中国地质大学"十一五"规划教材
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变质地质学

METAMORPHIC GEOLOGY

Roger Mason　Sang Longkang

China University of Geosciences Press

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内容提要

《变质地质学》是随着20世纪60年代板块构造学兴起而迅速发展起来的地质学科，作为课程，它属于地质专业课程性质，具有显著的地质前沿和岩石学与构造学学科交叉特点。由英国著名岩石学家R. Mason教授和我校桑隆康教授合著的该课程双语教学教材《Metamorphic Geology》全面介绍了变质岩石学和变质地质学的基础理论、基础知识和基本技能。内容主要包括变质作用通论、接触变质、动力变质和区域变质及地外变质五大部分。与国内其他类似教材的内容相比，本课程具有明显的先进性，介绍了包括 *P*-*T*-*t* 轨迹、缓冲平衡、超高压变质、超高温变质、地外变质等前沿课题。其中，缓冲平衡、超高温变质、地外变质等课题国内教材很少涉及。此外，教材强调用 *AFM* 图对变泥质岩进行共生分析，对世界著名的Barrow变质带、Sulitjelma变质带、Skiddaw接触晕和塞浦路斯蛇绿岩带等经典的介绍比较详细、生动。与国外类似教材相比，该教材介绍了国外课程通常没有的我国周口店、北戴河、三峡、秦岭、嵩山、大别山变质作用方面的内容，具有明显的中国特色。该教材的出版是双语教材建设方面取得的突破性进展。

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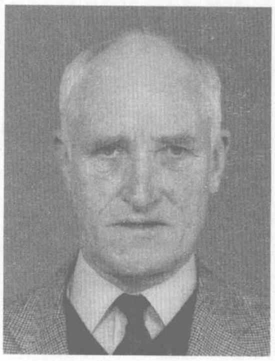
Author Introduction

Roger Mason was born in London, England on May 4, 1941. He received a Bachelor of Arts degree from Christ's College, Cambridge University in 1963, a Doctor of Philosophy degree of Cambridge University in 1967, and a Postgraduate Certificate in Education from the University of Hertfordshire, England in 1990. From 1966 to 1996, he taught Metamorphic Petrology, Tectonics, Geology and Field Geology at University College London, Birkbeck College, London University, and Luton University. He taught a special course in Metamorphic Petrology at Wuhan College of Geoscience in 1986. He has been teaching bilingual courses Metamorphic Petrology and Metamorphic Geology at China University of Geosciences (Wuhan) since 1996 to both National Science and Engineering Base Classes. He is a professor of Mineralogy, Petrology and Mineral Deposits at China University of Geosciences (Wuhan) and an education advisor in London, England. His research areas are Metamorphic Petrology, Metamorphic Geology and bilingual education. His textbook *Petrology of the Metamorphic Rocks* (1st edition, 1978) was translated into Russian in 1981 and published by the Russian World Publishing House. *Petrology of the Metamorphic Rocks* (2nd edition, 1990) is cited in Petrology teaching materials in Britain, America, China and Russia. He won the China International Friendship Prize in 2001, the highest prize awarded by our government to foreign experts, for his prominent contribution to bilingual teaching and Chinese-English international cooperation.

Sang Longkang was born in Jiujiang City, Jiangxi Province. He graduated from the Geology Department of Hefei University of Industry in 1969. He received a Master of Science degree from Wuhan College of Geosciences in 1982 . From 1970 to 1979, he was engaged in geologic survey of metamorphic phosphorite deposits and prospecting work in the No. 311 geology team of the Geology Bureau of Anhui Province. Since 1982, he has been teaching Petrology, Metamorphic Petrology, Metamorphic Geology etc. in courses at China University of Geosciences (Wuhan). Now he is a professor of Mineralogy, Petrology and Mineral Deposits, a doctoral tutor, the principal of advanced petrology courses. He has been made a Foreign Member of the Russian Academy of Natural Sciences for his contributions to Russian-Chinese geological collaboration. His main research areas are Petrology, Metamorphic Geology and Geological Education. He has won teaching and scientific research rewards at the province and ministerial level many times. Professor Lu Fengxiang and he are joint editors in chief of the *Petrology* in the Higher Education Textbook Series for the 21st Century, published by the Geology Publishing House in 2002.

