1 Introduction

This book is the result of over three decades of deliberation by The International Union of Geological Sciences (IUGS) Subcommission on the Systematics of Igneous Rocks.

The Subcommission was originally set up after the International Geological Congress meeting in Prague in 1968 as the result of an earlier investigation into the problems of igneous rock classification that had been undertaken by Professor Albert Streckeisen from 1958 to 1967 (Streckeisen, 1967). He was appointed the first Chairman of the Subcommission, a position he held from 1969 to 1980 and was followed by Bruno Zanettin (1980–1984, Italy), Mike Le Bas (1984–2001, UK) and Bernard Bonin (2001–, France). The secretaries of the Subcommission have been V. Trommsdorff (1970–75, Switzerland), Rolf Schmid (1975–80, Switzerland), Giuliano Bellieni (1980–84, Italy) and Alan Woolley (1984–2001, UK).

During this time the Subcommission has held official meetings in Bern (1972), Montreal (1972), Grenoble (1975), Sydney (1976), Prague (1977), Padova (1979), Paris (1980), Cambridge (1981), Granada (1983), Moscow (1984), London (1985), Freiburg im Breisgau (1986), Copenhagen (1988), Washington D.C. (1989), Southampton (1996) and Prague (1999).

For these meetings the secretaries distributed 52 circulars to the members of the Subcommission containing a total of 164 contributions from petrologists throughout the world. All of these contributions have now been deposited in the Department of Mineralogy at the Natural History Museum in London and in the Library of the Geological Museum, University of Copenhagen.

Records of the Subcommission also indicate that 456 people from 52 countries participated in the formulation of the recommendations in various ways. Of these, 52 were official members of the Subcommission representing their countries at various times; 201 were members of various working groups that were periodically set up to deal with specific problems; 176 corresponded with the Subcommission; and 27 attended meetings as guests. These people are listed in **Appendix A**.

All the recommendations of the Subcommission were published as individual papers as soon as they were agreed upon. However, it was decided, at the 1986 meeting in Freiburg im Breisgau, to present all the results under one cover to make access easier, even though parts of the classification were still unresolved. This resulted in the first edition of this book being published (Le Maitre *et al.*, 1989).

Although the concept of a glossary was mentioned by the Subcommission in 1976, it was not until late 1986 that the work on creating it was started in earnest. The original idea for the glossary was that it should only include those names that were recommended for use by the Subcommission. However, it soon became obvious that for it to be really useful it should be as complete as possible.

1.1 CHANGES TO THE 1ST EDITION

During the last decade a considerable amount of work has been undertaken by the Subcommission to resolve those loose ends left after the publication of the 1st edition. In particular, the Subcommission has had two very active groups working on the problems of the "high-Mg" rocks and on the classification of the lamproites, lamprophyres and kimberlites. Also discussed at length were the classification of the melilite-, kalsilite- and leucite-bearing rocks and the chemical distinction between basanites and nephelinites.

All of these recommendations were approved at the 1999 meeting in Prague, which meant that the Subcommission was in a position to publish a much more comprehensive classification than that presented in the 1st edition.

Hence this book, which is in effect the second edition, although it does have a different title and publisher from the 1st edition.

Apart from minor rewriting and corrections, the main changes to this edition are as follows:

