1 Introduction

Inzwischen herrscht in den mineralogischen Schriften eine erstaunliche Verwirrung in der Bestimmung dieser Gesteinsarten, und in dem Gebrauche der Benennungen.

Werner, 1786

(Meanwhile there prevails in mineralogical literature an astonishing confusion in the determination of rock types and in the nomenclature.)

This position described by Werner still has a certain resonance today. Despite many excellent works proposing classification schemes for metamorphic rocks, much of the terminology remains ill-defined and ambiguous. Practice differs across the international geological community and even such core words as 'gneiss' and 'schist' vary in their usage and meaning. To some extent this position reflects the fact that metamorphic rocks, and here we include metasomatic and diagenetic rocks, represent a vast range of lithologies and processes, overlapping with the nomenclature of sedimentary rocks on the one hand and with that of igneous rocks on the other. It also involves a range of processes from sedimentation and burial through deep-seated orogenesis to planetary collision.

Against this background the aim of the Subcommission on the Systematics of Metamorphic Rocks (SCMR) is to present a systematic nomenclature and to present an agreed definition of all related terms. The SCMR took its remit to cover all metamorphic rocks including quenched rocks not normally considered as igneous rocks, such as fulgurite, tektite and pseudotachylite. It also covered structural terms including fault structures and the systematics of impactites. The prime objective was to provide a scheme for naming and describing metamorphic rocks; no attempt has been made to cover the terminology relating to the detail or theory behind metamorphic processes, mineral chemistry, graphical presentations, etc.

It was agreed that rock names should, as far as possible, be applicable at the hand-specimen scale, that they should be based on non-genetic criteria and that these criteria should be measurable in the field or under the microscope. Nomenclature based on criteria such as rock chemistry or metamorphic grade was obviously unsuitable and a systematic scheme was devised based on compound names with structural root terms and mineral qualifiers (see Schmid *et al.*, Section 2.1). This scheme allows a systematic name to be given to any rock. However, it was accepted that there were many well-established specific names, such as *marble*, *amphibolite* and *eclogite*, that would have to remain and could potentially be used as alternative names. In addition many metamorphic rocks can be named by reference to their protolith. Thus, metamorphic rocks may potentially have up to three acceptable names, that is a systematic name, a specific name and a protolith-based name, for example *carbonate granofels – marble – metalimestone* or *hornblende-plagioclase schist – amphibolite – metabasalt*. The nomenclature scheme has to take account of this situation.

This book is accordingly structured in two main parts, the first dealing with the classification and nomenclature scheme, the second consisting of a glossary containing comprehensive definitions of all terms related to metamorphic terminology. The first part contains 12 sections: the first deals with the basis of the systematic scheme and how it should be used, the remainder deal with various specialist areas and discuss, as appropriate, the evolution of the terminology in these areas or the rationale that lies behind approved definitions. The second part is the glossary, which consists of around 1100 entries. It gives comprehensive definitions, etymology and source references, and categorizes the terms into three classes, namely: *recommended use, restricted use* and *obsolete* or *unnecessary*.

All the terms were fully researched and the source and significant references individually checked. In addition, all the principal terms were considered by the Study Groups. In some cases this involved intense debate and wide

Metamorphic Rocks: A Classification and Glossary of Terms. Recommendations of the International Union of Geological Sciences, eds. Douglas Fettes and Jacqueline Desmons. Published by Cambridge University Press.

consultation with the international community before a consensus was reached. It is hoped therefore that it will be accepted that these definitions are designed for international use and may differ in detail from established usage in some areas.

1.1 Guidelines on how to use the book

1. The **systematic scheme for naming a rock** is given in section 2.1. The basis of the scheme is given in subsections 2.1.1 to 2.1.7. The procedure for naming a rock is given in subsections 2.1.8 onwards. This includes a flow chart with accompanying guidelines and a table outlining the use of qualifiers.
2. The **specialist sections** (2.2–2.12) should be consulted for extra information. A list of approved terms (recommended and restricted) arranged by specialist subject is given in section 3.3 of the glossary, and this may be used to find out the **terminology related to a specialist subject**.
3. The **glossary** should be used for the definition, source references etc. of all terms. It contains summary lists of all approved terms arranged alphabetically (section 3.2) and by subject (section 3.3).
4. All **references** cited in the book are in a consolidated list at the end.