作者简介

梅森



1941年5月4日生于英国伦敦，1963年获剑桥大学理学学士学位，1967年获剑桥大学哲学博士学位，1990年获英国Hertfordshire大学教育学研究生证书。1966—1996年，先后在在英国伦敦大学大学学院、伦敦大学Birkbeck学院、Luton大学讲授《变质岩岩石学》、《构造地质学》和《地质学》等课程，其中1986年在武汉地质学院讲授《变质岩石学》。1996年起，在中国地质大学(武汉)为国家理科基地班和工科基地班讲授双语课程《变质岩石学》和《变质地质学》。现为中国地质大学(武汉)矿物学岩石学矿床学教授、英国伦敦教育顾问。主要研究领域包括变质岩石学、变质地质学、双语教育。他的《变质岩岩石学(第一版,1978)》于1981年被译成俄文在苏联世界出版社出版。他的《变质岩岩石学(第二版,1990)》被英、美、中、俄众多岩石学教材引用。由于他在双语教学和中英交流所作的突出贡献，2001年获得我国政府授予外籍专家的最高奖——友谊奖。

桑隆康

1945年10月25日生于江西省九江市，1969年毕业于合肥工业大学地质系，1982年获武汉地质学院理学硕士学位，1970—1979年在安徽省地质局311地质队从事变质磷矿地质调查和找矿勘探工作。1982年起，在中国地质大学(武汉)讲授《岩石学》、《变质岩石学》和《变质地质学》等课程。现为中国地质大学(武汉)矿物学岩石学矿床学教授、博士生导师、精品课程《岩石学》负责人，俄罗斯自然科学院外籍院士。主要研究领域包括岩石学、变质地质学、地学教育。多次获得省部级教学和科研奖励。他与路凤香教授联合主编的教材《岩石学》作为高等教育面向21世纪课程教材于2002年在地质出版社出版。

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Foreword

This book is designed to accompany a junior year course entitled *Metamorphic Geology* that I teach in English to Geology and Earth Resources major students in their junior year of study at China University of Geosciences (CUG), Wuhan, Hubei, China. At the present time of writing the course consists of eleven lectures, eight practical classes and a one-day field class. The course has two aims: to improve the students' understanding of metamorphic rocks, and to improve their English.

In their Earth science aspects, course and book focus on recognizing and understanding the nature of equilibrium in metamorphic mineral assemblages, and using mineral assemblages to estimate temperatures and pressures of metamorphism. I aim to encourage students to understand what they see in the field and through the petrological microscope, rather than to give them a comprehensive overview of all types of metamorphism and all types of metamorphic rocks. The CUG students have already studied metamorphic rocks in Chinese, and so I am more concerned with developing skills of observation and intelligent scientific inference than with a didactic presentation of current theories and research methods. Nevertheless, my subject matter ranges much wider than what is usually taught in petrology. In particular, I am keen to correct a traditional view of metamorphism as a process that only occurs over the range of temperatures and pressures found in the Earth's crust.

As far as Chinese students' ability in English is concerned, there has been a revolution since I first taught this course in 1986 with Prof. Han Yujing's continuous support as translator. Even when the course started in its present form in 1999 and I lectured in English without a translator, I used to ask for a show of hands at the end of classes to find out how many students understood my words. Now students are beginning to ask questions and to argue with my assumptions. The introduction of Powerpoint slides in place of the old overhead and slide projectors has also revolutionized the presentation of diagrams. I am concerned that using Powerpoint as a communication medium discourages independent thought, and we still have a long way to go to persuade Chinese students to seek out and read primary English source material. None ever criticize what they have read and they are anxious when I disagree with published teachers and researchers, for example by insisting that triangular diagrams and mineral lists characterizing metamorphic facies include only equilibrium mineral assemblages.

