Research article

JGS
Journal of the Geological Society

https://doi.org/10.1144/jgs2020-212 | Vol. 178 | 2021 | jgs2020-212

BRUCS: a new system for classifying and naming mappable rock units

Martin R. Gillespie and A. Graham Leslie*

British Geological Survey, The Lyell Centre, Research Avenue South, Edinburgh EH14 4AP, UK
MRG, 0000-0002-1585-7344; AGL, 0000-0003-1932-8420
* Correspondence: agle@bgs.ac.uk

Abstract: A new scheme is introduced for classifying and naming mappable rock bodies that lack primary stratification. In recognition of their distinctive geological characteristics, these 'nonstratiform' bodies are defined and classified according to their 3D form, spatial distribution and genetic relationships, in two hierarchical (parent–child) chains: one for intrusions and one for tectonometamorphic units. Geologically complex units, encompassing bodies of different genetic classes, are classified in a third chain reserved specifically for 'mixed-class' units. The new classification scheme is offered as an alternative to existing recommendations in the International Stratigraphic Guide and North American Stratigraphic Code, in which nonstratiform bodies are recognized and defined primarily by their lithological character. BRUCS (the *BGS Rock Unit Classification System*) combines the three new parent–child chains for nonstratiform units with the well-established chain for stratiform units (bed–member–formation–group–supergroup) to create a flexible, practical and effective solution for classifying and naming all mappable rock bodies. The taxonomic rigour of BRUCS means that the considerable capabilities of modern digital systems for managing and communicating mapping data can be exploited fully.

Received 11 November 2020; **revised** 1 February 2021; **accepted** 1 February 2021

How we classify and name mappable rock bodies is fundamentally important in geology, for two main reasons. First, the approach we choose guides and influences our decisions about how rock bodies should be recognized, how they are related and how they should be divided or grouped. Second, and equally important, the end-result communicates those decisions to others, allowing them to be applied, tested and correlated, thereby advancing geological understanding. A systematic and consistent approach to both classification and nomenclature, at a national and, ideally, a global scale, is desirable for several reasons, not least because it simplifies correlation and reduces ambiguity. Modern digital systems offer increasingly powerful means of storing, organizing, searching, linking, displaying and sharing geological data, but their effectiveness in this regard is limited by data propriety. Thus, the ideal taxonomic system for rock bodies will provide both the flexibility that geologists need to resolve complex natural associations and the rigour that allows modern digital systems to function optimally.

All mappable rock bodies can be classified to a first order according to whether they conform to the Law of Superposition (first formulated by Nicolaus Steno in 1669). Those that do comprise layered successions of sedimentary and/or extrusive igneous rocks, and can be described as 'stratiform'. Those that do not consist predominantly of intrusive, highly deformed and/or highly metamorphosed rocks, and can be described as 'nonstratiform'.

In recent decades, the British Geological Survey (BGS) has converted its analogue geological maps and records of the UK into digital datasets and products. This task required all of the mapped rock bodies of the UK to be classified and named in a consistent, logical (i.e. database-friendly) and geologically appropriate manner. During that process, it became apparent that the guidance relating to nonstratiform bodies in the two most widely used schemes for classifying and naming rock bodies, the *International Stratigraphic Guide* and the *North American Stratigraphic Code*, did not allow that goal to be realized satisfactorily, in the UK at least. In this paper, we review the relevant guidance in those schemes and then consider the key requirements of a modern, robust taxonomic scheme for nonstratiform bodies, based on the UK experience. We then describe a new scheme for classifying and naming nonstratiform bodies that takes into account all of those key requirements and that experience, and we explain how that new scheme for nonstratiform bodies has been combined with the well-established scheme for stratiform bodies to create BRUCS (the *BGS Rock Unit Classification System*), a unified system for classifying and naming all rock bodies at all normal mapping scales. BRUCS has been used successfully in the UK, where it has been shown to meet both the scientific needs of practitioners and the practical demands of the digital age; the scheme therefore may have worldwide application.

Existing recommendations for classifying and naming nonstratiform bodies

For several decades, most efforts to classify and name mappable rock bodies have drawn on the recommendations presented in two authoritative schemes (Fig. 1): the *International Stratigraphic Guide* (ISG; International Subcommission on Stratigraphic Classification, ISSC 1976, 1994; Murphy and Salvador 1999), and the *North American Stratigraphic Code* (NASC; North American Commission on Stratigraphic Nomenclature, NACSN 1983, 2005). Both the ISG and NASC take as their basis the principles of stratigraphy, the branch of geology concerned with the order and relative positions of rock units, and provide guidance on the different types of stratigraphic unit that are now widely recognized, including lithostratigraphic, biostratigraphic and chronostratigraphic units. Both schemes agree that the 'basic units' of mapping and general geological work are rock bodies defined primarily by their lithological properties.

A key element of the ISG is the simple, and now well-established, parent–child chain that forms the basis for classifying and naming stratiform rock bodies, namely ***bed/flow–member–formation–***

	Rank 6	Rank 5	Rank 4	Rank 3	Rank 2	Rank 1
Lithostrati-graphic units	bed flow	member	formation	subgroup	group	supergroup
Lithodemic units			lithodeme		suite	supersuite

Fig. 1. Key features of the ISG and NASC schemes for classifying rock units distinguished primarily by lithological properties. The parent–child chain for 'lithostratigraphic' units is used to classify stratiform bodies in both the International Stratigraphic Guide (ISG) and North American Stratigraphic Code (NASC). The ISG considers nonstratiform bodies to be lithostratigraphic units too, but does not provide a set of unit terms for nonstratiform bodies that is comparable with those used for stratiform bodies. The parent–child chain for 'lithodemic' (i.e. nonstratiform) units was introduced in the NASC and has not been adopted by the ISG. The NASC considers lithodeme, suite and supersuite to be comparable with formation, group and supergroup, respectively.

group–supergroup. The ISG allows that '*Exceptionally, a group may be divided into subgroups*', which effectively adds another unit term (***subgroup***) and rank to the chain between formation and group (Fig. 1). The ***formation*** is considered the 'primary unit of lithostratigraphy' in the ISG. In classification, formations are identified first and the ranks below and above that rank allow formations to be subdivided or grouped, respectively. The method recommended for naming units is to combine a geographical name with the appropriate unit term to indicate the rank; for example, the *Someplace Formation*. This scheme works well for stratiform rock bodies and has been applied widely to such bodies in many geological settings.

The ISG considers nonstratiform bodies to be lithostratigraphic units, because they are '*defined, classified, and mapped on the basis of their distinguishing lithologic properties and stratigraphic relationships*'. However, the ISG also acknowledges that '*most geologists may agree that the terms 'group', 'formation', and 'member' imply stratification and position within a stratified sequence showing original layering*', and suggests that for nonstratiform bodies '*it may be more appropriate to use simple field lithologic terms such as 'granite', 'gneiss', and 'schist'*' in place of the standard unit terms. Additional guidance on how nonstratiform bodies should be classified and named is rather limited and vague, and neither a set of unit terms nor a classification hierarchy comparable with that applied to stratiform bodies is provided. The use of lithological terms in place of unit terms yields names like *Someplace Granite* and *Someplace Schist*, but these names do not denote a rank and therefore do not allow a hierarchical classification. Using terms that '*express form or structure, as, for example, 'dike', 'sill', 'batholith', 'pluton', 'diapir', 'stock', 'pipe' and 'neck' or the more general term 'intrusion'*' in unit names is strongly discouraged in the ISG, on the basis that such terms '*do not indicate the lithology of the rock body, are not unit-terms in the lithostratigraphic hierarchy, and are not, therefore, lithostratigraphic terms*'. The term 'complex' is allowed for '*igneous and/or metamorphic rock bodies of diverse and irregularly mixed lithology, whether or not they are strongly deformed and/or metamorphosed*', and should be used to indicate that '*the stratigraphic relations of the individual lithologies … are poorly known or unidentifiable and that the body, therefore, cannot be subdivided on stratigraphic grounds*'; again, the term carries no connotation of rank. Using the term 'suite' is considered 'inadvisable', on the basis that '*the term has been commonly used for associations of apparently co-magmatic intrusive igneous rock bodies of similar or related lithologies and close association in time, space, and origin*'. There is no guidance on how nonstratiform bodies should be grouped or divided.

The NASC adopted, with minor amendments, the ISG recommendations for classifying and naming stratiform bodies but introduced a new concept and term, the lithodemic unit, for nonstratiform bodies. This was done specifically to address perceived limitations in the way both the ISG and precursors to the NASC treated such bodies, and the '*recognized need to develop modes of establishing formal non-stratiform … rock units*'. Nonstratiform (lithodemic) and stratiform (lithostratigraphic) bodies are thus considered distinct, and so are treated in different ways in the NASC (NACSN 1983, 2005). The NASC defines a lithodemic unit as '*a defined body of predominantly intrusive, highly deformed, and (or) highly metamorphosed rock, distinguished and delimited on the basis of rock characteristics*'. ***Lithodeme*** is the 'fundamental unit' in lithodemic classification, and thus performs a similar role to formation in the classification of stratiform units. Two or more associated lithodemes of the same class (e.g. composed entirely of intrusive rock) can be grouped in a ***suite***, and two or more suites '*having a degree of natural relationship to one another*' can be grouped within a ***supersuite***. These three types of lithodemic unit effectively define a hierarchy of three ranks (Fig. 1). Lithodeme, suite and supersuite are considered comparable with formation, group and supergroup, respectively, '*for cartographic and hierarchical purposes*' (Fig. 1). The absence of formally recognized lithodemic units equivalent to member and bed means that any subdivision of a lithodeme is informal. The term 'complex' has a more specific meaning in the NASC than it does in the ISG. Following a recent slight revision to the definition (Easton *et al.* 2016), 'complex' is a lithodemic unit comprising '*An assemblage or mixture of rocks, typically of two or more genetic classes, i.e., igneous, sedimentary, or metamorphic, with or without highly complicated structure*'; the term may be assigned '*where the mapping of each separate lithic component is impractical at ordinary mapping scales*'. ***Complex*** is unranked in the NASC but is considered '*commonly comparable to suite or supersuite*'; two or more associated complexes can be grouped within a supersuite. The approach used to name lithodemic units is to combine a geographical name with a '*descriptive or appropriate rank term*'. Although it is not stated explicitly in the NASC, the unit term ***lithodeme*** apparently is not intended to be used in unit names.

When naming lithodemes, a lithological term is preferred (e.g. *Someplace Granite*, *Someplace Schist*), but in recognizing that '*many bodies of intrusive rock … are difficult to characterize with a single lithic term*' the important exception is made that a term to '*denote form (e.g. dike, sill)*', or a term that is '*neutral (e.g. intrusion, pluton)*' can be used instead, if necessary; thus, names like *Someplace Pluton* and *Someplace Intrusion* are permissible. However, definitions for such 'form' terms, and guidance on how a 'fundamental unit' (lithodeme) should be identified, and where appropriate divided, are not provided. Furthermore, because the lithological terms and form terms do not denote a rank, it is unclear how any hierarchical classification below the rank of suite should be constructed. For suites, an adjective '*denoting the fundamental character*' is added, creating names like *Someplace Metamorphic Suite* and *Someplace Plutonic Suite*.

Shortly after the NASC was first published in 1983, the International Subcommission on Stratigraphic Classification (ISSC) completed a review of the 'stratigraphic classification and nomenclature of igneous and metamorphic rock bodies' (ISSC 1987), and drew two important conclusions. First, and having appraised the issues behind the '*considerable disagreement*' over whether the study of nonstratiform rock bodies should be considered part of stratigraphy, the ISSC concluded that '*intrusive igneous bodies and metamorphic rocks of undetermined origin have unequivocal stratigraphic significance and should be included … within the scope of stratigraphy and stratigraphic investigation. They are, therefore, subject to the rules of stratigraphic classification and nomenclature*.' Second, and having considered the introduction of lithodemic units by the NASC, the ISSC concluded that '*it does not seem advisable … to establish a new category of stratigraphic units and a new hierarchy of terms only on the basis of compliance or non-compliance with the Law of Superposition. It is preferable to consider all kinds of rock bodies that are defined and recognized on the basis of their diagnostic lithology as lithostratigraphic units*.'

