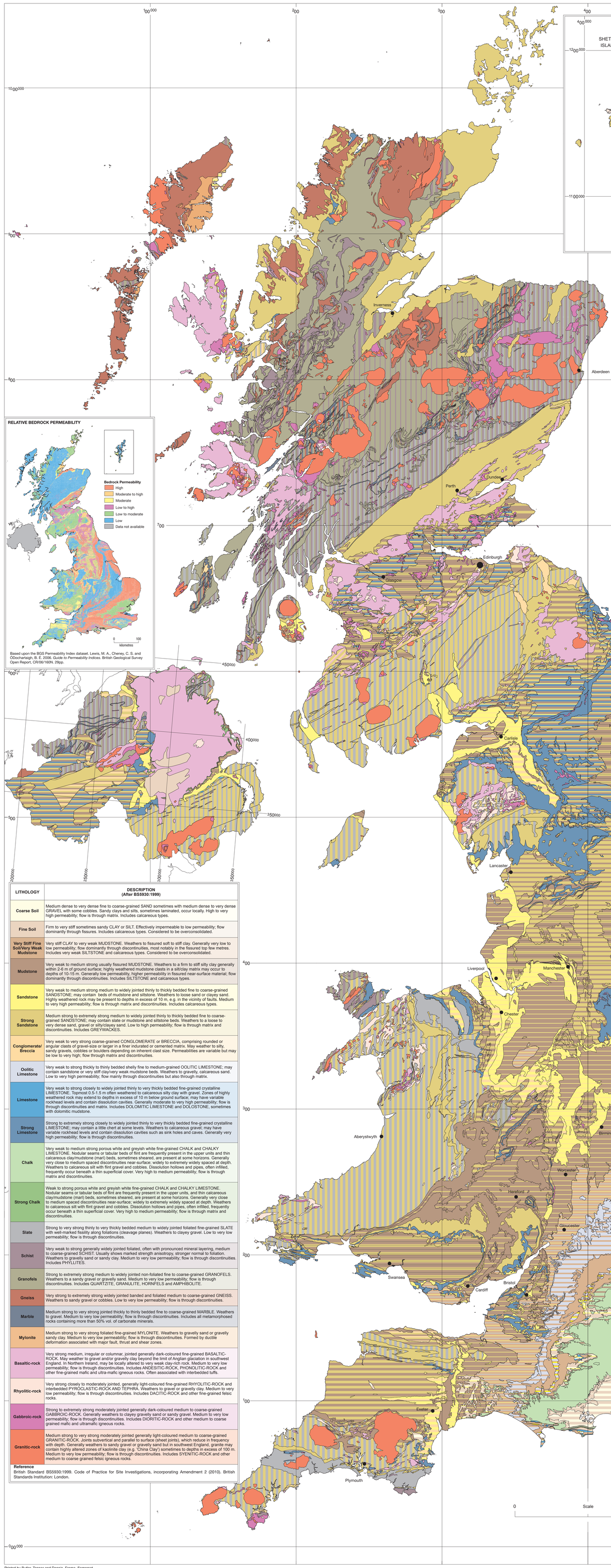
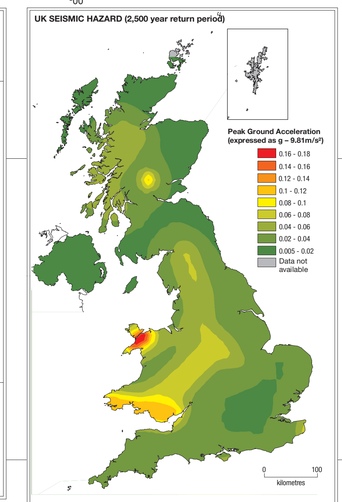


