British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey scheme for classifying discontinuities and fillings

Research Report RR/10/05

BRITISH GEOLOGICAL SURVEY

REPORT REPORT RR/10/05

British Geological Survey scheme for classifying discontinuities and fillings

M R Gillespie, R P Barnes and A E Milodowski

Keywords

BGS, British Geological Survey, classification, discontinuity, filling, fracture, fault, joint, unconformity, fault-rock, vein

Bibliographical reference

Gillespie, M R, Barnes, R P and Milodowski, A E. 2011. British Geological Survey scheme for classifying discontinuities and fillings. *British Geological Survey Research Report*, RR/10/05. 56pp.

ISBN 978 85272 674 7

Keyworth, Nottingham British Geological Survey 2011

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk
Tel 0115 936 3143 Fax 0115 936 3276
email enquires@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

BGS London, 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

Acknowledgements

The authors would like to thank the following people for providing constructive reviews that significantly improved the final document: Maxine Akhurst, Diarmad Campbell, Graham Leslie, Tim Pharaoh, Nick Robins, Richard Shaw, Mike Styles and Colin Waters (all BGS); Professor Quentin Fisher (Centre for Integrated Petroleum Engineering and Geosciences, University of Leeds), and Dr Robert Maddock (Baker Atlas Geoscience, Aberdeen).

Contents

Summary

This report presents a scheme for classifying and naming geological discontinuities and their fillings, and provides guidance for describing discontinuities in rock masses. The scheme is a new BGS corporate standard analogous to more established standards like the BGS Rock Classification Scheme. Its purpose is to provide geologists with the means to collect and store discontinuity and filling data succinctly and consistently, in any setting and at any scale; to supply a set of approved terms and their definitions to the dictionaries that support BGS databases, and to permit BGS staff, customers and other users to better understand BGS outputs that incorporate discontinuity data.

1 Introduction

Discontinuities interrupt or terminate the continuity of rocks and other geological materials. They include, among many other types, unconformities, fractures (joints and faults), solution cavities, and rock–water interfaces. To a large degree, discontinuities control the strength and stability of rock masses and commonly act as conduits for, or barriers to, migrating fluids like groundwater, waste leachate, oil, gas, and ore-forming solutions. Discontinuities also form the limits to all mappable geological units, and are therefore fundamental to geological models. With increasing focus on issues in which discontinuities play a major role — including geohazards, enhanced resource recovery, CO_2 sequestration, radioactive waste disposal, and subsurface pollution — comes a pressing need for a logical, flexible and robust system of classification, and consistency and clarity in the associated terminology.

Discontinuities have a number of features that make them difficult to classify and name in a rigorous and consistent way:

- they occur at all geological scales
- they can persist over long periods of geological time and may undergo many stages of evolution
- they can form in response to, and be modified by, a very wide range of processes
- collectively, they are exceptionally variable in character
- their character can change significantly depending on the location and scale of observation
- many contain fillings (e.g. fault-rock or mineral veins), which require their own system of classification and nomenclature
- they may be classified and described individually or in terms of their collective expression in a rock mass
- the information available to enable classification depends on the medium used to observe them (e.g. aerial photograph, seismic image, field exposure, borehole core, thin section)
- they have properties that can be observed (e.g. condition, form), measured (e.g. size, attitude, persistence), or interpreted (e.g. process of formation)
- there are many potential end-users of discontinuity data, with diverse requirements.

Perhaps because of these difficulties, no published comprehensive scheme exists for classifying and naming either discontinuities or their fillings. Instead, a vast, non-systematic and commonly confusing vocabulary is contained within geological dictionaries, textbooks, and published papers.

This report presents, as a BGS corporate standard, a scheme for classifying and naming single discontinuities, multiple discontinuities and fillings, and provides guidance for describing discontinuities in rock mass. The purpose of the scheme is:

- to provide geologists with the means to collect and store discontinuity and filling data succinctly and consistently, in any setting and at any scale
- to supply a set of approved terms and their definitions to the dictionaries ('controlled vocabularies') that support BGS databases
- to permit BGS staff, customers and other users to better understand BGS outputs that incorporate discontinuity data

Single discontinuities and fillings are classified in separate hierarchies (Figures 1 and 2). These illustrate how the most commonly encountered classes of feature are related conceptually, and they provide the basis for a formal terminology. Each class of discontinuity and filling has a name from which is derived a 'root term' that should be used to name all features assigned to that class. The scope of the scheme does not extend into developing fields that are covered in detail by modern textbooks and scientific papers, such as fault architecture and fractography.

This new scheme represents an important step forward in formalising the way that discontinuities and their fillings are classified and named. However, like most natural features, discontinuities and fillings resist the constraints of systematic classification, and commonly defy succinct nomenclature. Constructive feedback from users is encouraged to enable the scheme to be improved and developed further.

Discontinuity information (whether for a single feature, multiple features, or rock mass) can be recorded in the form of a name, as a free text description, or in a spreadsheet. Names are a good way of recording information quickly, in a condensed form and in one place, but they can quickly become long and clumsy. Descriptions can be of any length and can be adapted easily to suit user requirements, but they are an inconvenient way of storing and retrieving data. Spreadsheets (and databases) provide an excellent medium for recording data consistently and for storing, managing and retrieving data quickly and easily. The range of data recorded in spreadsheets can be varied to suit requirements and constraints, however they can be inflexible. Spreadsheets are particularly suited to situations requiring systematic description of a predetermined set of properties from numerous discontinuities, for example when preparing a systematic log of discontinuities in borehole cores or along extended line-samples. In this report, examples of the nomenclature proposed for discontinuities and fillings are given mainly in the form of names and free text descriptions. An example of a spreadsheet approach is provided in section 10.2.

Several publications describe systems for recording discontinuity information in a manner that is suited to a specific field, notably engineering geology. The International Society for Rock Mechanics has published a book (Brown, 1981) describing methods for rock characterisation, testing and monitoring. British Standard BS 5930, 1999 (*Code of practice for site investigation)*, outlines a system for recording discontinuity information that is used widely in the UK as a civil engineering industry standard[1]. This and other similar schemes are fundamentally observational (rather than interpretive), which is an advantage in their

[1]BS5930 was amended in December 2007 to avoid conflict with Eurocode 7: Geotechnical design (a European Standard for the design of geotechnical structures), which became mandatory in EU member states in March 2010.

field of application. However, they are designed for, and suited only to, a range of scales and a subset of discontinuity classes and attributes that are relevant to civil engineering projects. The scheme presented here should be used in all BGS projects that do not specifically require the use of an alternative scheme.

Section 2 of this report introduces the principles and procedures of classification and nomenclature that underpin the scheme. Proposals for classifying and naming single discontinuities are set out in Section 3, and those for classifying and naming fillings are set out in Section 4. Some discontinuities and/or fillings have a compound character, usually interpreted to be a result of reactivation (i.e. they preserve a record of more than one geological event); brief guidelines for dealing with such features are presented in Section 5. Recommendations for classifying and naming multiple discontinuities (e.g. sets and networks of features), and features that occur in zones, are presented in Section 6. Issues of scale and size in discontinuity classification are discussed in Section 7, with recommendations for indicating size in discontinuity names and descriptions. Terms that refer to the material hosting discontinuities are covered in Section 8. Terminology and procedure for describing the nature and distribution of multiple discontinuities in rock mass are set out in Section 9. Finally, examples of how the different parts of the scheme should be used in specific situations are given in Section 10. Tables 1–8 contain all the terms for discontinuities, fillings, and their properties that are approved by the scheme, organised by category. The report concludes with a comprehensive Glossary.

2 Foundations

The procedure proposed here for classifying and naming single discontinuities and their fillings shares many features with that used to classify and name rocks and non-consolidated materials in the BGS Rock Classification Scheme (RCS; http://www.bgs.ac.uk/bgsrcs/home.html).

2.1 CLASSIFICATION

Discontinuities and fillings are classified in two separate hierarchies encompassing six and four ranks, respectively (Figures 1 and 2). In each case, Rank 1 is taken to be the 'lowest' because it involves the least precise classification. Each rank contains one or more named classes of discontinuity or filling feature(s). Relationships between the different classes are generally described using familial terminology: a class is said to be a 'parent' to one of higher rank to which is it linked directly, a 'child' of one of lower rank to which is it linked directly, and a 'sibling' of one of the same rank with the same parent.

The logic of the hierarchical approach requires that classification begins at the lowest rank and works towards the higher ranks. Classification proceeds up the hierarchy, to the highest rank that is consistent with the amount and type of information that is available and/or the expertise of the geologist. An important aspect of this approach is that a single discontinuity or filling is classified concurrently at every rank up to and including the highest rank to which it is assigned. For example, a discontinuity may be classified concurrently in the 'Discontinuities class' (Rank 1), the 'Breaks class' (Rank 2), the 'Deformation breaks class' (Rank 3), the 'Sharp deformation breaks class' (Rank 4), and the 'Faults class' (Rank 5). Each of these is equally valid, but they are increasingly precise. In most cases, a classified feature will be referred to using its most 'precise' name (in this case, 'fault').

2.2 NOMENCLATURE

Formal names given to classified features have one essential component, the 'root' term, and a discretionary component consisting of one or more 'qualifier' terms.

Root terms are the product of formal classification, and each is specific to a particular class of features. Where a root term consists of more than one word, the words must be linked using hyphens (e.g. alteration-interface). In BGS databases and other forms of corporately held data, this convention indicates to users that the features in question have been classified and named according to corporately approved guidelines, thereby distinguishing them from 'legacy' and other data. However, the convention does not conform to normal writing practice, and may need to be dropped in some circumstances (e.g. in manuscripts submitted to scientific journals).

More familiar terms can substitute for some of the formal root terms for discontinuities. As well as being more recognisable, these approved synonyms are usually shorter, for example 'fracture' is an approved synonym of the formal root term 'sharp-deformation-break'. The root terms (including approved synonyms) that can be used with each class of feature are shown on Figures 1 and 2.

Qualifier terms are used to convey important or useful information that is not implied by the root term, for example details of the size and attitude of a discontinuity. Qualifier terms precede the root term in discontinuity names.

In the remaining text, and in all tables, figures and the Glossary, the names of discontinuities and fillings are presented with the root terms in bold text, for example **fault**, and qualifier terms in italicised text, for example *planar, reverse* **fault**. This convention is to enhance clarity in this document, not for use in normal practice. Terms that are relevant to this scheme and are 'approved' but are not root terms or qualifiers are presented hereafter in underlined text, for example footwall.

3 Classifying and naming single discontinuities

Single discontinuities are classified into 36 classes, in a simple hierarchical arrangement spanning six ranks (Figure 1). Rank 1 contains only one class of features, labelled Discontinuities. Any feature considered to be a single discontinuity can be classified at Rank 1 and assigned the root term **discontinuity**.

The 'Discontinuities class' is divided at Rank 2 into classes representing the two fundamental types of discontinuity: Interfaces and Breaks.

3.1 INTERFACES

Interfaces are boundaries between two materials of contrasting character. As such, interfaces represent a termination of continuity, and across them there is a change from one material, condition, or state to another. Material on either side of interfaces can be solid, unconsolidated, fluid, or magma. Interfaces occur between: a pluton and its country rock; soil and bedrock; crystals and melt in magma; contiguous clasts, crystals and grains in rocks and sediments; altered and unaltered rock; adjacent volumes of hydrocarbon and water; superposed beds in a sedimentary deposit; a fracture surface and filling; many other materials of contrasting character. Any discontinuity that is considered to be an interface can be classified at Rank 2 and assigned the root term **interface**. It will be sufficient in some cases to classify interfaces no further than Rank 2, and to use qualifier terms in names and descriptions to describe the nature of materials forming their opposing sides (e.g. '.. the core has parted along a *mudstone-sandstone* **interface** ..'). Section 3.4 provides more details of this approach.

3.1.1 Rank 3

Interfaces are divided at Rank 3 into two child classes comprising 'Primary interface' and 'Secondary interface'.

- Features encompassed by the 'Primary interfaces' class develop in the course of accumulation (e.g. sedimentation) or loss (e.g. erosion) of the host material. A primary interface therefore separates material that predates it (on one side) from material that postdates it (on the other side). The root term for any feature assigned to this class is **primary-interface**.
- Features encompassed by the 'Secondary interfaces class' develop after the host material has formed (i.e. they are superimposed on pre-existing material). A secondary interface therefore typically separates materials of essentially the same age but with contrasting histories. The root term for any feature assigned to this class is **secondary-interface**.

3.1.2 Rank 4

The Primary interfaces and Secondary interfaces classes are divided at Rank 4 into child classes according to the process by which the interfaces form. For example, the 'Sedimentation interfaces class' encompasses interfaces that form as a result of sedimentation[2], and the 'Alteration interfaces class' encompasses those that form during a process of alteration (hence they separate materials of contrasting alteration state). The list of classes in this rank shown on Figure 1 represent the more common interface-forming processes, but they are a subset of all those that occur naturally. Table 1, which presents a list of the approved terms for geological processes that are relevant to discontinuities and fillings, includes some other processes that can create interfaces.

The root terms for features classified at Rank 4 are generally the singular, hyphenated form of the class name, for example **solution-interface**. The following exceptions should be noted:

- Terms with more specific meaning can, where appropriate, substitute for the 'process' term in the root terms; for example, **weathering-interface** and **redox-interface** instead of **alteration-interface**; **abrasion-interface** instead of **erosion-interface**; and **precipitation-interface** instead of **deposition-interface**.
- The term 'front' can substitute for 'interface' in the root terms for interfaces that migrate as they develop; for example, **alteration-front**, **sedimentation-front**, and **solution-front**.

The points of contact between contiguous clasts, grains and crystals in rocks and sediments are interfaces. For example, contiguous crystals in crystalline materials are separated by a **crystallisation-interface** if the crystals are the product of primary crystallisation, or by a **recrystallisation-interface** if the crystals formed in the solid state. Two contiguous crystals or grains of the same mineral can be said to be separated by an **interface** (a boundary between two materials of contrasting character) because there will always be some contrast in their crystallographic character (though it may be subtle). The terms 'surface' and 'boundary' can be used to refer informally to the interface(s) between a clast, grain or crystal and some other material, for example '.. detrital grain surfaces are commonly armoured beneath diagenetic overgrowths ..', and '.. some crystal boundaries are sutured ..'.

The same process can create interfaces at a range of scales; for example, a **deposition-interface** can separate two contiguous quartz grains in a sand unit, and a **deposition-interface** can also separate two rock layers of regional extent.

Primary interfaces that develop initially through loss of substrate (e.g. by erosion, solution or melting) can subsequently be the focus of material accumulation (e.g. by sedimentation, precipitation or crystallisation); such interfaces are therefore the product of more than one process. Geologists can choose to classify these features according to either the younger or older process; for example, the interface between limestone wallrock and a cavity formed by solution that has subsequently been filled

[2]Note that sediment must occupy the 'younger' side of a sedimentation-interface but may or may not occupy the 'older' side.

with sediment could be classified as a **sedimentation-interface** (reflecting the younger process) or as a **solution-interface** (reflecting the older process).

3.1.2 Rank 5

The 'Sedimentation interfaces class' (Rank 4) is divided at Rank 5 into two child classes according to whether the materials on opposing sides of the interface have a conformable or unconformable relationship. Features assigned to the 'Conformable sedimentation interfaces' class can be given the root term **conformable-sedimentation-interface**, or the approved synonym **bedding-plane**. Features assigned to the 'Unconformable sedimentation interfaces class' can be given the root term **unconformable-sedimentation-interface**, or the approved synonym **unconformity**. Unconformities are usually a product of both erosion and sedimentation, but for the purposes of this classification they are considered to be 'children' of the 'Sedimentation interfaces' class. The root terms **bedding-plane** and **unconformity** are used in the remainder of this report instead of the longer, more formal, synonyms.

3.2 BREAKS

Breaks are discontinuities along which the physical integrity of a material is, or has been, disrupted. Fractures and solution cavities are examples. Breaks therefore generally represent an interruption in the physical continuity of material on either side of them (by contrast with interfaces, which represent a termination of continuity). However, breaks can exploit interfaces, and displacement along a break can juxtapose materials of contrasting character; in these cases there can be a change of character across breaks. Breaks generally form when a material suffers deformation or selective solution. Any openings generated as a break is created may become closed or filled, and they can heal, but the original feature is still classified as a break. Any discontinuity that is considered to be a break can be classified at Rank 2 and assigned the root term **break**.

3.2.1 Rank 3

The 'Breaks class' is divided at Rank 3 into two classes, Chemical-solution breaks and Deformation breaks. The 'Chemical-solution breaks class' encompasses breaks formed by the process of chemical solution; i.e. it excludes breaks formed by pressure solution (breaks formed by this process are addressed in sections 3.2.3 and 3.2.4). The 'Deformation breaks class' encompasses breaks formed by all natural causes of deformation (tectonic events, burial compaction, erosional unloading, slope failure, cooling, etc.). The root terms for features assigned to these classes are **chemical-solution-break** and **deformation-break**, respectively.

3.2.2 Rank 4

Chemical-solution breaks and deformation breaks are divided into child classes at Rank 4, essentially on the basis of their geometry. There are three classes of chemical-solution breaks and two classes of deformation breaks.

3.2.2.1 Chemical-solution breaks

Most breaks are essentially sheet-like features (i.e. they have two relatively long dimensions and one relatively very short dimension). However, breaks formed purely or primarily by the process of chemical solution can develop in a wide range of geometries. The 'Chemical-solution breaks class' (Rank 3) is therefore divided at Rank 4 into three classes — 'Solution cavities', 'Solution sheets' and 'Solution tubes' — that encompass features approximating to equant, sheet-like, and tubular shapes, respectively. Features assigned to these classes can be given the root terms **solution-cavity**, **solution-sheet**, and **solution-tube**, respectively. The highly irregular geometry of some chemical-solution breaks cannot be described adequately using these three root terms alone, even if they are taken to be only approximations to a geometrical form. Where appropriate, more accurate and more detailed information can be conveyed using qualifiers with the non-geometric Rank 4 root term **chemical-solution-break** (see Section 3.4 for an example). Some highly irregular features will be a product of chemical solution around two or more features that originally were discrete, and it may be more appropriate to classify these as a type of multiple discontinuity feature (e.g. as a *chemical-solution-break* **network**; see Section 6).

3.2.2.2 Deformation breaks

The hierarchical classification of deformation breaks is based largely on the proposals of Schultz and Fossen (2008). These authors reviewed the terminology and classifications that previously had been used for 'geologic structural discontinuities' and proposed a new framework and rationalised terminology with accompanying definitions. Their review and proposals are presented mainly from a reservoir performance perspective, but the resulting discontinuity classes, terms and definitions can be applied to the full range of deformation breaks in all geological materials. The 'framework' has been converted into a hierarchical classification and incorporated into ranks 4 and 5 of Figure 1.

The 'Deformation breaks class' has two child classes at Rank 4: Sharp deformation breaks and Tabular deformation breaks. Figure 3 illustrates the basis for this division. Sharp deformation breaks are characterised by a discontinuous change in strength and/or stiffness, such that there is a stepwise change in the displacement distribution across them. The volume of deformed material associated with them typically has negligible thickness at the scale of observation (hence they are 'sharp'); such features typically consist of two sharply delineated and well-defined opposing surfaces in contact or close proximity. Features assigned to the 'Sharp deformation breaks class' can be given the root term **sharp-deformation-break** or the approved synonym **fracture**. By contrast, tabular deformation breaks are characterised by a continuous change in strength and/or stiffness across a band of deformed material whose thickness is clearly resolvable at the scale of observation. Features assigned to the 'Tabular deformation breaks class' can be given the root term **tabular-deformation-break** or the approved synonym **deformation-band**. The root terms **fracture** and **deformation-band** are used in the remainder of this report instead of the longer, more formal, synonyms.

Fractures are formed by brittle deformation, while deformation bands can be formed by ductile deformation, brittle deformation, or both. Recognising and distinguishing 'brittle' and 'ductile' behaviours is fundamental to detailed studies of deformation breaks (e.g. Ramsay, 1980; van der Pluijm and Marshak, 1997; Mandl, 2000). However, the business of distinguishing brittle and ductile origins is commonly not straightforward, with widespread confusion over the meaning and recognition of the two behaviours, and problems of scale-dependent variations in character. Process of formation is therefore not a suitable basis for the primary classification of deformation breaks in this scheme (which aims to provide a simple and robust system for classifying discontinuities). The observational approach ('sharp' *versus* 'tabular') used here to classify deformation breaks at Rank 4 is simple to use (in the field and elsewhere), and avoids many of the complications associated with the process terms 'brittle' and 'ductile'. A large body of literature deals with the complex topic of defining, distinguishing and characterising brittle and ductile behaviours in geological materials. When an assessment of the process of formation of deformation bands is required, the specialist literature should be consulted if necessary and appropriate information should be included in descriptions or in names using qualifier terms (e.g. *ductile* **deformation-band** and *brittle-ductile* **deformation-band**). The scale and medium of observation should always be recorded.

It is relatively common for a deformation-band to contain or be bounded by one or more fractures, which can form during the event that formed the deformation-band, or as a result of later, unrelated, structural reactivation. Such features could be classified in several ways, for example:

- If the fractures are minor, and the essential character of the feature is of a deformation-band, then the geologist could choose to ignore the fractures and classify the feature as a single **deformation-band**
- The **deformation-band** and each **fracture** within it or bounding it could be classified and named separately
- The feature as a whole could be treated as a compound discontinuity (see Section 5) and assigned a name like *fracture-bounded* **deformation-band** or *fracture-reactivated* **deformation-band**.

