Atlas of Igneous Rocks and Their Textures

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ELBS

LOW-PRICED EDITION

Atlas of Igneous Rocks and Their Textures

Part 1

The textures of igneous rocks

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Introduction

To English-speaking petrologists *textures* are the geometrical relationships among the component crystals of a rock and any amorphous materials (glass or gas in cavities) that may be present. They comprise the following properties:

1. Crystallinity (degree of crystallization) – i.e. the relative proportions of glass and crystals.
2. Granularity (grain size) – i.e. the absolute and the relative sizes of crystals.
3. Crystal shapes.
4. Mutual relations or arrangement of crystals and any amorphous materials present.

In this part of the book textures in each of these categories are described and illustrated, some in plane-polarized light (PPL), some in cross-polarized light (XPL) and some in both. Some textures exhibit more than one of the above properties and we have indicated where this is so.

Petrography, of which textural relations are a part, is the descriptive and factual side of *petrology*, whereas *petrogenesis* is the interpretive side. Thus genetic terms, such as *cumulate, cumulus crystal, cumulate texture, synneusis texture, exsolution texture* and *fluxion texture* should be avoided, as they combine factual description with interpretation; they rob any person reading a petrographic description of unbiased observations and can cast doubt on the objectivity of the petrographer who wrote the description. For this reason, genetic textural terms are not included in this book, there being suitable non-genetic terms available for all of them.

Remarkably few igneous textures have been reproduced in the laboratory and the origins of even fewer could be claimed to be adequately understood. For these reasons, we have made no comment on the origin of most of the textures; readers should consult the texts by Iddings (1909), Holmes (1921), Niggli (1954), Hatch, Wells and Wells (1972) or Cox, Bell and Pankhurst (1979), for discussion of the origin of textures and their implications. However, it should be noted that many textures are open to more than one interpretation and the newcomer to the subject is advised to consider the possible origins and implications for himself before reading one of these texts. He is then likely to interpret the crystallization of a rock more objectively and flexibly than if the 'standard interpretation' is adopted slavishly. This comment is particularly relevant to the interpretation of 'order of crystallization' of minerals in a rock. We have found that both students and teacher can benefit from a two-hour discussion of the subject; the student who is unencumbered by preconceptions can be remarkably inventive and provide his teacher with copious new ideas for consideration.

In studying rocks in thin section we must not forget that only a two-dimensional view is present and hence the true three-dimensional texture has to be deduced from examination of the dispositions of many crystals in the section. In rocks with a strong preferred orientation of crystals, two or more sections of different attitude may be required to reveal the texture adequately.

Longman Scientific & Technical
Longman Group UK Ltd,
Longman House, Burnt Mill, Harlow,
Essex CM20 2JE, England