RELATIVE BEDROCK PERMEABILITY

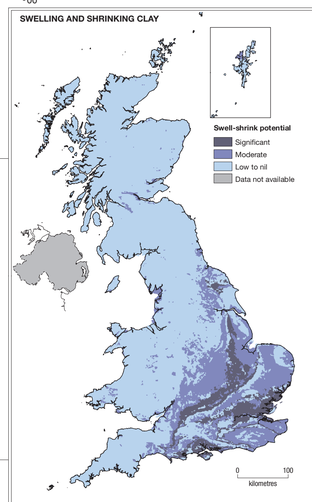
Based upon the BGS Permeability Index dataset. Lewis, M. A., Cheney, C. S. and ODochartaigh, B. E. 2006. *Guide to Permeability Indices*. British Geological Survey Open Report, CR/06/160N. 29pp.

UK SEISMIC HAZARD (2,500 year return period)



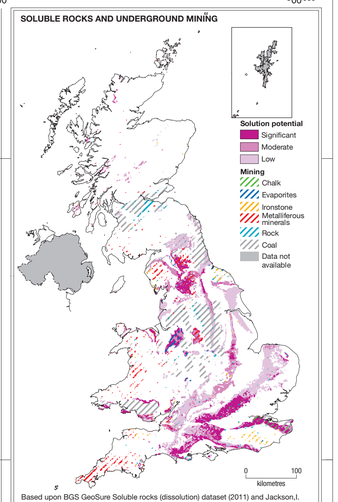
From Musson, R.M.W. and Sargeant, S.L. 2007. *Eurocode 8 seismic hazard zoning maps for the UK*, British Geological Survey Technical Report, CR/07/125. 70pp.

SWELLING AND SHRINKING CLAY



Based upon BGS GeoSure Shrink-Swell dataset (2011). Further information can be found on the GeoSure webpages: http://www.bgs.ac.uk/products/geosure/home.html

SOLUBLE ROCKS AND UNDERGROUND MINING



Based upon BGS GeoSure Soluble rocks (dissolution) dataset (2011) and Jackson,I. (editor). 2004. *Britain beneath our feet*. (Keyworth, Nottingham: British Geological Survey Occasional Publication No. 4.) Further information can be found on the GeoSure webpages: http://www.bgs.ac.uk/products/geosure/home.html

SEISMICITY

Seismicity is the magnitude, intensity, frequency and distribution of earthquake activity in an area. Globally, most earthquakes are caused at the boundaries of moving tectonic plates. However, they can also be caused by smaller scale fault movements away from plate boundaries, by volcanic activity, by major landslides and by human activity such as mining, disposal of fluids in the ground, infilling of reservoirs and underground nuclear testing. Earthquakes can occur at depths ranging from one to hundreds of kilometres.

Seismic hazard is the probability of a given magnitude earthquake occurring in a specified area in a given period of time. Structural engineers need to know the level of seismic hazard to enable them to design more resistant buildings.

Earthquakes can also trigger other secondary hazards. For example, ground motions are amplified when seismic waves slow down as they move through softer and weaker materials (particularly Quaternary sediments) nearer the ground surface. Earthquakes can also trigger landslides and tsunamis and cause liquefaction of water-saturated sandy soils.

In the UK, earthquake magnitudes are usually relatively small (less than 6 on the Richter magnitude scale). However, information is required for the design of sensitive structures such as nuclear power stations.

WEATHERING

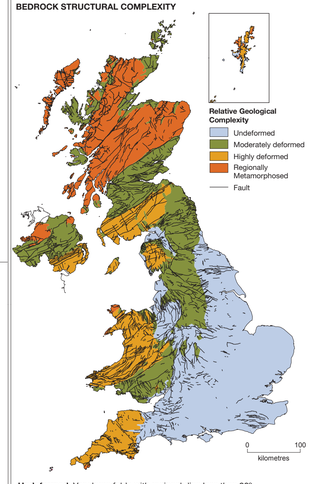
Weathering is a process of alteration and breakdown of rock and soil materials at, and near, the Earth's surface by chemical decomposition and physical disintegration. Biological processes have a significant effect on chemical conditions increasing the rate of weathering. The style of weathering and the nature of the weathering products are strongly influenced by climate (mainly rainfall and mean temperature) and lithology. Physical and chemical weathering commonly act together, the progress of chemical weathering usually relying on discontinuities opened, or formed, partly as a result of physical weathering. Similarly, discontinuities may develop in response to changes in volume and weakening induced by chemical weathering (Anon. 1995).

