefore prone to cause damage to foundations by heave or subsidence. The controlled area could have been based on a 1:50 000 scale geohazard map that was itself derived from an older 1:63 360 scale (one-inch to one-mile) geological map, in which case the cartographical accuracy of this derivation process may need to be considered. Also, the accuracy with which the area of clay was originally mapped is relevant. If the clay area is concealed and its limits poorly defined it may be appropriate to regard the mapped boundaries as approximations only, and in some cases they may best be considered as zones, say 50 or 100 m wide, within which the actual boundary is likely to occur.

3 Making geological maps

In order to better appreciate the accuracy of the digital geological map data, it helps to understand the various factors that determined the accuracy of the source printed paper geological maps, and so this section explains some of the principles of their survey and compilation.

3.1 THE AIM OF THE GEOLOGICAL MAP

It is one of the main aims of the geological map to depict the composition of the Earth's surface, and by extrapolation the deep subsurface, and thereby help explain its structure and origin.

The Earth is a natural system of infinite complexity and it is impossible to record it in complete detail. The geologist observes some of this great variability, recognises the similarities and differences, filters out the irrelevant intricacies and selects those features that are important to understanding the Earth and its materials. The geology is thus rationalised into packages of similar bedrock formations or superficial deposits that can be described more easily. They may be internally uniform or variable, simple or complex.

Their arrangement in the Earth's crust, and more particularly on the ground surface, is recorded on the geological map. This is a graphic means of summarising the geologist's interpretation in a way that is readily understood by those familiar with geological map conventions.

3.2 GEOLOGICAL INTERPRETATIONS AND MAP-MAKING

Geological mapping is not an exact science and is based on the evidence and data available at the time of survey. Whilst all maps are representations, geological maps are often also largely interpretations. This is particularly true in countries like the UK that have relatively poor exposure because of extensive vegetation and soil cover. There is often, therefore, limited direct observation of the bedrock and superficial deposits, and where the geology is not visible in the UK it is usually interpreted. (In contrast to BGS, some surveys produce 'outcrop' maps that make no attempt to extrapolate bedrock beneath superficial deposits where there are no observations.)

Some geological features may be visible in transient excavations, river and sea cliffs, and in upland areas, or they may be known from boreholes, but superficial deposits or man-made developments usually cover the bedrock. Water conceals the geology beneath lakes and sea.

In making maps, geologists study the landscape on stereo aerial photographs, digital terrain models and at first hand 'in the field'. They observe the shape of the landforms, the soil types and subsoil material revealed by ploughing, ditch excavations, hand-auger holes, rock exposures, vegetation etc; anything that might give a clue to the nature of the underlying strata. These observations are combined with information from boreholes or geophysical surveys to construct a conceptual three-dimensional model of the geology at the ground surface and shallow subsurface. With advances in computer software these models may now also be tested using mathematical modelling packages. The final geological interpretation is represented by lines and polygons on a two-dimensional geological map.

The geological map is thus an interpretation, derived commonly from a variety of types of information available at the time of survey, inferences, and in some cases data from pre-existing geological maps. Most observations are at the surface, rather than the subsurface, and include for example dip and strike measurements on rock exposures and the type of rock detritus or 'brash' in the soil. Most geological features are concealed in the subsurface and cannot therefore be observed directly, precisely defined or measured. It follows that the majority of geological map interpretations can be improved with more information, especially on the concealed subsurface rocks. Sometimes previous interpretations may be replaced completely, but more often they are refined by periodic revision.

3.3 TYPES OF GEOLOGICAL BOUNDARY

Geological boundaries are the junctions between different types of rock or deposit. Their recognition and depiction are fundamental to the map-making process. There are many different types of boundary; some relate to bedrock, some to superficial deposits (including mass movements such as landslips and artificial ground such as embankments). This section describes some of them and how they are represented on a map.

- **Sharp planar** boundaries are the simplest type of geological junction. They are planar and distinct (like those between books in a pile) and occur between recognisably different strata; for example a soft, thin-bedded, grey mudstone resting on the flat upper surface of a firm, thick-bedded, yellow limestone. If such a boundary is exposed in an opencast quarry it can be very accurately mapped (provided the geologist can determine its position relative to recognisable OS surveyed points on the base map).
- **Sharp non-planar** junctions are distinct boundaries that are not flat, but corrugated (like a roofing sheet) or irregular with bumps and hollows. A typical example is where the grey Thanet Sand rests on the irregular upper surface of white Chalk. In this case, although the junction might be easily recognisable in a road cutting for example, it would not normally be possible to map the individual irregularities at 1:10 000 scale. The map would therefore be a simplification, representing the general position of the junction quite accurately, but lacking some of the more precise detail.

- **Diffuse or gradational** boundaries between rock units are less easily defined in the field, even when exposed, and consequently it is more difficult to depict their position accurately on a map. For example, the strata towards the top of the London Clay Formation often become progressively sandier upwards, and a separate, overlying unit, the Claygate Member, is then routinely mapped. The base of this unit is usually defined, somewhat arbitrarily, as the bottom of the first significant sand bed, but this sand may be difficult to find on the ground and hence to locate precisely. Similar gradational boundaries may be defined at the change in formation composition from predominantly sandstone to predominantly mudstone, for example, and whilst it might be possible to fix such boundaries in a borehole core it could be impossible to determine them on the ground in routine geological mapping. The mapped geological line here is again an approximation and represents a zone of poorly defined width within which one unit passes into another. Most geological maps do not distinguish between gradational and sharp boundaries.
- **Superficial** or Quaternary deposit boundaries, used for example around glacial and postglacial sediments, tend to be ill-defined or gradational and can be mapped only approximately. Most of the deposits are soft and unconsolidated and easily smoothed off by weathering and erosion. The margins of some may be associated with well-defined changes of slope, such as the edge of an alluvial floodplain, and these may be traceable with greater accuracy, particularly as digital terrain models permit finer resolution than the 5 m contours of the traditional OS topographical base map. Conversely, many margins of superficial deposits are ‘feather-edged’, where a gradual lateral diminution of thickness makes it very difficult to determine the position of the extent of a deposit.