Associated companies throughout the world

First published 1982
Reprinted 1984, 1988

ELBS edition first published 1988

ISBN 0 582 02641 5

Printed in Great Britain by
William Clowes Ltd, Beccles and London

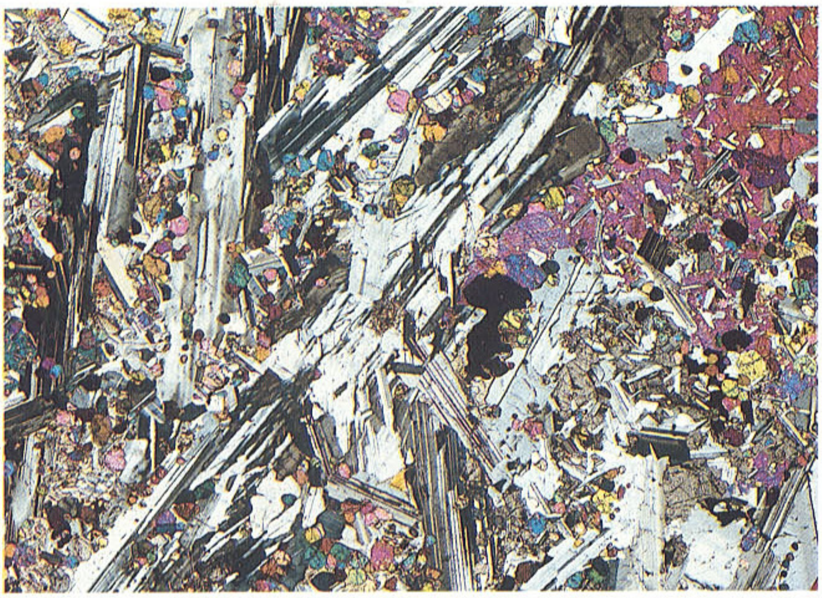
Crystallinity

Igneous rocks range in crystallinity from entirely crystals to entirely glass. Adjectives used to describe these states are shown on the following scale:

100% crystals		*100% glass*
holocrystalline	*hypocrystalline*[1] or *hypohyaline*	*holohyaline*

The adjectives *glassy*, *vitreous* and *hyaline* all indicate that a rock is more or less completely glass.

[1] *Hypocrystalline rocks can be described more precisely by stating the relative proportions of crystals to glass.*



1 Holocrystalline anorthositic gabbro

Elongate crystals of plagioclase feldspar, some wrapped round olivine crystals, form a framework in this rock, the interstices of which are filled with smaller plagioclase, olivine and augite crystals. The purplish-blue area at the top right of this photograph is an augite crystal which includes a number of small plagioclase and olivine crystals.

Perpendicular Feldspar gabbro from Middle Border Group of the Skaergaard intrusion, East Greenland; magnification ×7, XPL.

2 Holocrystalline granite

Crystals of biotite, quartz, 'perthitic' potassium-rich feldspar (large crystal bottom right) and zoned sodium-rich feldspar makes up this granite. The speckled appearance in the cores of the plagioclase feldspars is caused by fine inclusions of mica.

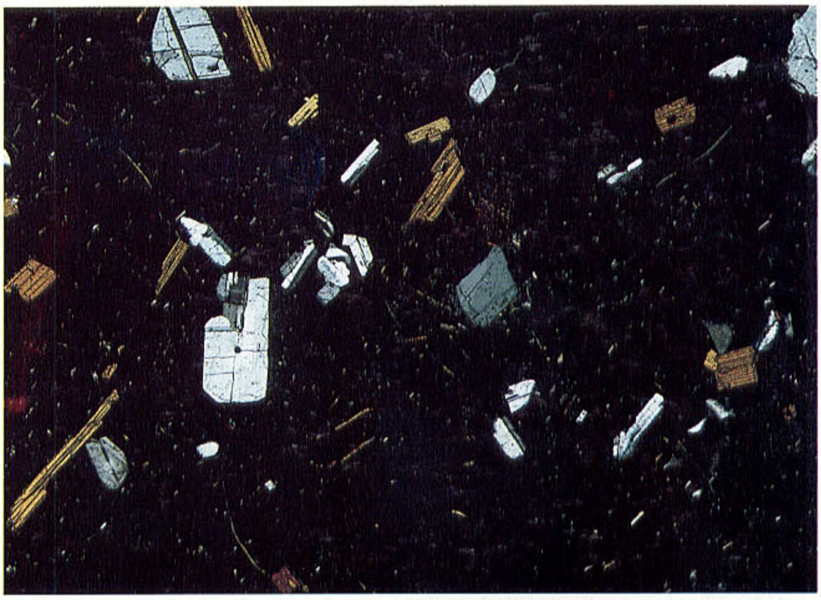
Granite from Ross of Mull, Scotland; magnification × 14, XPL.

Contents

3 Hypocrystalline pitchstone with perlitic cracks

Crystals of plagioclase, biotite and magnetite in this rock are set in glass (black in XPL) which has spherical fractures known as *perlitic cracks*: these appear as circles in thin section.