(1) following the Contents is a **List of Figures** on p.vi and a **List of Tables** on p.vii
(2) a change in the **hierarchy of classification** (section 2.1.3, p.6)
(3) a rewrite of the **pyroclastic classification** (section 2.2, p.7) to bring it into line with the latest volcanological terminology
(4) a complete rewrite of the **melilite-bearing rocks** (section 2.4, p.11)
(5) a new section on the **kalsilite-bearing rocks** (section 2.5, p.12)
(6) the replacement of the section on "lamprophyric rocks", which is no longer approved by the Subcommission, with three new individual sections, i.e. **kimberlites** (section 2.6, p.13), **lamproites** (section 2.7, p.16) and **lamprophyres** (section 2.9, p.19). Certain melilite-bearing rocks that were previously included in the lamprophyre classification are now classified under melilite-bearing rocks
(7) a new section on the **leucite-bearing rocks** (section 2.8, p.18)
(8) the section on detecting certain rock types, such as **"high-Mg" rocks**, before using the TAS classification has been rewritten and had **nephelinites** and **melanephelinites** added to it (section 2.12.2, p.34)
(9) the sections dealing with TAS fields **U1** and **F** have been rewritten (section 2.12.2, p.38–39)
(10) the section on **basalts** in TAS (section 2.12.2, p.36) has been expanded
(11) all the **Figures** have been redrawn and the **Tables** redrafted, hopefully for the better
(12) all figures, tables and sections of the book referred to in the glossary are now accompanied by a **page number**
(13) the **statistics** given in Chapters 3 and 4 have been completely **recalculated** in accordance with the extra entries in the glossary. Unfortunately during this process it was discovered that, in some cases, the number of references used in the 1st edition had included some that should not have been present. This has now been corrected
(14) the **glossary** now contains an extra 51 terms giving a total of 1637, of which 316 or 19% have been recommended and defined by the Subcommission and are given in bold capitals in the glossary in Chapter 3. These names are also listed in **Appendix B** at the end of the book for easy reference. The glossary rock **descriptions** have been changed in accordance with recommendations made by the International Mineralogical Association. However, with the **amphiboles** and **pyroxenes** the old names have been retained for historical and other reasons as explained in section 3.1.2 (p.44)
(15) the **bibliography** now contains a total of 809 references, an increase of 18 over the previous edition. The names of terms in square brackets for which the reference is not the prime source are now given in ***italics***
(16) the **List of Circulars** (Appendix A in the 1st edition) has been omitted
(17) a new **Appendix C** giving details of a C++ software package **IUGSTAS** to determine the TAS name of an analysis has been added

2 Classification and nomenclature

This chapter is a summary of all the published recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks together with some other decisions agreed to since the last Subcommission meeting in Prague in 1999.

2.1 PRINCIPLES

Throughout its deliberations on the problems of classification the Subcommission has been guided by the following principles, most of which have been detailed by Streckeisen (1973, 1976) and Le Bas & Streckeisen (1991).

(1) For the purposes of classification and nomenclature the term "*igneous rock*" is taken to mean "Massige Gesteine" in the sense of Rosenbusch, which in English can be translated as "igneous or igneous-looking". Igneous rocks may have crystallized from magmas or may have been formed by cumulate, deuteric, metasomatic or metamorphic processes. Arguments as to whether charnockites are igneous or metamorphic rocks are, therefore, irrelevant in this context.

(2) The **primary classification** of igneous rocks should be based on their **mineral content** or **mode**. If a mineral mode is impossible to determine, because of the presence of glass, or because of the fine-grained nature of the rock, then other criteria may be used, e.g. chemical composition, as in the TAS classification.

(3) The term **plutonic rock** is taken to mean an igneous rock with a phaneritic texture, i.e. a relatively coarse-grained (> 3 mm) rock in which the individual crystals can be distinguished with the naked eye and which is presumed to have formed by slow cooling. Many rocks that occur in orogenic belts have suffered some metamorphic overprinting, so that it is left to the discretion of the user to decide whether to use an igneous or metamorphic term to describe the rock (e.g. whether to use gneissose granite or granitic gneiss).

(4) The term **volcanic rock** is taken to mean an igneous rock with an aphanitic texture, i.e. a relatively fine-grained (< 1 mm) rock in which most of the individual crystals cannot be distinguished with the naked eye and which is presumed to have formed by relatively fast cooling. Such rocks often contain glass.

(5) Rocks should be named according to what they are, and not according to what they might have been. Any manipulation of the raw data used for classification should be justified by the user.

(6) Any useful classification should correspond with natural relationships.

(7) The classification should follow as closely as possible the historical tradition so that well-established terms, e.g. granite, basalt, andesite, are not redefined in a drastically new sense.

(8) The classification should be simple and easy to use.

(9) All official recommendations should be published in English, and any translation or transliteration problems should be solved by members in their individual countries. However, publications by individual Subcommission members, in languages other than English, were encouraged in order to spread the recommendations to as wide an audience as possible.

2.1.1 PARAMETERS USED

The primary modal classifications of plutonic rocks and volcanic rocks are based on the relative proportions of the following mineral groups for which **volume modal data** must be determined:

Q = quartz, tridymite, cristobalite
A = alkali feldspar, including orthoclase, microcline, perthite, anorthoclase, sanidine, and albitic plagioclase (An_0 to An_5)
P = plagioclase (An_5 to An_{100}) and scapolite
F = feldspathoids or **foids** including nepheline, leucite, kalsilite, analcime, sodalite, nosean, haüyne, cancrinite and pseudoleucite.
M = mafic and related minerals, e.g. mica, amphibole, pyroxene, olivine, opaque minerals, accessory minerals (e.g. zircon, apatite, titanite), epidote, allanite, garnet, melilite, monticellite, primary carbonate.