The different ways in which the ISG and NASC view and treat nonstratiform bodies has remained essentially unchanged in later editions and reprints of both schemes (ISSC 1994 (reprinted 2013); Murphy and Salvador 1999; NACSN 2005). The ISSC has made clear it is content to allow the '*tests of time and usage … to … determine the ultimate practicality and validity of the practices and procedures advocated* [by both schemes]' (ISSC 1987). To date, however, no consensus has emerged, effectively leaving geologists without a scheme for classifying and naming nonstratiform rock bodies that is comparable, in terms of its utility and global reach, with the existing scheme for stratiform bodies. Several authors have highlighted perceived flaws with the ISG and NASC schemes. For example, Laajoki (1988) argued against the approach advocated in the ISG and in favour of the '*dual classification to lithology-based stratigraphy*' advocated in the NASC, and commented that '*To unite the lithology-based stratigraphy of rock strata … with that of massive igneous bodies* [as in the ISG] … *entangles stratigraphy as a science and lowers its value as a framework knowledge for petrological and other studies of rock bodies*.' Rawson *et al.* (2002) noted that the ISG '*provides little help to geologists mapping in complicated basement and plutonic terrains*', and highlighted several perceived shortcomings with the NASC, including the inadequacy of a three-rank hierarchy, problems in applying the recommendations to zoned plutons, and issues surrounding the use of the term 'complex'. A category of mappable unit that is not included in the ISG and NASC recommendations, the tectonostratigraphic(al) unit, is recognized and used alongside 'lithostratigraphic' and 'lithodemic' units in Norway, Finland and Sweden (Nystuen 1989; Strand *et al.* 2010; Kumpulainen 2017), where tectonically displaced allochthonous sheets are developed on a regional scale. A tectonostratigraphic unit in this context is defined as '*a generally flat-lying, scale-independent, tectonic unit that is bounded by zones of high strain*' (Kumpulainen 2017).

Requirements of a new scheme for classifying and naming nonstratiform bodies

In the 1990s, the British Geological Survey (BGS) began converting analogue maps and records into digital datasets describing the geology of the UK; these include a publicly accessible database of all the named rock units of the UK (*The BGS Lexicon of Named Rock Units* (BGS 2020*a*)), and a range of digital geological maps (e.g. *DiGMapGB-50* (BGS 2020*b*) and the latest 1:625 000 scale map of the UK (BGS 2008*a*, *b*)). With this change came a need to manage relevant data within multiple linked relational databases, and thus the requirement to apply rigorous and consistent standards to the method of how mapped rock bodies of the UK are classified, named and organized at a nationwide scale. In the course of reassessing UK geology for that purpose, it became clear that neither the ISG nor NASC provided an adequate solution for classifying and naming the nonstratiform rock bodies of the UK (Gillespie *et al.* 2008; Leslie *et al.* 2012), and that a new scheme was needed. The key requirements of that new scheme, as deduced from the reassessment of UK bodies and subsequent attempts to create hierarchical classifications of nonstratiform units for use in BGS databases and digital products, are summarized below.

Nonstratiform bodies should not be considered part of stratigraphy

Nonstratiform rock bodies do not conform to the Law of Superposition, and thus are of fundamentally different character to stratiform bodies. As such, they should not '*fall within the general scope of stratigraphy and stratigraphic classification*' as advocated in the ISG, although undoubtedly they can (and do) contribute to stratigraphic knowledge through absolute and relative geochronology. Instead, separate classification schemes for stratiform and nonstratiform bodies should be provided that acknowledge their differences and cater to their separate needs. Ideally, however, those separate schemes should be complementary so that they can be used together, with minimal difficulty, in areas (and in datasets) containing both stratiform and nonstratiform bodies.

Genetically distinct classes of nonstratiform unit should be recognized

The great majority of rock bodies are created by just a small number of geological processes: by *accumulation* of various materials at Earth's surface (through deposition, effusion, evaporation, etc.); by *emplacement* of magma in the subsurface; and by *deformation* and/or *metamorphism* of pre-existing rocks. Classified units that group more than one mapped body can be categorized according to whether those bodies are of one genetic class (e.g. all formed by emplacement), or more than one class (e.g. some formed by emplacement and some by accumulation). Thus, classified units are either 'single-class' or 'mixed-class'. Two categories of single-class nonstratiform unit can be recognized and should be distinguished: those formed by emplacement of magma (i.e. intrusions), and those formed by deformation and/or metamorphism. Only one category of single-class stratiform unit, those formed by accumulation, need be recognized; such units typically form stratiform successions.

Nonstratiform bodies should be classified hierarchically

A hierarchical system of classification, where components are organized by rank, and related rock bodies can be divided or grouped along a parent–child chain, has been shown to work well for stratiform bodies (i.e. the well-established *bed–member–formation–group–supergroup* chain advocated in the ISG and NASC). The advantages of a hierarchical system apply equally well to intrusions (for example, related dykes can be grouped within a dyke-swarm, a dyke-swarm can be grouped with other related intrusions into a parent unit of higher rank, and so on); the concept of classifying intrusions hierarchically has existed for some time (e.g. NACSN 1983; White *et al.* 2001). The geological validity of classifying bodies formed by deformation and/or metamorphism in a hierarchical manner is perhaps less obvious, but a comparable system of classification for such bodies would allow them to be grouped with those of other single-class categories (e.g. intrusions) to form mixed-class units, and so is desirable for that reason alone.

A hierarchical classification of nonstratiform bodies therefore makes sense, and it follows that a hierarchy of unit types should form the basis of a classification scheme. However, it is important to stress that the nature of a hierarchical relationship, and therefore the evidence-base needed to support it, is very different in nonstratiform and stratiform bodies. A hierarchical relationship in a stratiform succession generally manifests at outcrop as a spatially 'nested' arrangement of the component units, where, for example, a *member* typically exists within the extent of its parent *formation*, and a formation typically exists within the extent of its parent *group*. By contrast, related nonstratiform units can be dispersed and/or contiguous and/or nested at outcrop; this means they are often distributed in a much less regular and predictable way than stratiform units, so a hierarchical relationship is usually less easy to establish and demonstrate on the basis of field relations alone. The individual intrusions associated with a major tectonothermal episode might, for example, be scattered across tens of thousands of square kilometres, and confirming the existence and nature of a genetic relationship between the component units in such a situation will generally require detailed laboratory analysis (e.g. mineral and whole-rock geochemistry, isotope geochemistry and geochronology) as a complement to mapping data.

Nonstratiform bodies should be delimited by their geological boundary

In the ISG and NASC, the boundaries of lithostratigraphic and lithodemic units are '*placed at positions of lithologic/lithic change*'. Whereas this may be a helpful starting point for some stratiform successions, it makes less sense for nonstratiform bodies because many have inherent, well-defined geological boundaries that can manifest in various ways. For example, all intrusions (initially at least) are delimited by a contact, and most bodies produced by deformation are delimited by faults or shear zones. Thus, a range of other features, including chilled margins and zones of deformation, may be at least as important as lithological change in identifying such boundaries. Furthermore, a significant proportion of nonstratiform bodies are markedly and irregularly heterolithic as a consequence of, for example, a complex history of magmatism, deformation or metamorphism; such bodies will contain numerous examples of lithological change that are irrelevant in defining a meaningful mapped boundary. Consequently, geologists mapping nonstratiform bodies generally look first for discrete, inherent geological boundaries, however they manifest; only part of the defining character of such boundaries may be put down to lithological change.

Nonstratiform bodies should be defined primarily by their 3D form

The 3D form of the smallest mappable nonstratiform bodies can usually be determined or inferred by mapping, albeit with varying degrees of confidence. The great majority of intrusions display a restricted set of form types, for which a set of well-established terms already exists (e.g. pipe, dyke, laccolith, pluton). Groups of related intrusions often share the same form type because they have similar magma character and/or were emplaced into the same tectonic environment. Form can therefore play an important role in identifying and defining related intrusions, and can convey useful information about geological setting. Although perhaps less significant, the form displayed by bodies of deformed and/or metamorphosed rock nevertheless can be useful; for example, bodies with rectilinear and lensoidal boundaries are likely to have developed in different tectonic settings. For these reasons, form should be a key criterion in classifying and naming individual nonstratiform bodies, and should play a role in identifying groups of related bodies.

Nonstratiform units should be grouped primarily on the basis of genetic relationship

A scheme for classifying nonstratiform bodies should reflect modern research goals and current geological understanding if it is to be useful and widely adopted. In recent decades, the main objective of research involving intrusions has been to understand their genesis, in particular the nature of source rocks, controls on melting and emplacement, processes involved in magma evolution, and relationships to large-scale crustal events such as subduction and orogeny. Thus, groups of related intrusions, such as might be indicated in map legends and discussed in scientific journals, are usually recognized on the basis of interpretations regarding their genesis, in particular whether they are inferred to be comagmatic or cogenetic. Similarly, research will aim to set mappable bodies of deformed rocks, such as those within a large shear zone, in the context of the causative deformation event(s). Thus, the primary criterion for grouping nonstratiform bodies in a hierarchical classification should be the current understanding of their genetic relationships. Interpretations of a genetic relationship can be based on whatever information is available at the time. For example, an inferred genetic relationship between a number of dykes can be based initially on observable field criteria, such as lithological similarity and co-alignment; additional, more sophisticated data (e.g. laboratory analyses) obtained at a later date may provide a more robust basis for the interpretation or indicate that a new interpretation is required. Successful classifications must be reasonably robust (not incorporating too much fine detail, and not subject to frequent change), so genetic interpretation should be used judiciously, particularly in situations where there is not yet a mature understanding of such relationships.

A classification hierarchy for nonstratiform units should have six formal ranks

Logically, the smallest mappable bodies should be classified in the lowest rank of a hierarchy, with groups of related bodies representing increasingly broad 'families' classified in successively higher ranks. The highest formal rank of a hierarchy ideally would unite all the units of a particular genetic class that formed in association with a major tectonothermal episode, regardless of their present geographical distribution. How many ranks might ultimately be needed to accommodate the most complex situations globally (e.g. all bodies related to a continent-scale tectonothermal episode) is not clear. However, it has been shown that all the nonstratiform bodies of the UK can be classified adequately in a hierarchy spanning six ranks (Gillespie *et al.* 2012; Leslie *et al.* 2012). The well-established hierarchy for stratiform units also has six ranks (when *subgroup* is included), and a unified classification system for all (stratiform and nonstratiform) rock units arguably is more logical and more likely to be successful if the different hierarchies within it have the same number of ranks. A hierarchy of six formal ranks therefore seems a pragmatic solution for nonstratiform units, and does not preclude the possibility that one or more ranks above the top rank could be added informally if needed.

Tripartite names should be permissible for nonstratiform units

In the context of a taxonomic system for mappable rock bodies, the goal of nomenclature is to differentiate units and, within reason, communicate key information about them. Both the ISG and NASC advocate that names assigned to nonstratiform units should generally be bipartite, comprising a geographical name and a lithological or 'descriptive' term (e.g. the *Someplace Granite*). However, the 'key' information relating to a lower-rank nonstratiform unit arguably can include its geographical location, lithological character, form type, style of spatial distribution and rank, and this breadth of information cannot be conveyed within a bipartite name. Formal names for lower-rank nonstratiform units therefore should be tripartite, comprising a geographical component, a lithological component and a unit term that conveys both their rank and form type or style of spatial distribution. Higher-rank units generally group numerous related bodies, which typically will display a broad range of characteristics that cannot be conveyed meaningfully in a name (i.e. lithological components, form types and types of spatial distribution). Thus, formal names for higher-rank units can more often be bipartite, comprising just a geographical component and a unit term.

BRUCS: the *BGS Rock Unit Classification System*

The BGS has created a new scheme for classifying and naming nonstratiform rock units that takes into account all of the key requirements described above. The key features of the new scheme (i.e. the hierarchical arrangement and unit types) are shown in Figure 2, alongside the well-established hierarchy for classifying stratiform bodies. Succinct definitions for the unit types associated with each of the new hierarchies are provided in Tables 1–3. The term 'related' is used in these tables, and hereafter, to refer to situations where a genetic relationship between units is established or inferred.

The 'unified' configuration presented in Figure 2 forms the basis of the *BGS Rock Unit Classification System* (BRUCS), which provides a flexible and practical means of classifying and naming all (stratiform and nonstratiform) mappable rock bodies. BRUCS has been designed with the geology of the UK in mind; however, it should be applicable to any setting, and particularly to those situations where the resolution of mapping and level of geological understanding together allow a full and detailed classification across multiple ranks.

Examples of how BRUCS has been, and could be, used to classify nonstratiform units are presented in Figures 3–10. Each of these figures is presented as a 'classification grid', with individual ranks extending from top to bottom, individual parent–child chains from left to right, and box colour denoting unit class (intrusion, tectonometamorphic, etc.). No stratigraphic or tectonostratigraphic order is implied by the way units are arranged in these figures; they merely illustrate the hierarchical relationships between units. An extended caption for each figure provides the necessary geological background and relevant details of how BRUCS has been applied in each example.