3.2.3 Rank 5

At Rank 5, child classes of the 'Sharp deformation breaks' and 'Tabular deformation breaks' classes are distinguished according to the sense of displacement associated with the break.

The 'Sharp deformation breaks class' is divided into three child classes at Rank 5:

- 'Cracks' — features formed by opening displacement (i.e. the opposing sides of the break have moved away from each other)
- 'Anticracks' — features formed by closing displacement (i.e. the opposing sides of the break have moved towards each other)
- 'Faults' — features formed by shearing displacement (i.e. the opposing sides of the break have moved relative to each other in a plane parallel to the bounding surfaces)

The root terms for features assigned to these three classes are **crack**, **anticrack** and **fault**, respectively. The widely-used term **joint** is an approved synonym of **crack**, and is used throughout the remainder of this report.

As defined here, the term **joint** does not imply near-planar form; a wide range of forms (including *curved*, *planar*, *stepped* and *tapered*) can be created by opening displacement on a **fracture**. Opening displacement on fractures is commonly a consequence of bulk extension of the rock mass, but this need not always be the case. For example, in units of columnar basalt the opening displacement across the joints that bound and define each column is a consequence of bulk contraction of the rock mass driven by cooling.

Anticracks generally form by the process of pressure solution (also known as 'chemical compaction'). Crystalline carbonate rocks most commonly present the combination of conditions and host-rock composition needed to allow this process to occur.

In the strict sense of the classification, a **fault** can be defined simply as two opposing surfaces accommodating any discernible component of shearing displacement. However, the displacement on many features that are taken to be single faults is commonly accommodated on several or many 'surfaces', and reference to a 'fault' *sensu lato* commonly includes other genetically and spatially associated elements, notably a damage zone (which can include joints, other smaller faults and deformation bands) and a **filling** (i.e. **fault-rock**; see Section 4).

The 'Tabular deformation breaks class' is divided into five child classes at Rank 5:

- 'Dilation bands' — features formed by opening displacement
- 'Dilational-shear bands' — features formed by a combination of opening displacement and shearing displacement
- 'Shear bands' — features formed by shearing displacement
- 'Compactional-shear bands' — features formed by a combination of closing displacement and shearing displacement
- 'Compaction bands' — features formed by closing displacement

The root terms for features assigned to these five classes are **dilation-band**, **dilational-shear-band**, **shear-band**, **compactional-shear-band** and **compaction-band**, respectively.

Features formed by closing displacement (with or without a component of shearing displacement) show a decrease in volume across the discontinuity, and are therefore largely restricted to porous materials. A range of names, including band fault, deformation band, granulation seam, microfault and shear fracture, has been used previously to refer to features formed in this way. These terms are not approved here (although **deformation-band** is approved in a different context); such features should instead be assigned either of the approved root terms **compactional-shear-band** or **compaction-band** (Rank 5) if the sense of displacement can be ascertained, or **deformation-band** (Rank 4) if it can't. Features formed by opening displacement (with or without a component of shearing displacement) show an increase in volume across the discontinuity.

3.2.4 Rank 6

Two child classes of the 'Anticracks class' are distinguished at Rank 6. The 'Dentate anticracks class' encompasses anticracks that display a broadly dentate pattern (see the Glossary definition of **dentate-anticrack** for a fuller description of this character). Features assigned to this class can be given the root term **dentate-anticrack** or the approved synonym **stylolite**. The 'Smooth anticracks class' encompasses anticracks with a relatively even and regular form, free from the projections, indentations and roughness that characterise dentate anticracks. Features assigned to this class can be given the root term **smooth-anticrack**. The terms 'dissolution seam' and 'solution seam', which have been used in some publications to refer to smooth anticracks, are not approved here because of the potential for confusion with chemical-solution breaks.

3.3 OTHER APPROVED TERMS FOR SINGLE DISCONTINUITIES

Some discontinuity types and terms do not fit readily into the hierarchical classification proposed here, and are therefore not included on Figure 1. They include the following (see also Section 4.4):

- Man-made discontinuities, which are increasingly abundant in the near surface. Terms that imply a man-made origin can be used as root terms for some of these, for example **borehole** and **mineshaft**. For others, the qualifier term *induced* can be appended to the root term for a natural discontinuity, creating names like *induced* **fracture**. More specific terms can substitute for *induced*, for example *blasting* **fracture** and *drilling* **break**. Terms for man-made discontinuities (and fillings) are not included in the tables or Glossary.
- Linear features of unspecified origin and uncertain significance, at any scale. The root term **lineament** can be used for all such features, though the term is usually used at larger scales (outcrop scale and bigger), and commonly for features identified by remote sensing.
- The root term **fissure** can be used for fractures or solution breaks that form at, and propagate downwards from, the land surface (though they may subsequently be buried). Discontinuities formed below the land surface and exhumed subsequently are not fissures. Where appropriate, an approved term to indicate the feature type should precede the word 'fissure' to create a more informative root term, for example **joint-fissure**, **solution-fissure**, **desiccation-fissure**. Downward-propagating fissures may intersect, or merge with, discontinuities that formed entirely in the subsurface.
- The root term **tension-gash** can be used for a short dilatant **fracture** that is part of an en echelon grouping of similar features.
- The term 'slip-surface' is commonly used for the discontinuities along which slopes fail and slumping occurs in the formation of landslides. Such features involve shearing displacement and are faults in the sense of this classification. The root term **slip-surface** can be used in this context (formation of landslides) as an approved synonym of **fault**. Other root terms approved by this scheme, including **joint**, **fault**, **fissure** and **tension-gash**, should be used where appropriate for the range of other discontinuities that can form in association with landslides.

3.4 QUALIFIER TERMS

Information about a discontinuity that is not implied by its root term can be added to a name or description using a wide range of approved qualifier terms. These are arranged according to class and category in Table 2, and all are defined in the Glossary.

Qualifier terms can be recorded in several ways: if incorporated into the name for a discontinuity they should precede the root term, without being linked to it with a hyphen (e.g. *steeply dipping, normal* **fault**); they can be introduced at any point in a free-text description (e.g. '.. the **fault** is *steeply dipping* and has a *normal* sense of displacement ..'); and they can be entered in appropriate spreadsheet cells (see Section 10.2). To keep names reasonably short and manageable, only the most important or relevant qualifier terms should be used. The order in which two or more qualifier terms are listed in names cannot be prescribed, but it would be good practice to maintain a consistent system within a project.

Interfaces can in some cases be classified and named adequately by using qualifiers to describe the nature of materials forming their opposing sides. Table 2 includes a list of some of these materials. For example, a discontinuity could be classified at Rank 2 as an interface and given the name *solid–fluid* **interface**. More specific terms can substitute for the qualifier terms where appropriate, for example *crystal-liquid* **interface**, or, even more specifically, *calcite-brine* **interface**. Other examples include *oil–gas* **interface**, *crystal–melt* **interface**, *mudstone–sandstone* **interface**, *ice–till* **interface**, and *soil–rock* **interface**. The root term **rockhead** (see full definition in the Glossary) can be used instead of a name like *soil–bedrock* **interface**[3].

The following examples combine root terms with approved qualifier terms to make full discontinuity names:

- *curved, dilatant, 3 mm-wide* **joint**
- *diffuse, irregular* **weathering-front**
- *sediment-filled* **solution-cavity**
- *near-planar, angular* **unconformity**
- *mm- to m-range aperture, highly irregular* **chemical-solution-break**
- *10 metre-offset, reactivated, planar* **fault**.

[3]The term rockhead has a slightly different meaning depending on whether it is used in a purely geological or an engineering context. Where appropriate, a qualifier term should be used to make clear the context in which the root term is used, i.e. *engineering* **rockhead** and *geological* **rockhead**; see the Glossary entry for 'rockhead' for a fuller definition of these terms.

4 Classifying and naming fillings

Filling is the material that occupies part or all of the space (if any) in a **break**. The term 'filling' is preferred to 'fill' because the latter term is already defined in BGS Rock Classification Scheme Volume 4 (McMillan and Powell, 1999) as anthropogenic material 'used to infill a void or cavity in the earth's surface or subsurface'. Fillings are diverse in terms of their component materials and texture. In common with single discontinuities they are classified here using a simple hierarchical arrangement, in this case with four ranks (Figure 2). Root terms for fillings are generally the singular form of the associated class name (e.g. a filling assigned to the 'Veins class' will generally be given the root term **vein**). Further information can be added to the root terms for fillings using qualifier terms (Section 4.3).

Fillings generally consist of material that is introduced after the host **break** has formed, or during its formation. Some filling components can be derived locally (e.g. wallrock clasts) but they nevertheless will have been detached and moved from their point of origin such that they now lie within the boundaries of the break. Identifying **filling** in some deformation breaks is less straightforward, particularly those formed largely or entirely by ductile deformation. Such features commonly have gradational boundaries and consist largely of the original rock, modified to varying degrees by physical and/or chemical alteration. Geologists will need to decide, on a case-by-case basis, whether such material constitutes **filling** or just modified host rock.

4.1 CLASSIFICATION

The hierarchical classification of fillings is shown in Figure 2.

4.1.1 Rank 1

All fillings are grouped at Rank 1 in a single class of features called 'Fillings'. Any material recognised as a filling can be classified at Rank 1 and given the root term **filling**.

4.1.2 Rank 2

Fillings can be classified at Rank 2 according to their components or their type (Table 3).

4.1.2.1 Classification according to filling components

The common filling components are: authigenic minerals (formed from fluid or magma), clasts, organic matter, recrystallised rock, and fluid. Other potential filling components include gel, slurry, sol, and (injected) salt. Formal definitions for these terms are given in the Glossary. Many fillings consist in part, or entirely, of fluid in either liquid (e.g. groundwater, oil) or gaseous (e.g. air, methane) form. This component of fillings is usually not visible or not present during bedrock or core examination, and is commonly ignored; its presence is, however, typically implied by terms like porous and vuggy. The qualifier term *non-filled* (e.g. *non-filled* **solution-sheet**) can be used to imply 'not occupied by solid matter', though all such features in their natural state probably have fillings of fluid. The qualifier term *open* (e.g. *open* **joint**) can be used to describe a **break** that is permeable at the scale of observation and which may or may not contain a partial **filling** of solid matter.

The principal classes of filling defined by components include those that consist of only one component (e.g. Authigenic mineral fillings, Organic matter fillings) and those consisting of two or more components (e.g. Clast and authigenic mineral and fluid fillings). A large number of possible combinations of the common filling components yield a large number of potential classes of fillings; only a selection of these is shown on Figure 2.

Root terms for fillings classified in this way are constructed by linking with hyphens a list of the components and the term 'filling', for example **authigenic-mineral-filling** (a single-component filling) and **fluid-authigenic-mineral-filling** (a two-component filling). More specific terms can substitute for the basic component names, for example **calcite-filling** or **quartz-filling** instead of **authigenic-mineral-filling**, and **groundwater-calcite-filling** instead of **fluid-authigenic-mineral-filling**. Where a filling consists of two or more authigenic minerals, they should be linked to create names like **calcite-quartz-filling** and **hematite-epidote-quartz-filling**. Following the principle introduced in the BGS Rock Classification Scheme, strings of mineral names used as qualifiers should be listed in order of increasing proportion; in the latter example, the filling contains more epidote than hematite, and more quartz than epidote. Similarly, the names of multiple-component fillings should be constructed with the components listed in order of increasing proportion; for example, a **groundwater-calcite-filling** contains volumetrically more calcite than groundwater.

If a filling formed from magma, an appropriate rock name from Volume 1 (Igneous materials) of the BGS Rock Classification Scheme (Gillespie and Styles, 2011) should be used, for example **basalt-filling**.

4.1.2.2 Classification according to filling type

Five classes at Rank 2 (Figure 2) encompass the most commonly encountered types of filling: 'Crusts', 'Veins', 'Sediments', 'Breccias', and 'Fault-rocks'. The root terms for materials assigned to these classes are **crust**, **vein**, **sediment**, **breccia**, and **fault-rock**, respectively.

Veins and crusts represent different degrees of 'completeness' of authigenic mineral fillings. Veins effectively fill, or nearly fill, space within the host break, and the opposing surfaces of the host break are generally connected across the mineral filling. Crusts are partial fillings developed on one or both surfaces of the host break, and they can range from a single crystal covering a tiny fraction of the break surface, to complete coatings of one or both surfaces (with a non-filled gap between them); in some instances a crust may 'bridge' the gap (i.e. heal the break locally). It is not practical to provide a specific threshold of filling 'completeness' to distinguish veins and crusts; geologists must consider each instance on its merits, and judge whether the essential character of the feature in question is of a 'complete or near-complete' filling (**vein**) or a 'partial' filling (**crust**).

Qualifier terms can provide more information in filling names and descriptions, as described in Section 4.3. Note that fillings consisting wholly or largely of fluid or organic matter are not classified according to filling type; they should instead be classified according to filling component (e.g. **groundwater-filling** and **bitumen-filling**; see Section 4.1.2.1). Alternatively, such features can be referred to using filling qualifier terms with a discontinuity root term, for example *groundwater-filled* **solution-cavity** and *oil-filled* **fracture**.

Fillings of authigenic minerals that crystallised from magma, or a material transitional in character between magma and fluid, can be named using an appropriate rock name from Volume 1 (Igneous materials) of the BGS Rock Classification Scheme (Gillespie and Styles, 2011) as a qualifier to the root term **vein**, for example *basalt* **vein**, *microgranite* **vein**, *pegmatitic tourmaline-muscovite-quartz-feldspar* **vein**. Many mappable occurrences of magmatic rock fillings will be classified formally as lithodemic units, and named or referred to (following the recommendations of Gillespie et al., 2008) using rock name qualifiers and lithodemic root terms; for example, *basalt* **dyke**, *agglomerate* **pipe**. The names assigned to mapped units that have formal status in the BGS Lexicon of Named Rock Units include a geographical term, for example Alnwick Quartz-dolerite Sill.

4.1.3 Rank 3

Two classes of filling at Rank 2 are divided at Rank 3, again according to their type (Figure 2). The 'Crusts class' is divided into four child classes: 'Dendrites', 'Layers', 'Patches', and 'Spots'. 'The Fault-rocks class' is divided into two classes: 'Cataclasites' and 'Mylonites'. As at Rank 2, the root terms for materials assigned to these classes are the singular form of the class name, for example '.. joints above the water table have fillings of *Mn-oxyhydroxide* **dendrite** and **air** ..'. Fault-rock classification and nomenclature is described in more detail in Section 4.2.

4.2 CLASSIFYING FAULT-ROCK

The character of fault-rock depends to a large degree on three factors:

- the interplay between strain and strain recovery
- the degree to which authigenesis has modified the product
- the state of consolidation

The first of these can be summarised in the following manner (quoting from, and slightly paraphrasing, Wise et al., 1984). Strain manifests as brittle deformation, which creates fractures and causes grain-size reduction, or as ductile processes that reshape surviving grains and store strain energy in crystal lattices. Most recovery processes, on the other hand, involve release of strain energy stored in crystal lattices through processes such as recrystallisation and annealing. Competition between rate of strain and rate of recovery/recrystallisation is a major determinant of the texture of fault-rock, the rates being functions of temperature, composition, grain size, fluids, and the stress field. At one extreme, most materials subjected to rapid strain at relatively low temperature, with modest or no recovery, yield **cataclasite**. At the other extreme, where recovery/recrystallisation dominates, the result is an ordinary metamorphic rock. Between these two extremes is a spectrum of brittle to ductile behaviours and associated rock types. **Mylonite** occupies that part of the spectrum marked by relatively high strain rate combined with appreciable recovery rate; diminution of grain size is achieved by syntectonic recrystallisation associated with ductile strain or crystal-plastic processes.

The hierarchical classification of fault-rocks (Figure 2) incorporates the basis described above for defining and recognising cataclasites and mylonites, while using the definitions for fault-rock terms presented in Brodie et al. (2007); the latter have been modified to varying degrees to be consistent with other terminology used in this scheme. Definitions for all the fault-rock terms presented below are provided in the Glossary. Root terms for the various fault-rock types (Table 4) are always the singular form of the associated class name, hyphenated where this consists of two words, for example **fault-breccia** and **ultramylonite**.

The 'Fault-rocks class' (Rank 2) is divided into two classes at Rank 3: 'Cataclasites' and 'Mylonites'. The two may be difficult to distinguish in the field, however cataclasites are typically characterised by a poorly developed or absent schistosity, and mylonites by the presence of a well-developed schistosity. In most cases, classification of cataclasites and mylonites beyond Rank 3 requires an accurate assessment of the proportion of 'clasts' and 'matrix' in the fault-rock; microscope examination will commonly be required to achieve this. In cataclasites, the 'clasts' form through the formation of fractures and rotation of crystals and crystal aggregates, while the 'matrix' consists of distinctly finer (mainly comminuted) material. In mylonites, the 'clasts' are porphyroclasts showing little sign of significant recrystallisation (representing survivors from destruction of pre-existing, less ductile material), occurring in a finer matrix in which the original crystals and texture of the protolith have been destroyed by intense syntectonic recrystallisation (and, commonly, subsequent annealing).

The 'Cataclasites class' is divided at Rank 4 into seven classes. Two of these, 'Fault gouges' and 'Fault breccias', are reserved for those materials in which a significant proportion of very fine authigenic minerals (generally clay with or without iron oxide/oxyhydroxide) has formed through syn- or post-faulting alteration of finely comminuted rock. In fault gouges less than 30 per cent of the fault-rock volume consists of visible clasts (i.e. more than 70 per cent is fine authigenic minerals), whereas in fault breccias more than 30 per cent is visible clasts. Fault gouges and fault breccias are likely to be a product of relatively near-surface faulting, where comminution has been accompanied or followed by groundwater flow producing substantial authigenesis; they are commonly incohesive and their clay-rich character can render them malleable, or friable if they dry out.

Fine authigenic minerals are generally minor or absent in the remaining five child classes of cataclasite. Four of these are distinguished according to the proportion of clasts and matrix: protobreccias have less than 10 per cent matrix; protocataclasites have 10–50 per cent matrix, mesocataclasites have 50–90 per cent matrix, and ultracataclasites have greater than 90 per cent matrix. The definition proposed by Brodie et al. (2007) for protocataclasite encompasses all cataclasites with up to 50 per cent matrix. The 'Protobreccias class' is introduced here to include incipient or weakly developed cataclasites, so that they may be classified and named separately from those that are better developed (i.e. have a greater proportion of matrix). The 'Pseudotachylites class' encompasses cataclasites that form when extreme cataclasis yields highly strained but non-foliated rock consisting typically of fine clasts enclosed in glass.

The 'Mylonites class' is divided at Rank 4 into five classes. Four of these are distinguished according to the proportion of rock that has undergone grain-size reduction: in 'protomylonitic' breccias less than 10 per cent of the rock has undergone grain size reduction, in 'protomylonites' it is 10–50 per cent, in 'mesomylonites' 50–90 per cent, and in 'ultramylonites' it is greater than 90 per cent. The definition proposed by Brodie et al. (2007) for protomylonite encompasses all mylonites in which less than 50 per cent of the rock volume has undergone grain-size reduction. The 'Protomylonitic breccias class' is introduced here to include incipient or weakly developed mylonites, so that they may be classified and named separately from those that are better developed (i.e. have a greater proportion of rock that has undergone grain size reduction). The 'Blastomylonites class' encompasses mylonites that display a significant degree of grain growth related to, or following, deformation.

The consolidation state of cataclasites is an important aspect of their character and has obvious engineering significance. The qualifiers *incohesive* and *cohesive* can be used to indicate consolidation state, for example *incohesive* **fault-gouge** and *cohesive* **mesocataclasite**. Following Brodie et al. (2007), an *incohesive* **fault-rock** is one that can be broken into component granules with fingers or with the aid of a pen knife. Mylonites are, by definition, cohesive (see the Glossary), so a qualifier describing their consolidation state is not necessary.

4.3 QUALIFIER TERMS

Further information can be added to the root terms for fillings using a wide range of approved qualifier terms, which are arranged according to class and category in Table 5.

When fillings are classified according to their type (see Section 4.1.2.2), a term to describe the filling type forms the root term and further information is provided using qualifier terms. The authigenic mineral(s) forming a vein should be listed as described in Section 4.1.2.1, for example *hematite-calcite* **vein**. Crusts are partial (i.e. incomplete) fillings and therefore are always accompanied by another filling component, usually **fluid**; the presence of fluid within a break is implicit in a filling name like *calcite* **crust**. An indication of crust size and form should be given (using the recommendations set out in Section 7); for example '.. the **joint** surface has *mm-range pyrite* **spots** … or …*10 mm long Mn-oxyhydroxide* **dendrites** … or …*10 cm wide calcite* **patches** … or … a *1 mm thick hematite* **layer** ..'.

The terms for grain-size divisions used in the BGS Rock Classification Scheme (e.g. Gillespie and Styles, 2010) can be used to supplement the root term **sediment**, where appropriate; for example, '.. the **joint** has a filling of *fine-sand -grade* **sediment** ..'.