2 Classification and nomenclature scheme

2.1 How to name a metamorphic rock

ROLF SCHMID, DOUGLAS FETTES, BEN HARTE, ELEUTHERIA DAVIS and JACQUELINE DESMONS

2.1.1 Introduction

The usage of some common terms in metamorphic petrology has developed differently in different countries and a range of specialized rock names have been applied locally. The SCMR aims to provide systematic schemes for terminology and rock definitions that are widely acceptable and suitable for international use. This first section explains the basic classification scheme for common metamorphic rocks proposed by the SCMR, and lays out the general principles which were used by the SCMR when defining terms for metamorphic rocks, their features, conditions of formation and processes. Subsequent sections discuss and present more detailed terminology for particular metamorphic rock groups and processes.

The SCMR recognizes the very wide usage of some rock names (for example, amphibolite, marble, hornfels) and the existence of many name sets related to specific types of metamorphism (for example, high P/T rocks, migmatites, impactites). These names and name sets clearly must be retained but they have not developed on the basis of systematic classification. Another set of metamorphic rock names, which are commonly formed by combining mineral names with structural terms (for example, quartz-mica schist, plagioclase-pyroxene granofels) is capable of being used in a systematic way. The SCMR recommends that such compound names are systematically applied using three root names (schist, gneiss and granofels), which are defined solely by structural criteria. Such systematic names are considered particularly appropriate when specific names are unknown or uncertain. A flow chart on 'How to name a metamorphic rock' enables any earth scientist to assign a name to a metamorphic rock, following this scheme. The section further gives guidelines on the appropriate use of these systematic names and on the use of possible alternatives based on the protolith and other specific names.

PRINCIPLES OF NOMENCLATURE

A nomenclature scheme consists of defined terms and the rules governing their use. In erecting a nomenclature scheme the SCMR was guided by the following underlying principles.

(a) The scheme must provide a consistent set of names to cover the spectrum of rock types and their characteristics without any terminology gaps.
(b) The scheme must ensure that all users can apply the same criteria to give any rock or its characteristic features the same name. These names should be understood uniquely and without ambiguity.

In any system of nomenclature a number of characteristic features or parameters are used to divide rocks into groups or sets, and the criteria for such divisions or subdivisions are fundamental to the terminology. The SCMR decided (see Schmid & Sassi, 1986) that the above principles would only be fulfilled if the criteria for any specific division/subdivision were defined using only one type of characteristic feature. For example, the criterion for a specific division/subdivision might be a particular feature of mineral content or structure, but it should not be both mineralogical and structural. In a series of divisions/subdivisions in a classification scheme, structure and mineral content may be applied at different stages, but they should not be applied simultaneously.

At a given stage of division/subdivision a set of rock groups may be recognized in a classification scheme, and these will be given group names (or **root names** in the case of major divisions).

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Such names form a fundamental element of the classification. The development of a nomenclature scheme in this way follows that used for the classification of igneous rocks (Le Maitre, 1989, 2002).

One of the main purposes of this section is to propose that a simple but comprehensive terminology for common metamorphic rocks may be based on their division into three major groups on the basis of their structure (as seen in hand specimen). These three groups are given the structural root names: **schist**, **gneiss** and **granofels**. In conjunction with the recognition of a systematic terminology of this type, the SCMR has also recognized a number of non-systematic names or *specific names*, which may be used as alternatives to the systematic names or to impart additional information. A flowchart and guidelines for the use of the nomenclature scheme are presented below.

2.1.2 Potential bases for the classification of metamorphic rocks

Ignoring characteristics like magnetic or electrical properties or age, which can rarely be determined or even inferred without special equipment, the major features of metamorphic rocks that can be widely used for classification are:

(a) the minerals present
(b) the structure of the rock
(c) the nature of the rock prior to metamorphism
(d) the genetic conditions of metamorphism (usually in terms of pressure and temperature, with or without deformation).
(e) the chemical composition of the rock.

