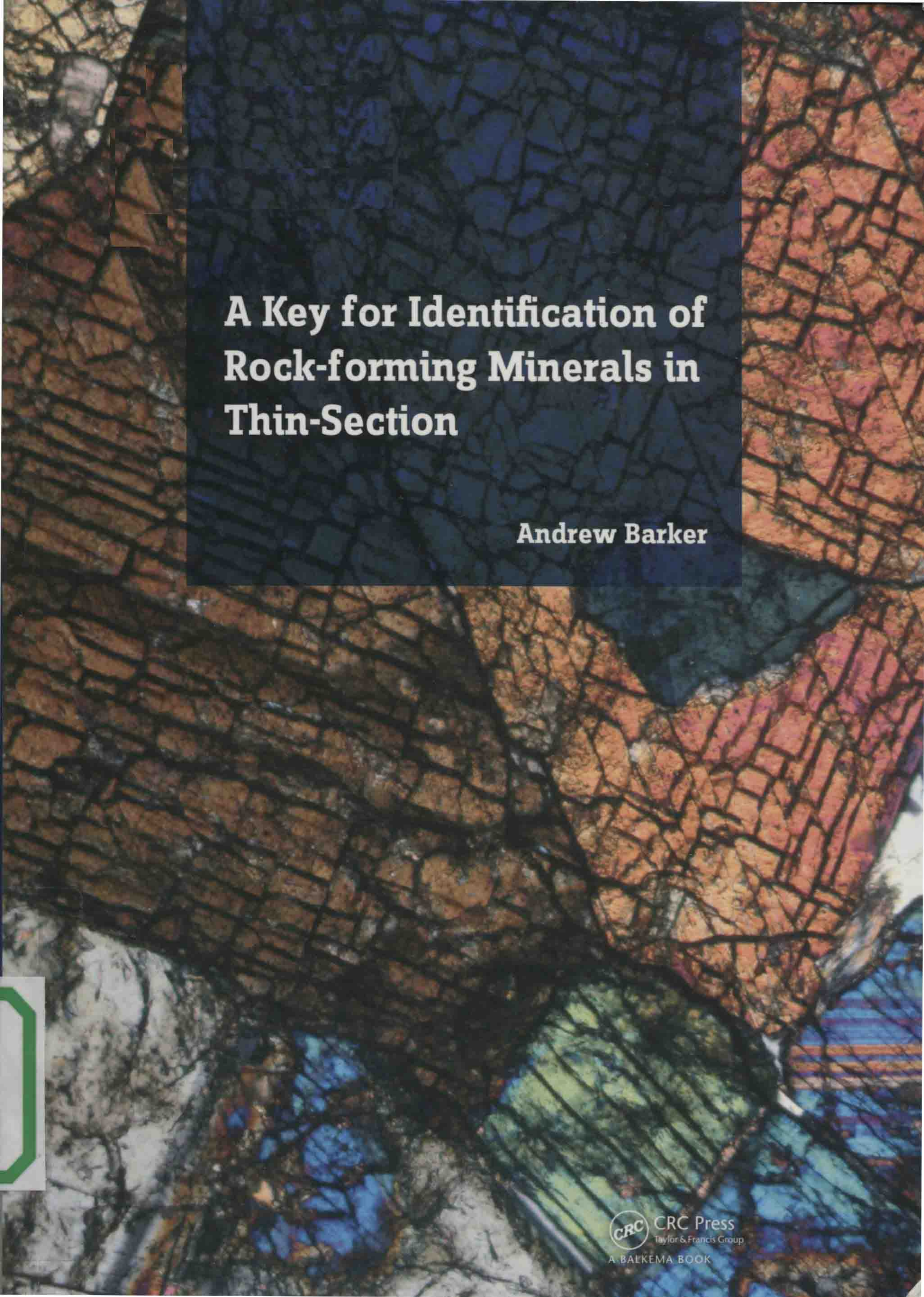


A Key for Identification of Rock-forming Minerals in Thin-Section

Andrew Barker

CRC Press
Taylor & Francis Group
A BALKEMA BOOK

A Key for Identification of Rock-forming Minerals in Thin-Section

Andrew J. Barker
University of Southampton, UK

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

Typeset by diacriTech Limited, Chennai, India
Printed and bound in India by Replika Press Private Limited

Published by: CRC Press/Balkema
P.O. Box 11320, 2301 EH Leiden, The Netherlands
e-mail: Pub.NL@taylorandfrancis.com
www.crcpress.com – www.taylorandfrancis.com

Library of Congress Cataloging-in-Publication Data

Barker, Andrew J., author.
A key for identification of rock-forming minerals in thin section / Andrew J. Barker, University of Southampton, UK.
pages cm
Includes bibliographical references and index.
ISBN 978-1-138-00114-5 (paperback)—ISBN 978-1-315-77869-3 (ebook)
1. Rock-forming minerals—Identification. I. Title.