BRUCS has been used within the BGS to create a full classification of most of the Phanerozoic intrusions of the UK (Gillespie *et al.* 2012). These intrusions, which number many tens of thousands, formed in association with three major tectonothermal episodes. The units occupying ranks 1–3 of the classification relating to each episode are shown in Figure 3, and the full parent–child chains for two of the component units, the *Lake District Suite* and *Skye Central Complex*, are presented in Figures 4 and 5. The BGS is in the process of creating similar classifications for all other

				Rank 6	Rank 5	Rank 4	Rank 3	Rank 2	Rank 1
Stratiform	Single-class units	Stratigraphic	Accumulated units	bed flow	member	formation	subgroup	group	supergroup
Nonstratiform	Single-class units	Morphogenetic	Intrusions	cone-sheet diatreme dyke intrusion laccolith neck pipe plug ring-dyke sheet sill vein vent	lopolith pluton ring-intrusion swarm*	centre cluster	subsuite	suite	supersuite
Nonstratiform	Single-class units	Morphogenetic	Tectono-metamorphic units	block layer lens mass	parcel * swarm * train *	ophiolite package set	subassemblage	assemblage	superassemblage
Nonstratiform	Mixed-class units					ring-complex sheet-complex sill-complex vein-complex	central complex subcomplex volcano-complex	complex	supercomplex

Fig. 2. Key features of the BGS Rock Unit Classification System (BRUCS). The hierarchy and unit terms for classifying 'stratiform' units are those recommended in the ISG (and thus are the same as those for 'lithostratigraphic' units in Fig. 1). The hierarchies and unit terms for classifying 'nonstratiform' units are published here for the first time. The types of mixed-class unit are limited to those required by UK geology. *In unit names, this term may be preceded by one or more terms from Rank 6 (e.g. dyke-swarm, lens-swarm, layer-parcel and block-train).

Table 1. *Definitions for unit terms in the hierarchy for intrusions*

Unit term	Rank	Definition
Centre	4	A group of two or more related units of lower rank focused tightly around a central point and usually intersecting to some degree
Cluster	4	A group of two or more related units of lower rank, associated spatially but not focused tightly
Cone-sheet	6	A *sheet* with a cone shape that dips inwards towards a central 'focal' point
Diatreme	6	A *pipe* filled with volcanic breccia that is inferred to form through gaseous disruption
Dyke	6	A *sheet* emplaced along a steep to vertical fracture, normally discordant to host-rock structure
Intrusion	6	*Sensu lato*: any rock body formed when magma solidifies before reaching the surface. As a unit term in Rank 6: any intrusion whose form is not known or does not conform to one of those denoted by another unit term
Laccolith	6	An intrusion *sensu lato* that is roughly circular in plan, generally with a planar floor and domed roof
Lopolith	5	An intrusion *sensu lato* that is kilometre-scale or larger and broadly saucer-shaped
Neck	6	A *pipe* inferred to have fed a volcano, now infilled with collapsed material from the *vent*
Pipe	6	An intrusion *sensu lato* that is cylindrical and normally steeply oriented
Plug	6	A *pipe* inferred to have fed a volcano, but generally lacking collapsed material from the *vent*
Pluton	5	An intrusion *sensu lato* that is kilometre-scale or larger, and cylindrical, lenticular or tabular
Ring-dyke	6	A *sheet* that is arcuate or annular in plan, and usually vertical or inclined steeply outwards
Ring-intrusion	5	An intrusion *sensu lato* that is emplaced within, or bounded by, a ring-fracture
Sheet	6	An intrusion *sensu lato* with broadly parallel margins and one dimension much shorter than the other two
Sill	6	A *sheet* emplaced along a gently inclined to horizontal fracture; normally broadly concordant in strata
Subsuite	3	A group of two or more units of lower rank that display shared characteristics and belong to the same *suite*
Suite	2	A group of two or more related units of lower rank
Supersuite	1	A group of two or more related *suites* with or without other units of lower rank that are not part of those *suites*
Swarm	5	A group of two or more related units of lower rank that are spatially associated
Vein	6	An intrusion *sensu lato* that is sheet-like, but generally narrower and less regular than a *sheet*
Vent	6	An opening at Earth's surface through which volcanic material has been, or is being, extruded

Table 2. *Definitions for unit terms in the hierarchy for tectonometamorphic units*

Unit term	Rank	Definition
Assemblage	2	A group of two or more related units of lower rank
Block	6	A unit with rectilinear boundaries that does not conform to the description of a *layer*
Layer	6	A unit that is tabular, with parallel or near-parallel (co-planar) bounding surfaces
Lens	6	A unit that is broadly lensoidal
Mass	6	A unit whose form is geometrically irregular and/or does not conform to the description of a *block*, *layer* or *lens*, or is unknown
Ophiolite	4	A unit formed of obducted oceanic crust, traditionally recognized as several layers of ultrabasic and basic igneous rock, dykes and other intrusions, pillow lavas and sea-floor sediments, with or without subjacent mantle
Package	4	A group of two or more related units of lower rank that are essentially contiguous at outcrop
Parcel	5	A group of two or more related units of lower rank that are essentially contiguous at outcrop
Set	4	A group of two or more related units of lower rank that are essentially dispersed (not contiguous) at outcrop
Subassemblage	3	A group of two or more units of lower rank that display shared characteristics and belong to the same *assemblage*
Superassemblage	1	A group of two or more related *assemblages* with or without other units of lower rank that are not part of those *assemblages*
Swarm	5	A group of two or more related units of lower rank that are essentially dispersed (not contiguous) at outcrop
Train	5	A group of two or more related units of lower rank that are essentially dispersed (not contiguous) and have a broadly linear disposition at outcrop

Table 3. *Definitions for unit terms in the hierarchy for mixed-class units*

Unit term	Rank	Definition
Central complex	3	A unit comprising multiple related intrusions, usually with screens and irregular masses of associated extrusive rocks and/or country rocks, and commonly but not necessarily arranged spatially around one or more focal points. *Central complexes* are commonly composed of two or more spatially associated (and commonly intersecting) *centres*, and may generally be considered to represent the roots of a central volcano at a relatively shallow crustal level; however, that association is not essential to this definition
Complex	2	A group of two or more related units of lower rank
Ring-complex	4	A unit comprising multiple *ring-intrusions* and/or *ring-dykes*, *cone-sheets*, *ring-dyke-swarms* and *cone-sheet-swarms*, and their country-rock
Sheet-complex	4	A unit comprising multiple *sheets* and their country-rock
Sill-complex	4	A unit comprising multiple *sills* and their country-rock
Subcomplex	3	A group of two or more units of lower rank that display shared characteristics and belong to the same *complex*
Supercomplex	1	A group of two or more related units of lower rank
Vein-complex	4	A unit comprising multiple *veins* and their country-rock, the whole being typically intermediate in character between a xenolith-rich *intrusion (sensu lato)* and veined country-rock
Volcano-complex	3	A unit comprising all the related units, extrusive, intrusive and sedimentary, formed at a site of persistent volcanic activity

Rank 3	Rank 2	Rank 1
East Shetland Subsuite	Shetland Islands Suite	Caledonian Supersuite
West Shetland Subsuite		
Shetland Minor Intrusion Subsuite		
Northeast Grampian Basic Subsuite	Scottish Highlands Ordovician Suite	
Northeast Grampian Granitic Subsuite		
Northwest Grampian Granitic Subsuite		
Alford Subsuite		
Highlands Ordovician Minor Intrusion Subsuite		
Deeside Subsuite	Scottish Highlands Silurian Suite	
Skene Subsuite		
South Grampian Subsuite		
Glencoe Caldera Volcano-complex		
Argyll–Northern Highlands Subsuite		
Northwest Highlands Alkaline Subsuite		
Highlands Silurian Minor Intrusion Subsuite		
Lowlands Minor Intrusion Subsuite	Scottish Lowlands Suite	
Galloway Subsuite	Trans-Suture Suite	
North England Subsuite		
Trans-Suture Minor Intrusion Subsuite		
Cumbrian Mountains Felsic Subsuite	Lake District Suite	
Midlands Minor Intrusion Subsuite	Central England Suite	
Cymru Minor Intrusion Subsuite	Wales Suite	
Laxey Minor Intrusion Subsuite	Isle of Man Suite	
	Ireland Ordovician Suite	
North Ireland Silurian Minor Intrusion Subsuite	Ireland Silurian Suite	
South Scotland Early Carboniferous Mafic Subsuite	Scotland Alkaline Suite	Variscan Supersuite
South Scotland Trachyte–phonolite Subsuite		
South Scotland Late Carboniferous–Permian Mafic Subsuite		
Scotland Lamprophyre Subsuite		
	North Britain Tholeiitic Suite	
Derbyshire Mafic Subsuite	Central–South Britain Alkaline Suite	
West Midlands Mafic Subsuite		
South Britain Lamprophyre Subsuite		
Southwest England Felsite Subsuite	Cornubian Suite	
Mull Central Complex	Hebrides Subvolcanic Suite	Atlantean Supersuite
Ardnamurchan Central Complex		
Skye Central Complex		
Rum Central Complex		
Blackstones Bank Central Complex		
Carlingford Central Complex		
Slieve Gullion Central Complex		
Mourne Mountains Subsuite		
Arran Subsuite		
	Rockall Suite	
Tardree Volcano-complex		
West Scotland Palaeogene Sill Subsuite	Celtic Palaeogene Minor Intrusion Suite	
Atlantic Margin Sill Subsuite		
West Scotland Palaeogene Plug Subsuite		
North Britain Palaeogene Dyke Subsuite		
North Ireland Palaeogene Dyke Subsuite		
Antrim Plug-and-vent Subsuite		
Antrim Sills Subsuite		

Fig. 3. Classification of Phanerozoic intrusions in the UK (Ranks 3–1), using BRUCS. Colours denote unit class (see Fig. 2.) The classification shown here is based on Gillespie *et al.* (2012). Intrusions of Phanerozoic age in the UK have formed in association with one of three tectonothermal episodes; the classified rock units associated with each episode are grouped within a supersuite at Rank 1. The name *Trans-Suture Suite* was introduced in a relatively recent publication (Brown *et al.* 2008) and is retained to respect that precedent, although the first term of the name ('Trans-Suture') does not conform to the naming convention generally used in BRUCS. The *Atlantean Supersuite* was proposed by Gillespie *et al.* (2008) to encompass all the intrusions (and other related rocks) resulting from magmatism associated with the opening of the North Atlantic Ocean. The *Atlantean Supersuite*, and to a much smaller extent the *Caledonian Supersuite*, include mixed-class units at Rank 3. Every unit at Rank 2 and Rank 3 is the 'parent' to numerous 'child' units that are classified at ranks below Rank 3 and therefore do not appear in this figure.

nonstratiform units of the UK, and work is ongoing to incorporate the new hierarchical relationships and unit names into BGS databases and digital products.

In practice, formal unit names are likely to be assigned only to the larger or more important mapped bodies, and to some bodies that are too small to map but are well known or geologically significant (e.g. a thin but richly mineralized band in a layered intrusion). Although they can be classified, many smaller mappable bodies, and nearly all unmapped bodies, may never be assigned a name, in which case they will not be recorded individually in a formal classification of units. However, their presence ideally should be recorded; for example, in the description of their immediate parent unit (e.g. 'the Someplace Basalt Dyke-swarm consists of numerous dykes that have not been mapped or named individually'). Examples of how unnamed units can be acknowledged in classification grids are provided in Figures 4–10.

The key features and principles of BRUCS are as follows (see also Fig. 2).

- Stratiform and nonstratiform bodies are treated separately.
- Three categories of single-class unit are recognized, based on their genesis: accumulated units, intrusions and tectono-metamorphic units. Each category has its own set of unit terms arranged in a hierarchy of up to six ranks. Mixed-class units have their own hierarchy, which of necessity spans fewer ranks.
- *Accumulated units* are bodies formed by processes that cause geological materials to accumulate at Earth's surface, such

Rank 6	Rank 5	Rank 4	Rank 3	Rank 2	Rank 1
unnamed sills	*undefined sill-swarms*	Borrowdale Sill Cluster		Lake District Suite	**Caledonian Supersuite** (encompasses other child units)
unnamed plugs and sheets of microdiorite	Embleton Microdiorite Plug-and-sheet-swarm	Derwent Mafic Minor Intrusion Cluster			
Dash Hornblendite Plug	Bassenthwaite Microdiorite Plug-and-intrusion-swarm				
unnamed intrusions of microdiorite					
unnamed plugs, necks, pipes and dykes of andesite	Pike de Bield Andesite Swarm				
unnamed dykes of basalt	Wasdale Basalt Dyke-swarm				
Wallow Crag Gabbro Plug	Haweswater Gabbro–microdiorite Plug-and-dyke-swarm				
Naddle Beck Dolerite Plug					
Birkhouse Hill Microdiorite Plug					
unnamed plugs and dykes					
Harestones Rhyolite Intrusion		Carrock Fell Centre			
Red Covercloth Microgranite Intrusion					
Rae Crags Granite Intrusion	Carrock Gabbro–granite Pluton				
Miton Hill Microgabbro Intrusion					
Buck Kirk Quartz-gabbro Intrusion	Mosedale Gabbro Pluton				
White Crags Gabbro Intrusion					
Black Crag Gabbro Intrusion					
	Eskdale Granite Pluton		Cumbrian Mountains Felsic Subsuite		
	Broad Oak Granodiorite Pluton				
	Ennerdale Granite Pluton				
unnamed dykes of felsic rock	Wast Water Felsic Dyke-swarm				
Threlkeld Microgranite Intrusion					
unnamed minor intrusions of microgranite and microgranodiorite					
	Wensleydale Granite Pluton				

Fig. 4. Classification of the Lake District Suite, northern England, using BRUCS. Colours denote unit class (see Fig. 2). The *Lake District Suite* is a component of the *Caledonian Supersuite*. The classification shown here is based on Millward (2002). All classified components of the suite are intrusions. A subset of the units encompassed by the suite is grouped within a subsuite, the *Cumbrian Mountains Felsic Subsuite*, at Rank 3. Other units of lower rank are grouped within three units, two clusters and a centre, at Rank 4. Two plutons in the *Carrock Fell Centre*, the *Carrock Gabbro–granite Pluton* and *Mosedale Gabbro Pluton*, encompass two or more mappable intrusions that are classified and named at Rank 6. Many of the smaller mappable units classified at Rank 6 are currently unnamed.

as deposition, effusion and evaporation. They are generally stratiform and typically form successions. They should be classified and named using the well-established hierarchy and procedure for lithostratigraphic units that is advocated in the ISG (ISSC 1994).