3.4 REPRESENTATION OF GEOLOGICAL BOUNDARIES

Some of the different types of geological boundary are represented by different line styles on BGS maps and these vary with the map scale. They can be downloaded from the BGS web site at:

http://www.bgs.ac.uk/downloads/home.html

At 1:10 000 scale two main styles are used for the bedrock strata:

——— Geological boundary bedrock [solid], observed.

— — — Geological boundary bedrock [solid], inferred.

A different line style is used for the superficial deposits:

- - - - - - - Geological boundary, superficial deposits [drift].

The original digital geological map data retains these and other distinctions between the different boundary types. These line styles have not been supplied routinely to licensees to date, though it is planned to do so in future versions of the DiGMapGB datasets.

3.5 POSITIONAL RELIABILITY OF GEOLOGICAL BOUNDARIES

The position of the defined boundary, whether sharp or gradational, planar or non-planar, may be known to varying degrees of confidence depending upon the exposure. BGS 1:10 000 scale maps commonly distinguish between observed and inferred boundaries depending on their reliability. However, the differences have not been closely defined so geologists have not always used the terms consistently. The three main types of boundary, according to their reliability are:

- **Observed** boundaries are the most reliable and may be regarded as accurate, but they are used infrequently as most boundaries are inferred. Observed boundaries are used for the bedrock, ideally where the junction is visible on the ground and there is no doubt about its position, for example one exposed in a road cutting or a bare mountainside. However, a junction that is not directly visible may have been regarded as ‘observed’ by one geologist (because of a distinct and sharp change of slope) whilst another would have regarded it as ‘inferred’ (because the rock junction was covered by grass and soil).
- **Inferred** boundaries are less reliable and regarded as approximate. This category is usually used for bedrock junctions that are concealed beneath vegetation, soil and superficial deposits or younger rocks making it more difficult to determine their position accurately. There will probably be some evidence available, though, which constrains the geological interpretation and allows the geologist to construct the inferred boundary. For example, a marked topographical feature such as an increase in slope profile or a ridge may be caused by a change to harder rock; a hollow may be caused by softer rock. In these circumstances, it might be possible to infer the boundaries between the different hidden rock units fairly accurately, though never as precisely as when exposed. Also, aerial photographs of the ground may reveal different textures, colours or vegetation that correspond to different rock types, and allow the geologist to infer boundaries between them that are not visible or apparent at the surface.

In the UK, the vast majority of geological lines and boundaries are best regarded as inferred irrespective of classification; this includes the boundary lines of superficial deposits.

- **Conjectural** boundaries are the least reliable and may be little more than educated guesses. This category is not often used on BGS maps but is appropriate in some places, for example to show the bedrock geology beneath a broad coastal plain of superficial deposits. Here it may be necessary to estimate the position of concealed geological features such as rock boundaries, faults or coal seams, where there is little borehole or other information available and the geological interpretation is therefore only loosely constrained – in reality ‘a best fit’ solution.

A basalt dyke may be conjectured in bedrock beneath river gravel; but later gravel workings may prove it does not extend beneath the gravel at all.

Conversely, a geological map may indicate a mudstone bedrock sequence concealed beneath river alluvium; but a later borehole may prove the presence of an unsuspected intervening layer of sandstone. This occurrence could be conjectured as a down-faulted block, in which case available information would be re-examined for any evidence that would support this new interpretation.

3.6 SOME PRACTICAL PROBLEMS IN MAPPING GEOLOGICAL BOUNDARIES

All geological units are represented either by a polygon surrounded by a geological line or by the line itself, so the mapped geological boundary line is fundamentally important, but what does a line mean?

In the case of polygons, the line represents the mappable limit of a geological unit. It marks the place where there is one unit on one side of the line and another unit on the other side. Where BGS has mapped an 'observed geological boundary' in ideal circumstances there may, for example, be two distinctive units separated by a sharp planar junction that can be clearly seen in bedrock exposures on the ground. Whilst comparatively rare, it may then be possible to stand on the junction, represented by the geological line on the map, and with certainty step one way on to one unit and the other way on to a different unit.

Even with distinctive units it is much more likely, given the vegetation and soil cover of the UK, that the actual geological boundary cannot be located on the ground with certainty. In these circumstances, the best one can say is that it will be in the vicinity. How precisely the boundary can be located will depend on many variable factors, some unquantifiable, including the type of rocks or deposits, type of boundary, degree of exposure, effects of weathering, scale of mapping, and the experience and skill of the geologist. So, on one 1:50 000 scale map, the uncertainty could vary along a particular boundary and might be expressed as likely to occur within a 20 m radius circle in one place, 200 m in another.

Some units, such as marine bands or coal seams, even though thin are nevertheless important, whether for economic or other reasons and need to be recorded. Usually they cannot be shown as polygons, and are therefore depicted as lines of varying thickness and style on large-scale maps. Even so a one-metre coal seam, shown as a 0.55 mm thick line at 1:10 000 scale (representing 5.5 m on the ground) is likely to be considerably exaggerated. A key bedrock marker bed would, for example, be mapped even where it thins down to fossil shells on a single bedding plane because its unique characteristics allow the stratigraphical position in the geological sequence to be determined.

Superficial deposits present particular problems in mapping as they are often thin and may have a patchy distribution. Despite this they are an important factor in man's economic activities, as they occur on the Earth's surface, influencing soil type and hence agriculture and biodiversity; mineral resources, hence extraction; ground conditions, hence planning and development. They are therefore significant and worth recording and describing.

We can further examine some of the practical problems involved in map-making by using hypothetical examples:

- Suppose a river has deposited a thin layer of gravel in the bottom of its valley. Typically, the mappable river gravel is at least one metre thick; anything less is generally regarded as being too thin to routinely record. Away from the river the gravel has a poorly defined, irregular outer limit where it feathers out effectively to nothing. Beyond this there may be discontinuous patches of thin gravel, no more than 0.5 m thick, and thought to be relics of a former more extensive spread. Ordinarily these might be ignored as unmappable at 1:10 000 scale.
- In one place the edge of the gravel deposit is actually exposed in a pit and the mapped boundary line there records the position where the deposit tapers out to zero thickness.
- Suppose there is a veneer of silty material washed off the nearby hillside and re-deposited in the valley bottom so masking the gravel. The geologist then has the task of deciding where the edge of the concealed gravel is and where it will be recorded on the map. With no clear topographical feature to determine the position the geologist may have to rely on hand-augering through the soil and hillwash, bearing in mind for example the disturbance caused by ploughing. Clearly it is not feasible to auger the ground every metre or so in order to determine the positions of deposit margins. It is more likely the geologist would attempt to bracket a boundary by placing one auger hole near the gravel margin and another directly into the bedrock some 50 or 100 m away and then splitting the difference and recording the boundary midway between the two. (On steep slopes it could be appropriate to bracket boundaries by augering at much closer intervals, perhaps 5 or 10 m apart.)