Information about fillings can also be conveyed in qualifier terms accompanying discontinuity root terms; for example, *sediment-filled* **solution-cavity**, or, using more specific grain-size terms, *sand-filled* **solution-cavity**, *sand- and silt-filled* **solution-cavity**. Other examples of names created in this way include *calcite-filled* **joint**, *sediment- and breccia-filled* **solution-sheet**, *calcite-crusted, groundwater-filled* **joint**, and *pyrite-spotted and Mn-oxyhydroxide dendrite-crusted* **joint**.

4.4 TERMS THAT COMBINE DISCONTINUITY AND FILLING INFORMATION

The well-established term 'pore' is defined here as a fluid-filled break of any size and shape, formed by any geological process. The term therefore combines information about a discontinuity *and* its filling, and as such a 'pores' class does not appear in either of the hierarchies presented in Figures 1 and 2. The broad definition proposed for the term simplifies an area of potentially complex terminology, and is consistent with widely accepted definitions for the derivative terms porous and porosity. The root term **pore** can be used for all features that match the definition given above.

Not all pores are discontinuities *sensu stricto*, and, as with other features, their status as discontinuities can be scale-dependent. An isolated pore (such as a non-cemented gap in largely cemented **breccia**) represents a discontinuity, whereas one pore in uniformly porous sandstone does not. However, viewed at a larger scale, the boundary between any **pore** and the medium that hosts it can be classified as an **interface**.

Cavities, sheets, and tubes are pores that are, respectively, near-equant, sheet-like, and tubular. The root terms **cavity**, **sheet**, and **tube** can be used for such features when the mode of origin is not known, or when it is sufficient to provide in the root term only an indication of their approximate shape; for example, '.. a *20 metre wide* **cavity** formed when the tunnel roof collapsed ..'.

5 Compound discontinuities and fillings

Discontinuities and fillings commonly have a compound character, i.e. they consist of two or more parts. In most cases this character is interpreted to be a result of the original feature being modified by one or more subsequent events (i.e. it has reactivated). For example, a compound character may result if a **fault** reactivates structurally one or more times, if a **fracture** exploits a **bedding-plane**, and if a **filling** forms in two or more stages separated by structural reactivation of the host discontinuity. Some fillings can reactivate without structural reactivation of the host discontinuity; for example, a change in the composition of a dynamic body of groundwater could lead some or all of the minerals in a **vein** to dissolve, with or without subsequent precipitation of new minerals.

Such features can be difficult to classify and name, particularly if they have a complicated history. The vast range of compound discontinuities that can form, and the diverse requirements of individual end-users of discontinuity data, make it impractical to propose a consistent approach to classifying and naming compound features. The following guidance is offered, but ultimately geologists will have to decide how best to deal with compound features on a case-by-case basis.

At a basic level, discontinuities and their fillings can be classified as either simple (i.e. essentially the product of one 'event') or compound (i.e. reactivated). Unless it is indicated to the contrary, it should be assumed that a classified discontinuity is simple; there is no need to include this information in a name, description, or spreadsheet. For compound features, the term 'compound' can be appended as a qualifier to the root term for a discontinuity or filling to produce names like *compound* **fault** (meaning a fault along which displacement is known or inferred to have occurred more than once) and *compound* **vein** (meaning a vein formed in two or more discrete stages of mineralisation ± solution).

Such names are relatively uninformative, and in many cases it will be preferable to provide more information. One way to achieve this is to divide compound discontinuities and fillings into two categories: those in which the same process is repeated to generate the compound character, and those formed by two or more different processes.

In examples of the former category, qualifier terms can be used to provide information on the number, effect, or character of reactivations; for example, *twice-reactivated* **fault**, *multiply reactivated* **fault**, *weakly reactivated* **fault**, and *part-dissolved dolomite-calcite* **vein**. Some examples can be named using established terminology: for example, in a *crack-seal* **vein** the filling develops through repeated opening and mineralisation of a fracture.

In examples of the latter category, it is probably simplest to indicate one process using the root term, and the other(s) in qualifier terms. A **bedding plane** exploited by a **joint** is a good example. The geologist must decide which process is the more important (and therefore determines the root term). This decision may be based on the relative size of each feature or the effect of each process. For example, a major **bedding plane** with a small parting (joint) along it could be named *joint-reactivated* **bedding plane**, whereas a minor bedding plane exploited by a large joint could be named *bedding plane* **joint**.

Dedicated cells or 'comments' sections can be used in spreadsheets to provide detailed information about compound features, where appropriate. Examples of compound features and their nomenclature are given in Section 10.

6 Classifying and naming multiple discontinuities and zones

Four classes of feature that encompass associations of two or more discontinuities are defined herein (Table 6): Networks, Sets, Systems, and Arrays. Unlike single discontinuities, these classes are not united within a hierarchical (or any other) framework. The singular forms of the class names are used as root terms for the features assigned to them (i.e. **network**, **set**, **system**, and **array**).

Networks encompass all of the discontinuities in a defined rock mass, or a subset of the discontinuities that is characterised by one or more common parameters. Where appropriate, an approved term indicating the common nature of the parameter(s) should be linked to the word 'network' to create a more informative root term, for example **discontinuity-network**, **joint-network**, **solution-break-network**. A **discontinuity-network** may consist of several discrete networks, for example a **joint-network**, a **stylolite-network**, and a **solution-sheet-network**. The root term **vein-network** can be used to denote a network of mineralised joints.

Sets are groups of discontinuities with parallel or near-parallel disposition. Where appropriate, an approved term to indicate the feature type should be linked to the word 'set' to create a more informative root term, for example, **joint-set**.

Arrays are groups of discontinuities displaying an ordered arrangement. Where appropriate, an approved term to indicate the feature type should be linked to the word 'array' to create a more informative root term; for example '.. the **fracture-array** consists of three orthogonally disposed **joint-sets** ..'.

Systems are groups of related discontinuities. Where appropriate, an approved term to indicate the feature type should be linked to the word 'system' to create a more informative root term, for example, **fault-system**.

Zones are volumes of material in which the frequency of a feature, or the degree to which a particular state or condition is developed, is measurably different compared to the background. Where appropriate, an approved term to indicate the type of feature, state, or condition should be linked to the word **zone** to create a more informative root term; for example, **altered-zone**, **fracture-zone**, **shear-zone**. As usual, more specific terms can substitute for generic ones, for example **chloritised-zone** instead of **altered-zone**.

Qualifier terms can be used to add further information to root terms for multiple discontinuities and zones, in the same way as for single discontinuities and fillings; for example, *10 metre wide* **anhydrite-cemented-zone**, and *multiply reactivated, strike-slip, 100 metre wide* **fault-zone**. Approved terms for describing the disposition of individual features (e.g. anastomosing, en echelon) and the measurable properties of multiple discontinuities (e.g. frequency, spacing) are listed in Table 6. Definitions for the measurable properties of discontinuities and the methodologies for dealing with them are described in more detail in Section 9.

The terms strand and splay (as defined in the Glossary) can be used only for features that are part of a **fault-system** or **fault-zone**.

7 Dealing with scale and size

The key physical characteristics of most classes of discontinuity and filling stay essentially the same regardless of their size. For example, a **fault** is a **fracture** along which there has been discernible displacement parallel to surfaces, regardless of whether the feature is 1 μm wide or 1 km wide. Discontinuity classification is therefore based on properties other than size. This allows the great majority of discontinuities to be classified and named using a relatively small number of root terms. However, whilst in theory the physical characteristics of each class of discontinuity and filling are not size dependent, the practicalities of observation and measurement confer an implicit scale dependency on classification and nomenclature. This can cause difficulty and confusion when investigations take place over a range of scales. For example:

- A **fracture** (Rank 4) in crystalline rock showing no shearing displacement at core scale or outcrop scale should be classified at Rank 5 as a **joint**, whereas if the same feature observed at thin section scale showed shearing displacement of even a fraction of a millimetre it should be classified at Rank 5 as a **fault**.
- A single **fault** interpreted from seismic data may manifest as a number of faults (a **fault-zone**) distributed within tens of metres of borehole core. Similarly, a single **fracture** at outcrop scale may consist of several discrete fractures at thin section scale.

There is no easy solution to these problems. It is simplest and generally good practice to always state the medium and the scale or scale range at which measurements/observations are made and to which they apply. Use of the term 'scale' should be restricted to a record of the scale or scale range appropriate to a group of measurements or observations (e.g. '.. the following description was made at thin-section scale ..', and '.. several exposures of decametre- to 100 metre-scale crop out on the hillside ..'). It should not be used to record the extent of a feature property; for example, a phrase like '.. the fracture is mm scale width ..' should not be used (see Section 7.1 for the preferred alternative).

7.1 INDICATING SIZE

The term size refers to the relative bigness or extent of a measurable property. Use of terms that imply only relative size, such as 'large-scale' and 'micro-fault', is discouraged (because they depend on the scale of observation) in favour of measured or estimated sizes and size ranges. Discontinuity properties that have a size include length, width, persistence, displacement, aperture, and spacing (Tables 2 and 6). Size may be recorded as a specific measured or estimated value (e.g. 15 mm, 263 km), as a measured or estimated range (e.g. 5–15 mm), or as a size range (e.g. mm range, km range; see Table 7 for a full list of these terms and the size ranges to which they refer). Any reference to size must be accompanied by an indication of the measurable property to which it refers (e.g. '.. the **vein** is 15 mm wide ..', '.. the **fault** has a 3.5 metre offset ..', '.. the joints have 10 metre-range spacing ..').

In constructing a name for a discontinuity or filling, terms to indicate size and the measured property should precede the root term as qualifiers, for example *15 mm wide* **cataclasite**, *10 μm aperture* **pore**, *52 km long* **fracture-zone**. The size range terms in Table 7 can be used for generalised characterisation of the measured or estimated size of a property. When indicating a size range, the term 'range' must be included in the name or description, for example *km-range length* **fault** and *metre-range persistence* **joint**; this is because *km-range length* denotes 'between 1 and 10 km long' (see Table 7), whereas *km-length* could be taken to mean '1 km long'. The same approach should be used in descriptions of discontinuities; for example, '.. one set of 5–15 mm wide joints has 10 metre-range persistence and metre-range spacing at outcrop-scale ..'. When size data are included in tabulations of discontinuity data the measured properties will usually appear as column headers (e.g. 'Feature width', 'Persistence', 'Spacing'). More examples of the terminology recommended for providing details of size are given in Section 10.

The terms for grain-size divisions used in the BGS Rock Classification Scheme (e.g. Gillespie and Styles, 2011) can be used instead of numerical terms for grain size (e.g. '.. the **cavity** has a filling of *fine-sand-grade* **sediment** ..').

8 Terms to refer to the material hosting discontinuities

The terms damage zone, footwall, hanging wall, host rock and wallrock (all defined in the Glossary) should be used to refer generally to, or to specific parts of, the material hosting one or more discontinuities. For example, '.. the **fault-zone** has a damage zone up to 10 metres wide ..', and '.. the host rock to the **fault** is granite, but whereas the footwall contains numerous **joints** the hanging wall does not ..'.

9 Describing discontinuities in rock mass

There are many occasions when a geologist or engineer needs to describe the physical condition of a rock mass in terms of the nature and distribution of discontinuities. Applications can be divided into five categories:

- General information that should be acquired as part of any regional study in order to provide basic characterisation of a rock mass and provide baseline data for specialist applications.
- Civil engineering – characterisation of the rock mass as a whole for assessing the stability and/or support requirements for foundations, cuttings, tunnels etc. (e.g. Brown, 1981; Priest, 1993; Singh and Goel, 1999; BS5930, 1999).
- Structural geology – interpretation of the kinematic evolution of a rock mass, for example stress/strain analysis, fault movement history (e.g. Hobbs et al., 1976; Ramsay and Huber, 1983; Ameen, 1995; Jones et al., 2005).
- Studies of rock deformation – including analysis of the effect of discontinuities at the microscopic or sub-microscopic scale on the properties and behaviour of geological materials.
- Hydrogeology – understanding or predicting the influence of discontinuity distribution and transmissive properties on deep groundwater flux and potential contaminant transport.

The last four of these are specialised and each is associated with an extensive technical literature. Appropriately trained and experienced personnel generally carry out data acquisition and interpretation. The techniques depend upon the nature of the application, but they can be laborious, time-consuming, and expensive. A detailed description of these applications is therefore beyond the scope of this scheme.

The following descriptions concentrate on a general characterisation of rock mass that should be carried out during routine logging and/or mapping activities and is aimed at producing useful baseline data in a time- and cost-effective way. The approach to rock mass classification depends on the nature of the exposure. Information will typically be acquired from one- or two-dimensional exposures (borehole core or rock exposure). Some three-dimensional information will be provided by core volume, by the irregularity of a surface, or by two or more closely spaced boreholes or surfaces in different orientations. However, these tend to be treated as separate one- or two-dimensional exposures from which three-dimensional (3D) data can be interpreted. True 3D exposures (e.g. shafts, tunnels, and other large cavities) are encountered rarely and can be difficult to work in; even here, data acquisition is usually best carried out on two or more differently orientated, 2D surfaces.

The quality of the sample or exposure should be recorded, as this will influence the nature and quality of the description and classification.

9.1 SOME TERMS USED IN STUDIES OF DISCONTINUITIES IN ROCK MASS

The terms line-sample and scan-line (sometimes written as 'scan line' and 'scanline') are synonymous, and describe a linear sample of rock, in any attitude. The terms apply, for example, to descriptions of borehole core and linear traverses across a section. Section describes an areal sample of rock, in any attitude (e.g. an outcrop surface, thin section). Volume describes a 3D mass or sample of rock; the term applies, for example, to 3D exposures, interpretation/extrapolation of line-sample and/or section data to model the characteristics of a rock volume, and in seismic interpretation (particularly 3D). These terms apply at the full range of scales, including thin section scale, outcrop surface scale, aerial image scale, and satellite image scale.

Bias is the propensity of any exposure to provide only restricted information on the full range of discontinuities and fillings (or any other feature type) in the rock mass as a whole. This is related most commonly to the sample orientation compared with the range of discontinuity orientations (Terzaghi, 1965). Other examples of bias include the absence from some natural exposures of a soluble mineral filling, and poor core recovery in strongly jointed and faulted zones leading to an erroneous view of attributes such as fracture frequency and filling type. Censoring occurs when a method of data acquisition excludes or poorly represents discontinuities or fillings with a particular characteristic. For example, interpretation of borehole imagery by sine-curve fitting is ineffective for discontinuities that are near-parallel to the borehole orientation.

9.2 DATA LIMITATION

In any survey of a **discontinuity-network** the limitations of the sample, the scale, and the measurement techniques must be appreciated fully and recorded.

The orientation of a borehole or of a line-sample on a surface, and that of the surface itself, must be determined, as this is crucial for predicting and compensating for the effects of bias.

The maximum dimensions of discontinuities that can be determined from a borehole sample are a function of the discontinuity orientation relative to that of the borehole axis, and the diameter of the borehole (or imagery) and core. Similarly, data acquired from an exposure are limited in maximum length and spacing by the dimensions of the surface(s) available.

Lower limits of resolution of discontinuity length and width may be determined automatically by what is visible or resolvable; for example, hairline fractures may not be visible in wet core; a single feature observed by eye at exposure-scale may consist of several features at thin-section scale, and features identified from an aerial photograph or satellite image may have minimum dimensions of metres or tens of metres. In practice, it may be appropriate to place arbitrary minimum dimensions on the features that will be recorded, especially in rock containing a large number of discontinuities; for example, in a study of outcrop the minimum dimension of recorded features could be set at 10 cm.

The use of particular names may also be determined by scale and resolution. A feature recorded as a *non-filled* **joint** during core logging may contain a film of mineralisation, and would be recorded as a *mineralised* **joint** during thin section examination. Classifying a feature as a **fault** or a **shear-band** can be particularly difficult in this context because of the need to identify a shearing-displacement, giving a cut-off that may vary from several metres or more in seismic data to a millimetre or two in exposure and core, and less in thin section.

9.3 DISCONTINUITY FREQUENCY AND DENSITY

Some quantification of the number or proportion of discontinuities in a rock mass is fundamental to describing a **discontinuity-network**, or some part of it. A range of approaches can be used, the simplest of which involves measurements of discontinuity frequency and density.

Frequency (e.g. Priest, 1993) is the number of discontinuities in a unit volume, unit area, or unit length of a rock mass sample. It is relatively easy to calculate from a line-sample or section, but is of limited use without some means of combining information relating to discontinuity length. Volumetric frequency is more comprehensive as it requires definition of some unique point on each feature (usually the centre) whose location can be determined. This can then be coupled with length information.

Density provides a measure of the proportion of discontinuities in a rock mass, expressed per metre, and determined by either the number of discontinuities intersecting a line-sample, the trace length of discontinuities per unit area measured on a section, or (in theory, being difficult to achieve in practice) the area of discontinuities per unit volume. This fully quantifies the proportion of discontinuity in a rock mass, although it provides no information about their distribution, organisation or connectivity.

In a borehole sample, scan-line or other measurement on an exposure surface, the discontinuity frequency or density is relatively simple to determine. It may, however, be subject to bias (see above) if the sample is not orientated at a high angle to the discontinuities. It must also take account of core sections that are not intact or are missing, or non-exposed areas that may render the measured value(s) inaccurate.

A very large body of published literature relates to rock mass characterisation for engineering purposes, the details of which are beyond the scope of this report. Rock quality designation (RQD; e.g. BS5930, 1999) is used extensively for engineering purposes, providing a relatively simple measure of core recovery combined with some information relating to fracture frequency and spacing. Other measures such as the volumetric joint count and weighted joint density (e.g. Palmstrom, 1996; Singh and Goel, 1999) attempt to relate surface observations to those made from core, the latter incorporating information on fracture orientation relative to the borehole or scan-line. The rock mass quality index (Barton et al., 1974) incorporates RQD, number of joint sets, joint roughness and alteration, and measures of water pressure and stress, to produce a comprehensive classification of rock strength for civil engineering purposes.

9.4 DISCONTINUITY SPACING

A **discontinuity-network** in which the features are randomly orientated is characterised adequately by the discontinuity density (see above), or by the size range of blocks bounded by the discontinuities. As the network becomes more organised, sets of discontinuities can be identified and characterised by means of their spacing and attitude. Spacing can be expressed either numerically as a range (e.g. *10–50 cm*) or by means of descriptors (e.g. *closely spaced*, *widely spaced*) applied to pre-defined class intervals (e.g. BS5930, 1999). Expression as a numerical range (see Section 7) is strongly preferred, especially where variation is such that the range encompasses two or more class intervals.

9.5 DISCONTINUITY ATTITUDE

Discontinuity attitude is characterised by measurement of dip amount and dip or strike direction. A range of conventions can be used to record this information, but 'dip and dip azimuth' (e.g. 40/140, meaning 'dipping 40º towards 140º') is arguably the simplest to understand and the least confusing. This convention has been adopted by the BGS SIGMA (System for Integrated Geoscience Mapping) project, and it should be used for measuring the attitude of discontinuities in any setting.

Class intervals of dip angle (e.g. *gently dipping*; Table 2) and dip direction (north, south-east, west-south-west etc.) can be used where a more general description is appropriate, but numerical ranges should be recorded where possible. Class intervals are most useful where features are not perfectly exposed, for example when a discontinuity manifests only as a trace on a smooth exposure surface, such that only a general indication of dip and/or dip direction can be determined.

In core, without additional information, it is possible only to derive dip relative to the core axis and dip direction relative to other features within each intact core stick. Core orientation is carried out routinely by various methods, allowing the original attitude of many features to be determined, although particular care has to be taken in data processing. Discontinuity attitude data can be obtained from processed images of the borehole wall, which commonly provide better coverage than core. Whilst these produce accurate orientation of imaged features, not all discontinuities will be imaged satisfactorily, and some features may be misinterpreted as discontinuities. Integration of data from core examination and borehole images is ideal, but rarely achievable, although the two datasets can be used side-by-side to good effect (e.g. Barnes et al., 1998, 2003).

Users of discontinuity attitude data must bear in mind the bias inherent in such data. Where possible, bias should be compensated for (e.g. Terzaghi, 1965; Priest, 1993; Barnes et al., 2003) to improve estimates of the attitude and density of discontinuity networks.

9.6 DISCONTINUITY LENGTH

Discontinuity length data quantify the vertical and horizontal extent of a discontinuity. It is an important parameter, best acquired from the study of two or more approximately perpendicular surfaces of dimension greater than that of the longest features. In practice, the data are 'capped' by the extent of the available exposure. The degree of resolution, and any arbitrary parameters that are fixed to restrict data acquisition, also limit the data (see above). In particular, single long features viewed from a distance may, with greater resolution, be composed of much shorter en echelon or parallel overlapping (e.g. left stepping or right stepping) features.

When making summary observations, length is best presented as a numerical range (e.g. *10–200 cm*) and should be defined for each discontinuity **set**, noting any restrictions on the data (e.g. the extent of the exposure).

In scan-line studies, discontinuity length is measured in two parts on either side of the line. The nature of any terminations should also be noted (e.g. in rock or at intersection with another discontinuity).

9.7 DISCONTINUITY CONNECTIVITY

Connectivity is a measure of the degree to which discontinuities in a **network** intersect other discontinuities. This is a function of the length, spacing, and attitude of the component discontinuities. For general purposes connectivity is usually quantified qualitatively, using terms like *poorly connected* and *well connected* (e.g. *poorly connected* **joint-network**). In practice, the term 'connectivity' usually refers to the extent to which a **discontinuity-network** affects the passage of fluid through a rock mass; in this context it is a measure of the degree to which transmissive discontinuities in a network intersect other transmissive discontinuities. This will be a function of aperture and filling character, as well as length, spacing, and attitude.