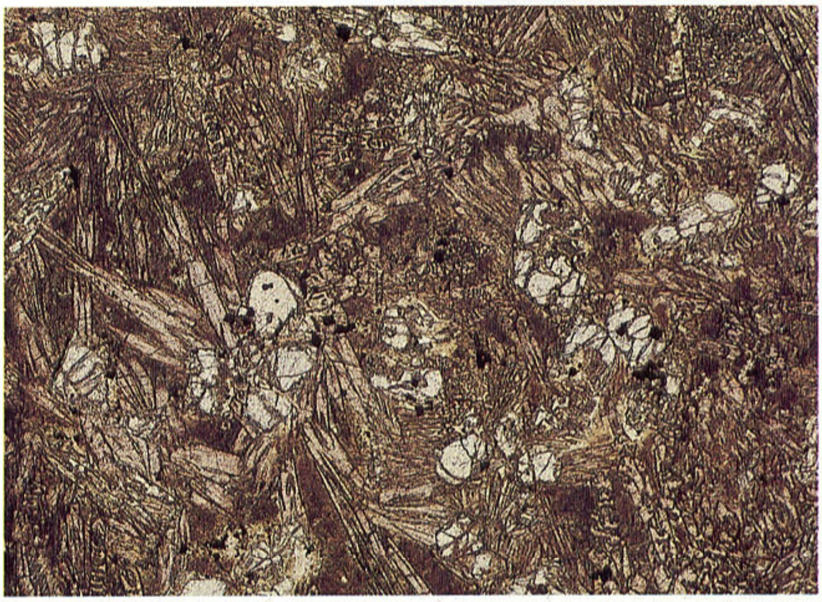
Dacite from Chemnitz, East Germany; magnification × 20, PPL and XPL.



4 Hypocrystalline basalt

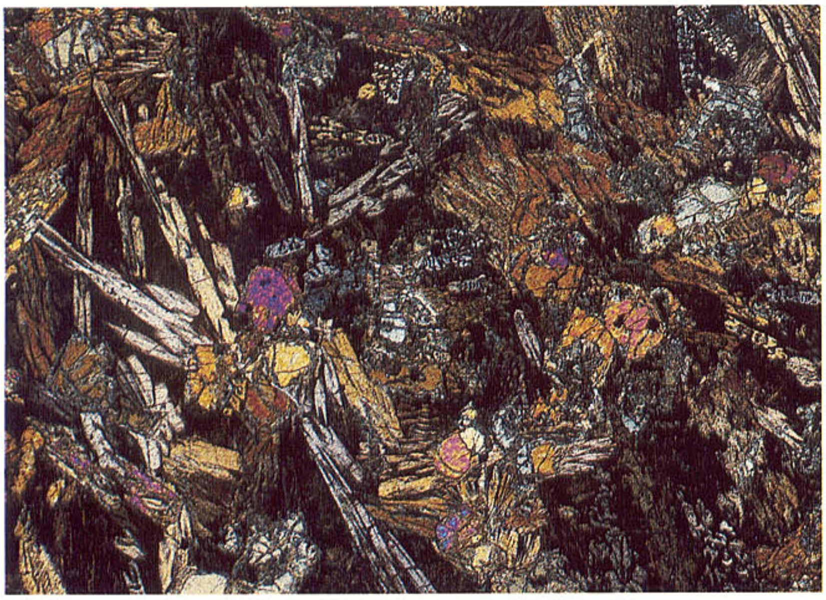
Small olivine phenocrysts (colourless in PPL) and columnar, skeletal titanaugite crystals (pinkish-beige colour in PPL) are enclosed by murky brown glass. No plagioclase has crystallized in this rock. The deeper pink colour around the margin of some of the titanaugites is a narrow mantle of Ti-rich amphibole.

Basalt from Quarsut, West Greenland; magnification × 35, PPL and XPL.