QE397.B37 2014
549'.114—dc23

2014024200

ISBN: 978-1-138-00114-5 (Pbk)
ISBN: 978-1-315-77869-3 (eBook PDF)

A Key for Identification of Rock-forming Minerals in Thin-Section

Acknowledgements

The idea for a key to minerals under the microscope began many years ago, but due to various other commitments it has taken a while to complete. My wife, Linda, has given me encouragement and support throughout, so I would like to start by giving her my sincere thanks. This book would not have been possible without her.

Secondly, I would particularly like to thank all undergraduate and postgraduate students past and present who have taken my mineralogy and petrology courses at the University of Southampton. Their questions, comments and suggestions have guided me greatly in developing the present mineral key. Their interest and enthusiasm has certainly encouraged me throughout my career, and I hope this book lives up to expectations as an aid to mineral identification under the microscope.

I would also like to acknowledge the University of Southampton, for access to its excellent thin-section collection, build up over many years, and from which the vast majority of the minerals photographed were sourced. In this regard, I would also like to give special thanks to Rex Taylor, for the use of his microscope and camera, and for helpful feedback on early drafts of the key. I would also like to thank John Ford and Bob Jones for their support with thin-section preparation over many years.

Special thanks are also extended to colleagues at other Universities who have helped in providing photographs and thin-sections of minerals that I had found difficult to source. In this regard I would like to pay special thanks to Giles Droop (University of Manchester) for his considerable effort in providing many excellent photographs of minerals I was looking for. He also reviewed an early draft of the manuscript, and provided constructive criticism and helpful suggestions for improvements to the key. Others who have helped with thin-section materials and advice include Colin Wilkins and Arjan Dijkstra (University of Plymouth), Dean Bullen (University of Portsmouth) and Dave Waters (University of Oxford).

Finally, I would like to thank Jenny and Michael Manson for their enthusiasm and support of this publication. Needless to say I've tried to ensure complete accuracy throughout, but given the nature of the challenge I accept full responsibility for any errors or omissions that may have occurred.

To all those mentioned, and to anyone I might have inadvertently overlooked, I would like to say a big thank you.

Andrew Barker, June 2014, Southampton

Contents

Appendices:

Chapter 1

Introduction

Being able to accurately identify minerals in thin-section is an essential skill for any geologist, and is vital for the correct interpretation of rocks and their petrogenesis. It can be a particularly challenging prospect for students new to the subject. However, with a basic understanding of microscopy, petrology and optical mineralogy, coupled with some reference text books, it is soon possible to identify some of the major rock-forming minerals with confidence. However, being able to move beyond this, to efficiently and reliably identify newly encountered unknown minerals can prove difficult. Students may resort to flicking through the pages of one of the many beautifully illustrated atlases of rock-forming minerals (e.g. MacKenzie & Adams, 1994; MacKenzie & Guilford, 1980) or may use an optical mineralogy book such as Kerr (1977), or the superb "*Introduction to Rock-forming Minerals*" by Deer et al. (1992, 2013). To the novice, however, the latter can seem impenetrable at first glance, but with time becomes an essential companion. It is hoped that by producing a key to mineral identification, an efficient and systematic approach to identifying minerals in thin-section will be provided. This is not intended to replace the detailed optical mineralogy text book, but rather to complement it.