Various rock weathering engineering classifications are available depending upon the nature of the rock mass (for example, uniform materials, heterogeneous masses). These are described in detail in the British Standard for site investigations (British Standard BS5930:1999).

References

Anon. 1995. Geological Society Engineering Group Working Party Report: The description and classification of weathered rock for engineering purposes. Quarterly Journal of Engineering Geology, 28, 207-242.
British Standard BS5930:1999. Code of Practice for Site Investigations, incorporating Amendment 2 (2010). British Standards Institution: London.

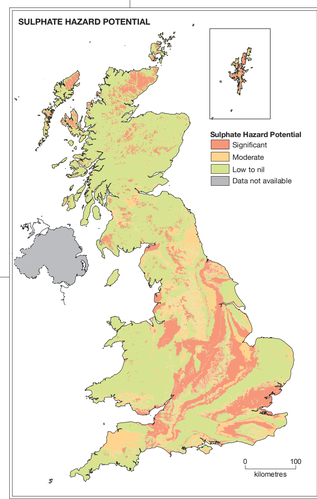
BEDROCK STRUCTURAL COMPLEXITY



Undeformed: Very large folds with regional dips less than 20°.
Moderately Deformed: Large scale folds with wavelengths measured in kilometres, bedding may dip at more than 20°. Numerous faults do not affect continuity.
Highly Deformed: Folds small scale, amplitudes less than 30 metres. May be intruded by granites.
Regionally Metamorphosed: Often intensely folded on both large and small scales. There may be more than one cleavage, intruded by granites.

After Dearman, W.R. 1991. Engineering Geological Mapping. Butterworth-Heinemann Ltd. Oxford, UK. Reproduced with permission. Copyright Reed Elsevier plc.

SULPHATE HAZARD POTENTIAL



SULPHATE HAZARD

The deleterious effect of aqueous sulphate on buried concrete structures has been recognised in the UK since the mid 20th Century. In addition, ground heave associated with sulphate attack, has also become widely recognised. The principal form of sulphate attack occurs when sulphates react with calcium hydroxide and calcium aluminate hydrate to form gypsum and ettringite. The formation of Thaumasite may also occur at low temperatures (5 - 15°C) in the presence of high pH water and free carbonate ions. Thaumasite formation is accompanied by large increases in volume and massive reduction in strength (BRE. 2005).

Sulphates occur naturally within the ground and groundwater, but can also be introduced from man-made sources. The primary sources of sulphate are sulphate minerals (e.g. anhydrite, epsomite and gypsum) and sulphide minerals (e.g. galena, marcasite and pyrite) which oxidise to form sulphates. The natural concentration of these minerals varies greatly between different geological deposits and may also vary within a single deposit due to leaching and/or the concentration of sulphate and sulphide minerals in specific beds. Furthermore, relatively permeable formations which are not primary sources of these minerals may contain groundwater with high sulphate concentrations due to their proximity with sulphate and sulphide rich deposits.

The design and specification of earthworks and concrete for buried structures requires comprehensive assessment of both ground and groundwater conditions. This should include not just the testing of the total sulphate, but also, where appropriate: the total potential sulphate (i.e. concentrations of sulphide and sulphur); concentrations of other potentially aggressive compounds; and swelling tests. The rigour of the sampling and testing regime should be appropriate to the potential hazard posed by the deposits under investigation and the vulnerability of the construction works.

Reference

Building Research Establishment. 2005. *Concrete in aggressive ground*. BRE Special Digest 1, third edition. BRE, Watford.