If a volume of rock contains only features that are near-parallel and/or relatively short, such that they do not intersect, then the discontinuities can store fluid in **pores** but transmission is limited by the permeability of the intervening rock matrix. Such a network may be termed *non-connected*. If a few features intersect but the majority do not, then it is a *poorly connected* **network**. At the other end of the spectrum, three mutually orthogonal sets of joints, each with a minimum length of twice the spacing of the two other sets, would be a *very well connected* **joint-network**. Note that, depending on the detail of the **discontinuity-network**, small parts may be relatively well connected but not linked to any other part, forming isolated or dead-end 'sub-networks'.

Accurate determination of connectivity is generally possible only by well testing or by excavating the entire rock mass. Otherwise it is limited by the same factors that restrict the determination of length, attitude, and spacing. Direct information is best acquired from a study of two or more approximately perpendicular surfaces, of dimension greater than the largest spacing between the features within the scale of interest.

10 Examples of how the scheme should be used

This section presents examples of natural discontinuities encountered in a range of lithologies and geological situations, and at a range of scales. It aims to provide guidance in applying the classification scheme and the terminology described above, and to illustrate some of the practical problems in describing natural discontinuities.

Discontinuity characteristics may be described for individual features or in summary terms for networks and other associations. To an extent this is a matter of the scale of observation. For example, joints or veins at outcrop may be distributed throughout the rock mass and will commonly be described in summary terms, whereas relatively few faults may be observed, and consequently these will be described individually. In borehole core it is common practice to describe each feature individually.

It is important to record, at least in general terms, the <u>spacing</u>, <u>length</u>, nature of terminations (if seen), and <u>attitude</u> of discontinuities. Observations should be made of any relationship with other geological features (e.g. sedimentary structures, igneous or metamorphic fabric), as these may have influenced the development of discontinuities in terms of spacing and continuity/length. In a well-organised **discontinuity-network** it should be possible to record the nature of discrete sets of features (as opposed to individual features), and to document their inter-relationships. A less well-organised to randomly orientated **discontinuity-network** may be more difficult to characterise in this way, and it may be appropriate to make summary observations of the size and shape of the blocks between discontinuities. Note that both disorganised and organised discontinuities may form parts of a **discontinuity-network** within the same rock mass.

The names and descriptions of discontinuities will, to some extent, be context-specific; for example, a feature can if necessary be named/described as a *sub-mm width, non-filled, gently dipping (0–10°, bedding-parallel), planar* **joint**, but commonly a name like *bedding-parallel* **joint** or simply **joint** will be sufficient, especially once the feature has been classified and named formally.

The examples shown below can only be indicative of the process of discontinuity description and name construction. The order in which qualifier terms are listed in names cannot be prescribed, but it would be good practice to maintain a consistent approach within a project.

10.1 DISCONTINUITIES AT OUTCROP SCALE

This section provides a few examples that illustrate a practical application of this scheme at the outcrop scale.

10.1.1 Bedding and joints in Triassic sandstone

The St Bees Sandstone Formation, well exposed at St Bees Head, Cumbria (Figure 4), is a fluviatile succession in which the sandstone forms tabular beds of metre-range thickness, separated by well-defined bedding planes that may exploit thin mudstone beds. Tabular and lenticular cross-laminated units dominate the internal structure of the sandstone beds, but the upper part of depositional units may be laminated parallel to bedding. The **fracture-network** is relatively simple, comprising gently dipping fractures parallel to bedding and one set of steeply dipping fractures at a high angle to bedding.

Bedding-parallel fractures (Figure 4) correspond with the main bedding planes, especially at thin mudstone beds, but also occur within beds along lamination or unrelated to observable sedimentary features. The main bedding planes are laterally very extensive (hundreds of metres are visible along the surface of the exposure), whereas breaks, either along lamination or unrelated to observable sedimentary features, vary from a few tens of centimetres to a few metres in length, and die out within the rock. Spacing varies within the height of the 50 metre cliff; in the lower part a small number of fractures have 10 cm- to m-range spacing, but in the upper 20–30 metres bedding-parallel discontinuities become common, with spacing typically of 10 cm-range. Attitude is generally as for bedding, dipping 5–10° south-south-east, but some variability is introduced where fractures are developed along cross-lamination. There is little or no basis for establishing displacement because these features are parallel to the bedding planes, although in this situation it is reasonable to assume that no movement has occurred. Most of the features have no observable aperture, but some can 'weep' in dry weather indicating that they have sufficient aperture to allow the passage of water. There is no visible filling.

Summary description: non-filled, planar, gently dipping (0–10°, bedding-parallel) joints of m- to 100 m-range length, sub-10 μm width, and cm- to m-range spacing.

At high angle to bedding, a set of near-vertical discontinuities (dipping 80–90° towards 070° ±10° and 250° ±10°) has spacing from a few tens of centimetres to 2 metres. Length is generally a few metres but ranges up to at least 50 metres (the height of the cliff) in a few cases. These features commonly terminate at bedding-parallel fractures. Their shape can be determined in three dimensions where both cliff and foreshore exposures are available; most are planar although some may be slightly curved. In the cliff, most have an observable (sub-100 μm width) aperture, but this may be due to cliff instability; fractures exposed on rock surfaces on the beach tend to have no observable aperture. Most have no visible filling.

Summary description: non-filled, planar joints of m- to dm-range length, sub-10 *μm*- to 100 *μm*-range width, cm- to m-range spacing, dipping 80–90° towards 070° ±10° and 250° ±10°.

It is not evident in this example, but in sequences with variable bed thickness there is commonly a crude relationship between the spacing of fractures at a high angle to bedding and bed thickness, with fractures spaced more closely in thinner beds (e.g. Ladeira and Price, 1981).

10.1.2 Deformation bands, Triassic sandstone

Exposures of laminated sandstone of the Helsby Sandstone Formation, Sherwood Sandstone Group, in Wirral, Cheshire, display two sets of breaks dipping 50–60° towards the north-west and 60–70° towards the south-east (Figure 5). Spacing in each set varies from 10 cm-range to m-range, although on close inspection some apparently discrete structures are composed of two or more features with mm-range spacing. Length is usually greater than the 2–3 metres height of the exposure, although within this a few features terminate in rock or at intersections with other features. The breaks consist of a clearly resolvable band (i.e. they have a perceptible width) and generally lack an obvious discrete filling, hence they can be assigned to the 'Tabular deformation breaks class' and each can be given the root term **deformation-band**. Each band ranges from 1 to 10 mm wide and consists of a conspicuous, fine-grained, white or pale grey material. The 3D form of these discontinuities cannot be determined from the smooth exposure surface, beyond observing that their traces are straight.

Though the texture of the deformation-bands is too fine-grained to examine in detail in the field, their overall appearance and location within a unit of porous aeolian sandstone suggests they are a product largely of closing displacement. They can be divided into two classes according to their effect on the sandstone lamination:

- Most have caused no perceptible surface-parallel displacement of the lamination and could therefore be described as 'planar, moderately to steeply north-west- and south-east-dipping compaction-bands of m-range length, mm-range width, and 10 cm- to m-range spacing'.
- A few have caused visible surface-parallel displacement of the lamination of a few mm to a few cm, either down-dip of the feature (normal) or up-dip (reverse), and could therefore be described as 'planar, moderately to steeply north-west- and south-east-dipping compactional-shear bands of m-range length and mm-range width, with mm- to cm-range normal or reverse displacement, and m- to dm-range spacing'.

The features could be described collectively as 'planar, moderately to steeply north-west- and south-east-dipping compaction-bands and compactional-shear bands of m-range length, mm range-width, and 10 cm- to m-range spacing'.

Discontinuities of this type are common in aeolian sandstone, typically where porosity is high. Thin section examination of one feature (Figure 5) reveals comminuted crystals of the host rock, authigenic clay, significantly reduced porosity relative to the host rock, and rather diffuse, irregular interfaces with the wallrock. The field evidence for a small amount of surface-parallel displacement on some features, and the presence of authigenic clay, suggests that some contain fault-rock (i.e. there is a filling component within the discontinuity). Much of this is non-porous **mesocataclasite**, with several very thin bands of pale green **ultracataclasite**. The **discontinuity** is clearly much less permeable than the host porous sandstone, and will act as a baffle or barrier to intergranular fluid flow. This feature could be described as 'planar, 0.5 mm wide **compactional-shear-band**, with a compound **filling** of **mesocataclasite** and several 10 μm-range width bands of clay-rich **ultracataclasite**'.

10.1.3 Faults in Triassic sandstone

In the southern part of St Bees Head, the St Bees Sandstone Formation includes a zone of faults (Figure 6) orientated almost perpendicular to the **joint-set** described in Section 10.1.1.

The fractures fall largely into two steeply inclined sets (both dipping approximately 70°, symmetrical about normal to bedding), with m- to dm-range spacing, although features may locally be clustered with cm- to 10 cm-range spacing. Length varies from m-range to dm-range, with many features persisting throughout the 30–40 metre high cliff. Little foreshore exposure is available, therefore observations of form are restricted to the straight trace on the cliff surface; limited depth of exposure suggests they are planar. Most of these fractures show a measurable, down-dip (normal) displacement of the bedding, typically ranging from a few mm to a few metres. Smaller features tend to have little or no perceptible aperture but some longer features may be mm- to cm-range width, with a filling of fine **fault-breccia**.

Summary description: non-filled or locally fault-breccia-filled, planar, steeply north-east- and south-west-dipping **faults** of m- to dm-range length and sub-10 μm- to cm-range width, with mm- to dm-range displacement and m- to dm-range spacing.

The two sets have an angular relationship of about 60° and thus may be said to be conjugate, implying a genetic relationship. Fractures in both sets may terminate or displace features of the other set, suggesting they formed contemporaneously.

10.1.4 Fractures in Ordovician ignimbrite

The discontinuity characteristics of massive or foliated ignimbrite, exposed in Borrowdale Volcanic Group rocks in west Cumbria, were studied in some detail as part of the 1980s and 1990s UK Nirex Ltd. Programme, researching a possible underground repository for nuclear waste in an analogous lithology at depth to the west. Data were obtained by means of trace maps and scan-lines from mainly near-horizontal surfaces up to a few metres in extent, but including near-vertical surfaces where available. Examples of the trace maps are shown in Figures 7, 8, 9, and 10.

Trace mapping could take several days at each site: exposures were cleaned of all soil and vegetation; scale-accurate maps were made on graph paper facilitated by a 1 metre x 1 metre grid divided into 10 cm squares moved incrementally over the exposure. A 50 cm fracture length cut-off was commonly used but some small areas were mapped in greater detail. Details of individual discontinuity properties (orientation, length, aperture, width, filling etc.) were tabulated.

Scan-lines (e.g. Figure 11) provided more systematic measurement of each feature encountered along a line across the exposure surface. For the example illustrated on Figure 11, the line, on a gently sloping surface, was provided by a tape measure.

With either method, accurate measurement of dip can be difficult on smooth exposure surfaces; this is particularly so if the features have eroded into recesses, hence study of adjoining steep or vertical faces can be invaluable.

Fractures observed in the ignimbrite unit exposed at outcrop vary in character. They are typically non-filled, planar or curved, and commonly have perceptible width or aperture; they could be described as 'non-filled, planar and curved, gently, moderately and steeply dipping fractures with cm- to m-range length and spacing, and <10 μm-range aperture'. Some of these discontinuities have a visible aperture, generally mm-range or less (commonly varying along the length of a single discontinuity); a few have a mineral filling and could be described as 'hematite-quartz veins of 100 μm- to mm-range width'. The massive nature of the rock means it is rarely possible to demonstrate whether or not displacement has occurred, hence the term fracture is preferred to joint or fault. Crossing fractures may appear to be offset, suggesting displacement, but this may be misleading; if displacement can be demonstrated then it would be appropriate to classify such a feature as a fault.

10.2 DISCONTINUITY OBSERVATIONS IN BOREHOLE CORE

Figure 12 is a mock discontinuity log for an imaginary borehole core, illustrating how a spreadsheet could be designed to suit a specific task and populated using the terms and conventions proposed in this scheme.

The example in Figure 13 is a real log of discontinuities and fillings in borehole core, used for parameterisation of geotechnical and hydrogeological models in the 1990s UK Nirex Ltd. investigation of a proposed site for an underground nuclear waste repository at Sellafield, Cumbria. A detailed key to the information and abbreviations used in creating the log accompanies the full log document. A key should accompany any log or spreadsheet designed for a specific project or purpose.

The page shown in Figure 13 (one of many hundreds required to log over 1100 metres of core in this borehole) is divided into three parts. The top and bottom parts contain details of the client, borehole, relevant core run and stick depths, logger and logging date, and quality control information and checks. The log forms the major, central part of the page. At the right, a hand-drawn graphical log at a scale of 1:10 illustrates the distribution of discontinuities on the top surface of the core, as seen when the core is laid out horizontally for logging with the reference lines at the top. Every discontinuity illustrated on the graphical log is assigned a number, usually in sequence from the top to the base of each core run. Each discontinuity is uniquely identified by the borehole number, core run number, and discontinuity number, for example 'borehole 12A, feature 164/23'. The discontinuity number is repeated at the far left, at the horizontal position on the page where the same number appears adjacent to the graphical log, and information about each discontinuity is recorded in a row between the two numbers.

The log illustrated in Figure 13 has been designed specifically to record information about discontinuity depth, type, attitude, width, aperture, filling, and surface character; there is also a separate column for comments. Key features are summarised below.

- The depth of discontinuity is given in metres below rotary table, measured to the mid-point of inclined discontinuities.
- Discontinuity 'type' is divided into two categories, recorded as single letter abbreviations in parallel columns. The left column records whether the feature type is bedding (B), cleavage (C), fracture (F), joint (J), stylolite (S), vein (V), or fault (Z). The right column records a combination of the origin and character of the feature: natural break–continuous (C); natural break–discontinuous (T); physical break of uncertain origin (U); healed discontinuity–continuous (H); healed discontinuity–discontinuous (G); physical break–drilling induced along existing plane (D); physical break–drilling induced unrelated to plane (B).
- Attitude is recorded as separate dip and dip azimuth values, the latter measured in degrees clockwise from a red reference line drawn on the core surface and parallel to the core axis, to the maximum dip direction on the lower surface of the discontinuity. These 'relative' attitude data can subsequently be corrected to 'true' attitude if the core stick can be orientated, for example by matching the discontinuities in the core to those displayed in borehole wall imagery.
- Minimum and maximum discontinuity width is recorded using a standard set of abbreviations from BS5930 (1999); for example, W (wide) = >200 mm; MN (moderately narrow) = 20–60 mm; VN1 (very narrow subdivision 1) = 4–6 mm; EN2 (extremely narrow subdivision 2) = 0.5–1 mm; and T (tight) = <0.1 mm.
- Discontinuity aperture is recorded as four variants: T (tight) = <0.1–0.5 mm; G (gapped) = 0.5–2 mm; O (open) = >2 mm; and V (vuggy). The aperture of vuggy pore space is usually recorded in the 'Comments' column.
- The nature of fillings (the term 'infill' is used instead of 'filling' in the example shown) is recorded as single letter abbreviations of, or codes for, mineral names and other materials, for example, C (calcite), E (epidote), G (fault gouge), H (hematite). Two or more of the mineral abbreviations are listed to note the presence of two or more minerals.
- Finally, discontinuity surface information is recorded using two sets of abbreviations from BS5930 (1999). Four describe waviness (W), namely: I (irregular), P (planar), S (stepped), and U (undulating). Four describe roughness (R), namely: R (rough), S (smooth), P (polished), and K (slickensided).

Cross-hatching is used on the graphical log to indicate sections of non-intact core or partial core loss, and single hatching (not shown on this example) is used to indicate a zone of many discontinuities.

Example descriptions made using the terminology and conventions set out in these proposals for a range of discontinuities and fillings in borehole cores are presented in Figures 14, 15, 16, 17.

10.3 DESCRIPTION OF A DISCONTINUITY AND FILLING IN THIN SECTION

A photomicrograph of a thin section containing several generations of discontinuities and fillings, and a description of it using the terminology and conventions set out in these proposals, are presented in Figure 18.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

AMEEN, M S (editor). 1995. Fractography: fracture topography as a tool in fracture mechanics and stress analysis. *Geological Society of London Special Publication*, No. 92.

BARNES, R P, DEE, S J, SANDERSON, D J, and BOWDEN, R A. 1998. Interpretation of structural domains in discontinuity data from Nirex deep boreholes at Sellafield. *Proceedings of the Yorkshire Geological Society*, Vol. 52, 177–187.

BARNES, R P, DEE, S J, and SANDERSON, D J. 2003. Characterization of fracture networks using data from boreholes: an example from the concealed Borrowdale Volcanic Group in West Cumbria, UK. Chapter 19 *in* Geological applications of well logs. LOVELL M, and PARKINSON, N (editors). *American Association of Petroleum Geology, Methods in Exploration*, No. 13.

BARTON, N, LIEN, R, and LUNDE, J. 1974. Engineering classification of rock masses for the design of tunnel support. *Rock Mechanics*, Vol. 6, 183–236.

BRODIE, K, FETTES, D, and HARTE, B. 2007. Structural terms including fault rock terms. 24–31 in *Metamorphic rocks: a classification and glossary of terms*. FETTES, D, and DESMONS, J (editors). (Cambridge: Cambridge University Press.)

BROWN, E T. 1981. *Rock characterisation, testing and monitoring: ISRM suggested methods*. International Society for Rock Mechanics. (Oxford: Pergamon Press.)

BS5930. 1999. *Code of practice for site investigations*. (London: British Standards Institution.) ISBN 978 0 580 61622 8.

GILLESPIE, M R, and STYLES, M T. in press. BGS Rock Classification Scheme Volume 1 (rev. 2010): Classifying and naming igneous materials. *British Geological Survey Research Report*.

GILLESPIE, M R, STEPHENSON, D, and MILLWARD, D. 2008. BGS classification of lithodemic units: proposals for classifying units of intrusive rock. *British Geological Survey Research Report*, RR/08/05.

HOBBS, B E, MEANS, W D, and WILLIAMS, P F. 1976. *An Outline of Structural Geology*. (New York: Wiley.)

JONES, R R, HOLDSWORTH, R E, MCCAFFREY, K J W, CLEGG, P, and TAVARNELLI, E. 2005. Scale dependence, strain compatibility and heterogeneity of three-dimensional deformation during mountain-building: a discussion. *Journal of Structural Geology*, Vol. 27, 1190–1204.

LADEIRA, F L, and PRICE, N J. 1981. Relationship between fracture spacing and bed thickness. *Journal of Structural Geology*, Vol. 3, 179–183.

MANDL, G. 2000. *Faulting in brittle rocks: An introduction to the mechanics of tectonic faults*. (Heidelberg: Springer.)

MCMILLAN, A A, and POWELL, J H. 1999. BGS Rock Classification Scheme Volume 4: classification of artifical (man-made) ground and natural superficial deposits. *British Geological Survey Research Report,* RR/99/04.

NEUENDORF, K K E, MEHL JR, J P, and JACKSON, J A (editors). 2005. *Glossary of Geology.* Fifth Edition. (Alexandria, Virginia: American Geological Institute.)

PALMSTROM, A. 1996. Characterizing rock masses by the RMi for use in practical rock engineering — Part 1: the development of the rock mass index (RMi). *Tunneling and Underground Space Technology*, Vol. 11, 175–188.

PRIEST, S D. 1993. *Discontinuity analysis for rock engineering*. (London: Chapman and Hall.)

RAMSAY, J G. 1980. Shear zone geometry: a review. *Journal of Structural Geology*, Vol. 2, 83–99.

RAMSAY, J G, and HUBER, M I. 1983. *The techniques of modern structural geology, Volume 1.* (London: Academic Press.)

SCHULTZ, R A, and FOSSEN, H. 2008. Terminology for structural discontinuities. *Bulletin of the American Association of Petroleum Geology*, Vol. 92, 853–867.

SINGH, B, and GOEL, R K. 1999. *Rock mass classification: a practical approach in civil engineering*. (Oxford: Elsevier.)

TERZAGHI, R D. 1965. Sources of error in joint surveys. *Geotechnique*, Vol. 15, 287–304.

VAN DER PLUIJM, B A, and MARSHAK, S. 1997. *Earth structure: An introduction to structural geology and tectonics*. (New York: McGraw-Hill.)

WISE, D U, DUNN, D E, ENGELDER, J T, GEISER, P A, HATCHER, R D, KISH, S A, ODOM, A L, and SCHAMEL, S. 1984. Fault-related rocks: suggestions for terminology. *Geology*, Vol. 12, 391–394.