More than a century ago, Johannsen (1908) produced a "*Key for the determination of rock-forming minerals in thin sections*", which although largely forgotten is a very useful publication. Johanssen (1908) used combinations of various optical properties to separate minerals into small groups. Although not providing a unique solution, it gives the reader a short-list of possibilities, that can be further refined with reference to other optical properties not previously considered. In terms of a "modern" equivalent to this, the closest would be the "Mineral Tables" in Chapter 10 of Kerr (1977), but even this is now more than 35 years old. Like Johanssen's key, the tables of Kerr (1977) and Ehlers (1987b) provide the petrologist with a systematic approach to narrow down to a group of minerals with similar properties, after which, the detailed optical characteristics of each should be considered before concluding on the identity of the mineral in question. The present author has always found Kerr (1977) to be an excellent text, and very easy to use, but once again, the Tables of this text do not provide a unique solution for mineral identification.

The present key, comprises eight "Sections", and as far as possible attempts to key out to a specific mineral. The key assumes that the user has a basic understanding of optical mineralogy and is able to determine essential mineral properties in thin-section using plane-polarised and cross-polarised light. Even so, a brief summary of mineral properties in thin-section is provided in the introduction. In some cases it may be necessary to determine an optic figure for closely similar minerals. However, this is something not routinely employed as it is technically more challenging, and may not be feasible in small, deformed, or heavily included crystals. If this point is reached and uncertainty remains concerning the mineral identification, consider all remaining possibilities (usually only two or three minerals). It may be necessary to employ analytical techniques if the identity of the mineral is still in question.

The present key is designed in a manner comparable to dichotomous botanical keys such as Clapham *et al.* (1981) and Stace (1999), which are widely used by botanists in the UK. It involves a stepped sequence defining characteristic features to arrive at a unique mineral identification. At this point, it should be stated that the present author strongly encourages all those using the key to start by building up a full portfolio of properties for a given mineral before trying to identify it. Only then should the stepped sequence of the key be used.

Starting from couplet 1 (in the appropriate Section), successive numbered steps give two options for a particular characteristic (sometimes with letter-coded illustration). Decide which option fits the mineral being identified and go to the next step as indicated by the number to the right-hand side. Repeat the process until the point where a mineral is named. Having keyed-out the mineral, cross-check with an optical mineralogy text book (eg Kerr, 1977; Ehlers, 1987a, b; Deer *et al.*, 1992, 2013), to confirm that all the properties agree. Also check that the rock and mineral assemblage seem realistic. If the result seems impossible or unlikely, back-track to points of uncertainty. For example, if uncertain whether a particular mineral is moderate or high relief, follow what you think first of all (eg high), but if this fails to produce a realistic answer, back track and follow the other route (ie moderate relief). Please also recognise that whilst 150+ of the most common rock-forming minerals are included in the key, other minerals are not, so some minerals may not key-out.

The key has been designed in such a way as to prioritise those properties that are most easily defined, and thus less ambiguous. It is hoped that this will minimise the chance of misidentification and enable the less experienced petrologist to use the key with confidence. Since in many cases (eg small crystals) the idealised crystal form and characters may not be encountered, the key attempts to "error-trap" by including some minerals in more than one Section (eg plagioclase feldspars may seemingly lack cleavage and often not show twinning in metamorphic rocks). Recognising that end-sections and side sections of minerals such as amphiboles and pyroxenes have different properties, they can be keyed out in different Sections. To aid in the identification of closely similar minerals that have very different petrogenesis, the bulk rock chemistry, environment of formation, and P-T-fluid conditions may be referred to. To the purist some aspects of this approach may seem rough and ready, but to the student or practising geologist who does not have the time or suitable crystals to check 2V optic axial angles and optic sign, this guide should prove highly useful. It should be stated, however, that when using shape, textural relationships or occurrence as primary identifiers, caution must be exercised. Such characteristics can be broadly useful, in the same way that in botanical keys plants may have an association with a particular habitat or geographical area. Ultimately, however, it is the anatomical features of the plant and optical properties of the mineral that are critical to the correct identification. In all cases, therefore, once a mineral identification has been arrived at using the key, it is recommended that a final check of all properties is made with reference to an optical mineralogy text such as Kerr (1977) or Deer *et al.* (1992, 2013).

To the beginner, it is hoped that the key provides a systematic approach to defining unknown minerals, rather than simply defining a few of the optical properties then searching through a mineralogy or petrology text hoping to find a mineral that matches. A glossary is given at the back to provide definitions of various technical terms used in the key and introductory sections. Also included are a tabulation of mineral abbreviations used on photographs, a polarisation colour chart, and birefringence values for all minerals referred to in the key.

