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User Guide DiGMapPlus Engineering Properties: Bulking of soils and rocks dataset (version 1)

Environmental Modelling Directorate

Open Report OR/14/054

BRITISH GEOLOGICAL SURVEY
ENVIRONMENTAL MODELLING DIRECTORATE
OPEN REPORT OR/14/054

User Guide DiGMapPlus Engineering Properties: Bulking of soils and rocks dataset (version 1)

D C Entwisle, R S Lawley & M R Dobbs

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Contributor/editor

K A Lee, P Hobbs

Keyworth, Nottingham British Geological Survey 2015

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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

Environmental Science 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 bgs london@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

Contents

1	Introduction.....	1
1.1	Background.....	1
2	Who would benefit from the dataset?	2
3	What the dataset shows	2
3.1	Classification	2
3.2	Field descriptors	4
4	How the dataset was created	5
5	Technical information.....	6
5.1	Scale.....	6
5.2	Coverage	6
5.3	Data history.....	6
5.4	Limitations.....	6
6	Contact information.....	7
Appendix 1	Engineering Properties: Field Properties.....	8
Appendix 2	Bulking values from the literature	9
Appendix 3	Distribution of data	11
Appendix 4	Mapping Scales	12
References		13

TABLES

Table 1.	Bulking class and nominal bulking factor range with typical lithology characteristics ...	3
Table 2.	Explanation of the nominal scales of geological map data	5

1 Introduction

This document provides information for users of the ‘Engineering Properties: Bulking of soils and rocks’ dataset.

The excavation of rocks or soils is usually accompanied by a change in volume. This change in volume is referred to as ‘bulking’ and the measure of the change is the ‘bulking factor’. The ‘bulking’ of excavated rocks and soils is an important consideration in civil engineering and extractive industry.

The bulking factor is the ratio or percentage of the volume change of excavated material to the volume of the original *in situ* volume before excavation. The swelling factor is similar. The bulking factor B may be defined by the equation

$$B = (V_B / V) - 1 \quad 1$$

Where V_B is the volume of the excavated material and V the initial volume.

Bulking factor may also be expressed as parameter B_1 related to B from the following equation.

$$B_1 = (V_B / V) = 1 + B \quad 2$$

The bulking factor equates to the swell or swelling factor F_s :

$$F_s (\%) = 100 \times [(\rho_i / \rho_e) - 1] \quad 3$$

Where ρ_i is the *in situ* density and ρ_e is the excavated density. Swelling factor from *in situ* to excavated condition is equivalent to bulking factor for stockpiled material under gravity loading.

The bulking factor is used to estimate the likely excavated volumes that will need to be moved, stored on site, or removed from site. The excavated volumes have to be managed safely and efficiently on- and off-site and are critical to the footprint, stability and construction of the stockpile. It is also used to calculate the number vehicle movements and might have an impact on the type of plant (for instance dumper truck) used. The bulking factor is used with the shrinkage factor (the reduction of volume due to compaction) for earthwork calculations and for the accurate planning of quantity estimated for budgeting.

The bulking factor might be influenced by a number of different elements including lithological properties (specifically mineralogy, particle-size distribution, particle shape, porosity, density, and strength), alteration (weathering, hydrothermal alteration, metamorphism) and the excavation method (digging, ripping or blasting).

The ‘Engineering Properties: Bulking of soils and rocks’ dataset is intended to provide information about the bulking factor of soils and rocks at a formation scale in order to facilitate preliminary research for the planning and design of buildings, infrastructure, and resource extraction.

1.1 BACKGROUND

The properties and behaviour of rocks and soils fundamental to the planning and development of buildings and infrastructure were included in a series of BGS Technical Reports (‘A geological background for planning and development’) funded by the Department of the Environment during the 1980’s and 1990’s (reviewed in Smith and Ellison, 1999). Many of these characteristics were also included in a number of British Geological Survey 1:50 000 geological sheet brief explanations and the 1:1 000 000 scale engineering geology maps of the United Kingdom (Dearman et al., 2011, Dobbs et al., 2012).