The course has its roots in my two textbooks (Mason, 1990) which in their turn were strongly influenced by Professor Akiho Miyashiro's work (1973, 1994). All teachers of metamorphic geology at CUG, including me, owe an immense debt to Professor You Zhendong. In its present form, the course was launched by Professor Jin Zhenmin and I could not have done it without a huge amount of support from Dr. Liu Rong, Dr. Tao Xian, Professor Ma Changqian, Professor Zhou Hanwen and most of the teaching and technical staff of the Petrology and Mineralogy section of the CUG Earth Sci-

ence Faculty. Professor Sang Longkang has worked tirelessly to develop the course as an educational innovation in China, discuss its content and presentation with me and obtain funds to support us. He is therefore deservedly co-author of the present volume, because without his energy, patience and enthusiasm as co-writer and editor it would never have been finished. Dr. Wendy Kirk of University College London generously shared her teaching notes with me to prepare the first two versions of this book. I must also thank the staff of CUG's International Cooperation Office who provide a huge amount of support for living in China, and have become personal friends. My special thanks go to Director Professor Lai Xulong and Vice Director Professor Shao Xuemin for nominating me for high honours from provincial and national governments in China.

China University of Geosciences

8 January 2007

Roger Mason

Contents

Chapter 1 Definition of metamorphism, classification of metamorphic rocks

1.1 Definition of metamorphism

"Metamorphism" is a general name for processes of *change* of pre-existing igneous or sedimentary rocks. The original rock, before metamorphism, is called the parent rock or protolith.

The name metamorphism is derived from Ancient Greek $\mu\epsilon\tau\alpha$ (meta)=*change* and $\mu o\rho\phi\eta$ (morphe)=*form*, *shape*.

Metamorphic changes take place in solid rocks with only a small volume of fluid present or sometimes none. Metamorphism is therefore a set of *solid-state* processes, in contrast to igneous processes that are solid-melt interactions. The temperatures and pressures of metamorphism are higher than those found at the surface of the lithosphere and this distinguishes metamorphism from sedimentary processes that are interactions between the atmosphere, hydrosphere and solid earth materials at or near the surface.

All metamorphic rocks were once igneous or sedimentary rocks.

Because metamorphism is a process that occurs in solid rocks, metamorphic rocks must have formed from pre-existing igneous or sedimentary rocks. During the process of metamorphism, their original igneous or sedimentary minerals and microstructures broke down and new metamorphic minerals and microstructures took their place. There may have been more than one cycle of metamorphism, with metamorphic rocks forming from older metamorphic rocks of an earlier cycle. We call the original igneous or sedimentary rock the parent rock or protolith. If the process of metamorphism has been intense or if there have been several cycles of metamorphism, we may find it difficult to discover what kind of rock the protolith was.

Table 1.1 Metamorphic rocks and their protoliths

Protolith (parent rock)	Metamorphic rock
mudrock	slate
mudrock	schist
mudrock	gneiss
limestone	marble
limestone and chert	skarn
sandstone	quartzite
peridotite	serpentinite
basalt	greenschist
basalt	greenstone
basalt	amphibolite
basalt	pyroxene granulite
basalt	eclogite
granite	gneiss
granite	charnockite

Table 1.1 gives some examples of sedimentary and igneous protolith rock-types and the metamorphic rocks that they might change to. One kind of protolith can yield different types of metamorphic rock because it can undergo different kinds of metamorphism. Different kinds of protolith (e.g. sedimentary marls and volcanic tuffs) can yield the same type of metamorphic rocks because similar metamorphism produces rocks with similar characteristics.