DISCONTINUITIES – JOINTS, SHEAR SURFACES AND FAULTS

Discontinuities are mechanical breaks, fractures or planes of weakness of negligible tensile strength in a rock mass.
Joints are discontinuities showing little or no shear displacement, usually formed by stress relief processes such as cooling after the emplacement of igneous rocks, weathering/erosion or tectonic forces. They may be open, closed or infilled and often occur in sub-parallel groups or sets.
Shear surfaces (or *planes*) are surfaces along which differential movement has taken place, evidence for which may be shown by the presence of 'polished' and striated surfaces ('slickensides'), which indicate the direction of movement. Shear surfaces include fault planes and shear (slip) surfaces resulting from slope movements (landslides). Pervasive small-scale, convex-concave shear surfaces, probably resulting from expansion/contraction during pedogenesis, are found near the surface in clay/mudstone strata. Movements along them are generally restricted to only a few tens of millimetres. However, they create planes of weakness that may be followed by later larger movements arising from landsliding or faulting.
Faults are planes about which adjacent blocks of rock strata have moved relative to each other. They are commonly complex, sheared zones rather than discrete planes. Therefore, the portrayal of such faults as a single line on a geological map is a generalisation. Faults zones of weak broken rock may promote deeper weathering and provide preferential pathways for water, leachates and even gases. If filled with clay gouge they may create barriers to groundwater flow. Faults pose particular problems if penetrated by tunnels or mineworkings. Foundations built across a faulted contact between lithologies of contrasting characteristics may be prone to differential movement unless accounted for in engineering design.