In 2010 the British Geological Survey initiated a development programme to produce thematic datasets that identified and assessed a variety of engineering and soil properties in Great Britain. These include datasets for strength, excavatability, corrosivity (ferrous) and fill. Additional data for discontinuities, foundation conditions, sulphate content and engineering rockhead are in development.

Along with the engineering properties datasets, the Baseline Products and Derived Products Programmes have also generated:

- Parent Material Model
- Superficial Thickness Model
- GeoSure ground stability data
- Methane and carbon dioxide from natural sources and mining
- Mining hazard (not including coal)
- Radon potential dataset
- Scans of onshore borehole logs for Great Britain
- Scans of geology and historic topography maps
- Aquifer Designation Data
- Permeability
- Infiltration SuDS map
- Susceptibility to Groundwater Flooding
- Geological Indicators of Flooding
- Soil Chemistry for Environmental Assessments

2 Who would benefit from the dataset?

It is envisaged that the ‘Engineering Properties: Bulking of soils and rocks’ dataset will be of use to companies involved in the estimation of the volume of excavated material for civil engineering operations. These operations may include, but are not limited to, resource estimation, transportation, storage, disposal and the use of excavated materials as engineered fill (Entwisle *et al.*, 2012).

Although the information presented in the ‘Engineering Properties: Bulking of soils and rocks’ dataset (at a 1:50 000 scale) provides only a generic assessment, and isn’t intended for specific site-design purposes, however, it is intended to inform engineering geologists and ground engineers (geotechnical engineers, geo-environmental engineers, rock engineers etc.) at the ‘desk study stage’ of investigation thereby allowing for more efficient planning and execution of proceeding ground investigations.

3 What the dataset shows

3.1 CLASSIFICATION

The ‘Engineering Properties: Bulking of soils and rocks’ dataset forms part of a suite of GIS layers for different engineering parameters. The purpose of this dataset is to provide general guidance on the bulking factor of rocks and soils present within geological units up to 20 m below ground level, as defined on DiGMapGB-50.

The GIS model displays the spatial variation of bulking factor as two fields, ‘bulking factor class’ and ‘bulking factor range’.

3.1.1 Bulking factor class

The classification of bulking factors uses values from the literature (Appendix 2) to identify the characteristics of similar soils and rocks. Five classes are used as in Table 1 (Section 3.2).

The ‘bulking factor class’ uses two figures to represent the variation in bulking factors that might occur where different lithologies are present within a geological unit or the effect of partial alteration within a geological unit.

Where the lithology of the geological unit is considered to have one bulking class the classification is as in Figure 1. This may be where there is only one lithology present within the geological unit or where there are only minor beds of other materials.

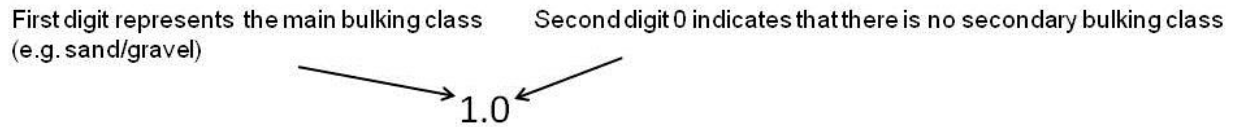


Figure 1. Bulking classification for a geological unit with one bulking class, in this case for a sand/gravel, e.g. (Pocklington Gravel Formation).

For a geological unit that has different bulking classes, the classification is as given in Figure 2. This might be where a geological unit that comprises mostly one lithology type, but has significant interbeds of another lithology that has a different bulking class.

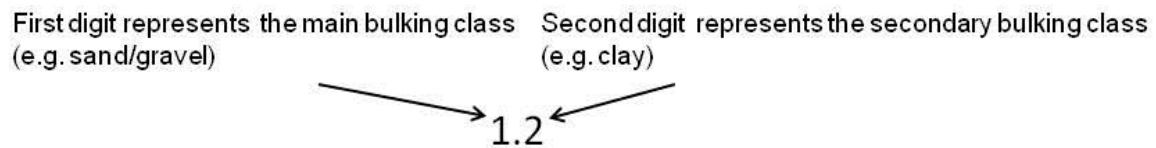


Figure 2. Bulking classification for a geological unit with two different bulking classes, for example a sand and gravel with clay or silt beds, e.g. EA-SSCL (Earnley Sand Formation).