3.7 GEOLOGIST'S ORIGINAL SELECTION AND SIMPLIFICATION

The geologist records the significant details on the map as far as is practicable in the time available at the scale of mapping, usually 1:10 000. In assessing what is significant there are no 'hard and fast' rules that can be applied rigidly across the whole country. The criteria vary according to the geology and to the demands of particular projects. They may also vary with time, whether because of new geological discoveries or changing political and economic priorities.

This selection process depends in part on the experience and judgement of the individual geologist. One who has mapped similar rocks for many years may be able to assess quickly the important features whereas one without this background may record additional details that are ultimately omitted from the finished map. This procedure can be illustrated with some examples:

- If there were a soft, black mudstone resting on hard, brown sandstone this readily identifiable junction would, for instance, be selectively recorded and mapped as a line on a map if it represented an important and significant boundary between two named bedrock units such as Coal Measures mudstone on Millstone Grit sandstone. It might not be mapped if it were just one of many such changes in lithology within a thick package of similar interbedded rocks. It would depend, in part, on the thickness and lateral extent of the rock units and their relative significance in recording changes in Earth history or the economic value of the strata; thus it might be impracticable to map individual sandstone beds less than a metre or so thick, but possible, and indeed desirable, to map beds of 10–20 m thick.
- A 0.5 m thick lens of sand on top of a deposit of sandy gravel might not be regarded as significantly different and not worth mapping separately. In contrast a peat deposit, 0.3 m thick, could be regarded as significant because it is compressible and potentially a hazard to buildings so it would be recorded.

- Consider the igneous basalt dykes shown on Figure 1. Here, we can suppose that 100 identifiable dykes of all sizes have been intruded or injected into a sequence of red sandstones, and all are now exposed on a 100 m stretch of rocky coastline. The dykes range in thickness from a few millimetres up to many metres. In routine geological mapping a single dyke, a metre wide, might be recorded as a line on the field-map. However, where there is a swarm of closely spaced parallel dykes it is cartographically impossible to record each one as the lines would be too close together and indecipherable. The geologist has therefore selected ten of the larger dykes to record at 1:10 000 scale (1a); chosen to give a fair impression of their extent and trend, if not their quantity.

3.8 FURTHER CARTOGRAPHICAL GENERALISATION

Having made initial selections and simplifications to prepare the original field map the geologist or cartographer may then have to modify the linework in order to depict the geology satisfactorily on the published map at the same scale. For example a small but crucial outcrop may need to be exaggerated in size on the printed map in order to produce a polygon large enough to take enough colour to distinguish it.

Further modifications are made each time a map is reduced to a smaller scale. Some of the cartographical procedures used are graphically illustrated in Figure 1, a hypothetical example. This shows the geology of a one kilometre square at 1:10 000 scale (1a), and how the same area is depicted as it is progressively reduced, first to 1:50 000 scale (1b), then 1:250 000 scale (1c) and finally 1:625 000 scale (1d). At each step two processes take place: selection and simplification. Some geological features are selected and retained; some are removed. The amount of detail shown is also reduced; thus intricate lines, like the limit of alluvium (river deposits) on Figure 1a, may be generalised to simple curves on 1b. From the 10 basalt dykes recorded on the 1:10 000 map (1a) the geologist and cartographer have selected a new subset of three for the 1:50 000 map (1b). A further reduction was made to just one dyke at 1:250 000 scale (1c); and none at 1:625 000 scale (1d).

Although not evident in this example the data may be modified at each stage to fit the new topographical base map. This is most likely to be evident along the coast, which may change markedly from one map to another and the geology may have to be modified accordingly to fit each coastline.

The peat shown on Figure 1 provides an example where several small deposits (1a) mapped at 1:10 000 scale have been amalgamated into a single deposit at 1:50 000 scale (1b), whilst another small isolated deposit has been omitted.

Also, users need to consider the exaggeration in size that may result if a small feature is retained on small-scale maps. Thus if a one-metre wide dyke is depicted by a 0.2 mm thick line at 1:10 000 scale, this line, if true to scale, represents a width of 2 m on the ground. At 1:50 000, scale the same line represents 10 m, and at 1:250 000 scale 50 m.

4 Accuracy of Ordnance Survey base maps

4.1 CARTOGRAPHICAL ACCURACY OF OS MAPS

All maps are representations that contain inherent simplifications. Many points on OS maps represent ‘hard’ features such as buildings, roads, railways, field boundaries and rivers. These are clearly defined, measurable physical features that can be observed directly. Thus, different surveyors using similar surveying techniques and standards would record them in the same positions, subject to acceptable observational accuracy limits. However, when they are represented on paper maps the purpose and scale of the map determines the level of detail shown. Of necessity some features, for example major roads, are selected whilst others, such as farm tracks, are omitted. A road may be exaggerated in width but a pavement left off. Shapes may be simplified; irregular or complex-shaped buildings shown by symbols or standard rectangles; roads given standard widths. Some features may be moved; for example, in the case of a close parallel road and railway the railway line may be shown in the correct position and the road displaced sideways. In the case of a fence/stream pair, the stream may be drawn in the correct position with the adjacent fence shown as a line a set distance away from the stream.

So, as some topographical features are cartographically adjusted to a particular scale, their positions on the OS base map are less accurate, relative to their ‘true’ position expressed for example by the OS National Grid.

4.2 POSITIONAL ACCURACY OF LARGE-SCALE OS MAPS

Most BGS geological maps are surveyed on large-scale 1:10 000 OS base maps so their accuracy depends, in part, on the accuracy of the OS base. The OS recognises absolute and relative accuracy:

- **absolute accuracy**, the position of a point relative to the National Grid
- **relative accuracy**, the position of a point relative to another point in the data.