- *Intrusions* are rock bodies formed when magma solidifies in the subsurface. Bodies that may have formed *in situ*, and as such may not have been intruded *sensu stricto*, are included.
- *Tectonometamorphic units* are rock bodies that cannot reliably be classified as an accumulated unit or an intrusion as a result of superimposed deformation and/or metamorphism.
    - o Those resulting primarily from deformation include allochthonous bodies in thrust zones and new bodies formed in shear zones through intense tectonic interleaving; such bodies are defined by discrete, high-strain boundaries (a focus for either brittle or ductile deformation), and have become physically separated from their original geological context by displacement associated with those boundaries. Some of these units will contain or consist of rocks in which primary stratification or original intrusion form are still discernible and can be mapped; in many cases, it will be possible to relate these stratiform bodies or intrusions to their original geological context, but where that is not possible the host tectonometamorphic unit can be described as *isolated*.
    - o Those resulting primarily from metamorphism have been modified by that metamorphism to the extent that the original unit category (e.g. accumulated unit or intrusion), and/or the nature of the original relationship with adjacent units (unconformable, depositional, intrusive or structural), cannot be deduced or inferred reliably. High-grade gneiss terranes, such as the Lewisian rocks of NW Scotland, generally contain many such tectonometamorphic units.
- Intrusions and tectonometamorphic units are referred to collectively as *morphogenetic units*, to reflect the two key criteria (form/morphology and genesis) used to classify them.
- Formal classification takes place within the six ranks of Figure 2, and using the unit terms therein. Any other terms, including those that connote a subdivision of an individual intrusion (e.g. 'facies' and 'zone') or a large-scale grouping of units (e.g. 'province'), must not be used in the parent–child chain of a formal classification.

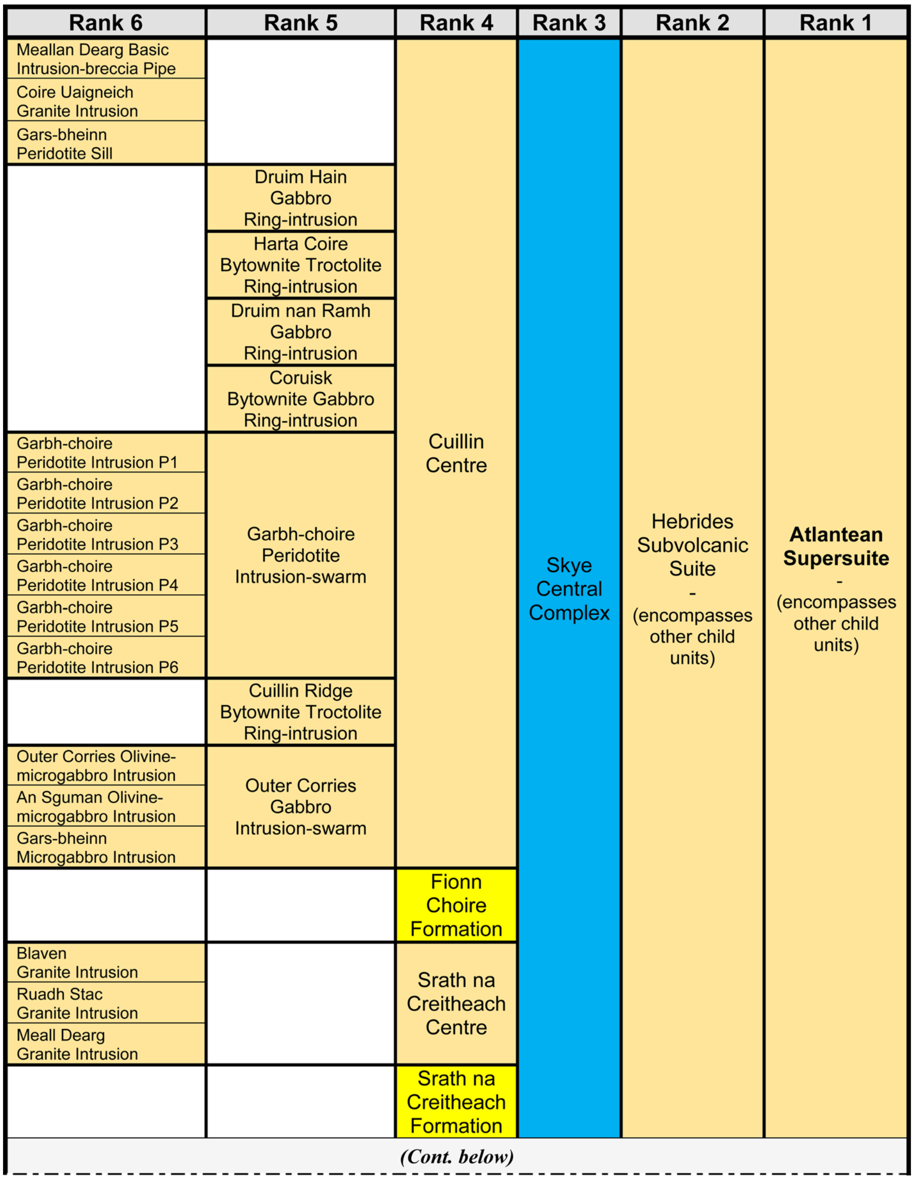

Fig. 5. Classification of the Skye Central Complex, NW Scotland, using BRUCS. Colours denote unit class (see Fig. 2). The classification shown here is based on Emeleus and Bell (2005) and BGS (2005*a*). The *Skye Central Complex* (Rank 3) is a component of the *Hebrides Subvolcanic Suite* (Rank 2), which in turn is a component of the *Atlantean Supersuite* (Rank 1). The central complex consists mainly of four centres (Rank 4), which are related genetically and intersect each other at outcrop to varying degrees. Each centre encompasses multiple units of lower rank (Rank 5 and 6). However, many other units classified at these two lowest ranks have no parent at Rank 4 but are still recognized as part of the *Skye Central Complex*. Some ring-intrusions consist of several mappable components that are considered to be zones of the ring-intrusion rather than discrete intrusions within it; as such, they are not morphogenetic units and are not included in this classification grid. All of the morphogenetic units of the *Skye Central Complex* are intrusions. Two related stratiform units (the *Srath na Creitheach Formation* and the *Fionn Choire Formation*) are contained within its outcrop. Some of the smaller mappable units classified at Rank 6 are currently unnamed.

- The smallest mappable morphogenetic units are delimited by their geological boundary and classified in the lowest rank of their hierarchy (Rank 6), primarily according to their 3D form (observed or inferred). *Pluton*, *lopolith* and *ring-intrusion*, each of which *can* be essentially one intrusion, are placed at Rank 5 because they can also consist of two or more discrete mappable intrusions that would be classified at Rank 6.
- Groups of related morphogenetic units are defined and classified by their spatial and genetic relationships at ranks 5 and 4, and by genetic relationship alone in higher ranks. Information based on genetic interpretations should be used judiciously in classification, especially in those circumstances where a mature understanding of such relationships has not yet become established.
- The size of a mappable body is irrelevant in determining the rank at which it should be classified. A ***dyke*** is classified at Rank 6 regardless of whether its outcrop is 10 m or 100 km long, and a ***parcel*** is classified at Rank 5 regardless of whether its outcrop covers 1 km^2 or 1000 km^2.
- The number of units in a group of related units is irrelevant in determining the rank at which it should be classified. For example, two or any larger number of dykes can be grouped within a ***dyke-swarm***.
- A specific 'entry point' for classification, equivalent to the role played by ***formation*** in classifying a stratiform succession, and a preferred 'direction of travel' within a hierarchy (i.e. bottom-up or top-down) are not prescribed for morphogenetic units and mixed-class units, but are left to the geologist's discretion. In deciding how to proceed with classification in any particular area, geologists will need to account for the state of existing mapping and knowledge, the time and resources available to gather new information, and the overall objectives of the work in hand. In poorly understood or geologically complicated ground, or if the goal is simply a reconnaissance-level survey, classification may begin in, and be limited to, the mid- to high ranks, with refinement and expansion into other ranks happening subsequently as new information becomes available.
- A classified unit does not need to have a related 'parent' or 'child' unit in any other rank. For example, a unit could be classified at Rank 5, with no parent or child at any other rank, either because it actually has no known 'relatives' or because its relationship with other units is unknown or uncertain. It is also acceptable for a parent–child relationship to skip one or more ranks. For example, two or more ***plutons*** (Rank 5) may be grouped within a ***suite*** (Rank 2), with no 'relatives' in intervening ranks.

<table>
<tr><th colspan="6">(Cont.)</th></tr>
<tr><th>Rank 6</th><th>Rank 5</th><th>Rank 4</th><th>Rank 3</th><th>Rank 2</th><th>Rank 1</th></tr>
<tr><td>Eas Mor Granite Ring-dyke</td><td rowspan="3"></td><td rowspan="12">Western Red Hills Centre</td><td rowspan="28">Skye Central Complex</td><td rowspan="28">Hebrides Subvolcanic Suite - (encompasses other child units)</td><td rowspan="28">Atlantean Supersuite - (encompasses other child units)</td></tr>
<tr><td>Meall Buidhe Granite Ring-dyke</td></tr>
<tr><td>Maol na Gainmhich Granite Ring-dyke</td></tr>
<tr><td rowspan="2"></td><td>Loch Ainort Granite Ring-intrusion</td></tr>
<tr><td>Beinn Dearg Mhor Granite Ring-intrusion</td></tr>
<tr><td>Marsco Granite Ring-dyke</td><td rowspan="3"></td></tr>
<tr><td>Southern Porphyritic Granite Ring-dyke</td></tr>
<tr><td>Glen Sligachan Granite Intrusion</td></tr>
<tr><td></td><td>Glamaig Granite Ring-intrusion</td></tr>
<tr><td>Northern Porphyritic Felsite Intrusion</td><td rowspan="3"></td></tr>
<tr><td>Marsco Hybrid Ring-dyke</td></tr>
<tr><td>Marsco Summit Gabbro Intrusion</td></tr>
<tr><td></td><td>Beinn na Caillich Granite Ring-intrusion</td><td rowspan="9">Eastern Red Hills Centre</td></tr>
<tr><td>Creag Strollamus Granite Intrusion</td><td rowspan="3">Outer Granite Pluton</td></tr>
<tr><td>Beinn an Dubhaich Granite Intrusion</td></tr>
<tr><td>Beinn na Cro Granite Intrusion</td></tr>
<tr><td></td><td>Glas Bheinn Mhor Granite Ring-intrusion</td></tr>
<tr><td>Broadford Gabbro Intrusion</td><td rowspan="2"></td></tr>
<tr><td>Beinn na Cro Gabbro Intrusion</td></tr>
<tr><td>unnamed intrusions of hybrid rock</td><td>Kilchrist Hybrid Intrusion-swarm</td></tr>
<tr><td>unnamed coalescing vents</td><td>Kilchrist Intrusion-breccia Vent-swarm</td></tr>
<tr><td>Raasay Granite Sill</td><td rowspan="7"></td><td rowspan="7"></td></tr>
<tr><td>Scalpay Granite Intrusion</td></tr>
<tr><td>An Sithean Granite Intrusion</td></tr>
<tr><td>unnamed sheets of basalt-andesite and rhyolite</td></tr>
<tr><td>unnamed sheets of granite and microgranite</td></tr>
<tr><td>unnamed intrusions of gabbro and dolerite</td></tr>
<tr><td>unnamed intrusions & vents of volcaniclastic breccia</td></tr>
</table>

Fig. 5. Continued.

However, any unit classified as a ***subsuite*** or ***subassemblage*** (at Rank 3) must have a parent at Rank 2.

- Formal names for units classified at ranks 6 and 5 are generally tripartite, comprising a geographical term, lithological term and unit term, in that order; for example, the *Cairngorm Granite Pluton*. Although such names can be relatively cumbersome, they are informative and can be presented in a shortened form (e.g. ‘Cairngorm pluton’) once the formal name has been introduced and defined. As far as possible, geographical terms should be unique (not used in more than one unit name), so that shortened names are also unique.
- The requirements for providing formal descriptions and achieving formal status for all units classified using BRUCS are essentially the same as those required for lithostratigraphic units in the ISG; for example, descriptions should include details of lithological character, boundary character, hierarchical relationships (parent unit and child units, where appropriate) and details of a type locality.