In addition, the secondary bulking class might also describe parts of the geological unit that are altered or weathered. For example:

- Dartmoor Intrusion – the unaltered granite will be primarily class 5 but the altered material, sand and clay, is classified as 2. The classification is 5.2.
- Kidderminster Sandstone Formation – The upper metre or more of the Kidderminster Sandstone Formation is often sand (Class 1) below this it is generally extremely weak to weak sandstone (Class 4). The classification is 4.2.

3.1.2 Bulking factor range

The ‘bulking factor values’ field represents the bulking factor range or ranges expected, as indicated by the bulking factor class or classes.

Table 1. Bulking class and nominal bulking factor range with typical lithology characteristics

Class	Typical class lithology	Bulking factor (%)
1	Sand and/or gravel, very soft to soft clay or silt.	5 to 20

2	Firm (and stiffer) clay and silt, mudstones that break-up easily during excavation, peat.	20 to 40
3	Weaker rocks that are likely to break into a wide variety of particle sizes, sand to cobble or even boulder.	40 to 55
4	Medium strong rocks (and stronger) that are likely to break into a variety of blocks sizes and block shapes.	50 to 65
5	Strong (and stronger) rocks that form generally blocky material when excavated.	>65
6	Not applicable, relates to non-geological deposits e.g. water bodies.	N/A

Please note: The ‘bulking of soils and rocks’ model primarily provides information for the uppermost 2 m of the ground surface for all geological units distributed across Great Britain.

3.2 FIELD DESCRIPTORS

The data fields included in this dataset are described below. Field descriptions as they appear in the dataset are shown in Appendix 1.

General lithology (GEN_PMLITH)

This is a simplified geological description of the parent material geology and is derived from the DiGMapGB-50 BGS rock classification coding (see LEX-RCS below). In general the aim is to provide the user with a simplified, easy to use, lithological description.

Lexicon Rock Classification Scheme (LEX_RCS)

This field is the standard DiGMapGB-50 code that describes the lithostratigraphy of the geological units found in Great Britain. It provides the starting point for the parent material characterisation. It comprises a ‘stratigraphic’ code (LEX) and ‘Lithology’ code (RCS).

Bulking factor class (BULK_CLASS)

This is the class or classes of the ‘bulking factor’ and is derived from the original DiGMapGB-50 LEX-RCS coding compared with the hierarchical classification of UK rocks from the BGS RCS system. It relates to lithology type, as described in Table 1 above.

Bulking factor values (BULK_FACTR)

This field contains the bulking factor (range or ranges) expected for each LEX-RCS code, as indicated by the bulking class or classes (Table 1). The range is separated by ‘to’, and where there are two bulking classes the ranges are separated by ‘,’. They are described as primary and secondary factors.

Nominal Scale (NOM_SCALE)

This field describes the notional x-y spatial scale of the data. Most geological map data in the dataset is captured and presented at a scale of 1:50 000. The field identifies a combination of scales used to create the map from the bedrock and superficial map sources. The available scales are show as follows:

Table 2. Explanation of the nominal scales of geological map data

Field Value	Meaning
50	No superficial data is present for this sheet and bedrock data is available at 1:50 000 scale
250	No superficial data is present for this sheet and bedrock data is available at 1:250 000 scale
625_50	Superficial data is present for this sheet at a scale of 1:625 000 and Bedrock data is available at a scale of 1:50 000
50_50	Superficial data is present for this sheet at a scale of 1:50 000 and Bedrock data is available at a scale of 1:50000
35_50	Superficial data is present for this sheet at a scale of 1:35 000 and Bedrock data is available at a scale of 1:50 000
35_250	Superficial data is present for this sheet at a scale of 1:35 000 and Bedrock data is available at a scale of 1:250 000

4 How the dataset was created

In the absence of primary bulking factor data from site investigations, bulking factor values were sourced from literature from a variety of sources (Appendix 2). These included values from the United States of America (Church et al., 1981, Hartman, 1992), the UK (Horner, 1988) and web resources such as the Engineering Tool Box, Durham University and Mal January's site (january.id.au).

