

BRITISH GEOLOGICAL SURVEY

**RESEARCH REPORT
NUMBER RR 99-02**

BGS Rock Classification Scheme
Volume 2
Classification of metamorphic rocks

S Robertson

Subject index	Rock classification, metamorphic rocks
Bibliographical Reference	Robertson, S. 1999. BGS Rock Classification Scheme Volume 2 Classification of metamorphic rocks. British Geological Survey Research Report, RR 99-02.
© NERC Copyright 1999	British Geological Survey Keyworth Nottingham NG12 5GG UK

HOW TO NAVIGATE THIS DOCUMENT

HOW TO NAVIGATE THIS DOCUMENT

- ❑ The general pagination is designed for hard copy use and does not correspond to PDF thumbnail pagination.
- ❑ The main elements of the table of contents are bookmarked enabling direct links to be followed to the principal section headings and sub-headings, figures and tables irrespective of which part of the document the user is viewing.
- ❑ In addition, the report contains links:
 - ⌘ from the principal section and sub-section headings back to the contents page,
 - ⌘ from each reference to a figure or table directly to the corresponding figure or table,
 - ⌘ from each figure or table caption to the first place that figure or table is mentioned in the text and
 - ⌘ from each page number back to the contents page.

[Return to
contents page](#)

Contents

1	Introduction
1.1	Definition of metamorphism
1.2	Basic principles
2	Metamorphic rock nomenclature
2.1	Construction of rock names.
2.2	How to use the classification scheme
3	Sedimentary protolith: metasedimentary rocks
3.1	Protolith name
3.2	Modal composition
3.2.1	Rocks composed largely of quartz ± feldspar ± mica with less than 10% carbonate and/or calcsilicate minerals
3.2.2	Rocks composed of 10 to 50% carbonate and/or calcsilicate minerals and at least 50% quartz ± feldspar ± mica
3.2.3	Rocks composed of more than 50% calcsilicate and carbonate minerals
3.3	Textural attributes
4	Volcaniclastic rock protolith: metavolcaniclastic rocks
5	Igneous protolith: meta-igneous rocks
5.1	Protolith name
5.2	Modal composition
5.2.1	Metafelsic rocks
5.2.2	Metamafic rocks
5.2.3	Meta-ultramafic rocks
5.3	Textural attributes
6	Unknown or undefined protolith and preliminary field classification
6.1	Textural attributes
6.2	Modal features
6.2.1	Amphibolite
6.2.2	Eclogite
6.2.3	Marble
7	Mechanically broken and reconstituted rocks
7.1	Rocks without primary cohesion
7.2	Unfoliated rocks with primary cohesion: cataclastic rocks
7.3	Foliated rocks with primary cohesion: mylonitic rocks
7.4	Glassy rocks
8	Metasomatic and hydrothermal rocks
9	Special case metamorphic rock groups and their place in the classification scheme
9.1	Charnockites
9.2	Granulite facies rocks
9.3	Migmatitic rocks
9.4	Blueschists and greenschists
9.5	Slate and phyllite
9.6	Contact metamorphism
10	Qualifiers
10.1	Textural qualifiers
10.2	Mineralogical qualifiers

10.3	Colour qualifiers
10.4	Qualifiers based on protolith structures

References

Appendix	List of approved rock names
----------	-----------------------------

Figures

Figure 1	Flow diagram for assigning root names to metamorphic rocks
Figure 2	Temperature and pressure fields of various metamorphic facies and examples of diagnostic minerals and assemblages
Figure 3	Classification scheme for metamorphic rocks
Figure 4	Changing nomenclature with increasing metamorphism and deformation of a mudrock protolith
Figure 5	Subdivision of rocks composed largely of quartz ± feldspar ± mica
Figure 6	Subdivision of rocks composed of up to 50% carbonate and/or calcsilicate minerals and at least 50% quartz ± feldspar ± mica
Figure 7	Subdivision of rocks containing more than 50% carbonate and calcsilicate minerals
Figure 8	Meta-igneous rocks classified by modal composition
Figure 9	British Geological Survey grain size scheme

Tables

Table 1	Classification of rocks composed largely of quartz, feldspar and mica	3.2.1
Table 2	Subdivision of metavolcaniclastic-rocks based on primary grain size	4.
Table 3	Classification of fault rocks without primary cohesion	7.1
Table 4	Classification of cataclastic rocks	7.2
Table 5	Classification of mylonitic rocks	7.3
Table 6	Examples of protolith structure qualifiers	10.4
Table 7	Colour index qualifiers	10.4

ACKNOWLEDGEMENTS

I would like to thank the review panel and other members of BGS staff together with Dr K Brodie and Dr N Fry for comments on previous versions of the report. The Review Panel consisted of Dr M T Styles, Mr K A Holmes, Mr K Bain, Mr R J Merriman and Dr J Carney. The manuscript was edited by Dr A A Jackson.

This volume was prepared for BGS use, and is released for information. Comments on its applicability for wider use would be welcome and should be sent to the Rock Classification Coordinator Dr M T Styles, BGS, Keyworth, Nottingham NG 12 5GG.

1 INTRODUCTION

The use of computers as primary tools for carrying out geological research and databases for storing geological information has grown considerably in recent years. In the same period there has been a dramatic increase in the degree of collaboration between scientific institutions, universities and industry, and between geologists working in different countries. To facilitate collaborative work amongst geologists and to maximise efficiency in the use of geological databases a common approach to classifying and naming rocks is essential. This publication presents a scheme for the classification and nomenclature of metamorphic rocks that is practical, logical, systematic, hierarchical and uses clearly defined, unambiguous rock names.

Producing a classification scheme with a hierarchical structure is an important objective for three reasons: firstly, it is a 'user-friendly' system in that the very wide range of rock types can be divided and classified in a logical and readily understood manner; secondly, the classification and naming of rocks can be varied according to the expertise of, and the level of information available to, the user — the more information that is available, the higher is the level of the hierarchy at which the rock can be classified and named; thirdly, it provides a convenient and simple system for inputting, storing and retrieving data on databases.

The diversity of metamorphic rocks result from the combined effects of a range of tectonic and/or metamorphic processes acting on the wide spectrum of protoliths; these may be sedimentary, igneous or previously metamorphosed rocks. The names given to metamorphic rocks are diverse. Similar rocks are given different names within the same geographical area due to the prejudices of workers or in different areas due to continued use of traditional terms. This reflects the lack of any internationally recognised scheme for defining and classifying metamorphic rocks.

The IUGS Subcommittee on the Systematics of Metamorphic Rocks is working towards a classification and nomenclature scheme. This will take several years to complete. The principles of the IUGS have however been considered in erecting this scheme.

The objective of this classification scheme is to introduce a system of nomenclature for metamorphic rocks that is based as far as possible on descriptive attributes (Figure 1). Rock names that are constructed of descriptive terms are more informative to both specialist and non-specialist users, and allow any rock to be placed easily into its position in the hierarchy. The approach to rock nomenclature outlined below allows the vast majority of all metamorphic rocks to be named adequately using a relatively small number of **root names** with or without **qualifier terms**.

1.1 Definition of metamorphism

Metamorphism encompasses all the solid state changes that occur between the upper and lower limits of metamorphism. Major changes in bulk composition are referred to as **metasomatism**. Figure 2 indicates diagnostic minerals and assemblages at various temperatures and pressures.

Lower limit of metamorphism: Transformations begin to take place in sedimentary rocks shortly after deposition and continue with increasing burial. The initial transformations are generally referred to as **diagenesis** although the boundary between diagenesis and metamorphism is somewhat arbitrary and strongly dependent on the lithologies involved. For example changes take place in organic materials at lower temperatures than in rocks dominated by

silicate minerals. In mudrocks, a white mica (illite) crystallinity value of $< 0.42\Delta \cdot 2\Theta$ obtained by X-ray diffraction analysis, is used to define the onset of metamorphism (Kisch, 1991). In this scheme, the first appearance of glaucophane, lawsonite, paragonite, prehnite, pumpellyite or stilpnomelane is taken to indicate the lower limit of metamorphism (Frey and Kisch, 1987; Bucher and Frey, 1994). Most workers agree that such mineral growth starts at $150 \pm 50^\circ \text{C}$ in silicate rocks. Many lithologies may show no change in mineralogy under these conditions and hence the recognition of the onset of metamorphism will vary with bulk composition.

Therefore, at the lower limits of metamorphism, it is likely that the choice of classification of a rock in either the igneous, sedimentary or metamorphic classification schemes will be somewhat arbitrary as many original features may still be preserved. Subsolvus changes during cooling of igneous rocks from magmatic temperatures, including the growth of K-feldspar megacrysts in granites, are not considered to be metamorphic changes for the purpose of this scheme.

Upper limit of metamorphism: At the highest grades of metamorphism, rocks begin to melt. The temperatures and pressures of the onset of melting range from approximately 650°C to more than 1100°C depending on bulk composition and the proportion of water in the fluid phase. The upper limit of metamorphism is defined here as the point when the rock as a whole no longer behaves as a solid due to the presence of melt. This will be dependent on the proportion of melt and the strain rate. These factors make it inevitable that the upper limit of metamorphism is defined somewhat arbitrarily, with an overlap with igneous rocks occurring where, with increasing proportion of melt, migmatitic rocks grade into granitic rocks.

1.2 Basic principles

The following basic principles used in this classification are amended after the IUGS scheme for the Classification of Igneous Rocks (Le Maitre et al., 1989) and the pending IUGS classification scheme for metamorphic rocks.

- i Metamorphic rock names should reflect the features that can be recognised in the rock. These may be inherited from the protolith, they may reflect modal composition, or texture. On this basis, the scheme should strive to allow categorisation at various levels of detail within a hierarchy.
- ii There should be sufficient flexibility to encompass reclassification when additional information is obtained. This enables a rock to be classified in the field, in hand specimen and using microscopic investigations as part of the same scheme.
- iii The rock names should provide the maximum information available about the nature of the rock without becoming too cumbersome.
- iv The scheme should be sufficiently simple and flexible to facilitate use by workers of varying experience and expertise.
- v Well-established names should be used/retained where practicable so as to avoid drastic changes in nomenclature and to ensure maximum adherence to the proposed scheme. However, this should not stand in the way of change where this is necessary.

- vi The name given to a rock should be appropriate for the information available and the expertise of the geologist. In most cases it is not desirable to ‘underclassify’ a rock. However, many metamorphic rocks can be classified using one of several root names reflecting particular aspects that are considered important.
- vii In situations where several root names could be applicable to a particular rock, then the root name that best emphasises the important geological aspects of that particular study should be chosen. For example metasandstone emphasizes the sedimentary protolith whereas chlorite–biotite psammite gives information on the modal composition and the metamorphism.

2 METAMORPHIC ROCK NOMENCLATURE

2.1 Construction of rock names

Rock names consist of a **root name** prefixed by qualifiers. Compound root names are hyphenated as are two or more qualifiers. However, qualifiers are not linked to the root name with a hyphen. This allows differentiation of qualifiers and root names, for example garnet-biotite schist, schistose semipelite, schistose-cordierite-sillimanite semipelite. Compound root names are hyphenated, for example calcsilicate-rock, metavolcaniclastic-rock, metamafic-rock. Compound words should be hyphenated where two vowels occur together, for example ortho-amphibolite in contrast to orthogneiss. All rock names are shown in **bold type**; root names are highlighted in **bold type and underlined** in the remainder of this scheme. Qualifiers are shown in italics. (It is emphasised that this is done here to help the reader, and is not suggested for general use.)