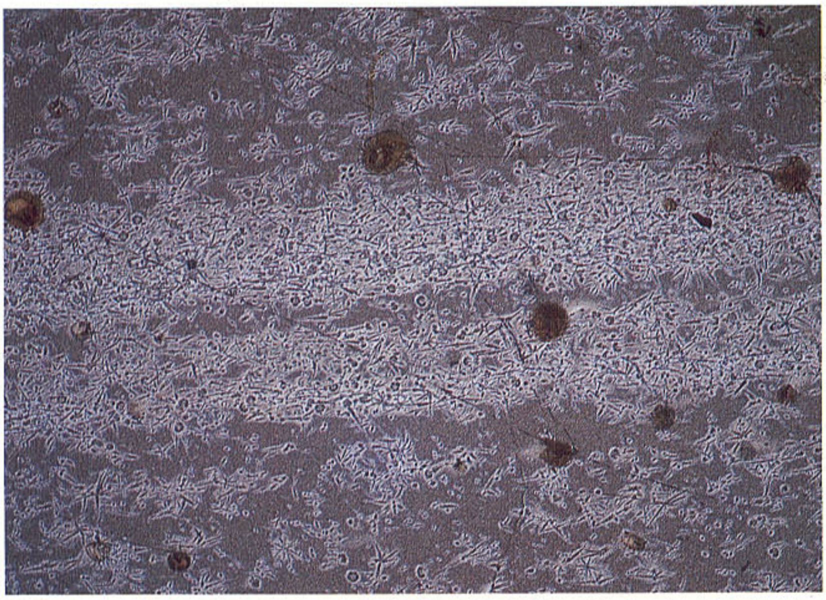


Part 2 Varieties of igneous rocks

(Numbers refer to photographs – not to pages)



Hypocrystalline basalt (continued)



5 Glassy rock

The photograph shows abundant, very small crystals (probably quartz or feldspar) enclosed by glass. Note the banding caused by (a) differences in abundance of crystallites, (b) crystallites in the lighter bands having a slight preferred alignment and (c) differences in colour of the glass. The small brown, isolated round objects are known as 'spherulites' (see *Spherulitic texture*, p. 54). (See also **14**.)

Pitchstone from Arran, Scotland; magnification × 12, PPL.

6 Glassy basalt threads – Pele's hair

These filaments of basalt glass form when particles in a molten lava spray are caught by the wind and drawn out. Pele is a mythical lady, believed by native Hawaiians to reside within the volcano Kilauea. (Contrast 7.)

Specimen from Erta Alé volcano, Ethiopia; magnification × 8, PPL.