Of the above, (a) and (b) form the most obvious major parameters for rock classification or nomenclature, and would also often be involved indirectly in classifications based on (c) and (d). The variety of minerals present would necessarily also provide much basic information for (e) if this were not to depend on the use of specialized techniques for chemical analysis.

Examination of metamorphic rocks shows great mineralogical, structural and chemical diversity. Their chemical and mineralogical diversity results in a large part from the fact that they may be formed from any pre-existing igneous or sedimentary rock. Added to this diversity of rock types subjected to metamorphism, there are wide variations in the conditions (temperature, pressure, deformation) of metamorphism itself; and as a consequence the metamorphic rocks derived from only one igneous or sedimentary precursor may show an extensive range of mineral assemblages and structures.

In contrast to igneous rocks, the large range in mineral content and chemistry for even common metamorphic rocks means that schemes of classification cannot be devised using a small number of parameters. Thus there are no simple metamorphic equivalents to classification plots based on SiO_2 vs. $Na_2O + K_2O$, or quartz, feldspar, feldspathoid ratios, as used by igneous petrologists (e.g. Le Maitre, 1989, 2002). The only way of reducing the number of mineralogical variables in metamorphic rocks to a small number of defining parameters is by inferring conditions of genesis (usually pressure–temperature conditions of formation). The metamorphic facies classification is very useful in this context, but assignment of facies to specific genetic conditions (e.g. pressure and temperature) rests on a number of assumptions and is susceptible to changes in knowledge and understanding. It also essentially ignores the structure of the rocks concerned. Furthermore, although facies terms are based on mineralogical changes, they do not imply that rocks of all chemical compositions have different mineral assemblages in each facies; nor do they imply that rocks of a particular chemical composition must have constant mineral content within a particular facies. Thus a facies terminology does not match one-to-one with the actual mineral assemblages seen in all rock compositions.

Following the precedents set by most other rock classification schemes, the SCMR decided, therefore, that the most comprehensive and applicable nomenclature scheme should be based on the following two principles:

1. Metamorphic rocks should be named, in the first instance, on **directly observable features, preferably at the mesoscopic scale, but where necessary at the microscopic scale**. (Thus the

definitions of rock terms recommended by the SCMR refer, as far as possible, to features observable in hand specimen, making allowance for the possible need for microscopic examination in some cases.)

2. **Genetic terms should not be the basis of primary definition of rock types**. (Genetic terms are clearly useful in genetic discussions, but should only be applied to a rock if the genetic process concerned is clearly defined and criteria for its recognition are clearly stated.)

The directly observable features of all rocks are their mineral content and structure. These have been the basis for common rock names in the past and, following the principles given above, are the primary basis for the metamorphic rock names recommended by the SCMR. (In some instances this allows for the use of a protolith term in describing and defining metamorphic rocks; see below.)

2.1.3 Previous terminology largely based on mineralogical and structural characteristics

COMPOUND NAMES

Metamorphic petrologists have traditionally coped with the variety and complexity of mineral content and structure, as outlined above, by using a series of compound hyphenated names (e.g. quartz-mica schist, lawsonite-glaucophane schist) in describing metamorphic rocks. The final or root word in such names may be based on structural, mineralogical or protolith characteristics (e.g. garnet-mica-quartz *schist*, garnet-biotite *amphibolite*, garnet-pyroxene *metabasic rock*, respectively), and the mineralogical prefixes provide further information on the mineral content of the rock being described. These compound terms have provided for an immense flexibility of description and naming of metamorphic rocks, and the SCMR has seen them as having considerable merit. However, their widespread usage has not usually been systematic, and the SCMR strongly recommends that they should now be used in a systematic way (see below) to provide a wide-ranging system of nomenclature for metamorphic rocks in general.