1.1 Photographs and their captions

Unless otherwise stated, all photographs have been taken by the author. In addition to naming the mineral, each image includes details of the image magnification, a scale-bar, and whether taken in plane-polarised light (PPL), cross-polarised light (XPL), or reflected light (RL). Wherever possible, brief details are given of the rock type and sample location.

Image magnifications and scale-bars

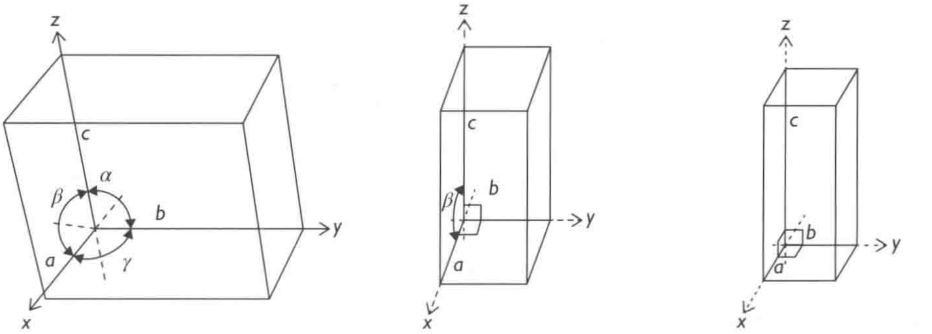
The majority of photographs were taken at x50 or x100 magnification (as specified), with the original horizontal fields of view in such images being 2.7 mm and 1.35 mm, respectively. Unless specified otherwise, all scale-bars represent a distance of 0.25 mm on the image. Where higher magnifications (x400, field of view 0.34 mm, i.e. 340 µm) and close-ups are shown, the field of view is considerably smaller and an appropriate scale-bar is given.

1.2 Crystal systems

Before proceeding to consider rock-forming minerals in thin-section using a polarising microscope it is useful to firstly consider the fundamental crystals systems and the inherent link with particular crystal shapes, forms and mineral cleavage orientations. It is outside the scope of the present text to cover this in detail, but a basic awareness of angular and length relationships for crystals of particular systems is helpful when identifying minerals based on cleavage orientations, and crystal shapes formed by thin-sections cut both perpendicular and oblique to crystallographic axes.

The schematic illustrations of Fig. 1.1 show the principal crystal systems of rock-forming minerals. The varying fundamental relationships between principal cell lengths a, b, c, and angles α, β, γ are specified for each system beneath the respective diagrams. The principal crystallographic axes x, y, z are also shown. To avoid any confusion, please note that the present author has used the x, y, z notation for consistency with Deer *et al.* (1992, 2013), but in other texts (e.g. Kerr, 1977; Ehlers 1987a, b), the principal crystallographic axes are labelled a, b, c.

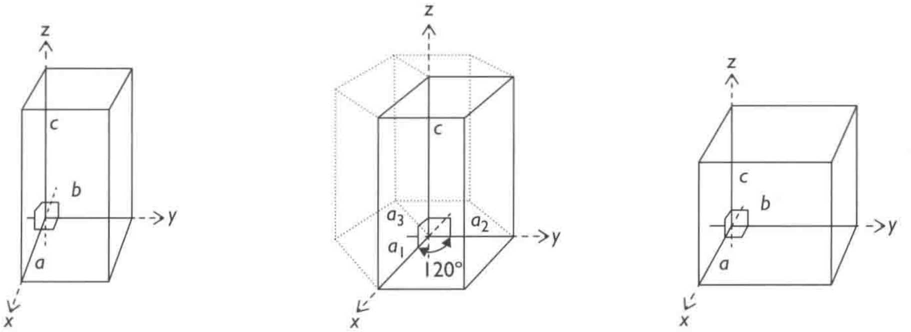
In the rather special case of the hexagonal system, rather than defining the cell dimensions in terms of two horizontal axes (a, b) as in other systems, there are three axes (a_1, a_2, a_3) of equal length and angular relationship (120°), perpendicular to the



TRICLINIC $a \neq b \neq c; \alpha \neq \beta \neq \gamma$

MONOCLINIC $a \neq b \neq c; \alpha = \gamma = 90°; \beta \neq 90°$

ORTHORHOMBIC $a \neq b \neq c; \alpha = \beta = \gamma = 90°$



TETRAGONAL $a = b \neq c; \alpha = \beta = \gamma = 90°$

HEXAGONAL & TRIGONAL $a_1 = a_2 = a_3 \neq c; \alpha = \beta = 90°; \gamma = 120°;$

CUBIC $a = b = c; \alpha = \beta = \gamma = 90°$

Figure 1.1 Various crystal systems represented as unit cell with lattice parameters *a*, *b*, *c* (lengths) and α, β, γ (angles), with crystallographic axes *x*, *y*, *z*.

vertical *c*-axis (e.g. Beryl). For further detail on crystal systems of minerals, the text by Wenk & Bulakh (2004) provides a useful introduction.

