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Classification of igneous rocks

M R Gillespie and M T Styles

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British Geological Survey
Keyworth
Nottingham NG12 5GG
UK

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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 NG12 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 igneous 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 igneous 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 objective of this classification scheme is to introduce a system of nomenclature for igneous rocks that is based as far as possible on descriptive attributes. 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 igneous rocks to be named adequately using a relatively small number of **root names** with or without **qualifier terms**.

The basic classification system established by the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks (referred to hereafter as IUGS) (Le Maitre et al., 1989; Le Bas and Streckeisen, 1991; Woolley et al., 1996) is adopted here; parts of the text and several diagrams have been taken from these works. However, this scheme contains many refinements and changes to the IUGS recommendations, where it was considered necessary and appropriate, and the resulting scheme is more logical, consistent, systematic and clearly defined. It is hoped that the scheme will receive widespread support and will be adopted by a broad spectrum of geologists.

A genetic approach to classification was not adopted because it is less informative about the mineral/ chemical composition of the rock, the information required to make an interpretation of rock genesis is not always available to the geologist, and ideas about petrogenesis change with time. Names that have a genetic meaning or connotation, and also those names which are more suitable for describing rock units rather than individual rock types, have been excluded wherever possible. However, in some cases a genetic aspect to rock classification and nomenclature is unavoidable, and attention is drawn to these exceptions at appropriate points in the text (see Section 8.2 *Rock names based on processes*).

Using the descriptive approach recommended here, it should be possible to classify and name any igneous rock without knowledge of its field setting and without making assumptions about its mode of origin.

One of the main challenges in constructing this scheme was to make it equally appropriate to geologists working in the field and in the laboratory. The level and type of information available to geologists in these environments varies considerably. The hierarchical approach allows the user to assign a name to any igneous rock at the level of the hierarchy most appropriate to the type and level of information available to them. In general, rock names in the lower and middle levels (Levels 1 to 7) of the hierarchy will be used by geologists in the field, while those in the higher levels will be used where more detailed petrographical and/or geochemical information is available.

There are drawbacks to the scheme. For example the approach to rock nomenclature that is recommended here can result in rock names that are longer than equivalent ‘traditional’ terms. Also, guidelines are introduced for using qualifier terms and hyphens in constructing rock names, and users will need to familiarise themselves with these (see Section 2.1 *Constructing a rock name* and 2.2 *Use of hyphens*).

As with all previous attempts to create a taxonomy for igneous rocks, it has not been possible to keep the scheme wholly logical. Despite significant improvements, there are still instances where the range and complexity of natural processes has produced igneous rocks that defy a logical system of classification. In the future, refinements to the scheme will be made with advances in rock characterisation methods and a better understanding of igneous processes.

1.1 Principles behind the classification scheme

i The term ‘igneous rock’ is taken to mean ‘igneous or igneous-looking’. Igneous rocks may have crystallised from magmas or may have formed or been modified by eruptive, deuteric, metasomatic or metamorphic processes. Igneous rocks include fragmental rocks formed as a direct result of volcanic processes. Arguments as to whether a rock is igneous, sedimentary or metamorphic become irrelevant in this context

ii Classification is based on descriptive attributes, such as composition and grain size, not interpreted attributes. The classification is non-genetic as theories on genesis can change with time and fashion but observed or measured parameters should stay the same.

iii Classification is based on what rocks are, not what they might have been.

iv In general, it should be possible to classify a rock from features observable in a hand specimen or thin section; it should not be necessary to see field relationships. The main groups of rocks can be classified without recourse to petrographical or geochemical analysis. If such features cannot be determined due, for example, to the presence of glass or to the very fine-grained nature of the rock, then other criteria such as chemical composition are used, where appropriate.

v Types, or groups of rock types, are defined by boundary conditions such as grain size and proportions of certain minerals or clasts. These boundaries generally follow natural or well-established groupings to make application of the scheme easier and acceptable to a wide range of geologists.

vi Well-established rock names are retained wherever possible to avoid drastic changes of nomenclature and ensure widespread adherence to the scheme, though some terms are defined more rigorously. Where many names have been used in the past for a particular rock type a preferred name has been chosen and the use of synonyms is discontinued.

vii The scheme is essentially hierarchical; the lower levels can be used by less skilled scientists or where little information is available, and the higher levels where more information is available.

viii Rock names are assigned using a system of approved root names and qualifier terms.

ix Hyphens are used in rock names to improve clarity and to assist searching by computers.

There are, of course, occasions when strict adherence to these principles is not possible. For example, there are many cases where igneous rocks have a strong superimposed metamorphic fabric. They may not *look* igneous, however in the context of a particular study a geologist may consider that an igneous root name with appropriate qualifier terms is more appropriate than a metamorphic rock name. A basalt that has been buried and metamorphosed such that a visible fabric has been superimposed could be named *schistose* **metabasalt** using the BGS igneous or metamorphic schemes.

Strict adherence to Principle (ii) could also lead to differences to common usage in some cases. For example, fine-grained rocks from the chilled margins of a large sill should be named according to the 'fine-grained' scheme. Basalt and gabbro could be part of the same body and occur adjacent to each other at outcrop. Allowances must be made for special cases such as this.

1.2 Changes to the IUGS recommendations

The IUGS recommendations for igneous rock classification, though widely accepted, are not cast in stone but are under constant review; sections are revised or changed completely as discussion continues and new agreements are reached by the Subcommission. Contact with the current IUGS chairman has been established and will be maintained so that the BGS classification scheme can be updated where necessary to reflect future changes to the IUGS scheme.

The scheme outlined here broadly follows the IUGS recommendations of Le Maitre et al. (1989), Le Bas and Streckeisen (1991) and Woolley et al. (1996), and adopts much of their basic taxonomy, however some of the terms used by the IUGS to denote the major classes of igneous rocks have been changed. The group name 'Volcaniclastic rocks and sediments' is preferred to the IUGS name 'Pyroclastic rocks and tephra' because the group includes rocks and deposits that are volcaniclastic but not necessarily pyroclastic. The terms 'plutonic' and 'volcanic', as defined and used by the IUGS, are basically descriptive and distinguish essentially coarse-grained crystalline igneous rocks from essentially fine-grained crystalline igneous rocks. 'Plutonic' is often considered to be synonymous with 'deep seated', and 'volcanic' is considered synonymous with 'shallow', and to imply association with volcanism. The term 'volcanic' is also sometimes mistakenly taken to be synonymous with 'extrusive'. To eliminate the potential confusion caused by these terms, the descriptive, non-genetic terms 'coarse-grained crystalline' and 'fine-grained crystalline' are used in this scheme in place of 'plutonic' and 'volcanic', respectively. Other, less fundamental, changes to the IUGS recommendations are noted at appropriate points in the text.

1.3 Using the hierarchy

The BGS hierarchical rock classification scheme has up to ten levels which can be used to classify virtually all geological materials. Figure 1 illustrates the lower levels of this system.

At Level 1 'All rocks and deposits' are grouped together.

The four principal types of geological materials are placed at Level 2 — 'Artificial and natural superficial deposits', 'Sedimentary rocks and sediments', 'Igneous rocks and sediments' and 'Metamorphic rocks'. The divisions at Level 2 are clearly based on genetic principles, but beyond this level most igneous rocks are classified and named on the basis of descriptive attributes. In future, additional 'types' of geological materials may be added to Level 2, for example 'Vein materials and ores'. In general, at each successive level of the hierarchy, rock names are more definitive than at the previous level. The level of the hierarchy at which a particular rock is classified and named will depend mainly on the amount and type of information that is available to the geologist at the time, but it will also depend on the expertise of the geologist, for example in terms of familiarity with the particular rock type.

At Level 3 'Igneous rocks and deposits' are divided into two groups: 'Fragmental igneous rocks and sediments' and 'Crystalline igneous rocks'. 'Fragmental igneous rocks and sediments' are those constituted of mixtures of fragments of rocks, crystals and glass. 'Crystalline igneous rocks' are those comprised essentially of interlocking crystals and/or glass.

At Level 4 'Volcaniclastic igneous rocks and sediments' is the only group belonging to the 'Fragmental igneous rocks and sediments'. The term 'volcaniclastic' has genetic connotations and is used in preference to 'volcanogenic' which has even stronger genetic associations. However, as all fragmental igneous rocks are essentially related in some way to volcanic processes, a genetic aspect to this part of the classification is unavoidable. The 'Crystalline igneous rocks' are divided into those that are chemically and/or mineralogically 'exotic' and those that are chemically and/or mineralogically 'normal'. This division separates the relatively large number of 'exotic' groups, which between them comprise a very small proportion of all crystalline igneous rock, from the two 'normal' groups that together comprise the vast majority of all crystalline igneous rock. The 'normal' groups correspond to the 'plutonic' and 'volcanic' divisions of the IUGS scheme.

Level 5 and above is indicated in the right hand column of Figure 1 where the rocks have been divided into 12 groups. This column does not correspond to a particular level of the hierarchy because all igneous rocks cannot be classified sensibly according to one system. Consequently, beyond Level 4 of the hierarchy, each group of rocks has its own classification scheme, or schemes, depending on the level and type of information available to the geologist. The flow charts in Figures 2a and 2b illustrate the sequence that should be followed to ensure correct classification. Higher levels of the hierarchy are illustrated in detail on other diagrams.

'Normal' crystalline igneous rocks are classified at Level 5, according to grain size, into groups termed 'Coarse-grained crystalline' and 'Fine-grained crystalline'. 'Exotic' crystalline rocks are classified and divided into 'Carbonatites', 'Melilitic rocks', 'Kalsilitic rocks', 'Kimberlites', 'Lamproites', 'Leucitic rocks' and 'Lamprophyres'. Lamprophyres, lamproites, kimberlites and the kalsilite-, melilite- and leucite-bearing rocks have traditionally been difficult to classify, there being widespread disagreement over their principal mineralogical and textural characteristics, and their genesis. The recently published recommendations of the IUGS (Woolley et al., 1996), which include new mineralogical and/or geochemical definitions and a revised sequence for the systematic classification of these rocks (Figure 2b), have been partly adopted here. However, even these new recommendations do not provide completely satisfactory definitions and classification schemes for some of these rocks, and further revision is to be expected.

2 IGNEOUS ROCK NOMENCLATURE

Publication of the IUGS recommendations for igneous rock classification made hundreds of rock names redundant. Most of these were either synonyms for 'approved' names, names for minor local variants of a rock type, or names that have become so poorly defined that they no longer serve a useful purpose. However, even after the IUGS 'rationalisation' there is still an unnecessarily large number of igneous rock names in current usage.

Many traditional names for igneous rocks tell the geologist only the geographical area in which the 'type' rock was first identified (for example gabbro, tonalite, dunite, lherzolite, andesite, dacite). Such names provide no petrologically useful information, such as an indication of the chemical, mineralogical or textural nature of the rock, to the non-specialist user. However, the names of many of the more common rocks, particularly those that appear in widely used classification schemes, are now generally understood to imply a particular set of chemical, mineralogical and grain size characteristics. Traditional names for less common rocks (for example craignurite and essexite), particularly those which are mineralogically and/or chemically unusual, are much less useful to non-specialist users.

One of the principal objectives of this work is to tackle these deficiencies by introducing a system for naming igneous rocks which further reduces the number of names needed to cover all the main variants, and simultaneously creates names that are more informative to geologists.

2.1 Constructing a rock name

In the BGS rock classification scheme, rock nomenclature is based on the principle that each distinct rock type has a unique **root name**, which is assigned <u>only</u> when the geologist has all the modal and chemical or fragment size and origin information that is needed to classify it fully. Thus, in most cases the root name represents the 'end-point' in classification, and root names appear only at the highest levels of the hierarchy.

Approved names are also unique, and are assigned to a rock where there is insufficient information to classify it fully. Approved names therefore occupy all levels of the hierarchy below those containing root names.

Appendix 1 contains a list of most of the approved names and root names for igneous rocks in the BGS scheme. Approved names and root names can be refined further by prefixing one or more **qualifier terms**. The procedure for assigning qualifier terms is described in Section 7. Special cases where particular qualifier terms should be used for certain rock types are noted at appropriate points in the text.

In the remaining text and on all the figures, rock names are shown as follows:

- approved names are in bold text, for example **granitic-rock**
- root names are in bold and underlined text, for example <u>**granite**</u>
- qualifier terms are italicised, for example *biotite* <u>**granite.**</u>

This convention is for clarity in this report only; it is not intended that it should be used in normal practice.

Some root names are compound names consisting of a typical root name and a mineral qualifier, for example <u>**quartz-trachyte**</u>.

To avoid confusion in determining which parts of a name represent qualifier terms and which represent the root name, a scheme has been developed for using hyphens in rock nomenclature.

2.2 Use of hyphens

The following guidelines are suggested for the use and placement of hyphens:

- approved names that consist of more than one word should be hyphenated, for example <u>**quartz-syenite**</u>, <u>**alkali-feldspar-granite**</u> or **basaltic-rock**, to show that they are a compound name
- hyphens should not be used between qualifiers and root names, for example *biotite* <u>**alkali-feldspar-granite**</u>, not *biotite*-<u>**alkali-feldspar-granite**</u>
- hyphens should be used to link two or more qualifiers applied to a rock name, for example *biotite-muscovite* <u>**alkali-feldspar-granite**</u>

Standardising the use and placement of hyphens in igneous (and other) rock names has two principal advantages: (i) it can promote the efficient and successful use of search and retrieval systems on computer databases; (ii) it indicates clearly to geologists and other users (for example non-geologists entering rock names onto a database) where a rock name starts and ends, and it can help to clearly distinguish qualifier terms from root names. For example, the suggested use of hyphens enables compound root names (such as <u>**quartz-syenite**</u>) to be distinguished from root names with separate qualifiers (such as *biotite* <u>**granite**</u>). Rock names assigned by a geologist can also be more readily identified in a piece of text, for example in the sentence 'The rock is an altered, reddish, *plagioclase-phyric-olivine-bearing* <u>**basalt**</u>' the use of hyphens helps to distinguish qualifier terms in the rock name from adjectives not intended to be included in the rock name. The geologist must choose which qualifiers are sufficiently important to include in a rock name, and hence be retrievable from a database.

The present chairman of the IUGS Subcommission on the Systematics of Igneous Rocks (Dr M J Le Bas) has indicated strong support for the introduction of hyphenated igneous rock names.

2.3 Naming rocks at low levels of the hierarchy

In cases where it is not possible, or is considered unreliable, to assign a root name to a rock, the rock should be classified and given an approved name at the highest level of the hierarchy at which the geologist can confidently assign a name, given the amount of information that is available and the familiarity that the geologist has with the rock type. Qualifier terms should include some reference to colour, grain size and composition, for example *hornblende-phyric* **mafite**.

2.4 Difficulties in applying the nomenclature system

As with the introduction of any system, there will be a transitional period during which some difficulties in applying the new rock names are to be expected. For example, problems may arise during work in areas where old names, which now have new equivalents, have been in common use. In such instances, the new approved name(s) should always be noted in published work and included on databases, however reference to the equivalent old name(s) can also be made, for example '…the rock is an **analcime gabbro** (known formerly as teschenite)…'. Local names which have new equivalents should never be used outside the geographical area in which they were used originally. All efforts should be made to phase out redundant names.

3 MAIN DISCRIMINANT FEATURES USED IN IGNEOUS ROCK CLASSIFICATION

Three principal discriminant features are used in the classification of virtually all igneous rocks: modal parameters, grain size characteristics and chemical characteristics. The method for determining modal parameters and definitions of grain size divisions are given below. Chemical discriminant features vary between classification schemes and they are described at appropriate points in the text of Section 5.

3.1 Determination of modal parameters

Many of the classification schemes described here rely on modal parameters, which should be determined as follows:

Q = quartz, tridymite, cristobalite
A = alkali feldspar, including orthoclase, microcline, perthite, anorthoclase, sanidine and sodic albite (An_0 to An_5)
P = plagioclase (An_5 to An_{100}) and scapolite
F = feldspathoids (foids) including nepheline, leucite, pseudoleucite, kalsilite, sodalite, nosean, haüyne, cancrinite, analcime, etc
M = mafic and related minerals, that is all other minerals apart from QAPF; this includes all micas (including muscovite), amphibole, pyroxene, olivine, opaque minerals, accessory minerals (zircon, apatite, titanite etc.), epidote, allanite, garnet, melilite, monticellite, wollastonite, primary carbonate, etc

Q, A, P and F comprise the felsic minerals; minerals included under M are considered to be mafic in the context of the modal classifications. The sum of Q + A + P + F + M must be 100%. Minerals in Q and F are mutually exclusive. For each rock, the modal volumes for each group of minerals must be known and QAP or APF recalculated so that their sum is 100%. For example, a rock with Q = 10%, A = 30%, P = 20% and M = 40% would give recalculated values of Q, A and P as follows:

$Q = 100 \times 10/60 = 16.7$
$A = 100 \times 30/60 = 50.0$
$P = 100 \times 20/60 = 33.3$

This information can be plotted directly onto the QAP diagram (Figure 11).

The colour index M' (dark minerals) is defined (Streckeisen, 1973; 1976) as M (mafic and related minerals) minus muscovite, apatite, primary carbonate and other minerals which can be considered as 'colourless' for the purpose of the colour index. The terms 'leucocratic', 'mesocratic' and 'melanocratic' are defined on the basis of M' values (see Section 7.3 *Qualifiers based on colour*). These are based on **absolute** values of M' and are different to the prefixes 'leuco'- and 'mela-' which designate relatively light or dark variants of a rock type.

3.2 Grain size definitions

Grain size is an important parameter in classifying and naming the vast majority of igneous rocks, and it is important therefore that grain size divisions are defined clearly and have practical meaning. The IUGS is currently considering a suitable grain size scheme for igneous rocks, however for the purposes of the present scheme we have developed a simplified and unified grain size classification for all the principal rock types covered in the various BGS rock classification schemes (Figure 3). The new grain size scheme has a number of advantages.

i The scheme is based on the Wentworth *phi* scale which is used widely for defining the size ranges of clasts in sediments and sedimentary rocks. Virtually all the boundaries between grain size divisions in the crystalline rock types now match a boundary in those for sedimentary clasts. This ensures a broad uniformity between the different rock types, and the grain size division boundaries for all rocks can be conveyed simply in a single diagram (Figure 3).

ii Rocks comprised of similar components share the same grain size division boundaries. Thus, the boundaries between fragment size divisions in volcaniclastic rocks are the same as those for sedimentary clasts and grains, while the boundaries between crystal size divisions in crystalline igneous rocks are the same as those in metamorphic rocks.

iii The boundary between coarse- and very-coarse-grained is taken at 16 mm, roughly the size of an adult thumbnail and a convenient scale for field use.

iv The boundary between 'coarse-grained' and 'medium-grained' crystals in crystalline rocks has been placed at 2 mm (instead of the traditionally used 5 mm). Tests have shown that rocks which geologists would generally consider to be coarse grained and to have crystallised at depth have a grain size much finer than 5 mm. Putting the boundary at 2 mm means that such rocks will be assigned names which imply 'coarse-grained', instead of names which imply 'medium-grained' and therefore have connotations of shallow depth emplacement. For example, a rock of granitic composition with an average grain size of 3 mm will be called **granite**, not **microgranite** as it would be if 'medium-grained' extended up to 5 mm. Careful examination of a large number of rocks which have in the past been termed 'granites' has shown that many of them have an average grain size of less than 5 mm.

v Placing the boundary between 'medium-grained' and 'fine grained' crystals in crystalline igneous and metamorphic rocks at 0.25 mm essentially divides aphanitic rocks (in which individual crystals are too fine grained to be distinguished by the naked eye) from phaneritic rocks (in which individual crystals can be distinguished by the naked eye), and thereby matches the definitions for 'volcanic' and 'plutonic' rocks, as used in the original IUGS recommendations. 0.25 mm is therefore a more logical value at which to place this division than the traditionally-used 1 mm. This is also the boundary between medium and fine sand for sedimentary clasts.

vi The use of 0.032 mm as an important division boundary in all the main rock types reflects the importance of this value in sedimentary materials as the diameter below which grains cease to follow Stokes' Law in water.

vii The term cryptocrystalline is introduced for rocks that are so fine-grained that crystals cannot be readily differentiated under the optical microscope. The upper limit is placed at 4 µm, the same as the upper limit for clay in sedimentary rocks.

The recommended boundaries between crystal size divisions in crystalline igneous rocks are:

very coarse-grained	= ≥ 16 mm
coarse grained	= ≥ 2 < 16 mm
medium grained	= ≥ 0.25 < 2 mm
fine grained	= ≥ 0.032 < 0.25 mm
very fine-grained	= ≥ 0.004 mm < 0.032 mm
cryptocrystalline	= < 0.004 mm (4 µm)

The boundaries between fragment size divisions in volcaniclastic rocks and deposits are shown in Figure 3 and described in Section 4.1.1 *Pyroclastic fragments.*

When assessing the grain size of a rock the following guidelines should be applied.

i The relative *volume* of a rock occupied by crystals or fragments in any one size division is the important factor, not the *number* of crystals or fragments. For example, a rock in which relatively few medium-grained crystals occupy a greater combined volume than a much larger number of fine-grained crystals should be classified as medium grained.

ii Rocks which have a wide range of grain sizes and no dominant size class should be classified according to the average grain size.

iii Crystal or fragment diameters should be measured. A meaningful grain size term is difficult to assign to rocks consisting largely of elongate, fibrous or platy crystals. In such cases an estimate should be made of the *volume* of an average individual crystal; the diameter of a sphere of the same volume is considered as a measure of the grain size.

4 FRAGMENTAL IGNEOUS ROCKS: VOLCANICLASTIC ROCKS AND SEDIMENTS

The general term 'volcaniclastic' was introduced by Fisher (1961) and redefined in Fisher and Smith (1991) to include 'the entire spectrum of clastic materials composed in part or entirely of volcanic fragments, formed by any particle-forming mechanism (e.g. pyroclastic, hydroclastic, epiclastic, autoclastic [see following section for definitions of these terms]), transported by any mechanism, deposited in any physiogeographic environment or mixed with any other volcaniclastic type or with any nonvolcanic fragment types in any proportion'. The term volcanogenic is used by other authors and has a broadly similar meaning. To be classified as 'volcaniclastic', we suggest that a rock or unconsolidated deposit must have more than 10% by volume of volcanic debris. Volcanic debris is defined as fragments originating by volcanic processes, either primary or after redeposition. Many volcaniclastic rocks and sediments can also be classified within the scheme for 'Sedimentary rocks and sediments' or the scheme for 'Artificial and natural superficial deposits' (Figure 1). It is up to the geologist to decide which scheme is most appropriate in the context of the study being undertaken.

The 'Volcaniclastic rocks and sediments' group, as defined here (Figure 4), contains the same range of geological materials as the 'Pyroclastic rocks and tephra' group of the IUGS scheme. The IUGS defined Pyroclastic rocks and tephra as 'formed by disruption as a direct result of volcanic action', however the group also includes rocks and deposits comprised of fragments formed by sedimentary as well as volcanic processes (mixed pyroclastic-epiclastic) and deposits comprised of fragments formed only by sedimentary processes (wholly epiclastic). For this and other reasons the scheme presented here contains some important differences to the present IUGS scheme.

4.1 Types of volcaniclastic fragments

Recognition of, and distinction between, the various types of volcaniclastic fragments is fundamental to the classification of volcaniclastic rocks and sediments. Existing, widely used classification schemes (e.g. Le Maitre et al., 1989; Fisher and Schminke, 1984; Cas and Wright, 1987) rely on the identification of two basic types of volcaniclastic fragments: pyroclastic fragments and epiclastic fragments. There is, however, some disagreement and much debate between workers about the definitions of the terms 'pyroclastic' and 'epiclastic', and on what the important discriminating factors are in terms of classifying and naming volcaniclastic rocks and sediments. According to Fisher and Schminke (1984), for example, the key aspect is the volcanic origin of the fragments. In their scheme, all fragments formed by the direct action of volcanic activity are considered to be pyroclastic up to the point where they become refragmented following lithification, regardless of whether they have been reworked, whether their shape has been changed by transport processes or whether they have been lithified. Other workers take the view that it is the mode of deposition that is important. In the classification scheme of Cas and Wright (1987), for example, pyroclastic fragments become epiclastic as soon as they have been reworked by surface (sedimentary) processes, even if this only involves rolling down a hillside in response to gravitational forces.

From discussions presented in the literature it is clear that, for a rock classification scheme to work successfully, there is a need to discriminate three principal types of volcaniclastic fragment: (i) fragments that have formed as a direct result of volcanic activity and have not been reworked by sedimentary processes; (ii) fragments that have formed as a direct result of volcanic activity and have been reworked by sedimentary processes; (iii) fragments whose origin, *as fragments*, is a direct result of surface (sedimentary) processes. We propose that (i) should be considered as 'pyroclastic fragments', (ii) as 'reworked pyroclastic fragments' and (iii) as 'epiclastic fragments'.