2.2 How to use the classification scheme

In this classification scheme for metamorphic rocks each rock name consists of a root name with one or more prefix qualifiers. The rocks are divided into six categories as follows (Figure 3 Column 1):

Metamorphic rocks with
 a sedimentary protolith
 a volcaniclastic protolith
 an igneous protolith
 a protolith of unknown or undefined origin
 mechanically broken and reconstituted rocks
 metasomatic and hydrothermal rocks

The first stage in classifying a rock is to allocate the rock to one of these categories. Rocks known to have a sedimentary, volcaniclastic or igneous protolith are discussed in Sections 3, 4 and 5 respectively. They are classified using either a protolith name (Section 3.1, 4.1 and 5.1), a name based on the modal composition (Section 3.2 and 5.2), or if neither of these is possible, the name is based on textural criteria (Section 3.3 and 5.3). Rocks allocated to the category of unknown or undefined protolith are discussed in Section 6. They include rocks with textural root names (Section 6.1) and rocks largely defined in terms of modal composition (Section 6.2); some of these should only be used for preliminary field classification. Fault and shear zone rocks are discussed in Section 7. Rocks whose characteristics are the result of metasomatic and hydrothermal processes form the sixth category and are discussed briefly in Section 8.

Textural root names recognised in this scheme are **slate**, **schist**, **gneiss** and **granofels**. Other textural terms such as

migmatitic and *phyllitic* may be used only as specific qualifiers (Sections 9.3 and 9.5).

Some rock names previously entrenched in the literature such as blueschist, granulite and migmatite do not feature in this scheme. Many granulite facies rocks can be comprehensively described using appropriate mineral and textural qualifiers although for some granulite facies rocks, the specific qualifier *charnockitic* may be used (Section 9.2). Similarly, *migmatitic* may be used as a specific textural qualifier (Section 9.3). Other rock names such as **marble** may be used as a last resort if a more specific root name cannot be determined (Section 6.2).

A rock classified initially in one category may at a later time be reclassified either elsewhere within the same category or even within a different category as more information becomes available. This is particularly the case for rocks originally of unassigned protolith and classified only on a textural basis (Section 6). Another example could be a **leucogneiss** which may be reclassified as a **paragneiss** when it is recognised as having a metasedimentary protolith and as a *gneissose psammite* once the rock is known to be composed largely of quartz and feldspar. Similarly, a *quartz-feldspar-biotite schist* may be reclassified as a *schistose semipelite* if the rock is derived from a sedimentary protolith and contains 60 to 80% quartz + feldspar. A flow diagram illustrating how a rock can be classified in terms of its root name is shown in Figure 1. Care must be taken not to classify a rock beyond a point appropriate to the information available. For example, a massive, compact, fine-grained rock should be classified as a *fine-grained granofels* and not a **hornfels** if there is no direct evidence for contact metamorphism. The most appropriate name for a metamorphic rock will also depend on the grade of metamorphism and the intensity of deformation. Figure 4 illustrates the possible evolution of nomenclature of a mudstone as metamorphism progressively modifies protolith features and eventually makes them unrecognisable.

The use of prefix qualifiers is important in conveying as much information as possible about a rock. Qualifiers are divided into four types covering textural features (Section 10.1), mineralogical features (Section 10.2), colour (Section 10.3) and protolith structures (Section 10.4). Not all are applicable to all root names. For example, textural qualifiers are unnecessary for rocks classified with a textural root name, with the exception of *phyllitic* and *migmatitic*. Conversely other types of qualifier are essential for some categories of root name. Thus, textural qualifiers are desirable with rocks defined with root names based on modal composition. More than one type of qualifier may be used in conjunction with a root name, as for example a *gneissose-garnet-sillimanite semipelite*.

Qualifiers should be used in the following order: colour, texture, mineral, protolith structure, root name.

Mineralogical qualifiers are listed in increasing order of abundance

Further guidance on the use of qualifiers is given in Section 10. The position of qualifiers with respect to root names can convey additional information as to the nature of a metamorphic rock and must be carefully considered. For example a meta-*orthopyroxene-gabbro* is an orthopyroxene gabbro that has been metamorphosed, that is the orthopyroxene is an igneous mineral whereas an *orthopyroxene metagabbro* contains metamorphic orthopyroxene. Similarly, the position of the qualifier *hornfelsed* will give information as to whether the hornfelsing is superimposed on a previously metamorphosed rock (Section 9.6).

The scheme does not restrict the use of descriptors for metamorphic rocks although these do not form part of the rock name.

3 SEDIMENTARY PROTOLITH : METASEDIMENTARY ROCKS

If the rock is known to be derived from a sedimentary protolith, either because of the lithological characteristics or the lithological associations of the rock, it should be classified within this category of metamorphic rocks. This category is subdivided into three according to protolith name (Section 3.1), on the basis of modal composition (Section 3.2) and on the basis of texture (Section 3.3).

3.1 Protolith name known

Root names: prefix **meta** on the appropriate term from the sedimentary rock classification scheme.

If the sedimentary protolith of a metamorphic rock is clearly recognisable, then the rock should be classified using a name from the sedimentary rock classification scheme (Hallsworth and Knox, 1999) prefixed by 'meta'. However, an underlying principle of the scheme must be upheld, namely that the rock name must describe the rock as it appears now and not what it might have been. A number of factors will determine whether a particular rock retains features of the protolith, not least of which is the nature of the lithology. For example sandstones which are siliciclastic rocks defined in terms of grain size (.032 mm to 2 mm) in the sedimentary scheme are likely to retain sufficient protolith features at low and even medium grades of metamorphism enabling classification with a name from the sedimentary scheme hierarchy such as **metasandstone**. Mudstones, defined as siliciclastic rocks with a grain size of < .032 mm in the classification scheme for sedimentary rocks, will readily develop metamorphic mineral assemblages even at very low grades of metamorphism. These may be difficult to relate directly to the protolith at any level beyond the general term **metamudstone**. In many cases, they would be more appropriately classified on the basis of modal composition, for example **metamudstone** becomes **semipelite** or **pelite** (Figure 4). Metamorphosed carbonate rocks must be classified with due regard to mineralogical changes that accompany metamorphism. These changes make the use of modal names (Section 3.2.3) preferable in the majority of cases. Dolomite readily reacts to a combination of calcite and calcsilicate minerals in the presence of impurities such as quartz. Therefore, as metamorphism progresses, the mineralogical composition of an impure dolostone will be similar to that of a tremolite, diopside and/or forsterite **metalimestone**. It must be stressed that the rock name must reflect the present nature of the rock. Metadolostone can therefore only be used for pure carbonate rocks that are still composed dominantly of dolomite. If the carbonate minerals are dominantly calcite but the rock contains a significant component of Mg-bearing minerals such as tremolite, diopside or forsterite, the rock may have originated as a dolostone. The rock no longer fulfills the definition of metadolostone; it is also likely that it is not derived from a limestone protolith (calcite dominant) and therefore must not be named a metalimestone even though modally it may now meet the criteria for a limestone.

In these circumstances, it should be classified using a modal name (Section 3.2) such as a *tremolite* **metacarbonate-rock**.

Qualifiers

Textural, mineral, colour and protolith qualifiers are used as appropriate, for example, *schistose* **metasandstone**, *chlorite-biotite* **metamudstone**, *cross-bedded* **metasandstone**.

3.2 Modal composition

Where a metasedimentary rock cannot be classified according to protolith name, modal composition can be used. Modally classified rocks are divided into three categories according to the proportions of quartz, feldspar, mica, carbonate and calcsilicate minerals (Table 1; Figures 5, 6 and 7).

3.2.1 ROCKS COMPOSED LARGELY OF QUARTZ ± FELDSPAR ± MICA WITH LESS THAN 10% CARBONATE AND/OR CALCSILICATE MINERALS

Root names: **quartzite**
psammite
semipelite
pelite

These rock types are classified according to their quartz + feldspar content. Traditionally they have been classified in terms of their 'mica' content; however this is unsatisfactory for rocks which contain minerals other than quartz, feldspar and mica. Here the 'mica' component includes metamorphic minerals such as chlorite, garnet, cordierite, staurolite, andalusite, kyanite, sillimanite and other minor components. It does not include calcsilicate or carbonate minerals (see below) which are considered neutral in this part of the classification and are not included in calculation of the modal proportions. **Psammites** containing more than 80% quartz are referred to as **quartzite**.

There will be 'grey areas' where a rock could be classified with either a protolith or modal root name. Such a situation may arise where there is doubt as to whether the nature of the protolith can be clearly recognised. In these circumstances, the rock name chosen should reflect the particular context and should emphasise either the protolith or the modal composition, as considered more appropriate.

Qualifiers

Textural qualifiers should be used with these rock names, for example *gneissose* **psammite**. Mineralogical and colour qualifiers should also be used where necessary, for example *pale-pink-gneissose-garnet* **psammite**. The terms *-rich* and *-bearing* (see Section 10.2) may give additional useful information, for example *quartz-rich* **psammite** implies that the **psammite** contains significantly more quartz than feldspar. Similarly *schistose-biotite-rich* **semipelite** implies that mica comprises 20 to 40% of the rock and that biotite is significantly more abundant than muscovite. Protolith qualifiers are not used, since if these are apparent the rock should be classified according to the protolith name (Section 3.1).

Table 1 Classification of rocks composed largely of quartz, feldspar and mica.

Root name	% 'mica' *	% quartz + feldspar
Psammite	0–20	80–100
Semipelite	20–40	60–80
Pelite	> 40	< 60

* 'mica' component includes all minerals other than quartz and feldspar with the exception of calcsilicate and carbonate minerals

3.2.2 ROCKS COMPOSED OF 10 TO 50% CARBONATE AND/OR CALCSILICATE MINERALS AND AT LEAST 50% QUARTZ ± FELDSPAR ± MICA

It may be difficult to identify the mineral proportions or estimate the mode of many rocks in this category without microscopic examination. They are classified using the qualifier *calcareous* attached to the relevant root name applicable to the non-carbonate ± calcsilicate component (Figure 6). For example *calcareous psammite* may contain up to 50% carbonate and/or calcsilicate minerals with at least 80% of the remainder of the rock composed of quartz and feldspar. Other qualifiers may be appended, for example, *schistose-garnet-calcareous semipelite*. Subsequent microscopic study may allow more specific mineral qualifiers to be added, for example, *granofelsic-calcite-calcareous psammite* or *gneissose-garnet-bearing-tremolite-rich-calcareous semipelite* (see Section 10.2).

3.2.3 ROCKS CONTAINING MORE THAN 50% CALCSILICATE MINERALS AND/OR CARBONATE MINERALS

Rocks containing more than 50% calcsilicate and/or carbonate minerals are classified as **calcsilicate-** or **metacarbonate-rocks** (Figure 7). Note that calcsilicate is not hyphenated in this scheme but both calcsilicate and metacarbonate are hyphenated to 'rock' since this is a compound root name.

Calcsilicate-rocks

Root names: **calcsilicate-rock**
para-amphibolite

If the modal calcsilicate mineral content exceeds the modal abundance of carbonate minerals, lithologies should be classified as **calcsilicate-rocks** (Figure 7). Calcsilicate minerals contain significant amounts of Ca ± Mg and Si and include diopside, epidote, grossular, calcic-amphiboles, sphene, uvarovite, wollastonite, vesuvianite and calcic-plagioclase. Mg-rich minerals such as forsterite and phlogopite are also common constituents of **calcsilicate-rocks**. As a general rule, plagioclase may be considered a calcsilicate mineral if it has more than 50% anorthite. Mineralogical qualifiers (Section 10.2) are used to give more specific rock names. For example, *garnet-wollastonite calcsilicate-rock*. An additional term used for rocks composed largely of hornblende and plagioclase is **para-amphibolite**. Note that the prefix 'para' indicates that the amphibolite is thought to have a sedimentary protolith in contrast to **ortho-amphibolite** which has an igneous protolith and **amphibolite** where the nature of the protolith is not defined.

Metacarbonate-rocks

Root name: **metacarbonate-rock**

If the modal content of carbonate minerals exceeds that of calcsilicate minerals the rock should be classified as a **metacarbonate-rock** (see Figure 7). The nature of the carbonate mineral is unspecified. If the carbonate is dominantly calcite, the rock may be referred to as *calcitic metacarbonate-rock*. If the carbonate is dominantly dolomite, the rock may be referred to as *dolomitic metacarbonate-rock*.