Groups Q, A, P and F comprise the **felsic** minerals, while the minerals of group M are considered to be **mafic** minerals, from the point of view of the modal classifications.

The sum of Q + A + P + F + M must, of course, be 100%. Notice, however, that there can never be more than four non-zero values, as the minerals in groups Q and F are mutually exclusive, i.e. if Q is present, F must be absent, and vice versa.

Where modal data are not available, several parts of the classification utilize chemical data. In these cases all oxide and normative values are in **weight %,** unless otherwise stated. All normative values are based on the rules of the CIPW norm calculation (see p.233).

2.1.2 NOMENCLATURE

During the work of the Subcommission it was quickly realized that the classification schemes would rarely go beyond the stage of assigning a general **root name** to a rock. As such root names are often not specific enough, especially for specialist use, the Subcommission encourages the use of additional qualifiers which may be added to any root name.

These additional qualifiers may be mineral names (e.g. biotite granite), textural terms (e.g. porphyritic granite), chemical terms (e.g. Sr-rich granite), genetic terms (e.g. anatectic granite), tectonic terms (e.g. post-orogenic granite) or any other terms that the user thinks are useful or appropriate. For general guidance on the use of qualifiers the Subcommission makes the following points.

(1) The addition of qualifiers to a root name must not conflict with the definition of the root name. That means that a biotite granite, porphyritic granite, Sr-rich granite, and post-orogenic granite must still be granites in the sense of the classification. Quartz-free granite, however, would not be permissible because the rock could not be classified as a granite, if it contained no quartz.
(2) The user should define what is meant by the qualifiers used if they are not self-explanatory. This applies particularly to geochemical terms, such as Sr-rich or Mg-poor, when often no indications are given of the threshold values above or below which the term is applicable.
(3) If more than one mineral qualifier is used the mineral names should be given in order of increasing abundance (Streckeisen, 1973, p.30; 1976, p.22), e.g. a hornblende-biotite granodiorite should contain more biotite than hornblende. Notice that this is the opposite of the convention often adopted by metamorphic petrologists.
(4) The use of the suffix **-bearing**, as applied to mineral names, has not been consistently defined, as it is used with different threshold values. For example, in the

QAPF classification, 5% Q in Q + A + P is used as the upper limit of the term quartz-bearing, while 10% F in A + P + F is used as the upper limit of the term foid-bearing. The value of 10% is also used for plagioclase-bearing ultramafic rocks (Fig. 2.6, p.25), but for glass-bearing rocks 20% is the upper limit (Table 2.1, p.5).

(5) For volcanic rocks containing glass, the amount of glass should be indicated by using the prefixes shown in Table 2.1 (from Streckeisen, 1978, 1979). For rocks with more than 80% glass special names such as **obsidian**, **pitchstone** etc. are used. Furthermore, for volcanic rocks, which have been named according to their chemistry using the TAS diagram, the presence of glass can be indicated by using the prefix **hyalo-** with the root name, e.g. hyalo-rhyolite, hyalo-andesite etc. For some rocks special names have been given, e.g. **limburgite** = hyalo-nepheline basanite

(6) the prefix **micro**- should be used to indicate that a plutonic rock is finer-grained than usual, rather than giving the rock a special name. The only exceptions to this are the long-established terms **dolerite** and **diabase** (= microgabbro) which may still be used. These two terms are regarded as being synonymous. The use of diabase for Palaeozoic or Precambrian basalts or for altered basalts of any geological age should be avoided.

(7) The prefix **meta-** should be used to indicate that an igneous rock has been metamorphosed, e.g. meta-andesite, meta-basalt etc., but only when the igneous texture is still preserved and the original rock type can be deduced.

(8) Volcanic rocks for which a complete mineral mode cannot be determined, and have not yet been analysed, may be named provisionally following the terminology of Niggli (1931, p.357), by using their visible minerals (usually phenocrysts) to assign a name which is preceded by the prefix **pheno**- (Streckeisen, 1978, p.7; 1979, p.333). Thus a rock containing phenocrysts of sodic plagioclase in a cryptocrystalline matrix may be provisionally called pheno-andesite. Alternatively the provisional "field" classifications could be used (Fig. 2.19, p.39).