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1.2 Classification and nomenclature of metamorphic rocks

There are several systems for classifying metamorphic rocks and the one we use depends on our reason for studying them. If we are making a field geological survey or logging rocks from a borehole we must give them a name and short description so that we can study them in more detail later. If we are doing petrological or geochemical research, we shall make more detailed descriptions including study of thin sections and chemical analyses so we can use more precise schemes of classification. If we are investigating tectonics, we shall use metamorphic rocks to calculate temperatures and pressures deep in the Earth at some time during the tectonic evolution. If we are investigating a sedimentary basin, we may use metamorphic rocks to understand the evolution of the basin and the maturation of sediments that might be source rocks of oil and natural gas. In all these cases, we need to choose suitable metamorphic rocks and focus our study on them.

The system we use also depends on the equipment we have. Are we doing fieldwork with only a hammer, hand lens and penknife? Do we have facilities for making thin sections and studying them under a microscope? Are we fortunate enough to use a full range of analytical equipment for chemical analysis of rocks and minerals, optical and electron microscopy, stable and unstable isotope analysis (including age dating), mineral spectroscopy and determinations of crystal structure? Our descriptions and identifications will depend on our equipment.

1.2.1 A simple descriptive classification

The first scheme I introduce is mainly used during fieldwork, though you should check your conclusions if possible by studying thin sections of the rocks under a petrological microscope later. Table 1.2 gives an outline of the scheme. The first column lists protolith compositions, the second the main types of metamorphic minerals in the rock and the last four columns corresponding metamorphic rock types, subdivided according to their microstructure. For an alternative scheme see Fry (1984).

In my scheme, the main criteria for naming rocks are:

(1) The composition of the protolith – pelitic, psammitic, semi-pelitic, marble etc.

(2) The metamorphic minerals present in the rock.

(3) Aspects of the rock microstructure: ①grain-size, which distinguishes the members of the series slate→phyllite→schist→gneiss for example and ②the presence or absence of metamorphic banding.

The composition of rocks needs further explanation. If metamorphism has changed all the minerals in a rock, the kinds of minerals will depend on the rock's bulk chemical composition. But bulk compositions of rocks are usually not used for classifying sedimentary rocks and the chemical subdivisions of igneous rocks are often too detailed for the broad classification that we are making in our scheme. So we metamorphic petrologists use our own names for broad compositional categories of rocks, listed below noun first, adjective second.

Pelite, pelitic: rocks that were originally sedimentary mudrocks (shale), rich in Al.

Psammite, psammitic: rocks that were originally sedimentary sandstones, rich in Si.

Semi-pelite, semi-pelitic: rocks that were originally sandy shales, i.e. intermediate between pelites and psammites.

Metabasite, metabasic: rocks that were originally basic igneous rocks, basalt, dolerite (diabase) and gabbro, rich in Mg, Fe and Ca.

Limestone: rocks composed of carbonate minerals, especially calcite and dolomite.

Marl: rocks intermediate in composition between pelites and limestones.

Chert: rocks composed of very fine-grained SiO_2, i. e. chert or flint.

The microstructural subdivisions are based first of all on the grain-size of the metamorphic minerals. We take the size limit between fine-grained and medium-grained rocks at 0.125mm from the standard classification of sedimentary rocks. A grain 0.125mm across is approximately the smallest that you can see with your naked eye, without a hand-lens. 2mm is the limiting grain-size between medium and coarse-grained sedimentary rocks, approximately the diameter of this letter O.