This OS accuracy depends principally on the scale and the techniques used in the original topographical survey. Thus maps of urban areas are typically the most accurate, surveyed at 1:1250 scale; small towns, villages and rural areas are less accurate, at 1:2500 scale; and mountain and moorland areas are least accurate, at 1:10 000 scale. The OS formerly provided a leaflet of technical information regarding Land-Line® data, from which Table 1 below is derived. This shows the ‘expected absolute accuracy values for well-defined points within each accuracy category of mapping contained in the National Topographical Database’ of their large-scale maps at different confidence levels.

The most detailed map scale routinely used by BGS is 1:10 000 scale for which 99 per cent of well-defined OS points will theoretically be within 8.8 m of their true National Grid position. However, there is some topographical generalisation at this scale for cartographical reasons so some details may appear to be less accurately located than would appear from these quoted OS standards

Table 1 Ordnance Survey absolute accuracy.

Scale of original survey	**Expected absolute accuracy at differing confidence levels**		
	63%	95%	99%
1:1250	0.5 m	0.8 m	1.0 m
1:2500	2.8 m	4.7 m	5.8 m
1:10 000	4.1 m	7.1 m	8.8 m

Following the withdrawal of Land-Line® in October 2008 and its replacement by OS MasterMap® this table has been superseded but the same or very similar figures are quoted on the OS website.

4.3 POSITIONAL ACCURACY OF MEDIUM- AND SMALL-SCALE OS MAPS

Smaller-scale OS base maps were traditionally produced by progressive reductions and ad hoc cartographical simplification or exaggeration of selected features as required, with consequent loss of accuracy. Comparison of the 1:50 000 and 10 000 scale bases suggests that the positions of topographical features at the 1:50 000 scale may be displaced by up to 50 m with respect to the OS grid.

At smaller scales such as 1:250 000, and even more so at 1:625 000, the exaggeration of some features like roads may be so large that it is no longer appropriate to fit the large-scale geology to them. Geology is, however, usually fitted to the coastline at these scales, as there may be significant differences in its position on different OS editions, particularly in estuaries with extensive shifting mudflats.

4.4 GPS ACCURACY AND THE OS GRID

The Ordnance Survey's definitive transformation, OSTN02, which links GPS co-ordinates to Britain's map system (the OSGB36 National Grid), as described by Greaves and Cruddace (2001) is available on its web site. It is accurate to 10 cm at the 68 per cent confidence level.

Previously, the National GPS Network (and transformation OSTN97) was defined by the National Grid positions of the old triangulation points. Now, OSTN02 defines the OSGB36 National Grid in terms of the National

GPS Network stations. As a result the National Grid co-ordinates of an existing OSGB36 point, refixed using GPS from the National GPS network and OSTN02, will be the correct ones. The original OSGB36 National Grid co-ordinates will no longer be true, by definition, but the two co-ordinates will be within 10 cm (at 68%) of each other. For practical purposes concerning 'real world' geology such small differences are of no importance as there are minute compared to most other sources of 'error'.

References:

GREAVES, M and CRUDDACE, P. 2001. The OS's new coordinate transformation for Great Britain- GPS to OSGB36 National Grid transformation. Geomatics World November/ December, p 34–36. Available at http://www.ordnancesurvey.co.uk/oswebsite/gps/docs/Geomatics_world.pdf

OS LAND-LINE® Technical information leaflet. Land-Line user guide, 2004, version 5.2, chapter 6, p 167 (no longer available).

OS MASTERMAP® User guide and technical specification. 2009, version 1.7, chapter 6, p 80. Available online at: http://www.ordnancesurvey.co.uk/oswebsite/products/osmastermap/userguides/docs/OSMMTopoLayerUserGuide.pdf

For OS GPS and positioning services see http://www.ordnancesurvey.co.uk/oswebsite/gps/osnetfreeservices/about/surveying_osnet.html#6

5 Accuracy of British Geological Survey maps

5.1 CARTOGRAPHICAL ACCURACY OF BGS MAPS

Geological maps are representations that include simplifications. Relatively few lines on most geological maps of lowland Britain may be regarded as ‘hard’ or ‘certain’, that is geological structures or elements that are clearly defined, of unambiguous interpretation, directly observable, and therefore precisely locatable and measurable.

An example of a well-defined element is a sharp junction or boundary separating two different and distinctive bedrock units seen in a rock exposure.

This boundary (of essentially zero thickness) if mapped by traditional paper methods, will be recorded first on the geologist’s ‘field-map’ as a pencil line about 0.2 mm thick (which at 1:10 000 scale represents a distance of 2 m on the ground).

The pencil line will subsequently be ‘inked-in’ by the geologist, with consequential slight differences in positioning, and on the final map at 1:10 000 scale will be printed as a 0.25 mm thick line (representing 2.5 m on the ground).

Similarly, a precisely locatable fault plane (perhaps also of zero thickness) is shown on the final map as a 0.35 mm thick line (representing 3.5 m on the ground).

A coal seam is represented by a 0.55 mm line on the final 1:10 000 scale map. Depending upon the actual seam thickness (commonly up to a metre or more), the dip of strata, and the slope of the ground – the width of the coal seam at outcrop might actually be greater than 5.5 m (as represented on the ground). If there are several coal seams close together, each say 0.5 m thick and therefore individually worth mapping, it may be possible to record them initially using a relatively thin line but impossible to show them all on the final printed map with 0.55 mm linework.

In contrast to examples of exposures at the surface, described above, many geological structures or boundaries are often concealed beneath vegetation and soil or other deposits. Whilst it may be possible to determine the exact position by digging a trial pit for example, this will only provide an observation at a particular point. Away from that point the boundary will have to be extrapolated, with varying degrees of uncertainty. The mapped location may therefore be based on interpretation, possibly ambiguous, rather than direct observation. The actual location of the boundary could fall outside the 2.5 m wide ‘footprint’ of the mapped geological line on the ground surface.

Like topographical maps, the scale of printed geological maps determines the level of detail that can be shown. A 0.2 mm bedrock boundary line on a 1:50 000 map represents 10 m on the ground, and a 0.35 mm coal seam line represents 17.5 m. Where several coal seams are mapped closely together at 1:10 000 scale some may have to be removed for the 1:50 000 scale printed map.