The DiGMapPlus datasets follow a standard workflow to create each dataset:

- Step 1: Identify characteristic, measurements and observations from archive records and literature.
- Step 2: Categorise the observations into classes/groups of similar behaviours. Where possible using published standards of classification such as BS 5930, Eurocode 7 or other similar international or national standard.
- Step 3: Assess the range of lithostratigraphic variation of geological materials across Great Britain, in terms of the categories and classes identified in step 2 to create a 'lookup' dataset of expected attributes (material characteristics and behaviours) per lithostratigraphic unit.
- Step 4: Compile the spatial (map) components of the DiGMapPlus datasets with the 'lookup' dataset using standard GIS and data techniques to create a new 'map' of bulking factor.

Categorization of the data, and assessment of the bulking factor values of rocks and soils within the UK, has been made by expert judgement in order to create 'look up tables' of lithostratigraphic rock type and associated engineering properties. Assignments of characteristics and descriptors has been made at the 'formation' level of lithostratigraphic classification.

Spatial data-creation and bulking attribution has been completed using ESRI ARCGIS software.

5 Technical information

5.1 SCALE

The ‘Engineering Properties: Bulking of soils and rocks’ dataset is produced for use at 1:50000 scale providing 50 m ground resolution.

The data are released in ESRI shapefile formats. Other formats such as MapInfo TAB are available on request. The standard data supplied to customers has polygons or areas in a single layer or theme.

5.2 COVERAGE

Data is provided to indicate the likely bulking factor of rocks and soils across Great Britain. The scales of map data available to create this dataset are shown in Appendix 4.

5.3 DATA HISTORY

Version 1 (released 2015): Derived from DiGMapGB-50 version 6.

5.4 LIMITATIONS

- The ‘Engineering Properties: Bulking of soils and rocks’ dataset has been developed to provide general guidance on the bulking volume of soils and rocks within geological units up to 2 m below ground level, as defined on DiGMapGB-50.
- The ‘Engineering Properties: Bulking of soils and rocks’ dataset has been developed at 1:50 000 scale and must not be used at larger scales. All spatial searches against the data should be done with a minimum 50 m buffer
- The ‘Engineering Properties: Bulking of soils and rocks’ dataset has been developed for units included in DigMap50 primarily at formation scale, as such it does not detail all intra-formational variation.
- The spatial distribution of the data is limited by the distribution of the site investigation exploratory holes from which the geotechnical data have been extracted and the distribution of available information from sheet memoirs, reports, images and digital geological map data (DiGMapGB-50) (Appendix 3 & Appendix 4). Although the National Geotechnical Properties Database is the ‘first port of call’ for data it has limited coverage so other descriptive data from exploratory logs or from Site Investigation Reports has been used.
- Local conditions might vary and this dataset should not replace detailed site investigations. Further detail of the geology might be available on more detailed 1:10,000 scale geological maps.
- The spatial distribution of the data is limited by the spatial accuracy and resolution of the digital geological map data (DiGMapGB-50) (Appendix 4). Spatial mismatches of bulking factor related to mismatches in lithology type (i.e. variation in LEX_RCS across map-sheet boundaries) are related to the primary digital geological map data. Further detail of the geology might be available on 1:10,000 scale geological maps which might provide more detail.
- ‘Engineering Properties: Bulking of soils and rocks’ data are created as vector polygons and are available in a range of GIS formats, including ArcGIS (.shp), ArcInfo Coverages and MapInfo (.tab). More specialised formats might be available but might incur additional processing costs.
- The ‘Engineering Properties: Bulking of soils and rocks’ dataset is concerned with the properties of NATURAL geological deposits and conditions only. It does NOT cover any man-made constructions or materials.

- The ‘Engineering Properties: Bulking of soils and rocks’ dataset is based on, and limited to, an interpretation of the records in the possession of The British Geological Survey at the time the dataset was created.
- An indication of the typical bulking factor of rock or soil does not necessarily mean that the rock properties are consistent throughout the outcrop. Such an assessment can only be made by inspection of the area by a qualified professional.