Classifying and naming intrusions

Classification at ranks 6, 5 and 4. Thirteen types of intrusion are placed at Rank 6 of the intrusions hierarchy (Fig. 2 and Table 1). Eight, ***cone-sheet***, ***dyke***, ***laccolith***, ***pipe***, ***ring-dyke***, ***sheet***, ***sill*** and ***vein***, are distinguished purely on the basis of their form. Three, ***diatreme***, ***neck*** and ***plug***, include in their definition an element of setting or genesis. One, ***vent***, connotes a setting but not a specific form, and one, ***intrusion***, carries no connotation of shape, setting or genesis (other than that it is an intrusion), but may be used to classify a unit at Rank 6 whose form is not known or that is not one of the other unit types at Rank 6.

Four unit types are placed at Rank 5. Related and spatially associated units classified at Rank 6 can be grouped at Rank 5 in a ***swarm***. The term can be used on its own in this context but can be made more informative by concatenation with one or more of the unit terms from Rank 6. Thus, a group of dykes is a ***dyke-swarm***, and a group of cone-sheets is a ***cone-sheet-swarm***. Longer names may be constructed to denote related groups of more than one type of intrusion (e.g. ***dyke-and-sill-swarm***); such names are not shown in Figure 2, or included in Table 1, but many such combinations are possible. The three other unit types at this rank, ***pluton***, ***lopolith*** and ***ring-intrusion***, are for bodies that can consist of a single intrusion or multiple intrusions (i.e. they can be 'simple' or 'composite'); placing them at Rank 5 means that the individual intrusions in a composite pluton, for example, can be classified at Rank 6. The definitions for pluton and lopolith include a lower size limit to ensure the terms are reserved for relatively large intrusions (Table 1).

Rank 4 contains two types of unit, ***centre*** and ***cluster***, that can group units of lower rank in a way that conveys a particular spatial as well as a genetic relationship. A ***centre*** encompasses units that spatially are tightly focused around a central point, and a ***cluster*** encompasses units that are associated spatially but not tightly focused (i.e. are more scattered than those forming a centre). A ***centre*** could, for example, comprise two intersecting plutons, and several ring-dykes, a dyke-swarm and a number of pipes that intersect the plutons or are spatially closely associated with them. A ***cluster*** might consist of two dyke-swarms, a sill-swarm and numerous pipes, which are related but scattered over a wide area.

Figures 4 and 5 include examples of how BRUCS has been used to classify and name many of these unit types at ranks 6, 5 and 4.

Classification at ranks 3, 2 and 1. The three highest ranks of the intrusions hierarchy each contain only one unit type, which in each case is used to group two or more units of lower rank. At these high ranks, the unit terms carry no connotation of form type or spatial relationship, but simply imply an inferred genetic relationship. Figures 3–5 include examples of how BRUCS has been used to classify and name units in these higher ranks.

Where a higher rank classification is appropriate, a group of related units from ranks 6, 5 and 4 should first be classified at Rank 2 as a ***suite***. This term has been used widely in the past to refer to groups of related rock bodies (usually, but not always, intrusions), although definitions vary. As defined here, 'suite' is used simply to group related intrusions of lower rank; these must be inferred to have some degree of genetic relationship but need not be comagmatic.

A subset of the units in a suite may be grouped within a ***subsuite***, at Rank 3, if they display shared characteristics and it is useful to distinguish them in this way. A subsuite can be identified only after its 'parent' suite has been defined. Not all suites will contain a subsuite, and there is no requirement to group all the units in a suite into subsuites. A suite could, for example, consist of a subsuite of three plutons and several other units not assigned to a subsuite. Two or more related suites, with or without other units of lower rank that are not part of those suites, may be grouped within a ***supersuite***.

Nomenclature at ranks 6 and 5. Formal names for units classified at ranks 6 and 5 should consist of a geographical term, a lithological term and a unit term, in that order (e.g. *Eskdale Granite Pluton*). The geographical term should refer to a district, settlement or feature within, or adjacent to, the outcrop of the unit. The lithological term should convey the essential character of the unit as accurately as the concise format allows. Two rock name terms linked by an *en dash* (–) may be used where units have two important lithological components, or to indicate the principal end-members in a unit characterized by lithological diversity (e.g. *Comrie Diorite–granite Pluton*). In BGS databases and products, all of the lithological terms used in unit names must be consistent with the definitions in the *BGS Rock Classification Scheme* (Gillespie and Styles 1999; Hallsworth and Knox 1999; Robertson 1999). The unit term (e.g. plug, dyke, pluton) should be selected from an appropriate rank of the hierarchy.

Nomenclature at ranks 4, 3 and 2. The names of units classified at these ranks should consist of a geographical term and a unit term (e.g. *Carrock Fell Centre* and *Shetland Suite*). Terms to indicate other characteristic or distinctive features of a unit (e.g. its broad compositional character (mafic, alkaline, etc.), chronostratigraphic division or the typical 3D form of its constituent units) can be inserted between the two principal components of the name to help distinguish one unit from another in areas where multiple units have overlapping extents and/or suitable geographical terms are at a premium. Chronostratigraphic terms have been inserted in the names *Scottish Highlands Ordovician Suite* and *Scottish Highlands Silurian Suite* to address such a situation in the UK (Fig. 3).

Nomenclature at Rank 1. Supersuites should be assigned a bipartite name consisting of a term to indicate the tectonothermal episode with which the magmatism is associated, followed by the unit term ***supersuite***; thus, the name *Caledonian Supersuite* (e.g. Fig. 3) denotes a Rank 1 unit that embraces all of the intrusions that formed in association with the Caledonian Orogeny.

Classifying and naming tectonometamorphic units

Classification at Rank 6. Four unit types at Rank 6 are distinguished by their form (Fig. 2): ***lens*** and ***layer*** are units that approximate to lensoidal and tabular form, respectively, a ***block*** has rectilinear boundaries but is not tabular, and a ***mass*** is a unit whose character is not well described by any of these terms, or is unknown.

Definitions of these unit terms, and of those in higher ranks of the hierarchy for tectonometamorphic units, are provided in Table 2.

Classification at ranks 5 and 4. Two or more tectonometamorphic units classified at Rank 6 may be united within one of three unit types at Rank 5, according to the nature of their spatial relationship (Fig. 2): ***train*** and ***swarm*** denote dispersed associations, the former in a broadly linear arrangement, whereas ***parcel*** denotes a contiguous association. Where appropriate, terms from Rank 6 and Rank 5 can be linked to make compound unit terms like ***block-train*** (a train consisting largely or entirely of blocks) and ***lens-swarm***; such names are not shown in Figure 2, or included in Table 2, but several such combinations are possible. Two or more units classified at Rank 6 and/or 5 may be united within one of two unit types at Rank 4, also according to the nature of their spatial relationship; ***set*** denotes a dispersed association, whereas ***package*** denotes a contiguous association.

Ophiolite, a fragment of obducted oceanic crust (e.g. Dewey 1976), is a specific type of isolated tectonometamorphic unit classified at Rank 4 (Fig. 2). Classic examples of ophiolite have a mixed-class character in lithological terms, typically comprising several layers of ultrabasic and basic igneous rock, 'sheeted' dykes and other intrusions, with pillow lavas and sea-floor sediments (e.g. Morag *et al.* 2016; Guilmette *et al.* 2018). However, the lithological character of an ophiolite (prior to any alteration) derives from its pre-obduction setting (i.e. autochthonous oceanic crust), whereas the mapped boundary of an ophiolite derives from the later tectonic process of obduction; thus, for the purposes of classification, ophiolite is considered to be a tectonometamorphic unit with a particular lithological character and structural history. Not all of the lithological components listed above need be present to classify a unit as ophiolite, but there must be enough evidence to support an interpretation that the body in question represents former oceanic crust. Any mappable bodies within an ophiolite unit can be classified as child units of the parent, and named using lower-rank unit terminology from the hierarchy for tectonometamorphic units;

Rank 6	Rank 5	Rank 4
unnamed layers of carbonate-mylonite	Someplace Carbonate-mylonite Layer-parcel	Moine Thrust Mylonite Set
unnamed layers of quartzitic-mylonite	Someplace Quartzitic-mylonite Layer-parcel	
unnamed layers of mylonitic gneiss	Someplace Mylonitic Gneiss Layer-parcel	
unnamed layers of Oystershell Rock	Someplace Oystershell Rock Layer-parcel	

Fig. 6. A possible classification of rock units in the Moine Thrust Zone, NW Scotland, using BRUCS. Colours denote unit class (see Fig. 2). The classification shown here is adapted from Leslie *et al.* (2012). The Moine Thrust Zone, in NW Scotland, consists of tectonically 'stacked' rock units that are intensely deformed (mylonitic) and allochthonous ('isolated'). The mylonitic rocks are derived from quartzite, carbonate-rock and gneiss protoliths, and include the enigmatic 'Oystershell Rock' (e.g. Peach *et al.* 1907; Holdsworth *et al.* 2001; BGS 2002, 2007). Currently, none of the mapped units in the Moine Thrust Zone can be correlated unambiguously with any formally classified units outside the zone, so they are treated here as tectonometamorphic. The units have yet to be formally classified using BRUCS, but this figure shows a possible solution. The four Rank 5 parcels reflect the lithological character of multiple unnamed 'child' layers at Rank 6. The parcels are related, so are united at Rank 4 in the *Moine Thrust Mylonite Set* (formerly the Moine Thrust Zone Mylonite Complex). The unit type 'set' is preferred to 'package' because the relevant map polygons are distributed intermittently as thin slivers within the 200 km long zone (i.e. they are dispersed rather than contiguous). The *Moine Thrust Mylonite Set* has not been correlated with any other tectonometamorphic unit, so has no parent at a higher rank.

for example, *Someplace Peridotite Layer*, *Someplace Basalt Sheeted-dyke Swarm* and *Someplace Metamudstone Layer*. The Rank 4 position allows individual related occurrences of ophiolite to be grouped in higher-rank associations.

Figures 6, 8, 9 and 10 include examples of how BRUCS has been used to classify and name many of the types of lower-rank tectonometamorphic units.

Classification at ranks 3, 2 and 1. In common with the other hierarchies for single-class units, the three highest ranks of the hierarchy for tectonometamorphic units each contain only one unit type, which in each case is used to group two or more units of lower rank (Fig. 2). At these higher ranks, the unit terms carry no connotation of form type or spatial relationship, but simply imply an inferred genetic relationship. Where classification at a higher rank is appropriate, a group of related units from ranks 6, 5 or 4 should first be classified at Rank 2 as an ***assemblage***. A subset of the units in an assemblage may be grouped within a ***subassemblage***, at Rank 3, if they display shared characteristics and it is useful to distinguish them in this way. A subassemblage can be identified only after its 'parent' assemblage has been defined. Not all assemblages will contain a subassemblage, and there is no requirement to group all the units in an assemblage into subassemblages. Two or more related assemblages, with or without other units of lower rank that are not part of those assemblages, may be grouped within a ***superassemblage***.

Rank 6	Rank 5	Rank 4	Rank 3	Rank 2	Rank 1
several named beds	Dalness Ignimbrite Member	Glencoe Volcanic Formation	Glencoe Caldera Volcano-complex	Scottish Highlands Silurian Suite (encompasses other child units)	**Caledonian Supersuite** (encompasses other child units)
several unnamed flows of andesite	Bidein nam Bian Andesite Member				
several unnamed beds	Glas Choire Sandstone Member				
unnamed flows of andesite, with intercalated sediment and subordinate intrusions	Upper Streaky Andesite Member				
several named beds	Three Sisters Ignimbrite Member				
unnamed flows of andesite with subordinate intrusions	Lower Streaky Andesite Member				
several named beds and flows	Etive Rhyolite Member				
unnamed sills of andesite	Achtriochtan Andesite Sill-swarm				
unnamed intrusions of gabbro, diorite, tonalite, monzonite & granite	Glencoe Gabbro–granite Intrusion-swarm				
unnamed sheets of andesite					
unnamed dykes of tuffisite and pyroclastic-breccia					

Fig. 7. Classification of the Glencoe Caldera Volcano-complex, Scotland, using BRUCS. Colours denote unit class (see Fig. 2). The classification shown here is based on BGS (2005*b*). The *Glencoe Caldera Volcano-complex* (Rank 3) is a component of the essentially intrusive *Scottish Highlands Silurian Suite* (Rank 2), which in turn is a component of the *Caledonian Supersuite* (Rank 1). The volcano-complex is a mixed-class unit encompassing: (1) a stratiform unit at Rank 4 (the *Glencoe Volcanic Formation*), which has numerous named and unnamed child units at ranks 5 and 6; and (2) numerous intrusions, including two named units at Rank 5 and numerous unnamed ones at Rank 6.