1.2.1 Miller indices

Miller (1839) devised a convenient method for describing the lattice planes of a mineral with reference to the orientation of the plane with respect to the three principal crystallographic axes (*x*, y, *z* of Fig. 1.1). With the exception of the slightly more complicated hexagonal system (see above), which has four axes, and thus four digits, the index is given as a three digit integer value. The figures are derived from the reciprocal values of the axis intercepts, normalised to the lowest common denominator to give integers.

If we consider the cubic system illustrated in Fig. 1.1, the diagram below (Fig. 1.2a) depicts a simple cubic mineral (e.g. pyrite, fluorite) with Miller indices given for the three visible faces. The top face, being parallel with axes *x* and *y* and perpendicular to *z* has the Miller index (001). The face front left is perpendicular to *x* and parallel to *y* and *z*, so has the idex (100), and finally the face front right is parallel to *x* and *z* and perpendicular to *y* so has the index (010).

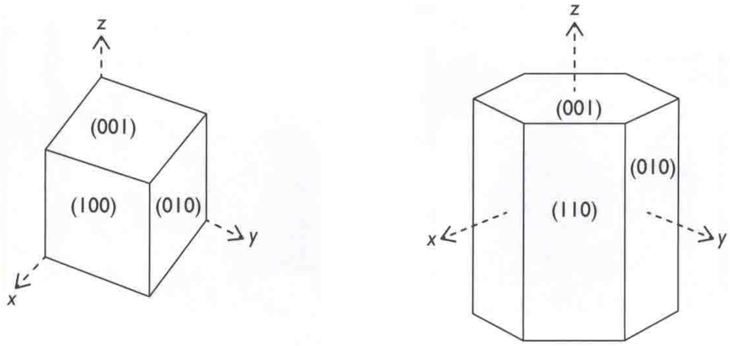


Figure 1.2 Miller indices for selected faces on a) simple cube (e.g. pyrite, fluorite), and b) staurolite.

For faces perpendicular to the negative end of a particular axis the notation is with a bar above the integer, so the face on the bottom of the cube (Fig. 1.2a) illustrated (not visible), would be (00$\bar{1}$), the one back right (hidden) would be ($\bar{1}$00), and the one back left (hidden) would be (0$\bar{1}$0). A face at a 45° angle to (100) and (010) would have the value (110), (see Fig. 1.2b) and so on. It is outside the scope of present text to provide a more detailed account of Miller indices, but for further information see Wenk and Bulakh (2004). The reason for briefly mentioning Miller indices in this introduction is because on some occasions within the mineral key, reference is made to particular crystal faces, cleavage or twinning in specific planes using Miller indices. For example, see couplet 2. of Section 1.