The depiction of thin beds of distinctive lithology, for example a sandstone bed within a mudstone succession, is also scale dependent. In traditional mapping the narrowest polygon that can be drawn with a discernible colour infill is 1.0 mm wide. At 1:10 000 scale this represents 10 m on the ground; so a bed with 5 m wide outcrop would be effectively doubled in size. If this bed is geologically important and is also shown on the published 1:50 000 scale map the same 1.0 mm wide polygon will then represent 50 m on the ground, a further five-fold exaggeration and ten times the actual bed.

5.2 POSITIONAL ACCURACY OF BGS LARGE-SCALE MAPS

Almost all BGS large-scale legacy maps have been compiled on to Ordnance Survey base maps at 1:10 000 or 1:10 560 scales. The geological lines were drawn up relative to the topographical base during fieldwork or interpreted soon afterwards using the field observations. For example, when an observation is made near the corner of a particular field it is typically located by the geologist using measured paces on the ground from that corner. This point is then positioned on the geologist’s working field-map using a graduated scale and measuring from the same intersection, as mapped by OS. The accuracy of this pacing depends on the skill and experience of the individual, the topography, ground cover, soil conditions and the distance from the nearest reference point. In general, on flat to low relief, paced distances should be within about +/-5 per cent of true at 100 m. On uneven or steep relief, pacing is more difficult and accuracies are likely to be reduced, perhaps to as little as +/-20 per cent or worse on difficult ground.

The locations of point observations are initially recorded on the field map as pencil dots, which should be correct to +/- 0.5 mm on the map face (or a 10 m circle on the ground at 1:10 000).

Given good topographical reference points, the positional accuracy of a well-defined geological element is therefore likely to be correct to +/- 1.0 mm on the map face (or +/- 10 m on the ground at 1:10 000).

Away from good reference points, where pacing is not practicable, locations may be determined by compass triangulation or reference to aerial photographs, and could be less accurate. Positioning, for example, in a large featureless field, a hill top peat bog, or inside a wood is difficult and is liable to more inaccuracy without the use of surveying aids.

As geological linework is, usually, fitted to the topographical base that linework may not be drawn in its ‘true’ position relative to the National Grid. For example, where a geological boundary is seen exposed in a ditch on the side of a road it would probably be mapped or recorded alongside the road as shown, even if the road had an exaggerated width on the topographical base, and the boundary should strictly be underneath the road symbol. Such fitting may result in a loss of spatial accuracy whilst retaining correct topographical relationship. In the paper environment the latter may be most appropriate; increasingly in the digital environment the former may be preferred.

Subsequent inking-in of these locations and later copying on to final clean copies can result in further generalisation and loss of positional accuracy.

If the base map is inaccurate then the geological map and derived data will also be inaccurate in terms of true spatial position. However, in many practical applications of the geological information, this may be preferable to having a geological map that is correct in the absolute sense but incorrect relatively. For example, a gold vein is found in a riverbed at its junction with a tributary. If a geologist records the vein at that confluence, as shown on the base map, the correct relationship between topography and geology is preserved and anyone who wants to find the gold may do so by finding the actual confluence on the ground. If the geologist checks the spatial co-ordinates of the confluence by GPS and finds that when plotted on the base map, using grid references, it lies on the adjacent hillside they have a dilemma. If they plot the vein there it may be correct spatially but it will be incorrect relative to the topography and anyone looking on the hillside would not find the vein. They need to record the vein correctly at the confluence and note its correct GPS location, explaining the apparent conflict between the two caused by the incorrect base. Ideally the base then needs correcting. The critical things are the intended purpose, and the medium within which the geological data are used: paper or digital.

In all legacy maps we can assume that the geological linework was fitted to a particular OS base which maintained ‘correct’ relationships with the topographical features. The geological map data may not, however, fit a different topographical base of the same area. In the future, with the advent of GPS, geological observations may not always be fitted to a particular OS base.

5.2.1 GPS and positional accuracy

Hand-held GPS devices are now used routinely in geological field-mapping to capture the National Grid Reference or latitude and longitude co-ordinates of points surveyed or sampled on the ground. In good conditions they provide positions with a typical accuracy of 5 to 10 m. They are especially useful where traditional pacing methods are impracticable such as in extensive featureless floodplains with no field boundaries. In woodland, without a good line of sight to several satellites, the accuracy may be of the order of 100 m but even this might be better than pacing.

The portable tablet PC now used for field observation by BGS has a built-in GPS device which can automatically track locations on the digital base map. This has largely superseded the use of separate hand-held GPS devices to obtain co-ordinates and then plot the positions manually, whether on a traditional paper map or a digital base. However, the use of a GPS device can provide apparently conflicting information. For example, a GPS-derived grid reference could place a sample site on one side of a field boundary, whilst on the ground it is actually on the other side. Depending on circumstances, in particular the likely accuracy of the GPS-determined position at that moment, it may be more useful to preserve the correct relative position of a geological feature relative to the OS topography, rather than its ‘absolute’ position. This is the approach taken by traditional geological maps where the geological interpretation is fitted to the topographical base map, thereby preserving the correct spatial relationship with the landscape. Digitally, such information can be held as coordinates with a +/- error and may be represented by a small circle (point together with a buffer) when viewed at large scale.

5.3 POSITIONAL ACCURACY OF BGS MEDIUM-SCALE MAPS

All the above considerations of accuracy that apply to 1:10 000 large-scale maps also apply to 1:50 000 or 1:100 000 medium-scale maps. In 1998 an assessment was made of the cartographical accuracy of the 1:50 000 maps that had typically been achievable up to that time using various traditional techniques. For example, many maps were compiled using a mosaic of photo reductions to 1:50 000 scale of each detailed 1:10 000 scale component map. At each stage in this process small errors or generalisation could be introduced. It was estimated from a comparison of the published 1:50 000 maps and their 1:10 000 scale sources that the typical compilation accuracy was about 1 mm at the 1:50 000 compilation scale. This equates to 50 m on the ground.

The same accuracy level is the basis for the ‘accuracy statement’ quoted at the start of this report for 1:50 000 digital map data stating that the geological lines supplied from DiGMapGB-50 (Version1) have a spatial cartographical accuracy of ±1.0 mm at 1:50 000 (equivalent to 50 m on the ground) when compared to the original source lines at 1:10 000 scale.

A misfit between two adjacent tiles should therefore have a spatial error of no more than twice this, ±2.0 mm (equivalent to 100 m on the ground).