In consolidated rocks it is difficult if not impossible to recognise minor reworking, and for the purposes of classification all pyroclastic fragments and reworked pyroclastic fragments, as they are defined above, should be treated as pyroclastic. However, if reworked pyroclastic fragments form more than 50% of the pyroclastic fragments in a pyroclastic rock or sediment, the qualifier term 'reworked' can be used, for example *reworked* **lapilli-tuff**.

The same classification procedure has traditionally been used for both ancient and modern volcaniclastic rocks and sediments. However, accurate identification of pyroclastic and epiclastic fragments, and quantification of their relative proportions, is often difficult or impossible, particularly in older, consolidated deposits. While it is possible to know a great deal about the depositional history and fragment origin of modern deposits, it is often the case that relatively little can be said with confidence about the depositional history and fragment origin of older, usually compacted and altered, volcaniclastic rocks. Where a volcaniclastic rock has undergone compaction and/or alteration to an extent that the nature of the original constituent fragments cannot be determined with confidence, it should be classified and named as a tuffaceous sedimentary rock (see Section 4.2.2 *Tuffites*) or as a volcaniclastic sedimentary rock (see Section 4.2.3 *Volcaniclastic sedimentary rocks and sediments*), as appropriate.

4.1.1 Pyroclastic fragments

Pyroclastic fragments are generated by disruption as a direct result of explosive volcanic action. Three principal types of pyroclastic fragment can be distinguished.

i Juvenile fragments. These form directly from cooling magma during transport prior to primary deposition. Juvenile pyroclastic fragments may be subdivided, as follows:

pyroclasts—form directly from cooling magma during aerial and subaerial transport. They may be individual crystals, crystal fragments, glass fragments or rock fragments, or they may consist of a combination of these.

hydroclasts—are chilled glass particles that form by magma–water interactions during subaqueous or subglacial extrusion.

autoclasts—are fragments formed by mechanical friction of moving lava flows, or through gravity crumbling of spines and domes.

ii Cognate fragments. These are fragments of rock which formed during earlier volcanic activity, but which have been detached and ejected with other pyroclastic debris during a later eruption. Although these are most likely to have an 'igneous' composition they can, in theory, be composed of any rock type.

iii Accidental fragments. These are fragments of rock generated by disruption as a direct result of volcanic action, but were not formed by previous activity of the volcano. They are generally derived from the subvolcanic basement and they can, therefore, be composed of many rock types.

The genetic basis of the definitions presented above does not conform to the stated principle of using descriptive attributes only to classify igneous rocks, however the approach and terminology are so deeply engrained in, and relevant to, the field of volcaniclastic research that the terms have been retained here. More detailed definitions and descriptions of pyroclastic fragments are presented in Fisher and Smith (1991), in Heiken and Wohletz (1985; 1991) and in Marshall (1987), among other publications.

Despite the genetic basis for distinguishing fragment types, the origin of pyroclastic fragments is not taken into consideration in the classification and nomenclature of volcaniclastic rocks and sediments. For the purposes of classification, pyroclastic fragments are distinguished by their size (Figures 3 and 5) and shape in the following way:

bombs—are pyroclastic fragments whose mean diameter exceeds 64 mm and which have a shape (generally rounded) or texture (e.g. 'bread-crust' surface) which indicates that they were in a wholly or partly molten state during their formation and subsequent transport.

blocks—are pyroclastic fragments whose mean diameter exceeds 64 mm and which have an angular or subangular shape indicating they were solid during transport.

lapilli—are pyroclastic fragments of any shape with a mean diameter of 2 mm to 64 mm.

ash—grains are pyroclastic fragments with a mean diameter of less than 2 mm. These are subdivided into coarse ash grains (0.032 mm to 2 mm) and fine ash grains (less than 0.032 mm).

In many pyroclastic rocks and sediments, pyroclasts are dominant volumetrically and the above terms, where they are used alone, can be assumed to refer to pyroclasts. However, the terms can be modified to identify other types of pyroclastic fragments, for example 'ash-grade hydroclast', 'lapilli-grade autoclast' and 'block-grade cognate clast'.

If pyroclastic fragments have been moved and redeposited prior to lithification they may be termed 'reworked pyroclasts'.

4.1.2 Epiclastic fragments

Epiclasts are fragments in volcaniclastic rocks and sediments that have not been generated by disruption as a direct result of volcanic action. They are defined, according to Schmid (1981), as 'crystals, crystal fragments, glass and rock fragments that have been liberated from any type of pre-existing consolidated rock (volcanic or non-volcanic) by weathering or erosion and transported from the site of origin by gravity, air, water or ice'. Thus, epiclasts can be volcanic or non-volcanic, and they can be non-igneous.

4.2 Classification of volcaniclastic rocks and sediments

Root names used in the classification describe only the granulometric state of the rocks and sediments. Grain size limits used for defining volcaniclastic fragments match those used in the classification scheme for Sedimentary rocks and sediments (Figure 3). These should be regarded as provisional until there is international agreement on the granulometric divisions of sedimentary materials. The hierarchical scheme for classifying Volcaniclastic rocks and sediments is shown in Figure 4.

4.2.1 Pyroclastic rocks and sediments (tephra)

Pyroclastic rocks and sediments contain more than 75% by volume of pyroclastic fragments, the remaining materials being generally of epiclastic, organic, chemical sedimentary or authigenic origin. If predominantly consolidated they should be classified as pyroclastic rocks, and if predominantly unconsolidated they should be classified as tephra (Figure 4). The term 'tephra' is synonymous with 'pyroclastic sediment'.

4.2.1.1 Tephra

The following root names should be used for unimodal, well-sorted sediments comprised of more than 75% pyroclastic fragments (see Figures 5 and 8a).

The names **block-tephra** or **bomb-tephra** or **block-bomb-tephra** or **bomb-block-tephra** should be used where the average size of more than 75% of the pyroclastic fragments exceeds 64 mm. The relative proportions of angular (i.e. block) and rounded (i.e. bomb) fragments exceeding 64 mm is indicated in the following way: in a **block-tephra** more than 75% of all pyroclastic fragments exceeding 64 mm are angular, in a **bomb-block-tephra** 50 to 75% are angular, in a **block-bomb-tephra** 25 to 50% are angular and in a **bomb-tephra** less than 25% are angular.

The name **ash-breccia** should be used where the tephra contains more than 25% of each of the main fragment size divisions (i.e. block/bomb, lapilli and ash).

The names **lapilli-tephra** or **lapilli-ash** or **ash** should be used where the average size of more than 75% of the pyroclastic fragments is less than 64 mm. The relative proportions of lapilli- and ash-grade fragments is indicated in the following way: in a **lapilli-tephra** more than 75% of the pyroclastic fragments are lapilli (i.e. in the range 64 to 2 mm), in a **lapilli-ash** between 25 and 75% of the fragments are lapilli, and in an **ash** less than 25% of the fragments are lapilli (i.e. > 75% are ash-grade).

4.2.1.2 Pyroclastic rocks

The following root names should be used for unimodal and well-sorted pyroclastic rocks, (see Figures 5 and 8a).

The names **agglomerate** or **pyroclastic-breccia** should be applied to a rock in which more than 75% of the pyroclastic fragments exceed 64 mm. The relative proportions of angular (i.e. block) and rounded (i.e. bomb) fragments exceeding 64 mm is indicated in the following way: in an **agglomerate** more than 50% of the fragments are rounded (i.e. bombs). This is the consolidated equivalent of a **bomb-tephra** or **block-bomb-tephra**. In a **pyroclastic-breccia** more than 50% of the pyroclastic fragments are angular (i.e. blocks). This is the consolidated equivalent of a **block-tephra** or **bomb-block-tephra**.

The name **tuff-breccia** should be used where a pyroclastic rock contains more than 25% of each of the main fragment size divisions (i.e. block/bomb, lapilli and ash).

The names **lapillistone** or **lapilli-tuff** or **tuff** should be used where the average size of more than 75% of the pyroclastic fragments is less than 64 mm. The relative proportions of lapilli- and ash-grade fragments is indicated in the following way: in a **lapillistone** more than 75% of the fragments are lapilli (i.e. in the range 64–2 mm), in a **lapilli-tuff** between 25 and 75% of the fragments are lapilli, and in a **tuff** less than 25% of the fragments are lapilli (i.e. > 75% are ash-grade).

The term **lapillistone**, as defined above, comes from the classification scheme of Fisher and Schminke (1984) for pyroclastic rocks. It is preferred to the term ‘lapilli-tuff’, which is recommended by the IUGS for the same rock type. The term **lapilli-tuff** is used in this classification for a poorly sorted pyroclastic rock containing lapilli-sized and ash-sized fragments (see Section 4.2.1.4 *Poorly sorted pyroclastic rocks and tephra*).

4.2.1.3 Special qualifier terms for pyroclastic rocks and tephra

Each of the root names listed above may be qualified further on the basis of fragmental composition, as shown in Figure 7. Thus, a *lithic* **lapillistone** is comprised predominantly of rock fragments, a *crystal* **lapillistone** is comprised predominantly of crystal fragments and a *vitric* **block-tephra** is comprised predominantly of glassy and pumiceous fragments. Vitric components include ‘shards’, which are glassy fragments, and highly vesiculated, frothy (i.e. pumiceous) material which can be separated into ‘scoria’ (dark-coloured) and ‘pumice’ (light-coloured). Note that the terms ‘lithic’, ‘vitric’ and ‘crystal’ are used as qualifiers and are not part of the root name.

Special qualifier terms may be used to divide tuffs and ashes into *coarse* **tuff** and *coarse* **ash**, which have an average pyroclast size of between 2 mm and 0.032 mm, and *fine* **tuff** and *fine* **ash** which have an average pyroclast size of less than 0.032 mm (Figure 5).

The qualifier term *reworked* can be used as a prefix to a standard root name for pyroclastic rocks and tephra which consist of more than 50% reworked pyroclastic fragments, as defined in Section 4.1 *Types of volcaniclastic fragments* above, for example *reworked* **lapillistone**, *reworked* **ash**.

Most pyroclastic rocks and tephra are composed dominantly of pyroclasts. Where no other indication is given in the name assigned to a pyroclastic rock or to tephra it should be assumed that pyroclasts are volumetrically the dominant type of pyroclastic fragment. Where other types of pyroclastic fragment (hydroclasts, autoclasts) are identified the geologist should decide whether their presence is sufficiently important to merit inclusion in the name assigned to the rock or sediment. For example, a rock or sediment in which most or all of the pyroclastic fragments are hydroclasts could be assigned a root name in the normal way, that is according to the origin (pyroclastic *versus* epiclastic) and granulometric state of the fragments, to which the qualifier term *hydroclastic* is added. In this way, names such as *hydroclastic* **lapilli-tuff** are generated. Where hydroclasts form only a small proportion of the total volume of pyroclastic fragments, but their presence is still considered important, the qualifier term could be modified to reflect this, for example *hydroclast-bearing* **lapilli-tuff**.

The name ‘hyaloclastite’ has been used traditionally to describe rocks or sediments composed entirely of shattered, angular, glassy fragments created by quenching of lavas during subaqueous or subglacial extrusion. As such, the name implies only a process and gives no information about fragment size. In keeping with the root name and qualifier approach, names such as *hyaloclastite* **tuff** and *autoclastite* **block-tephra**, should be used in preference to terms such as ‘hyaloclastite’ and ‘autoclastite’.

4.2.1.4 Poorly sorted pyroclastic rocks and tephra

The current IUGS recommendations suggest that where pyroclastic rocks and tephra are poorly sorted the name assigned to them should be composed of an appropriate combination of the terms described above (for example ‘ash-lapilli-tuff’ where lapilli > ash, or ‘lapilli-ash-tuff’ where ash > lapilli). However, this approach is not used widely because it is unwieldy and can result in rock names with ambiguous meaning. The scheme proposed by Fisher and Schminke (1984), in which poorly sorted volcaniclastic rocks and sediments are named using the ternary diagrams shown in Figures 8a and 8b, is more popular and is generally considered more practical; for these reasons it is recommended here. According to this scheme, a pyroclastic rock or sediment can be defined as poorly sorted where no one glanulometric class of pyroclastic fragment (i.e. ash, lapilli or blocks and bombs) exceeds 75% of the volume. The root names **tuff-breccia**, and **lapilli-tuff** are generated for poorly sorted pyroclastic rocks, and **ash-breccia** and **lapilli-ash** for poorly sorted tephra.

4.2.2 TUFFITES

The general term **tuffite** can be used for volcaniclastic rocks and sediments which consist of between 25% and 75% by volume of pyroclastic fragments (see Figures 4 and 6). The prefix ‘tuffaceous’ should be used with standard root names for clastic sediments and sedimentary rocks to produce root names such as **tuffaceous-sand** and **tuffaceous-mud** for unconsolidated deposits, for which the consolidated equivalents would be **tuffaceous-sandstone** and **tuffaceous-mudstone**. Figure 3 shows the grain size ranges for clastic sediments. Poorly sorted tuffites should be treated using a similar approach to produce names such as *pebbly* **tuffaceous-sandstone** and **tuffaceous-wacke**.

4.2.3 Volcaniclastic sedimentary rocks and sediments

Volcaniclastic accumulations that contain more than 10% volcanic debris but less than 25% pyroclastic fragments can be classified according to either the igneous or sedimentary schemes, depending on the geologist's preference. If the igneous scheme is used, they should be classified as 'Volcaniclastic sedimentary rocks and sediments'(Figure 4). The prefix 'volcaniclastic' should be used with standard root names for clastic sediments and sedimentary rocks to produce root names such as **volcaniclastic-sand** and **volcaniclastic-mud** for unconsolidated deposits, for which the consolidated equivalents would be **volcaniclastic-sandstone** and **volcaniclastic-mudstone**, respectively. Figure 3 shows the grain size ranges for clastic sediments. Poorly sorted volcaniclastic sedimentary rocks and sediments should be treated using a similar approach to produce names such as *pebbly* **volcaniclastic-sandstone** and **volcaniclastic-wacke**.

4.2.4 Using genetic qualifier terms to name pyroclastic rocks and tephra

The study of pyroclastic rocks in modern volcanic settings often places great emphasis on genesis and on the landforms produced during volcanic eruptions. This approach requires a terminology which is outside the scope of rock classification. Terms such as 'ignimbrite', 'pyroclastic flow' and 'lag breccia', among many others, play an important role in the field description of pyroclastic rocks and sediments, but they are not rock names as they describe a deposit that may consist of many rock types. Where it is considered important to include some indication of genesis in a pyroclastic rock name the appropriate term should be appended as a qualifier to one of the recommended root names, for example *ash-flow* **tuff**. However, many pyroclastic deposits are too heterogeneous to be assigned a single root name. In such instances, terms such as 'distal ignimbrite', 'proximal pyroclastic surge deposit' or 'co-ignimbrite air-fall deposit' should be used, though it must be emphasised that these are names describing the origin and nature of a *deposit*, and should never be considered as rock names.

Small volumes of volcaniclastic materials are associated with kimberlitic and lamproitic volcanism (the mineralogical and chemical characteristics of kimberlites and lamproites are described in more detail in Section 6.4 *Kimberlites* and 6.5 *Lamproites*). Diatreme facies kimberlitic rocks have been classified as 'tuffisitic kimberlites' and as 'tuffisitic kimberlitic breccias' (Clement, 1979; Clement and Skinner, 1979), however Mitchell (1986) suggested that the term 'volcaniclastic kimberlites' might be more appropriate until the volcanic processes governing their formation are better understood. Pyroclastic fragments, reworked pyroclastic fragments and epiclastic fragments are all associated with volcaniclastic kimberlites and lamproites. More detailed description of these very rare and unusual rock types is provided in Mitchell (1986) and in Mitchell and Bergman (1991). For the purposes of non-specialised classification we suggest that such rocks should be named in the normal way, that is according to the origin (pyroclastic *versus* epiclastic) and granulometric state of the fragments, to which the qualifier terms *kimberlitic* or *lamproitic* are added. In this way, names such as *kimberlitic* **lapilli-tuff** and *lamproitic* **tuffaceous-sandstone** are generated.

5 CHEMICALLY AND/OR MINERALOGICALLY NORMAL CRYSTALLINE IGNEOUS ROCKS

5.1 Coarse-grained crystalline igneous rocks

This classification (Figure 9) should be used for coarse-grained crystalline igneous rocks, provided they do not fit one of the rock types encountered at an earlier stage in Figure 2. The group is equivalent to the 'Plutonic rocks' of the IUGS scheme, but the name has been changed here to avoid genetic connotations. For rocks which are essentially medium grained, the coarse-grained crystalline root name should be given and prefixed with the term 'micro', for example **microgabbro** or **foidmicrosyenite**. Chilled margins of intrusions are treated as a special case (see Section 8.1 *Rocks names based on field association*)

5.1.1 Classification of coarse-grained crystalline igneous rocks

The classification is based on modal parameters and is divided into three parts.

i If an accurate mineral mode is not available the rock should be classified at Level 6 of the hierarchy using the 'field' classification illustrated in Figure 10.

ii If an accurate mineral mode is available and M (defined in Section 3.1 *Determination of modal parameters*) is less than 90% the rock is classified at Level 7 or 8 of the hierarchy according to its felsic minerals using the QAPF diagram (Figures 10 and 11). A refinement of the QAPF name can be made using the colour index prefixes 'leuco' and 'mela' (see Section 5.1.6 *Modification of root names using colour index prefixes*).

iii If an accurate mineral mode is available and M is more than 90% the rock is ultramafic (Figure 15) and is classified at Level 7 or 8 of the hierarchy according to its mafic minerals (Figure 16).

5.1.2 Field classification

When an accurate mineral mode from thin section examination is not available, a 'field classification' (Level 6), based on a simplified version of the QAPF diagram for coarse-grained crystalline rocks, should be used. It should be possible to constrain the relative proportions of quartz, alkali feldspar, plagioclase and feldspathoids sufficiently accurately from hand specimen assessment to place most coarse-grained normal crystalline rocks into one of the ten 'field' divisions shown on Figures 9 and 10. Note that the suffix '-ic rock' should be used with these terms instead of '-oid' (for example, **granitic-rock** not 'granitoid').

5.1.3 QAPF classification (M < 90%)

Root names for this classification and the relevant QAPF field numbers are given in Figures 9 (column headed 'QAPF classification'), 13 and 14. Field details are outlined below.

Field 1a **Quartzolite** is a collective term for coarse-grained crystalline rocks in which quartz comprises more than 90% of the felsic minerals. These extremely rare rocks are unlikely to be wholly of primary igneous origin.

Field 1b **Quartz-rich-granitic-rock** is a collective term for granitic rocks in which quartz comprises more than 60% of the felsic minerals.

Field 2 **Alkali-feldspar-granite** is a granitic rock in which plagioclase comprises less than 10% of the total feldspar. If one particular type of alkali feldspar is dominant (> 50% of alkali feldspar) the mineral name can be used in place of alkali feldspar, for example **albite-granite**, **orthoclase-granite**. This also applies to QAPF fields 6, 6* and 6'. **Alkali-feldspar-granite** is not synonymous with *alkali* **granite** which should be restricted to rocks containing alkali amphiboles and/or alkali pyroxenes.

Field 3 **Granite** may be divided into **syenogranite** (Figure 11 and 12, field 3a) and **monzogranite** (field 3b). Note that the term 'adamellite' should no longer be used as a subdivision of the granite field.

Field 4 The root name **granodiorite** should be used.

Field 5 The root name **tonalite** should be used.

Fields 6 The root name **alkali-feldspar-syenite** should be used.

Field 7 The root name **syenite** should be used.

Field 8 The root name is **monzonite**; many so-called 'syenites' fall into this field.

Field 9 The two root names in this field, **monzodiorite** and **monzogabbro**, are separated according to the average composition of their plagioclase:
if An (the anorthite content of plagioclase) is less than 50% the rock is **monzodiorite**:
if An exceeds 50% the rock is **monzogabbro**

Field 10 The three root names in this field–**diorite**, **gabbro** and **anorthosite**–are separated according to the average composition of their plagioclase and the colour index: if M is less than 10% the rock is **anorthosite** if An is less than 50% the rock is **diorite** if An is greater than 50% the rock is **gabbro** and may be subdivided further, as shown below.
Rocks which plot in field 10 of the QAPF diagram (Figures 11 and 12) and in which the An content of plagioclase exceeds 50% (Gabbro QAPF) may be subdivided according to relative abundance of the mafic minerals orthopyroxene, clinopyroxene, olivine and hornblende, as shown in Figures 13 and 14. Some of the special terms used are:
gabbro (s.s.) = plagioclase + clinopyroxene
norite = plagioclase + orthopyroxene
troctolite= plagioclase + olivine
gabbronorite = plagioclase with almost equal amounts of clinopyroxene and orthopyroxene
orthopyroxene-gabbro = plagioclase + clinopyroxene with lesser amounts of orthopyroxene
clinopyroxene-norite = plagioclase + orthopyroxene with lesser amounts of clinopyroxene
hornblende-gabbro = plagioclase + hornblende, with pyroxene < 5%.

The term 'dolerite' has been used traditionally for medium-grained rocks of gabbroic/basaltic composition. Use of this term is discussed in Section 8.1 *Rock names based on field association.*

In several places IUGS use names such as gabbro for both a group of rocks and one rock type within the group. In this scheme the specific rock types are given the suffix **(*s.s*),** an abbreviation for *sensu stricto* meaning the precise usage of the term.

Field 11 **Foid-syenite** is the root name. Where it is known, the name of the most abundant foid mineral should appear in the rock name, for example **nepheline-syenite**.

Field 12 The root name is **foid-monzosyenite**. Where it is known, the name of the most abundant foid mineral should appear in the rock name, for example **nepheline-monzosyenite**, **sodalite-monzosyenite.**

Field 13 The two root names in this field, **foid-monzodiorite** and **foid-monzogabbro**, are distinguished according to the average composition of their plagioclase: if An is less than 50% the rock is **foid-monzodiorite**; if An exceeds 50% the rock is **foid-monzogabbro**. Where it is known, the name of the most abundant foid mineral should appear in the rock name, for example **nepheline-monzodiorite**.

Field 14 The two root names in this field, **foid-diorite** and **foid-gabbro**, are distinguished according to the average composition of their plagioclase:
if An is less than 50% the rock is **foid-diorite**:
if An exceeds 50% the rock is a **foid-gabbro**.
Where it is known, the name of the most abundant foid mineral should appear in the rock name, for example **nepheline-diorite**.

Field 15 This field contains rocks in which the light-coloured minerals are almost entirely foids, and is given the root name **foidolite** to distinguish it from the fine-grained equivalent, which is called **foidite**. As these rocks are rare the field has not been divided. Where it is known, the name of the most abundant foid mineral should appear in the rock name. According to the root-name-and-qualifier scheme adopted here this would produce names such as **nepheline-foidolite** and **leucite-foidolite**, however for the sake of simplicity, and to remain in agreement with the IUGS recommendations, these should be shortened to make single root names such as **nephelinolite** and **leucitolite**.

5.1.4 Ultramafic coarse-grained crystalline rocks (M > 90%)

These (Figure 15) are grouped as 'ultramafic rocks', and are classified according to their content of mafic minerals, namely olivine, orthopyroxene, clinopyroxene and hornblende. They fall in Field 16 of the QAPF (M) diagram (Figure 12). Two diagrams can be used for classification, one for rocks containing pyroxene and olivine, the other for rocks containing hornblende, pyroxene and olivine (Figure 16).

Peridotites are distinguished from pyroxenites by containing more than 40% olivine. This value was chosen by IUGS instead of 50% because many lherzolites contain up to 60% pyroxene. The peridotites are divided into **dunite**, **pyroxene-peridotite**, **pyroxene-hornblende-peridotite** and **hornblende-peridotite**. **Pyroxene-peridotite** is further divided into **harzburgite**, **lherzolite** and **wehrlite**.

Pyroxenites contain less than 40% olivine and have pyroxene dominant over hornblende. They are divided into **olivine-pyroxenite**, **pyroxenite (*s.s.*)**, **hornblende-pyroxenite** and **olivine-hornblende-pyroxenite**. **Olivine-pyroxenite** is further divided into **olivine-orthopyroxenite**, **olivine-websterite** and **olivine-clinopyroxenite**, and

pyroxenite (s.s.) is divided into **orthopyroxenite**, **websterite** and **clinopyroxenite**.

Hornblendites contain less than 40% olivine and have hornblende dominant over pyroxene. They are divided into **olivine-hornblendite**, **olivine-pyroxene-hornblendite**, **pyroxene-hornblendite** and **hornblendite (s.s.)**.

The terms **pyroxenite** and **hornblendite** are used as group names for the pyroxene- and hornblende-rich rocks containing less than 40% olivine (Level 7 of the hierarchy, Figure 15). For clarity, and to distinguish them from essentially monomineralic rocks at Level 8 that have the same names according to the IUGS scheme, the term **pyroxenite (s.s.)** is used for pyroxene-rich (>90%) pyroxenite**,** where the type of pyroxene has not been determined, and the term **hornblendite (s.s.)** is introduced for hornblende-rich hornblendite.