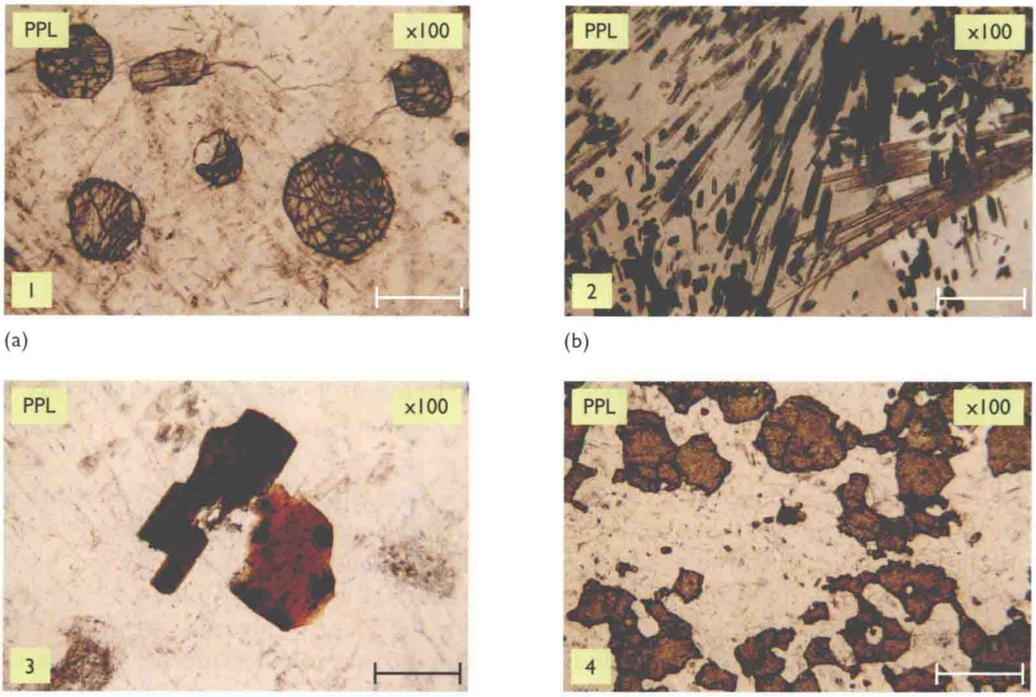
1.3 Mineral properties in plane-polarised light (PPL)

1.3.1 *Shape and form*

Many crystals, especially those of fine grained aggregates, or forming the matrix of rocks, have rather poor crystal form, and would be described as anhedral or irregular. Other crystals, however, may show rather good crystal form, indicative of the crystal system of the particular mineral concerned. This is especially true of phencrysts, porphyroblasts and vein minerals, where unimpeded growth has occurred. If some of the crystal faces are present, the crystal is said to be subhedral, and if all sides of the crystal are well formed it is described as euhedral. Fig. 1.3 illustrates a few examples of distinctive crystal shapes, and the mineral key itself includes schematic illustrations of all shapes and forms as necessary. For more detailed information on the topic see Barker (1998, pp 65–75), MacKenzie *et al.* (1982), and Table 10.3 of Kerr (1977). The latter provides a very useful summary of minerals commonly observed with euhedral form, grouped according to form (e.g. acicular, lath-like, radiating).

1.3.2 *Textural relationships*

As well as general shape providing a clue to the identity of well-formed minerals, there are also textural features that can sometimes further aid identification, and may sometimes be referred to in the mineral key presented in part 2. Some of these features such