This reduction in spatial accuracy is one reason why it is inadvisable to use medium-scale data to solve large-scale site-specific queries. The user must not enlarge 1:50 000 data for use at 1:10 000 scale once it has been generalised and fitted to a 1:50 000 base. This is graphically shown in Figure 2; which shows the 1:50 000 scale geology of Figure 1b (and 2a) enlarged back to 1:10 000 scale (Figure 2b). A comparison of Figures 1a and 2b clearly shows 2b is less accurate. The peat components cannot be recovered, and the intricate linework has been lost, including most of the basalt dykes, and the widths of dykes have been altered.

The user should also note that there is variation in the true scale accuracy of BGS paper maps caused by stretching or shrinking during the printing process or subsequent storage or use. This is evident if the kilometre grid is measured precisely with an accurate graduated ruler. There is often a discrepancy of 2 or 3 mm, and sometimes more, across a single printed 1:50 000 map sheet. This is corrected, as far as possible, before the digitisation process by adjusting or ‘warping’ the raster scan of the paper map so that the corners of the map face are correctly placed at their true National Grid positions. Even so, some distortions might remain within the map. Furthermore, during compilation of medium-scale geological maps from more-detailed large-scale ones, the cartographer commonly simplifies and adjusts the geological linework to correspond with relevant topographical detail as depicted on the medium-scale base map. So, for example, a geological boundary recorded along the sides of a railway cutting may need to be adjusted in order to fit the same cutting depicted on a different base map where the cutting's position has been changed by the OS cartographical generalisation

5.4 POSITIONAL ACCURACY OF BGS SMALL-SCALE MAPS

Medium scale maps may be further reduced and simplified to prepare small-scale 1:250 000 and 1:625 000 maps as shown in Figures 1c and 1d. At each stage the main factors governing the representation of the geology are cartographic and the 'accuracy' is progressively reduced. This is a one-way process only. The user must not enlarge 1:250 000 data for use at 1:50 000 scale once it has been generalised and fitted to a 1:250 000 base. This is graphically shown in Figure 1c; where if the 1:250 000 scale geology were enlarged back to 1:50 000 scale neither the missing dykes nor the window through superficial deposits of Figure 1b could be recovered.

It should be noted that BGS does not normally use small-scale maps to create larger scale datasets where these are not available. An exception may be made, for example, in order to provide complete coverage of the superficial deposits theme in order to create derived geohazard data.

5.5 ACCURACY OF DIGITISATION

Geological lines are digitised to an accuracy of ±0.2 mm, that is they should not deviate from the centre line of the source line by more than 0.2 mm at the map compilation scale. At 1:10 000 scale digital lines should therefore be within 2 m on the ground of the source line; and at 1:50 000 scale, within 10 m on the ground.

As experienced cartographers digitise linework they may smooth geologist's linework, where it is particularly angular or untidy, to give a more natural curve even though this might take it outside the theoretical line accuracy limits noted above.

Formerly a digitisation table would have been used to digitise printed geological lines at true scale on paper maps; and this required considerable expertise to acquire high quality vector data.

Now the technology has advanced and a 'head-up' display technique is used. First the printed map is scanned to produce a digital raster image. This image is then shown on screen, usually magnified, and the source geological lines digitised with great accuracy.

Sometimes a scan itself may introduce small errors because of slight distortions or displacements during the scanning process.

5.6 SUMMARY OF THE SOURCES OF POSITIONAL ACCURACY ON GEOLOGICAL MAPS

At each scale of geological map the accuracy is dependent upon the accuracy of the OS base map to which the geological lines are fitted. Also, at each stage in their preparation there are possible sources of variation in positional accuracy as summarised in Figure 3.

Firstly, there are potential inaccuracies associated with the original geological observations in the field, their interpretation and survey, and their recording on to field-maps (3a).

Secondly, as the interpretation of those field observations is further refined and a manuscript 'fair' copy drawn up there may be generalisations introduced through transcription (3b). If the field observations are complex this may involve some simplification. If the map is digitised for publication at 1:10 000 scale further variations in spatial accuracy may be introduced by the scanning and digitisation process.

Thirdly, for the compilation at 1:50 000 scale there are generalisations and simplifications of transcription (3c) together with scanning and digitisation errors associated with the routine publication of printed map sheets.

Lastly, each time subsequent reductions are made for compilations at 1:250 000 and 1:625 000 scales there are further possible inaccuracies introduced by transcription, generalisation and simplification, and by the digitisation process.

The right-hand side of the figure also shows that having obtained digital data at 1:10 000 scale the software is now becoming available that may make it possible in the future to generalise it automatically or semi-automatically by, for example, reducing the number of data points. Manual intervention is still likely to be needed, to decide which units should be amalgamated, and carry out any refitting to topography.

6 Concluding remarks

In conclusion it should be noted that the BGS maps of the UK at 1:10 000 and 1:50 000 scale are probably amongst the most accurate geological maps in the world.

They are compiled on topographical bases from the Ordnance Survey, renowned for their accuracy and mapping expertise.

The relative importance or magnitude of the different factors that influence the accuracy of large- and medium-scale geological maps is summarised in Table 2. Some of these factors are quantifiable and can be allowed for in any automated systems dealing with the digital data. Others, however, are not, and as a result are more difficult to deal with.

For legacy data, the accuracy of the BGS geological map is closely tied to that of the OS topographical base. The accuracy of observed geological features is comparable to the accuracy of the OS base as the errors resulting from the recording and digitisation process are quite minor, particularly when compared with those in the compilation of 1:50 000 legacy sheets by traditional methods.

It can be seen from Table 2 that the greatest potential for error or inaccuracy is in the original geological interpretation, particularly where the geological boundaries are not observed but are either inferred (well constrained) or conjectural (loosely constrained).

The 1:10 000 scale BGS geological maps form the most detailed national series in the world and many of them have been revised or resurveyed, some several times, since their original compilation. The geological survey work continues with the aim of extending the detailed coverage, improving the interpretations and keeping the maps up-to-date as far as possible and improving their accuracy.

Table 2 Summary table of accuracy factors.