Ultramafic rocks containing garnet or spinel should be named in the following manner (see Section 7.1 *Qualifiers based on mineralogical criteria*): if garnet or spinel is less than 10% of the mode use *garnet-bearing* **peridotite**, *chromite-bearing* **dunite** etc.; if garnet or spinel is greater than 10 to 20% of the mode use *garnet* **peridotite**, *chromite* **dunite**, etc.

5.1.5 Charnockitic rocks

This classification should be used only if the rock is considered to belong to the charnockitic suite of rocks, which is usually characterised by the presence of orthopyroxene (or fayalite plus quartz, though in such assemblages fayalite is invariably altered) and, in many rocks, perthite, mesoperthite or antiperthite (Streckeisen, 1974; 1976). Primary hydrous minerals are generally absent. They are commonly associated with norites and anorthosites and are linked closely with high-grade metamorphic terrains. Despite being composed largely of feldspar and quartz, charnockitic rocks are generally melanocratic due to very dark feldspar crystals, which also have a characteristically ‘greasy’ appearance. Although signs of metamorphic overprinting such as deformation and recrystallisation are common, many conform to the definition ‘igneous and igneous-looking rocks’ and they have, therefore, been included in this classification scheme as a variant of coarse-grained crystalline rocks.

5.1.5.1 Classification of charnockitic rocks

Charnockitic rocks can be classified and named readily using the QAP triangle (Figure 11) and this scheme is preferred to the plethora of traditional ‘local’ terms, as the rock name becomes more logical and informative and is consistent with terms used for the ‘normal’ coarse-grained crystalline rocks. To distinguish them from the normal crystalline rocks, the QAP root name should be prefixed with the qualifier *charnockitic*. Thus, ‘charnockite’ becomes *charnockitic* **granite** and rocks with the traditional names ‘mangerite’ and ‘enderbite’ become *charnockitic* **monzonite**, and *charnockitic* **tonalite**, respectively. Note that these are qualifiers with root names, not compound root names. This approach is more appropriate than using the prefix ‘hypersthene-’ (as recommended by the IUGS [Le Maitre et al., 1989]) in front of the QAP root name, for the following reasons:

- some charnockitic rocks do not contain hypersthene
- some coarse-grained igneous rocks containing hypersthene are not charnockitic
- the orthopyroxene in charnockitic rocks is not always hypersthene
- charnockitic rocks should be recognised on the basis of a range of distinctive features, not simply by the presence or absence of orthopyroxene

Perthite, in various forms, is characteristic of charnockitic rocks. For the purposes of classification, the perthitic feldspars should be distributed between A and P in the following way:

perthite	assign to A, as the major component is alkali feldspar
mesoperthite	assign equally between A and P as the amount of alkali feldspar and plagioclase (usually oligoclase or andesine) is approximately equal
antiperthite	assign to P, as the major component is andesine with minor albite as the alkali feldspar mineral

5.1.6 Modification of root names using colour index prefixes

For the coarse-grained rocks in the QAPF classification the prefixes ‘leuco’ and ‘mela’ may be used to designate the more felsic (lower colour index) and mafic (higher colour index) types respectively within each rock group, when compared with the ‘normal’ types in that group. Mesocratic is the normal form of the rock and hence is assumed and becomes redundant.

Threshold values of M’ (see Section 3.1 *Determination of modal parameters*) vary from rock group to rock group. Figures 33 and 34 show the limits within which each of these terms may be applied in the various rock groups. Colour index prefixes, where used with other types of qualifier, should immediately precede the root name. They are appended to the root name, for example **leucogranite** and **melagabbro**, but where the root name starts with a vowel a hyphen must be used, for example *muscovite* **leuco-alkali-feldspar-granite.**

5.1.7 ‘Plutonic’ (TAS) classification

The total alkali silica (TAS) diagram is frequently used for the chemical classification of fine-grained crystalline rocks (see Section 5.2.5 *TAS classification*). In recent years it has been suggested that the TAS diagram can also be used for classifying coarse-grained (plutonic) rocks and in certain cases produces a rock name similar to QAP-based classification (Bellieni et al., 1995). The system shows possibilities and may be appropriate for a restricted range of rock types, but there are problems where rocks contain a large proportion of non-QAPF minerals. Plutonic TAS is being considered by IUGS but a decision regarding its use has not been reached. Its use for classification is not recommended here but it may have a place in future editions.

5.2 Fine-grained crystalline igneous rocks

This classification (Figure 17) should be used for fine-grained, very fine-grained and glassy crystalline igneous rocks, provided they do not fit one of the rock types encountered at an earlier stage in Figure 2. The group is identical to the ‘Volcanic rocks’ of the IUGS scheme, but the name has been changed here to avoid possible genetic connotations.

5.2.1 Classification of fine-grained crystalline igneous rocks

Classification of the fine-grained crystalline rocks is divided into three parts.

(i) If neither an accurate mineral mode nor chemical analysis is available, the rock should be classified at either Level 6 or Level 7 (Figures 17 and 18).

(ii) If an accurate mineral mode can be determined, the rock should be classified at Level 8 using the QAPF diagram (Figure 19).

(iii) If a mineral mode cannot be determined and a chemical analysis is available, the rock should be classified at Level 9 or 10 of the hierarchy using the TAS classification (Figure 20a and b).

Some of the root names given to fine-grained crystalline igneous rocks appear in both the QAPF and TAS classification schemes, and it is important to distinguish which of these methods has been used in determining a rock name. Where the QAPF method has been used the root name only should be given, but where the TAS method has been used the root name should be followed by 'TAS', for example **trachyte** (**TAS**) and **latite** (**TAS**).

5.2.2 Field classification

A field classification at Levels 6 or 7 of the 'normal' fine-grained crystalline rocks should be used only when neither an accurate mineral mode nor a chemical analysis is available. Classification at Level 7 is based on a simplified version of the QAPF diagram for fine-grained crystalline rocks, and is shown in Figure 18. Note that the suffix '-ic rock' should be used with these terms instead of '-oid' (for example, **rhyolitic-rock**, not 'rhyolitoid'). Where there is insufficient information to confidently assign one of the names at Level 7 to a rock in the field, it should be named at Level 6 (Figure 17). At this level, all fine-grained normal crystalline igneous rocks are covered by just two names, **felsite** and **mafite**. These terms are intended to be used in the field for generally light- and generally dark-coloured, aphanitic rocks, respectively. Use of the term 'mafite' to mean a dark-coloured mineral has long been redundant, and the International Mineralogical Association agrees that use of the term as recommended here is both useful and appropriate. It is possible that the chemistry and/or mineralogy of rocks assigned one of these names in the field may not always match that of the rock types at Level 7 to which they are associated on Figure 17.

Other approved field terms for very fine-grained or glassy igneous rocks, including **porphyry**, **obsidian** and **pitchstone**, are defined in Section 7.2 *Qualifiers based on textural criteria.*

5.2.3 QAPF classification (M < 90%)

Root names for the classification are given in Figures 17 and 19. The numbers of the QAPF fields are the same as those for the coarse-grained crystalline rocks classification. Field details are outlined below.

Field 1	The IUGS subcommission recommendations do not give a name to this field, presumably because extremely silica-rich volcanic rocks are not known.
Field 2	The root name **alkali-feldspar-rhyolite** is the fine-grained equivalent of **alkali-feldspar-granite**. A specific mineral name can be used in place of alkali feldspar, as in the coarse-grained scheme. The qualifier term *alkali* can be used when the rock contains alkali pyroxene and/or alkali amphibole, but a mineral qualifier such as *aegerine* or *riebeckite* is preferable.
Field 3	In a manner analogous to the granites (Figure 12), **rhyolite** covers fields 3a and 3b. The term **rhyodacite**, which has in the past been used ambiguously for rocks of fields 3b and 4, is permitted by IUGS for rocks transitional between **rhyolite** and **dacite** without attributing it to a distinct field. Here, the name **felsite** is preferred if there is inadequate information to assign to a specific field.
Fields 4 and 5	Rocks in both these fields are covered by the root name **dacite**.
Fields 6, 7, 8	Rocks with the root names **alkali-feldspar-trachyte**, **trachyte** or **latite**, which contain no modal foids but do contain nepheline in the norm, may be qualified with *ne-normative* to indicate that they would fall in subfields 6'–8', respectively. The qualifier term *alkali* may be used for trachytes containing alkali pyroxene and/or alkali amphibole, though a mineral qualifier such as *aegirine* or *riebeckite* is preferable.
Fields 9, 10	The large majority of fine-grained crystalline igneous rocks fall in these fields, including **andesite**. and **basalt**. They are separated tentatively using colour index, with an upper limit of 40 wt% or 35 vol% for andesite, and chemically using 52% SiO_2 as the lower limit for andesite, as shown in Figure 21. Plagioclase composition (at a limit of An_{50}) is less suitable for distinguishing **basalt** and **andesite** because many andesites contain 'phenocrysts' of labradorite or bytownite. It is unlikely that many of these rocks will be classified using the QAPF diagram, as the modes of most basalts and andesites are difficult to determine accurately due to very fine-grained groundmass. The TAS classification is used in most cases.
Field 11	The root name **phonolite** is used for rocks consisting essentially of alkali feldspar, any feldspathoid and mafic minerals. The name of the most abundant foid mineral should be added as a qualifier to the root name, for example *leucite* **phonolite**, *analcime* **phonolite**, *leucite-nepheline* **phonolite**. Phonolite rocks containing nepheline and/or haüyne as the main foid mineral(s) are commonly described simply as **phonolite**.
Field 12	The root name for these rather rare rocks is **tephritic-phonolite**.
Field 13	This field contains the root names **phonolitic-basanite** and **phonolitic-tephrite**, which are distinguished by the amount of olivine in the CIPW norm: if normative olivine exceeds 10% the rock is called a **phonolitic-basanite**; if less than 10% it is a **phonolitic-tephrite**.
Field 14	This field contains the root names **basanite** and **tephrite**, which are distinguished by the amount of olivine in the CIPW norm in the same way as rocks in field 13. The nature of the most abundant foid mineral should be indicated in the name, for example *nepheline* **basanite** and *leucite* **tephrite**.
Field 15	The general root name in this field is **foidite**, but as these rocks occur relatively

frequently the field has been divided into three subfields:

Field 15a — The root name is **phonolitic-foidite**, but wherever possible the name of the most abundant foid mineral should be included, and the name shortened in a manner similar to that for field 15 of the coarse-grained crystalline rocks classification, to create more specific names such as **phonolitic-nephelinite** and **phonolitic-leucitite**.

Field 15b — The root names are **basanitic-foidite** and **tephritic-foidite**, and are distinguished by olivine content as in field 13. Wherever possible, more specific terms, such as **basanitic-nephelinite** and **tephritic-leucitite** should be used.

Field 15c — The root name is **foidite**. Wherever possible, the name of the most abundant foid mineral should be used in the root name, to create names such as **nephelinite** and **leucitite**.

5.2.4 Ultramafic fine-grained crystalline rocks

These rocks fall in field 16 of the QAPF (M) diagram. In the absence of a chemical analysis they should be referred to by the general name **ultramafitite**.

5.2.5 TAS classification

This classification should be used only if the mineral mode of a 'normal' fine-grained crystalline rock cannot be determined due either to the presence of glass or to the fine-grained nature of the rock. The main part of the classification is based on the total alkali silica (TAS) diagram (Figure 20a). The root names for the classification and the field symbols are given in Figures 20a and 20b, respectively. The classification requires only the values of $Na_2O + K_2O$ and SiO_2, however if an analysis falls within certain fields additional calculations, such as the CIPW norm, must be performed in order to derive the correct root name.

The TAS classification is descriptive and no genetic significance is implied. Furthermore, analyses of rocks that are weathered, altered, metasomatised, metamorphosed or have undergone crystal accumulation should be used with caution, as spurious results may be obtained. As a general rule, only analyses with $H_2O^+ < 2\%$ and $CO_2 < 0.5\%$ should be used, except if the rock is a **picrite**, **komatiite**, **meimechite** or **boninite**, in which cases this restriction is withdrawn. The application of TAS to altered rocks has been discussed by Sabine et al. (1985), who found that many low-grade metavolcanic rocks could be classified satisfactorily.

5.2.5.1 Using the TAS classification

Before using the TAS classification the following procedures must be adopted.

i All analyses must be recalculated to 100% on an H_2O- and CO_2-free basis.

ii If a CIPW norm has to be calculated the amounts of FeO and Fe_2O_3 should be left as determined, in order to generate the correct root name. If total iron only has been determined it is up to the user to justify the method used for partitioning the iron between FeO and Fe_2O_3. In the absence of any other overriding factors, such as compatibility with previous work, it is suggested that Fe_2O_3/FeO of 0.2 (FeO/Fe total 0.83) is used for rocks where (Na_2O+K_2O) <6%, and Fe_2O_3/FeO of 0.3 (FeO/Fe total 0.75) is used for rocks, where (Na_2O+K_2O) >6% (after Middlemost, 1989).

Each analysis must then be checked to establish whether it is a 'high-Mg' rock, i.e. a **picrite**, **komatiite**, **meimechite** or **boninite** (see Figure 17 for the position of these rocks in the hierarchy). This is done as follows (Figure 22).

boninite — $SiO_2 > 53\%$, $MgO > 8\%$ and $TiO_2 < 0.5\%$.
picritic rocks — $SiO_2 < 53\%$, $Na_2O+K_2O < 2.0\%$ and $MgO > 18\%$.

Picritic rocks are divided into-

picrite	$Na_2O + K_2O > 1\%$
komatiite	$Na_2O + K_2O < 1\%$ and $TiO_2 < 1\%$
meimechite	$Na_2O + K_2O < 1\%$ and $TiO_2 > 1\%$

If the rock is not one of these 'ultramafic' types, it should be classified using the TAS diagram. Some of the fields on the TAS diagram of Figure 20 can be divided as described below.

Field B — The root name **basalt** may be divided into *alkali* **basalt** and *subalkali* **basalt** according to the state of silica saturation. If the analysis contains normative nepheline the rock may be called an *alkali* **basalt**; if the analysis contains no normative nepheline it may be called a *subalkali* **basalt**. 'Tholeiitic basalt' is a sub-group of *subalkali* **basalt**. It is recommended that use of the terms 'tholeiite' and 'tholeiitic' as rock names or as part of rock names be discontinued, though 'tholeiitic' may still be used to denote a suite of rocks displaying characteristic chemical features (e.g. a 'tholeiitic trend'; see Section 8.4 *Terms used to name suites of rocks*). The terms 'tholeiite' and 'tholeiitic' have, in the past, also been used to denote a textural variant; such usage should be discontinued.

Fields B, O_1, O_2, O_3, R — The root names **basalt** (if $SiO_2 > 48\%$), **basaltic-andesite**, **andesite**, **dacite** and **rhyolite** may be qualified using the terms *low-K*, *medium-K* and *high-K*, as shown in Figure 23. The term *high-K* is not synonymous with the term *potassic*, which is defined below.

Field R — The term *peralkaline* may be used as a qualifier if the peralkaline index, (molecular $[Na_2O + K_2O]/Al_2O_3$) is greater than 1, for example *peralkaline* **rhyolite**.

Field T — This field contains the root names **trachyte** and **trachydacite**, which are distinguished by the amount of CIPW normative Q in Q + An + Ab + Or (i.e. the normative equivalent of Q and QAPF). If the value is less than 20% the rock is called **trachyte**; if greater than 20% it is a **trachydacite**. The term *peralkaline* may be used as a qualifier if the peralkaline index (see 'Field R', above) is greater than 1, for example *peralkaline* **trachyte**.
Peralkaline **rhyolite** and *peralkaline* **trachyte** can be divided into *comenditic* **rhyolite**, *comenditic* **trachyte**, *pantelleritic* **rhyolite**, and *pantelleritic* **trachyte** according to the method of Macdonald (1974), which is based on the relative amounts of Al_2O_3 *versus* total iron as FeO, as shown in Figure 24.

Field S1 — Rocks with the root name **trachybasalt** may be named more precisely according to the relative amounts of Na_2O and K_2O. If Na_2O minus 2 is greater than K_2O the rock is considered to be sodic and is called **hawaiite**; if Na_2O minus 2 is less than K_2O the rock is considered to be potassic and is called **potassic-trachybasalt**.

Field S2 — Using the same criteria as for Field S1, rocks with the root name **basaltic-trachyandesite** may be named more precisely as **mugearite** (sodic), and **shoshonite** (potassic), respectively.

Field S3 — Using the same criteria as for Field S1, rocks with the root name **trachyandesite** may be named more precisely as **benmoreite** (sodic), and **latite** (potassic), respectively.

Fields U1, F — Field U1 contains rocks with the root names **basanite** and **tephrite**, while Field F contains **foidite**, of which the two main varieties are **nephelinite** and **leucitite**. The boundary between these fields is dashed on the TAS diagram, as nephelinites and leucitites can fall in both. Additional parameters are required to distinguish these rocks more effectively (see Le Maitre et al., 1989).

6 'EXOTIC' CRYSTALLINE IGNEOUS ROCKS

Seven groups of crystalline igneous rocks — the Carbonatites, Melilitic rocks, Kalsilitic rocks, Kimberlites, Lamproites, Leucitic rocks and Lamprophyres — are classified as mineralogically and chemically 'exotic' (Figures 1 and 2). Rocks in these groups have sufficiently unusual mineral and chemical compositions that they are not classified using the modal (QAPF and ultramafic diagrams) or chemical (e.g. TAS) methods by which 'normal' crystalline igneous rocks are classified. Although they comprise only a tiny proportion of all crystalline igneous rocks, the unusual characteristics and distinctive field settings of the exotic igneous rocks means they have attracted a large amount of attention from geologists. As a result, there exists a large and confused nomenclature and a variety of classification schemes. The IUGS has recently published new recommendations for the classification of lamprophyres, lamproites, kimberlites and the kalsilite-, melilite- and leucite-bearing rocks following an extensive review (Woolley et al., 1996). New 'characterisations' of the rock types are given in mineralogical and/or geochemical terms, and a revised sequence for the systematic classification of the rocks is provided which integrates with the existing IUGS system of Le Maitre et al. (1989). The revised scheme is presented as the best *compromise* that was achievable, however it still suffers from somewhat confusing terminology and a lack of clear definitions.

The exotic alkaline rocks have never been classified satisfactorily, and this remains so despite recent advances, particularly in kimberlite and lamproite nomenclature. The recent publication by the IUGS has tightened up aspects of the nomenclature, definitions and classification of these rocks, however a detailed petrographical and chemical examination is still required before most of these rocks can be classified satisfactorily, and in many cases a knowledge of the field setting provides a crucial piece of evidence. Any classification of a rock as a **lamprophyre**, **kimberlite** or **lamproite** using this system should be considered provisional until further investigations using the specialised literature as a key to correct classification have been undertaken. For no other groups of igneous rocks is the petrogenetic component of classification more important than for lamprophyres, lamproites and kimberlites.

In this section, definitions or characterisations for each of the main 'exotic' rock types are presented, as they are given by the IUGS (Woolley et al., 1996). If the precise mineralogical and/or chemical nature of the rocks is not known, no attempt should be made to classify them or to assign a root name unless unequivocal evidence is provided by either the field setting or by a characteristic mineralogical assemblage that is identifiable in hand specimen. In the absence of either of these, a more general field name should be used, such as *biotite-phyric-exotic* **mafite**. Only when sufficient mineralogical and/or chemical evidence has been obtained to assign a rock unequivocally to one of the main 'exotic' rock types, as they are defined below, should a more specific name such as *biotite-phyric* **lamprophyre** or an approved root name such as **spessartite** be assigned.

6.1 Carbonatites

Carbonatites are defined as igneous rocks that contain more than 50% modal primary carbonate (Streckeisen, 1978; 1979). They are known to occur in extrusive, shallow and deep-seated environments.

6.1.1 Classification of carbonatites

The hierarchical classification scheme for carbonatites is shown in Figure 25. In mineralogical terms the following types of **carbonatite** can be distinguished:

calcite-carbonatite	more than 90% of the carbonate is calcite.
dolomite-carbonatite	more than 90% of the carbonate is dolomite.
ferroan-carbonatite	the main carbonate mineral is ferroan dolomite, ankerite or siderite. These can be distinguished from other carbonates by stain tests.
natrocarbonatite	composed essentially of sodium, potassium and calcium carbonate minerals.

6.1.2 Use of qualifier terms in naming carbonatites

The root names for carbonatites have no grain size connotations, so it is important that grain size qualifier terms (see Section 3.2 *Grain size definitions* and 7.2.1 *Qualifiers to indicate grain size*) are used in the rock name, for example *fine-grained* **dolomite-carbonatite**. Mineral qualifiers should be used to indicate the presence of minor components of carbonate minerals that are not implied by the root name, for example *calcite-bearing-fine-grained* **dolomite-carbonatite**. Mineral qualifiers should be used for non-carbonate components, for example *apatite-bearing* **calcite-carbonatite**. Mineral qualifiers should also be used where non-carbonatitic igneous rocks contain significant proportions (but less than 50%) of primary carbonate, for example *carbonate-bearing* **nephelinite** (> 10% modal primary carbonate) or *calcite-rich* **nephelinite** (20 to 50% modal primary calcite). Colour index qualifiers (see Section 7.3 *Qualifiers based on colour*) should not be used when naming carbonatitic rocks as all primary carbonate minerals fall into group M. A qualifier term to indicate the colour of the rock can, however, be given. General guidelines are provided in Section 7 for applying qualifier terms.

6.1.3 Chemical classification of carbonatites

If a carbonatite is too fine grained for an accurate mode to be determined, or if the carbonate minerals are complex Ca-Mg-Fe solid solutions, the chemical classification shown in Figure 26 should be used. The root names **calciocarbonatite**, **magnesiocarbonatite** and **ferrocarbonatite** should be used only when the chemical classification of Figure 26 has been used.

In the IUGS recommendations for classifying igneous rocks (Le Maitre et al., 1989) the name **ferrocarbonatite** could be assigned through either the modal or chemical methods of classifying carbonatitic rocks. In the present scheme, the name assigned on modal grounds has been changed to **ferroan-carbonatite** so that it is clear by which method the rock has been assigned a name.

6.2 Melilitic rocks

All rocks which contain more than 10% modal melilite should be classified according to the scheme for melilitic rocks (Streckeisen, 1978; 1979).

Although light-coloured, melilite is classified as a mafic mineral belonging to group M. Melilitic rocks are divided into ultramafic and non-ultramafic sub-groups (Figure 27). If melilite can be determined modally and is more than 10%, and M is greater than 90%, the triangular diagrams of Figure 28 should be used for classifying coarse-grained and fine-grained rocks.

6.2.1 Classification of ultramafic melilitic rocks

The general name for coarse-grained melilitic rocks is melilitolite, and they are classified according to their mineral content, as shown in Figure 28a, to produce the root names **melilitolite**, **olivine-melilitolite**, **pyroxene-melilitolite**, **pyroxene-olivine-melilitolite** and **olivine-pyroxene-melilitolite**. The root names **pyroxene-melilitolite**, **olivine-melilitolite** and **olivine-pyroxene-melilitolite** replace the special varietal terms 'uncompahgrite', 'kugdite' and 'olivine uncompahgrite', respectively.

The general name for fine-grained melilitic rocks is melilitite and, where possible, they should be classified according to their mineral content, as shown in Figure 28b, to produce the root names **melilitite** and **olivine-melilitite**. Even in fine-grained rocks melilite can usually be identified in thin section when it is present in essential proportions (i.e. > 10%). If the rock is altered the melilite is usually carbonated. If the mode cannot be determined, the total alkali silica (TAS) classification (shown in Figure 20) should be used along with the following instructions:

- the rock should plot in the foidite field
- if it has > 10% larnite (synonymous with calcium orthosilicate [cs]) in the norm it is a **melilitite**
- if it has > 10% larnite and $K_2O < Na_2O$ (wt.%) then it is a **melilitite** or **olivine-melilitite**
- if $K_2O > Na_2O$ and $K_2O > 2$ wt.% it is a *potassic* **melilitite** or *potassic* **olivine-melilitite**. Previously, the latter would probably have been called a katungite; now it may be a *leucite* **olivine-melilitite** or a *kalsilite* **olivine-melilitite**
- if it has <10% larnite in the norm the rock is a *melilite* **nephelinite** or a *melilite* **leucitite** according to the nature of the most abundant foid mineral.

Where the TAS classification has been used to classify and name a rock this should be indicated with the rock name, for example *potassic* **melilitite** (**TAS**).

6.2.2 Non-ultramafic rocks containing melilite

Rocks that are not ultramafic (i.e. M< 90%), but contain more than 10% melilite should be given the prefix 'melilite' with the appropriate root name from either the coarse-grained or fine-grained QAPF classifications (see Section 5.1 *Coarse-grained crystalline igneous rocks* and 5.2 *Fine-grained crystalline igneous rocks*), for example *melilite* **nephelinite**.

Even if melilite does not exceed 10% of the mode the presence of this mineral is so important that it should always be indicated in the rock name, for example *melilite-bearing* **nephelinite**, which indicates a nephelinite with <10% melilite.