Rank 6	Rank 5	Rank 4	Rank 3	Rank 2	Rank 1
Cnoc Gorm Metagabbro Mass	Cnoc Gorm Metagabbro Mass-swarm			Scourian Gneiss Assemblage	**Lewisian Supercomplex** - (encompasses other child units)
Ben Strome Metagabbro Mass					
Scouriemore Metagabbro Mass					
unnamed masses of metagabbro					
unnamed masses of mafic orthogneiss	Someplace Mafic Orthogneiss Mass-parcel	Someplace Gneiss Package			
unnamed masses of felsic orthogneiss	Someplace Felsic Orthogneiss Mass-parcel				
unnamed veins of pegmatitic granite	Someplace Pegmatitic Granite Vein-swarm				
unnamed masses of amphibolite	Foindle Amphibolite Mass-parcel	Claisfearn Supracrustal Set			
unnamed layers of psammite & quartzite	Tarbet Psammite–quartzite Layer-parcel				
unnamed masses of supracrustal rocks	Lochinver Supracrustal Mass-parcel				
unnamed masses of orthogneiss	Someplace Orthogneiss Mass-parcel			Inchard Gneiss Assemblage	
unnamed masses of mafic orthogneiss	Someplace Mafic Orthogneiss Mass-parcel				
unnamed veins of pegmatitic granite	Someplace Pegmatitic Granite Vein-swarm				
unnamed sheets of granite	Rubha Ruadh Granite Sheet-swarm	Laxfordian Granite Cluster			
unnamed sheets of granite	Loch Stack Granite Sheet-swarm				
unnamed masses of gneiss	Achall Gneiss Mass-parcel	Ullapool Gneiss Set			
unnamed masses of gneiss	Langwell Gneiss Mass-parcel				
unnamed masses of gneiss	Corrie Point Gneiss Mass-parcel				
unnamed masses of gneiss	*unnamed gneiss mass-parcels*	Gruinard Bay Gneiss Package			
unnamed masses of amphibolite	Aundrary Amphibolite Mass-parcel			Loch Maree Assemblage	
Flowerdale Marble Layer	Flowerdale Supracrustal Layer-parcel				
unnamed layers of supracrustal rocks					
unnamed masses of amphibolite	Kerrysdale Amphibolite Mass-parcel				
Ard Granite Gneiss Layer					
Mill na Claise Gneiss Mass					
unnamed masses of schist	Charlestown Schist Mass-parcel				
unnamed veins of pegmatitic granite	Someplace Pegmatitic Granite Vein-swarm				
unnamed masses of gneiss	Ialltaig Gneiss Mass-parcel				
unnamed dykes of metapicrite	Beannach Metapicrite Dyke-swarm			Scourie Dyke Suite	
unnamed dykes of metaclinopyroxene-norite	Badcall Metaclinopyroxene-norite Dyke-				
unnamed dykes of meta-olivine-gabbro	Sionascaig Meta-olivine-gabbro Dyke-				
unnamed dykes of dolerite	Someplace Dolerite Dyke-swarm				

Fig. 8. A possible classification of some rock units in the Lewisian basement of NW Scotland, using BRUCS. Colours denote unit class (see Fig. 2). The BGS has yet to formally classify the ancient 'Lewisian' rocks of NW Scotland using BRUCS, but this figure, which incorporates units from only the north and central parts of the outcrop, indicates how a partial reclassification might look. Three assemblages and one suite are united, with a number of units of lower rank, in a mixed-class unit at Rank 1: the *Lewisian Supercomplex*. The same rocks currently are referred to as Lewisian Gneiss Complex (e.g. Park 2002; Park *et al.* 2002; Kinny *et al.* 2005; Mendum *et al.* 2009), but, as illustrated in this example, the complexity of the unit overall almost certainly necessitates 'upgrading' the present 'complex' to supercomplex rank.

Figures 8, 9 and 10 include examples of how BRUCS has been used to classify and name some of these higher-rank tectonometamorphic units.

Nomenclature at ranks 6 and 5. Formal names for tectonometamorphic units classified at ranks 6 and 5 should consist of a geographical term, a lithological term and a unit term, in that order (e.g. *Scouriemore Metagabbro Mass*; Fig. 8). The geographical term should refer to a district, settlement or feature within, or adjacent to, the outcrop of the unit. The lithological term should convey the essential character of the unit as accurately as the concise format allows. Two rock name terms linked by an *en dash* (–) may be used where units have two important lithological components, or to indicate the principal end-members in a unit characterized by lithological diversity (e.g. *Tarbet Psammite–quartzite Layer-parcel*; Fig. 8). In BGS databases and products, all of the lithological terms used in unit names must be consistent with the definitions in the *BGS Rock Classification Scheme* (Gillespie and Styles 1999; Hallsworth and Knox 1999; Robertson 1999). The unit term (e.g. layer, lens-parcel) should be selected from an appropriate rank of the hierarchy.

Nomenclature at ranks 4 to 1. The names of units classified at these ranks should consist of a geographical term and a unit term (e.g. *Shetland Ophiolite* and *Menai Assemblage*). Terms to indicate other characteristic or distinctive features of a unit can be inserted between the two principal components of the name to help distinguish one unit from another in areas of significant geological complexity, or where suitable geographical names are at a premium. Similarly, terms to highlight a particular structural setting or lithological character can be inserted if it useful to do so (e.g. *Moine Thrust Mylonite Set*; Fig. 6). The term 'ophiolite' can precede the unit terms 'assemblage' and 'superassemblage' to denote high-rank associations involving ophiolite units. For example, the *Shetland Ophiolite* (Rank 4) could be a component of the *Shetland Ophiolite Assemblage* (Rank 2, grouping the *Shetland Ophiolite* and adjacent tectonometamorphic units that became detached and associated with the ophiolite during the obduction event), which could in turn be a component of the *Iapetus Ocean Ophiolite Superassemblage* (Rank 1, grouping all ophiolites and ophiolite assemblages formed by obduction around the Iapetus Ocean).

Classifying and naming mixed-class units

A mappable entity that encompasses multiple bodies of more than one genetic class, such that its essential character is of 'mixed' genetic class, should be classified using the hierarchy for mixed-class units (Fig. 2). This hierarchy will usually be used in two situations.

- Where it is impractical or undesirable to map or distinguish the smallest mappable bodies. This can be the case in, for example, a reconnaissance-level survey of geologically complicated ground, or where numerous small bodies of one class cut a 'host' body of another (e.g. a sill-swarm emplaced in a stratiform succession).
- Where it is useful to unite, in a single entity, rock units of two or more classes that display a close natural association. Examples include the conjunction of intrusive, extrusive and sedimentary rocks that commonly forms in volcanic settings (e.g. the Glencoe Caldera Volcano-complex; Fig. 7), and the intimate juxtaposition of metasedimentary and meta-igneous bodies commonly found in basement gneiss terranes (e.g. the Lewisian Supercomplex; Fig. 8).

Rank 6	Rank 5	Rank 4	Rank 3	Rank 2	Rank 1
		Scaraben Quartzite Formation		Sutherland Assemblage	**Moine Supergroup** - (as currently defined, but see caption for discussion)
		Suisgill Semipelite Formation			
		Kildonan Psammite Formation			
		Portskerra Psammite Formation			
unnamed sheets of granite	Badanloch Granite Sheet-swarm				
unnamed masses of migmatitic metasemipelite	Someplace Migmatitic Semipelite Mass-parcel	Loch Coire Migmatite Package			
unnamed masses of migmatitic metasemipelite	Someplace Migmatitic Semipelite Mass-parcel				
unnamed masses of migmatitic metapelite	Someplace Migmatitic Pelite Mass-parcel				
unnamed masses of migmatitic metapelite	Someplace Migmatitic Pelite Mass-parcel	Kirtomy Gneiss Set			
unnamed masses of metapelite	Swordly Pelite Mass-parcel				
unnamed masses of gneiss	*unnamed gneiss parcels*	Bettyhill Gneiss Package			
unnamed layers of migmatitic psammite and semipelite	Druim Chuibe Psammite–semipelite				
		numerous named formations		Loch Eil Group	
		numerous named formations		Glenfinnan Group	
		numerous named formations		Morar Group	

Fig. 9. A possible classification of the metamorphic rocks of Sutherland and Caithness, northern Scotland, using BRUCS. Colours denote unit class (see Fig. 2). The BGS has yet to formally classify the Moine Supergroup (Holdsworth *et al.* 1994) using BRUCS, but this figure shows one possible solution for part of the succession. It should be noted that although a stratigraphy for the Moine Supergroup has become well established in the literature (Johnstone *et al.* 1969; Roberts *et al.* 1987; Holdsworth *et al.* 1994; Strachan *et al.* 2002), that stratigraphy is currently undergoing review and may be very significantly changed (M. Krabbendam, pers. comm., 2020). A stratiform succession comprising numerous formations within three groups, the Loch Eil, Glenfinnan and Morar groups, can be recognized within most of the outcrop of the Moine Supergroup (as currently defined). However, original stratal boundaries are commonly obliterated by metamorphism and deformation in the northern part of the outcrop (Sutherland and Caithness), creating many tectonometamorphic units of migmatitic gneiss (e.g. *Loch Coire Migmatite Package*). Within the same area, several bodies have been classified as formations (e.g. *Scaraben Quartzite Formation*) because they still fulfil the criteria for a stratiform unit. However, neither the stratiform progenitor(s) of the tectonometamorphic units nor the parent group(s) of the formations in this area are currently known, so all of these units are united within a new tectonometamorphic unit, the *Sutherland Assemblage*. The *Badanloch Granite Sheet-swarm* is a product of anatexis within the *Loch Coire Migmatite Package* and the *Kildonan Psammite Formation*, and is confined within the outcrop of those two units; however, the sheet-swarm cannot have two parents in the hierarchy, so is classified with no parent at Rank 4. The essential character of the Rank 1 parent (*Moine Supergroup,* as currently defined) remains that of a stratiform unit. Many of the smaller mappable units shown at Rank 6 in this figure are currently unnamed.

Classification

Mixed-class units are inherently variable and often geologically complicated, and it is impractical to attempt to create a set of unit types that can account for all possible variations. In Figure 2, several specific types of mixed-class unit that occur in UK geology are included along with the three non-specific types *subcomplex*, *complex* and *supercomplex*; however, other specific types of mixed-class unit may need to be defined for work elsewhere. The variability of mixed-class units also means that the most appropriate rank at which to place the specific unit types may change in different settings; the arrangement shown in Figure 2 works well for UK geology but may not be ideally suited to other situations.

Each of the unit types ***subcomplex***, ***complex*** and ***supercomplex***, at ranks 3, 2 and 1 respectively, is used to group two or more units of lower rank (Fig. 2); these terms carry no connotation other than a mixed-class character and an inferred genetic relationship. As in the higher ranks of other hierarchies, a ***complex*** must be defined before a related ***subcomplex*** can be classified at Rank 3, and two or more related complexes, with or without other units of lower rank that are not part of those complexes, may be grouped in a ***supercomplex***. However, it is not essential for a complex or a supercomplex to incorporate units of lower rank from the hierarchy for mixed-class units; they can incorporate related units from any hierarchy within Figure 2, provided the essential character of the resulting complex or supercomplex is 'mixed class'. Figure 8 presents an example of a situation where a supercomplex consists entirely of units that have been classified in single-class hierarchies.

All of the specific types of mixed-class unit included in Figure 2 have a compound unit term that combines a term to convey the essential character or setting of the unit with the word 'complex'. The unit term for each of the four mixed-class units at Rank 4 incorporates a unit term (or part thereof) from Rank 6 of the hierarchy for intrusions: ***sheet-complex***, ***sill-complex***, ***ring-complex*** and ***vein-complex***. Two or more of these Rank 6 units might be united within a 'swarm' at Rank 5 of the intrusions hierarchy (e.g. a *sill-swarm*) before being grouped with units of another class, so the mixed-class units are placed at Rank 4 where they can, if necessary, incorporate single-class units classified at Rank 5, as well as at Rank 6. The term 'sill-complex' has been used in the past to refer simply to a number of associated sills, but as defined here the term is used only for a mixed-class unit at Rank 4 composed of a number of sills and the country-rock that lies within the boundary of the unit; if the sills were to be grouped by themselves, the term ***sill-swarm*** (Rank 5) should be used.