Table 1.2 Scheme of classification of metamorphic rocks

	Protolith composition	Main minerals	Fine-grained <0.125mm	Medium-grained 0.125~2.0mm	Coarse-grained >2.0mm
Foliated rocks	Pelite	sheet silicates, quartz, Al-silicates	slate	phyllite	schist, gneiss
	Semi-pelite	quartz, sheet silicates	sandy slate	quartz phyllite	quartz-schist
	Marl	sheet silicates, calcite, dolomite, epidote	calcareous slate	calcareous phyllite	calcareous schist or calc schist
	Rhyolite, granite	alkali feldspar, quartz, sheet silicates	—	granitic gneiss	granitic gneiss
	Basalt, gabbro	plagioclase feldspar, amphiboles, epidote	greenschist	schistose amphibolite	schistose amphibolite
	Pyroxenite, peridotite, dunite	serpentine, talc, olivine, pyroxene	—	talc phyllite	talc schist, foliated peridotite
Massive rocks	Psammite	Q	quartzite	quartzite	quartzite
	Limestone	Cc, Dol	marble	marble	marble
	Limestone and chert	Cc, Q, Dol, Tc, Tr, Fo, Di	—	Tc-, Tr-, Fo-, Di-marble	Tr-, Fo-, Di-marble
	Rhyolite, granite	Af, Q, sheet silicates	—	augen gneiss	augen gneiss
	Basalt, gabbro	Pl, Am, Ep	greenstone	amphibolite	amphibolite, Px granulite, eclogite
	Pyroxenite, peridotite, dunite	Serp, Tc, Ol, Px	soapstone, serpentinite	soapstone, serpentinite	Metapyroxenite, metaperidotite

Coarse-grained metamorphic rocks have undergone stronger metamorphism than finer grained ones and often develop a metamorphic layering or compositional banding, also called gneissosity (Fig. 1.1).

You can modify the names if there are obvious minerals in the rock, e. g. *kyanite schist*, *tremolite marble*.

To identify a metamorphic rock in the field, study it carefully using a hand lens in bright light. Identify as many kinds of minerals in the rock as you can, and estimate their grain-sizes and relative proportions. If you are used to identifying minerals or plutonic igneous rocks such as granite and gabbro in the lab, you will have to adjust to studying smaller crystals. As you gain experience you will be able to identify grains as small as 0.1mm across. If you cannot identify individual grains, test the bulk properties of the rock such as density, colour and hardness. You can identify a rock composed of quartz crystals that are too small to see because it will scratch a knife blade. You can distin-

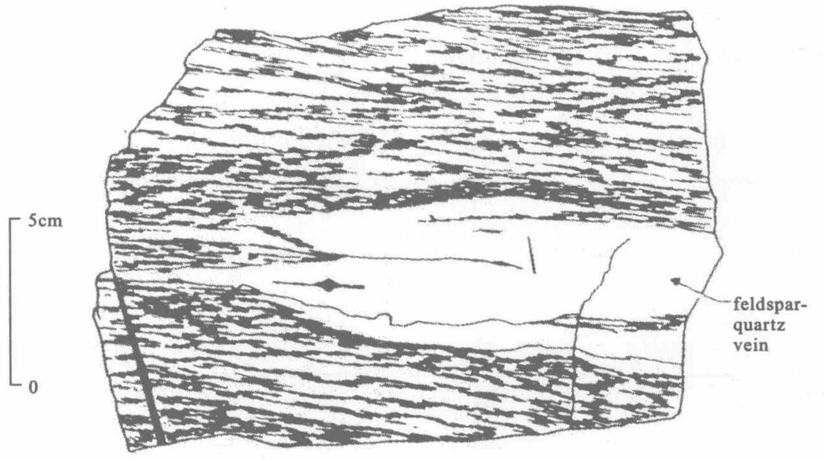

Fig. 1. 1　Gneiss with mm scale banding, Myrdal, Norway

guish fine-grained metamorphosed rhyolite mainly composed of quartz and alkali feldspar from metamorphosed basalt mainly composed of amphibole and plagioclase feldspar by its lower density. It is usually lighter in colour as well. This kind of classification is not very accurate, but it is much better than no classification.

Table 1. 2 only contains a selection of metamorphic rock names. There are also special metamorphic rock names such as hornfels and protomylonite that we give to rocks from certain geological settings (see Section 1. 2. 2).