6.3 Kalsilitic rocks

All rocks which contain more than 10% modal kalsilite should be classified as kalsilitic rocks.

6.3.1 Classification of kalsilitic rocks

Kalsilite is a very rare mineral, and its presence is sufficiently important to merit defining rocks with more than 10% kalsilite as a separate group. The current IUGS recommendations (Woolley et al., 1996) do not state a threshold value for kalsilite content above which a rock becomes a kalsilitite, and this presents a serious drawback in terms of defining and classifying such rocks. In the present scheme a threshold value of 10% modal kalsilite has been adopted, the same as the threshold for melilitic and leucitic rocks. Kalsilite behaves metastably and only rarely survives slow cooling, so virtually all rocks containing kalsilite are fine- or very fine-grained lavas. Coarse-grained rocks containing kalsilite (e.g. *kalsilite-bearing* **syenite** and *kalsilite-bearing-biotite* **pyroxenite**) have been reported from Russia; however they are extremely rare.

All rocks which contain more than 10% modal kalsilite should be classified as kalsilitic rocks. At present, only one true kalsilitic rock is known, namely *olivine-pyroxene* **kalsilitite**, known formerly as 'mafurite', from Uganda. No coarse-grained rocks containing more than 10% modal kalsilite have been found so far, but if such a rock is found, it should be called a **kalsilitolite**, following the convention used in the melilitic rocks. As with melilitic rocks, **kalsilitite** and **kalsilitolite** are the only possible root names in the kalsilitic classification, though mineral qualifiers should be used where appropriate.

Even if kalsilite does not exceed 10% of the mode, its presence should be indicated in the rock name using mineral qualifier terms (as described in Section 7.1 *Qualifiers based on mineralogical criteria*) with an appropriate root name from either the coarse-grained or fine-grained QAPF classifications (see Sections 5.1 *Coarse-grained crystalline igneous rocks* and 5.2 *Fine-grained crystalline igneous rocks*). For example, *kalsilite-bearing* **nephelinite** implies a nephelinite with < 10% kalsilite. Examples of kalsilite-bearing rocks and their recommended nomenclature are shown in Figures 29 and 30.

6.4 Kimberlites

According to the current IUGS recommendations of Woolley et al. (1996), kimberlites are defined (after Mitchell, 1986) as volatile-rich (dominantly CO_2), potassic, ultrabasic rocks which commonly exhibit a distinctive inequigranular texture resulting from the presence of macrocrysts (and in some instances megacrysts) set in a fine-grained matrix. The megacryst/macrocryst assemblage consists of anhedral crystals of some or all of the following phases: olivine, magnesian ilmenite, Cr-poor titanian pyrope, Cr-poor (commonly subcalcic) diopside, phlogopite, enstatite and Ti-poor chromite. Olivine macrocrysts are a characteristic feature in all but fractionated kimberlites. The matrix contains a second generation of euhedral olivine, which occurs together with one or more of the following primary minerals: monticellite, phlogopite, perovskite, spinel (solid solutions between magnesian-ulvospinel, magnesiochromite, ulvospinel-magnetite), apatite and serpentine. Many kimberlites contain late-stage poikilitic micas belonging to the barian phlogopite-kinoshitalite series. Nickeliferous sulphides and rutile are common accessory minerals. The replacement of early-formed olivine, phlogopite, monticellite and apatite by deuteric serpentine and calcite is common. Evolved members of the group may be devoid of, or poor in, macrocrysts and/or composed essentially of second generation olivine, calcite, serpentine and magnetite, together with minor phlogopite, apatite and perovskite. Kimberlites do not contain primary diopside; when present, diopside is a secondary phase, the crystallisation of which is induced by assimilation of siliceous xenoliths.

6.4.1 Classification of kimberlites

Kimberlites are currently divided into two groups. **Group-1-kimberlite** corresponds to archetypal rocks from Kimberley, South Africa that formerly were termed ‘basaltic kimberlites’ by Wagner (1914). **Group-2-kimberlite** corresponds to micaceous or lamprophyric kimberlites (Wagner, 1914). Note that these terms are compound root names. Recent studies (Smith et al., 1985; Skinner, 1989; Mitchell, 1995; Tainton and Browning, 1993) have demonstrated that these two groups are mineralogically different and petrogenetically separate rock types. The definition for kimberlite given above refers only to archetypal (Group 1) kimberlites. No modern definition of Group-2-kimberlites has yet been published. Rocks now known as Group-2-kimberlites, or micaceous kimberlites, are characterised by the presence of macrocrysts, phenocrysts and groundmass micas, which vary from phlogopite to tetraferriphlogopite. Rounded olivine macrocrysts and euhedral primary olivines are common, but not essential, major constituents. Characteristic primary groundmass minerals include diopside, spinel (Mg-chromite-Ti-magnetite), Sr- and REE-rich perovskite, Sr-rich apatite, REE-rich phosphates, potassic barian titanates belonging to the hollandite group, Nb-rutile, Mn-ilmenite, calcite, dolomite, ancylite and other REE carbonates, norsethite and serpentine. Rare, evolved members of the group contain sanidine and potassian richterite. Barite is a common secondary mineral.

Some kimberlites have a fragmental origin (i.e. they are volcaniclastic). The classification and nomenclature of these is described in Section 4. *Fragmental igneous rocks*.

6.5 Lamproites

The scheme for classifying lamproites described by Mitchell and Bergman (1991) has been recommended by the IUGS (Woolley et al., 1996) and is adopted here. There is no universally accepted definition for lamproites, however they occur characteristically as lavas, pipes and dykes and are identified by the criteria described below. Some lamproites have a fragmental origin (i.e. they are volcaniclastic). The classification and nomenclature of these is described in Section 4. *Fragmental igneous rocks*.

6.5.1 Mineralogy of lamproites

Lamproites are characterised by the presence of widely varying amounts (5–90 vol.%) of the following primary minerals:

- titanian (2–10 wt.% TiO_2), Al_2O_3-poor (5–12 wt.%), phenocrystic phlogopite
- titanian (5–10 wt.% TiO_2), groundmass poikilitic tetraferriphlogopite
- titanian (3–5 wt.% TiO_2), potassic (4–6 wt.% K_2O) richterite; forsteritic olivine
- Al_2O_3-poor (< 1 wt.%), Na_2O-poor (< 1 wt.%) diopside
- non-stoichiometric, Fe-rich (1–4 wt.% Fe_2O_3) leucite
- Fe-rich sanidine (typically 1–5 wt.% Fe_2O_3)

The presence of all the above minerals is not required in order to classify a rock as a lamproite. Any one mineral may be dominant and the association with two or three others suffices to determine the petrographic name. Minor and common accessory minerals include priderite, wadeite, apatite, perovskite, magnesiochromite, titanian magnesiochromite and magnesian titaniferous magnetite with, less commonly but characteristically, jeppeite, armalcolite, shchberbakovite, ilmenite and enstatite. The presence of the following minerals precludes a rock from being classified as a lamproite: primary plagioclase, melilite and/or monticellite, kalsilite, nepheline, Na-rich alkali feldspar, sodalite, nosean, haüyne, melanite, schorlomite or kimzeyite.

6.5.2 Chemistry of lamproites

Lamproites have the following chemical characteristics:

molar* $K_2O/Na_2O > 3$, i.e. they are ultrapotassic;
molar $K_2O/Al_2O_3 > 0.8$ and commonly > 1;
molar $(K_2O + Na_2O)/Al_2O_3 > 0.7$ and typically > 1, i.e. they are peralkaline; typically they have < 10 wt.% of each of FeO and CaO, Ba> 2000 and commonly > 5000 ppm, TiO_2 1–7 wt.%, Zr > 500, Sr > 1000 and La > 200 ppm.

* molar values are calculated by dividing the weight percent of an oxide in a chemical analysis by its molecular weight, for example: wt.% K_2O / molecular weight K_2O.

6.5.3 Nomenclature of lamproites

Mitchell and Bergman (1991) proposed that the historical names for lamproites be discarded in favour of names based on the predominance of phlogopite, richterite, olivine, diopside, sanidine and leucite. The IUGS (Woolley et al., 1996) has approved this approach. According to this scheme the root name becomes, **lamproite**, but the term must always be used with appropriate essential mineral qualifiers. The new IUGS-approved names (after Mitchell and Bergman, 1991) together with their historical equivalents are given below.

Historical name	New name
Wyomingite	*diopside-leucite-phlogopite* **lamproite**
Orendite	*diopside-sanidine-phlogopite* **lamproite**
Madupite	*diopside-madupitic* **lamproite**
Cedricite	*diopside-leucite* **lamproite**
Mamilite	*leucite-richterite* **lamproite**
Wolgidite	*diopside-leucite-richterite-madupitic* **lamproite**
Fitzroyite	*leucite-phlogopite* **lamproite**
Verite	*hyalo-olivine-diopside-phlogopite* **lamproite**
Jumillite	*olivine-diopside-richterite-madupitic* **lamproite**
Fortunite	*hyalo-enstatite-phlogopite* **lamproite**
Cancalite	*enstatite-sanidine-phlogopite* **lamproite**

The term *madupitic*, which is used as a qualifier in some of the new names, indicates that the rock contains poikilitic groundmass phlogopite, as opposed to a *phlogopite* **lamproite**, in which the phlogopite occurs as phenocrysts.

6.6 Leucitic rocks

Leucite-containing rocks, after elimination of rocks classified as lamproites, should be named according to the QAPF diagram for fine-grained crystalline rocks (Figure 19), with the prefix *leucite* or *leucite-bearing*, as appropriate. Rocks containing little or no feldspar, i.e. falling in field 15 ('foidite') of Figure 19, have the root name **leucitite**. In all known leucitic rocks the leucite occurs as phenocrysts and should be readily identifiable in hand-specimen. Three types of leucitite correspond to the three sub-fields of field 15 (described in Section 5.2.3).

i QAPF sub-field 15a, **phonolitic-leucitite**
foids constitute 60 to 90% of light-coloured constituents; alkali feldspar > plagioclase
ii QAPF sub-field 15b, **tephritic-leucitite**
foids constitute 60 to 90% of light-coloured constituents; plagioclase > alkali feldspar
iii QAPF sub-field 15c, **leucitite *s.s.***
foids constitute 90 to 100% of light-coloured constituents; leucite is the only, or virtually the only, feldspathoid mineral.

Leucitic rocks are classified on modal grounds only, as unambiguous chemical criteria have not been devised to distinguish this group of rocks. On TAS, leucitites extend grossly beyond the foidite field on to adjacent fields. They are distinguished more clearly from lamproites by other chemical properties, although even here some chemical gradation occurs. The chemical characteristics of the potassic rocks, and attempts at distinguishing lamproites and certain leucite-bearing rocks using a number of criteria, are explored by Foley et al. (1987) and by Mitchell and Bergman (1991).

6.7 Lamprophyres

Lamprophyres (Figure 31) are mesocratic to melanocratic igneous rocks, usually hypabyssal, with a panidiomorphic texture and abundant mafic phenocrysts of dark mica (biotite or Fe-phlogopite) and/or amphibole, with or without pyroxene, with or without olivine, and sometimes melilite, set in a matrix of the same minerals. Any feldspar, usually alkali feldspar, is restricted to the groundmass. They may be classified according to their mineral content as shown in Figure 32 (after Streckeisen, 1978). The term 'lamprophyric rocks' was used in Le Maitre et al. (1989) to include lamprophyres, lamproites and kimberlites, but in accordance with the recommendations of Woolley et al. (1996) such usage should now be discontinued.

A completely satisfactory definition of lamprophyre has yet to be agreed (see Woolley et al., 1996), and it is possible that other exotic rocks for which there is not yet a classification could be included.

7 QUALIFIER TERMS

Qualifier terms (shortened to 'qualifiers' hereafter) may be added to root names to make rock names more specific. Traditionally, the majority of qualifiers have belonged to one of six types: mineral names, textural terms, colour indicators, chemical terms, genetic terms and tectonic terms. To keep this classification relatively simple and essentially descriptive (i.e. non-genetic), it is recommended that qualifiers should henceforth be restricted to mineral names, textural terms and colour indicators.

Providing guidelines for the systematic use of qualifiers is highly problematic and, to be completely effective, would involve listing all the terms of potential significance, defining each of them clearly and unambiguously, and explaining how and when each should be used. At present, recommendations for the use of qualifiers are restricted to a list of general guidelines and definitions of some of the more commonly used ones. The lists of qualifiers given in this section are not intended to be exhaustive, but serve as examples of how qualifiers should be used in constructing a rock name. Qualifiers not listed here can be used, provided their presence in the rock name is considered important. In such cases the qualifier term(s) must be defined clearly in, for example, a notebook, report or publication. It is possible that a list of approved qualifier term definitions may be constructed in the future, to which new terms will be added when necessary.

The following general guidelines for the use of qualifiers should be applied in most cases.

i Qualifiers should be used only where they are contributing information of value to the rock name. For example:
• a mineral qualifier should be used only where a mineral is present that is not implicit in the rock name or normally associated with the rock in question.
• If a suite or unit of volcaniclastic rocks is welded, here is little point in applying the qualifier *welded* to every rock name — a simple reference to the fact could be made in a field notebook or on a field map. However, where there is local textural variation (e.g. welded and unwelded rocks) this important information could be recorded conveniently using qualifier terms in the rock name.

ii The number of qualifier terms used in a single rock name should be kept to a minimum — beyond two or three qualifier terms a rock name becomes unwieldy and clumsy to use. However, some rocks, particularly finer-grained ones and those in the 'exotic' crystalline igneous rocks, can only be described satisfactorily by using several mineral and/or textural qualifiers with a root name.

iii All qualifier terms should be linked by hyphens, but hyphens must not be used to link qualifiers with a root name (see setion 2.2 *Use of hyphens*). Colour index prefixes may be used with qualifiers in the same rock name the colour index prefix should be appended to the root name (see Section 5.1.6 *Modification of root names using colour index prefixes*), for example *biotite-bearing-hornblende* **meladiorite**.

iv It is neither possible, nor desirable, to have all observable petrographic features built into a rock name. Ultimately, the choice of what qualifiers to use will depend on the individual, and will probably be governed largely by factors that have direct relevance to the rocks in the sampling area or to the study for which the rocks are being mapped or collected.

7.1 Qualifiers based on mineralogical criteria

Mineral qualifier terms must not conflict with the definition of the root name. For example, *biotite* **granite**, must still be a granite in the sense of the classification. A name such as *quartz-free* **granite** is not permissible because a rock could not be classified as a granite if it contained no quartz. Conversely, there is no point in listing a mineral as a qualifier if it is an essential constituent and has been used to generate the root name, for example *quartz* **granite**.

A systematic approach to applying mineral names as qualifiers is complicated because the significance of a particular mineral can vary according to the nature of the host rock. For example, a small proportion of biotite is significant in gabbroic rocks but insignificant in granitic rocks. Suffixes to mineral qualifiers to indicate the abundance of a mineral should be used as follows:

- *-bearing* where the mineral comprises < 5% of the rock
- the mineral name only where it comprises > 5% and < 20% of the rock
- *-rich* where the mineral comprises >20% of the rock

Thus, the names **gabbro**, *biotite-bearing* **gabbro**, *biotite* **gabbro** and *biotite-rich* **gabbro** denote coarse-grained crystalline rocks of gabbroic composition with respectively greater biotite contents.

If more than one mineral qualifier is used, the name of the most abundant mineral should appear closest to the root name; for example, a *hornblende-biotite* **diorite** contains more biotite than hornblende, though each mineral constitutes between 15 and 20% of the rock. A *hornblende-bearing-biotite-rich* **diorite** would plot in the QAPF diorite field and would have less than 15% hornblende and more than 20% biotite.

7.2 Qualifiers based on textural criteria

The following is a list of some of the more common textural qualifiers, with an indication of how they should be applied.

7.2.1 Qualifiers to indicate grain size

The following grain size terms have already been defined in Section 3.2 *Grain size definitions*.

Very-coarse-grained	crystal diameters > 16 mm
Coarse-grained	crystal diameters > 2 mm < 16 mm
Medium-grained	crystal diameters > 0.25 mm < 2 mm
Fine-grained	crystal diameters > 0.032 mm < 0.25 mm
Very-fine-grained	crystal diameters > 0.004 mm < 0.032 mm
Cryptocrystalline	crystal diameters < 0.004 mm (4 µm)

In practice, only the terms *very-coarse-grained* and *very-fine-grained* will be used as qualifiers in most cases, as grain size is implicit in nearly all igneous rock names (for example, **gabbro** implies coarse- and/or very coarse-grained, **basalt** implies fine- and/or very fine-grained), provided the name is applied at a sufficiently high level in the hierarchy. The exceptions are carbonatites, kimberlites, lamproites and lamprophyres, and for these grain size qualifiers may be used more frequently. The terms 'micro-' or 'microcrystalline', which are used to imply 'too fine-grained to distinguish in hand specimen' should not be used in this context as they may be confused with the prefix 'micro', which in the present scheme is used with root names for coarse-grained crystalline rocks to denote a medium-grained rock (see Section 3.2 *Grain size definitions*).

Special grain size terms include *pegmatitic* and *aplitic* and these are discussed in Section 8.1 *Rock names based on field association*.

7.2.2 Qualifiers to indicate crystallinity

Where rocks contain glass, the amount of glass should be indicated by using the following prefixes (modified after Streckeisen, 1978; 1979):

glass-bearing	where the rock contains 0 to 20% glass
glass-rich	where the rock contains 20 to 50% glass
glassy	where the rock contains 50 to 100% glass

The current IUGS recommendations are similar, but differ slightly in that 'glassy' in the IUGS scheme implies 50 to 80% glass, and 'special terms such as obsidian, pitchstone, etc.' are to be used for rocks with more than 80% glass. These definitions have been modified slightly here so that, where possible, the root-name-and-qualifier approach can still be used for rocks containing any amount of glass; thus, glassy rocks which have been analysed chemically may be termed *glassy* **rhyolite**, or *glassy* **dacite**, for example. The terms **obsidian** and **pitchstone** may still be used, but only as they are defined in Section 8.3 *Sack names for rocks that are difficult to classify in the field.*

7.2.3 Qualifiers to indicate relative grain size in a rock

Granular	all crystals approximately of equal size
Inequigranular	crystals differ substantially in size

Phyric or porphyritic texture is an example of the latter, where relatively large crystals are embedded in a finer-grained groundmass. In naming such a rock the minerals that are present as phenocrysts should be listed and followed by the suffix *-phyric*, for example *hornblende-plagioclase-phyric* **basalt**.

The textural term *seriate* is used to denote a continuous range of crystal sizes of the principal minerals.

7.2.4 Qualifiers to indicate intergrowth textures

The following definitions are taken from MacKenzie et al. (1982).

Graphic	a regular intergrowth of two minerals producing the appearance of cuneiform, semitic or runic writing. The best-known instance is of quartz and alkali feldspar, the quartz appearing as isolated wedges and rods in the feldspar.
Granophyric	a variety of (micro)graphic intergrowth of quartz and alkali feldspar which is either crudely radiate or is less regular than (micro)graphic texture.

7.2.5 Qualifiers to indicate orientated, aligned and directed textures

The following definitions are taken from MacKenzie et al. (1982).

Pilotaxitic	a subparallel arrangement of tabular, bladed or prismatic crystals which are visible to the naked eye. The synonymous term 'trachytic' should no longer be used to avoid confusion with the rock names **trachyte** and **trachytic rock**, which have compositional meaning and no textural implications. Similarly, the terms 'flow' and 'fluxion-textured' should not be used because of their genetic implications.
Orbicular	orbs consisting of concentric shells of rhythmically alternating mineral constitution.

Variolitic	a fan-like arrangement of divergent, often branching fibres; usually the fibres are plagioclase and the space between is occupied by glass or granules of pyroxene, olivine or iron oxide.
Spherulitic	spheroidal bodies (spherulites) in a rock that are composed of an aggregate of fibrous crystals of one or more minerals radiating from a nucleus, with glass or crystals in between. The most common occurrence of spherulitic texture is a radiate aggregate of acicular alkali feldspars with glass between them, though quartz or other minerals may be present.

7.2.6 Qualifiers to describe cavity textures

The following definitions are taken from MacKenzie et al. (1982).

Vesicular	round, ovoid or elongate irregular holes formed by gas expansion.
Amygdaloidal	former holes occupied by late-stage or post-magmatic minerals, for example carbonate, zeolites, and quartz.
Miarolitic	irregularly shaped cavities (druses) in plutonic and near surface rocks into which euhedral crystals of the rock project.
Lithophysic	a sphere consisting of concentric shells with hollow interspaces.

7.2.7 Special qualifiers for pyroclastic rocks

Textural qualifiers may be added to pyroclastic rock root names. Some of the more common ones are defined below, however it must be stressed that these should be included in a rock name only where such textures are considered to be an essential characteristic or are an important aspect of the particular study for which the rocks are being collected.

Welded	used when glass shards in a pyroclastic deposit have been sufficiently plastic (high temperature) after settling to sinter together during compaction or flow.
Eutaxitic	denotes a planar foliation texture, formed principally by the welding compaction of pumice and glass shards. Pumice fragments that have become elongate and lenticular in this way are termed 'fiammé'.
Parataxitic	denotes an extreme form of eutaxitic texture in which highly flattened and often stretched fiammé produce a linear fabric as opposed to a planar fabric.

7.2.8 Qualifiers to indicate metamorphic overprinting

The term *meta* should be used with an igneous root name to indicate that an igneous rock has been metamorphosed, for example **metagabbro**, but only when there is sufficient information for the original rock type to be ascertained and assigned to a particular QAPF field. This is the border zone with metamorphic rocks and the rocks may not be strictly 'igneous or igneous looking'. Where there is insufficient information to be certain of the igneous protolith they should be classified according to the scheme for metamorphic rocks using terms such as **ortho-amphibolite**. Definitions of these terms are given in the metamorphic rock classification scheme. Textural terms for metamorphic rocks, such as *foliated*, *hornfelsed*, *schistose* nd *gneissose*, may be used as qualifiers for igneous rocks which display these features, provided the rocks have a recognisably igneous protolith. Where metamorphic qualifier terms are used, the 'meta' prefix on the igneous root name should be retained, for example *schistose* **metabasalt**. Where this creates a name with a double vowel a hyphen should be used, for example **meta-andesite.**

7.3 Qualifiers based on colour

Qualifiers can be used to describe the colour of a rock, for example *pink* **granite**, but in many cases this will be part of the general description of a rock. This is inherently rather subjective but it is difficult to incorporate a Munsell Colour Index into a rock name.

The colour of a rock is not the same thing as the colour index **M'**, a modal parameter (see Section 3.1 *Determination of modal parameters*) which defines the proportion of dark and light coloured minerals.

	Range of M'
leucocratic	0–35
mesocratic	35–65
melanocratic	65–90
ultramafic	90–100

These absolute values are independent of the prefixes 'leuco' and 'mela' which are used to denote relatively light and dark variants of rocks. For these prefixes the threshold values of M' vary from rock group to rock group. Figures 33 and 34 show the limits within which each of these terms may be applied in the various rock groups. Shortened forms for colour index qualifier terms can be used and linked directly to root names, for example **leucogranite**, **melagabbro**.

8 ROCK NAMES THAT DO NOT CONFORM WITH THE SCHEME

Some igneous rocks cannot be described adequately using the root-name-and-qualifier approach adopted for most of this scheme. Some of these, for example lamprophyres, have been treated elsewhere. The remainder fall into three groups: (i) those which are more usefully named according to their field association; (ii) those which are more easily named according to the process by which they formed; (iii) those which are 'sack' terms for rocks which are difficult to classify in the field.

8.1 Rock names based on field association

8.1. 1 Pegmatite and pegmatitic

Many rocks described traditionally as 'pegmatite' or as 'pegmatitic' probably crystallised from a fluid-dominated media rather than from a melt-dominated media. In other words, these rocks occupy an area of overlap between 'vein and ore rocks' (which are the product of hydrothermal processes) and igneous rocks (which are the product of igneous processes). However, as most pegmatites and pegmatitic rocks are closely associated both spatially and genetically with igneous rocks, they are included here. We recommend that the terms be used in the following way.

The term **pegmatite** should be used only for veins comprised of coarse or very coarse crystals. Such rocks should be named by listing the component minerals as qualifiers in front of the term **pegmatite**, for example *biotite-quartz-feldspar* **pegmatite**. Following the convention described in Section 7.1 *Qualifiers based on mineralogical criteria*, the mineral qualifiers should be listed in order of increasing abundance. This usage involves departure from both the root-name-and-qualifier approach to naming igneous rocks and from the principle of non-genetic classification, however the exception is made because the term **pegmatite** in this context is of considerable value to field geologists. **Pegmatite** is, however, not a root name as it has no compositional inference. Approved rock names should not precede the term **pegmatite**. Thus, names such as 'granite pegmatite' or 'granitic pegmatite' should no longer be used.