Qualifiers

Mineralogical qualifiers should be used where known, for example *garnet-wollastonite metacarbonate-rock*. Colour qualifiers are also important, particularly where mineralogy is not known. Textural qualifiers should be used where appropriate.

The rock name **marble** has been widely used as well as misused for some **metacarbonate-** and **calcsilicate-rocks**. It has been used for some non-metamorphic carbonate rocks, for example Purbeck Marble; it is also a stonemasons' term for decorative rocks that may or may not be carbonate-bearing, for example the Portsoy Marble which is a serpentinite. The name marble can be used as a general 'field' term where the proportions of carbonate/calcsilicate minerals is not known, but should not be used when there is sufficient information for the rock to be classified as either a **calcsilicate-** or **metacarbonate-rock** (Section 6.2.3).

3.3 Textural attributes

Rocks with known sedimentary protolith but where neither the exact nature of the protolith nor the modal composition is known or specified should be classified with a root name that reflects the textural characteristics of the rock. In many cases this is the easiest option in naming a rock but should only be used where a protolith or modal name cannot be applied; in particular it may be used for a preliminary field classification. Three textural root names are distinguished:

Root names: **paraschist**
paragneiss
paragranofels

A **paraschist** is defined as a medium-grained strongly foliated rock that can be readily split into flakes or slabs due to the well-developed preferred orientation of the majority of the minerals present, particularly those of platy or prismatic habit. Grain size qualifiers are listed in Figure 9. Lineated **paraschists** are rocks dominated by a strong linear fabric but fulfill the definitions of a schist when viewed parallel to the lineation. Schists occur characteristically in areas of medium-grade metamorphism and can encompass a wide range of lithologies. Qualifiers must be used to describe the rocks as fully as reasonable, for example *garnet-biotite paraschist*.

A **paragneiss** is a medium- to coarse-grained (Figure 9) inhomogeneous rock, commonly with a well-developed preferred orientation of constituent minerals, and characterised by a coarse foliation or layering that is more widely spaced, irregular or discontinuous than that in a schist. Adjacent layers generally exhibit contrasting texture, grain size and mineralogy. However, there is a continuum between schists and gneisses, with factors such as the spacing of the foliation and the degree of contrast between adjacent layers contributing to the assignment of a rock to either category. Gneiss is distinguished from schist where some layers are over 5 mm thick. Gneisses generally occur in areas of middle to upper amphibolite or granulite facies metamorphism and can encompass a

wide range of lithologies. Qualifiers are essential to describe the rock as fully as possible, for example *garnet-biotite paragneiss*, *cordierite-sillimanite paragneiss*.

A **paragranofels** lacks any obvious foliation or layering and is commonly characterised by a granoblastic texture. On this basis it does not meet the definitions of schist or gneiss. The term **granofels** has been proposed by the IUGS Subcommission and can be translated literally as granular rock. A **granofels** can occur at any metamorphic grade with a range of lithologies so qualifiers are essential. **Granofels** replaces ambiguous terms such as granulite which has been applied to granular psammitic rocks, particularly in the Scottish Highlands, for example Central Highland Granulites as well as granulite facies rocks.

Qualifiers

Mineralogical qualifiers should be used if possible as well as colour qualifiers. In the absence of mineral qualifiers, the use of colour qualifiers is essential. Textural qualifiers may also be appropriate, for example *greyish-pink-mylonitic paragneiss*.

Miscellaneous rocks with a textural root name

Unusual rocks are formed by the metamorphism of rocks such as ironstones, phosphate rock and evaporites. If they cannot be classified using a protolith name, they should be assigned a textural root name with appropriate mineral qualifiers.

4 VOLCANICLASTIC ROCK PROTOLITH: METAVOLCANICLASTIC-ROCKS

Root names: **metavolcaniclastic-conglomerate**
metavolcaniclastic-breccia
metavolcaniclastic-sandstone
metavolcaniclastic-mudstone

Metamorphic rocks known to be derived from volcaniclastic rocks should be classified with a name from the igneous rock classification scheme prefixed by 'meta'. The level in the igneous rock scheme hierarchy at which the rock can be classified depends on the extent of recrystallisation of original features. However, the distinction between volcaniclastic rocks, tuffites and pyroclastic rocks can be difficult, even in unmetamorphosed rocks since this relies on being able to recognise the proportion of pyroclastic fragments. This will mean that many metamorphosed rocks cannot be classified beyond the lowest level in the hierarchy, namely **metavolcaniclastic-rock**. In cases where the original grain size but not the proportion of pyroclastic fragments can be deduced, the terms **metavolcaniclastic-conglomerate**, **metavolcaniclastic-breccia**, **metavolcaniclastic-sandstone**, and **metavolcaniclastic-mudstone** may be used as shown in Table 2.

Table 2 Subdivision of **metavolcaniclastic-rocks** based on primary grain size. Clasts may be rounded or angular.

Rock name	Grain size (mm)
Metavolcaniclastic-conglomerate, metavolcaniclastic-breccia	> 2.0
Metavolcaniclastic-sandstone	0.032–2.0
Metavolcaniclastic-mudstone	< 0.032

5 IGNEOUS PROTOLITH: META-IGNEOUS ROCKS

Metamorphic rocks considered to be derived from an igneous protolith, either because of the lithological characteristics (i.e. preservation of igneous textures and in some cases composition or mineralogy) or the lithological associations of the rock, should be classified within this category of metamorphic rocks. Three categories are distinguished: on the basis of the igneous protolith (Section 5.1), in terms of modal composition (Section 5.2), and on the basis of textural attributes (Section 5.3).

5.1 Protolith name

If features of the igneous protolith of a metamorphic rock, such as texture and mineralogy, are recognisable then the rock should be classified using a rock name from the igneous rock classification scheme (Gillespie and Styles, 1997). The igneous scheme is based largely on modal composition; allowance must be made for changes in modal proportion due to metamorphism in assigning a meta-igneous rock name. This is particularly true for some parts of the igneous scheme which rely on mineral composition in naming rocks. A good example is the distinction between diorite and gabbro; diorites contain plagioclase with composition of less than An₅₀ and gabbros greater than An₅₀. The anorthite content of plagioclase in **metamafic-rocks** is a function of the temperature of metamorphism. The development of hornblende and epidote during metamorphism is generally accompanied by a reduction in the calcium content of the plagioclase so that many metamorphosed gabbros would fall within the diorite field according to their plagioclase composition discriminator in the igneous scheme. However, the rock name **metadiorite** is not appropriate since the rock is not a metamorphosed diorite. Some allowance must be made for such changes; in the absence of chemical evidence, the colour index of the rock should be used. If the colour index is greater than 35, the rock should be classified as a **metagabbro**. Low grade metamorphosed basaltic rocks previously referred to as spilites should be classified as either **metabasalt**, **metamafic-rock** or **metamafite** with suitable mineral qualifiers (Section 5.2) as most appropriate.

Qualifiers

Textural, mineralogical and colour qualifiers should be used as appropriate.

Protolith qualifiers should also be used where possible in the same sense as used in the igneous classification scheme, for example *leucocratic metadiorite*, *olive-grey-garnet metagabbro*.

5.2 Modal composition

Three categories of meta-igneous rock defined in terms of modal composition are distinguished on the relative proportions of quartz, feldspar and mafic minerals as indicated in Figure 8. Muscovite, carbonate and other generally pale-toned minerals are considered neutral and not used in the modal classification.

Root names: **metafelsic-rock**
metamafic-rock
meta-ultramafic-rock

Qualifiers

Textural, mineralogical and colour qualifiers will all add valuable information to the root name, for example *schistose-garnet-hornblende metamafic-rock*.

5.2.1 METAFELSIC ROCKS

Root names: **metafelsic-rock**
metafelsite

Metafelsic-rocks are defined as containing 65% or more felsic minerals and 35% or less mafic minerals. The word 'felsic' is a mnemonic adjective derived from feldspar, feldspathoid and silica and has been used for igneous rocks having abundant light coloured minerals. In practice the name will be used as a general term for felsic metamorphic rocks of unknown or unspecified igneous protolith. However, some metavolcaniclastic rocks such as **metarhyolitic tuff** may also fall into this category. In many cases coarse-grained rocks can be classified with an igneous protolith name, for example **metagranite**. If this is not possible they should be termed **metafelsic-rock** or *coarse-grained* **metafelsic-rock**. Fine-grained rocks should be termed **metafelsite**. See Figure 9 for grain size qualifiers.

5.2.2 METAMAFLIC ROCKS

Root names: **metamafic-rock**
metamafite
ortho-amphibolite

Metamafic-rocks contain between 35 and 90% mafic minerals. In practice this is a general name where the igneous protolith is not known or is unspecified. Metabasic or metabasite is not recommended because it covers a specified range of SiO₂ content and therefore requires chemical analysis; basic is defined as 45 to 52% SiO₂.

Mineral assemblages of **metamafic-rocks** reflect the grade of metamorphism. Low-grade **metamafic-rocks** have been traditionally referred to as 'greenschists' or 'greenstones'. These terms are not permissible here on the basis that many such rocks are neither green nor schistose and rocks previously referred to as greenschists do not necessarily have an igneous protolith. The now-redundant rock name 'greenstone' is replaced by a rock name such as *chlorite-actinolite* **metamafic-rock**. High-pressure metamorphic rocks have been referred to as blueschists. Again, for similar reasons, this term is not permissible as a specific rock name in this scheme. A rock name such as *glaucophane-lawsonite* **metamafic-rock** replaces 'blueschist'. Low-grade metamafic rocks should be classified either in terms of a protolith root name or a textural root name with appropriate mineral qualifiers, for example *schistose-actinolite-plagioclase* **metabasalt**, *schistose-glaucophane-rich* **metamafic-rock**. This is discussed further in Section 9.4. *Fine-grained* **metamafic-rocks** may be termed **metamafites**. Amphibolite facies metamafic rocks are traditionally termed **amphibolites**. Here the term **ortho-amphibolite** is retained and defined as a metamafic rock (i.e. of igneous origin) composed largely of feldspar and hornblende. This mineralogy reflects amphibolite facies conditions. Note the use of the terms **para-amphibolite** in Section 3.2.3 for rocks with a sedimentary protolith and **amphibolite** in Section 6.2.1 for rocks where the nature of the protolith is unspecified. Mafic rocks metamorphosed under conditions of high pressure with low P_{H₂O} have characteristic mineral assemblages, for example pyrope-rich garnet and jadeite-rich clinopyroxene, enabling them to be tightly defined in terms of modal composition as **eclogite**. However an essential requirement in the definition of **eclogite** is the absence of plagioclase. Therefore they cannot be classified in this part of the scheme since they are now strictly ultramafic metamorphic rocks; they are dealt with as a special case in Section 6.2.2.

5.2.3 META-ULTRAMAFLIC ROCKS

Root names: **meta-ultramafic-rock**
meta-ultramafite
serpentinite
talc-rock
hornblende-rock
pyroxene-rock

Meta-ultramafic-rocks contain 90% or more mafic minerals. If the mafic mineralogy is known, the rock is named after the most abundant mineral. Therefore rocks dominated by serpentine minerals are named **serpentinite**, rocks composed largely of talc are **talc-rocks**. However, hornblende and pyroxenite must be avoided since they are specific igneous rock names and cannot be used for metamorphic rocks. Rocks composed largely of hornblende, other amphibole or pyroxene are named **hornblende-rock**, **amphibole-rock**, **pyroxene-rock** or more explicitly *pyroxene-rich* **meta-ultramafic-rock** respectively with qualifiers where appropriate. The list of possible **meta-ultramafic-rocks** is obviously far longer than this; but the same principles are used.

5.3 Textural attributes

Where a rock is known to have an igneous protolith, but neither the protolith nor the modal composition is specified, then the rock may be classified with a root name based on textural attributes.

Root names: **orthoschist**
orthogneiss
orthogranofels

The definitions of **schist**, **gneiss** and **granofels** follow those given for metasedimentary rocks as in Section 3.3.