LITHOLOGY	DESCRIPTION (After BS5930:1999)
Coarse Soil	Medium dense to very dense fine to coarse-grained SAND sometimes with medium dense to very dense GRAVEL with some cobbles. Sandy clays and silts, sometimes laminated, occur locally. High to very high permeability; flow is through matrix. Includes calcareous types.
Fine Soil	Firm to very stiff sometimes sandy CLAY or SILT. Effectively impermeable to low permeability; flow dominantly through fissures. Includes calcareous types. Considered to be overconsolidated.
Very Stiff Fine Soil/Very Weak Mudstone	Very stiff CLAY to very weak MUDSTONE. Weathers to fissured soft to stiff clay. Generally very low to low permeability; flow dominantly through discontinuities, most notably in the fissured top few metres. Includes very weak SILTSTONE and calcareous types. Considered to be overconsolidated.
Mudstone	Very weak to medium strong usually fissured MUDSTONE. Weathers to a firm to stiff silty clay generally within 2-6 m of ground surface; highly weathered mudstone clasts in a silt/clay matrix may occur to depths of 10-15 m. Generally low permeability, higher permeability in fissured near-surface material; flow dominantly through discontinuities. Includes SILTSTONE and calcareous types.
Sandstone	Very weak to medium strong medium to widely jointed thinly to thickly bedded fine to coarse-grained SANDSTONE; may contain beds of mudstone and siltstone. Weathers to loose sand or clayey sand. Highly weathered rock may be present to depths in excess of 10 m, e.g. in the vicinity of faults. Medium to very high permeability; flow is through matrix and discontinuities. Includes calcareous types.
Strong Sandstone	Medium strong to extremely strong medium to widely jointed thinly to thickly bedded fine to coarse-grained SANDSTONE; may contain slate or mudstone and siltstone beds. Weathers to a loose to very dense sand, gravel or silty/clayey sand. Low to high permeability; flow is through matrix and discontinuities. Includes GREYWACKES.
Conglomerate/ Breccia	Very weak to very strong coarse-grained CONGLOMERATE or BRECCIA, comprising rounded or angular clasts of gravel-size or larger in a finer indurated or cemented matrix. May weather to silty, sandy gravels, cobbles or boulders depending on inherent clast size. Permeabilities are variable but may be low to very high; flow through matrix and discontinuities.
Oolitic Limestone	Very weak to strong thickly to thinly bedded shelly fine to medium-grained OOLITIC LIMESTONE; may contain sandstone or very stiff clay/very weak mudstone beds. Weathers to gravelly, calcareous sand. Low to very high permeability; flow mainly through discontinuities but also through matrix.
Limestone	Very weak to strong closely to widely jointed thinly to very thickly bedded fine-grained crystalline LIMESTONE. Topmost 0.5-1.5 m often weathered to calcareous silty clay with gravel. Zones of highly weathered rock may extend to depths in excess of 10 m below ground surface; may have variable rockhead levels and contain dissolution cavities. Generally moderate to very high permeability; flow is through discontinuities and matrix. Includes DOLOMITIC LIMESTONE and DOLOSTONE, sometimes with dolomitic mudstone.
Strong Limestone	Strong to extremely strong closely to widely jointed thinly to very thickly bedded fine-grained crystalline LIMESTONE; may contain a little chert at some levels. Weathers to calcareous gravel; may have variable rockhead levels and contain dissolution cavities such as sink holes and caves. Generally very high permeability; flow is through discontinuities.
Chalk	Very weak to medium strong porous white and greyish white fine-grained CHALK and CHALKY LIMESTONE. Nodular seams or tabular beds of flint are frequently present in the upper units and thin calcareous clay/mudstone (marl) beds, sometimes sheared, are present at some horizons. Generally very close to medium spaced discontinuities near-surface; widely to extremely widely spaced at depth. Weathers to calcareous silt with flint gravel and cobbles. Dissolution hollows and pipes, often infilled, frequently occur beneath a thin superficial cover. Very high to medium permeability; flow is through matrix and discontinuities.
Strong Chalk	Weak to strong porous white and greyish white fine-grained CHALK and CHALKY LIMESTONE. Nodular seams or tabular beds of flint are frequently present in the upper units, and thin calcareous clay/mudstone (marl) beds, sometimes sheared, are present at some horizons. Generally very close to medium spaced discontinuities near-surface; widely to extremely widely spaced at depth. Weathers to calcareous silt with flint gravel and cobbles. Dissolution hollows and pipes, often infilled, frequently occur beneath a thin superficial cover. Very high to medium permeability; flow is through matrix and discontinuities.
Slate	Strong to very strong thinly to very thickly bedded medium to widely jointed foliated fine-grained SLATE with well-marked fissility along foliations (cleavage planes). Weathers to clayey gravel. Low to very low permeability; flow is through discontinuities.
Schist	Very weak to strong generally widely jointed foliated, often with pronounced mineral layering, medium to coarse-grained SCHIST. Usually shows marked strength anisotropy, stronger normal to foliation. Weathers to gravelly sand or sandy clay. Medium to very low permeability; flow is through discontinuities. Includes PHYLLITES.
Granofels	Strong to extremely strong medium to widely jointed non-foliated fine to coarse-grained GRANOFELS. Weathers to a sandy gravel or gravelly sand. Medium to very low permeability; flow is through discontinuities. Includes QUARTZITE, GRANULITE, HORNFELS and AMPHIBOLITE.
Gneiss	Very strong to extremely strong widely jointed banded and foliated medium to coarse-grained GNEISS. Weathers to sandy gravel or cobbles. Low to very low permeability; flow is through discontinuities.
Marble	Medium strong to very strong jointed thickly to thinly bedded fine to coarse-grained MARBLE. Weathers to gravel. Medium to very low permeability; flow is through discontinuities. Includes all metamorphosed rocks containing more than 50% vol. of carbonate minerals.
Mylonite	Medium strong to very strong foliated fine-grained MYLONITE. Weathers to gravelly sand or gravelly sandy clay. Medium to very low permeability; flow is through discontinuities. Formed by ductile deformation associated with major fault, thrust and shear zones.
Basaltic-rock	Very strong medium, irregular or columnar, jointed generally dark-coloured fine-grained BASALTIC-ROCK. May weather to gravel and/or gravelly clay beyond the limit of Anglian glaciation in southwest England. In Northern Ireland, may be locally altered to very weak clay-rich rock. Medium to very low permeability; flow is through discontinuities. Includes ANDESITIC-ROCK, PHONOLITIC-ROCK and other fine-grained mafic and ultra-mafic igneous rocks. Often associated with interbedded tuffs.
Rhyolitic-rock	Very strong closely to moderately jointed, generally light-coloured fine-grained RHYOLITIC-ROCK and interbedded PYROCLASTIC-ROCK AND TEPHRA. Weathers to gravel or gravelly clay. Medium to very low permeability; flow is through discontinuities. Includes DACITIC-ROCK and other fine-grained felsic rocks.
Gabbroic-rock	Strong to extremely strong moderately jointed generally dark-coloured medium to coarse-grained GABBROIC-ROCK. Generally weathers to clayey gravelly sand or sandy gravel. Medium to very low permeability; flow is through discontinuities. Includes DIORITIC-ROCK and other medium to coarse grained mafic and ultramafic igneous rocks.
Granitic-rock	Medium strong to very strong moderately jointed generally light-coloured medium to coarse-grained GRANITIC-ROCK. Joints subvertical and parallel to surface (sheet joints), which reduce in frequency with depth. Generally weathers to sandy gravel or gravelly sand but in southwest England, granite may contain highly altered zones of kaolinite clay (e.g. 'China Clay') sometimes to depths in excess of 100 m. Medium to very low permeability; flow is through discontinuities. Includes SYENITIC-ROCK and other medium to coarse grained felsic igneous rocks.