The term *pegmatitic* can be used in a rock name only as a qualifier term in conjunction with a root name (or a less well-defined approved name) and only to describe a relatively coarser grained facies developed in a relatively finer-grained rock mass. Thus, the name *pegmatitic* **gabbro** denotes a coarse-grained rock of gabbroic composition containing areas which are markedly coarser-grained and of essentially the same composition, while *pegmatitic* **foid-syenitic-rock** denotes a coarse-grained rock of foid-syenitic composition containing areas which are markedly coarser-grained and of essentially the same composition. It should be emphasised that many igneous rock compositions can develop pegmatitic facies, and that the terms **pegmatite** and *pegmatitic* do not imply a granitic composition.

Veins and ore rocks will ultimately have their own classification scheme, and a more detailed account of how pegmatites and pegmatitic rocks should be classified and named may be presented in due course.

8.1.2 Aplite and aplitic

The name 'aplite' should no longer be used to denote a vein or facies of fine-grained crystals. Names such as 'felsite vein' or 'microgranite vein' should be used instead. Veins consisting of crystals that are very fine to medium grained, with mineral assemblages, textural features or field associations suggesting they are of igneous origin, should be named using the schemes described for fine-grained and medium-grained rocks.

The term *aplitic* can be used in a rock name only as a qualifier term in conjunction with a root name (or a less well defined approved name) and only to describe a relatively finer-grained facies developed in a relatively coarser-grained rock mass. Thus, the name *aplitic* **microgranite** denotes areas within medium-grained rock of granitic composition which are markedly finer grained and of essentially the same composition, while *aplitic* **foid-syenitic-rock** denotes a coarse-grained rock of foid-syenitic composition containing areas which are markedly finer-grained and of essentially the same composition. It should be emphasised that many igneous rock compositions can develop aplitic facies, and that the terms aplite and *aplitic* do not imply a granitic composition. The fine margin of a coarser grained intrusion could be described by using the qualifier *aplitic* with the rock name, for example *aplitic* **microgabbro** could have a grain size less than 0.25 mm, normally associated with basalt.

8.1.3 Dolerite

Dolerite is a very widely used name, synonymous with 'diabase', and traditionally denoting a medium-grained rock of basaltic composition, usually in hypabyssal (shallow) associations such as dykes and sills. According to the principle of naming all rocks using a root name and appropriate qualifiers, use of the names 'dolerite' and 'diabase' should be discontinued in favour of **microgabbro**. However, due to the very widespread usage of the name **dolerite**, it may be retained to denote a medium-grained rock of basaltic composition, with no textural or genetic implications. Use of the name 'diabase' should be discontinued.

8.2 Rock names based on processes

Some igneous rock names are used generally to describe deposits rather than rock types. These include the following:

Tuffisite, a term applied to intrusive fragmental igneous rocks, comprises brecciated and lithified country-rock fragments found in intrusive 'pipes' which are formed by the explosive release of gas.

Hyaloclastite is comprised of shattered, angular glassy fragments created by quenching of lavas (see Section 4.1.1 *Pyroclastic fragments*).

Pépérite is a lithified, fluidised mixture of hyaloclastite and sediment formed by the disruption and rapid chilling of magma when it is intruded into, or flows over, wet sediment.

Cumulates and rocks of restricted mineralogy

Igneous rocks of unusual composition can be found by extreme versions of magma differentiation and fractionation. Root names such as **chromitite** and **magnetite** can be used for rocks in which a single mineral exceeds 90% of the mode (except where approved QAPF names, such as **dunite** and **anorthosite** can be used instead). Where this is not the case, names for rocks of restricted minerology can be formed by listing the minerals present in ascending order of abundance, e.g. **olivine-chromite-rock** or **apatite-magnetite-rock**. 'Cumulate' is a term used for igneous rocks formed by crystal settling in a magma chamber, i.e. it is a genetic term. Some of the physical processes involved in producing cumulates result in sub-monomineralic layers. Rocks from such sequences may be named by using 'cumulate' as a qualifier term, to produce names such as *cumulate* **magnetitite** and *cumulate* **olivine-chromite-rock**.

8.3 'Sack' names for rocks that are difficult to classify in the field

These include the following:

Porphyry is a rock containing phenocrysts and with an aphanitic groundmass of indeterminate composition. Mineral qualifiers should be used with the term to indicate the phenocryst mineral(s), for example *hornblende*-**porphyry**.

Obsidian is a glassy, fresh, igneous rock. The term has no compositional inference.

Pitchstone is a glassy, altered (hydrated/devitrified) igneous rock. The term has no compositional inference.

8.4 Terms used to name suites of rocks

Rocks formed in a particular magmatic cycle or association may have common chemical or mineralogical characteristics and hence be grouped together as a rock series. There are many examples of series in the literature. Unfortunately, terms such as 'tholeiitic', 'calc-alkali' and 'appinitic' have in the past been used by different authors to mean different things and hence should not be used as individual rock names, or as part of a name. They should be restricted to naming suites of rocks with characteristic features, which may be petrographical or trends on chemical variation diagrams, for example in the phrase 'an appinitic suite of dykes'. Wherever they are used it is imperative that the user defines clearly what is implied by the term. Some examples of past use of series terms is given below.

'Tholeiitic' describes a variety of basalt which is saturated or slightly oversaturated in silica with respect to alkalis so that hypersthene appears in the CIPW norm and hypersthene or pigeonite amongst the modal pyroxenes. Olivine may be present in widely varying amounts, or absent. The term is also used for a suite of rocks showing marked iron-enrichment on AFM diagrams.

'Calc-alkali' describes a suite of basic to acid rocks that contain groundmass augite, plus hypersthene (basalts and andesites) or hornblende or biotite (dacites and rhyolites), and show little or no iron-enrichment on AFM diagrams.

'Appinitic' or 'appinite suite' denotes a group of deep-seated rocks where the dominant lithology is dioritic, with a characteristic texture of coarse-grained, euhedral hornblende in a matrix of anhedral to poikilitic feldspar. The suite includes meladiorites, gabbros, hornblendites and pyroxenites with abundant hydrous, mafic minerals, as well as granodioritic, monzonitic and syenitic rocks and lamprophyres. The rocks characteristically occur in sub-volcanic, zoned plugs, with a complex history of multiple intrusion, and are commonly associated with breccia pipes.

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APPENDIX

List of approved names for igneous rocks

This list contains most of the approved igneous rock names, with root names shown in **bold.** The aim of classification should always be to assign a root name whenever possible and practicable. Qualifier terms may be added to these names.

The column headed ‘Group’ shows which of the major groups the rock belongs to; ‘fgr’ indicates fine-grained crystalline rock, ‘cgr’ coarse-grained crystalline rock, ‘vclast’ volcaniclastic rocks, ‘lamp’ lamprophyre, ‘meli’ melilitic rocks, ‘leuci’ leucitic rocks and ‘carb’ carbonatites.

The column headed ‘QAPF Field’ shows the field in which relevant rocks plot on the QAPF diagram.

indicates that a second diagram needs to be used for full classification. Field 16 indicates ultramafic rocks that do not appear on the main QAPF diagram. **TAS** indicates that the rock is defined on chemical rather than modal criteria.

***** indicates that the word ‘foid’ can be replaced by the name of the dominant foid mineral or that ‘alkali-feldspar’ can be replaced by the dominant alkali feldspar mineral.

+ indicates that mineral qualifiers will often be used with this rock name

The column headed ‘Fig. no.’ indicates the number of the figure where the part of the classification scheme showing that particular rock is found.

Prefixes such as ‘micro’, ‘leuco’, ‘mela’ and ‘meta’ can be added to many of the names in the list.

Name	**Group**	**QAPF Field**	**Fig. no.**
agglomerate	vclast		4, 8
***alkali-feldspar-granite**	cgr	2	9, 11
***alkali-feldspar-rhyolite**	fgr	2	17a, 19
***alkali-feldspar-syenite**	cgr	6	9, 11
***alkali-feldspar-trachyte**	fgr	6	17a, 19
andesite	fgr	10	17a, 19
andesite(TAS)	fgr	TAS	17b, 20
andesitic-rock	field		17a, 18
anorthosite	cgr	10#	9, 11
anorthositic-rock	field		9, 10
ash	vclast		4, 5, 8
ash-breccia	vclast		4, 8
basalt	fgr	10	17a, 19
basalt(TAS)	fgr	TAS	17b, 20
basaltic-andesite	fgr	TAS	17b, 20
basaltic-rock	field		17a, 18
basaltic-trachyandesite	fgr	TAS	17b, 20
basanite	fgr	14	17a, 19
basanite(TAS)	fgr	TAS	17b, 20
***basanitic-foidite**	fgr	15b	17a, 19
benmoreite	fgr	TAS	17b, 20
block-tephra	vclast		4, 5, 8
bomb-tephra	vclast		4, 5, 8
boninite	fgr	TAS	17b, 22
calciocarbonatite	carb		25, 26
calcite-carbonatite	carb		25
camptonite	lamp		31
carbonatite	carb		1, 25
charnockitic-rock	charn		
charnockitic **+ QAP root- name**	charn		
chromitite			
clinopyroxene-norite	cgr	10#	1, 13, 14
clinopyroxenite	cgr	16#	15, 16
coarse-grained-normal-crystalline-rock			1
fine-grained-normal-crystalline-rock			1
comenditic **rhyolite**	fgr	TAS	24
comenditic **trachyte**	fgr	TAS	24
crystalline-igneous-rock			2
cumulate-rock			
dacite	fgr	4&5	17a, 19
dacite(TAS)	fgr	TAS	17b, 20
dacitic-rock	field		17a, 18
diorite	cgr	10	9, 11
dioritic-rock	field		9, 10
dolerite	cgr	10	
dolomite-carbonatite	carb		25
dunite	cgr	16#	15, 16
exotic-crystalline-igneous-rock			1
felsite	field		17
ferroan-carbonatite	carb		25
ferrocarbonatite	carb		25, 26
***foid-bearing-alkali-feldspar-syenite**	cgr	6’	9, 11
***foid-bearing-alkali-feldspar-trachyte**	fgr	6’	17a, 19
***foid-bearing-anorthosite**	cgr	10’	9, 11
***foid-bearing-diorite**	cgr	10’	9, 11
***foid-bearing-gabbro**	cgr	10’	9, 11
***foid-bearing-latite**	fgr	8’	17a, 19
***foid-bearing-monzodiorite**	cgr	9’	9, 11
***foid-bearing-monzogabbro**	cgr	9’	9, 11
***foid-bearing-monzonite**	cgr	8’	9, 11
***foid-bearing-syenite**	cgr	7’	9, 11
***foid-bearing-trachyte**	fgr	7’	17a, 19
***foid-diorite**	cgr	14	9, 11
*foid-dioritic-rock	field		9, 10
***foid-gabbro**	cgr	14	9, 11
*foid-gabbroic-rock	field		9, 10
***foid-monzodiorite**	cgr	13	9, 11
***foid-monzogabbro**	cgr	13	9, 11
***foid-monzosyenite**	cgr	12	9, 11
***foid-syenite**	cgr	11	9, 11
*foid-syenitic-rock	field		9, 10
***foidite**	fgr	15c	17a, 19
***foidite(TAS)**	fgr	TAS	17b, 20
*foiditic-rock	field		17a, 18
***foidolite**	cgr	15	9, 11
*foidolitic-rock	field		9, 10
fragmental-igneous-rock			1
fragmental-igneous-sediment			1
gabbro	cgr	10	9, 11
gabbro(s.s.)	cgr	10	13, 14
gabbroic-rock	field		9, 10
gabbronorite	cgr	10	13, 14
glassy-igneous-rock			1
granite	cgr	3	9, 11
granitic-rock	field		9, 10
granodiorite	cgr	4	9, 11
group-1-kimberlite	kimb		
group-2-kimberlite	kimb		
harzburgite	cgr	16#	15, 16
hawaiite	fgr	TAS	17b, 20
hornblende-gabbro	cgr	10#	13, 14
hornblende-peridotite	cgr	16#	15, 16
hornblende-pyroxenite	cgr	16#	15, 16
hornblendite	cgr	16#	15, 16
hornblendite(s.s.)	cgr	16#	15, 16
igneous-rock			1
igneous-sediment			1
ilmenitite			
kalsilitic-rock	kal		
kalsilitite	kal		
kalsilitolite	kal		

kersantite	lamp		31
kimberlite	kimb		
komatiite	fgr	TAS	22
lamproite	lamproite		
lamprophyre	lamp		31
lapilli-ash	vclast		4, 8
lapillistone	vclast		4, 5, 8
lapilli-tephra	vclast		4, 5, 8
lapilli-tuff	vclast		4, 8
latite	fgr	8	17a, 19
latite(TAS)	fgr	TAS	17b, 20
leucitite	fgr	15c and TAS	17b, 19, 20
leucitic-rock	leuci		
leucitolite	cgr	15	9, 11
leucitite (s.s.)	fgr	15c	17a, 19
lherzolite	cgr	16#	15, 16
mafite	field		17b
magnesiocarbonatite	carb		25, 26
magnetitite			
meimechite	fgr	TAS	22
melilite- (any QAPF root-name)	meli (where M< 90%)		
melitlite-bearing-ultramafic-volcanic-rock			28
melilitic-rock	meli (fgr)	TAS	27
melilitite	meli (fgr)	TAS	27, 28
melilitolite	meli (cgr)		27, 28
minette	lamp		31
monchiquite	lamp		31
monzodiorite	cgr	9	9, 11
monzogabbro	cgr	9	9, 11
monzogranite	cgr	3b	9, 11
monzonite	cgr	8	9, 11
mugearite	fgr	TAS	17b, 20
natrocarbonatite	carb		25
nephelinite	fgr	15c	17a, 19
nephelinolite	cgr	15	9, 11
non-ultramafic-melilitic-rock	meli		27
norite	cgr	10#	13, 14
normal-crystalline-igneous-rock			1
obsidian	field		
olivine-clinopyroxene-norite	cgr	10#	13, 14
olivine-clinopyroxenite	cgr	16#	15, 16
olivine-gabbro	cgr	10	13, 14
olivine-gabbronorite	cgr	10#	13, 14
olivine-hornblende-pyroxenite	cgr	16#	15, 16
olivine-hornblendite	cgr	16#	15, 16
olivine-melilitite	meli (fgr)		27, 28
olivine-melilitolite	meli (cgr)		27, 28
olivine-norite	cgr	10#	13, 14
olivine-orthopyroxene-gabbro	cgr	10#	13, 14
olivine-orthopyroxenite	cgr	16#	15, 16
olivine-pyroxene-hornblendite	cgr	16#	15, 16
olivine-pyroxene-melilitolite	meli (cgr)		27, 28
olivine-pyroxenite	cgr	16#	15, 16
olivine-websterite	cgr	16#	15, 16
orthopyroxene-gabbro	cgr	10#	13, 14
orthopyroxenite	cgr	16#	15, 16
pantelleritic **rhyolite**	fgr	TAS	24
pantelleritic **trachyte**	fgr	TAS	24
pegmatite + mineral prefix	field		
peridotite	cgr	16#	15, 16
phonolite	fgr	11	17a, 19
phonolite(TAS)	fgr	TAS	17b, 20

phonolitic-basanite	fgr	13	17a, 19
***phonolitic-foidite**	fgr	15a	17a, 19
phonolitic-leucitite	fgr	15a	17a, 19
phonolitic-rock	field		17a, 18
phonolitic-tephrite	fgr	13	17a, 20
phono-tephrite	fgr	TAS	17b, 20
picrite	fgr	TAS	17b, 22
picritic-rock	fgr	TAS	17b
picrobasalt	fgr	TAS	17b, 20
pitchstone	field		
porphyry + mineral qualifier prefix	field		
potassic-trachybasalt	fgr	TAS	17b, 20
pyroclastic-breccia	vclast		4, 5, 8
pyroclastic-rock	vclast		4
pyroclastic-sediment	vclast		4
pyroxene-hornblende-cpx-norite	cgr	10#	13, 14
pyroxene-hornblende-gabbro	cgr	10#	13, 14
pyroxene-hornblende-gabbronorite	cgr	10#	13, 14
pyroxene-hornblende-norite	cgr	10#	13, 14
pyroxene-hornblende-opx-gabbro	cgr	10#	13, 14
pyroxene-hornblende-peridotite	cgr	16#	15, 16
pyroxene-hornblendite	cgr	16#	15, 16
pyroxene-melilitolite	meli (cgr)		27, 28
pyroxene-olivine-melilitolite	meli (cgr)		27, 28
pyroxene-peridotite	cgr	16#	15, 16
pyroxenite	cgr	16#	15, 16
pyroxenite(s.s.)	cgr	16#	15, 16
quartz-alkali-feldspar-syenite	cgr	6*	9, 11
quartz-alkali-feldspar-trachyte	fgr	6*	17a, 19
quartz-anorthosite	cgr	10*	9, 11
quartz-diorite	cgr	10*	9, 11
quartz-gabbro	cgr	10*	9, 11
quartz-latite	fgr	8*	17a, 19
quartz-monzodiorite	cgr	9*	9, 11
quartz-monzogabbro	cgr	9*	9, 11
quartz-monzonite	cgr	10*	9, 11
quartzolite	cgr	1a	9, 11
quartz-rich-coarse-grained-crystalline-rock	field		9, 10
quartz-rich-granitic-rock	cgr	1b	9, 11
quartz-syenite	cgr	**7***	9, 11
quartz-trachyte	fgr	7*	17a, 19
rhyodacite	fgr	3b&4	17a, 19
rhyolite	fgr	3	17a, 19
rhyolite(TAS)	fgr	TAS	17b, 20
rhyolitic-rock	field		17a, 18
sannaite	lamp		31
shoshonite	fgr	TAS	17b, 20
spessartite	lamp		31
syenite	cgr	7	9, 11
syenitic-rock	field		9, 10
syenogranite	cgr	3a	9, 11
tephra	vclast		4, 8
tephri-phonolite	fgr	TAS	17b, 20
tephrite	fgr	14	17a, 19
tephrite(TAS)	fgr	TAS	17b, 20
***tephritic-foidite**	fgr	15b	17a, 19
tephritic-leucitite	fgr	15b	17a, 19
tephritic-phonolite	fgr	12	17a, 19
tephritic-rock	field		17a, 18
tonalite	cgr	5	9, 11
trachyandesite	fgr	TAS	17b, 20
trachybasalt	fgr	TAS	17b, 20

trachydacite	fgr	TAS	17b, 20
trachyte	fgr	7	17a, 19
trachyte(TAS)	fgr	TAS	17b, 20
trachytic-rock	field		17a, 18
troctolite	cgr	10#	13, 14
tuff	vclast		4, 5, 8
tuffaceous-sediment	vclast		4
tuffaceous-sedimentary-rock	vclast		4
tuffaceous- + sedimentary root name	vclast		4, 6
tuff-breccia	vclast		4, 8
tuffite	vclast		4
ultramafic-melilitic-rock	meli		27, 28

ultramafic-rock	field		9, 12
ultramafitite	fgr	16	17a, 19
vogesite	lamp		31
volcaniclastic-igneous-rock	vclast		1
volcaniclastic-igneous-sediment	vclast		1
volcaniclastic-sediment	vclast		4
volcaniclastic-sedimentary-rock	vclast		4
volcaniclastic- + sedimentary root name	vclast		4, 6
websterite	cgr	16#	15, 16
wehrlite	cgr	16#	15, 16

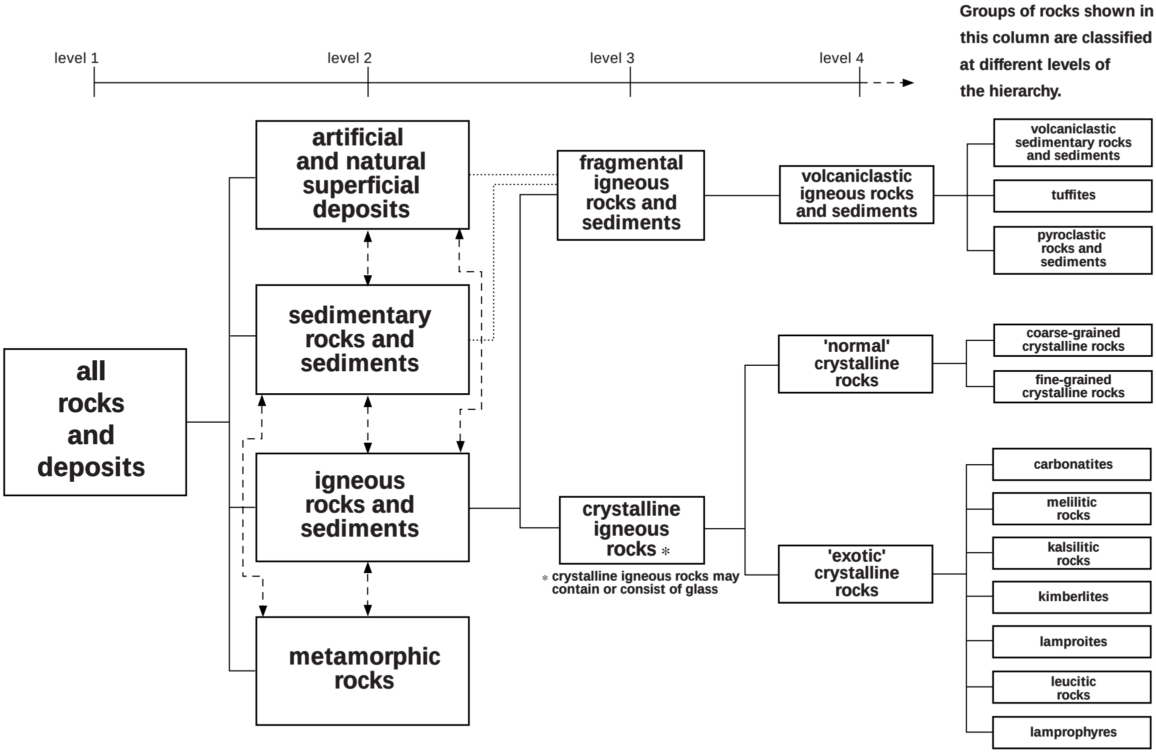


Figure 1 Hierarchical classification of igneous rocks and igneous sediments,
Dashed lines with arrows connect major groups of rocks and sediments between which there is a gradational 'boundary'. Dotted lines indicate that 'fragmental igneous rocks and sediments' may also or alternatively be classified within other schemes.

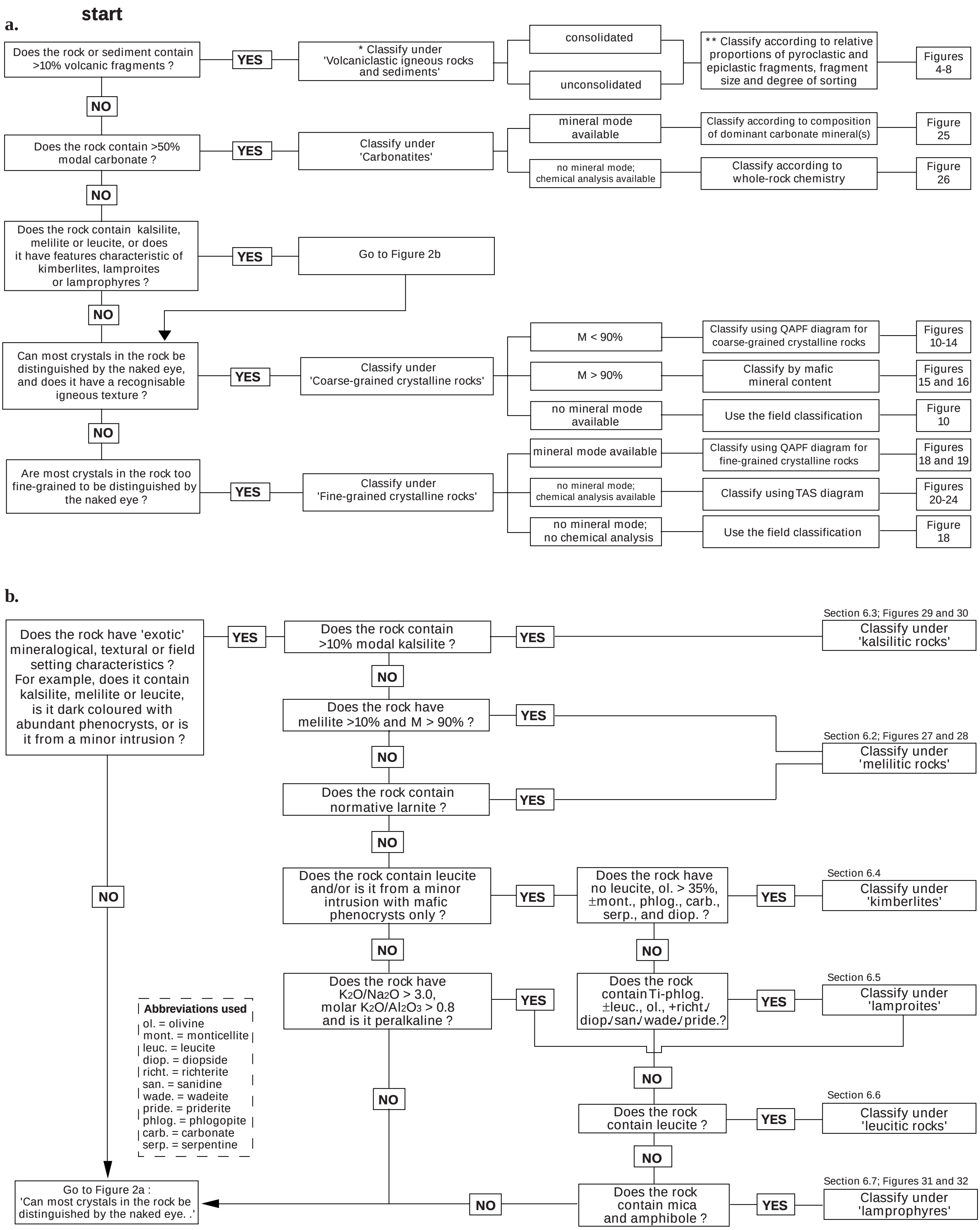


Figure 2

a. Generalised scheme for classifying igneous rocks and igneous sediments.

b. Generalised scheme for classifying kalsilitic, melilitic and leucitic rocks, kimberlites, lamproites and lamphrophyres.