Qualifiers

Mineralogical qualifiers are needed in order to convey anything more than the most basic level of information. For example **orthogneiss** used without qualifiers would merely refer to a gneiss known to have an igneous protolith and so should always carry qualifiers. Where mineralogy is unknown, or only a single mineral phase is known, colour or tonal qualifiers are especially valuable in conveying more information on the nature of the rock, for example *biotite* **orthogneiss** could imply an orthogneiss containing biotite or an orthogneiss with very abundant biotite whereas *pale-grey-biotite* **orthogneiss** implies that it contains a high proportion of light coloured minerals.

6 UNKNOWN OR UNDEFINED PROTOLITH AND PRELIMINARY FIELD CLASSIFICATION

If the nature of the protolith of a metamorphic rock is not known, then it should be classified either on the basis of textural attributes (Section 6.1) or on the basis of modal features (Section 6.2).

6.1 Textural attributes

Textural root names are generally the most descriptive rock names and therefore those with little genetic interpretation.

Root names: **slate**
schist

gneiss
granofels
hornfels

A **slate** is a compact, fine-grained rock with a strong fissility along planes in which the rock can be parted into thin plates indistinguishable from each other in terms of lithological characteristics. **Slates** are typically low-grade metamorphosed mudstones. However, some may be derived from volcanoclastic-rocks. **Slate** should only be used as a general name where little else is known about the rock. Where the protolith is known, it is preferable to use the textural qualifier *slaty* with a more specific root name, for example *slaty metasilstone*. The use of the name **slate** is discussed further in Section 9.5.

The definitions of **schist**, **gneiss** and **granofels** are those given in Section 3.3. **Hornfels** is a variant of **granofels**. It is applied to a hard fine- to medium-grained rock of unknown protolith and modal composition which lacks parting planes and has recrystallised as a result of contact metamorphism. See Section 9.6 Contact metamorphism for a fuller discussion on the use of the term **hornfels**.

Qualifiers

It is very important that mineralogical qualifiers are used with **schist**, **gneiss** and **granofels**. Rock names will be of the form *quartz-feldspar-biotite schist* or *garnet-biotite-quartz granofels*. Note that mineralogical qualifiers are always used in increasing order of abundance as described in Section 10.2. If it is not possible to identify specific minerals, other qualifiers should be used to give as much information as possible about the rock. Colour qualifiers may be particularly useful in these circumstances in distinguishing a rock composed largely of pale minerals from one composed largely of dark minerals. Specific textural qualifiers such as *phyllitic* (Section 9.5), *migmatitic* or one of the more specific types of migmatitic texture such as *stromatic* (Section 9.3) may also be used.

Few qualifiers other than colour will be appropriate for the root name **slate** since the use of the name implies that little is known about the rock other than that it is very fine-grained with a slaty cleavage, for example *greyish-green slate*.

Mineral and colour qualifiers should be used to indicate the nature of the hornfels. Textural qualifiers are not required since the use of **hornfels** implies a granofelsic texture.

6.2 Modal features

Root names: **amphibolite**
eclogite
marble

6.2.1 AMPHIBOLITE

Rocks composed largely of hornblende and plagioclase are termed **amphibolite**, where it is not known whether they have an igneous or sedimentary protolith.

Qualifiers

Textural and mineral qualifiers should be used where possible, for example *schistose-garnet amphibolite*.

6.2.2 ECLOGITE

Eclogite is defined by Carswell (1990) as a rock composed of more than 70% garnet and jadeitic clinopyroxene (omphacite). **Eclogites** do not contain plagioclase. They may contain other anhydrous minerals such as quartz,

kyanite, orthopyroxene and rutile, together forming no more than 30% of the rock. **Eclogites** result from metamorphism of basaltic or gabbroic igneous rocks under very low P_{H_2O} producing anhydrous mineral assemblages. They define a unique eclogite facies metamorphism, typically reflecting very high pressures although their local occurrence within amphibolite facies rocks suggests they may be formed over a significant range of pressure.

6.2.3 MARBLE

Rocks composed largely of calcisilicate and/or carbonate minerals, but where the relative proportions of either mineral group are unknown, may be classified as marble. Rocks initially classified as **marble** should be reclassified after further study as **metacarbonate-rock** or **calcisilicate-rock**.

Qualifiers

Textural, colour and mineralogical qualifiers may be used.

7 MECHANICALLY BROKEN AND RECONSTITUTED ROCKS

This part of the scheme covers principally fault and shear zone rocks. Wherever possible, mechanically broken and reconstituted rocks should be classified with a root name that reflects the pre-existing rock combined with a suitable qualifier (Tables 3, 4 and 5). If the nature of the pre-existing rock is not known, the root name should reflect the present nature of the rock.

Rocks are subdivided on the presence or absence of both primary cohesion and foliation. Rocks without primary cohesion are produced by brittle deformation with mechanical disaggregation of the rock. Unfoliated cohesive rocks (**cataclasites**) are generally the products of brittle deformation with grain size reduction (granulation). There may be some recrystallisation. Foliated cohesive rocks (**mylonites**) generally result from ductile strain with granulation dominant over recrystallisation producing a reduction in grain size. However, within a mylonitic rock some minerals behave in a brittle fashion and others ductile, for example in a granitic rock feldspar is likely to form augen resulting from brittle deformation, while ribbon textures show that quartz underwent plastic strain; micas show either sliding or buckling deformation.

Lithologies within each category are defined on the basis of the percentage and size of fragments occurring within the matrix produced by grinding and shearing processes.

Qualifiers

Mineralogical qualifiers may be used in some circumstances, particularly to give the nature of porphyroclasts, for example *plagioclase-porphyroclastic mylonite*. Broad features of the overall appearance may give useful information, for example *mafic ultracataclasite*.

7.1 Rocks without primary cohesion

Root names: **fault-breccia**
fault-gouge

This category is subdivided according to the proportion of visible fragments within a finer-grained matrix (Table 3), largely following Sibson (1977). The abundance and size of the fragments depends on the original character of the rock and also the rate and duration of movement. The resulting rocks range from coarse breccias with limited dis-

ruption of the original rock to fine gouge where the rock is largely reduced to a paste (Higgins, 1971). Any cohesion is the result of secondary cementation. Such rocks invariably form at low confining pressures.

Broken rocks contain no matrix and show little or no rotation or granulation of fragments. The nature of the original rock will be known and this should be used as a root name. The qualifier *broken* should prefix the root name. A **fault-breccia** is not foliated; it contains angular to rounded fragments that comprise more than 30% of the rock and which are significantly coarser than the matrix composed of mechanically broken rock fragments and/or mineral grains. Where the nature of the original rock can be recognised, then the root name should be prefixed by the qualifier *brecciated*. If the original rock cannot be recognised, the root name **fault-breccia** should be used with appropriate qualifiers. A **fault-gouge** may be strongly foliated and comprises less than 30% fragments lying in fine-grained, commonly clayey matrix. It is unlikely that a root name based on the original rock will be appropriate.

Table 3 Classification of fault rocks without primary cohesion.

Per cent fragments visible to naked eye	Qualifier where original rock is recognisable	Root name	Comments
100	<i>broken</i>		Root name not required since original rock can be identified
> 30	<i>brecciated</i>	fault-breccia	Use qualifier <i>brecciated</i> if original rock can be identified otherwise use root name
< 30 original		fault-gouge	Use where rocks cannot be identified, or where > 70% of the rock is fine-grained and clayey

7.2 Unfoliated rocks with primary cohesion: cataclastic rocks

Root names: **protocataclasite**
cataclasite
ultracataclasite

Rocks with primary cohesion are formed at higher confining pressures than those without cohesion. The nature of the rocks depends on factors such as confining pressure, original lithology, amount and duration of movement and the availability of fluids. Cataclastic rocks are not foliated and exhibit grain size reduction by fragmentation of grains during deformation. They are classified (Table 4) on the relative proportions of fragments and matrix (Sibson, 1977). Fragments are those parts of the rock that are significantly coarser than the grain size of the matrix which may be composed of broken rock fragments/minerals showing slight recrystallisation. If the fragments are composed of a single mineral as opposed to an aggregate of minerals, they are defined as porphyroclasts (Section 7.3).

Table 4 Classification of cataclastic rocks.

Volume per cent of fragments	Qualifier	Root name	Comments
> 50	<i>proto-cataclastic</i>	protocataclasite	
10–50	<i>cataclastic</i>	cataclasite	
< 10		ultracataclasite	original rock cannot be identified and therefore a qualifier for this category is not required

7.3 Foliated rocks with primary cohesion: mylonitic rocks

Root names: **protomylonite**
mylonite
ultramylonite
phylonite
blastomylonite

Mylonitic rocks represent the products of dominantly ductile deformation. They generally occur within restricted zones related to faults, thrusts or shear zones. These foliated rocks develop as a result of grain size reduction by a combination of breakage and plastic strain of grains. Plastic deformation increases the aspect ratio of affected minerals producing textures such as quartz ribbons and a foliated fine-grained matrix. Other minerals, for example feldspar and garnet, may resist ductile deformation or fracture in a brittle manner and remain significantly larger than the foliated matrix. These are commonly lens shaped and termed **porphyroclasts**. As mylonitisation proceeds, the porphyroclasts are progressively wrapped by and then become isolated within the foliated matrix. They also become smaller, either by fracturing or by marginal erosion. Porphyroclasts may develop asymmetrical tails which can indicate the sense of shearing (dextral or sinistral) within the mylonitic rocks. Classification is largely based on the percentage of visible porphyroclasts within the streaky, platy, fine-grained matrix (Table 5) (Sibson, 1977).

Two specific variants of mylonitic rocks not defined in terms of the proportion of fragments are **phylonites** and **blastomylonites**. **Phylonites** are defined as mylonitic rocks of phyllitic appearance and hence are dominated by platy minerals. **Blastomylonites** are formed where extensive recrystallisation

Table 5 Classification of mylonitic rocks

Volume per cent porphyroclasts	Qualifier	Root name	Comments
> 50	<i>protomylonitic</i>	protomylonite	
10–50	<i>mylonitic</i>	mylonite	
< 10		ultramylonite	original rock cannot be identified and therefore a qualifier for this category is not required

and mineral growth accompanied deformation, resulting, for example, in ribbon textures in quartzose rocks.

7.4 Glassy rocks

Root name: **pseudotachylite**

Pseudotachylite is a particular variety of **cataclasite** in which fragments occur in a glassy groundmass produced by frictional melting. It may be injected as veinlets into adjoining cataclasite. The name can be used in addition to the appropriate fault rock classification, for example pseudotachylite-bearing **cataclasite**.

8 METASOMATIC AND HYDROTHERMAL ROCKS

A comprehensive classification of metasomatic or hydrothermal rocks is not attempted here. Some examples are given although this list is by no means exhaustive.

Metasomatic-rocks are a heterogeneous group of metamorphic rocks where metamorphism has involved a significant change in the chemistry of the protolith. Problems arise in classifying such rocks and deciding what criteria are significant in judging whether sufficient chemical and mineralogical changes have occurred for it to be called metasomatism. Rocks commonly classified as metasomatic include:

- **rodingites** — rocks associated with serpentinites comprising Ca-rich minerals, for example Ca-pyroxene, grossular, hydrogrossular. They represent the Ca-rich fraction expelled during serpentinisation
- **fenite** — desilicated crustal rocks formed by reaction with Na- and K-rich fluids expelled during the emplacement of carbonatite or undersaturated alkaline magmas
- **skarn** — in many cases resultant from metasomatism of calcareous rocks in thermal aureoles. Other types exist, for example **magnetite-skarns**
- **greisen** — a granitic rock altered through interaction with Li- and F-rich, and/or B-rich, hydrothermal fluids

Hydrothermal-rocks are rocks whose characteristics are the result of the actions of hot aqueous solutions. Many mineral assemblages are possible. Where possible, the rock name should reflect the mineralogy of the rock. If the pre-existing rock (i.e. prior to hydrothermal/metasomatic alteration) can be recognised, mineral qualifiers that reflect the hydrothermal/metasomatic alteration should be added to that rock name, for example *epidote granite*, *tourmaline-fluorite granite*. If the pre-existing rock cannot be recognised, the rock should either be given one of the names listed above or mineral qualifiers should be added, for example *grossular-magnetite hydrothermal-rock*.