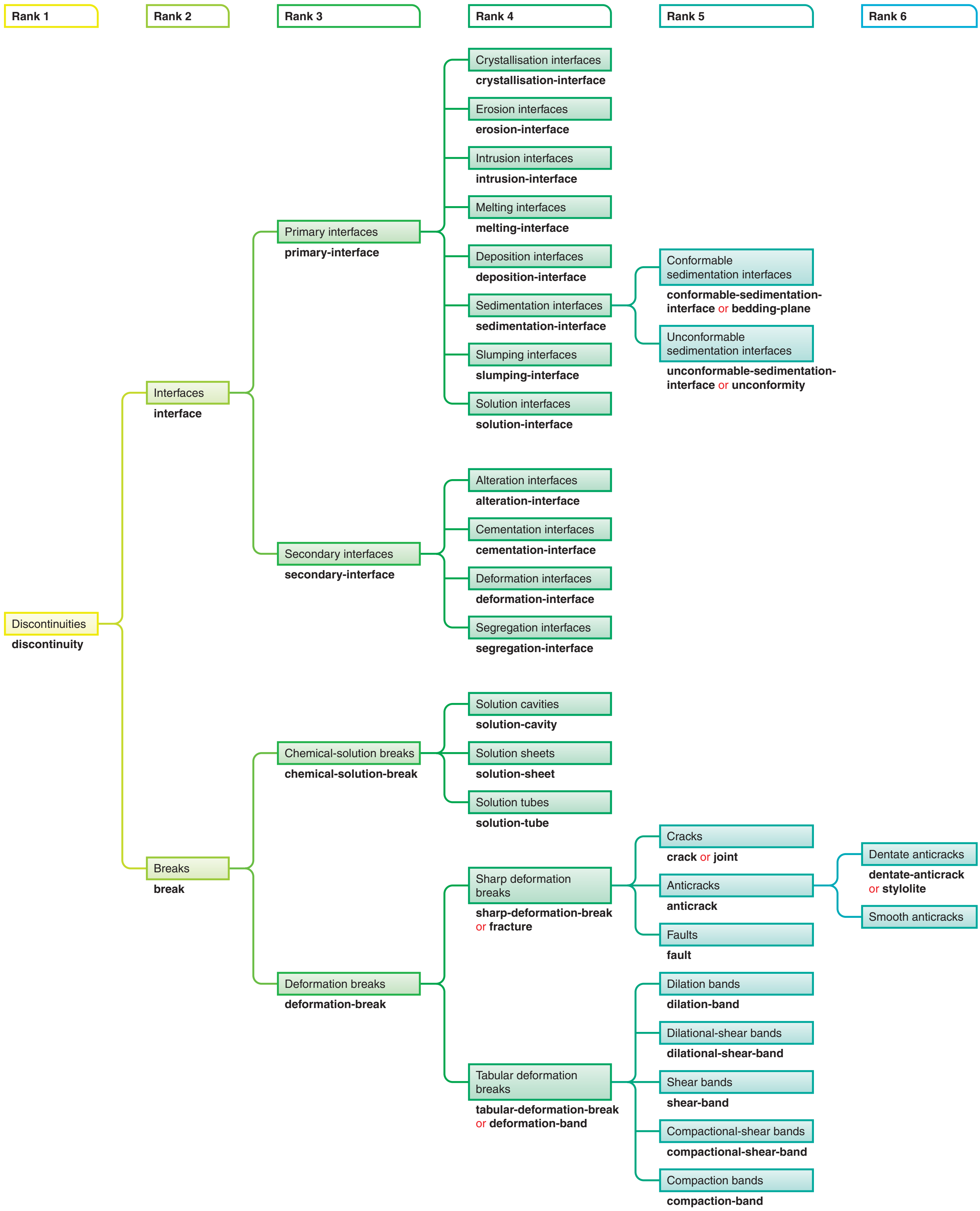


Figure 1 Hierarchical classification of natural discontinuities.

Terms within boxes are class names, terms in bold black text are the associated root terms.

Approved terms with more specific meaning can substitute for the 'process' term in the root terms for interfaces at Rank 4, for example **weathering-interface** and **redox-interface** instead of **alteration-interface**, **abrasion-interface** instead of erosion-interface, and **precipitation-interface** instead of **deposition-interface**.

The term 'front' can replace 'interface' in the root terms for interfaces that migrate as they form, for example **alteration-front**, **sedimentation-front**, and **solution-front**.

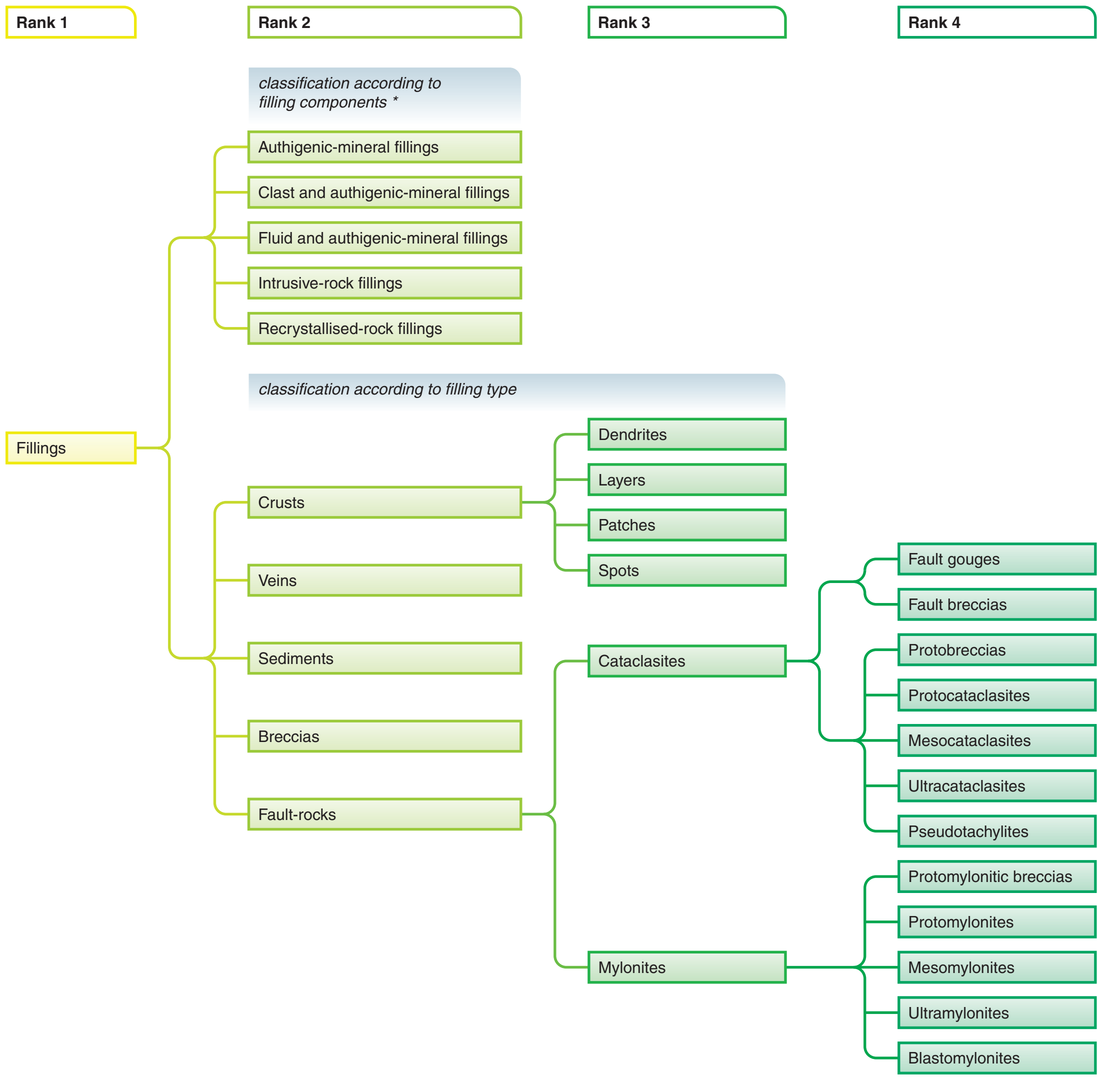


Figure 2 Hierarchical classification of fillings.

Terms within boxes are class names. Most classes in this figure have one associated root term, which is the singular form of the class name, hyphenated where it consists of more than one word; for example **vein**, and **fault-breccia**. However, more specific terms can substitute for general terms in the root terms for fillings classified according to filling component (Rank 2), yielding numerous possible root terms, for example **groundwater-calcite-filling** instead of **fluid-authigenic-mineral-filling**.

* This is a small selection of all possible classes of filling classified according to filling component.

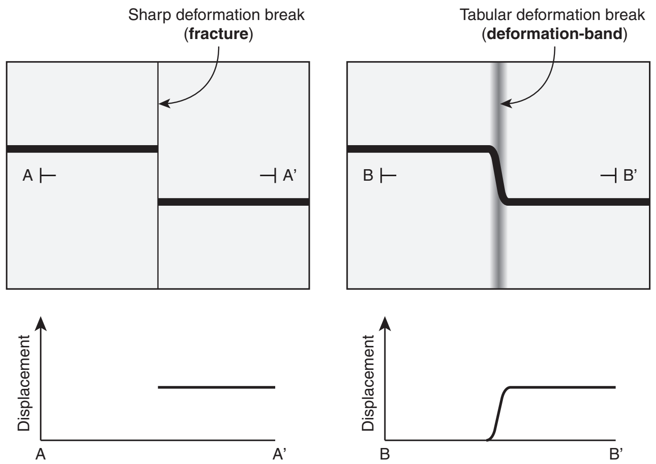


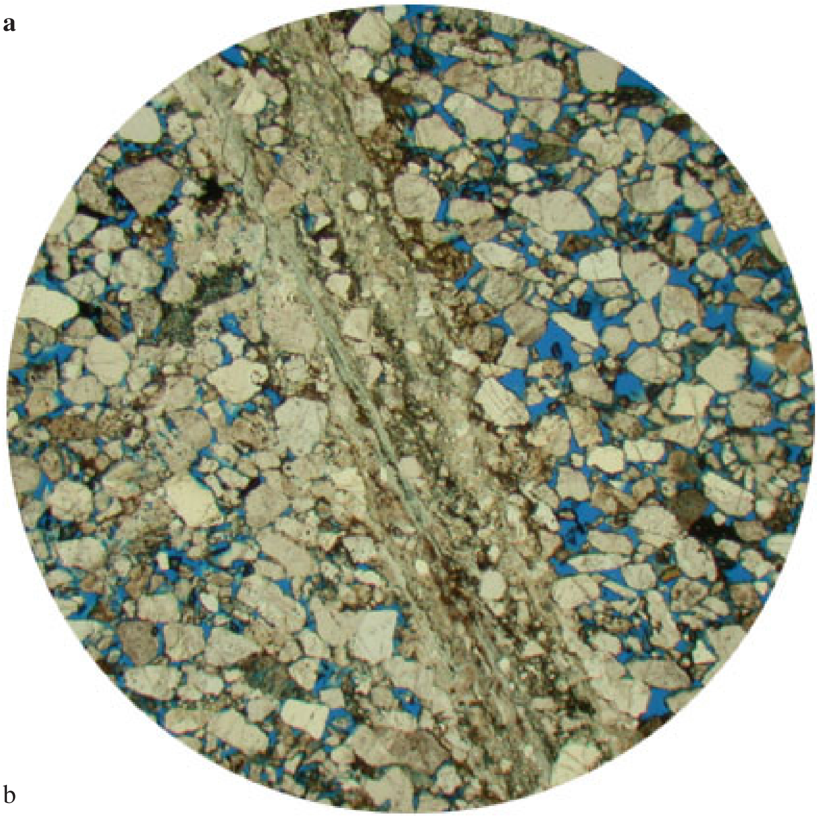
Figure 3 Schematic illustration of the basis for dividing and distinguishing fractures and deformation-bands (from Schultz and Fossen, 2008). An abrupt, stepwise change in the rate of displacement across a break creates a sharp deformation break (**fracture**). This typically has a negligible thickness of deformed material at the scale of observation, and consists of two sharply delineated and well defined opposing surfaces in contact or close proximity. A continuous change in the rate of displacement creates a tabular deformation break (**deformation-band**), which is characterised by a discernible band of deformed material at the scale of observation.

Figure 4 Example description of discontinuities at outcrop (St Bees Head, Cumbria).

Description: oblique view looking north of north-west-trending cliff up to 50 m high in the St Bees Sandstone Formation. The fracture-network consists of two sets of features: non-filled, planar, gently dipping (0–10°, bedding parallel) joints of m- to 100 m-range length, sub-10 µm width, and cm- to m-range spacing (developed along bedding-planes and within sandstone beds) are most evident in the upper part of the cliff; non-filled, planar joints of m- to dm-range length, sub-10 µm- to 100 µm-range width, cm- to m-range spacing, dipping 80°–90° towards 070°±10° and 250 ±10°.

See section 10.1.1 for more details.

a



b

Figure 5 Example description of discontinuities in Triassic sandstone at outcrop (a) and in thin section (b) (Thurstaston Hill, Wirral, Cheshire). See Section 10.1.2 for more details.

(a) Description: Perpendicular view of northwest-trending section, in a roadside cutting up to 2 m high. Two conjugate sets of moderately to steeply, north-west- and south-east-dipping compaction-bands and compactional-shear-bands are of m-range vertical length, µm- to mm-range width, and decimetre-range spacing.

(b) Description: A blue-dye resin impregnated thin section, prepared across a **compactional-shear-band** from Thurstaston Hill, reveals the feature to have rather diffuse, irregular interfaces with the wallrock, and a compound filling of **mesocataclasite** and several 10 µm-range width bands of **ultracataclasite**. Field of view about 2.5 mm.

Figure 6 Example description of discontinuities at outcrop (St Bees Head, Cumbria).

The gently dipping (bedding parallel) features are described in Figure 4, which shows a nearby section of the same cliff. See Section 10.1.3 for more details.

Description: Perpendicular north-east view of north-west-trending cliff up to 40 m high showing two conjugate sets of faults with normal (down-dip) displacements in the St Bees Sandstone Formation. Two through-going faults (1) are planar and steeply inclined (south-east dipping), with dm-range vertical length, mm- to cm-range width, and fillings of **fault-breccia**. Between these, a second set of faults (2) are planar and steeply north-west dipping, with m- to dm-range vertical length, mm-range width, mm- to cm-range displacement, and dm- to m-range spacing.

Figure 7 Example trace map of a discontinuity-network displayed on a sub-horizontal exposure surface in welded tuff, Gosforth, Cumbria. Three sets of discontinuities can be discerned: north- to north-north-west-trending, steeply dipping to vertical, dm-range horizontal length fractures have m-range spacing; west-north-west- to north-west- and east-north-east- to north-east-trending, vertical to moderately dipping, 10 cm- to m-range horizontal length fractures have cm- to 10 cm-range spacing. All are non-filled, with µm- to 1 mm- range apertures. The majority are straight (implying planar features), but some are curved or wavy (implying more irregular features). The **discontinuity-network** is well connected at the outcrop scale.

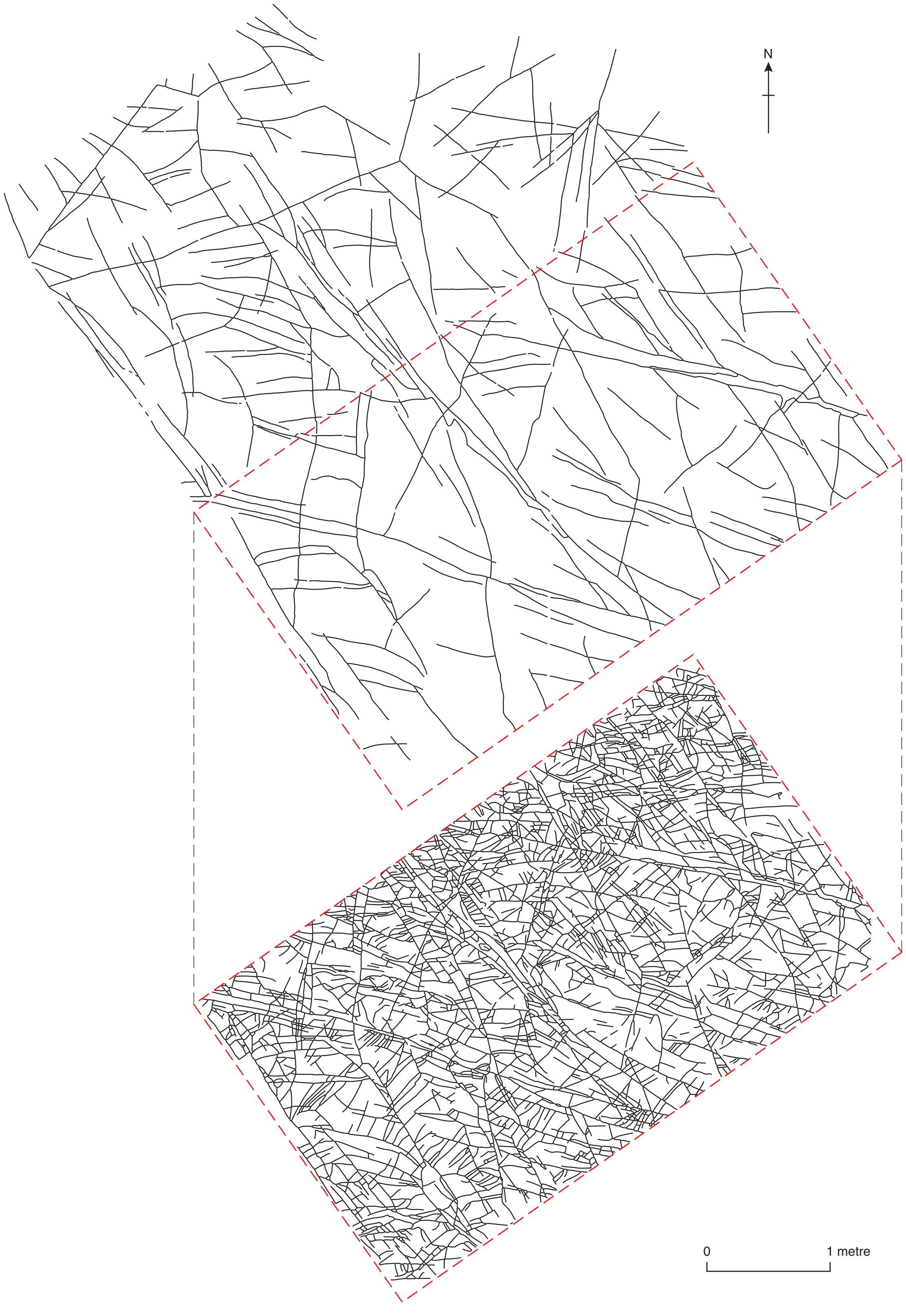


Figure 8 Example trace map of a **discontinuity-network** displayed on a subhorizontal exposure surface in welded tuff, Gosforth, Cumbria. This example presents an illustration of the effect of a size cut-off for mapped features: in the upper diagram, only discontinuities greater than 50 cm long were mapped, while the lower diagram shows a trace map of all the discontinuities that can be discerned on the exposure surface within the area outlined by the dashed red line.

Figure 9 Example trace map of a **discontinuity-network** displayed on a near-vertical exposure surface in a felsite intrusion, Gosforth, Cumbria. The face is inclined 84° south-south-east, and two discontinuity sets are evident: one has 10 cm- to m-range spacing, with an apparent dip to the west (left); in the other set, discontinuities with cm- to 10 cm-range spacing and a gentle/moderate apparent dip to the east form clusters with m-range spacing.

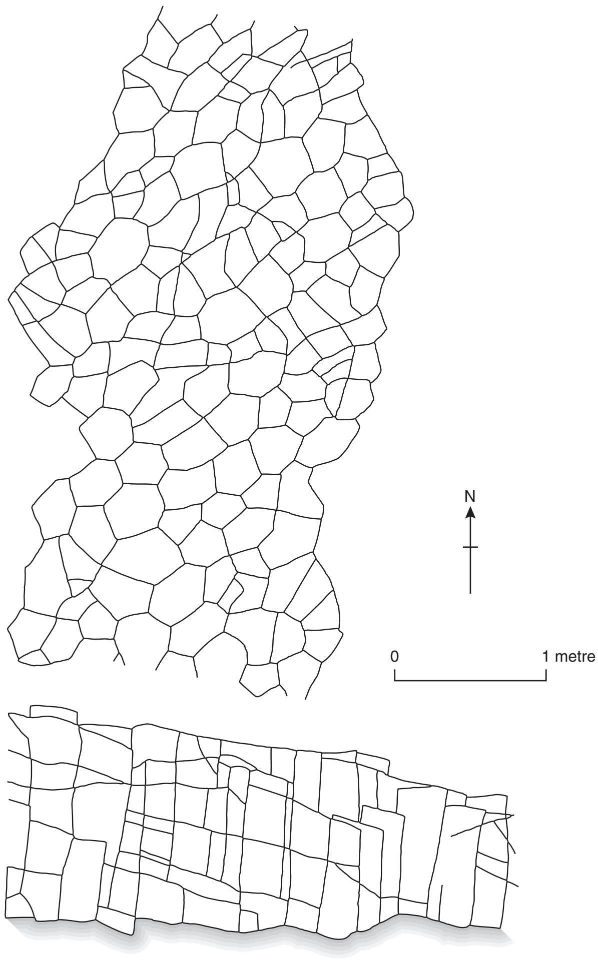


Figure 10 Example trace maps of a **discontinuity-network** displayed on adjacent gently inclined (upper diagram) and near-vertical (lower diagram) exposure surfaces in welded ignimbrite, Gosforth, Cumbria. Two discontinuity sets are evident in the vertical section, both with 10 cm-range spacing, one gently inclined, the other near-vertical; the plan view shows, however, that the latter 'set' consists of features with a wide range of orientations (and is therefore not a single set). Considered independently, both surfaces present strongly biased discontinuity information. In 3D the **discontinuity-network** defines near-equant blocks.