SPECIFIC ROCK NAMES AND NAME SETS

The existing terminology for metamorphism and metamorphic rocks includes many names based on specific mineralogical and/or structural and/or other criteria. These have been called *specific names* by the SCMR. Such names usually have very precise connotations, but have not been developed in a systematic way to embrace the whole range of metamorphic rocks: the exception being the metamorphic facies classification that, as discussed above, is not appropriate for a descriptive rock nomenclature.

Some of these specific names have become extremely widely used for common rock types. Examples of such terms are: amphibolite (for rocks largely made of amphibole and plagioclase); quartzite (in which quartz is by far the major constituent); marble (in which carbonate minerals predominate); slate (for a fine-grained rock with a well-developed regular fissility or schistosity). Amphibolite and slate illustrate names based on mineral content and structure respectively. The terms quartzite and marble are essentially mineralogical, as indicated, but it has also often been assumed that such rocks have equigranular or granofelsic structures.

Most of the specific terms including some of those just mentioned may be subdivided into groups associated with individual types of metamorphism (high P/T metamorphism, impactites, fault and shear rocks, migmatites, carbonate rocks, etc.). These groups have been called *specific name sets* by the SCMR. Many of the names making up these sets have a connotation for the context or genesis of the rock (ultramylonite, anatexite, skarn, etc.) and may provide important detail or additional information on these features.

As such, these specific terms are a fundamental part of metamorphic nomenclature. However, from the viewpoint of the development of an ordered system of classification, and the guiding principles outlined above, specific terms present a major problem. Specific names have not been developed into a general systematic framework that embraces the whole range of metamorphic rocks, even though some name sets, related to types of metamorphism, may

possess a systematic structure – for example mylonites, which may be subdivided into protomylonite, mesomylonite, ultramylonite, etc. Despite this lack of systematization, it has to be recognized that the specific terms are an integral part of metamorphic terminology and that allowance for their use has to be made in any scheme of common nomenclature. This fact has been recognized by the SCMR which has attempted to produce a definitive list of specific names and has set up guidelines on their use (see below).

PROTOLITH NAMES

Metamorphic rock names based on protoliths (the lithological compositions of rocks before metamorphism) are very useful for two reasons:

(a) Determination of the original nature of the rock is often a fundamental consideration in establishing geological history.
(b) In weakly metamorphosed rocks and particularly those subjected to little deformation, the structural and mineralogical features of the protoliths may still be the principal observable features.

In the second instance, use of a protolith-based name may be a more appropriate name for a rock than one emphasizing metamorphic characteristics. Metaconglomerate (for a metamorphosed conglomerate) is an obvious example where the structure of the protolith is usually still the most obvious characteristic of the rock (and in any case the metamorphic mineral content of such a rock will change with the bulk chemical composition of each pre-existing clast).

The use of protolith names in the nomenclature of metamorphic rocks is very straightforward, and largely consists of prefixing the name of the protolith with 'meta' or 'meta-' (e.g. metagranite, metabasalt, meta-arkose). As we have seen, protolith terms may be used in compound names and carry mineralogical prefixes (e.g. biotite metasandstone, garnet metabasalt) or structural prefixes or qualifiers (e.g. schistose garnet metabasalt).

Protolith-based names are clearly useful in cases where the characteristics of the metamorphic rock largely reflect those of the protolith and the nature of the protolith can be fully determined.[1]

However, this is usually only the case in rocks of low metamorphic grade and/or those that have been only weakly deformed. In most metamorphic rocks applying the protolith name is not a matter of direct observation but is a matter of inference after its mineral content and microstructure have been taken into account, with the mineral content serving as a guide to bulk chemical composition when a chemical analysis is not available. Thus in many cases protolith names do not reflect the principal minerals and structural features of the rocks under observation.

It follows that although protolith terminology for metamorphic rocks is clearly very useful and straightforward, and the SCMR recommends its continued usage (see below), it provides a poor basis for a comprehensive and mainly descriptive terminology.

2.1.4 Systematic classification scheme using root names

The sets of names referred to above clearly provide a means for naming metamorphic rocks and allow for flexibility in nomenclature which is necessary given the diverse structural, mineralogical and protolith (chemical) nature of metamorphic rocks as a whole. **However, none of them in their present form provides for a systematic classification of common metamorphic rocks using a simple set of criteria**.