Many hydrothermal/metasomatic rocks may be best described using descriptors that do not form part of the rock name, such as epidotised, epidote-veined, chloritised or propylitised, for example epidote-veined *quartz-tourmaline hydrothermal-rock*.

9 SPECIAL CASE METAMORPHIC ROCK GROUPS AND THEIR PLACE IN THE CLASSIFICATION SCHEME

A number of rock names that have been widely used are not permissible in this scheme whereas others that have

been used for diverse rocks are more strictly defined here. This section gives guidance on how to name rocks in these various categories.

9.1 Charnockites

The use of the term charnockite has been discussed in the igneous rock classification scheme with the recommendation that it be used as a qualifier to the appropriate igneous rock name such as charnockitic granite. It may also be used for granulite facies metamorphic rocks which possess charnockitic characteristics, namely a coarse grain size and a melanocratic, greasy-brown aspect (see Igneous Rock Classification Scheme; Gillespie and Styles, 1997). Feldspars are generally perthitic or antiperthitic, and many, but not all, are orthopyroxene-bearing.

9.2 Granulite facies rocks

Granulite facies rocks have commonly been referred to simply as 'granulites'. They formed at high temperatures and pressures where $P_{H_2O} \ll P_{TOTAL}$. Under such conditions, hydrous minerals such as muscovite are no longer stable. Dehydration reactions give rise to characteristic mineral assemblages with mafic minerals represented, at least in part, by anhydrous phases. Textural changes may accompany dehydration metamorphism; the development of granofelsic textures may partially or completely obliterate pre-existing textures. Colour changes may also occur, weathering surfaces in particular take on a greasy brown appearance and the rocks almost invariably appear darker than their lower-grade equivalents. Chemical changes occur in some granulite facies rocks with significant depletion in incompatible elements compared to amphibolite facies equivalents. The result is rocks with higher Fe, Mg and Ca contents. This has been attributed by various workers to either removal of mobile elements within the fluids given off during dehydration or to the loss to a partial melt phase.

The term 'granulite' is not permissible in this scheme. The purpose of a rock name is to convey the maximum descriptive information about the rock where as granulite only conveys the grade of metamorphism and nothing about the lithology.

In general, the high metamorphic grade must be conveyed by use of appropriate mineral qualifiers appended to a suitable root name as used throughout the classification scheme. Rocks with charnockitic characteristics (Section 9.1) may be given the qualifier *charnockitic*. In this context, *charnockitic* is a descriptive term which may be used for rocks with igneous, sedimentary or unknown protoliths that display charnockitic characteristics. It is particularly applicable for dark, homogeneous granulite facies rocks of unknown protolith which may be given names such as *charnockitic gneiss* or *charnockitic granofels*.

The majority of granulite facies rocks will require a textural root name, either **granofels** or **gneiss**. This may be preceded by 'para' or 'ortho' if the rock is known to have a sedimentary or igneous protolith. Mineral qualifiers will reflect the important features of the rock, giving rock names such as *garnet-clinopyroxene paragranofels*, *charnockitic-garnet paragranofels*, *hypersthene-plagioclase orthogneiss* or *charnockitic-hypersthene orthogneiss*. However, if more details of the rock are apparent, it may be possible to give a name such as *granofelsic cordierite-sillimanite-K-feldspar semipelite*. Colour qualifiers should be used particularly where the rock has an anomalous colour such as *mid-brown-granofelsic metagranite*.

9.3 Migmatitic rocks

The term 'migmatite' was originally introduced by Sederholm (1907) for gneisses composed of two genetically different components, one of which was a 'schistose sediment or foliated eruptive' and the other formed by 're-solution of material like the first or by an injection from without'. Mehnert (1968) proposed a much less restrictive and non-genetic definition which is adopted here: 'A *migmatite is a megascopically composite rock consisting of two or more petrographically different parts, one of which is the country rock in a more or less metamorphic stage, the other is of pegmatitic, aplitic, granitic or generally plutonic appearance*'.

Migmatitic rocks contain leucosomes, mesosomes and melanosomes. Leucosomes are defined as being of variable scale and comprising the leucocratic, quartzofeldspathic or feldspathic fraction of the rock. Mesosome is the part of the rock having the appearance of an ordinary metamorphic rock, that is **schist** or **gneiss**, and is generally of intermediate colour between the leucosome and melanosome. (Some authors have referred to this as the palaeosome). The melanosome is the melanocratic, mafic-rich fraction of the migmatitic rock, complementary to the leucosome. The neosome comprises both the leucosome and the melanosome.

'Migmatite' is not permissible as a root name in this scheme as it is not a single rock type. However, *migmatitic* may be used as a specific textural qualifier. This may supplement a textural root name such as *migmatitic-biotite-sillimanite* **paragneiss** or be added to a modal root name such as *migmatitic* **semipelite**. Rarely a protolith root name may be applicable, particularly for meta-igneous rocks such as *migmatitic* **metaquartz-diorite**.

Qualifiers giving information on the structural form of a migmatitic rock are also important. These include:

stromatic—where the neosome and mesosome have a layered structure

agmatitic—where the neosome or leucosome forms a network of veins within the mesosome, commonly imparting a brecciated appearance to the mesosome

schlieric—where streaks of non-leucosome components occur within the leucosome

nebulitic—where there are ghost-like relicts of pre-existing rocks within a largely reconstituted igneous-looking host rock

These names may be used in place of *migmatitic* as qualifiers, for example *agmatitic* **gneiss**, *schlieric* **orthogneiss**, *nebulitic-biotite-plagioclase-quartz* **paragranofels**, *stromatic* **semipelite**.

Stromatic migmatitic rocks are gneissose (see Section 10.1). However, not all migmatitic rocks are gneissose and not all gneissose rocks are migmatitic. For example a nebulitic migmatitic rock typically will have an igneous-like appearance but is still described as migmatitic as long as it contains relicts of metamorphic-looking rock. However, it does not meet the definition of a gneiss since it is not layered. Similarly a gneissose layering does not necessarily contain elements with igneous-like appearance.

Most migmatitic rocks occur in middle to upper amphibolite facies and granulite facies terrains. They may be produced by partial melting, injection or solid state diffusion processes. In practice, it may be very difficult to determine which process produced some migmatitic rocks, but this has no effect on the classification since migmatitic is used here as a purely descriptive term. Terms such as anatexite, metatexite, diatexite should be avoided as rock

names because they imply partial melting; the descriptive terms outlined above should be used.

9.4 Blueschists and greenschists

The terms 'greenschist' and 'blueschist' have been used traditionally for a range of rock types, commonly metabasalts, belonging to the greenschist and blueschist facies respectively. Greenschists are essentially fine grained and composed of chlorite + actinolite + albite + epidote, minerals which commonly impart a green colour to the rock, hence the term 'greenschist'. Unfortunately, greenschists are not necessarily green nor schistose. Furthermore, the term 'greenschist' has been applied to both metasedimentary and meta-igneous rocks. Due to the ambiguity, the term is considered unnecessary and unacceptable in this scheme. A suitable alternative rock name can be given using a protolith name with mineral qualifiers, for example *chlorite-actinolite* **metabasalt**. If the protolith was fine grained but it is not possible to be sure that it was basalt, use the root name **metamafite**, for example *chlorite-actinolite* **metamafite**. Alternatively, if the rock is of unknown protolith it will be better described in terms of a textural root name, for example *chlorite-actinolite-albite* **schist** or *chlorite-actinolite-albite* **granofels**.

Blueschists are essentially composed of glaucophane/crossite + lawsonite and/or epidote together with a range of other minor components. Albite is usually only a minor component. The presence of sodic amphibole, produced by reaction between albite and chlorite, imparts a blue colour to the rock giving rise to the term 'blueschist'. Many blueschists only contain small amounts of plagioclase and might be considered ultramafic in terms of a modal classification (Section 5.2.2). Since the original rock was mafic, it is incorrect to classify them as meta-ultramafic. Additionally, they are not necessarily schistose. Due to the ambiguity, the term blueschist is not acceptable. There is no suitable single alternative rock name. Therefore they should be described either in terms of a protolith name, for example *glaucophane-lawsonite* **metabasalt** or with a textural root name, for example *crossite-pumpellyite* **granofels**.

9.5 Slate and phyllite

The term **slate** has been used traditionally as a rock name for a compact, fine-grained, low-grade metamorphic rock with a slaty cleavage, that is, a strong fissility along planes that allow the rock to be parted into thin plates, indistinguishable from each other in terms of lithological characteristics. However, the name also has industrial connotations for a rock which is, or has been used for roofing, billiard tables, drawing boards, damp proof courses etc. on account of its strong fissility. In this context, the fissility may be of either tectonic or bedding depositional origin. The protolith of a 'slate' is almost invariably fine grained but can include mudstones, volcaniclastic rocks or even pyroclastic rocks. It may therefore be an igneous or sedimentary rock. On the basis of the range of lithologies that have been encompassed within the name slate, together with the practical connotations in the name, it is not a preferred root name. However, it is accepted that the name is entrenched in the literature and that it is useful as a general field name for fine-grained fissile rocks of undefined protolith, many of which may be hard to classify modally because of the fine grain size. Few qualifiers other than colour, for example *grey-green* **slate**, will be appropriate for the root name **slate** since the use of the name

implies that little is known about the rock other than grain size and texture. If a protolith or modal root name can be used, it is preferable to indicate the presence of a slaty cleavage by the textural qualifier *slaty*, for example *slaty metasediment*, *slaty semipelite*, *slaty metatuffite*.

The term phyllite has previously been used for rocks possessing a silky or lustrous sheen on foliation surfaces imparted by fine-grained (< 0.1 mm) white mica (including muscovite, paragonite and phengite) orientated parallel to the foliation in the rock. Individual mica flakes can be seen with the naked eye in contrast to slates where they cannot be distinguished. Most are probably derived by the low- to medium-grade metamorphism of mudstones although some rocks that have been described as phyllites may have been confused with **phyllonites** (see Fault and shear zone rocks, Section 7.3. Here 'phyllite' is classified as a specific variant of schist. It is therefore not permissible as a root name but may be used as a specific qualifier, namely *phyllitic*, for example *phyllitic semipelite*.

9.6 Contact metamorphism

Contact metamorphism results from the temperature perturbation associated with the emplacement of magma into the crust. The extent of the thermal perturbation will be determined by both the crustal level at which the magma was emplaced and the volume of the magma body; contact metamorphism will merge into regional metamorphism when a large body of magma is emplaced at greater depths. In many cases, contact metamorphism is not accompanied by recognisable tectonic effects, with the result that new mineral assemblages develop granoblastic textures. The amount of recrystallisation and the associated metamorphic mineral assemblages are largely a product of a combination of the heat energy available, nature and volume of fluid flow, lithology of the country rock and the distance from the heat source. A gabbroic magma is hotter than a granite magma and so would be expected to produce greater recrystallisation with higher temperature minerals. With increasing recrystallisation granoblastic textures progressively develop so that pre-existing features in the rock are destroyed, ultimately resulting in hard, fine- to medium-grained rocks lacking parting surfaces. Pre-existing features such as schistose or gneissose textures may be recognised by lithological heterogeneities.

In this scheme, rocks which have recrystallised as a result of contact metamorphism are named either by adding the qualifier *hornfelsed* to the appropriate protolith, modal or textural root name or by using **hornfels** as the root name with other suitable qualifiers.