* Note that rocks containing >10% volcanic fragments may also or alternatively be classified within the schemes for sediments and sedimentary rocks or artificial ground and natural superficial deposits. It is also possible for other igneous rocks to contain >10% volcanic fragments, for example as xenoliths in a crystalline rock. In such cases it is up to the geologist to decide which scheme is most appropriate for classifying and naming the rock.

** Some volcaniclastic rocks and sediments may also be classified usefully using the TAS method (Figures 20-24).

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

Figure 3 British Geological Survey grain size scheme.

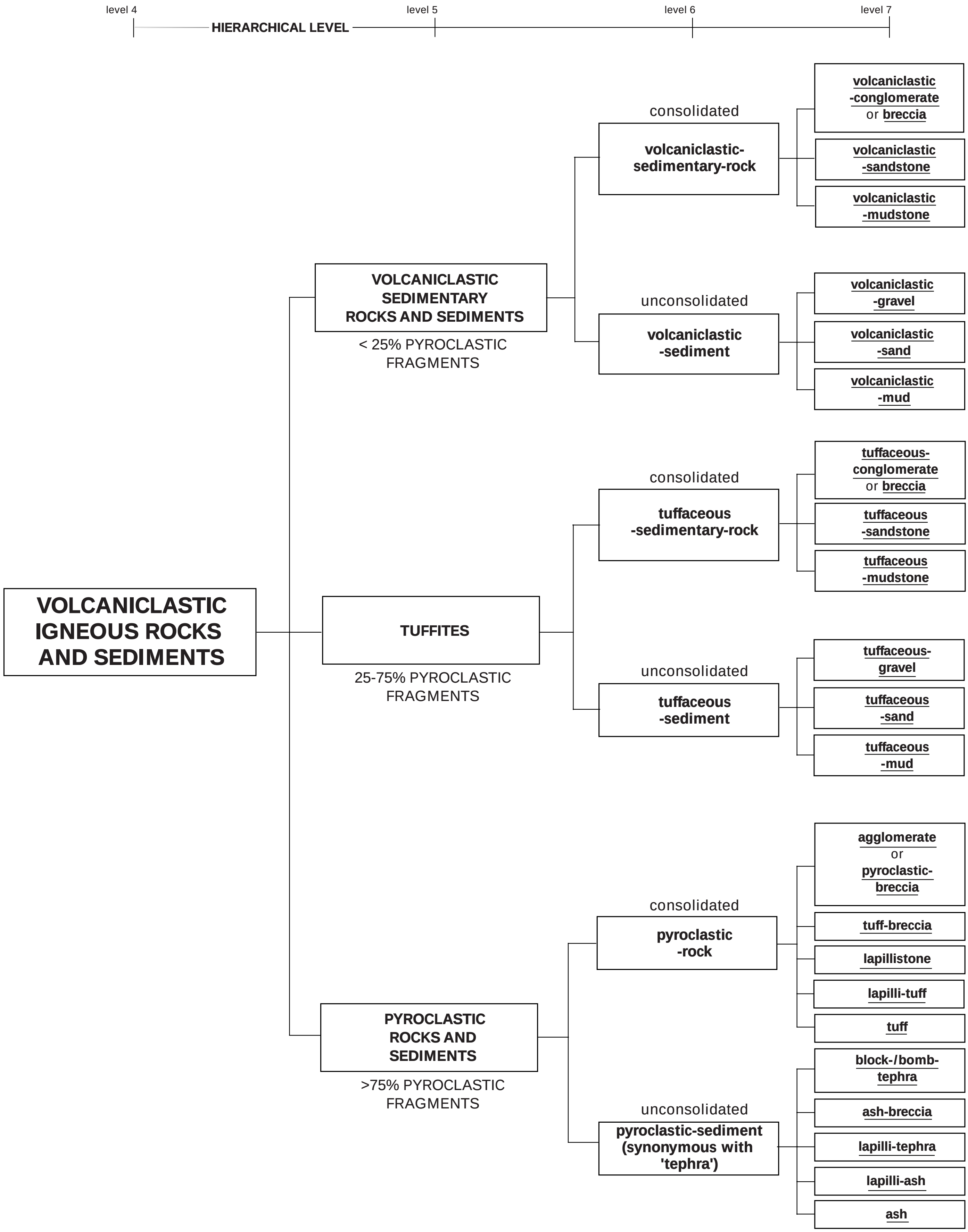


Figure 4 Hierarchical classification of volcaniclastic igneous rocks and sediments.

* Note that fragmental rocks containing >10% volcanic debris may additionally or alternatively be classified within the classification scheme for sediments and sedimentary rocks or the scheme for artificial ground and natural superficial deposits. It is up to the geologist to decide which scheme is most appropriate for classifying and naming the rock.

Figure 5 Classification and nomenclature of pyroclastic fragments and well-sorted pyroclastic sediments and rocks (after Schmid, 1981).

Fragment size in mm	Dominant pyroclastic fragment	Pyroclastic sediments	Pyroclastic rocks
	bomb, block	**bomb-tephra** **block-tephra**	**agglomerate** **pyroclastic-breccia**
64			
	lapillus	**lapilli-tephra**	**lapillistone**
2			
	coarse ash grain	*coarse* **ash**	*coarse* **tuff**
0.032			
	fine ash grain	*fine* **ash**	*fine* **tuff**

Figure 6 Classification of volcaniclastic rocks containing more than 10% volcanic debris (based on Schmid, 1981).

Average fragment size in mm	Pyroclastic rocks	Tuffites	Volcaniclastic sedimentary rocks
	agglomerate **pyroclastic-breccia**		
64		**tuffaceous-conglomerate**	**volcaniclastic-conglomerate**
	lapillistone		
2			
	coarse **tuff**	**tuffaceous-sandstone**	**volcaniclastic-sandstone**
0.032			
	fine **tuff**	**tuffaceous-mudstone**	**volcaniclastic-mudstone**
Amount of pyroclastic material	100%–75%	75%–25%	25%–0%

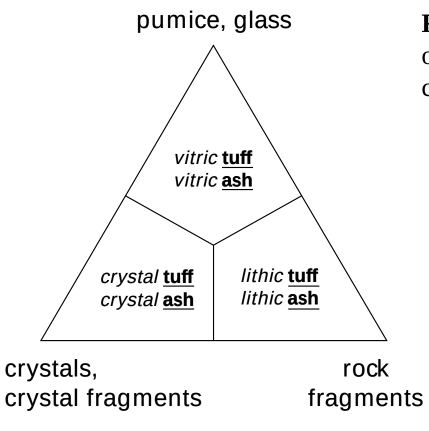
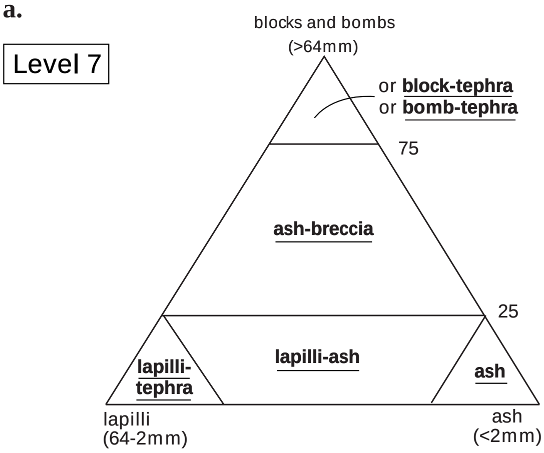


Figure 7 Classification and nomenclature of tuffs and ashes based on their fragmental composition (after Schmid, 1981).

a.



b.

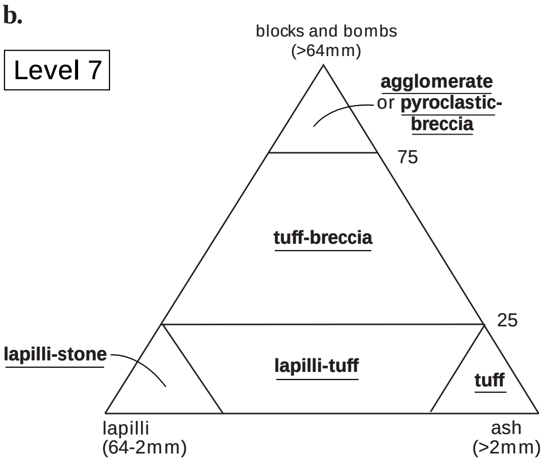


Figure 8
a. Classification of pyroclastic sediments.
b. Classification of pyroclastic rocks.
Both modified from Fisher and Schminke, 1984.

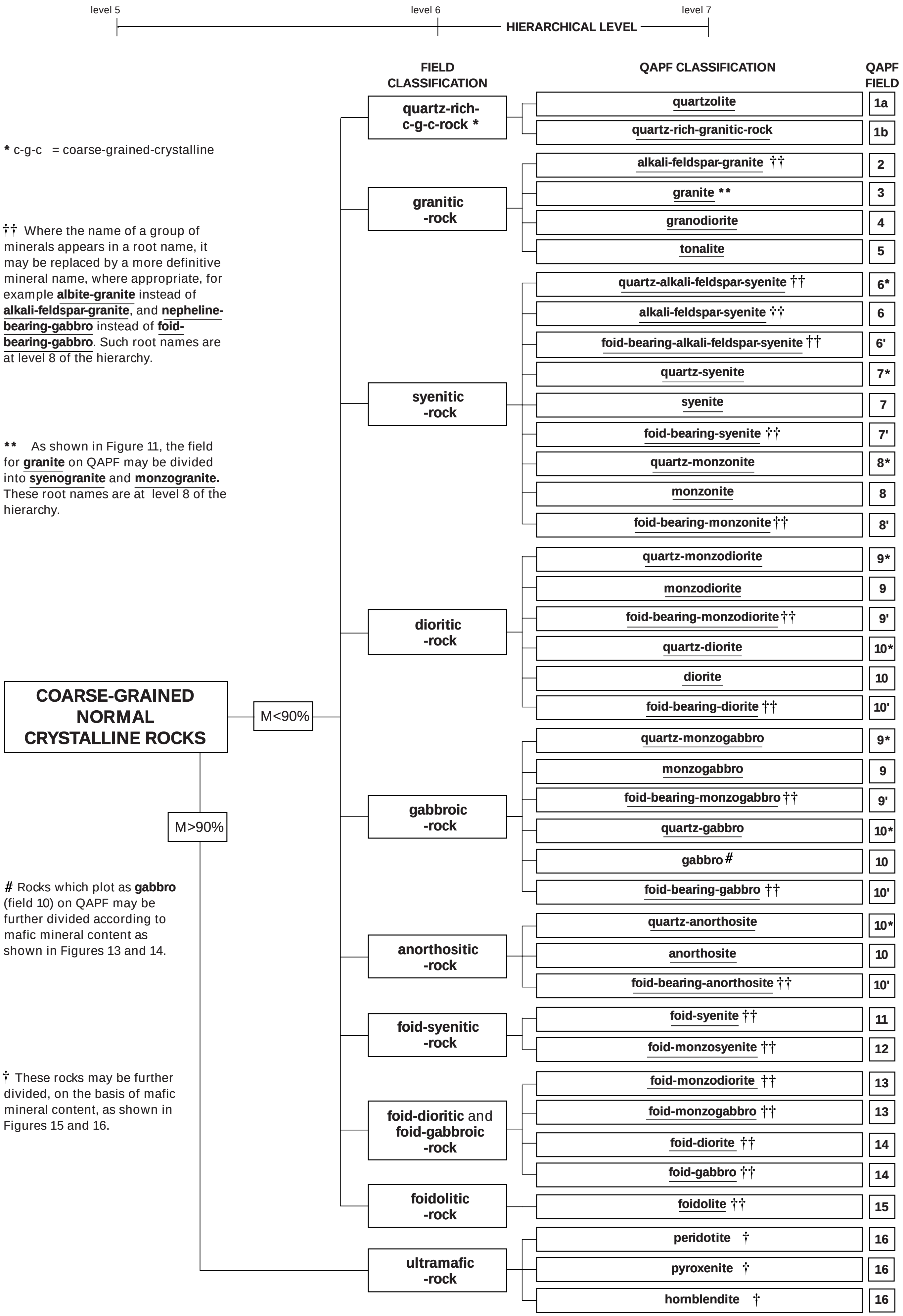


Figure 9 Hierarchical classification of coarse-grained normal crystalline rocks.

Level 6

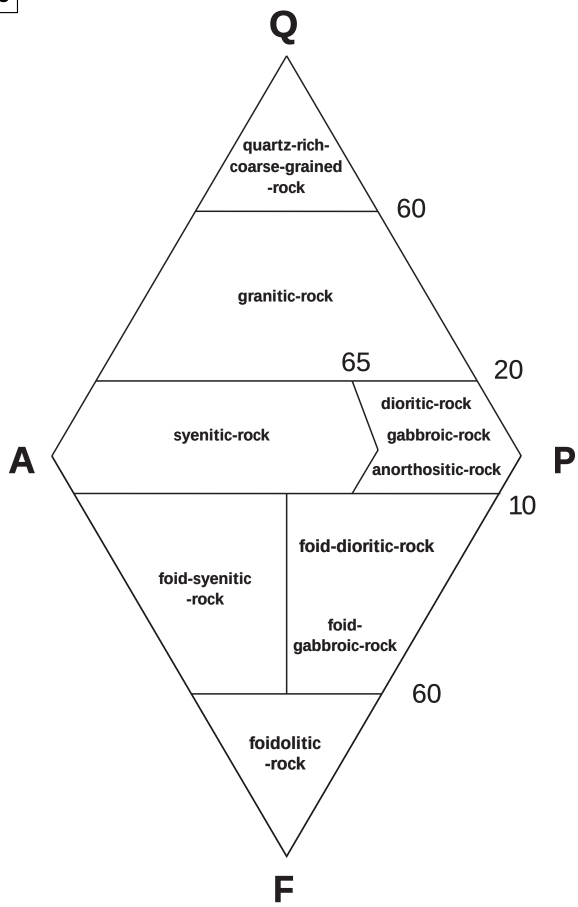


Figure 10 QAPF field classification of coarse-grained crystalline rocks (after Streckeisen, 1976).

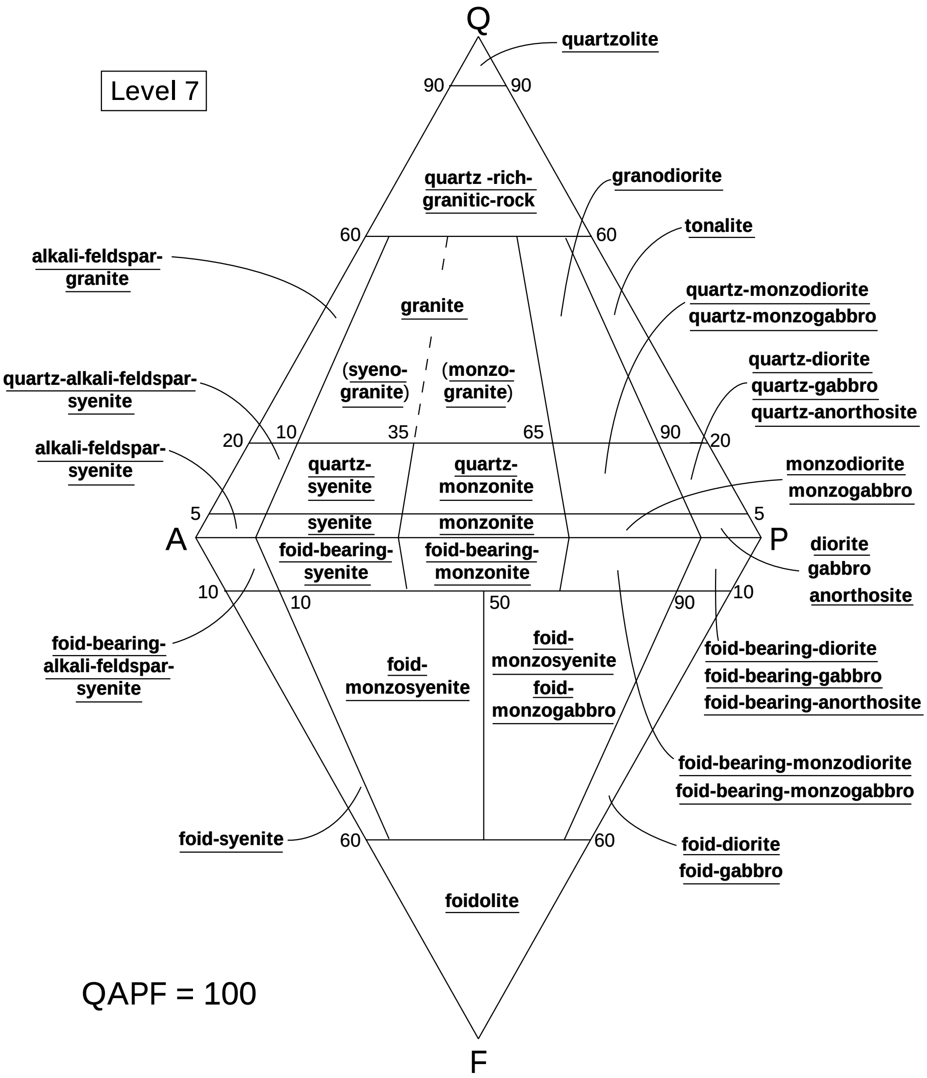


Figure 11 Classification and nomenclature of coarse-grained crystalline rocks according to their modal mineral contents using the QAPF diagram (based on Streckeisen, 1976). The corners of the double triangle are Q = quartz, A = alkali feldspar, P = plagioclase and F = feldspathoid. This diagram must not be used for rocks in which the mafic mineral content, M, is greater than 90%.

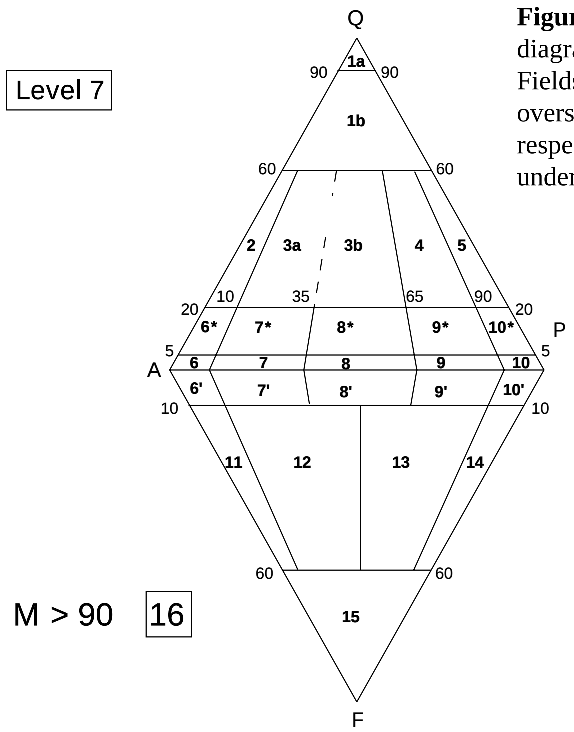


Figure 12 Field numbers of the QAPF diagram (based on Streckeisen,1976). Fields 6* to 10* are slightly oversaturated variants of fields 6 to 10, respectively, while 6' to 10' are slightly undersaturated variants.

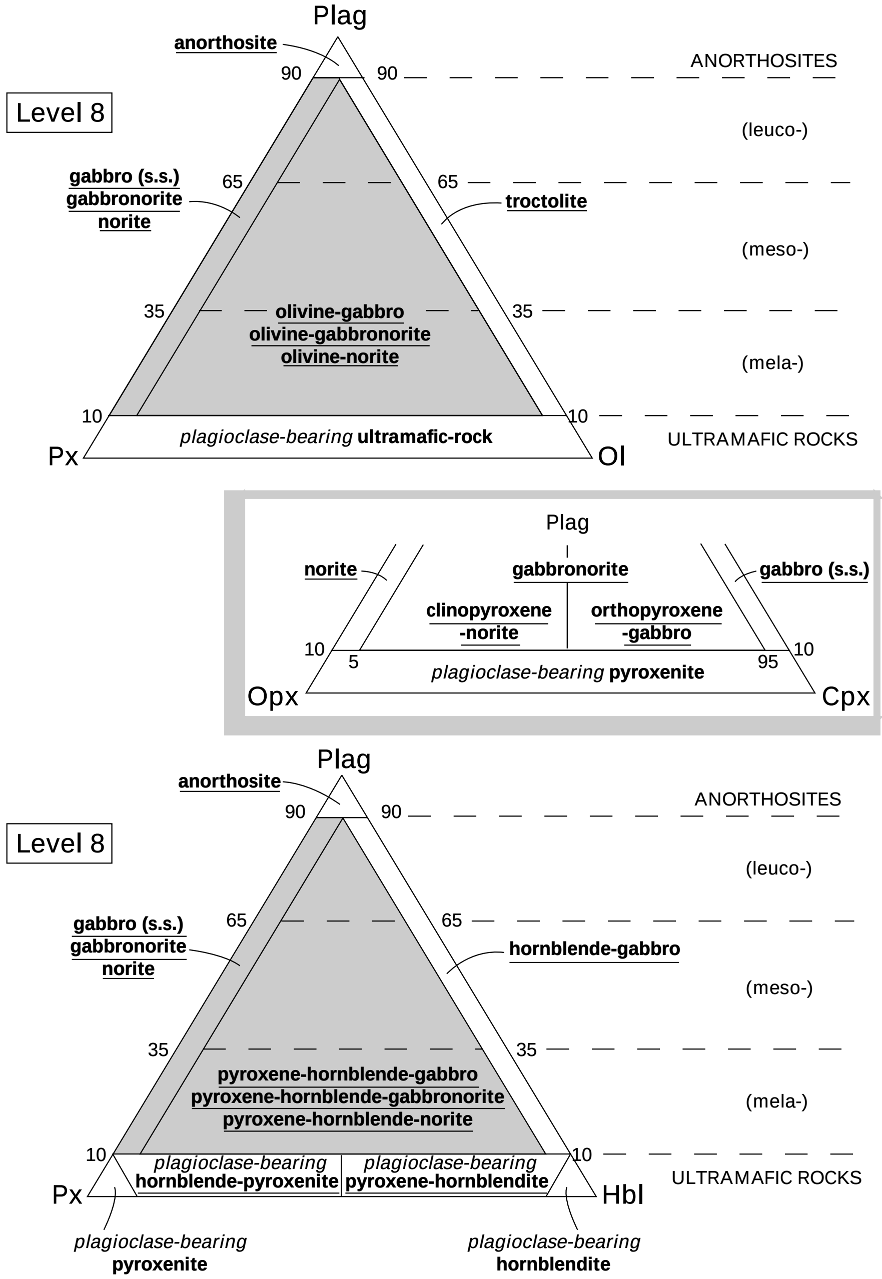


Figure 13 Triangular diagrams for the classification and nomenclature of gabbroic rocks based on the proportions of plagioclase (Plag), pyroxene (Px), olivine, (Ol), clinopyroxene (Cpx) and hornblende (Hbl) (after Streckeisen, 1976). Rocks falling in the shaded areas of the triangular diagrams may be further subdivided according to the diagram within the shaded rectangle.