1. 2. 2　Classification of metamorphic rocks by their field settings

The geological setting of metamorphic rocks often tells us a lot about the processes that caused their metamorphism. Contact metamorphic rocks occur near the contacts of igneous intrusions, dynamic metamorphic rocks close to faults and thrusts. This gives rise to a three-fold classification, outlined below.

1. 2. 2. 1　Contact metamorphic rocks

Contact metamorphic rocks occur adjacent to igneous intrusions. They occur over small areas (a few km^2), and formed by recrystallization of the original minerals in the igneous or sedimentary protolith because of the increase in temperature as heat flowed from the magma of the intrusion. Their mode of formation by heat from the intrusion is obvious from field study. The processes that transfer heat from the magma of the intrusion to cause metamorphism in the surrounding rocks are called contact metamorphism.

A small intrusion such as a dyke only bakes the country rock for a few millimetres. Around a larger intrusion, the contact metamorphic rocks form a contact metamorphic aureole that can vary in width from a few metres to kilometres. Therefore, contact metamorphic rocks outcrop over small areas ($<100km^2$). We can often see that the grain-size of the recrystallized minerals increases towards the intrusion, so that the largest grains are at the contact where the temperature of metamorphism was highest. The temperature of contact metamorphism also varies with the temperature of the intruded magma, being highest against ultra-basic igneous intrusions, intermediate against basic igneous intrusions and lowest against granitoid intrusions. At shallow levels in the Earth's crust ($<7km$) rocks are not usually deformed during contact metamorphism and thus do not display microstructures such as cleavage or foliation. They may inherit them from their sedimentary and igneous protoliths, or from earlier regional metamorphism. Because it is obvious that heat flowing from the intrusion caused this type of metamorphism, some geologists call contact metamorphism *thermal metamorphism*. In this section, however, I am emphasising the field relationships of metamorphic rocks, so I prefer the older term contact metamorphism.

1.2.2.2 Dynamic metamorphic rocks

Dynamic metamorphic rocks occur near major faults and thrusts especially major fractures with large displacements at plate boundaries. Like contact metamorphic rocks, they therefore outcrop over small areas (<10 km^2). They are the products of processes of fracture and plastic deformation that went on during the movement of the faults and thrusts.

1.2.2.3 Regional metamorphic rocks

The commonest metamorphic rocks outcrop over areas of hundreds of thousands of square kilometres. For example, over half the rocks outcropping in Canada are regional metamorphic rocks. Unlike contact and dynamic metamorphic rocks, the processes that caused their recrystallization from protoliths are not obvious from field study. There have been different theories about their origin since the beginning of geological research, and there still are. By describing these processes as regional metamorphism, we can classify the rocks without pre-judging their mode of origin, whereas if we use a term like *dynamothermal metamorphism* we are already expressing an opinion about the origin of the rocks. Using the prefix *dynamo*-(i. e. metamorphism associated with deformation) is wrong for many examples of regional metamorphism (e. g. burial metamorphism). Putting *dynamo*-ahead of *thermal* implies that deformation is more important than heat in the metamorphism of these rocks. Modern research has shown that this is wrong, although many well-known geologists (e. g. Harker, 1927) once thought otherwise. We call all rocks that are products of regional metamorphism, from sediments with only the smallest degree of metamorphism to ultra-high temperature gneisses regional metamorphic rocks.

This book is organised into sections based on this classification of metamorphic rocks.

1.2.3 Metamorphic facies

Metamorphic facies classifications divide metamorphic rocks with different protolith compositions into categories based on temperature and pressure at the peak of metamorphism. They rest on the application of equilibrium thermodynamic theory and the Phase Rule to metamorphic processes, which is explained and discussed in Chapter 2 of this book. Further explanation of metamorphic facies can be found in that Chapter.

1.2.4 Other classification schemes

There are other classifications of metamorphism in use, for example by their tectonic settings (e. g. subduction zone metamorphism, burial metamorphism, basin extension metamorphism). I shall describe these later.