Use of the qualifier 'hornfelsed'

If a hornfelsed rock contains features which allow classification either in terms of a protolith, modal composition or textural root name, then that root name should be prefixed by the qualifier *hornfelsed*. When hornfelsed is added to a protolith root name, the root name should only be prefixed by 'meta' where the rock is known to have been metamorphosed prior to hornfelsing, for example *hornfelsed metasediment* specifies hornfelsing of a **metasediment** whereas *hornfelsed sandstone* implies that no metamorphism is recognised prior to hornfelsing. The term hornfelsed carries the implication that the rock is now a metamorphic rock. Where the root name is based on the modal composition of the rock, mineral qualifiers should give information on the grade of metamorphism, for example

hornfelsed-cordierite-andalusite semipelite has more andalusite than cordierite (see Section 10.2) and the rock can still be classified as a **semipelite**. *Hornfelsed-gneissose-cordierite-andalusite semipelite* also implies that the pre-existing gneissose texture of the rock can still be recognised. If a textural qualifier, in addition to hornfelsed is not used, then the rock is assumed to be granofelsic. It is more important for mineral qualifiers to give information on the general characteristics of a hornfelsed rock where this is not self-evident from the root name as in rocks with a textural root name, for example *hornfelsed-biotite-feldspar-quartz schist*. Colour qualifiers may be appropriate in some circumstances.

Use of hornfels as a root name

Where features of the original rock have been modified by contact metamorphism to such an extent that the rock cannot be classified according to protolith or modal composition, then **hornfels** can be used as a root name. **Hornfels** is a specific variant of **granofels**. Textural qualifiers are not required since the root name implies that the rock has a granofelsic texture. Mineral qualifiers are essential.

10 QUALIFIERS

All terms used in the scheme should be given prefix qualifiers as appropriate, at any level of detail in the classification, in order to best describe a rock based on the information available. Qualifiers are based on colour, grain size, texture and mineralogy. Qualifiers particularly suitable for certain rock groups are listed in the appropriate section.

Qualifiers are used in the following order: colour-texture-mineralogy-protolith structure root name, for example *reddish-brown-schistose-cross-bedded metasediment* or *green-chlorite-biotite orthoschist*.

Qualifiers must be used sensibly to avoid terms becoming too cumbersome or complex. In practice, this probably means using no more than four qualifiers. It is not intended that the whole description of a rock should be included in its name; the geologist must choose only the most important attributes to be included in the name.

10.1 Textural qualifiers

Textural qualifiers reflect aspects of the rock texture that are not self-evident from the rock name. Most are descriptive, but genetic terms which give specific information are acceptable in some circumstances, for example *cataclastic* is derived from fault and shear zone rock terminology and infers an origin for the rock. This is considered acceptable in association with other evidence of faulting; similarly *hornfelsed* implies a contact metamorphic process which is acceptable where this process has clearly occurred. The qualifiers are listed and defined below.

Agmatitic rocks are a specific variant of migmatites in which the leucosome or neosome forms a network of veins within the mesosome, and may impart a brecciated appearance to the mesosome. A common example is where the mesosome is a **metamafic-rock** and the leucosome is feldspathic or quartz-feldspathic.

Augen are lensoid crystals or mineral aggregates, which in cross section are 'eye' shaped. These commonly occur in gneissose rocks, where the foliation wraps the augen structure.

Banded rocks exhibit some layering, but there is no evidence that the individual layers persist throughout the rock body.

Brecciated rocks show evidence of disruption (generally by brittle deformation or volcanogenic processes) on a relatively large scale to produce angular rock fragments usually greater than 64mm in diameter.

Broken rocks are fractured by brittle deformation but with little evidence of granulation. They are a specific variant of brecciated rocks in which matrix forms less than 10% of the rock.

Cataclastic rocks contain structures and textures produced during processes of grain size reduction through brittle processes with only minor recrystallisation.

Foliated is a general term for the planar textural or structural features in a rock and in particular the preferred orientation of inequidimensional minerals.

Gneissose rocks are inhomogeneous or layered and characterised by a coarse banding more widely spaced, in broad terms more than 15 mm, irregular or discontinuous than that in a schistose rock. Adjacent layers generally exhibit contrasting texture, grain size or mineralogy.

Grain size qualifiers follow the standard BGS Grain Size Scheme (Figure 9).

Granofelsic texture lacks any obvious foliation or layering and is characterised by a granoblastic texture.

Granoblastic texture is an aggregate of broadly equidimensional crystals of more or less the same size. In many cases crystals are anhedral.

Hornfelsed rocks are hard, fine- to medium-grained rocks which lack parting planes and have recrystallised as a result of contact metamorphism, generally in the inner parts of thermal aureoles.

Layered is defined as a tabular succession of differing components of the metamorphic rocks either in terms of mineralogy, texture or structure. Individual layers are inferred to be persistent throughout the rock body.

Lineated rocks contain linear structures, usually as a consequence of the preferred orientation of prismatic minerals.

Migmatitic rocks are megascopically composite, consisting of two or more petrographically different parts, one of which is the country rock in a more or less metamorphic state, the other is of pegmatitic, aplitic, or granitic appearance.

Mylonitic rocks are cohesive foliated porphyroclastic rocks, produced by grain-size reduction associated with pure or simple shear.

Nebulitic rocks contain ghost-like relicts of pre-existing rocks within a largely reconstituted igneous-looking rock. They are an extreme variety of migmatitic rocks.

Phyllitic rocks possess a silky or lustrous sheen on foliation surfaces imparted by microcrystalline white mica (including muscovite, paragonite and phengite), chlorite and may be biotite, orientated parallel to the foliation in the rock. Individual micas can usually be seen with the aid of a hand lens.

Phyllonitic rocks are intensely foliated phyllosilicate-rich rocks associated with ductile thrusts and shear zones.

Porphyroblastic rocks contain large metamorphic crystals within a finer-grained groundmass.

Porphyroclastic rocks contain large crystal fragments as opposed to lithic fragments within a finer-grained matrix.

Schistose rocks exhibit a recognisable schistosity defined as a foliation or lineation which allows the rock to be split easily along planes. Constituent minerals can be seen with the naked eye.

Schlieric rocks are migmatitic rocks which contain streaks of non-leucosome components within the leucosome.

Slaty is synonymous with a rock possessing a slaty cleavage, that is a strong fissility along planes in which the rock can be parted into thin plates indistinguishable from each other in terms of lithological characteristics.

Stromatic rocks are migmatitic rocks where the neosome and mesosome have a layered structure.

10.2 Mineralogical qualifiers

These designate metamorphic and/or significant descriptive features. Mineralogical qualifiers should not be used where the presence of those minerals is self evident from either the root name or another qualifier, for example *gneissose granite* requires the presence of quartz and feldspar and so they are not needed as qualifiers.

Use qualifiers in increasing order of abundance, for example *schistose-garnet-kyanite semipelite* indicates garnet < kyanite, and *sillimanite-cordierite-feldspar gneiss* indicates sillimanite < cordierite < feldspar. This is consistent with recommendations in the igneous scheme.

Where mineralogical qualifiers are the only qualifiers used, and particularly for root names based on texture, they should reflect all major minerals present in the rock in order to convey the maximum possible information about the rock within the constraints of restricting the rock name to 4 or 5 words.

Use 'bearing' if a significant mineral phase comprises less than 5% of the rock, for example *garnet amphibolite* implies more than 5% garnet whereas *garnet-bearing amphibolite* implies less than 5% garnet.

Use 'rich' if more than 20% of a significant mineral phase. The exception to this is if a rock contains a greater abundance of an essential mineral constituent than is implied by the root name. 'Rich' can also be used to indicate proportions of minerals, for example *schistose-muscovite-rich semipelite* implies significantly more muscovite than biotite although with a total mica content between 20 and 40% as constrained by the term **semipelite**.

Mineralogical qualifiers may also convey the presence of groups of minerals in a similar way, for example *calcisilicate-bearing metalimestone, amphibole-bearing-micaceous psammite*.

10.3 Colour qualifiers

Colour qualifiers should ideally follow those used in the Munsell Rock Colour Chart. Terms such as grey should be avoided; grey can range from almost white to almost black although if grey is unqualified, mid-grey is inferred. The type of grey should be specified.

10.4 Qualifiers based on protolith structures

Qualifiers within this category are derived from Section 13 in the sedimentary rock classification scheme (Hallsworth

and Knox, 1999) and Section 11 of the igneous rock classification scheme (Gillespie and Styles, 1997). The scope of sedimentary qualifiers is large and a few examples are given below.

This list gives only a selection of the possible depositional structure qualifiers; see the sedimentary scheme for a more complete list. It should be used with care and generally only for low-grade rocks, for example *cross-bedded* **metasandstone**.

Igneous structure qualifiers include special grain size terms including *pegmatitic*, qualifiers describing cavities, for example *vesicular*, and qualifiers based on colour index. The colour index is the modal proportion of mafic and mafic-related minerals in a rock. These do not include muscovite, apatite and carbonate minerals which are classed as light coloured minerals (Streckeisen, 1976).

Table 6 Examples of protolith structure qualifiers.

Sedimentary structure	Examples of qualifier
bed thickness	<i>thin-bedded, thick-laminated</i>
parting terms	<i>flaggy, blocky</i>
graded bedding	<i>graded-bedded, reverse-bedded</i>
cross-stratification	<i>cross-laminated</i>
bedding surface depositional structures	<i>dessication-cracked, rain-spotted</i>
soft-sediment deformation structures	<i>slumped, convolute-bedded</i>
chemical precipitation	<i>nodular, ooidal</i>
biogenic structures	<i>bioturbated, stromatolitic</i>

Table 7 Colour index qualifiers.

Qualifier	Colour index = volume per cent of mafic minerals
<i>leucocratic</i>	0 to 35%
<i>mesocratic</i>	35–65%
<i>melanocratic</i>	> 65%

Colour index terms should be used only for meta-igneous rocks.

REFERENCES

- BUCHER, K, and FREY, M. 1994. *Petrogenesis of metamorphic rocks*. 6th edition. (Berlin, Heidelberg: Springer-Verlag.)
- CARSWELL, D A. 1990. Eclogites and the eclogite facies. 1–13 in *Eclogite facies rocks*. CARSWELL, D A (editor). (Glasgow and London: Blackie.)
- FREY, M. 1987. Very low-grade metamorphism of clastic sedimentary rocks. 9–58 in *Low temperature metamorphism*. FREY, M (editor). (Glasgow and London: Blackie.)
- FREY, M, and KISCH, H J. 1987. Chapter 1 Scope of subject. 1–8 in *Low temperature metamorphism*. FREY, M (editor). (Glasgow and London: Blackie.)
- GILLESPIE, M R, and STYLES, M T. 1997. BGS Rock Classification Scheme Volume 1 Classification of igneous rocks. *British Geological Survey Research Report*, RR97–2.
- 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*, RR99–3.
- HARKER, A. 1956. *Metamorphism*. 362pp. (London: Methuen.)
- HIGGINS, M W. 1971. Cataclastic rocks. *Geological Survey Professional Paper*, No. 687.
- KISCH, H J. 1991. Illite crystallinity: recommendations on sample preparation, X-ray diffraction settings and interlaboratory standards. *Journal of Metamorphic Geology*, Vol. 9, 665–670.
- LE MAITRE, R W (editor). 1989. A classification of igneous rocks and glossary of terms. *Recommendations of the IUGS subcommission on the systematics of igneous rocks*. 193pp. (Oxford: Blackwell.)
- MEHNERT, K R. 1968. *Migmatites and the origin of granitic rocks*. 393pp. (Amsterdam: Elsevier.)
- PHILPOTTS, A R. 1960. Principles of igneous and metamorphic petrology. 498pp. (New Jersey: Prentice Hall.)
- SEDERHOLM, J J. 1907. Om granit och gneis. *Bulletin Commission Géologique Finlande*, No. 23.
- SIBSON, R H. 1977. Fault rocks and fault mechanisms. *Journal of the Geological Society of London*, Vol. 133, 191–213.
- STRECKEISEN, A. 1976. To each plutonic rock its proper name. *Earth Science Reviews*, Vol. 12, 1–33.
- WINKLER, H G F. 1979. *Petrogenesis of metamorphic rocks*. 348pp. (New York: Springer-Verlag.)
- WINKLER, H G F, and SEN, S K. 1973. Nomenclature of granulites and other high grade metamorphic rocks. *Neues Jahrbuch. Mineralogie. Monatshefte*, No. 9, 393–402.
- YARDLEY, B W D. 1989. *An introduction to metamorphic petrology*. 248pp. (London: Longman.)