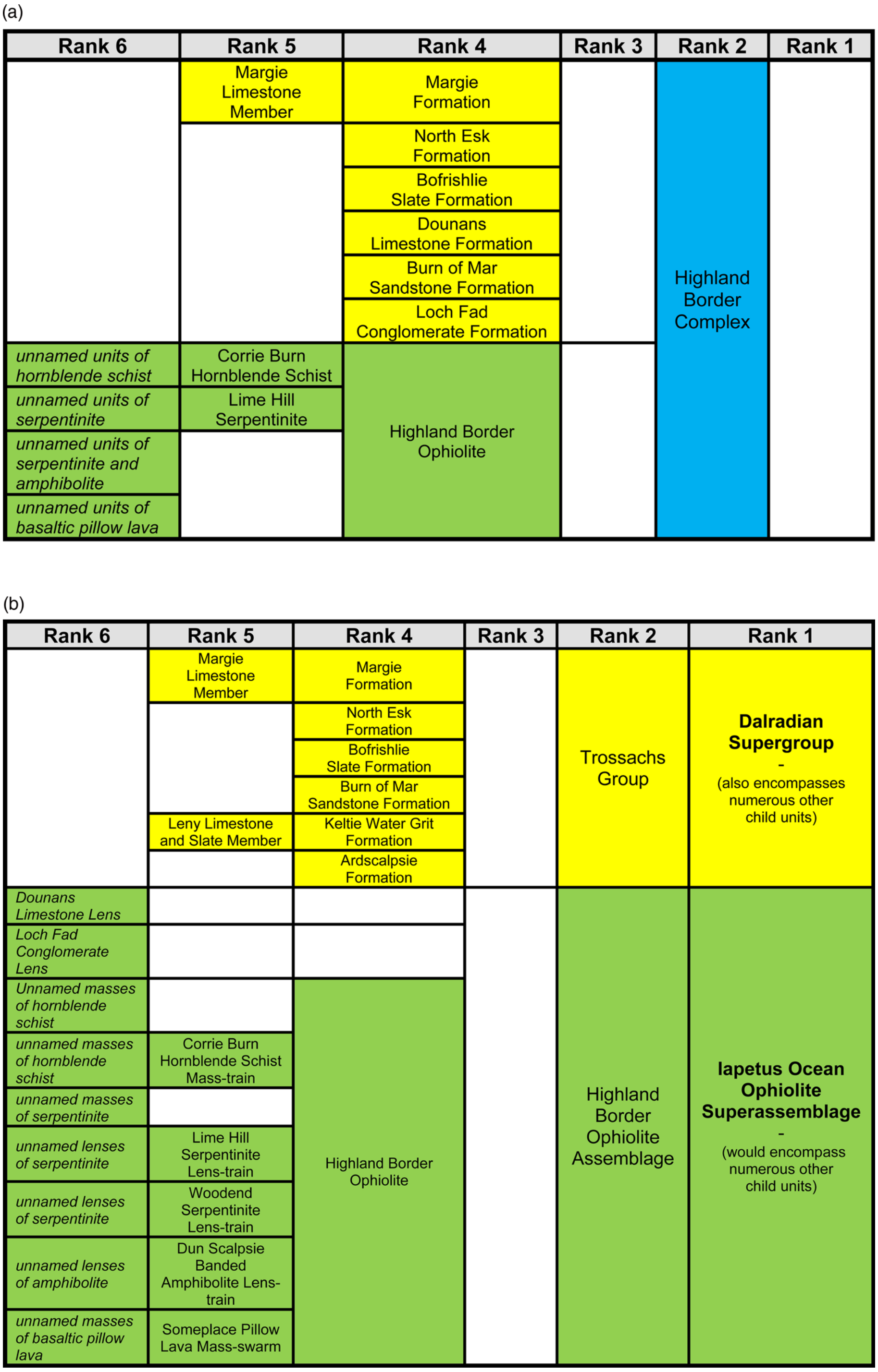

Fig. 10. A possible re-classification of rock units within the Highland Border Fault Zone (HFBZ), central Scotland, using BRUCS. Colours denote unit class (see Fig. 2). (**a**) A representation of the state of knowledge and classification within the HBFZ prior to 2007; although it did not exist at the time, the units are shown within a six-rank hierarchy for ease of comparison with (**b**). At that time, the Highland Border Ophiolite was a rather poorly defined unit, and the stratiform units that are complexly interleaved with it were named (as formations) but not correlated with units outside the HBFZ. The degree of geological complexity within the zone, and state of geological understanding at the time, were such that all components were united within a single parent unit denoting a complicated association, the 'Highland Border Complex'. (**b**) The units of the former 'Highland Border Complex', re-classified using BRUCS and taking into account the improved understanding obtained through detailed re-mapping of parts of the HBFZ by Tanner and Sutherland (2007). The stratiform units are now recognized as the youngest part of the *Dalradian Supergroup*, and placed in a new parent group (the *Trossachs Group*). The *Highland Border Ophiolite* is classified as a tectonometamorphic unit at Rank 4, uniting numerous child units all of which are likewise classified as tectonometamorphic units. The figure shows how the *Highland Border Ophiolite* might, in due course, be grouped with other fragments of Iapetus Ocean ophiolite (e.g. the *Ballantrae Ophiolite* and *Shetland Ophiolite Assemblage*) within a single parent, here named the *Iapetus Ocean Ophiolite Superassemblage*.

Two specific types of mixed-class unit are placed at Rank 3 alongside *subcomplex* (Fig. 2). A ***central complex*** is typically composed of two or more spatially associated (and commonly intersecting) ***centres***, together with screens and irregular masses of associated extrusive rocks and country rocks. The term 'central complex' has previously been used in this sense to name rock units in the UK that are interpreted to be the eroded roots of Paleogene volcanoes (Emeleus and Bell 2005). Central complexes thus generally form in shallow subsurface settings, and as such are of highly variable character. Some have an unambiguously 'mixed-class' nature, whereas others may be dominated by units of one class (usually intrusions), in which case the mixed-class character is less obvious; the *Skye Central Complex* is an example of the latter situation (Fig. 5). A ***volcano-complex*** might contain all the related materials, extrusive, intrusive and sedimentary, formed at a site of persistent volcanic activity; the *Glencoe Caldera Volcano-complex* is an example (Fig. 7).

By definition, all mixed-class units must consist of more than one mappable body, so Rank 6 of the hierarchy is not used; Rank 5 currently is also unused (Fig. 2).

Nomenclature. Names assigned to mixed-class units should consist of a geographical term and a unit term (e.g. *Someplace Ring-complex*). However, a term that reflects the geological setting (e.g. *Glencoe Caldera Volcano-complex*) and/or established nomenclatorial precedent (e.g. *Lewisian Supercomplex*; Fig. 8) can be used instead of, or in addition to, the geographical term, where appropriate.

Practical considerations

Geological relationships can be complicated, so the following additional guidance addresses some general points not covered above, and includes some suggested practical solutions for special situations. Inevitably, common sense and pragmatism will often be needed alongside the scheme guidelines in deciding how best to classify and name mapped units.

(1) In general, units should be classified and named in a way that reflects their *essential character*. For example, not all of the units grouped within a ***package*** need be contiguous, but the essential character of a package should be of largely contiguous units. Similarly, a group of spatially associated sheet intrusions of which 90% are dykes and 10% are sills could be classified as a ***dyke-swarm*** (rather than a ***dyke-and-sill-swarm*** or a ***sheet-swarm***), as that describes the essential character of the unit. Essential character can also be important in deciding which hierarchy to use when grouping units. In the UK, for example, multiple ***central complexes*** (each classified at Rank 2 in the hierarchy for mixed-class units) have been grouped at Rank 3 within a unit from the hierarchy for intrusions (in this case, within the *Hebrides Subvolcanic Suite* of the *Atlantean Supersuite*; see Fig. 3), rather than in a parent from the hierarchy for mixed-class units (***complex*** or ***supercomplex***), because their essential character when considered as a group (i.e. dispersed centres of localized magmatism) is represented and conveyed more effectively in this way. On a smaller scale, a ***pluton*** can enclose many mappable screens of sedimentary rock and still be classified as an intrusion rather than a mixed-class unit if its essential character remains that of an intrusion.

(2) Some units will contain within their mapped boundary smaller mappable bodies that are derived from units whose main outcrop (if it still exists) lies beyond the boundary of the host unit. For the purpose of this discussion, and following the familial phraseology used elsewhere, such units could be thought of as 'adopted' because they are now enclosed, or nearly enclosed, by one or more 'host' units at outcrop. In classification, such bodies should be treated as follows.

- Where it can be shown or reliably inferred that the adopted body and the host unit are related, both should be classified in the same parent–child chain. For example, a body of stratiform volcanic rocks that crops out within the boundary of a central complex that is otherwise dominated by intrusions should be classified as part of the central complex (i.e. in the same parent–child chain) if it is known or inferred to be a product of the same magmatism; the *Fionn Choire Formatio*n and *Srath na Creitheach Formation* of the *Skye Central Complex* are good examples (Fig. 5).
- Where it can be shown or reliably inferred that the adopted body and the host unit are not related, they should not be classified in the same parent–child chain. If the adopted body was derived from, or is still part of, a classified unit whose main outcrop is elsewhere, it retains the name assigned to the main outcrop; mappable screens of rock that are clearly derived from Lewisian Supercomplex country rocks but now occur as 'adopted' bodies within the outcrop of the Skye Central Complex are good examples. If the adopted body cannot be linked to a classified unit, it should not be classified within a parent–child chain but could be given an informal name if desired; a roof pendant or large xenolith of country rock that occurs as an adopted body within the outcrop of a pluton, and was derived from a body that no longer crops out elsewhere, is an example of such a situation.

(3) The most pragmatic way to classify some geological associations might require the creation of nonstandard parent–child relationships. The Moine Supergroup of NW Scotland (Fig. 9) contains good examples of situations where locally intense metamorphism has produced new mappable units of gneissose and/or migmatitic and/or igneous rock that occur within a regional-scale succession that generally can still be mapped and classified as stratiform. The original character and limits of some modified stratiform units may no longer be recognized with confidence, thus the new units are morphogenetic. It would be unhelpful and inappropriate to classify the parent body as a mixed-class unit where the proportion of morphogenetic units overall is very small and does not change the essentially stratiform character. It would also be unhelpful to classify the morphogenetic units formed within, and from, the parent body in a separate parent–child chain, as this might be taken to imply that they are unrelated. The pragmatic solution in this instance is to classify the main unit according to its essential (stratiform) character, and include at appropriate points within its parent–child chain some nonstratiform units. In Figure 9, the Sutherland Assemblage is a tectonometamorphic unit that is classified as a component of a much larger stratiform unit (the Moine Supergroup) in this manner. Figure 9 also shows an inverse version of this relationship, where several stratiform units (e.g. Scaraben Quartzite Formation) are classified within the Sutherland Assemblage; these units retain the essential character of stratiform units and their inclusion in the Sutherland Assemblage does not change its essential character as a tectonometamorphic unit.

(4) In some parts of the world, tectonic displacement has produced allochthonous sheets within regional-scale domains in which multiple related sheets are imbricated or 'stacked'. The individual sheets within such domains can be of regional extent and kilometre-scale thickness, and they can consist of or contain multiple mappable stratiform units and/or intrusions. These create a significant problem for a hierarchical classification system like BRUCS, because whereas the allochthonous sheets are tectonometamorphic units, the mappable units they contain often are not. Each sheet conceivably could be thought of as a mixed-class unit. However, the tectonometamorphic 'host' (i.e. the allochthonous sheet) would have to be classified one rank (at least) above the highest rank needed to classify all of the stratiform units and/or intrusions mapped within it, and in many situations (especially those where the allochthonous sheet is just one of multiple related sheets that could also be classified hierarchically) there will be insufficient ranks within a single parent–child chain in which to classify all the related units.

In Norway, Sweden and Finland, where much of the bedrock geology consists of allochthonous sheets on a range of scales, this problem is addressed by classifying allochthonous sheets as a distinct category of unit, the tectonostratigraphic(al) unit, and classifying the stratiform units and intrusions within each sheet as 'lithostratigraphical' and 'lithodemic' units respectively in separate hierarchies. A tectonostratigraphic unit in this context is '*a generally flat-lying, scale-independent, tectonic unit that is bounded by zones of high strain*' (Kumpulainen 2017). In Norway, up to four ranks of tectonostratigraphic unit are recognized (Nystuen 1989): 'nappe' is the fundamental unit; 'thrust sheet' is one rank below nappe; 'small thrust sheet' is one rank below thrust sheet; and both 'nappe complex' and 'nappe system' are one rank above nappe. Finland and Sweden have adopted the same hierarchy and terms to varying degrees (Strand *et al.* 2010; Kumpulainen 2017).

Allochthonous sheets comprise just a small proportion of the UK bedrock, and no attempt has been made thus far to apply a robust tectonostratigraphic classification to them. Consequently, it is not clear if such an approach is needed, or is compatible with BRUCS, and BRUCS currently does not contain a hierarchy for tectonostratigraphic units. However, in parts of the world where the geology consists of regional-scale, stacked allochthonous sheets, and where it would be beneficial in terms of achieving the objectives of mapping and classification, it may be appropriate to use a hierarchy of tectonostratigraphic units (following the guidance used in Norway, Finland or Sweden) alongside those in BRUCS.

(5) In many areas, the classification process is likely to be piecemeal and iterative, and achieving a full, robust classification of nonstratiform units across all necessary ranks will require sufficiently detailed mapping and a considerable amount of research. In some cases, agreement on cross-border correlations may also be needed. When new information allows, the previously classified components of a tectonometamorphic unit, or a mixed-class unit in which the nature of the components had not been fully resolved, should be reclassified and renamed as stratiform units or intrusions as appropriate. This process might result in established unit names becoming diminished in importance, or even obsolete. One such example of an evolving classification is presented in Figure 10.