To tackle this problem, the SCMR suggests the adoption of a standard procedure for applying compound hyphenated names. As discussed above, this type of name allows for considerable flexibility, but the final or root term may be based on diverse criteria. Standardization on the basis of mineral content is impossible without a huge array of root names, but standardization

[1] It is important in using names such as metabasalt and metagabbro that the grain-size criteria of the protoliths can be fully established.

on the basis of structural terms using a single criterion can be achieved quite simply.[2]

USE OF THE TERMS SCHIST, GNEISS AND GRANOFELS

Following widespread usage in the English language, three terms essentially cover the principal varieties of structure found in metamorphic rocks, particularly as seen in hand specimen (and therefore easily applicable). These three terms are *schist, gneiss* and *granofels*. The SCMR proposes that these terms are used as the fundamental *root terms* in the adoption of a systematic terminology. It is proposed that these terms have **only a structural connotation, with no mineralogical or compositional implication**.[3] Essentially the terms reflect the degree of fissility or schistosity shown by the rock. Their definitions (see also glossary and Brodie *et al*., Section 2.3) derive from the recommended SCMR definition of 'schistosity', which is as follows.

Schistosity: A preferred orientation of inequant mineral grains or grain aggregates produced by metamorphic processes. A schistosity is said to be *well developed* if inequant mineral grains or grain aggregates are present in a large amount and show a high degree of preferred orientation, either throughout the rock or in narrowly spaced repetitive zones, such that the rock will split on a scale of less than one centimetre. A schistosity is said to be *poorly developed* if inequant mineral grains or grain aggregates are present only in small amounts or show a low degree of preferred orientation or, if well developed, occur in broadly spaced zones such that the rock will split on a scale of more than one centimetre.

Thus, according to the SCMR scheme, if the schistosity in a metamorphic rock is well developed, the rock has a *schistose structure* and is termed a *schist*. If it is poorly developed, the rock has a *gneissose structure* and is termed a *gneiss*, and if schistosity is effectively absent the rock has a *granofelsic* structure and is termed a *granofels*.

It should be noted that each of these structural root terms will cover a number of specific rock names. Thus, the term 'schist' encompasses a number of names for rocks that possess a well-developed schistosity (as defined), for example, slate and phyllite. Similarly, the term granofels encompasses subsidiary names for rocks in which schistosity is essentially absent, for example hornfels.

Note: see below for the relative use of systematic names and specific names.

GENERAL PROCEDURE FOR NAMING A ROCK USING STRUCTURAL ROOT TERMS

In the system advocated by the SCMR the above fundamental or root terms (based on structure alone) are placed at the end of compound hyphenated names of the type described previously. The considerable diversity of mineralogical names found in metamorphic rocks can then be conveyed by the use of mineral names as prefixes to the root structural term (for example, staurolite-mica-quartz schist, plagioclase-pyroxene granofels, garnet-hornblende-plagioclase gneiss), the

[2] For the purposes of this discussion the term 'structure' refers to mesostructure or the structure of a rock at hand-specimen scale.

[3] The SCMR recognized that the use of the term 'gneiss' in a purely structural sense might prove a difficult concept to some geologists. For example, although the name has evolved in English language usage to imply a type of structure, for many non-English users the name also has mineralogical implications, in particular the presence of feldspar ± quartz. However, the suitability of the name as a structural root term to denote a poor fissility was very attractive and the SCMR decided to accept the English language meaning. This decision was taken after inquiry among the Working Group members, partly on the basis that the SCMR's recommendations were being made for English language use only, and also, critically, it was noted that all rocks currently considered as 'gneisses' would still be defined as such. A complementary concern was that a purely structurally based definition should not include rocks that in established practice could never be considered as gneisses, for example finely banded metasandstones and metamudstones at low/medium metamorphic grade. Although the SCMR accepted this difficulty, it was felt that in practice an adequate guideline could be provided to encourage the use of protolith-based terms to cover these limited cases. These points and the evolution of the terms 'schist' and 'gneiss' are further discussed in the paper on structural terms (Section 2.3), to which the interested reader is referred.