	Accuracy limits on the ground					
	0 to 1 m	**1+ to 10 m**	**10+ to 100 m**	**100+ to 1000 m**	**1000+ m other**	**comment**
Cartographical accuracy of OS 1:10 000 maps		●				
Cartographical accuracy of OS 1:50 000 maps			●			
Positional accuracy of OS 1:10 000 maps		●				
Positional accuracy of OS 1:50 000 maps			●			
Cartographical accuracy of BGS 1:10 000 maps		●				
Cartographical accuracy of BGS 1:50 000 maps			●			
Positional accuracy of BGS 1:10 000 geological map		●				
Positional accuracy of BGS 1:50 000 geological			●			
GPS accuracy		●				in field mapping
GPS to NGR transformations	●					
Geological interpretation observed		●				variable and not defined
Geological interpretation inferred		●	●	●		variable and not defined
Geological interpretation conjectural				●	●	variable and not defined
Accuracy of digitisation at 1:10 000 or 1:50 000		●				
Reliability of geological linework		●	●	●	●	variable and unquantifiable

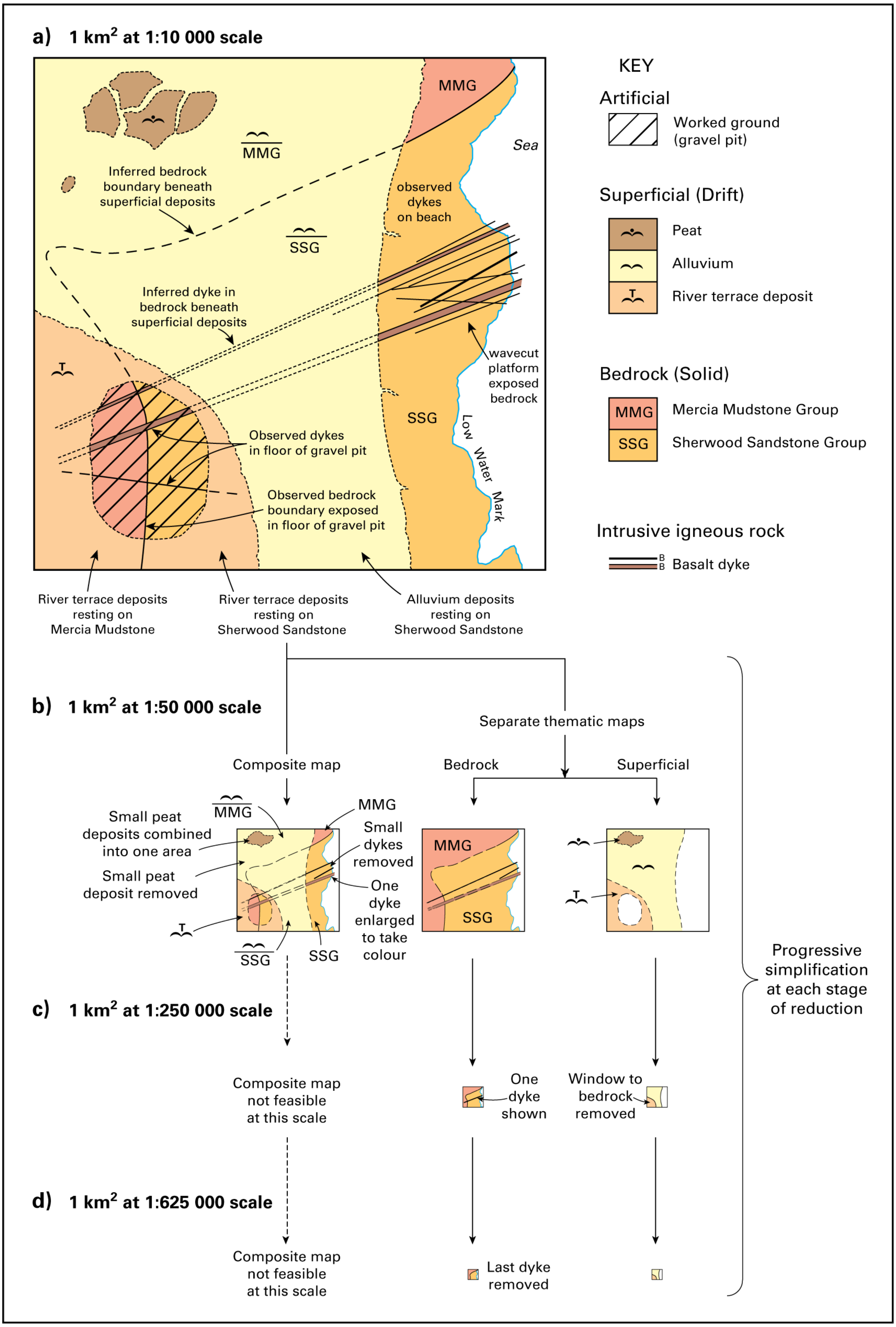

Figure 1 Simplification of geological maps by progressive reductions in scale.