APPENDIX: LIST OF APPROVED ROOT NAMES

Meta- prefix on any approved root name in the sedimentary and igneous rock classification schemes.

	Section		Section
Amphibolite	6.1	Metavolcaniclastic-mudstone	4
Blastomylonite	7.3	Metavolcaniclastic-rock	4
Broken Rock	7.1	Metavolcaniclastic-sandstone	4
Calcsilicate-rock	3.2.3	Mylonite	7.3
Cataclasite	7.2		
		Ortho-amphibolite	5.2.2
Eclogite	6.2.2	Orthogneiss	5.3
		Orthogranofels	5.3
Fault-breccia	7.1	Orthoschist	5.3
Fault-gouge	7.1		
Fenite	8	Para-amphibolite	3.2.3
		Paragneiss	3.3
Gneiss	6.1	Paragranofels	3.3
Granofels	6.1	Paraschist	3.3
Greisen	8	Pelite	3.2.1
		Phyllonite	7.3
Hornfels	6.1	Protocataclasite	7.2
Hydrothermal-rock	8	Protomylonite	7.3
		Psammite	3.2.1
Marble	6.2.3	Pseudotachylite	7.4
Metacarbonate-rock	3.2.3		
Metafelsic-rock	5.2.1	Quartzite	3.2.1
Metafelsite	5.2.1		
Metamafic-rock	5.2.2	Rodinsite	8
Metamafite	5.2.2		
Metasedimentary-rock	3	Semipelite	3.2.1
Metasomatic-rock	8	Serpentinite	5.2.3
Meta-ultramafic-rock	5.2.3	Schist	6.1
Meta-ultramafite	5.2.3	Skarn	8
Metavolcaniclastic-breccia	4	Slate	6.1
Metavolcaniclastic-conglomerate	4	Ultracataclasite	7.2
		Ultramafite	5.2.3
		Ultramytonite	7.3

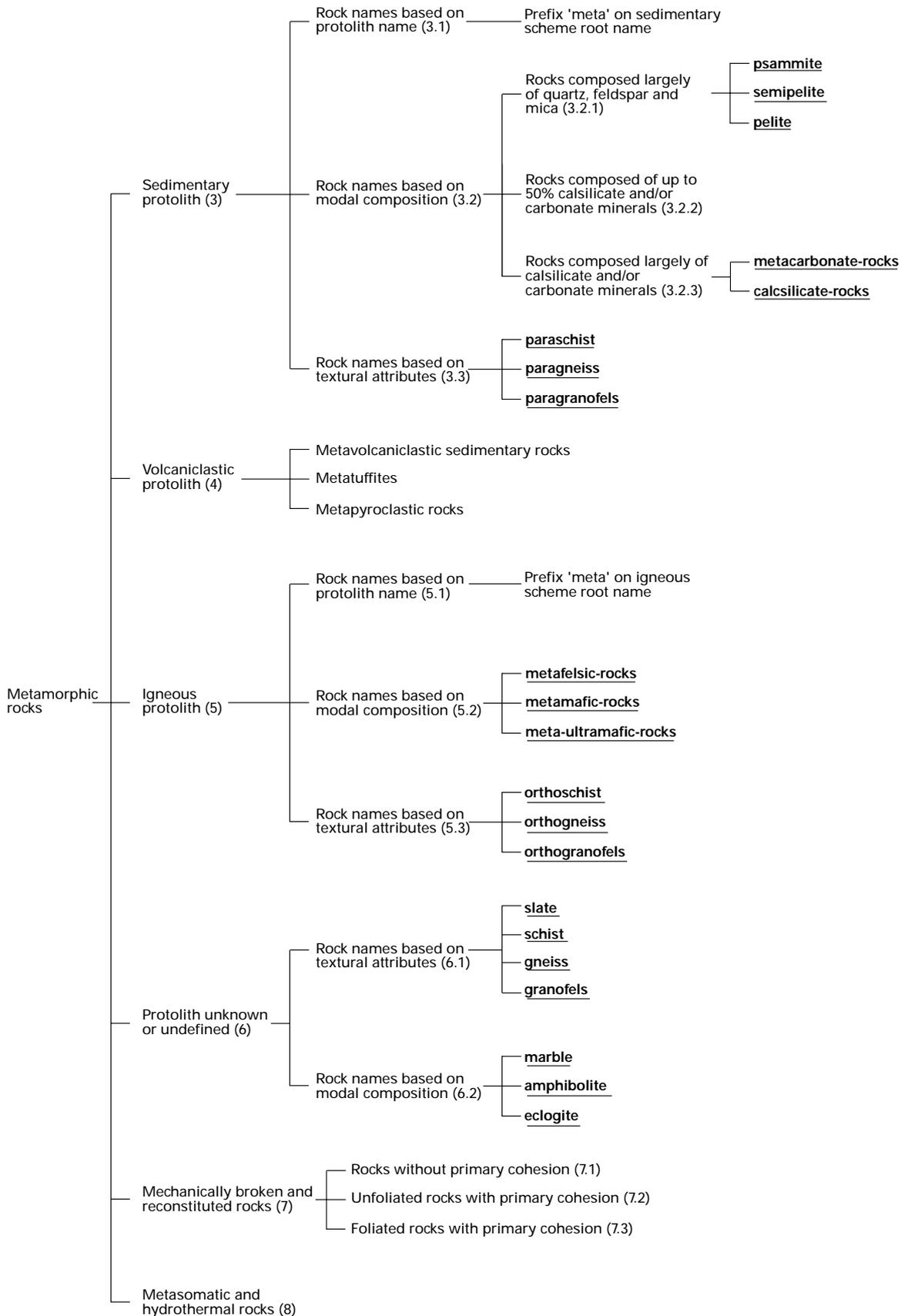


Figure 1 Classification scheme for metamorphic rocks. Numbers in brackets refer to relevant sections in text.

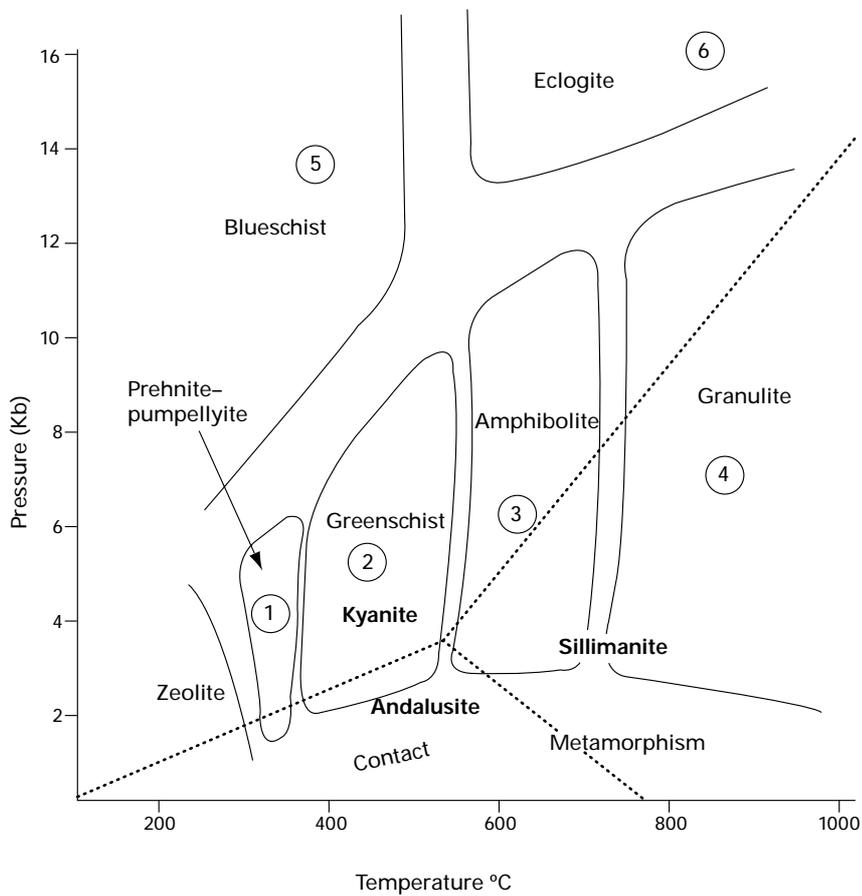


Figure 2 Temperature and pressure fields of various metamorphic facies and examples of diagnostic minerals and assemblages (after Bucher and Frey, 1994 and Yardley, 1989).

- 1 Laumontite, prehnite + pumpellyite, prehnite + actinolite, pumpellyite + actinolite, pyrophyllite.
- 2 Actinolite + chlorite + epidote + albite, chloritoid.
- 3 Hornblende + plagioclase, staurolite.
- 4 Orthopyroxene + clinopyroxene + plagioclase, sapphirine, osumilite, kornepupine.
NO staurolite, NO muscovite.
- 5 Glaucofanite, lawsonite, jadeitic pyroxene, aragonite. NO biotite.
- 6 Omphacite + garnet. NO plagioclase.

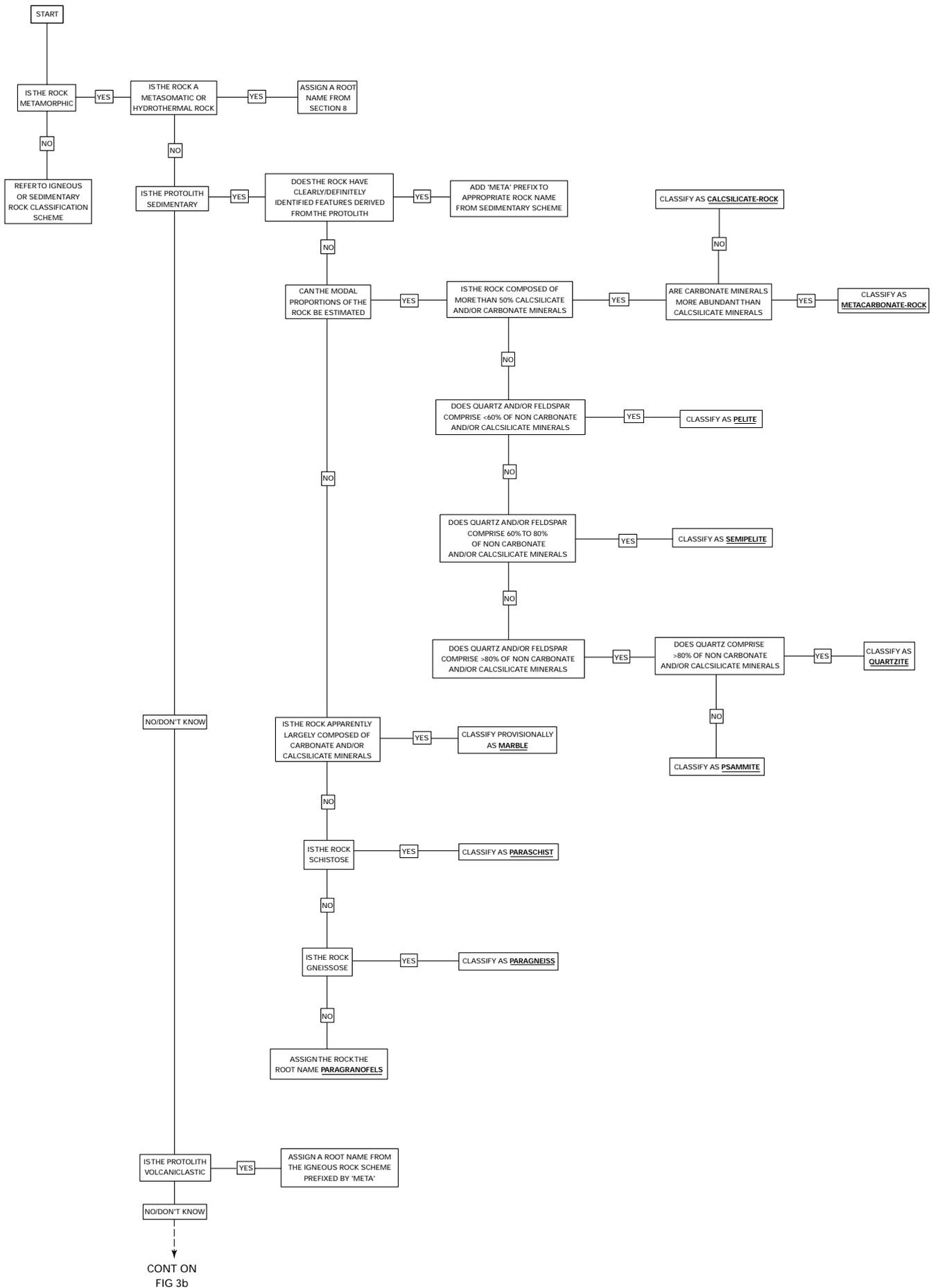


Figure 3a Flow diagram for assigning root names to metamorphic rocks.