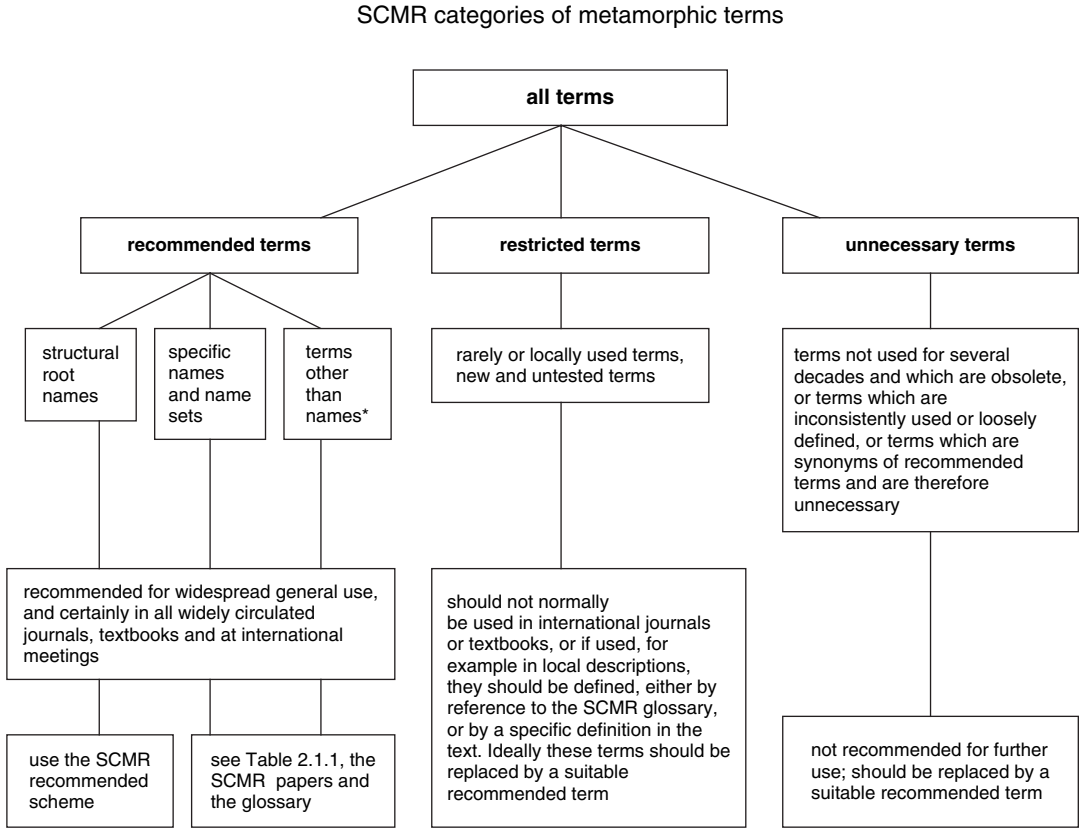

Fig. 2.1.1 Categories of rock terms as defined by the SCMR. The classification of a term as 'recommended', 'restricted' or 'unnecessary' is given in the SCMR glossary. * 'Terms' comprise the vocabulary of metamorphic nomenclature; 'names' are those terms used for the types of rock; 'terms other than names' therefore comprise all adjectives, process terms, etc.

mineral names being arranged in order of increasing modal abundance (see below).

Thus any metamorphic rock may be named by using one of the three terms to convey the basic structure, whereas the mineralogical features are given by prefixing the structural term with the names of the appropriate mineral constituents.

This nomenclature scheme for metamorphic rocks is set out in the lower part of the flowchart in Fig. 2.1.2. A compound hyphenated name of the type recommended may always be applied and allows a systematic set of names for petrographic descriptions. The only complexity to this simple scheme is the need to allow for the use of the specific names and name sets, described above, which have widespread usage.