6 Contact information

For all data and licensing enquiries please contact:

Central Enquiries

British Geological Survey

Kingsley Dunham Centre

Keyworth

Nottingham

NG12 5GG

Direct tel: +44(0)115 936 3143

Fax: +44(0)115 9363150

Email: enquiries@bgs.ac.uk

Appendix 1 Engineering Properties: Field Properties

Field name	Field description	Description
GEN_PMLITH TEXT	Generalised lithology description	This is a simplified geological description of the parent material and is derived from the original DiGMapGB-50 LEX-RCS coding compared with the hierarchical classification of UK rocks from the BGS RCS system. In general the aim is to provide the user with as simplified a lithological description as possible.
LEX_RCS TEXT	BGS Lexicon-rock classification scheme	This field is the standard DiGMapGB-50 code that describes the geological units found in Great Britain. It provides the starting point for the parent material characterisation. It comprises a 'stratigraphic' code (LEX) and 'Lithology' code RCS).
BULK_CLASS	Bulking factor classification	This field describes the class or classes of the 'bulking factor' and relates directly to a 'bulking factor' range.
BULK_FACTR	Bulking factor range	This field describes the range or ranges in 'bulking factor' expected, as indicated by the 'bulking factor' class.
NOM_SCALE TEXT	Nominal Scale	This field describes the notional x-y spatial scale of the data. Most geological map data in the dataset is captured and presented at a scale of 1:50,000. The field identifies a combination of scales used to create the map from the bedrock and superficial map sources.
UID	Unique identifier	Map metadata (identifies each spatial object uniquely)
VERSION	Version of the dataset	Map metadata (identifies dataset uniquely)

Appendix 2 Bulking values from the literature

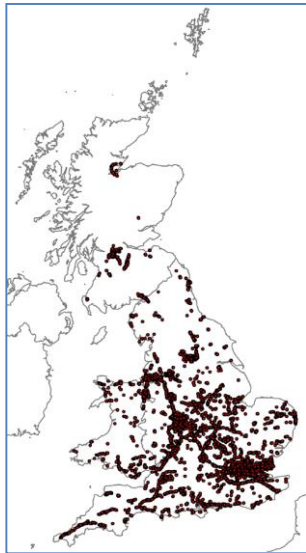
Rock class	Lithology	Initial bulk density Mg/m ³	Bulking factor %	Reference
Igneous rock	Andesite	2.94	67	Church (1981)
	Tuff	2.40	50	Church (1981)
	Basalt	2.94	64	Church (1981)
	Basalt	2.4 to 3.1	75 to 80	Engineering tool box
	Basalt	2.95	64	Durham University
	Diabase	3.00	67	Church (1981)
	Diorite	3.1	67	Church (1981)
	Felsite	2.5	67	Church (1981)
	Gabbro	3.1	67	Church (1981)
	Granite	2.675	50 to 86	Hartman (1992)
	Granite and porphyry	2.72	75	Hartman (1992)
	Granite	2.6 to 2.8	75 to 80	Engineering tool box
	Granite	2.41	72	Durham University
	Rhyolite	2.40	67	Church (1981)
	Igneous		50 to 80	Horner, 1988
Metamorphic rocks	Gneiss	2.70	67	Church (1981)
	Gneiss	2.69	75	Hartman (1992)
	Gneiss	2.69	75 to 80	Engineering tool box
	Marble	2.68	67	Church (1981)
	Marble	2.72	68 to 75	Hartman (1992)
	Quartzite	2.68	67	Church (1981)
	Schist	2.69	67	Church (1981)
	Slate	2.67	77	Church (1981)
	Slate	2.72 to 2.88	29 to 30	Hartman (1992)
	Slate	2.6 to 3.3	85 to 90	Engineering tool box
	Metamorphic		30 to 65	Horner, 1988
Sedimentary rock	Breccia	2.4	33	Church (1981)
	Conglomerate	2.21	33	Church (1981)
	Sandstone	2.31 to 2.45	39 to 50	Hartman (1992)
	Sandstone	2.42	61	Church (1981)
	Sandstone	2.1 to 2.4	75 to 80	Engineering tool box
	Sandstone	2.5	60	Durham University
	Sandstone	2.65	61	Durham University
	Shale	2.64	50	Church (1981)
	Shale	2.35	50	Durham University
	Siltstone	2.42	61	Church (1981)
	Limestone	2.60	63	Church (1981)
	Limestone (blasted)	2.5	68 to 75	Hartman (1992)
	Limestone	2.7 to 2.8	75 to 80	Engineering tool box
	Limestone	2.6	63	Durham University
	Dolomite	2.8	50 to 60	Engineering tool box
	Dolomite	2.88	67	Church (1981)
	Chalk	1.85	50	Durham University
	Chalk	2.2	30 to 45	January.id.au
	Chalk	2.41	33	Church (1981)
	Chalk		30 to 40	Horner, 1988
	Sedimentary		40 to 75	Horner, 1988
Soil	Clay	1.75	33	Hartman (1992)
	Clay	1.778	34	Hartman (1992)
	Clay	1.75 to 1.78	30 to 40	Engineering tool box
	Clay dry	1.362	25	Hartman (1992)
	Clay damp	1.99	40	Church (1981)
	Clay	1.8 to 2.6	20 to 40	Engineering tool box
	Clay	1.6 to 2.1	20 to 40	Engineering tool box
	Clay (low PI)	1.65	30	Durham University
	Clay (high PI)	2.1	40	Durham University
	Clay and gravel dry	1.602	41	Hartman (1992)
	Clay and gravel wet	1.826	41	Hartman (1992)
	Clay with gravel	1.8	35	Durham University