(6) The terminology used in BRUCS should not be confused with terrane nomenclature or used directly in terrane analysis, even where the extent of a classified unit (e.g. *complex*, *supercomplex* or *supergroup*) coincides wholly with a terrane, or where a terrane fulfils the criteria for a mixed-class unit. Stratiform and/or morphogenetic units may occur in more than one terrane but share in the distinct geological evolution of each. Indeed, a boundary between two complexes may be tectonic, intrusive or unconformable, but only in the first case could it qualify as a terrane boundary (e.g. Coney 1980).

Concluding remarks

A new scheme for classifying nonstratiform rock bodies (intrusions, tectonometamorphic units and mixed-class units) has been created to address a long-standing and significant deficiency in two previously published and widely used schemes for rock-unit classification, namely the *International Stratigraphic Guide* (ISG) and the *North American Stratigraphic Code* (NASC). The new scheme recognizes and reflects the distinctive geological characteristics of nonstratiform units, and the practices, needs and interests of geologists working with them. The importance of morphology and genesis in this classification, rather than lithological character and stratigraphic relationships, means that the new scheme differs fundamentally from those advocated in the ISG and NASC. Nevertheless, in terms of their basic design (a six-rank hierarchy) and taxonomic rigour, the new scheme for classifying nonstratiform bodies and the ISG scheme for classifying stratiform bodies are similar and complementary. The *BGS Rock Unit Classification System* (BRUCS) combines the two schemes to create a comprehensive, practical, robust and flexible means of classifying and naming all rock bodies at all normal mapping scales, in a manner that meets both the practical needs of researchers and the demands of the digital age. Although it has been designed with the geology of the UK in mind, BRUCS should be applicable to any setting, and particularly to situations where the resolution of mapping and the level of geological understanding together allow a full and detailed classification across multiple ranks. As with most attempts to systematize geology, BRUCS necessarily introduces some concepts and terms that geologists initially may find unfamiliar and perhaps peculiar; the authors would welcome feedback on its content and utility.

Acknowledgements The authors would like to thank D. Campbell, M. Krabbendam, D. Stephenson and D. Millward, who helped to devise earlier iterations of this classification scheme, and B. Bell, H. Emeleus, A. Kerr and B. Leveridge, who provided constructive reviews of those iterations. M. Krabbendam is thanked for an insightful review of the paper for the BGS. Ø. Nordgulen and S. Bergman are thanked for reviews carried out for the Geological Society of London for this publication. This paper is published with the permission of the Executive Director, BGS (UK Research and Innovation).

Author contributions **MRG**: conceptualization (lead), methodology (equal), writing – original draft (lead); **AGL**: methodology (equal), writing – original draft (supporting)

Funding This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability The article contains no conventional scientific data.

Scientific editing by Deta Gasser

References

BGS. 2002. *Loch Eriboll. Scotland Sheet 114W. Bedrock. 1:50 000*. British Geological Survey, Keyworth, Nottingham.
BGS. 2005*a*. *Skye Central Complex. Bedrock. 1:25 000 Geology Series*. British Geological Survey, Keyworth, Nottingham.
BGS. 2005*b*. *Glen Coe. Bedrock. 1:25 000 Geology Series*. British Geological Survey, Keyworth, Nottingham.
BGS. 2007. *Assynt. Scotland Special Sheet. Bedrock. 1:50 000*. British Geological Survey, Keyworth, Nottingham.
BGS. 2008*a*. *Bedrock Geology UK North. 1:625 000 Scale*. British Geological Survey, Keyworth, Nottingham.
BGS. 2008*b*. *Bedrock Geology UK South. 1:625 000 Scale*. British Geological Survey, Keyworth, Nottingham.
BGS. 2020*a*. *The BGS Lexicon of Named Rock Units* [online]. British Geological Survey, Keyworth, Nottingham, https://www.bgs.ac.uk/technologies/the-bgs-lexicon-of-named-rock-units/
BGS. 2020*b*. *BGS Geology 50 K (DigMapGB-50)* [online]. British Geological Survey, Keyworth, Nottingham, https://www.bgs.ac.uk/datasets/bgs-geology-50k-digmapgb/
Brown, P.E., Ryan, P.D., Soper, N.J. and Woodcock, N.H. 2008. The Newer Granite problem revisited: a transtensional origin for the Early Devonian Trans-Suture Suite. *Geological Magazine*, **145**, 235–256, https://doi.org/10.1017/S0016756807004219
Coney, P.J. 1980. Introduction. *Geological Society of America, Memoirs*, **153**, 3–6.
Dewey, J.F. 1976. Ophiolite obduction. *Tectonophysics*, **31**, 93–120, https://doi.org/10.1016/0040-1951(76)90169-4
Easton, R.M., Edwards, L.E., Orndorff, R.C., Duguet, M. and Ferrusquia-Villafranca, I. 2016. North American Commission on Stratigraphic Nomenclature Report 12 – Revision of Article 37, Lithodemic Units, of the North American Stratigraphic Code. *Stratigraphy*, **13**, 200–222.
Emeleus, C.H. and Bell, B.R. 2005. *British Regional Geology: The Palaeogene Volcanic Districts of Scotland*, 4th edn. British Geological Survey, Keyworth, Nottingham.
Gillespie, M.R. and Styles, M.T. 1999. *BGS Rock Classification Scheme Volume 1, Classification of igneous rocks*. British Geological Survey Research Report, 2nd edn, **RR/99/06**, http://nora.nerc.ac.uk/id/eprint/3223/1/RR99006.pdf
Gillespie, M.R., Stephenson, D. and Millward, D. 2008. *Proposals for Classifying Lithodemic Units of Intrusive Rock*. British Geological Survey Research Report, **RR/08/05**, http://nora.nerc.ac.uk/id/eprint/5226/
Gillespie, M.R., Campbell, S.D.G. and Stephenson, D. 2012. *BGS Classification of Lithodemic Units: A Classification of Onshore Phanerozoic Intrusions in the UK*. British Geological Survey Research Report, **RR/12/01**, http://nora.nerc.ac.uk/id/eprint/18279/
Guilmette, C., Smit, M.A. *et al.* 2018. Forced subduction initiation recorded in the sole and crust of the Semail Ophiolite of Oman. *Nature Geoscience*, **11**, 688–695, https://doi.org/10.1038/s41561-018-0209-2
Hallsworth, C.R. and Knox, R.W.O'B. 1999. *BGS Rock Classification Scheme Volume 3, Classification of Sediments and Sedimentary Rocks*. British Geological Survey Research Report, **RR/99/03**, http://nora.nerc.ac.uk/id/eprint/3227/1/RR99003.pdf
Holdsworth, R.E., Strachan, R.A. and Harris, A.L. 1994. Precambrian rocks in northern Scotland east of the Moine Thrust: the Moine Supergroup. *Geological Society, London, Special Report*, **22**, 23–32, https://doi.org/10.1144/SR22.3
Holdsworth, R.E., Strachan, R.A. and Alsop, G.I. 2001. *Solid Geology of the Tongue District; Memoir for 1:50 000 Geological Sheet 114 E (Scotland)*. British Geological Survey, Keyworth, Nottingham.
ISSC 1976. *International Stratigraphic Guide – A Guide to Stratigraphic Classification, Terminology and Procedure*. Hedberg, H.D. (ed.). Wiley, New York.
ISSC 1987. Stratigraphic classification and nomenclature of igneous and metamorphic rock bodies. *Geological Society of America Bulletin*, **99**, 440–442, https://doi.org/10.1130/0016-7606(1987)99<440:SCANOI>2.0.CO;2
ISSC 1994. *International Stratigraphic Guide: A Guide to Stratigraphic Classification, Terminology, and Procedure*, 2nd edn. Salvador, A. (ed.). International Union of Geological Sciences and Geological Society of America, Boulder, CO (reprinted 2013), https://doi.org/10.1130/9780813774022
Johnstone, G.S., Smith, D.I. and Harris, A.L. 1969. The Moinian Assemblage of Scotland. *AAPG Memoirs*, 159–180.

Kinny, P.D., Friend, C.R.L. and Love, G.J. 2005. Proposal for a terrane-based nomenclature for the Lewisian Gneiss Complex of NW Scotland. *Journal of the Geological Society, London*, **162**, 175–186, https://doi.org/10.1144/0016-764903-149

Kumpulainen, R.A. (ed.). 2017. Guide for geological nomenclature in Sweden. *GFF*, **139**, 3–20, https://doi.org/10.1080/11035897.2016.1178666

Laajoki, K. 1988. Stratigraphic classification and nomenclature of igneous and metamorphic rock bodies: Discussion and reply. *Geological Society of America Bulletin*, **101**, 753–754, https://doi.org/10.1130/0016-7606(1989)101<0753:SCANOI>2.3.CO;2

Leslie, A.G., Krabbendam, M. and Gillespie, M.R. 2012. *BGS Classification of Lithodemic Units: Proposals for Classifying Tectonometamorphic Units and Mixed-Class Units*. British Geological Survey Research Report, **RR/12/02**, http://nora.nerc.ac.uk/id/eprint/17949/

Mendum, J.R., Barber, A.J. *et al.* 2009. *Lewisian, Torridonian and Moine Rocks of Scotland*. Geological Conservation Review Series, **34**. Joint Nature Conservation Committee, Peterborough.

Millward, D. 2002. Early Palaeozoic magmatism in the English Lake District. *Proceedings of the Yorkshire Geological Society*, **54**, 65–93, https://doi.org/10.1144/pygs.54.2.65

Morag, N., Haviv, I. and Katzir, Y. 2016. From ocean depths to mountain tops: Uplift of the Troodos ophiolite (Cyprus) constrained by low-temperature thermochronology and geomorphic analysis. *Tectonics*, **35**, 622–637, https://doi.org/10.1002/2015TC004069

Murphy, M.A. and Salvador, A. (eds). 1999. International Stratigraphic Guide – An abridged version. *Episodes*, **22**, 255–272, https://doi.org/10.18814/epiiugs/1999/v22i4/002

NACSN. 1983. North American Stratigraphic Code. *AAPG Bulletin*, **67**, 841–875.

NACSN. 2005. North American Stratigraphic Code. *AAPG Bulletin*, **89**, 1547–1591, http://ngmdb.usgs.gov/Info/NACSN/05_1547.pdf, https://doi.org/10.1306/07050504129

Nystuen, J.P. (ed.). 1989. Rules and recommendations for naming geological units in Norway. *Norsk Geologisk Tiddskrift*, **69**(Supplement 2), 1–107, https://www.ngu.no/upload/publikasjoner/NGT/1_0/1_1.html

Park, R.G. 2002. *The Lewisian geology of Gairloch, NW Scotland*. *Geological Society, London, Memoirs*, **26**, https://doi.org/10.1144/GSL.MEM.2002.026.01.01

Park, R.G., Stewart, A.D. and Wright, D.T. 2002. The Hebridean terrane. *In*: Trewin, N.H. (ed.) *The Geology of Scotland*. Geological Society, London, 45–80.

Peach, B.N., Horne, J., Gunn, W., Clough, C.T., Hinxman, L.W. and Teall, J.J.H. 1907. *The Geological Structure of the North-West Highlands of Scotland. Memoir of the Geological Survey of Great Britain*. HMSO, Edinburgh.

Rawson, P.F., Allen, P.M. *et al.* 2002. *Stratigraphical Procedure. Professional Handbook*. Geological Society, London.

Roberts, A.M., Strachan, R.A., Harris, A.L., Barr, D. and Holdsworth, R.E. 1987. The Sgurr Beag nappe: a reassessment of the stratigraphy and structure of the northern Highland Moine. *Geological Society of America Bulletin*, **98**, 497–506, https://doi.org/10.1130/0016-7606(1987)98<497:TSBNAR>2.0.CO;2

Robertson, S. 1999. *BGS Rock Classification Scheme Volume 2, Classification of Metamorphic Rocks*. British Geological Survey Research Report, **RR/99/02**, http://nora.nerc.ac.uk/id/eprint/3226/1/RR99002.pdf

Steno, N. 1669. De solido intra solidum naturaliter contento dissertationis prodromus. Florence, Italy.

Strachan, R.A., Smith, M., Harris, A.L. and Fettes, D.J. 2002. The Northern Highland and Grampian terranes. *In*: Trewin, N.H. (ed.) *The Geology of Scotland*. Geological Society, London, 81–148.

Strand, K., Köykkä, J. and Kohonen, J. (eds). 2010. *Guidelines and Procedures for Naming Precambrian Geological Units in Finland. 2010 Edition Stratigraphic Commission of Finland: Precambrian Sub-Commission*. Geological Survey of Finland, Guide, **55**, https://tupa.gtk.fi/julkaisu/opas/op_055.pdf

Tanner, P.W.G. and Sutherland, S. 2007. The Highland Border Complex, Scotland; a paradox resolved. *Journal of the Geological Society, London*, **164**, 111–116, https://doi.org/10.1144/0016-76492005-188

White, A.J.R., Allen, C.M. *et al.* 2001. Granite suites and supersuites of eastern Australia. *Australian Journal of Earth Sciences*, **48**, 515–530, https://doi.org/10.1046/j.1440-0952.2001.00874.x