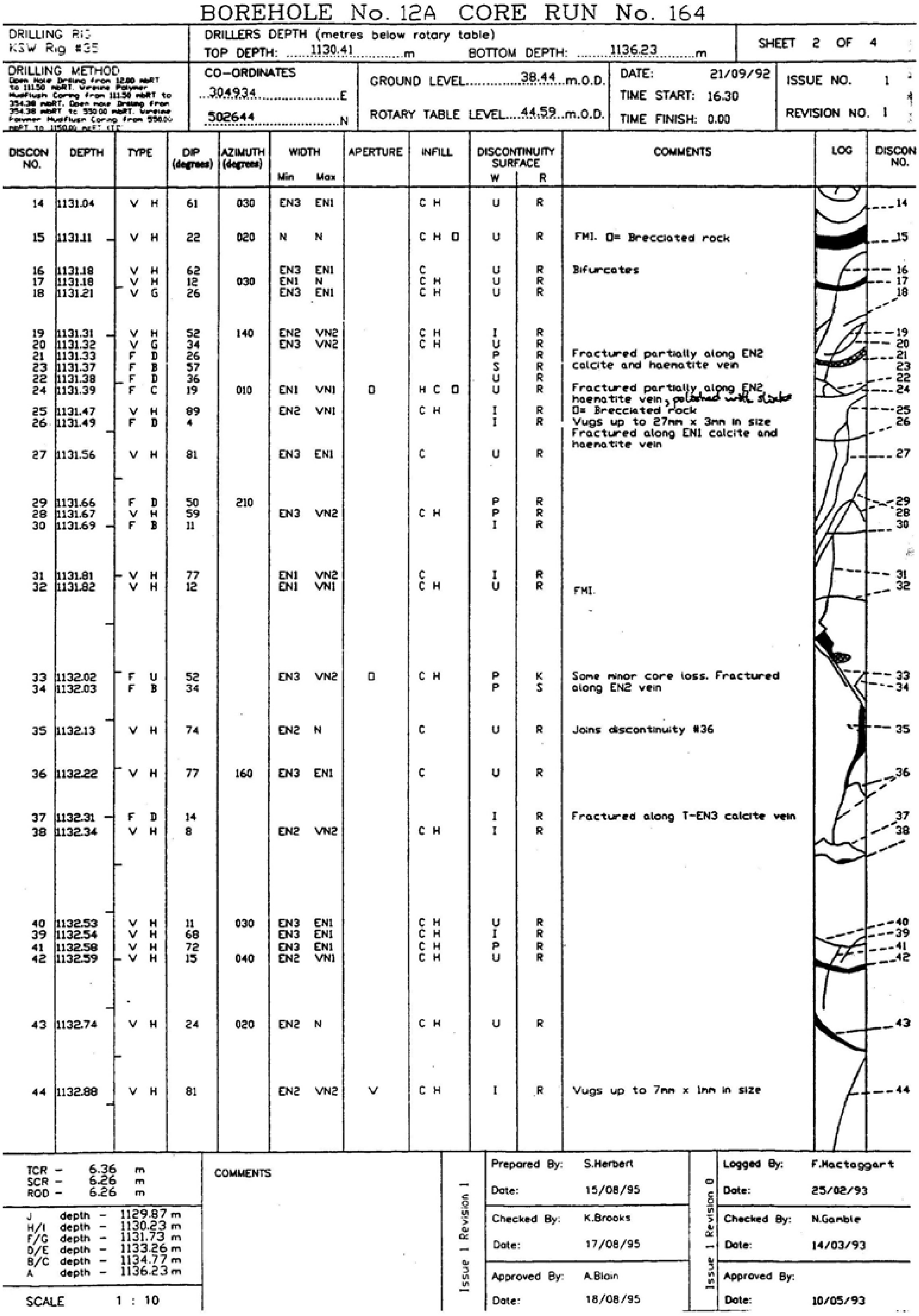
MP3 SCAN-LINE 1		
Proforma number	260-261	
Location	Mecklin Park	
Date	30.09.93	
Rock type	Andesite	
Site number	MP3	
Grid reference	Easting: 312093 Northing: 502274	
Scan-line length	6.3 metres	
Transverse length		
Face orientation	274/5	292/10
Scan-line orientation	344/04	342/07
(Scan-line section)	0-4.4 metres	4.4-6.3 metres
Minimum trace length recorded	0.1 metres	
Maximum extent of outcrop	20 metres	

No	Distance (m)	Type	Orientation				Length (m)		Termination		Roughness		Aperture (or range)	Width (or range)	Filling	Comments
			Dip	Strike	Dip azimuth	Measurement type	L	R	L	R	Interm	Small				
1	0.01	F	78	296	026	1	0.45	3.20	U	U	-	-	T	-	-	
2	0.47	F	82	223	313	1	0.39	0.31	T	T	C	-	N	-	-	
3	0.50	F	89	298	028	3	0.50	0.75	U	T	-	-	T	-	-	
4	0.79	F	65	292	022	1	0.20	0.35	T	T	-	-	T	-	-	
5	0.82	F	65	252	342	2	0.29	0.26	T	R	-	-	T	-	-	
6	0.96	F	62	196	286	1	0.08	0.12	T	T	-	-	T	-	-	
7	0.99	V	74	056	146	2	0.30	1.10	U	R	W	-	-	0.25	QS	
8	1.20	F	85	110	200	3	0.30	0.25	T	T	-	-	T	-	-	Iron oxide staining
9	1.46	V	70	022	112	3	0.05	0.35	R	T	-	-	-	<0.2	QS	
10	1.62	V	89	235	325	3	0.45	0.20	U	T	W	-	-	<0.2	QS	
11	1.70	F	82	279	009	2	0.30	0.17	U	T	-	-	T	-	-	
12	1.98	V	52	235	325	1	0.24	0.44	T	T	C	-	-	1 to 2	QS	

Figure 11 Example of scan-line data. The upper table provides location information and, importantly, information about the orientation of the exposure surface and the orientation of the scan-line, with minimum trace length recorded and maximum extent parameters. The lower table provides discontinuity data including a sequential number, location (as distance along scan-line), discontinuity type (F=fracture, V=vein; note that with respect to the proposals set out in this document, these terms equate to 'non-filled fracture' and 'vein-filled fracture', respectively), orientation, length, termination left and right of the scan line (T=truncation by other discontinuity, R=terminates in rock, U=unknown [usually passing beyond the extent of the exposure]), roughness (C=curved, W=wavy), aperture of non-filled features (T=tight, N=narrow), width and filling.

no.	mbRT	wallrock	Single discontinuities													Multiple discontinuities and zones			Fillings					
			Interfaces					Breaks																
			root term	transition	form	attitude	comments	root term	width (mm)	form	attitude	displacement sense	displacement size	condition	comments	type	disposition	comments	root term	components	texture	condition	pore charac.	comments
1	2.5	n/a	ground				soil																	
2	5.1	n/a	rockhead	diffuse		near-hor.																		
3	5.1-10.3	sandstone														weath.-zone	n/a	oxid. rock & fractures		goe, MnOx		perm.		
4	11.3	sandstone	bedding	abrupt	planar	near-hor.																		
5	12.1	sandstone						joint	5	near-plan.	steep			open	PFF				crust	cal, goe			sheet	orig. carb. vein part dissolved
6	12.6	sandstone	bedding	abrupt	planar	near-hor.																		
7	24.4-26.2	sandstone						faults	1-3	near-plan.	steep	normal	1-5 mm	sealed	barriers?	set	sub-parallel	~20 features	filling	qtz/silica	unknown		n/a	prob. cataclastic, poss. annealed
8	34.2	sandstone						joint	3	planar	steep			sealed					vein	calcite			n/a	
9	35.6	sandstone						joint	1	sinuous	steep			sealed					vein	hematite			?	
10	37.7	sandstone						fault	1	sinuous	steep	normal	2 mm	sealed	displ. bedding									
11	37.9	sandstone	bedding	abrupt	planar	near-hor.		drilling-break		planar	bed.-p'll				expl'ts bedding									
12	38.2	sandstone						joint	5	irregular	gentle			open					crust	cal			connected	
13	40.1-50.1	sandstone														cement.-zone	n/a	bed.-p'll, cal. cement						
14	51.1	sandstone	bedding	abrupt	planar	near-hor.		joint	1	planar	near-hor.			sealed	expl'ts bedding									
15	52.3	sstn/lmst	unconf'ity																					
16	56.1	limestone						solution-sheet	25															
17	58.3	limestone						stylolite	3															
18	62.2	limestone						joint	8															
19	66	lmst/granite	unconf'ity	abrupt	irreg.	gently-dip.																		
20	66.6	granite						joint	5	curved	steep			filled					vein	hem-ep-qz	crustiform		n/a	
21	66.9	granite						joint	6	planar	near-ver.			filled					vein	cal	isotropic		n/a	cuts feature #20
22	69.9	granite						fault	3	planar														
23	70.3	granite						comp. fault	18	near-plan.	steep	normal	40 mm	filled	reactiv. once				cataclasite					reactiv. by 5 mm wide ultracat'site
24	76.3	granite						fault	34															
25	78	granite						drilling-break		irregular	near-hor.													
26	79.1	granite						joint	12															
27	82.3	granite						joint	35	planar	gentle			filled					vein	pegmatitic			n/a	
28	85.9	granite						joint	6															

Figure 12 Example of a borehole core discontinuity log recorded in a spreadsheet.



BOREHOLE No. 12A CORE RUN No. 164

DRILLING RIG: KSW Rig #35

DRILLERS DEPTH (metres below rotary table) — TOP DEPTH: 1130.41 m — BOTTOM DEPTH: 1136.23 m — SHEET 2 OF 4

DRILLING METHOD: Open Hole Drilling from 12.00 mbRT to 1115.0 mbRT. Wireline Polymer Mudflush Coring from 1115.0 mbRT to 354.38 mbRT. Open hole Drilling from 354.38 mbRT to 550.00 mbRT. Wireline Polymer Mudflush Coring from 550.00 mbRT to 1150.00 mbRT (TD)

CO-ORDINATES: 304934 E, 502644 N

GROUND LEVEL 38.44 m.O.D. — ROTARY TABLE LEVEL 44.59 m.O.D.

DATE: 21/09/92 — TIME START: 16.30 — TIME FINISH: 0.00

ISSUE NO. 1 — REVISION NO. 1

DISCON NO.	DEPTH	TYPE	DIP (degrees)	AZIMUTH (degrees)	WIDTH Min	WIDTH Max	APERTURE	INFILL	DISCONTINUITY SURFACE W	DISCONTINUITY SURFACE R	COMMENTS
14	1131.04	V H	61	030	EN3	EN1		C H	U	R	
15	1131.11	V H	22	020	N	N		C H D	U	R	FMI. D= Brecciated rock
16	1131.18	V H	62		EN3	EN1		C	U	R	Bifurcates
17	1131.18	V H	12	030	EN1	N		C H	U	R	
18	1131.21	V G	26		EN3	EN1		C H	U	R	
19	1131.31	V H	52	140	EN2	VN2		C H	I	R	
20	1131.32	V G	34		EN3	VN2		C H	U	R	
21	1131.33	F D	26						P	R	Fractured partially along EN2 calcite and haematite vein
23	1131.37	F B	57						S	R	
22	1131.38	F D	36						U	R	
24	1131.39	F C	19	010	EN1	VN1	D	H C D	U	R	Fractured partially along EN2 haematite vein, polished with slicks
25	1131.47	V H	89		EN2	VN1		C H	I	R	D= Brecciated rock
26	1131.49	F D	4						I	R	Vugs up to 27mm x 3mm in size. Fractured along EN1 calcite and haematite vein
27	1131.56	V H	81		EN3	EN1		C	U	R	
29	1131.66	F D	50	210					P	R	
28	1131.67	V H	59		EN3	VN2		C H	P	R	
30	1131.69	F B	11						I	R	
31	1131.81	V H	77		EN1	VN2		C	I	R	
32	1131.82	V H	12		EN1	VN1		C H	U	R	FMI.
33	1132.02	F U	52		EN3	VN2	D	C H	P	K	Some minor core loss. Fractured along EN2 vein
34	1132.03	F B	34						P	S	
35	1132.13	V H	74		EN2	N		C	U	R	Joins discontinuity #36
36	1132.22	V H	77	160	EN3	EN1		C	U	R	
37	1132.31	F D	14						I	R	Fractured along T-EN3 calcite vein
38	1132.34	V H	8		EN2	VN2		C H	I	R	
40	1132.53	V H	11	030	EN3	EN1		C H	U	R	
39	1132.54	V H	68		EN3	EN1		C H	I	R	
41	1132.58	V H	72		EN3	EN1		C H	P	R	
42	1132.59	V H	15	040	EN2	VN1		C H	U	R	
43	1132.74	V H	24	020	EN2	N		C H	U	R	
44	1132.88	V H	81		EN2	VN2	V	C H	I	R	Vugs up to 7mm x 1mm in size

TCR – 6.36 m
SCR – 6.26 m
RQD – 6.26 m

J depth – 1129.87 m
H/I depth – 1130.23 m
F/G depth – 1131.73 m
D/E depth – 1133.26 m
B/C depth – 1134.77 m
A depth – 1136.23 m

SCALE 1 : 10

COMMENTS

Issue 1 Revision 1 — Prepared By: S.Herbert, Date: 15/08/95; Checked By: K.Brooks, Date: 17/08/95; Approved By: A.Blain, Date: 18/08/95

Issue 1 Revision 0 — Logged By: F.Mactaggart, Date: 25/02/93; Checked By: N.Gamble, Date: 14/03/93; Approved By:, Date: 10/05/93

Figure 13 Example of a borehole core discontinuity log incorporating a sketched representation of discontinuities in the core. From a report prepared for UK Nirex Ltd. See text (Section 10.2) for details.

Figure 14 Example description of filled discontinuities in a longitudinally sliced section of borehole core, 9 cm wide and 30 cm long in greyish green volcaniclastic rock. Acid etching and staining of the left-hand surface have been used to identify the carbonate minerals in fracture fillings.

Description: The cut surfaces reveal two main sets of mineral filled fractures. An older set of near-planar, gently to moderately dipping, 0.1 to 2.5 cm wide, sealed joints have fillings of ferroan calcite (pink stain)-chlorite-epidote-quartz veins; the larger features have faint (?epidotised) cm-range wide alteration-zones with gradational interfaces. A younger (cross-cutting) set of near-planar, very steeply inclined, 0.1 to 0.5 cm wide, sealed joints have fillings of barite-anhydrite-calcite veins. An induced fracture has opened along one of the latter features.

Figure 15 Example description of filled discontinuities in a longitudinally sliced section of borehole core, 9 cm wide and 30 cm long, in greyish green volcaniclastic rock; acid etching and staining of the right-hand side has been used to help identify carbonate minerals in fractures.

Description: A steeply inclined, near-planar, essentially sealed fracture up to 8 cm wide has a filling of hematite-dolomite-calcite-cemented wallrock breccia. Wallrock clasts are angular and up to 20 cm long; larger clasts are markedly elongate roughly parallel to the break plane, smaller clasts tend towards equant forms (in the plane of the slice). The breccia was cemented initially by dolomite (blue stain); massive calcite (pink stain) precipitated later, possibly after minor structural reactivation. Earthy hematite has formed within a discontinuous alteration-zone up to 1 cm wide in wallrock, imparting a chocolate-brown colouration; most of the smaller clasts in the breccia are also pervasively hematitised. Several induced fractures have developed along vein-wallrock interfaces lined by earthy hematite.

Figure 16 Example description of a filled discontinuity in borehole core.

Description: A planar, moderately dipping, 2 mm wide **j**oint in sandstone has a crust filling in which cm-range length dendrites of dark grey to black manganese oxyhydroxide line both wallrock surfaces beneath a discontinuous layer of mm-range diameter euhedra of translucent calcite.

Possible name:
Manganese-oxyhydroxide- and calcite-crusted, planar, moderately dipping **joint**

Figure 17 Example description of a partly filled discontinuity in borehole core.

Description: A 25 cm-long section of 9 cm-wide borehole core through pervasively reddened volcaniclastic rock. A steeply inclined, partly mineralised joint of 10 cm true width has a filling of angular wallrock clasts (~30 per cent) up to 13 cm long, cemented by carbonate minerals (dolomite and calcite; ~50 per cent) and minor hematite (~1 per cent). Connected vuggy pores (~20 per cent), with aperture up to 4 cm across on the core surface, are lined by 1 to 8 mm long euhedra of white dolomite and clear (translucent) calcite, with traces of fresh pyrite and chalcopyrite. No displacement can be discerned across the fracture, but the fracture wall and surfaces of several wallrock clasts have two or more thin layers of carbonate and hematite mineralisation, suggesting an early phase of fracture filling preceded the brecciation. The fracture therefore has a compound structural history. Close inspection shows the pore space to be lined locally by mouldic forms after probable anhydrite (not visible in this image) indicating that it is a product of anhydrite solution and is therefore of secondary origin. The translucent euhedra of calcite grew on pore surfaces after the solution event. This feature therefore also has a compound filling history.

Possible names:

pyrite-chalcopyrite-wallrock clast-fluid-calcite-dolomite filled, steeply inclined, 10 cm-wide **joint** or *vug-, carbonate- and wallrock breccia-filled, steeply inclined, 10 cm-wide* **joint**

Figure 18 Example description of filled discontinuities in a 2 x 3 cm area of blue-dye resin impregnated thin section prepared from altered volcaniclastic rock.

Description: The host volcaniclastic rock has a discontinuity-network within which four generations of discontinuity can be discerned. The earliest is dominated by two near-orthogonal sets of thin (mostly <0.2 mm wide; occasionally up to 1 mm), near-planar, sealed joints with very dark chlorite-hematite fillings. The second generation is dominated by a single, near-planar joint from 3 to 5 mm wide, which has essentially the same orientation (in the plane of the thin section) as the more closely spaced set of earlier features; it may have formed by exploiting one or more of these. The joint is sealed and filled by a compound hematite-chlorite-calcite-quartz vein, formed by several cycles of opening and mineral precipitation; the result is a complex texture that includes cross-fibre and crustiform elements. The third generation is also dominated by a single joint, which is weakly sinuous, up to 1 mm wide, and bifurcates at one point into two thinner near-parallel joints. The fracture formed at a high angle to the large second generation joint, though much of it is near-parallel (in the plane of the thin section) to the more widely spaced set of earliest generation fractures. It is sealed, and along most of its length has a compound filling of two adjacent, very thin veins of calcite. In cutting the earlier compound vein, the fracture steps 0.5 mm. The youngest feature is a very thin (<0.4 mm), non-filled (i.e. now occupied by blue-dye resin), near-planar to sinuous joint that locally exploits all three earlier generations; it is not clear if this feature is natural or induced.

Table 1 Geological processes associated with discontinuities and fillings.

abrasion	healing
alteration	hydrofracting
annealing	imbrication
authigenesis	induration
brittle deformation	intrusion
cataclasis	melting
cementation	mineralisation
chemical solution	polishing
comminution	precipitation
consolidation	pressure solution
cooling	reactivation
crack-seal	recrystallisation
crystallisation	reduction-oxidation (redox)
decomposition	reworking
deformation	sedimentation
deposition	segregation
desiccation	shearing
displace(ment)	slumping
ductile deformation	solution
erosion	strain recovery
fragmentation	weathering

This list is not exhaustive.
The terms can be used in other forms in discontinuity names and descriptions, e.g. *healed* **fault**.
All the terms are defined in the Glossary.

Table 2 Qualifier terms and other approved terms for single discontinuities.

Observable properties			**Measurable properties**	
Terms to describe interfaces	**Terms to describe breaks**	**Terms to describe interfaces & breaks**	**Type of property *****	**Terms to describe dip angle**
Material on opposing sides *	**Condition**	**Form**		
crystal	*closed*	*birfurcated*	aperture	*bedding parallel ***
gas	*compound*	*curved*	attitude	*gently dipping ******
ice	*dilatant*	*equant ***	dip	*horizontal ***
liquid	*filled*	*irregular*	dip-slip	*moderately dipping ******
magma	*healed*	*planar ***	displacement	*steeply dipping ******
organic matter	*incipient*	*ptygmatic*	heave	*vertical ***
rock	*non-filled*	*sigmoidal*	length ****	*a number from 1 to 90, e.g. 30º*
sediment	*open*	*sinuous*	oblique-slip	*a range, e.g. 30–40º*
soil	*sealed*	*stepped*	offset	
	simple	*straight*	persistence	
		sutured	strike	
		tabular	strike-slip	
		tapered	throw	
		tubular	width ****	
Nature of transition	**Sense of displacement on deformation breaks**			
abrupt	closing displacement			
alternating	opening displacement			
diffuse	shearing displacement			
gradational				
Relationship of opposing sides	**Sense of displacement on faults**			
conformable	*dextral*			
unconformable	*dip-slip*			
	normal			
	oblique-slip			
	reverse			
	sinistral			
	strike-slip			
	thrust			

* This list is a small selection of the full range of materials that can occupy opposing sides of geological interfaces; the terms in it can be substituted by more specific variants, e.g. 'sandstone' instead of 'rock' and 'oil' instead of 'liquid', yielding names like *mudstone–andstone* **interface**, *oil–water* **interface**, and *crystal–melt* **interface**; not all the terms in this list are defined in the Glossary.