	Clay and silt (fine)		20 to 40	Horner, 1988
	Silt (loam) dry	1.80	35	Church (1981)
	Silt (loam) damp	2	40	Church (1981)
	Mud	1.28 to 1.76	21	Hartman (1992)
	Mud	1.76 to 2.08	20 to 21	Hartman (1992)
	Mud	1.745	0	Church (1981)
	Loess, dry	1.911	35	Church (1981)
	Loess, moist	1.99	40	Church (1981)
	Silt (loam)		15 to 25	Engineering tool box
	Sand dry	1.30	10 to 16	Hartman (1992)
	Sand moist	2.018	15	Hartman (1992)
	Sand	2.00	5	Durham University
	Sand, wet	2.0	20 to 30	Engineering tool box
	Sand, dry	1.8	20 to 30	Engineering tool box
	Uniform sand	1.6 to 2.1	10 to 15	
	Well-graded sand	1.7 to 2.2	10 to 15	
	Sand and gravel dry	1.97	14	Hartman (1992)
	Sand and gravel, wet	2.31	15	Hartman (1992)
	Sand and gravel	1.95	15	Durham University
	Sand or gravel (coarse)		10 to 15	Horner, 1988
	Gravel	1.7 to 2.3	10 to 15	Engineering tool box
	Gravel Dry	1.79	15	Church (1981)
	Gravel, dry	1.46 to 1.92	12	Hartman (1992)
	Gravel wet	2.01	5	Church (1981)
	Gravel wet	2.31	10	Hartman (1992)
	Gravel	2.1	5	Durham University
	Peat/topsoil	1.1 to 1.4	25 to 45	Horner, 1988

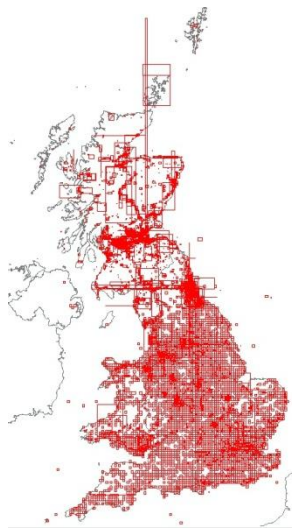
Appendix 3 Distribution of data

Data held in the (a) National Geotechnical Properties Database, (b) Site Investigation Records, (c) Geoscience Imagebase, (d) sheet memoirs, (e) borehole scans

(a)



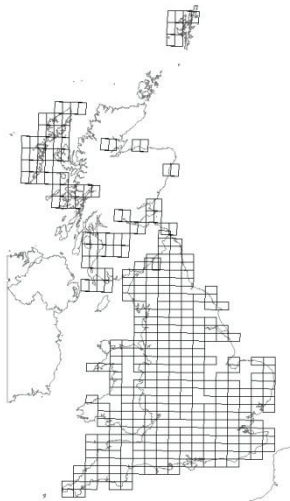
(b)