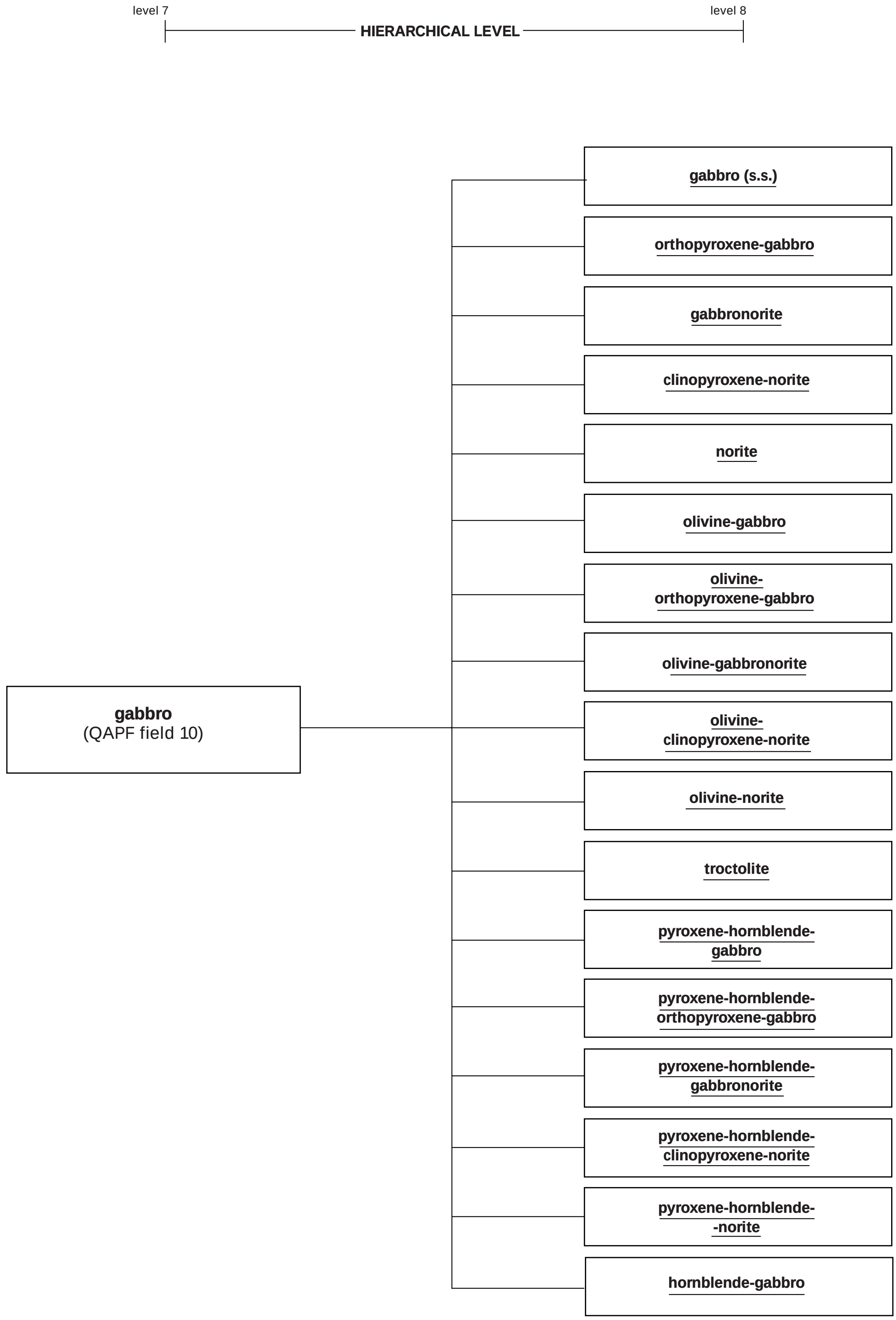


Figure 14 Hierarchical classification of 'gabbro QAPF Field10'.

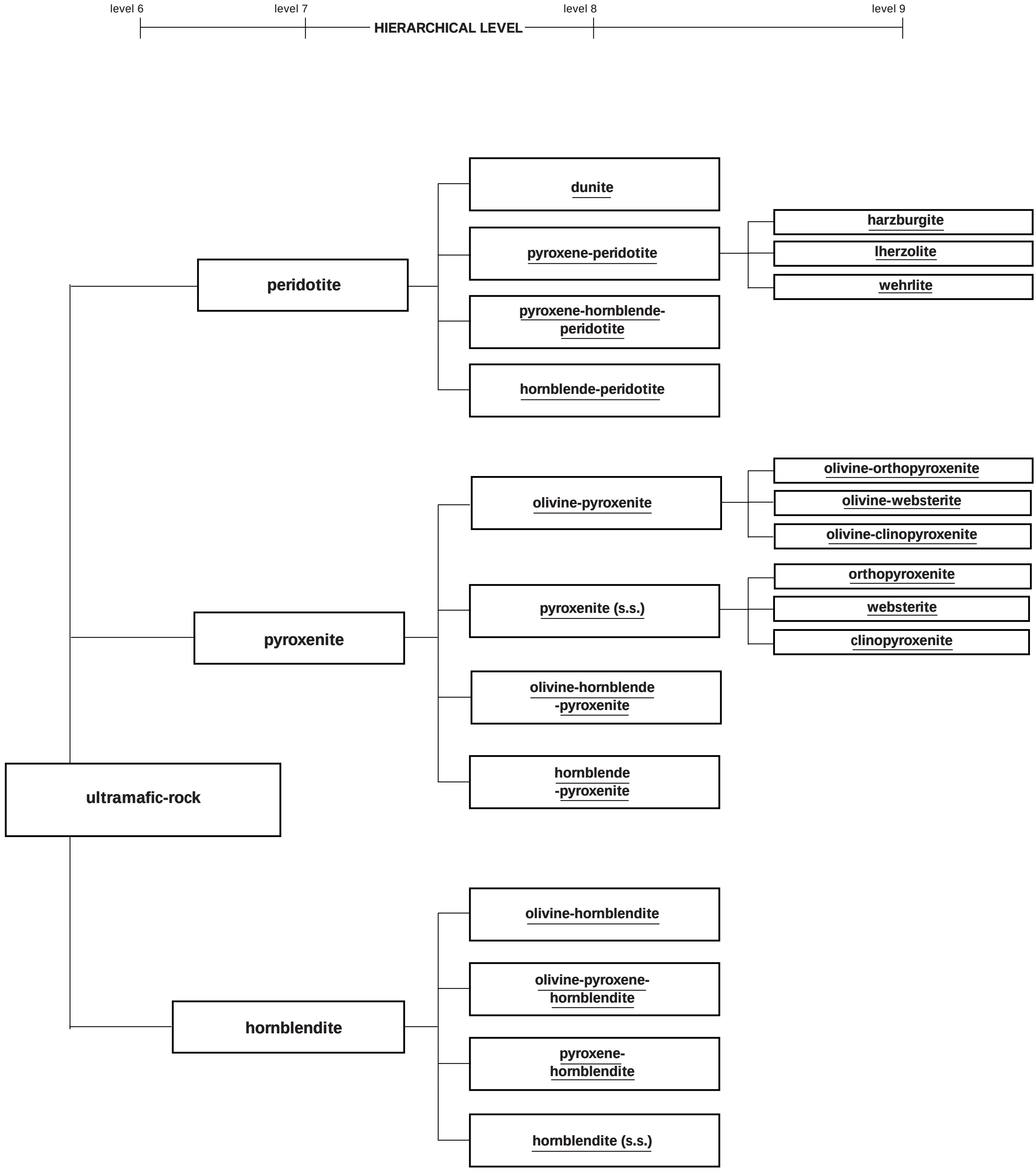


Figure 15 Hierarchical classification of ultramafic rocks.

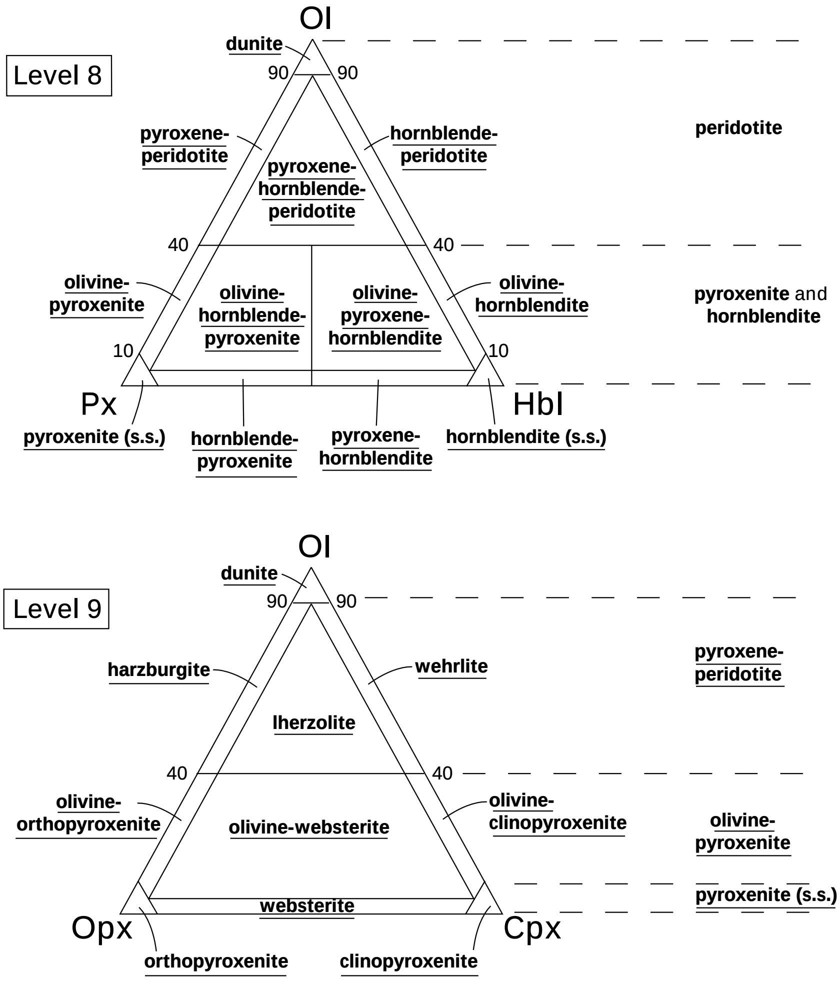


Figure 16 Triangular diagrams for the classification and nomenclature of ultramafic rocks based on the proportions of olivine (Ol),orthopyroxene (Opx), clinopyroxene (Cpx), pyroxene (Px) and hornblende (Hbl) (after Streckeisen, 1973).

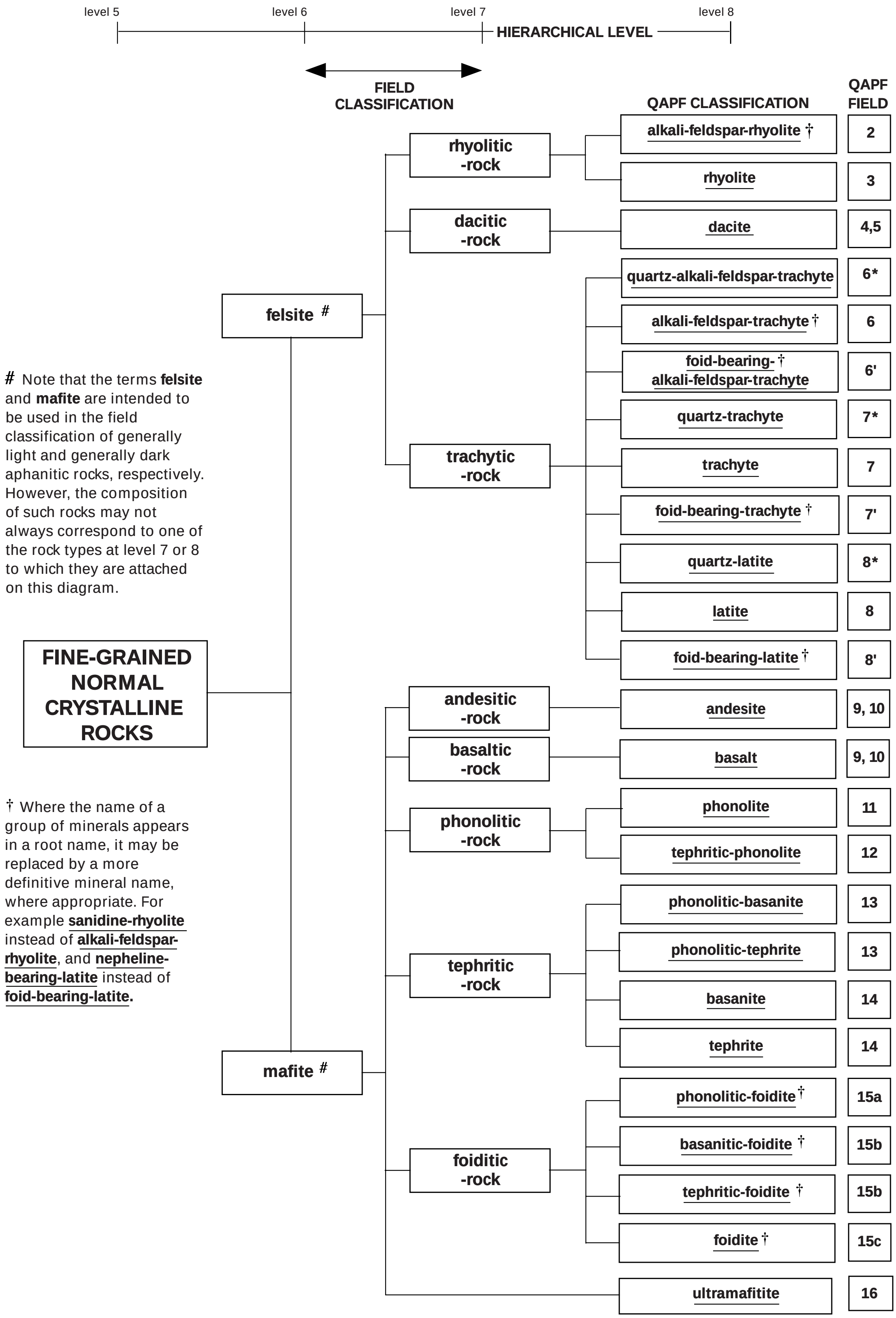


Figure 17a Hierarchical classification of fine-grained normal crystalline rocks with QAPF classification at level 8.

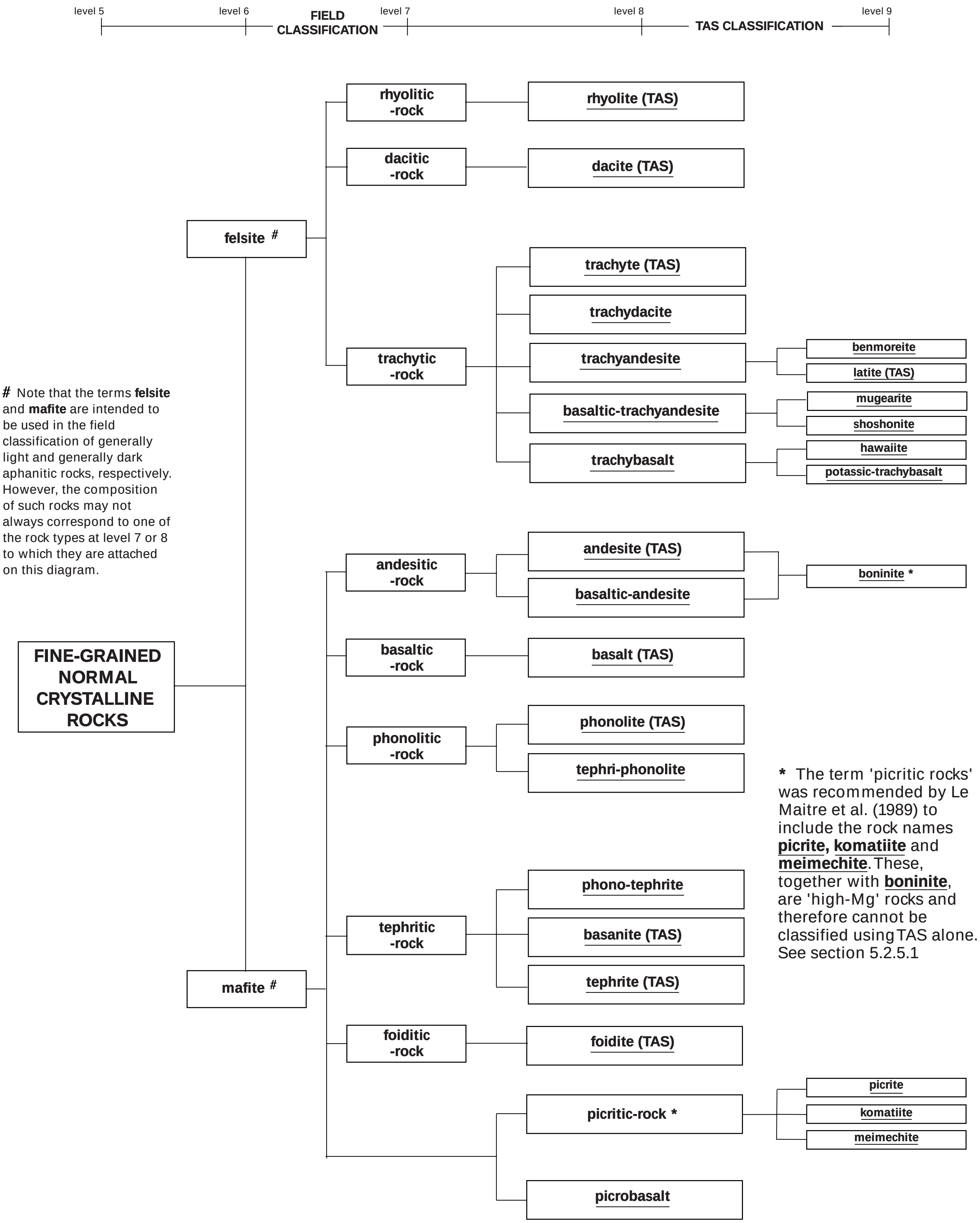


Figure 17b Hierarchical classification of fine-grained normal crystalline rocks with TAS classification at levels 8 and 9.

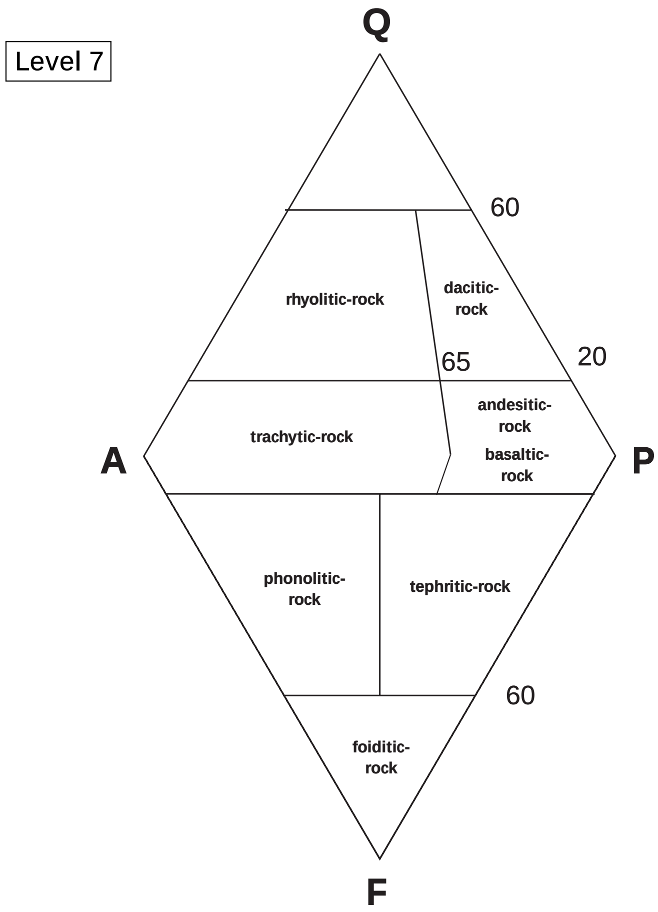


Figure 18 QAPF field classification of fine-grained crystalline rocks (after Streckeisen, 1979).

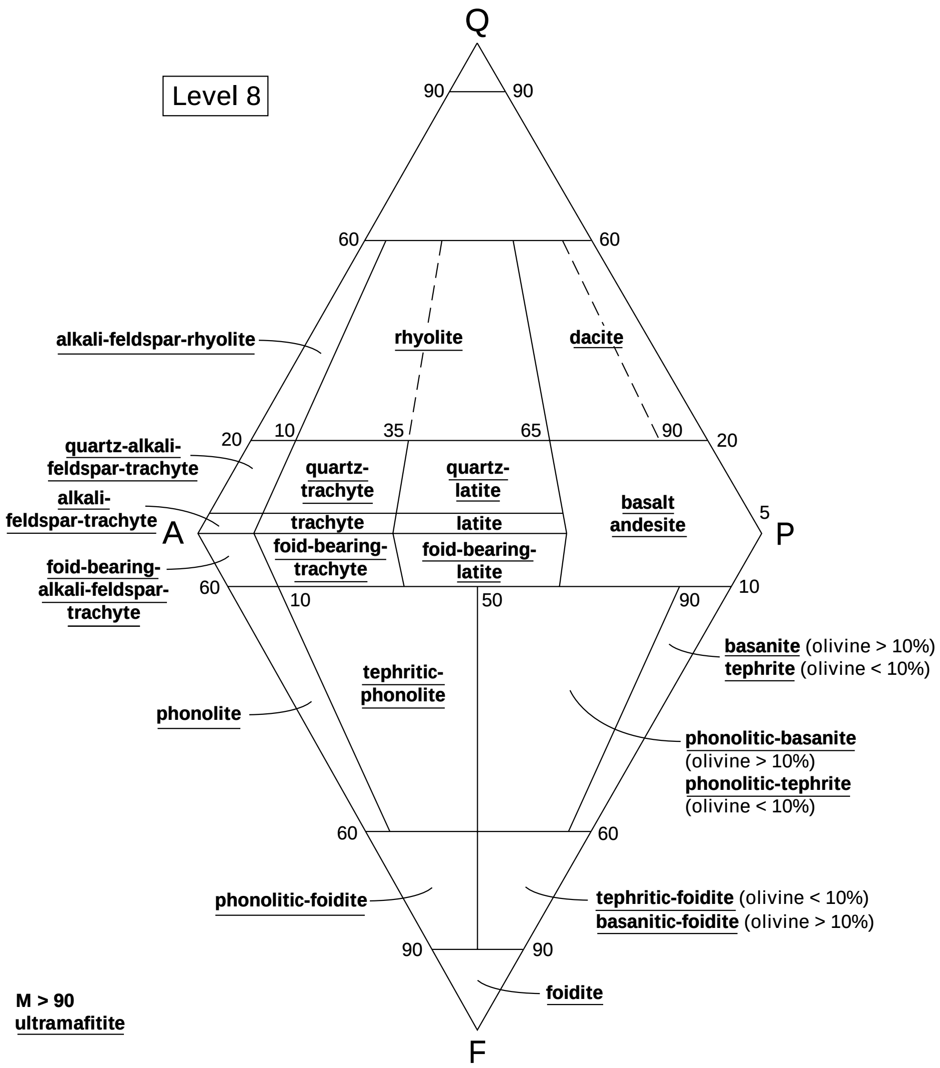


Figure 19 Classification and nomenclature of fine-grained crystalline rocks according to their modal mineral contents using the QAPF diagram (based on Streckeisen, 1978). Q = quartz, A = alkali feldspar, P = plagioclase, and F = feldspathoid.

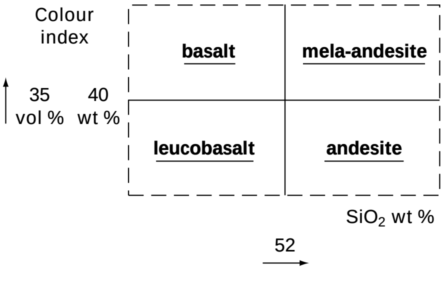
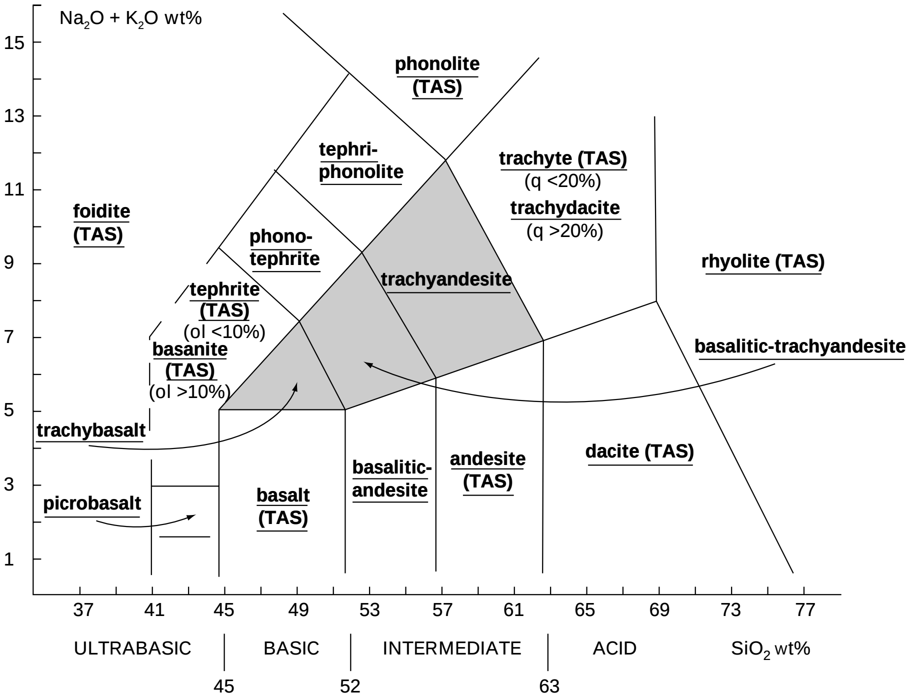


Figure 21 Division of rocks from QAPF fields 9 and 10 into basalt and andesite, using colour index and SiO_2 content (after Streckeisen, 1978).

a.