(9) The colour index **M′** is defined (Streckeisen, 1973, p.30; 1976, p.23) as **M** minus any muscovite, apatite, primary carbonates etc., as muscovite, apatite, and primary carbonates are considered to be colourless minerals for the purpose of the colour index. This enables the terms leucocratic, mesocratic, melanocratic etc. to be defined in terms of the ranges of colour index shown in Table 2.2. Note that these terms are applicable only to rocks and must not be used to describe minerals.

Table 2.1. *Prefixes for use with rocks containing glass*

% glass	Prefix
0 – 20	glass-bearing
20 – 50	glass-rich
50 – 80	glassy

Table 2.2. *Colour index terms*

Colour index term	Range of M′
hololeucocratic	0 – 10
leucocratic	10 – 35
mesocratic	35 – 65
melanocratic	65 – 90
holomelanocratic	90 – 100

2.1.3 Using the classification

One of the problems of classifying igneous rocks is that they cannot all be classified sensibly by using only one system. For example, the modal parameters required to adequately define a felsic rock, composed of quartz and feldspars, are very different from those required to define an ultramafic rock, consisting of olivine and pyroxenes. Similarly, lamprophyres have usually been classified as a separate group of rocks. Also modal classifications cannot be applied to rocks which contain glass or are too fine-grained to have their modes determined, so that other criteria, such as chemistry, have to be used in these examples.

As a result several classifications have to be presented, each of which is applicable to a certain group of rocks, e.g. pyroclastic rocks, lamprophyres, plutonic rocks. This, however, means that one has to decide which of the classifications is appropriate for the rock in question. To do this in a consistent manner, so that different petrologists will arrive at the same answer, a hierarchy of classification had to be agreed upon. The basic principle involved in this was that the "special" rock types (e.g. lamprophyres, pyroclastic rocks) must be dealt with first so that anything that was not regarded as a "special" rock type would be classified in either the plutonic or volcanic classifications which, after all, contain the vast majority of igneous rocks. The sequence that should be followed is as follows:

(1) if the rock is considered to be of **pyroclastic origin** go to section 2.2 "Pyroclastic Rocks and Tephra" on p.7
(2) if the rock contains > 50% of **modal carbonate** go to section 2.3 "Carbonatites" on p.10
(3) if the rock contains > 10% of **modal melilite** go to section 2.4 "Melilite-bearing Rocks" on p.11
(4) if the rock contains **modal kalsilite** go to section 2.5 "Kalsilite-bearing Rocks" on p.12
(5) check to see if the rock is a **kimberlite** as described in section 2.6 on p.13
(6) check to see if the rock is a **lamproite** as described in section 2.7 on p.16
(7) if the rock contains **modal leucite** go to section 2.8 "Leucite-bearing Rocks" on p.18
(8) check to see if the rock is a **lamprophyre** as described in section 2.9 on p.19. Note that certain melilite-bearing rocks that were previously included in the lamprophyre classification should now be classified as melilite-bearing rocks
(9) check to see if the rock is a **charnockite** as described in section 2.10 on p.20
(10) if the rock is **plutonic**, as defined in section 2.1, go to section 2.11 "Plutonic rocks" on p.21
(11) if the rock is **volcanic**, as defined in section 2.1, go to section 2.12 "Volcanic rocks" on p.30
(12) if you get to this point, either the rock is not igneous or you have made a mistake.

2.2 PYROCLASTIC ROCKS AND TEPHRA

This classification has been slightly modified from that given in the 1st edition.

It should be used only if the rock is considered to have had a pyroclastic origin, i.e. was formed by fragmentation as a result of explosive volcanic eruptions or processes. It specifically excludes rocks formed by the autobrecciation of lava flows, because the lava flow itself is the direct result of volcanic action, not its brecciation.

The nomenclature and classification is purely descriptive and thus can easily be applied by non-specialists. By defining the term "pyroclast" in a broad sense (see section 2.2.1), the classification can be applied to air fall, flow and surge deposits as well as to lahars, subsurface and vent deposits (e.g. intrusion and extrusion breccias, tuff dykes, diatremes).

When indicating the grain size of a single pyroclast or the middle grain size of an assemblage of pyroclasts the general terms "mean diameter" and "average pyroclast size" are used, without defining them explicitly, as grain size can be expressed in several ways. It is up to the user of this nomenclature to specify the method by which grain size was measured in those examples where it seems necessary to do so.

2.2.1 Pyroclasts

Pyroclasts are defined as fragments generated by disruption as a direct result of volcanic action.