** These terms may be preceded by *near-*, for example *near-vertical*.

*** To be used as qualifiers, the terms in this list should be preceded by a number or one of the size range divisions listed in Table 7, for example *3 metre offset* **fault**, and *10 metre range persistence* **joint-set**.

**** In names and descriptions, the term 'length' can be substituted by 'long' (e.g. *3 metre long* **fracture**) and 'width' can be substituted by 'wide' (e.g. *2 mm wide* **joint**)

*****Where: gently dipping = <30° from horizontal, moderately dipping = 30–60°, and steeply dipping = >60°.

Table 3 Approved terms for the properties used to classify fillings.

Filling property	
Components	**Type**
authigenic mineral	**breccia**
cement	**crust**
clast	**dendrite**
endoclast	**fault-rock**
exoclast	**layer**
fluid	**patch**
gel	**sediment**
organic matter	**spot**
pore space	**vein**
recrystallised rock	
salt	
slurry	
sol	
void	

Terms written in bold text are root terms.

Table 4 Root terms for fault-rocks.

fault-rock
cataclasite
fault-gouge
fault-breccia
protobreccia
protocataclasite
mesocataclasite
ultracataclasite
pseudotachylite
mylonite
protomylonitic-breccia
protomylonite
mesomylonite
ultramylonite
blastomylonite

Table 5 Qualifier terms for fillings.

Texture	Condition	Measurable properties
amorphous	*coherent**	aperture **
banded	*cohesive **	effective porosity
botryform	*compound*	grain size ***
cataclastic	*consolidated**	permeability ****
cockade	*impermeable*	porosity ****
colloform	*incohesive*	width **
cross-fibre	*incoherent*	
crustiform	*non-consolidated*	
decussate	*non-porous*	
disseminated	*permeable**	
drusy	*porous**	
foliated	*simple*	
idiotopic		
isotropic		
mammilliform		
mouldic		
mylonitic		
poikilotopic		
porphyrotopic		
radiating		
reniform		
spherulitic		
vuggy		
xenotopic		

* These terms may be preceded by one of the terms *weakly, moderately, strongly*.

** To be used as qualifiers, these terms should be preceded by a number or one of the size-range divisions listed in Table 7, for example *8 mm aperture* **pore**, and *cm-range width* **veins**.

*** Grain-size should be recorded using terms from the BGS Rock Classification Scheme (e.g. Gillespie and Styles, 2010), for example ' . . . the cavity has a filling of *fine-sand-grade* **sediment** . . .'.

**** These properties can be measured quantitatively but will more commonly be measured and recorded qualitatively, e.g. *weakly permeable calcite* **vein**, and '. . . the *clay* **filling** is essentially impermeable . . .'.

Table 6 Root terms and qualifier terms for multiple discontinuities.

Root terms	Qualifier terms and other approved terms	
	Disposition of features	**Measurable properties**
array	*anastomosing*	connectivity **
network	*antithetic*	density ***
set	*conjugate*	frequency ***
system	*en echelon*	*spacing*
	irregular	
	left-stepping	
	non-systematic	
	orthogonal	
	parallel *	
	regular *	
	right-stepping	
	synthetic	
	systematic	

* These terms may be preceded by *near-*, for example *near-parallel.*
** Usually expressed qualitatively, for example *well-connected calcite* **vein network**.
*** Usually recorded quantitatively.

Table 7 Terms to indicate scale- and size-range.

In words *	In numbers
sub-micron range	< 1 µm
micron range	1 to 10 µm
10-micron range	10 to 100 µm
100-micron range	100 µm to 1 mm
millimetre range	1 to 10 mm
centimetre range	10 to 100 mm
decimetre range	100 to 1000 mm
metre range	1 to 10 m
decametre range	10 to 100 m
100-metre range	100 m to 1 km
kilometre range	1 to 10 km
10-kilometre range	10 to 100 km
100-kilometre range	100 to 1000 km

* The terms used in this column for units of measurement may be replaced by standard abbreviations for them: µm for micron; mm for millimetre; cm for centimetre; dc for decimetre; m for metre; dm for decametre; km for kilometre.

Table 8 Other terms that are relevant to this scheme.

angular	potentially flowing feature
approved term	qualifier term
asperity	range
bias	**rockhead**
cavity	root term
censoring	scale
damage zone	scan-line
endogenic	schistosity
exogenic	section
fabric	shear stress
feature	**sheet**
fissure	size
flow-zone	**slip-surface**
foliation	splay
footwall	strain
front	strand
hanging wall	stress
host rock	striation
induce	**tension-gash**
lineament	**tube**
lineation	trace
line-sample	volume
massive	**vug**
penetrative fabric	wallrock
pore	**zone**

Terms written in bold text can be used as root terms.
The Glossary contains definitions for all these terms.

Glossary

This Glossary draws on many sources, however the main reference source for the definitions given here is the Glossary of Geology published by the American Geological Institute (Neuendorf et al., 2005). Many of the definitions in that book have been modified to be consistent with the hierarchy presented in this scheme and with the definitions for other terms. Some definitions have been created specifically for this scheme, commonly drawing on elements of several published definitions.

The definitions given here are relevant to the context of this classification of discontinuities and fillings. Some terms will be defined differently when they are used in a different context.

Many of the terms defined here can be used in more than one form (as a verb, noun, adjective etc). Where this is the case, the infinitive form of the verb (e.g. anneal) in general appears in the 'Terms' column; other terms that derive from the same root (e.g. annealing, annealed) can also be used. Where terms will typically only be used in a single form (e.g. as an adjective, like 'alternating'), that form appears in the 'Terms' column.

Terms in **bold** text are root terms. Terms in *italic* text are qualifier terms. Terms in underlined text have their own entry in the Glossary, though the form of the word that appears in the 'Terms' column may differ from that in the 'Definition' column (see above). Terms in red text are not approved; alternative approved terms are suggested.

Entries in the 'Table' and 'Figure' columns refer to tables and figures in the report where the term appears.

Terms	Definition	Table	Figure
abrade	wear, grind, scrape, or rub away (or down) rock surfaces by friction and impact of solid rock particles; the noun 'abrasion' is synonymous with corrasion and mechanical erosion	1	
abrupt	describes an **interface** that is sharply delineated and well-defined, at the scale of observation; cf. alternating, diffuse, gradational	2	
alter	change the mineralogical and/or chemical composition of a material by chemical means	1	
alteration-interface	an **interface** formed as a consequence of alteration; such features separate materials of contrasting alteration state or type		1
alternating	describes an interface across which the passage or transition from one side to the other occurs by alternation of the two materials, conditions, or states, at the scale of observation; cf. abrupt, diffuse, gradational	2	
amorphous	non-crystalline	5	
anastomosing	describes a **network** of branching and rejoining features	6	
angular	describes an **unconformity** between two units whose **bedding-planes** are not parallel or in which rocks of the older (usually underlying) unit dip at a different angle (usually steeper) than the younger (usually overlying) strata	8	
anneal	form new crystals in a rock by recrystallisation, usually at elevated temperature	1	
anticrack	a fracture formed by closing displacement; cf. **crack**, **fault**, **joint**		1
antithetic	describes a single **fault** or fault **set** that is conjugate to, and has an opposing sense of displacement to, a neighbouring larger fault or fault set; cf. synthetic	6	
aperture	the opening or gap of a space occupied by **void** in a **discontinuity**; also a measure of this	5	
approved term	a term that is approved by this scheme; all approved terms appear in this Glossary	8	
array	an ordered arrangement of **discontinuities**	6	
asperity	an irregularity on a surface, for example a step on an otherwise smooth surface	8	
attitude	the position of a **discontinuity** relative to the horizontal, expressed quantitatively by measurements of both strike and dip	2	

authigenesis	the process by which new minerals form in place	1	
authigenic mineral	a mineral formed in its present location, i.e. not transported	3	
banded	describes a **filling** consisting of nearly parallel layers that differ in colour or texture, and that may or may not differ in mineral composition; essentially synonymous with ribbon texture	5	
band fault	a term sometimes used synonymously with deformation band, granulation seam, microfault, shear fracture and some other terms to refer to **deformation bands**, typically those involving closing displacement; either of the root terms **compactional-shear-band** and **compaction-band** should be used instead for features of this type	n/a	
bedding-parallel	parallel to one or more **bedding-interfaces**	2	
bedding-plane	a **sedimentation-interface** that is conformable; synonymous with, and can substitute for, the formal root term **conformable-sedimentation-interface**		1
bias	the propensity of any exposure to provide restricted information on the full range of features in rock mass	8	
bifurcated	separated or branched into two parts	2	
blastomylonite	**mylonite** that displays a significant degree of grain growth related to or following deformation	4	2
botryform	a variety of colloform texture, in which a mineral has grown with a surface of spherical shapes	5	
botryoidal	use botryform	n/a	
braided	use anastomosing	n/a	
break	a **discontinuity** formed where the physical integrity of a material is, or has been, disrupted		1
breccia	a **filling** composed, or largely composed, of angular **clasts**	3	2
brittle deformation	**deformation** involving unevenly distributed strain, resulting in a permanent change in solid materials; cf. ductile deformation	1	
cataclasis	rock deformation achieved through the formation of **fractures** and rotation of constituent crystals, grains, or aggregates, without chemical reconstitution	1	
cataclasite	**fault-rock** that is cohesive with a poorly developed or absent schistosity, or which is incohesive, characterised by generally angular porphyroclasts and lithic fragments in a finer-grained matrix of similar composition; generally no preferred orientation of grains or individual fragments is present as a result of the deformation, but fractures may have a preferred orientation; a foliation is not generated unless the fragments are drawn out or new minerals grow during the deformation; plastic deformation may be present but is always subordinate to some combination of fracturing, rotation, and frictional sliding of particles; cf. **fault-breccia**, **fault-gouge**, **protobreccia**, **protocataclasite**, **mesocataclasite**, and **ultracataclasite**	4	2
cataclastic	texture produced by cataclasis, characterised by fractures, rotation of constituent crystals, grains, or aggregates	5	
cave	use a more specific name, such as *non-filled 2-metre wide* **solution-cavity**	n/a	
cavern	use a more specific name, such as *non-filled 2-metre wide* **solution-cavity**	n/a	
cavity	a near-equant **break** formed by any process and occupied largely or wholly by fluid (though it may subsequently be filled); cf. **sheet**, **tube**	8	
cement	authigenic mineral material, usually deposited or precipitated from solution, that binds geological materials and/or fills **void**	3	
cementation	the process by which geological material becomes bound through deposition or precipitation of minerals in **pores**	1	

cementation-interface	an **interface** formed by cementation; such features separate cemented material from non-cemented material		1
censoring	applies where a method of data acquisition excludes or poorly represents discontinuities with a particular characteristic	8	
channel	use **tube**	n/a	
chemical solution	solution that occurs when external pressure does not exceed the hydraulic pressure of interstitial fluid, i.e. not pressure solution; although solution is always a 'chemical' process, the term chemical solution is introduced here to distinguish this form of solution from pressure solution	1	
chemical-solution-break	a **break** formed by chemical solution		1
clast	an individual constituent, grain, or fragment of a sediment or rock, produced by disintegration; see **endoclast** and **exoclast**	3	
closed	describes a discontinuity whose wallrocks are in contact, preventing fluid flow	2	
closing displacement	displacement causing opposing sides of a **deformation-break** to move towards each other (generally through contractional strain or compaction); cf. opening displacement, shearing displacement	2	
cockade	successive comb-like layers of authigenic minerals developed around fragments of rock or older **vein** material	5	
coherent	a geological material that is consolidated, or that is not easily shattered	5	
cohesive	coherent, not friable, cemented, cannot be broken into component granules with fingers or with the aid of a pen knife; cf. incohesive	5	
colloform	a mineral precipitate that assumes a rounded, near-spherical or globular form; the term refers only to morphology and not to crystallinity or origin; colloform precipitates may contain fine rhythmic layering	5	
comminute	progressively reduce a material into smaller particles	1	
compactional-shear-band	a **tabular-deformation-break** formed by a combination of closing displacement and shearing displacement; cf. **compaction-band**, **dilational-shear-band**, **dilation-band**, **shear-band**		1
compaction-band	a **tabular-deformation-break** formed by closing displacement; cf. **compactional-shear-band**, **dilational-shear-band**, **dilation-band**, **shear-band**		1
compound	describes a feature that consists of two or more elements or has formed through two or more operations, e.g. *compound* **fault**, *compound* **vein**	2	
conformable	said of sediment layers deposited without disturbance or erosion on either side of a sedimentation-interface; cf. unconformable	2	
conformable-sedimentation-interface	a **sedimentation-interface** that is conformable; synonymous with **bedding-plane**		1
conjugate	a geometrical relationship (planes at c. 60°) between single **breaks**, or sets of breaks	6	
connectivity	a measure of the degree to which discontinuities in a **network** intersect other discontinuties; commonly quantified qualitatively (e.g. low connectivity/poorly-connected, high connectivity/well-connected)	6	
consolidate	bind the fragments of a material by any process to form a firm and coherent whole	5	
cool	remove heat from; in this context, leading to deformation that causes a **discontinuity** to form, for example *cooling* **joint**	1	
crack	a **fracture** formed by opening displacement; synonymous with **joint**; cf. **anticrack**, **fault**; the term 'crack' has a different meaning in rock mechanics studies and seismology		1
crack-seal	repeated opening and mineralisation of a **fracture**	1	

cross-fibre	describes a **vein** in which crystals are elongate with their long axes orientated at a high angle to the vein margins	5	
crush-breccia	use **protobreccia**	n/a	
crust	a development of authigenic minerals on the surface(s) of a partially filled **break**; **spot**, **patch**, **layer**, and **dendrite** are types of crust	3	2
crustiform	describes a **filling** in which minerals are deposited in layers (commonly as euhedral crystals)	5	
crystallisation-interface	an **interface** formed by crystallisation; such features include those that separate a crystal and the substrate it grows on, a crystal and the material it grows into or against, and cooling igneous rock from magma		1
crystallise	become crystalline, from a gaseous, fluid, or dispersed state	1	
curved	describes a line or surface that has along its length a regular deviation fom being straight or planar	2	
damage zone	a **zone** of elevated **fracture** frequency around a **fault**	8	
decompose	disintegrate/lose cohesion through **alteration**, specifically weathering	1	
decussate	a form of recrystallisation texture comprised of interlocking, randomly orientated, somewhat elongate, prismatic or near-idioblastic crystals, generally of one species	5	
deformation	the net effect of strain on rock mass or the components thereof	1	
deformation-band	a **deformation-break** characterised by a continuous change in strength and/or stiffness across a band whose thickness is clearly resolvable at the scale of observation; synonymous with, and can substitute for, the formal root term **tabular-deformation-break**; the term 'deformation band' has previously been used synonymously with band fault, granulation seam, microfault, shear fracture and some other terms to refer to **deformation bands**, typically those involving closing displacement; either of the root terms **compactional-shear-band** and **compaction-band** should be used instead for features of this type		1
deformation-break	a **break** formed by deformation		1
deformation-interface	an **interface** formed by deformation; such features separate materials of contrasting deformation state or type		1
dendrite	a **crust** displaying a branching or fern-like pattern of crystallisation; commonly developed by oxides of Fe and Mn on **discontinuity** surfaces; cf. **layer**, **patch**, **spot**	3	2
density	a measure of the proportion of discontinuities in a rock mass, expressed per metre, and determined by either the number of discontinuities intersecting a line-sample, the trace length of discontinuities per unit area measured on a section, or (in theory, being difficult to achieve in practice) the area of discontinuities per unit volume; cf. frequency	6	
dentate-anticrack	an **anticrack** that is marked by an irregular and interlocking penetration of the two sides; columns, pits and teeth-like projections on one side fit into their counterparts on the other, such that they display a 'saw-tooth' or 'dentate' character; between the two surfaces there is typically a concentration of insoluble constituents of the rock; dentate anticracks are thought to be formed by pressure solution; the term is synonymous with the more familiar term **stylolite**; cf. **smooth-anticrack**		1
deposit	lay, place, or throw down any material	1	
desiccate	remove moisture from; in this context, leading to deformation that causes a **discontinuity** to form, for example *desiccation* **crack**	1	
dextral	describes the sense of displacement on a **deformation-break** in which the relative movement of the block opposite an observer standing on one side is to the right; synonymous with right-lateral	2	

diffuse	describes an interface that is indistinct and/or poorly defined, at the scale of observation; cf. abrupt, alternating, gradational	2	
dilatant	describes a **fracture** whose wallrock surfaces are not in contact (though the fracture may be partly or wholly filled); cf. open, closed	2	
dilational-shear-band	a **tabular-deformation-break** formed by a combination of opening displacement and shearing displacement; cf. **compactional-shear-band, compaction-band**, **dilation-band**, **shear-band**		1
dilation-band	a **tabular-deformation-break formed** by opening displacement; cf. **compactional-shear-band**, **compaction-band, dilational-shear-band**, **shear-band**		1
dip	the angle between a (planar) feature and the horizontal as angular measure or class interval	2	
dip-slip	describes a **deformation-break** on which displacement is parallel to dip, e.g. *dip-slip* **fault**; also the component of displacement that is parallel to dip; cf. strike-slip	2	
discontinuity	a feature marking a change in the continuity of a material at the scale of interest or observation; also the generic term for all such features		1
displace	move the opposing surfaces or sides of a **break** relative to each other	1	
displacement	the size of the relative movement of the two sides of a break	2	
disseminated	scattered; usually used to desribe sparsely distributed crystals, e.g. disseminated pyrite crystals	6	
dissolution seam	use **smooth-anticrack**	n/a	
druse	a **pore** surface lined by euhedral crystals	5	
ductile deformation	deformation involving evenly distributed strain, resulting in a permanent change (through uniform flow) in solid materials; cf. brittle-deformation	1	
effective porosity	the percent of the total volume of a given mass of soil or rock, or of a **discontinuity**, that consists of connected **pores**; cf. porosity	5	
endoclast	a **clast** in **filling** that has been derived locally, e.g. from adjacent wallrock; an abbreviation of 'endogenic clast'; cf. **exoclast**	3	
endogenic	describes material derived from within the rock that hosts it	8	
en echelon	an arrangement of near-parallel **deformation-breaks** in a linear **zone** that is oblique to the breaks themselves; left-stepping and right-stepping features display a smaller degree of overlap than en echelon features	6	
equant	said of a **feature** having the same or nearly the same diameter in all directions; synonymous with equidimensional	2	
erode	wear away Earth's surface by the action of water, ice, wind etc	1	
erosion-interface	an **interface** formed by erosion		1
exoclast	a **clast** in **filling** that has not been derived locally, i.e. it has been transported from elsewhere; an abbreviation of 'exogenic clast'; cf. **endoclast**	3	
exogenic	describes material derived from outwith the rock that contains it	8	
fabric	the geometric and spatial relationships between the components of a material; the fabric can relate to the preferred orientations of grain shapes, to grain sizes, and to crystallographic orientations	8	
fault	a **fracture** formed by, or incorporating, shearing displacement, along which there is discernible displacement parallel to the bounding surfaces at the scale of observation or interest; cf. **anticrack**, **crack**, **joint**		1
fault-breccia	**cataclasite**, of which more than 30% consists of visible wallrock clasts, the remainder being dominated by very fine authigenic minerals (e.g. clay and Fe/Mn oxide/oxyhydroxide); cf. **fault-gouge**	4	2

fault-gouge	**cataclasite**, of which less than 30% consists of visible wallrock clasts, the remainder being dominated by very fine authigenic minerals (e.g. clay and Fe/Mn oxide/oxyhydroxide); cf. **fault-breccia**	4	2
fault-rock	**filling** formed as a direct result of shearing displacement	4	2
feature	an entity that can be defined	8	
filled	describes a **break** in which former space (if any) is essentially fully occupied by **filling**, usually solid matter, at the scale of observation; a filled break may still be *permeable*	2	
filling	material occupying part or all of the space (if any) in a **break**; also the generic term for all such features		2
fissure	a **fracture** or s**olution-break** formed at, and intersecting, Earth's surface (though it may subsequently be buried)	8	
flinty crush rock	use an appropriate **fault-rock** term, e.g. **ultramylonite**	n/a	
flow zone	a **zone** of relatively high permeability	8	
fluid	a substance, especially a gas or liquid, lacking definite shape and capable of flowing and yielding to the slightest pressure	3	
fluxion structure	essentially describes mylonitic foliation; use appropriate 'mylonite' terminology, e.g. *mylonitic* **quartzite**, **protomylonite**	n/a	
foliation	any repetitively occurring or penetrative planar feature in rock	5, 8	
footwall	the rock mass immediately underlying a **discontinuity**	8	
fracture	a **deformation-break** characterised by a discontinuous change in strength and/or stiffness, such that there is a stepwise change in the displacement distribution across it; the volume of deformed material associated with fractures (not including **filling**) typically has negligible thickness at the scale of observation (hence their surfaces are perceived to be sharply defined); such features typically consist of two opposing surfaces in contact or close proximity; synonymous with, and can substitute for, the alternative root term **sharp-deformation-break**		1
fracture intensity	use density or frequency	n/a	
fragment	break a geological material into clasts, by any process	1	
frequency	the number of **discontinuities** in a unit volume, unit area, or unit length of a sample; cf. density	6	
front	an **interface** that migrates as it develops; the term can substitute for 'interface' in root terms assigned at Rank 4, e.g. **alteration-front** instead of **alteration-interface**	8	1
gel	a semi-solid colloidal suspension that can sustain limited shear stress; a gel is in more solid form than a sol	3	
gently-dipping	inclined at less than 30 degrees from horizontal	2	
gouge	use **fault-gouge**	n/a	
gradational	describes an **interface** across which there is a gradual passing from one condition to another, at the scale of observation; cf. abrupt, alternating, diffuse	2	
granulation seam	a term sometimes used synonymously with band fault, 'deformation band', microfault, shear fracture and some other terms to refer to **deformation bands**, typically those involving closing displacement; either of the root terms **compactional-shear-band** and **compaction-band** should be used instead for features of this type	n/a	
grike	use a term consistent with this scheme, e.g. solution **fissure**	n/a	
hade	the inclination of a **fault** measured as the angle between the fault plane and the vertical (i.e. it is the opposite of dip); the present scheme recommends that inclination is always measured with respect to horizontal (or to borehole axis in inclined boreholes), however the term 'hade' may be encountered in historical records	n/a	
hanging wall	the rock mass immediately overlying a **discontinuity**	8	