1.3 The minerals of metamorphic rocks

The minerals in metamorphic rocks are new crystals formed by chemical reactions that occurred during the processes of metamorphism. Table 1.3 lists minerals that occur in metamorphic rocks, and is based on the textbook of Deer, Howie and Zussman (1992). You can see many minerals that are already familiar in sedimentary and igneous rocks (e. g. quartz, calcite, feldspar and mica). There are other minerals that only occur in metamorphic rocks (e. g. glaucophane, kyanite) or occur more commonly in metamorphic rocks (e. g. garnet, epidote). Kretz (1973) proposed a scheme of two or three letter abbreviations for metamorphic mineral names (e. g. Sph for sphene) and such schemes have since been widely adopted in both textbooks and research publications. The actual abbreviations used vary between different publications. In this book I follow Kretz (1994, Table 1. 1) and Sang et al. (2005). I have added the minerals' Chinese names from Sang et al. (2005).

Table 1. 3 Minerals of Metamorphic Rocks

(Deer, Howie & Zussman, 1992; Kretz, 1994; Sang et al, 2005)

Mineral Group	Abbreviation and Chinese name	Chemical formula	Hand specimen properties
Silicate Minerals			
Orthosilicates			
Olivine group	橄榄石族		
olivine	Ol 橄榄石	$(Mg,Fe)_2SiO_4$	Orth. *D* 3. 2～4. 4, *H* 7, # None, green, yellow.
forsterite	Fo 镁橄榄石	Mg_2SiO_4	Orth. *D* 3. 2, *H* 7, # None, yellow, colourless.
Garnet group	Gt 石榴石族		
almandine	Alm 铁铝榴石	$Fe_3Al_2Si_3O_{12}$	Cub. *D* 3. 6, *H* 6～7½, # None, red-black
pyrope	Prp 镁铝榴石	$Mg_3Al_2Si_3O_{12}$	Cub. *D* 3. 6, *H* 6～7½, # None, bright red
spessartine	Sps 锰铝榴石	$Mn_3Al_2Si_3O_{12}$	Cub. *D* 3. 6, *H* 6～7½, # None, black
grossular	Grs 钙铝榴石	$Ca_3Al_2Si_3O_{12}$	Cub. *D* 3. 6, *H* 6～7½, # None, red, yellow
andradite	Andr 钙铁榴石	$Ca_3Fe_2^{3+}Si_3O_{12}$	Cub. *D* 3. 6, *H* 6～7½, # None, red
Aluminium silicate group	Als 铝硅酸盐		
sillimanite	Sil 夕线石	Al_2SiO_5	Orth. *D* 3. 3, *H* 6～7, #1, None, grey
kyanite	Ky 蓝晶石	Al_2SiO_5	Tric. *D* 3. 6, *H* 5. 5～7 variable, #2, blue, grey
andalusite	And 红柱石	Al_2SiO_5	Orth. *D* 3. 1, *H* 6～7, #2, pink, grey
mullite	Mu 多铝红柱石	$3Al_2O_3 \cdot 2SiO_2$	Orth. *D* 3. 2, *H* 6～7, #1, None or pink, yellow
Other orthosilicates	其他正硅酸盐		
sphene (titanite)	Sph 榍石	$CaTi[SiO_4](O,OH,F)$	Mon. *D* 3. 5～3. 6, *H* 5, # 2, None, brown, black
chloritoid	Cld 硬绿泥石	$(Fe,Mg)_2(Al,Fe^{3+})(OH)_4Al_3O_2[SiO_4]_2$	Mon., Tric. *D* 3. 5～3. 8, *H*6½, #3, green to black
larnite	Lar 斜硅钙石	$Ca_2[SiO_4]$	Mon. *D* 3. 3, #1, white