(c)



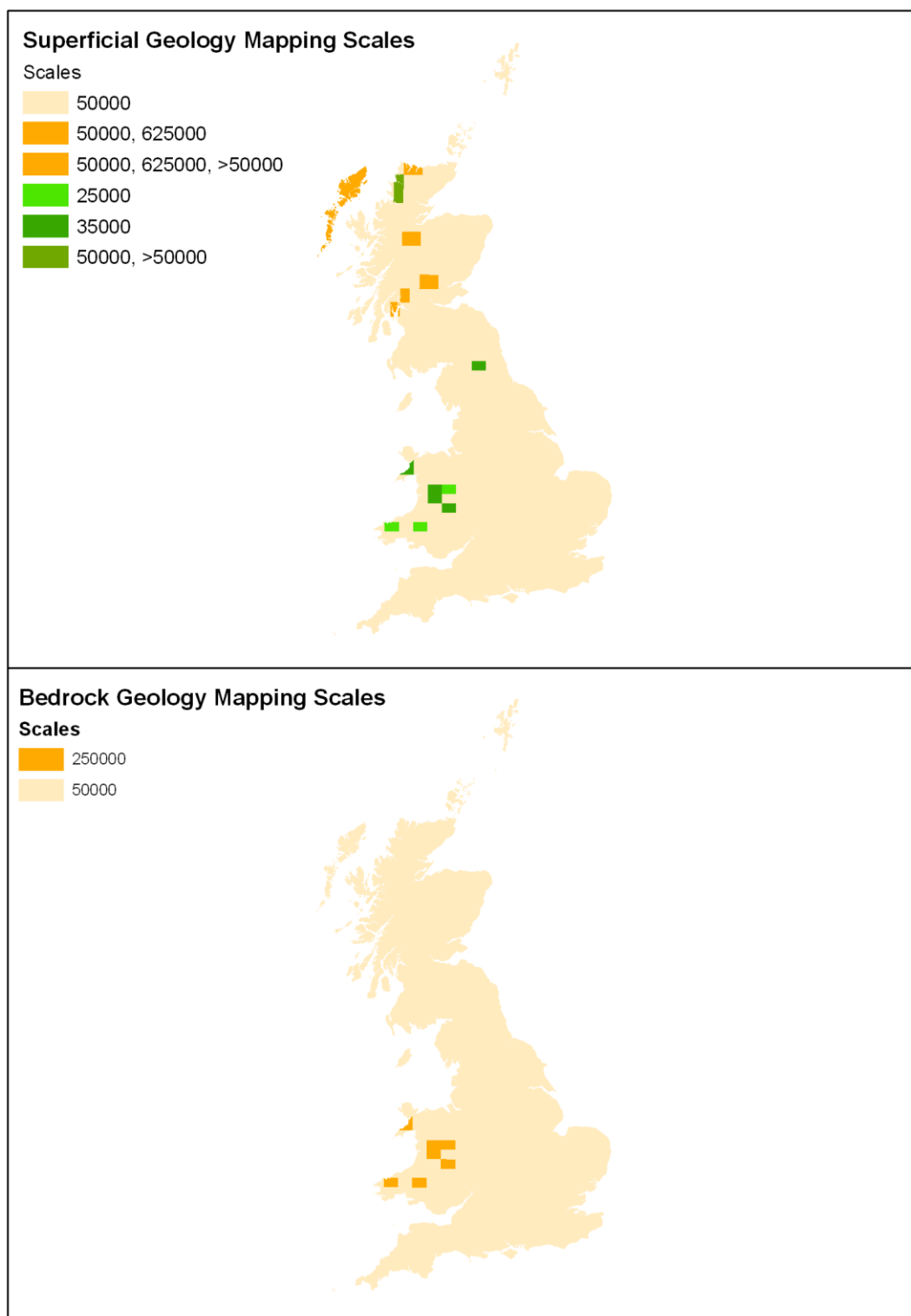
(d)



(e)



Appendix 4 Mapping Scales



References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: <http://geolib.bgs.ac.uk>.

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