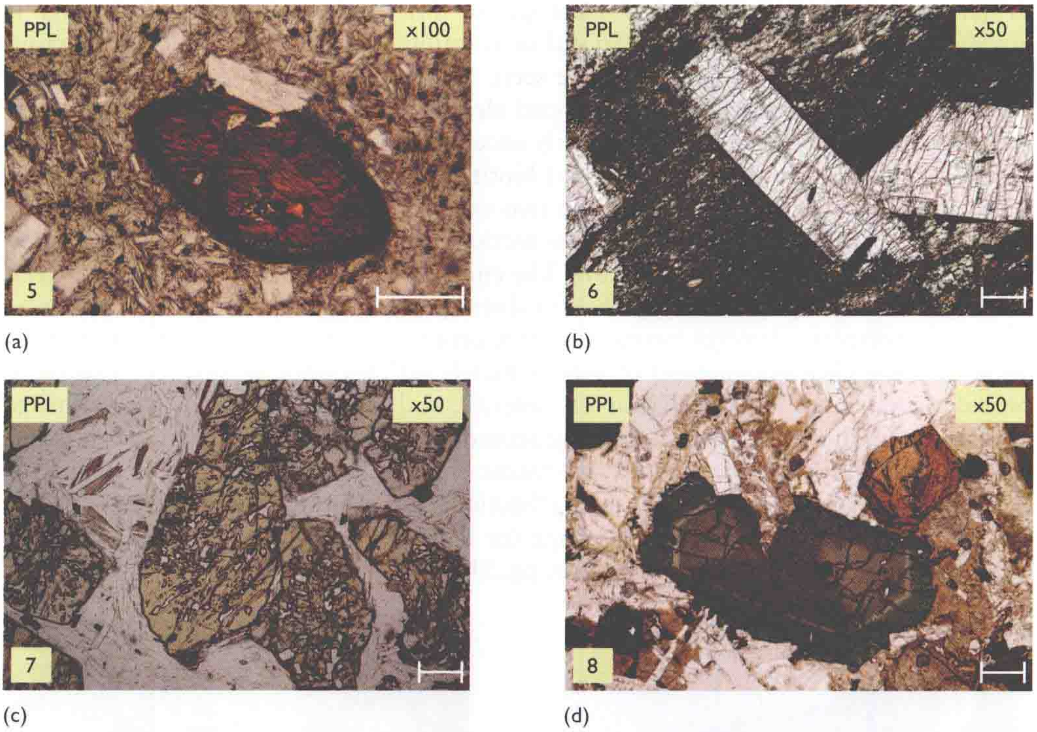


(a) (b) (c) (d)

Figure 1.3 Examples of different crystal shapes/forms: (a) Spodumene end-section; the classic euhedral octagonal shape of pyroxenes. Granite pegmatite; Leinster, Ireland. (b) Radiating acicular tourmaline (schorlite); Luxullyanite, Cornwall, England. (c) Two biotite crystals; the one on the left showing the typical subhedral lath-shaped side-section of biotite with {001} parallel cleavage traces along the length of the crystal, and parallel with crystal sides, whereas the subhedral, roughly hexagonal crystal to the right, with no cleavage, is a view straight down the z-axis (≡ *c*-axis) of the crystal, thus displaying the (001) face (ie end-section). Granite; St. Jacut, Brittany, France. (d) Anhedral spessartine garnet; Nisserdal, Telemark, Norway.

as porphyroblasts, phenocrysts, and colour zoned minerals due to chemical zonation, are evident in plane-polarised light (PPL). Other features, however, such as twins, and chemical zonation in colourless minerals (e.g. plagioclase, vesuvianite) only become more apparent in cross-polarised light (XPL) due to changes in interference colours (see 1.4.2 and 1.4.3 below). Mineral intergrowths can be seen in PPL if the intergrown phases have contrasting optical properties, but for minerals with similar properties such intergrowths are only obvious in XPL (see myrmekite image 116b below).

Phenocrysts of igneous rocks, and porphyroblasts of metamorphic rocks, are easily observed and, often easily identified, by virtue of their large size providing good information on most if not all of the mineral's optical properties. Their occurrence as phenocrysts or porphyroblasts in itself can be strongly indicative of particular minerals. Table 1 gives a list of commonly observed phenocrysts and porphyroblasts of igneous and metamorphic rocks, and Fig. 1.4 illustrates several representative examples. If the phenocryst or porphyroblast has abundant inclusions, the respective terms poikilitic and poikiloblastic are used (see Fig. 1.4c).



(a) (b) (c) (d)

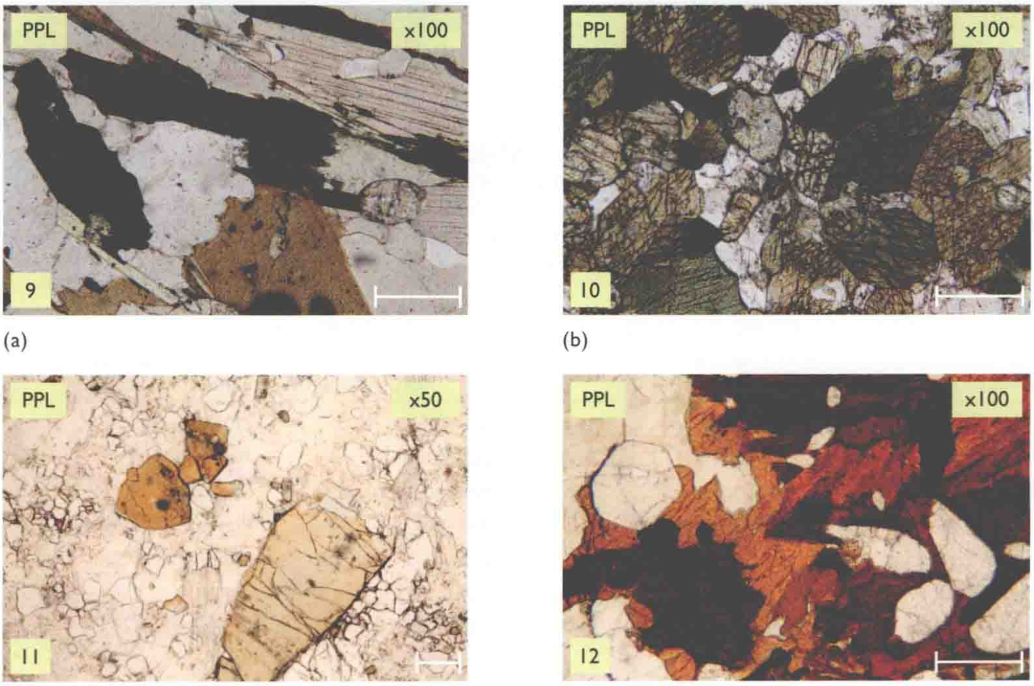
Figure 1.4 Textural relationships in plane-polarised light; a) Oxo-hornblende phenocryst in andesite; Mt.Shasta, CA, USA. b) Andalusite (var. chiastolite) porphyroblasts in chiastolite slate; Skiddaw Granite aureole, Lake District, England. c) Poikiloblastic staurolite porphyroblasts in stt-and-schist; Nauyago, Ghana. d) Colour zonation in titanaugite phenocryst in zeolitised basalt; Scawt, Antrim, N.Ireland.