Further subdivisions of shaded fields	trachybasalt	basaltic-trachyandesite	trachyandesite
$Na_2O - 2.0 \geq K_2O$	hawaiite	mugearite	benmoreite
$Na_2O - 2.0 \leq K_2O$	potassic-trachybasalt	shoshonite	latite (TAS)

b.

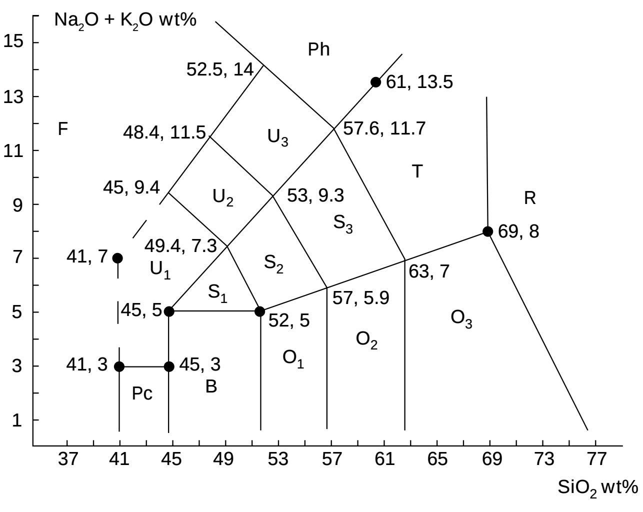


Figure 20

a. Chemical classification and nomenclature of fine-grained crystalline rocks using the total alkali silica (TAS) diagram (after Le Bas et al., 1986). Rocks falling on the shaded areas may be further subdivided as shown in the table underneath the diagram. The line drawn between the foidite field and the basanite-tephrite field is dashed to indicate that further criteria must be used to separate these types. Abbreviations: q = normative quartz; ol = normative olivine.

b. Field symbols of the total alkali silica (TAS) diagram (after Le Bas et al., 1986). The pairs of numbers are coordinates of the line intersections.

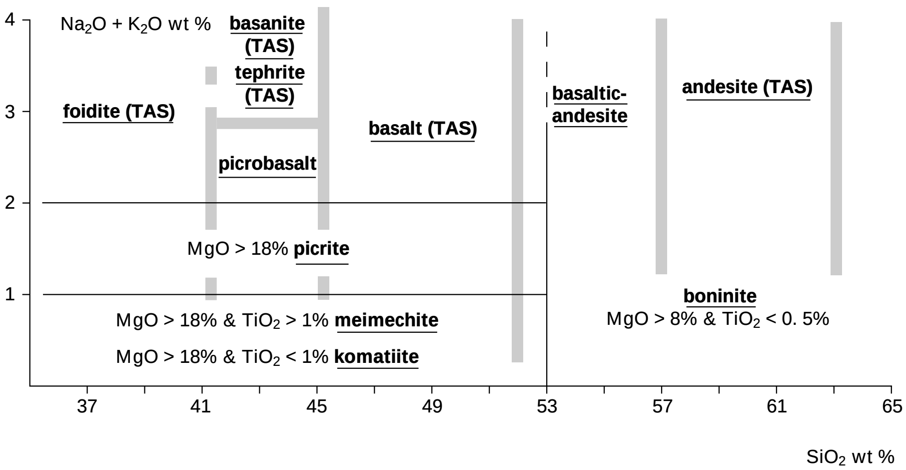


Figure 22 Classification and nomenclature of 'high-Mg' fine-grained crystalline rocks (**picrite**, **komatiite**, **meimechite** and **boninite**) using TAS together with wt % MgO and TiO_2. The thick stippled lines indicate the location of TAS fields. From Le Maitre et al., 1989.

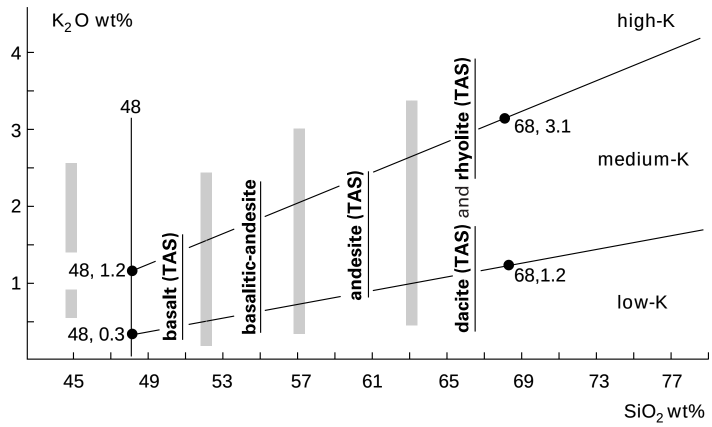


Figure 23 Division of basalts (with $SiO_2 > 48\%$), basaltic-andesites, andesites, dacites and rhyolites into 'low-K', 'medium-K' and 'high-K' types (from Le Maitre et al., 1989; modified after Peccerillo and Taylor, 1976). Note that 'high-K' is not synonymous with 'potassic'. The thick stippled lines indicate the equivalent position of the fields in the TAS diagram.

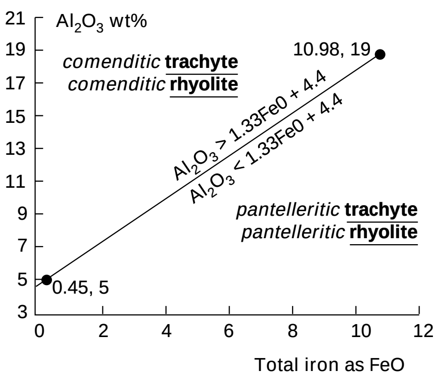


Figure 24 Separation of trachytes and rhyolites into comenditic and pantelleritic types using the Al_2O_3 versus total iron as FeO diagram (after MacDonald, 1974).

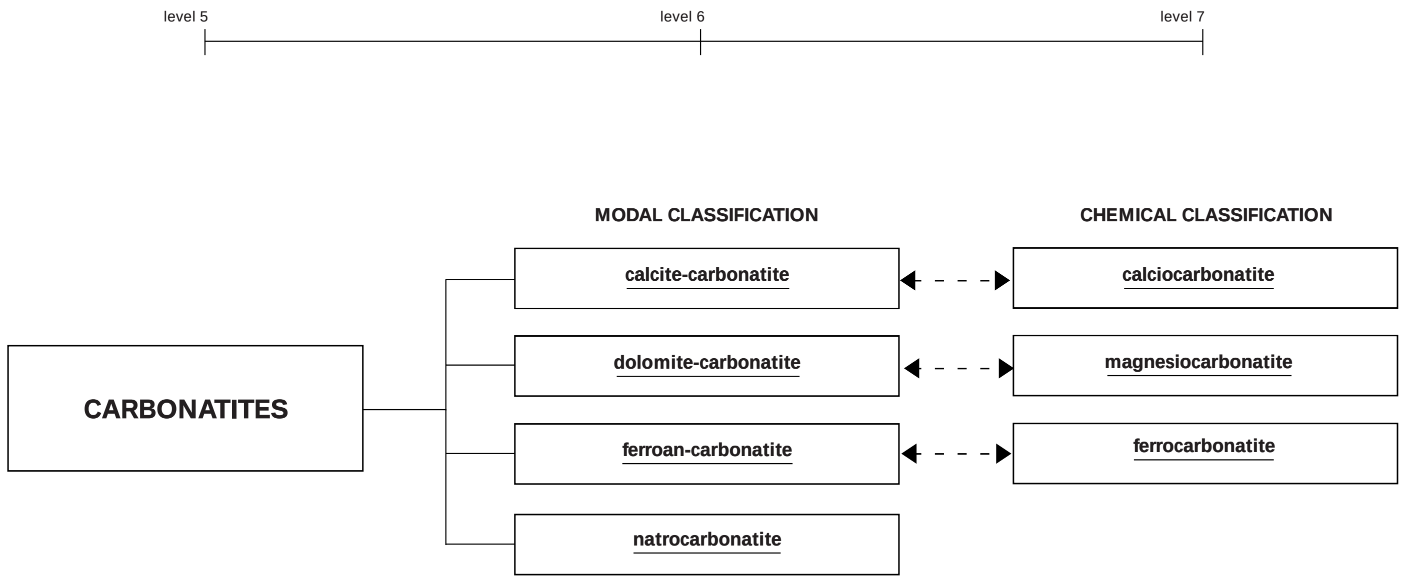


Figure 25 Hierarchical classification of carbonatites.

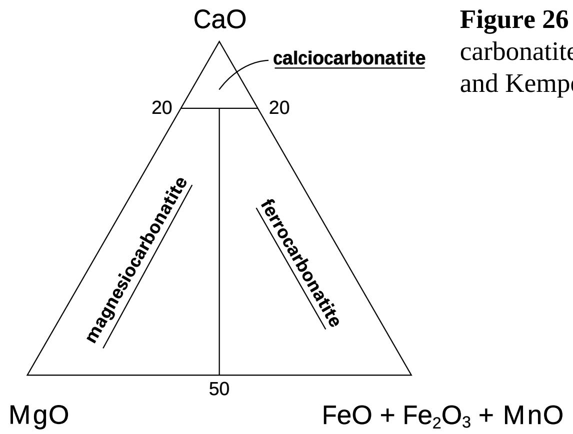


Figure 26 Chemical classification of carbonatites using wt % oxides (Woolley and Kempe, 1989).

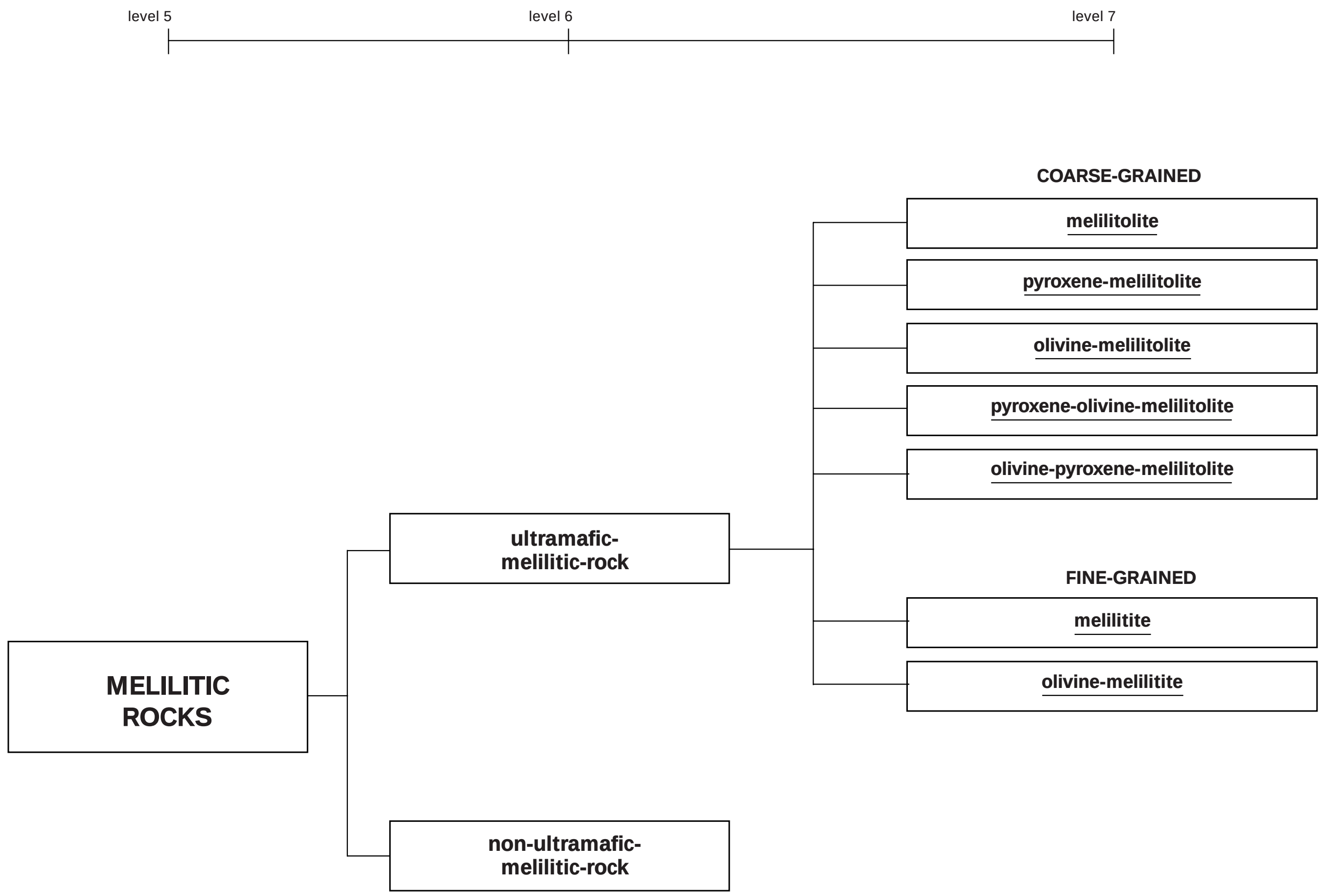


Figure 27 Hierarchical classification of melilitic rocks.

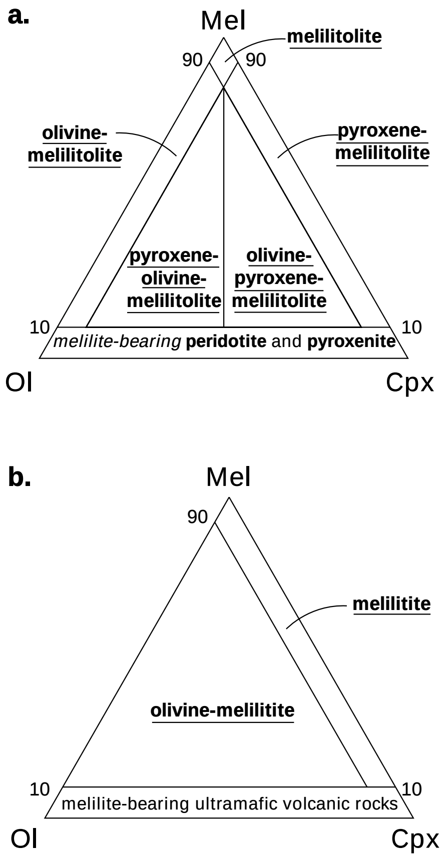


Figure 28 Classification and nomenclature of melilitic rocks based on melilite (Mel), olivine (Ol), and clinopyroxene (Cpx). After Streckeisen, 1978.
a. coarse-grained.
b. fine-grained.

'Old name'	phl	cpx	leu	kal	mel	ol	gls
mafurite	no	yes	no	yes	no	yes	yes
katungite	no	no	yes	yes	yes	yes	yes
venanzite	yes	yes	yes	yes	yes	yes	no
coppaelite	yes	yes	no	yes	yes	no	no

Figure 29 Mineral assemblages of the kalsilite-containing rocks (after Mitchell and Bergman, 1991).
where: phl = phlogopite; cpx = clinopyroxene; leu = leucite; kal = kalsilite; mel = melilite; ol = olivine; gls = glass.

'Old name'	New equivalent name
mafurite	*olivine-pyroxene* **kalsilitite**
katungite	*kalsilite-leucite-olivine* **melilitite**
venanzite	*kalsilite-phlogopite-olivine-leucite* **melilitite**
coppaelite	*kalsilite-phlogopite* **melilitite**

Figure 30 Recommended nomenclature of kalsilite-containing rocks (after Woolley et al.,1996).

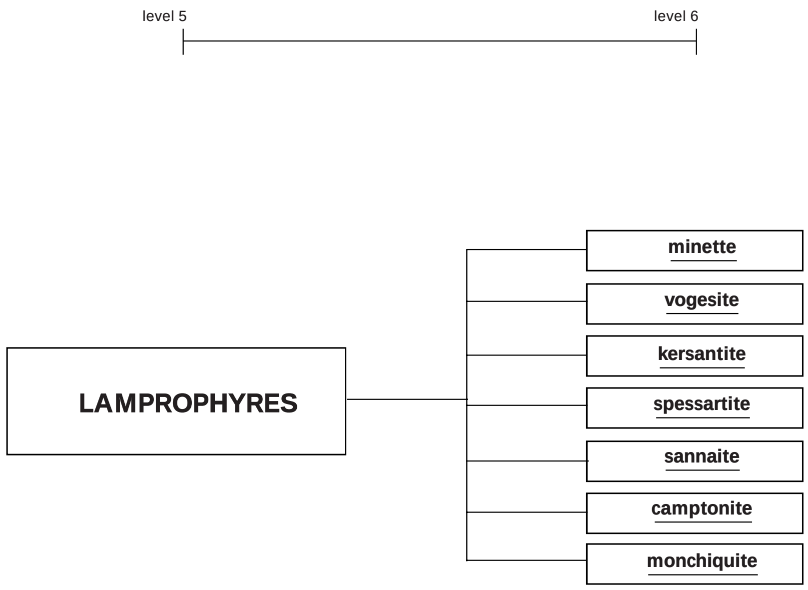


Figure 31 Hierarchical classification of lamprophyres.

Felsic minerals		Predominant mafic minerals		
feldspar	foid*	bi, diop aug (±ol)	hbl, diop aug (±ol)	amph, Ti-aug ol, bi
or > pl	–	**minette**	**vogesite**	–
pl > or	–	**kersantite**	**spessartite**	–
or > pl	feld > foid	–	–	**sannaite**
pl > or	feld > foid	–	–	**camptonite**
–	glass or foid	–	–	**monchiquite**
–	–	–	–	–

Figure 32 Classification of lamprophyres (after Streckeisen 1978).

* where : foid = feldspathoid; feld = feldspar; or = orthoclase; pl = plagioclase; bi = biotite; diop aug = diopsidic augite; ol = olivine; hbl=hornblende; amph = amphibole (barkevikite, kaersutite); Ti-aug = Ti-rich augite; mel =melilite; cal = calcite.

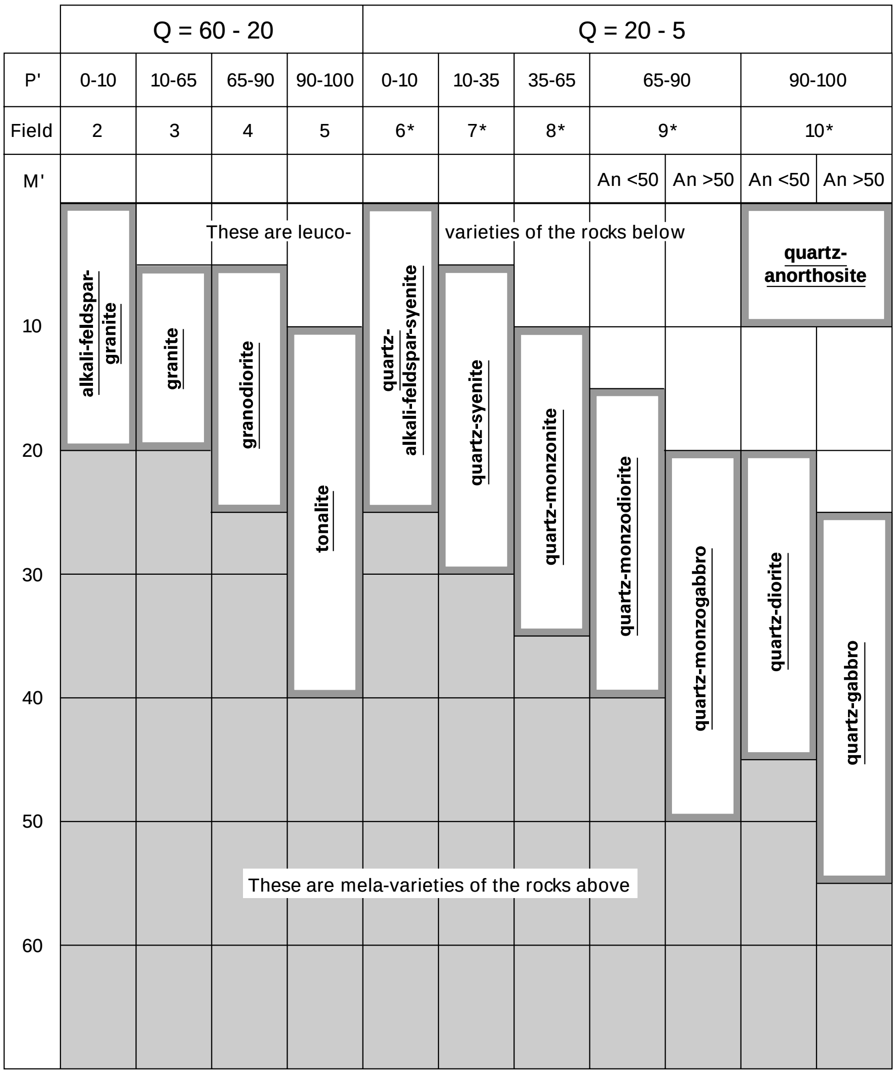


Figure 33 Limits of the use of the terms mela- and leuco- applicable to coarse-grained crystalline rocks classified by the QAPF diagram and with Q greater than 5% (after Streckeisen, 1976).
Abbreviations: P' = 100*P/(A+P); M' = colour index; An = anorthite content of plagioclase.

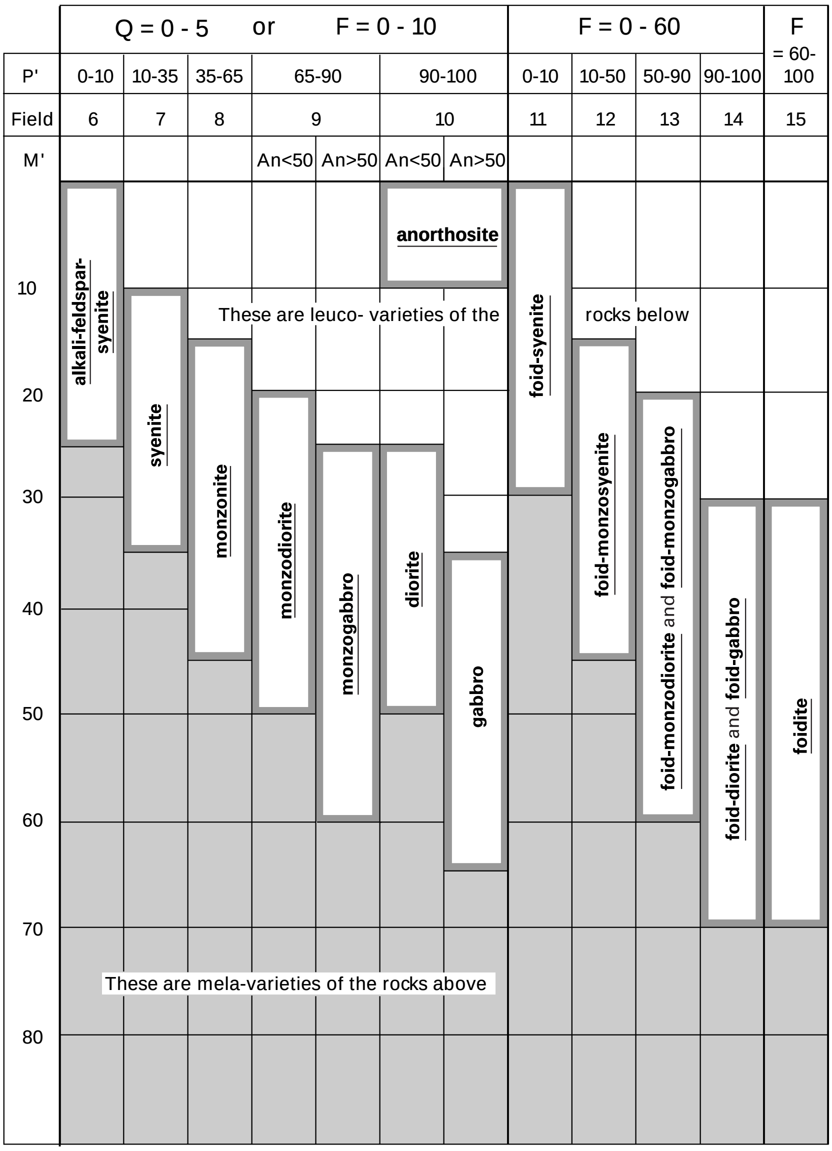


Figure 34 Limits of the use of the terms mela- and leuco- applicable to coarse-grained crystalline rocks classified by the QAPF diagram and with Q less than 5% or F present (after Streckeisen, 1976). Abbreviations: P' = 100*P/(A+P); M' = colour index; An = anorthite content of plagioclase.