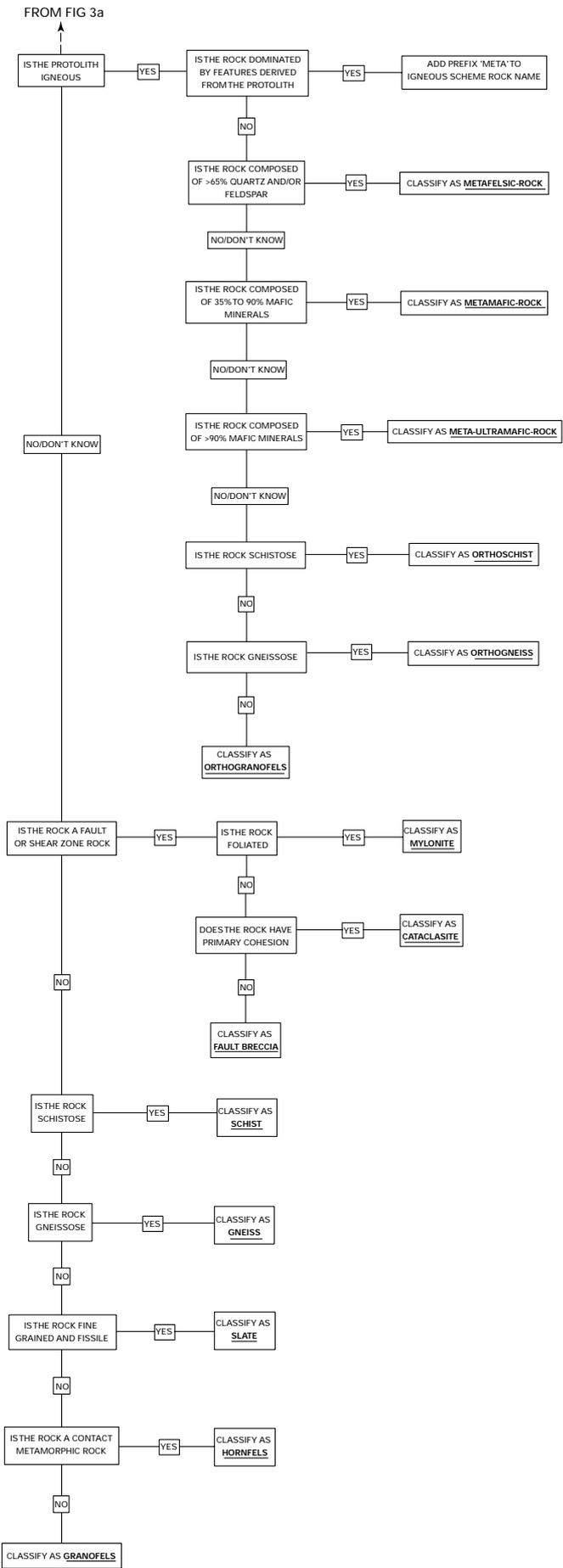


Figure 3b Flow diagram for assigning root names to metamorphic rocks.

Increasing metamorphism →					
Increasing deformation ↓	mudstone	<u>metamudstone</u>	<i>muscovite-biotite</i> <u>hornfels</u>	<i>cordierite-sillimanite</i> <u>hornfels</u>	
			<u>pelite</u>		<i>garnet-hypersthene</i> <u>granofels</u>
	<i>slaty</i> <u>metamudstone</u>	<i>slaty</i> <u>pelite</u>	<i>schistose</i> <u>pelite</u>		
	<u>slate</u>		<i>biotite-muscovite</i> <u>schist</u>	<i>garnet-biotite-muscovite-sillimanite</i> <u>gneiss</u>	<i>garnet-hypersthene</i> <u>gneiss</u>

Figure 4 Changing nomenclature with increasing metamorphism and deformation of a mudrock protolith.

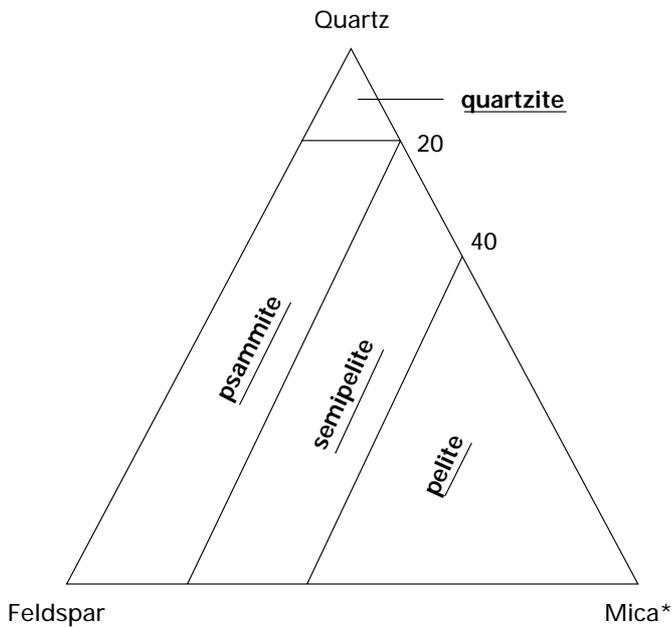


Figure 5 Subdivision of rocks composed largely of quartz ± feldspar ± mica.

* Mica includes all components other than quartz and feldspar.

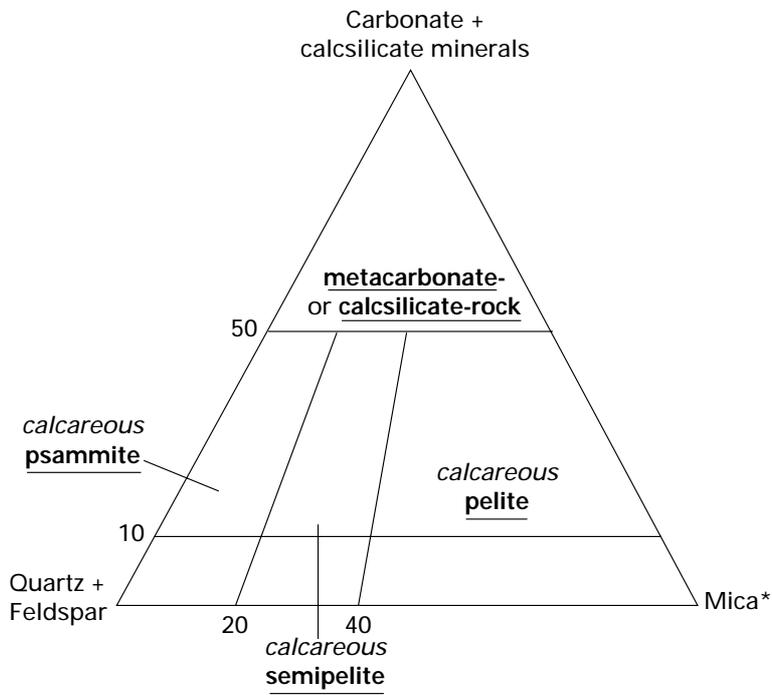


Figure 6 Subdivision of rocks composed of up to 50% carbonate and/or calcsilicate minerals and at least 50% quartz ± feldspar ± mica.

* Mica includes all components other than quartz, feldspar, carbonate and calcsilicate minerals.

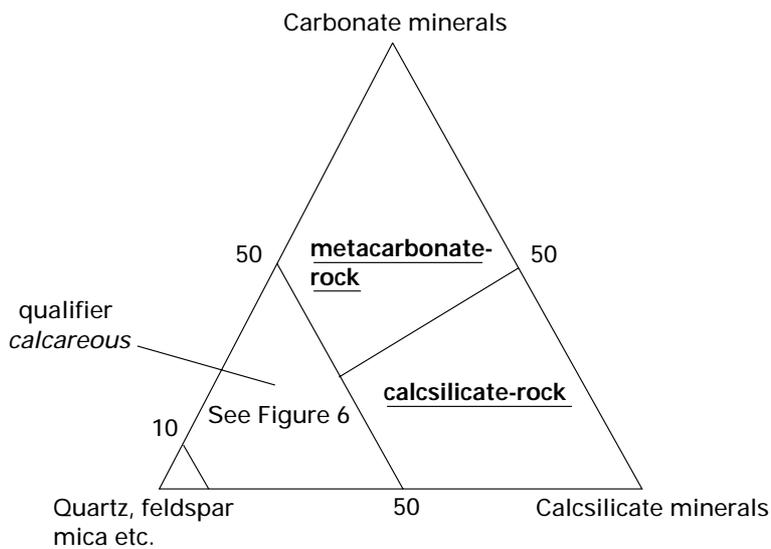


Figure 7 Subdivision of rocks containing more than 50% carbonate and calcsilicate minerals.

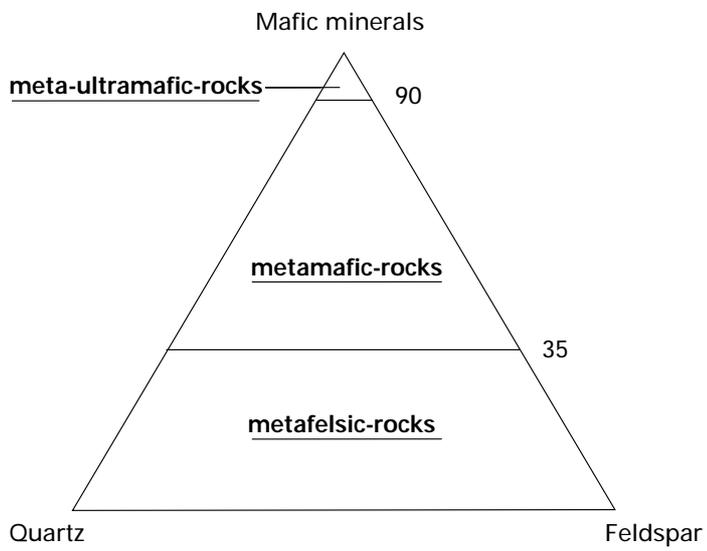


Figure 8 Meta-igneous rocks classified by modal composition.

Phi units	Clast or crystal size in mm. Log scale	Sedimentary clasts		Volcaniclastic fragments	Crystalline rocks, igneous, metamorphic or sedimentary	
-8	256	boulders	G	blocks and bombs	very-coarse-grained very-coarse-crystalline	
		cobbles	R			
-6	64	pebbles	A	lapilli		
			V			
-4	16	granules	E		coarse-grained coarse-crystalline	
			L			
-2	4					
-1	2					
0	1	very-coarse-sand	S	coarse-ash-grains	medium-grained medium-crystalline	
		coarse-sand				
1	0.5 (1/2)	medium-sand			A	
		2			0.25 (1/4)	fine-sand
3	0.125 (1/8)		very-fine-sand	D		
		5	0.032 (1/32)	silt	M	fine-ash-grains
U						
8	0.004 (1/256)	clay	D		cryptocrystalline	

Figure 9 British Geological Survey grain size scheme.