heal	modify a **discontinuity** by mineralisation and/or recrystallisation, such that shear and tensile strengths and permeability of the **feature** are essentially equal to or greater than those of enclosing rocks	1	
heave	the size of the horizontal displacement on a **fault**	2	
host rock	body of rock serving as the host for **discontinuities**; it implies less specific adjacency than wallrock	8	
hydrofract	generate, extend, or propagate a **fracture** or fractures through hydraulic pressure exerted by fluid	1	
idiotopic	said of the fabric of a crystalline **filling** in which the majority of the constituent crystals are euhedral; cf. xenotopic	5	
imbricate	cause overlapping of features	1	
impermeable	lacking permeability	5	
incipient	in an initial stage of development	2	
incoherent	loose or not consolidated, or easily shattered; cf. coherent	5	
incohesive	incoherent, friable, non-cemented; capable of being broken into component granules with fingers or with the aid of a pen knife	5	
induce	create (or open) a **discontinuity** through an unnatural process, for example drilling or handling of borehole core	8	
indurate	harden or consolidate a rock, soil or **filling** by pressure, **cementation**, or heat	1	
infilling	use **filling**	n/a	
interface	a **discontinuity** consisting of a boundary between two materials of contrasting character		1
interstice	use **pore**	n/a	
intrude	emplace or inject	1	
intrusion-interface	an **interface** formed by intrusion (of magma, salt, sediment etc) and separating intruded material from host material		1
irregular	not regular; unsymmetrical; uneven; varying in form	2, 6	
isotropic	having the same physical properties in all directions; the term can be used to describe essentially homogeneous **fillings**	5	
joint	a **fracture** formed by opening displacement; synonymous with **crack**; cf. **anticrack**, **fault**		1
layer	a **crust** that forms a complete, or near-complete coating; cf. **patch**, **spot**, **dendrite**	3	2
left-lateral	use sinistral	n/a	
left-stepping	describes a **zone** of **deformation-breaks** in which near-parallel segments step progressively to the left in plan view; en echelon features display a greater degree of overlap	6	
length	measurement or extent of a feature from end to end	2	
lineament	a linear feature of unspecified origin at any scale	8	
lineation	a general, non-generic term for any linear structure in a rock	8	
line-sample	a linear sample of rock or other material, in any attitude; synonymous with scan-line; cf. section, volume	8	
mammilliform	a variety of colloform texture, in which a mineral grows with a surface of smoothly rounded masses	5	
mammillated	use mammilliform	n/a	
massive	a term sometimes used to describe a rock mass with no or 'few' **joints** (ISRM, Brown, 1981); the term is commonly used imprecisely and its use is discouraged unless qualified with a spacing measurement or description, e.g. 'a massive rock with joint spacing in excess of 5 m'	8	
melt	become liquefied by heat	1	

melting-interface	an **interface** formed by melting, separating melted material from non-melted material		1
mesocataclasite	**cataclasite** in which the matrix forms more than 50% and less than 90% of the rock volume	4	2
mesomylonite	**mylonite** in which 50-90% of the rock volume has undergone grain size reduction	4	2
microfault	a term sometimes used synonymously with band fault, 'deformation band', granulation seam, shear fracture and some other terms to refer to **deformation bands**, typically those involving closing displacement; either of the root terms **compactional-shear-band** and **compaction-band** should be used instead for features of this type	n/a	
microfracture	use a name that incorporates an indication of actual size, e.g. *200-µm-wide* **fracture**	n/a	
mineralise	impregnate with mineral material	1	
moderately dipping	inclined at 30 to 60 degrees from horizontal	2	
mouldic	describes pore space formed by solution of a feature (usually a fossil or euhedral crystal) and retaining its form	5	
mylonite	**fault-rock** that is cohesive and characterised by a well-developed schistosity resulting from tectonic reduction of grain-size, and commonly containing rounded porphyroclasts and lithic fragments of similar composition to minerals in the matrix; fine layering and an associated mineral or stretching lineation are commonly present; brittle deformation of some minerals may be present, but deformation is commonly by crystal plasticity; cf. **protomylonitic-breccia**, **protomylonite**, **mesomylonite**, and **ultramylonite**	4	2
mylonitic	describes geological material with the textural characteristics of **mylonite**	5	
network	all of the **discontinuities** in a rock mass, or a subset of them that is characterised by one or more common parameters	6	
non-consolidated	not *consolidated*	5	
non-filled	without a filling of solid material	2	
non-porous	having no, or very few, **pores**	5	
non-systematic	said of **discontinuities** (usually **joints**) that are not part of a set; these will usually not cross other joints, they will commonly terminate at the boundaries of a geological unit, and they may be strongly curved; cf. systematic	6	
normal	describes the sense of displacement on a **deformation-break** in which the hanging wall appears to have moved downward relative to the footwall; cf. reverse	2	
oblique-slip	describes a **deformation-break** on which displacement involves a significant component of both dip-slip and strike-slip	2	
offset	the size of the horizontal component of displacement on a **fault**	2	
open	describes a **discontinuity** that is permeable at the scale of observation, i.e. has perceptible connected pore space; cf. closed	2	
opening displacement	displacement causing opposing sides of a **deformation-break** to move away from each other; cf. closing displacement, shearing displacement	2	
organic matter	material derived from plants or animals (including bacteria), and the products of their maturation, e.g. bitumen and oil	3	
orthogonal	describes two features that are approximately perpendicular	6	
parallel	describes two or more features that have broadly the same distance continuously between them	6	
patch	a partial, or patchy, **crust**; cf. **layer**, **spot**, **dendrite**	3	2
penetrative fabric	a dynamically produced structure pervading a rock mass	8	

permeability	the property or capacity of a rock, sediment, or soil for transmitting fluid; a measure of the relative ease of fluid flow under unequal pressure	5	
permeable	having permeability	5	
persistence	discontinuity trace length (observed in an exposure)	2	
planar	form approximating to that of a plane	2	
poikilotopic	a secondary (recrystallised) texture in which larger crystals enclose smaller ones; cf. porphyrotopic	5	
polish	create a surface texture characterised by high lustre and strong reflected light; polished **discontinuity** surfaces typically arise from compaction and/or friction as the opposing surfaces move relative to each other	1	
pore	a fluid-filled **break** of any size and shape, formed by any geological process	8	
pore space	the space within a **pore**; synonymous with **void**	3	
porosity	a measure (in percent) of the total volume of a given mass of material that consists of **pores**, whether isolated or connected; cf. effective porosity	5	
porous	having numerous **pores**, whether connected or isolated	5	
porphyrotopic	a secondary (recrystallised) texture in which larger crystals are set in a matrix of smaller crystals; cf. poikilotopic	5	
potentially flowing feature	a **discontinuity** that is considered to be naturally permeable and may conduct fluid	8	
precipitate	cause (a substance) to be deposited in solid form from a solution	1	
precipitation-interface	an **interface** formed by precipitation; such features include those that separate a precipitated material and the substrate it has been deposited on, and a precipitated material and the material it grows into		1
pressure solution	solution occurring preferentially at the contact surfaces of grains and crystals where the external pressure exceeds the hydraulic pressure of the interstitial fluid	1	
primary-interface	an **interface** formed in the course of accumulation (e.g. sedimentation) or loss (e.g. erosion) of the substrate, that consequently separates material that pre-dates it (on one side) from material that post-dates it (on the other side); cf. s**econdary-interface**		1
protobreccia	**cataclasite** in which the matrix forms less than 10% of the rock volume	4	2
protocataclasite	**cataclasite** in which the matrix forms between 10 and 50% of the rock volume	4	2
protomylonite	**mylonite** in which 10–50% of the rock volume has undergone grain size reduction	4	2
protomylonitic-breccia	**mylonite** in which less than 10% of the rock volume has undergone grain size reduction	4	2
pseudotachylite	**cataclasite** produced by frictional heating and melting (through extreme cataclasis) followed by quenching; the result is a highly strained but non-foliated rock consisting typically of fine clasts enclosed in glass; in hand specimen, the 'glass' is generally cryptocrystalline, vitreous-looking material, with a black, flinty appearance	4	2
ptygmatic	describes a **discontinuity** that is highly sinuous, with curved 'folds' and near-parallel or isoclinal limbs; commonly associated with ductile deformation and veining in metamorphic rocks	2	
qualifier term	an approved term used to record observed, measured, or interpreted properties of **discontinuities** and **fillings** in formal names, in descriptions, and in tabulations of data	8	
radiating	a divergent, fan-like grouping of acicular crystals normally nucleated from a point	5	

range	the region between limits of variation, e.g. scale range, size range	8	
reactivate	modify (by a process such as deformation or solution) after a period of inactivity	1	
recrystallise	form, essentially in the solid state, new crystals in a rock; this is essentially a strain recovery process by which a deformed crystal aggregate releases stored strain energy; recrystallisation typically involves migration of the interfaces between crystals and a change in crystal volume	1	
recrystallised rock	material that has recrystallised in the course of becoming a **filling**	3	
redox	an abbreviation of reduction–oxidation	1	
regular	said of **discontinuities** that display some uniformity of attributes, such as spacing and attitude	6	
reniform	a variety of colloform texture, in which a mineral grows with a surface of rounded, kidney-like shapes	5	
reverse	describes the sense of displacement on a **deformation-break** in which the hanging wall appears to have moved upward relative to the footwall; cf. normal	2	
rework	remove or displace geological material from its original position by natural agents	1	
ribbon (texture)	essentially synonymous with banded	n/a	
right-lateral	use dextral	n/a	
right-stepping	describes a **zone** of **deformation-breaks** in which near-parallel segments step progressively to the right in plan view; en echelon features display a greater degree of overlap	6	
rockhead	the **interface** above which Earth material has relatively little structural strength in contrast to that below: geological rockhead is taken as the base of Quaternary deposits; engineering rockhead is the boundary between an engineering soil and engineering rock (i.e. the base of the weathering profile) regardless of geological provenance, although this may be difficult to define in areas of complex weathering	8	
root term	the essential component in the formal name for a discontinuity or filling	8	
scale	used to make reference to the relative size of a thing, e.g. outcrop-scale, thin section-scale, scale of observation	8	
scan-line	a linear sample of rock or other material, in any attitude; synonymous with line-sample; cf. section, volume	8	
schistosity	a preferred orientation of inequant crystals or mineral grains produced by metamorphic processes	8	
sealed	describes a formerly open **discontinuity** that has been filled by solid materials such that it becomes essentially impermeable; cf. filled	2	
secondary-interface	an **interface** that is superimposed on the material that now hosts it, i.e. that develops after the host material has formed; cf. **primary-interface**		1
section	an areal sample of rock or other material, in any attitude, e.g. outcrop surface, thin section; cf. line-sample, scan-line, volume	8	
sediment	a **filling** composed of numerous **clasts** that have been deposited; also refers generally to solid fragmental material that originates from weathering of rocks, or that accumulates by other natural agents, and that forms in layers on the Earth's surface in a loose, non-consolidated form	3	2
sedimentation	the act or process of forming or accumulating sediment in layers	1	
sedimentation-interface	an **interface** formed by sedimentation; such features separate newly deposited sediment from older material of any type		1
segregate	separate from a mass and collect together; specifically as a consequence of metamorphism or magmatic processes	1	

segregation-interface	an **interface** formed by segregation; such features separate segregated material from non-segregated material or from other segregated material		1
set	a group of **discontinuities** with parallel or near-parallel disposition	6	
sharp-deformation-break	a **deformation-break** characterised by a discontinuous change in strength and/or stiffness, such that there is a stepwise change in the displacement distribution across it; the volume of deformed material associated with a **sharp-deformation-break** typically has negligible thickness at the scale of observation (hence their surfaces are perceived to be 'sharply' defined); such features typically consist of two opposing surfaces in contact or close proximity; synonymous with **fracture**		1
shear-band	a **tabular-deformation-break** formed by shearing displacement; cf. **compactional-shear-band**, **compaction-band**, **dilational-shear-band**, **dilation-band**		1
shear fracture	a term sometimes used synonymously with band fault, 'deformation band', granulation seam, microfault and some other terms to refer to **deformation bands**, typically those involving closing displacement; either of the root terms **compactional-shear-band** and **compaction-band** should be used instead for features of this type	n/a	
shear(ing)	deformation that causes contiguous parts of a body to slide relatively to each other in a direction parallel to their plane of contact	1	
shearing displacement	displacement caused by shearing, such that opposing sides of a **deformation-break** move relatively to each other in a plane parallel to the bounding surfaces; cf. closing displacement, opening displacement	2	
shear stress	stress parallel to a given plane	8	
sheet	a sheet-like break formed by any process and occupied largely or wholly by fluid (though it may subsequently be filled); cf. cavity, tube	8	
sigmoidal	curved, resembling the letter 'S'	2	
simple	describes a feature that consists of one element or has formed through a single operation, e.g. *simple* **fault**, *simple* **vein**; in practice, the term can be used sparingly, and features can be assumed to be simple unless they are named or classified as compound; cf. compound	2, 5	
sinistral	describes the sense of displacement on a **deformation-break** in which the relative movement of the block opposite an observer standing on one side is to the left; synonymous with left-lateral	2	
sinuous	with many curves; tortuous, undulating	2	
size	the relative bigness or extent of a measurable property	8	
slickenline	lineation on a **fracture** surface; use striation	n/a	
slickenside	lineation on a **fracture** surface; use striation	n/a	
slip-surface	the **deformation-break** along which shearing displacement and slumping occurs in the formation of landslides; in this context, the term is an approved synonym of **fault**	8	
slumping	the downward movement of material during a landslide	1	1
slumping-interface	an **interface** formed by slumping; such features separate slumped material from non-slumped material		1
slurry	a highly fluid mixture of water and finely divided material	3	
smooth-anticrack	an **anticrack** with a relatively even and regular form, free from the projections, indentations and roughness that characterise **dentate-anticracks**; between the two surfaces there is typically a concentration of insoluble constituents of the rock; **smooth-anticracks** are thought to be formed by pressure solution; cf. **dentate-anticrack**, **stylolite**		1

soil	generally taken to be the layer of disintegrated rock at Earth's surface, in places modified or even made by man and usually with an admixture of organic matter, which contains living matter and supports or is capable of supporting land plants; to engineers it is all non-consolidated materials above bedrock	2	
sol	a homogeneous suspension or dispersion of colloidal matter in fluid; a sol is in more fluid form than a gel	3	
solution	the process of converting a solid into a liquid by mixing it with a liquid solvent	1	
solution-cavity	a **chemical-solution-break** that is approximately equant		1
solution-interface	an interface formed by solution		1
solution seam	use **smooth-anticrack**	n/a	
solution-sheet	a **chemical-solution-break** with an approximately sheet-like shape		1
solution-tube	a **chemical-solution-break** with an approximately tube-like shape		1
spacing	the perpendicular distance between adjacent **discontinuities**; usually given as the range and/or average over the length of a sample (borehole, scan-line); strictly, only applies to near-parallel features and thus should be given for each set where possible	6	
spherulitic	a radial arrangement of fibrous crystals with an overall spherical form	5	
splay	a **fault** developed as an offshoot from another fault	8	
spot	a **crust** that consists of one or more isolated occurrences of **filling**, usually crystals, on a discontinuity surface; cf. **layer**, **patch**, **dendrite**	3	2
steeply-dipping	inclined at more than 60 degrees from horizontal	2	
stepped	describes near-parallel **fracture** segments that step progressively in plan view (cf. en echelon)	2	
straight	extending uniformly in the same direction; without a curve or bend	2	
strain	change in the shape or volume of a body as a result of stress	8	
strain recovery	release of strain energy accumulated in crystal lattices; this may be achieved through several processes, including recrystallisation (commonly with a reduction in grain-size) and annealing; much recovery represents strain relief either by complete recrystallisation or by migration of dislocations to crystal boundaries or into less strained subgrains	1	
strand	an individual **fault** of a **fault-system** or **fault-zone**	8	
stress	in a solid, the force *per* unit area acting on any surface within it; also, by extension, the external pressure that creates the internal force	8	
striation	a small groove or lineation on a **fracture** surface	8	
strike	the direction or trend taken by a structural surface or **discontinuity** as it intersects the horizontal	2	
strike-slip	describes a **deformation-break** on which displacement is parallel to strike, e.g. *strike-slip* **fault** (also referred to as wrench, tear and transcurrent faults); also the component of displacement that is parallel to strike; cf. dip-slip	2	
stylolite	an **anticrack** that is marked by an irregular and interlocking penetration of the two sides; columns, pits and teeth-like projections on one side fit into their counterparts on the other, such that they display a 'saw-tooth' or 'dentate' character; between the two surfaces there is typically a concentration of insoluble constituents of the rock; stylolites are thought to be formed by pressure solution; the term is synonymous with, and can substitute for, the formal root term **dentate-anticrack**; cf. **smooth-anticrack**		1

sutured	describes a highly irregular, acutely angular, serrated or jagged feature with zig-zag profile	2	
suture joint	use **stylolite**, **dentate-anticrack** or **smooth-anticrack**	n/a	
synthetic	describes a single **fault** or fault set that is near-parallel to, and has the same sense of displacement as, a neighbouring larger fault or fault set; cf. antithetic	6	
system	a group of related **discontinuities**	6	
systematic	said of **discontinuities** (usually **joints**) that occur in sets or patterns; they will usually cross other joints, and are commonly planar or nearly so; cf. non-systematic	6	
tabular	said of a feature having two dimensions that are much larger or longer than the third	2	
tabular-deformation-break	a **deformation-break** characterised by a continuous change in strength and/or stiffness across a band whose thickness is clearly resolvable at the scale of observation; synonymous with **deformation-band**		1
tapered	diminish or reduce in width or thickness towards one end	2	
tension-gash	a short, dilatant **fracture** that is part of an en echelon **array**; may be open, but typically mineralised	8	
throw	the size of the vertical displacement on a **fault**	2	
thrust	describes displacement on a **deformation-break** with a dip of 45 degrees or less over much of its extent, on which the hanging wall appears to have moved upward relative to the footwall	2	
trace	the intersection of a **discontinuity** with a near-planar surface, e.g. a **fracture** with an outcrop surface, and a **bedding-plane** with one surface of a **fault**	8	
tube	a tubular **break** formed by any process and occupied largely or wholly by **fluid** (though it may subsequently be filled); cf. **cavity**, **sheet**	8	
tubular	tube-shaped	2	
ultracataclasite	**cataclasite** in which the matrix forms more than 90% of the rock volume	4	2
ultramylonite	**mylonite** in which more than 90% of the rock volume has undergone grain-size reduction	4	2
unconformable	said of the relationship of units on either side of a **sedimentation-interface** where the **interface** represents a substantial break or gap in the geological record; cf. conformable	2	
unconformable-sedimentation-interface	a **sedimentation-interface** that is unconformable; synonymous with **unconformity**		1
unconformity	a **sedimentation-interface** that is unconformable; synonymous with, and can substitute for, the formal root term **unconformable-sedimentation-interface**		1
vein	a complete or near-complete **filling** of **minerals** grown *in-situ* in a **joint** or **solution-break**; opposing surfaces of the **discontinuity** are generally connected across the mineral filling (cf. **crust**)	3	2
void	space in geological material not occupied by solid matter; all natural 'void' probably consists of fluid; synonymous with pore space	3	
volume	a three-dimensional mass or sample of rock or other material; cf. line-sample, scan-line, section	8	
vug	a **pore** left after mineralisation or created by solution, the surfaces of which are typically lined by euhedral crystals	5, 8	
wallrock	the rock adjacent to, enclosing, or including a **discontinuity**; the term implies more specific adjacency than host rock	8	
weather	undergo changes, such as discolouration, softening, crumbling, and pitting, brought about by exposure to the atmosphere and its agents	1	

width	measurement or distance of a feature from side to side; cf. aperture	2, 5	
wrench fault	use *strike-slip* **fault**	n/a	
xenotopic	said of the fabric of a crystalline **filling** in which the majority of constituent crystals are anhedral; cf. idiotopic	5	
zone	a volume in which the frequency of a feature, or the degree to which a particular state or condition is developed, is measurably different than in the background	8	