The fragments may be individual crystals, or crystal, glass or rock fragments. Their shapes acquired during disruption or during subsequent transport to the primary deposit must not have been altered by later redepositional processes. If the fragments have been altered they are called "reworked pyroclasts", or "epiclasts" if their pyroclastic origin is uncertain.

The various types of pyroclasts are mainly distinguished by their size (see Table 2.3, p.9):

Bombs — pyroclasts the mean diameter of which exceeds 64 mm and whose shape or surface (e.g. bread-crust surface) indicates that they were in a wholly or partly molten condition during their formation and subsequent transport.

Blocks — pyroclasts the mean diameter of which exceeds 64 mm and whose angular to subangular shape indicates that they were solid during their formation.

Lapilli — pyroclasts of any shape with a mean diameter of 64 mm to 2 mm

Ash grains — pyroclasts with a mean diameter of less than 2 mm They may be further divided into **coarse ash grains** (2 mm to 1/16 mm) and **fine ash (or dust) grains** (less than 1/16 mm).

2.2.2 Pyroclastic deposits

Pyroclastic deposits are defined as an assemblage of pyroclasts which may be unconsolidated or consolidated. They must contain more than 75% by volume of pyroclasts, the remaining materials generally being of epiclastic, organic, chemical sedimentary or authigenic origin. When they are predominantly consolidated they may be called **pyroclastic rocks** and when predominantly unconsolidated they may be called **tephra**. Table 2.3 shows the nomenclature for tephra and well-sorted pyroclastic rocks.

However, the majority of pyroclastic rocks are polymodal and may be classified according to the proportions of their pyroclasts as shown in Fig. 2.1 as follows:

Agglomerate — a pyroclastic rock in which bombs > 75%.

Pyroclastic breccia — a pyroclastic rock in which blocks > 75%.

Tuff breccia – a pyroclastic rock in which bombs and/or blocks range in amount from 25% to 75%.

Lapilli tuff – a pyroclastic rock in which bombs and/or blocks < 25%, and both lapilli and ash < 75%.

Lapillistone – a pyroclastic rock in which lapilli > 75%.

Tuff or **ash tuff** – a pyroclastic rock in which ash > 75%. These may be further divided into **coarse (ash) tuff** (2 mm to 1/16 mm) and **fine (ash) tuff** (less than 1/16 mm). The fine ash tuff may also be called **dust tuff**. Tuffs and ashes may be further qualified by their fragmental composition, i.e **lithic tuff** would contain a predominance of rock fragments, **vitric tuff** a predominance of pumice and glass fragments, and a **crystal tuff** a predominance of crystal fragments.

Any of these terms for pyroclastic deposits may also be further qualified by the use of any other suitable prefix, e.g. air-fall tuff, flow tuff, basaltic lapilli tuff, lacustrine tuff, rhyolitic ash, vent agglomerate etc. The terms may also be replaced by purely genetic terms, such as hyaloclastite or base-surge deposit, whenever it seems appropriate to do so.

2.2.3 MIXED PYROCLASTIC–EPICLASTIC DEPOSITS

For rocks which contain both pyroclastic and normal clastic (epiclastic) material the Subcommission suggests that the general term **tuffites** can be used within the limits given in Table 2.4. Tuffites may be further divided according to their average grain size by the addition of the term "tuffaceous" to the normal sedimentary term, e.g. tuffaceous sandstone.

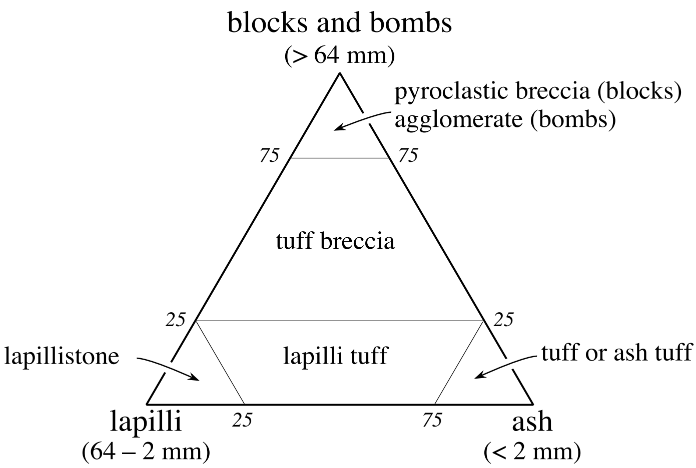

Fig. 2.1. Classification of polymodal pyroclastic rocks based on the proportions of blocks/bombs, lapilli and ash (after Fisher, 1966).