2.1.5 Categories of rock terms: existing and proposed

In parallel with adopting the structural root name system as a comprehensive nomenclature, the SCMR has examined and categorized all the rock terms used in metamorphic nomenclature. Three classes of terms are recognized, namely 'recommended terms', 'restricted terms' and 'unnecessary terms' (Fig. 2.1.1). The **recommended rock names** are the basis of the SCMR nomenclature scheme.

They comprise the systematic **root names** and a comprehensive range of **specific names**.

THE RECOMMENDED SPECIFIC NAMES

In selecting the recommended specific names and name sets for use in the nomenclature scheme the SCMR relied on the work of its various Study Groups who established and defined the specific names and sets of names for their respective subjects. The conclusions of the Study Groups are contained in the following sections, which form part of the products of the SCMR. These sections are an essential element of the nomenclature scheme: they contain a range of terms related to their area of study (e.g. the specific name sets), background information on the terms, and figures and subsidiary flowcharts.

The recommended specific names range from particularly well-established terms for common rock types (e.g. amphibolite, marble, eclogite) to terms that describe relatively uncommon rock types or features of rocks (e.g. arterite, mesocataclasite). The latter are most likely to be used to give information when the context of the rock is known, whereas the former names may provide concise and widely acceptable alternatives to the structural root names (e.g. marble in place of calcite granofels).

Examples of well-established specific names, which may commonly be given preference over the equivalent structural root names, are listed in Table 2.1.1. The list is presented for information only; it is not intended to be exhaustive.

Table 2.1.1 *Examples of some of the most common specific names (definitions and full list of names by subject are given in the glossary).*

Such names would commonly be given precedence over the equivalent structural root names: see text for discussion.

Amphibolite	Greenschist	Phyllite
Calc-silicate rock	Hornfels	Quartzite
Cataclasite	Marble	Serpentinite
Eclogite	Migmatite	Skarn
Granulite	Mylonite	Slate

As discussed above, the specific names may also be grouped into *specific name sets* (e.g. migmatites, fault rocks) linked to individual types of metamorphism (see the other sections in this volume).

2.1.6 The SCMR glossary

During the course of its work the SCMR has sought to compile a comprehensive glossary of all metamorphic rock terms, structural terms and a few process-related terms, which will hopefully be of international usefulness. The list contains about 1100 entries. Each entry gives the approved SCMR definition, the first usage wherever possible, the etymology and the categorization of the terms as 'recommended', 'restricted' or 'unnecessary'. The basis of the categorization of the terms is given in Fig. 2.1.1. That is, 'recommended terms' are those that are required for an internationally applicable nomenclature; 'restricted terms' are those that are only used locally or rarely and require further definition if used; and 'unnecessary terms' are those that are no longer required.

2.1.7 Recommended guidelines for naming a rock

The procedure for giving a systematic name to any metamorphic rock, based on structural root terms, is given above and in the lower part of Fig. 2.1.2 starting with step 3. It is understood that this process does not encompass the use of specific rock names, which form an important aspect of the overall nomenclature scheme and which is outlined in the upper part of the flowchart, starting at step 1. Specific names may commonly provide a more concise, refined and detailed terminology than is available with the systematic structural root terms. In addition, it is recognized that under particular circumstances a protolith name may be the most descriptive name for a metamorphic rock.

It follows from these points that a single metamorphic rock may have up to three correct names, that is, a protolith, non-systematic/specific and systematic/structural root name