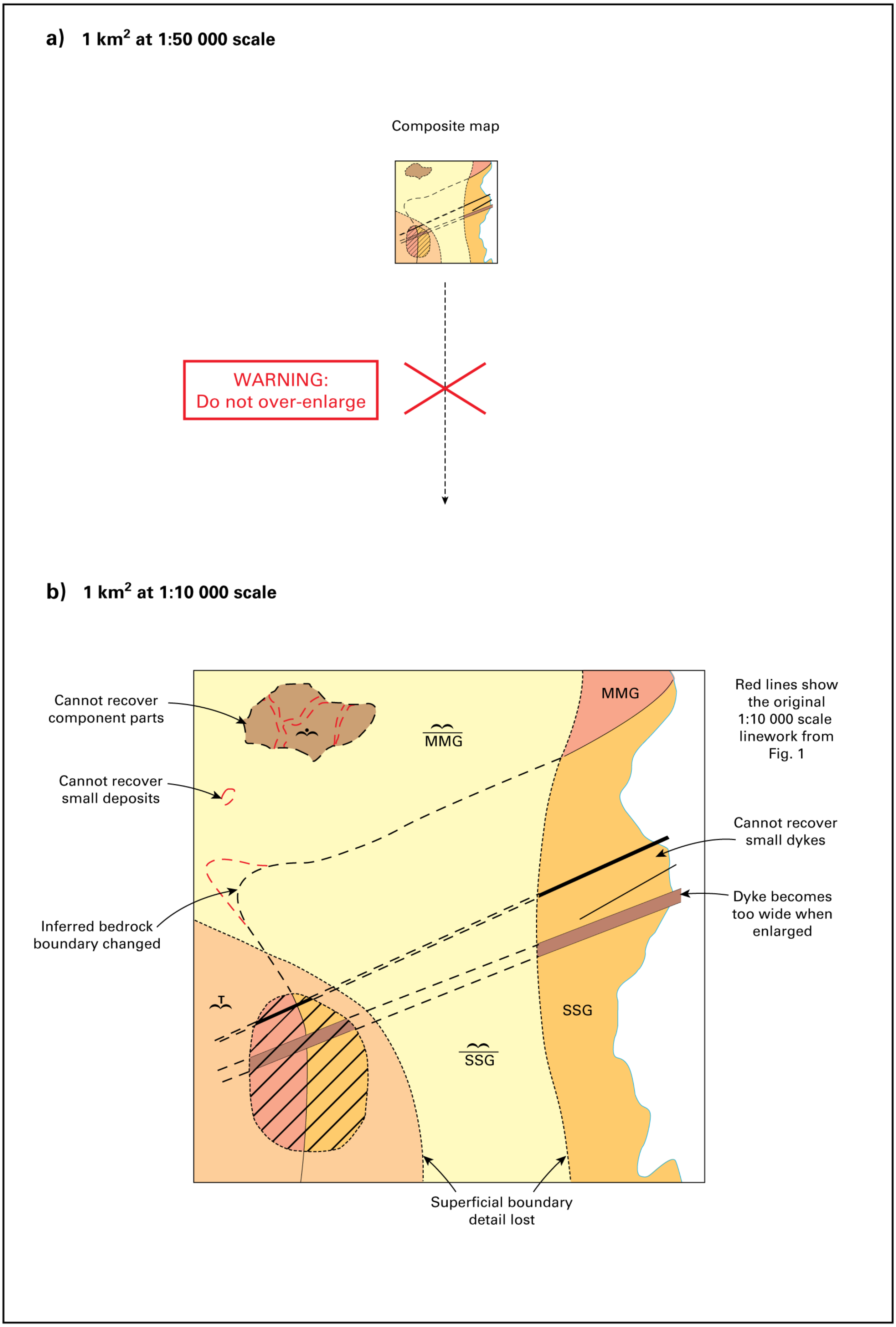

Figure 2 Accuracy problems caused by over-enlarging geological maps.

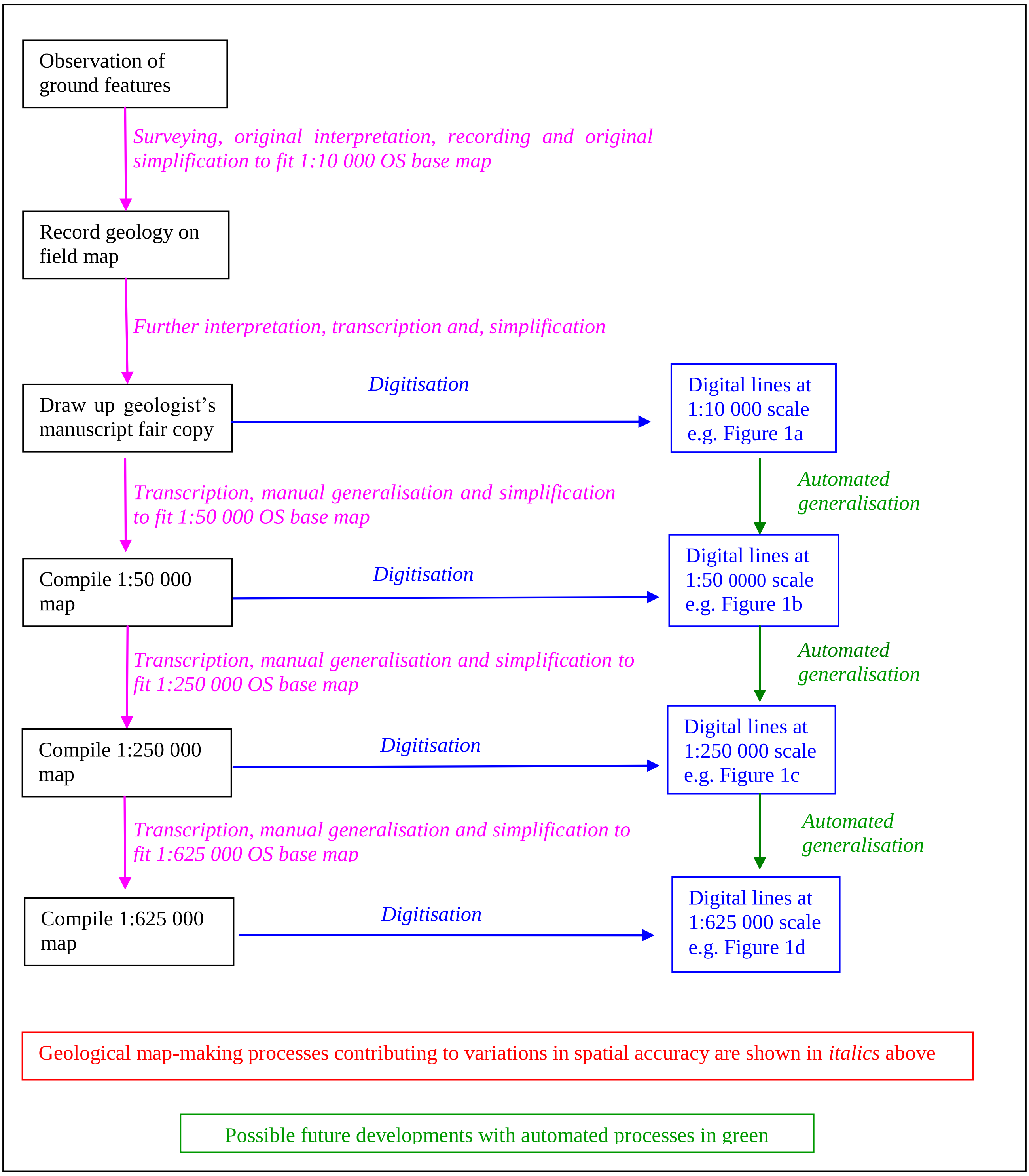

Figure 3 Summary of the sources of variation in spatial accuracy in geological map-making.