Reference

British Standard BS5930:1999. Code of Practice for Site Investigations, incorporating Amendment 2 (2010). British Standards Institution: London.

KEY

- Fine Soil
- Fine Soil and Coarse Soil 8:1
- Fine Soil and Sandstone 1:1
- Fine Soil, Coarse Soil and Sandstone 4:1:1
- Coarse Soil
- Coarse Soil and Fine Soil 1:1
- Very Weak Mudstone/Very Stiff Clay
- Very Weak Mudstone/Very Stiff Clay, Sandstone and Oolitic Limestone 8:1:1
- Mudstone
- Mudstone and Sandstone 8:1
- Mudstone and Strong Sandstone 1:1
- Mudstone and Strong Sandstone 2:1
- Mudstone and Strong Sandstone 4:1
- Mudstone and Strong Sandstone (Coal Bearing) 1:1
- Mudstone and Strong Sandstone (Coal Bearing) 2:1
- Sandstone
- Sandstone and Coarse Soil 4:1
- Sandstone and Very Weak Mudstone/Very Stiff Clay 1:1
- Sandstone and Conglomerate/Breccia 8:1
- Sandstone and Limestone 2:1
- Sandstone, Very Weak Mudstone/Very Stiff Clay and Oolitic Limestone 2:2:1
- Strong Sandstone
- Strong Sandstone and Mudstone 2:1
- Strong Sandstone and Slate 1:1
- Strong Sandstone and Slate 2:1
- Strong Sandstone, Strong Limestone and Mudstone 2:1:1
- Conglomerate/Breccia
- Conglomerate/Breccia and Sandstone 1:1
- Conglomerate/Breccia and Strong Sandstone 1:1
- Conglomerate/Breccia, Sandstone and Mudstone 1:1:1
- Conglomerate/Breccia, Strong Sandstone and Mudstone 1:1:1
- Conglomerate/Breccia, Strong Sandstone and Mudstone 2:2:1
- Conglomerate/Breccia, Strong Sandstone and Slate 1:1:1
- Oolitic Limestone
- Oolitic Limestone and Sandstone 1:1
- Oolitic Limestone and Very Weak Mudstone/Very Stiff Clay 2:1
- Oolitic Limestone, Sandstone and Very Weak Mudstone/Very Stiff Clay 2:1:1
- Limestone
- Limestone and Very Weak Mudstone/Very Stiff Clay 1:1
- Limestone, Coarse Soil and Sandstone 2:1:1
- Strong Limestone
- Strong Limestone, Mudstone and Strong Sandstone 2:2:1
- Strong Limestone, Strong Sandstone and Mudstone 1:1:1
- Strong Sandstone, Conglomerate/Breccia and Basaltic-rock 2:1:1
- Chalk
- Chalk and Mudstone 2:1
- Strong Chalk
- Strong Chalk and Mudstone 2:1
- Slate
- Slate and Strong Sandstone 4:1
- Slate and Schist 1:1
- Slate and Basaltic-rock 1:1
- Slate, Granofels and Schist 1:1:1
- Slate, Granofels, Schist and Gneiss 1:1:1:1
- Schist
- Granofels
- Granofels and Slate 1:1
- Granofels and Schist 1:1
- Granofels and Schist 4:1
- Granofels, Gneiss and Marble 1:1:1
- Gneiss
- Mylonite
- Marble
- Granitic-rock
- Rhyolitic-rock
- Gabbroic-rock
- Basaltic-rock