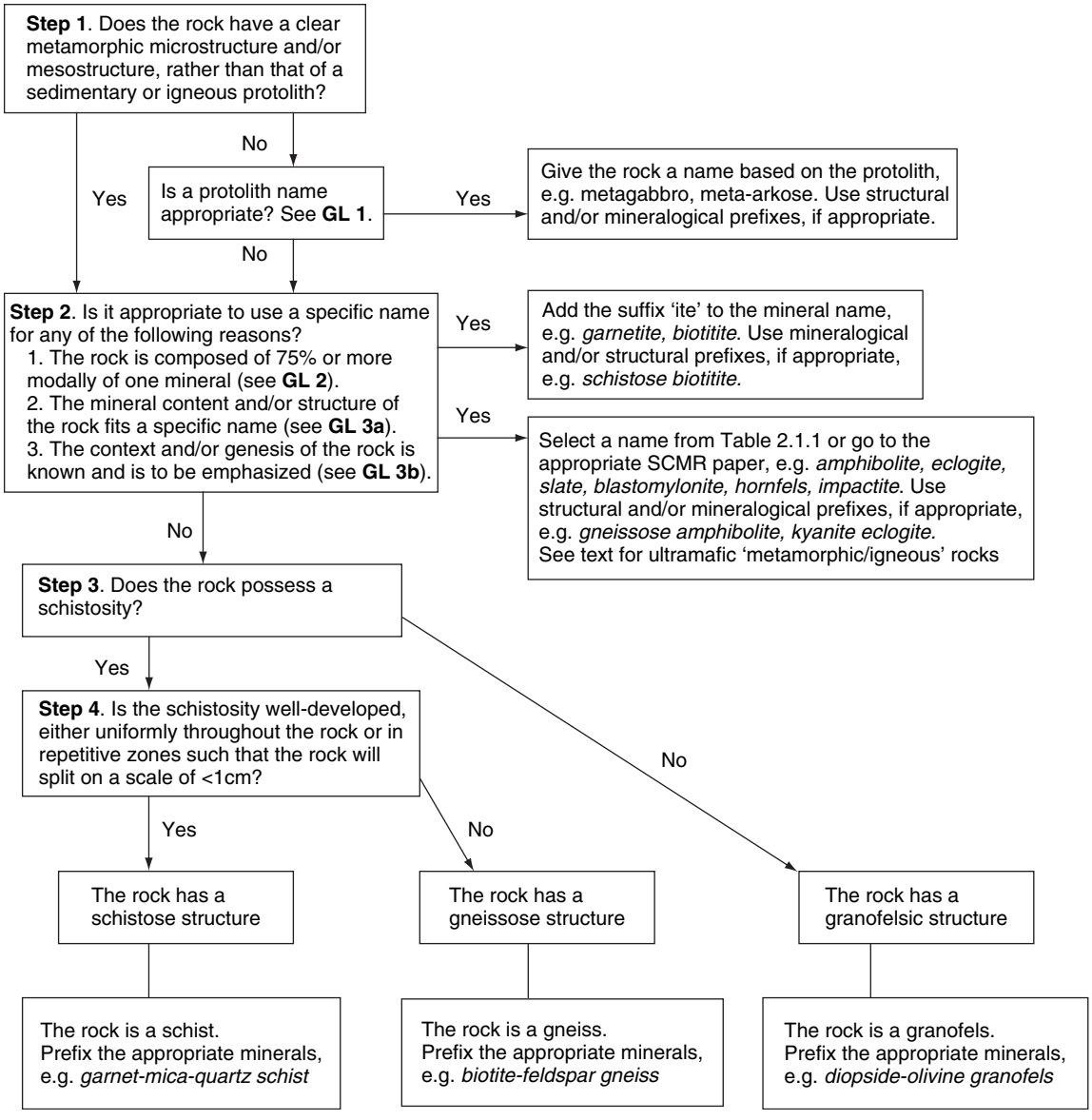

Fig. 2.1.2 How to name a metamorphic rock.
The upper part of the chart (steps 1 and 2) outlines the procedure for deriving a non-systematic name; the lower part (steps 3 and 4) outlines the procedure for deriving a systematic structural root name (use only the lower part to go directly to a structural root name).

(e.g. metabasalt, amphibolite, hornblende-plagioclase gneiss or metalimestone, marble, calcite granofels). The choice of which name to use depends partly on the information available to the user and partly on which aspect the user may wish to emphasize.

It is an underlying principle of the SCMR recommendations that the systematic nomenclature scheme exists in parallel with the use of non-systematic names (specific names, protolith-based names, etc.). The systematic nomenclature scheme is intended to complement, not replace,