Table 1.1 Minerals commonly occurring as phenocrysts or porphyroblasts.

Phenocrysts *(igneous rocks)*		Porphyroblasts *(metamorphic rocks)*	
Hornblende	Augite	Garnet	Hornblende
Biotite	Olivine	Staurolite	Actinolite
Quartz	Pigeonite	Andalusite	Lawsonite
Plagioclase	Orthopyroxene	Kyanite	Plagioclase (albite)
Orthoclase	Anorthoclase	Biotite	K-feldspar
Sanidine	Oxo-Hornblende	Chlorite	Pyrite
Nepheline		Chloritoid	Dolomite
Leucite		Cordierite	
Analcite		Muscovite	

1.3.3 Mineral cleavage

The distinction between those minerals that show cleavage from those that do not is one of the most useful characteristics for distinguishing some of the major mineral groups in both hand-specimen and thin-section. Minerals such as amphiboles, pyroxenes and micas have well developed cleavage, whereas common minerals such as quartz, garnet and olivine lack cleavage. In thin-section, the trace of cleavage is observed, and depending on the crystal orientation with respect to the thin-section cut one or more cleavage traces will be seen. Minerals such as micas (e.g. muscovite and biotite) display a single well developed cleavage trace {001} in almost all crystals within a thin-section (Fig. 1.5a). The only exceptions are crystals cut parallel to {001}, which show no cleavage (see hexagonal biotite crystal in Fig. 1.3c). Other minerals such as pyroxenes and amphiboles, have two well developed cleavages, and whilst only displaying a single cleavage trace in side-sections, generally show two well developed cleavages in end-sections (see Fig. 1.5b). The end-section angular relationships between cleavage traces are particularly useful for distinguishing pyroxenes from amphiboles. The former displays cleavage intersecting at approximately 90°, whereas the latter gives an acute angle cleavage intersect of approximately 60°. Presence or absence of cleavage provides such an important division of minerals, and for those minerals with cleavage there is the further possibility of dividing according to the number of cleavages present. In view of this, the number of cleavage traces present, provides much of the basis for construction of the broad sub-divisions ("Sections") of the present mineral key (see 2.1 below). Accordingly, identifying cleavage (or lack of it is critical to deciding which Section of the present Key to start in (see pg.33 below).



(a) (b) (c) (d)

Figure 1.5 Cleavage traces in minerals. a) Single cleavage traces {001} in biotite and muscovite. Biotite schist; Dublin, Ireland. b) Two cleavage traces {110} at 56° and 124° in end-sections of hornblende. Hornblende gneiss; Sleat, Skye, Scotland. c) Irregular but somewhat arranged fractures (not cleavage) in oblique section of tourmaline (main crystal, lower right). Also note the end-section of yellow-green tourmaline (left centre) showing the classic triangular form with curved convex-outward faces. Tourmaline granite; Cornwall, England. d) Colourless apatite crystals with no cleavage, including euhedral hexagonal crystal (left) in larvikite; Dalheim, Larvik, Norway.