Table 1.3 continued

Mineral Group	Abbreviation and Chinese name	Chemical formula	Hand specimen properties
spurrite	Spu 灰硅钙石	$2Ca_2[SiO_4] \cdot CaCO_3$	Mon. *D* 3.0, *H* 5, #1, white
Disilicates			
Epidote group	绿帘石族		
epidote	Ep 绿帘石	$Ca_2Al_2O \cdot (Al,Fe^{3+})OH [Si_2O_7][SiO_4]$	Mon. *D* 3.4, *H* 6, #1, yellow, green
zoisite	Zo 黝帘石	$Ca_2Al_2O \cdot AlOH [Si_2O_7][SiO_4]$	Orth. *D* 3.2~3.3, *H* 6~7, #2, grey, green.
clinozoisite	Czo 斜黝帘石	$Ca_2Al_2O \cdot AlOH [Si_2O_7][SiO_4]$	Mon. *D* 3.2~3.4, *H* 6½, #1, None, pale green
Other disilicates	其他双硅酸盐		
lawsonite	Lw 硬柱石	$CaAl_2[Si_2O_7](OH)_2 \cdot H_2O$	Orth. *D* 3.1, *H* 6, #2, None, bluish green
carpholite	Car 纤锰柱石	$(Mg,Fe^{2+})Al_2[Si_2O_6](OH)_4$	
pumpellyite	Pu 绿纤石	$Ca_2Al_2(Mg,Fe,Al)[Si_2(O,OH)_7](OH,O)_3$	Mon. *D* 3.2, *H* 5~6, #2, green, brown
rankinite	Ran 硅钙石	$Ca_3[Si_2O_7]$	Mon. *D* 3.0, *H* 5½, # None, white
kilchoanite	Kl 斜方硅钙石	$Ca_3[Si_2O_7]$	Orth. polymorph of Ran
tilleyite	Til 粒硅钙石	$Ca_3[Si_2O_7] \cdot 2CaCO_3$	Mon. *D* 2.8, #1, white
Ring silicates			
cordierite	Crd 堇青石	$(Mg,Fe)_2[Si_5Al_4O_{18}] \cdot n(H_2O, CO_2)$	(Hex.) *D* 2.5~2.8, *H* 7, #1, dark blue, green-blue
tourmaline	Tur 电气石	$(Na,Ca)(Mg,Fe,Mn,Li,Al)_3[Si_6O_{18}](BO_3)_3(O,OH)_3(OH,F)$	Trig. *D* 3.0~3.2, *H* 7, # None, black, blue, green, yellow.
Single chain silicates			
Orthopyroxene group	Opx 斜方辉石族		
enstatite	En 顽火辉石	$Mg[SiO_3]$	Orth. *D* 3.2, *H* 5~6, #2, None, yellow
hypersthene	Hy 紫苏辉石	Orthopyroxene intermediate between $Mg[SiO_3]$ and $Fe[SiO_3]$	Orth. *D* 4.0, *H* 5~6, #2, dark brown
Clinopyroxene group	Cpx 单斜辉石族		
diopside	Di 透辉石	$CaMg[Si_2O_6]$	Mon. *D* 3.2, *H* 5½, #2, white, green
hedenbergite	Hd 钙铁辉石	$CaFe[Si_2O_6]$	Mon. *D* 3.6, *H* 6½, #2, Brown, dark green, black
omphacite	Om 绿辉石	$(Ca,Na)(Mg,Fe,Fe^{3+},Al)[Si_2O_6]$	Mon. *D* 3.2~3.4, *H* 5~6, #2, green
jadeite	Jd 硬玉	$NaAl[Si_2O_6]$	Mon. *D* 3.2~3.4, *H* 6, #2, None, green, blue
other single chain silicates	其他单链状硅酸盐		
wollastonite	Wo 硅灰石	$Ca[SiO_3]$	Tric. *D* 2.9~3.1, *H* 4½~5, #3, white, grey
sapphirine	Sap 假蓝宝石	$(Mg,Fe^{2+},Fe^{3+},Al)_8O_2[(Al,Si)_6O_{18}]$	Mon. *D* 3.4~3.6, *H* 7½, #1, light blue, green, grey

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