Note: To better represent the geology, a system of stripes has been used to show where more than one lithology may be present and with what relative proportion. The stripes have also been angled horizontally, acutely and vertically to differentiate between rocks with a sedimentary, igneous and metamorphic origin respectively.
Data for Northern Ireland, the Isle of Man and the Shetland Islands has been provided where available.

INTRODUCTION TO THE MAP

Engineering geology is a broad discipline within geology that is defined by the International Association for Engineering Geology and the Environment (IAEG) as: "... the science devoted to the investigation, study and solution of the engineering and environmental problems which may arise as the result of the interaction between geology and the works and activities of man as well as to the prediction of and the development of measures for prevention or remediation of geological hazards." Engineering geology is important, therefore, in the maintenance of public health, safety and welfare during development and redevelopment of the earth's surface and shallow subsurface, in safeguarding the geological aspects of the environment and in delivering economic benefit.

Two engineering geological maps of the UK have been produced at a scale of 1:1 million. One map shows the engineering geological characteristics of the bedrock, that is, those soils and rocks that were in place before the Quaternary Period. The second map shows the engineering geological characteristics of the superficial deposits emplaced during approximately the last 2 million years in the Quaternary Period. The reason for this separation is that Quaternary materials cover about 60% of the UK's surface and hence mask large parts of the earlier geology. However, they are often relatively thin (less than 10 m) so the bedrock is frequently intersected during building and construction.

These maps should not be used for site specific purposes, their intention is to provide an introduction to the engineering geology of the UK by presenting a broad overview of how engineering geological conditions change across the country. They provide the first stage to understanding the consequences of the interaction between human development, the ground and the natural processes acting upon it. For further information regarding engineering geological hazards, GeoSure products and other BGS datasets visit the BGS website http://www.bgs.ac.uk/ or contact BGS Enquiries enquiries@bgs.ac.uk.

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

1:1 000 000 SERIES

ENGINEERING GEOLOGY (BEDROCK) MAP OF THE UNITED KINGDOM

Compiled by William R Dearman, Marcus R Dobbs, Martin G Culshaw, Kevin J Northmore, David C Entwisle and Helen J Reeves.

Published 2011. John N Ludden, PhD, Director, British Geological Survey.

Engineering geological mapping units based on British Geological Survey 1:625 000 Geological Map of the United Kingdom (North and South sheets).

Bibliographic reference:
BRITISH GEOLOGICAL SURVEY 2011. Engineering Geology (Bedrock) Map of the United Kingdom. WILLIAM R DEARMAN, MARCUS R DOBBS, MARTIN G CULSHAW, KEVIN J NORTHMORE, DAVID C ENTWISLE and HELEN J REEVES (compilers). British Geological Survey.

Published 2011. British Geological Survey, Natural Environment Research Council.

Data preparation by Antony H Myers.
Digital cartography by Caron Simpson, BGS, Keyworth.

Printed by Butler, Tanner and Dennis, Frome, Somerset