Table 2.3. *Classification and nomenclature of pyroclasts and well-sorted pyroclastic rocks based on clast size*

Average Clast size in mm	Pyroclast	Pyroclastic deposit: Mainly unconsolidated: tephra	Pyroclastic deposit: Mainly consolidated: pyroclastic rock
	bomb, block	agglomerate bed of blocks or bomb, block tephra	agglomerate pyroclastic breccia
64			
	lapillus	layer, bed of lapilli or lapilli tephra	lapillistone
2			
	coarse ash grain	coarse ash	coarse (ash) tuff
1/16			
	fine ash grain (dust grain)	fine ash (dust)	fine (ash) tuff (dust tuff)

Source: After Schmid (1981, Table 1).

Table 2.4. *Terms to be used for mixed pyroclastic–epiclastic rocks*

Average clast size in mm	Pyroclastic		Tuffites (mixed pyroclastic –epiclastic)	Epiclastic (volcanic and/or non-volcanic)
	agglomerate, pyroclastic breccia		tuffaceous conglomerate, tuffaceous breccia	conglomerate, breccia
64				
	lapillistone			
2				
	(ash) tuff	coarse	tuffaceous sandstone	sandstone
1/16				
		fine	tuffaceous siltstone	siltstone
1/256				
			tuffaceous mudstone, shale	mudstone, shale
Amount of pyroclastic material	100% to 75%		75% to 25%	25% to 0%

Source: After Schmid (1981, Table 2).

2.3 CARBONATITES

This classification should be used only if the rock contains more than 50% modal carbonates (Streckeisen, 1978, 1979). Carbonatites may be either plutonic or volcanic in origin. Mineralogically the following classes of carbonatites may be distinguished:

Calcite-carbonatite — where the main carbonate is calcite. If the rock is coarse-grained it may be called **sövite**; if medium- to fine-grained, **alvikite.**

Dolomite-carbonatite — where the main carbonate is dolomite. This may also be called **beforsite**.

Ferrocarbonatite — where the main carbonate is iron-rich.

Natrocarbonatite — essentially composed of sodium, potassium, and calcium carbonates. At present this unusual rock type is found only at Oldoinyo Lengai volcano in Tanzania.

Qualifications, such as dolomite-bearing, may be used to emphasize the presence of a minor constituent (less than 10%). Similarly, igneous rocks containing less than 10% of carbonate may be called calcite-bearing ijolite, dolomite-bearing peridotite etc., while those with between 10% and 50% carbonate minerals may be called calcitic ijolite or carbonatitic ijolite etc.

If the carbonatite is too fine-grained for an accurate mode to be determined, or if the carbonates are complex Ca–Mg–Fe solid solutions, then the chemical classification shown in Fig. 2.2 can be used for carbonatites with $SiO_2 < 20\%$.

However, if $SiO_2 > 20\%$ the rock is a **silicocarbonatite**. For a more detailed chemical classification of **calciocarbonatites**, **magnesiocarbonatites** and **ferrocarbonatites** refer to Gittins & Harmer (1997) and Le Bas (1999).

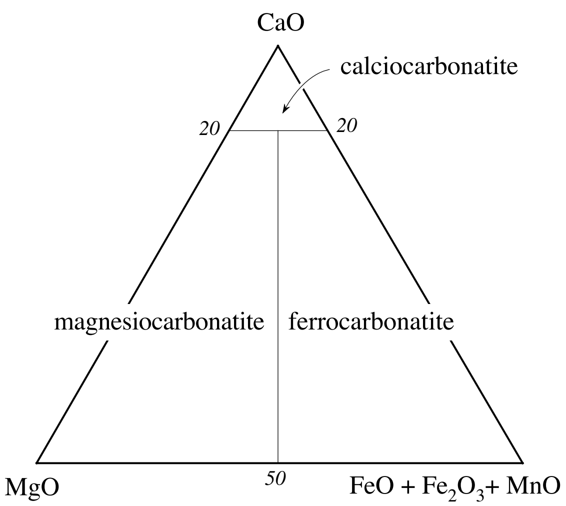

Fig. 2.2. Chemical classification of carbonatites with $SiO_2 < 20\%$ using wt % oxides (Woolley & Kempe, 1989). Carbonatites in which $SiO_2 > 20\%$ are silicocarbonatites.