Intermediate rocks

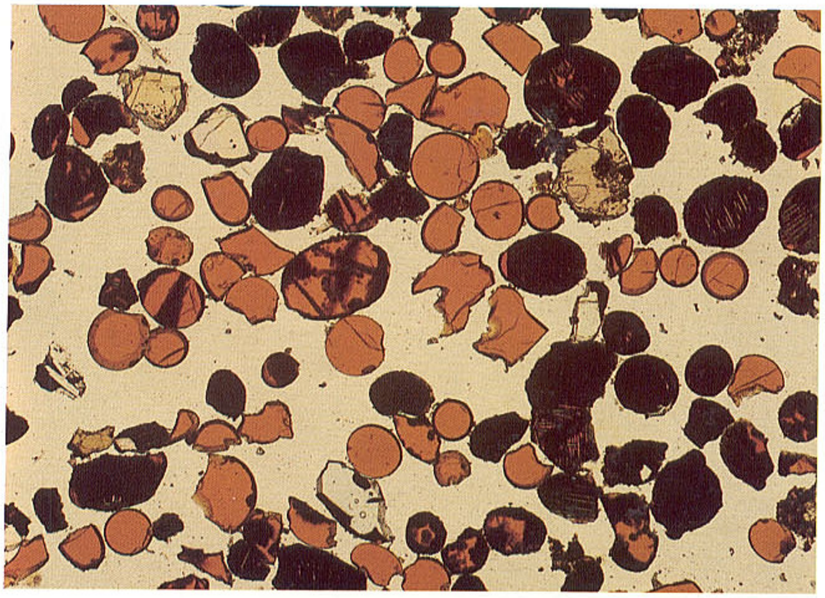
Acid rocks

Alkaline and miscellaneous rocks

7 Glassy particles of mare basalt in lunar soil

Pieces of glass, many of them spherical, are orange-brown or black in colour. Some of the darker ones are partially crystalline. These particles were formed by rapid cooling of droplets of basalt melt; it has been suggested that the droplets formed either in a fire-fountaining lava eruption, or by meteorite impact into a lava lake or into a molten or solid lava flow. (Contrast **6**.) The scarce, irregularly shaped fragments are pyroxene (pale brown) and feldspar (colourless).

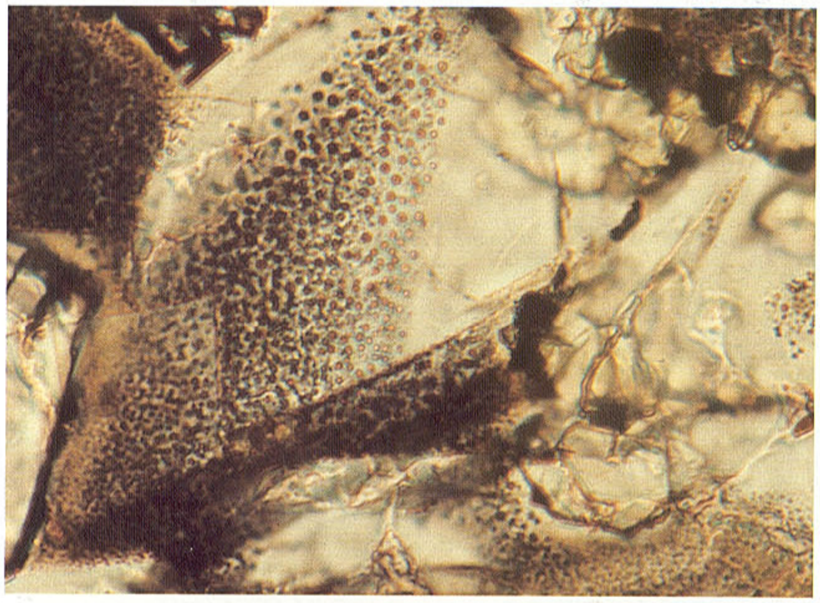
Lunar basalt 74220 from Taurus Littrow Valley collected by Apollo 17 astronauts; magnification × 43, PPL.



7a Liquid Immiscibility

Globules of one glass in another are found in some rocks and these are attributed to immiscibility of the two liquids. In this rock they can only be seen at very high power in thin films of glass between laths of plagioclase.

Specimen from basalt lava, Lava beds National Monument California, U.S.A.: magnification × 600, PPL.



Glass, or devitrified glass, is often an important constituent of the pyroclastic rocks known as *ash-fall tuffs* and *ash-flow tuffs* (or *ignimbrites*). Such rocks typically have *fragmental textures*, i.e. they comprise mixtures of fragments of rocks, crystals and glass, predominantly less than a millimetre in size (**8–9**). In an ash-flow deposit the glass fragments may initially be plastic enough to be partly or wholly welded together as the weight of overlying material causes compaction of the constituent fragments; such a rock is known as a *welded tuff* (**8b**). If sufficient heat is available, glassy fragments devitrify.

Preface

The commonest means of studying an igneous rock is to examine it in thin section, either with a petrographic microscope or a hand lens, which permits identification of the minerals present and investigation of their textural relations. From such study the skilled petrographer can interpret details of the history of the magma which crystallized to form the rock.

To become skilled requires many hours of study and training. Much of the training is acquired by patient attention by the teacher to the student. The student needs his observations verified and this can result in the teacher being summoned every minute or so; with a class of ten or more, the student is for long periods unattended, becomes frustrated and loses interest. The remedy is for the student to be able to verify his own observations by comparison with a photograph of a rock of the same type or showing the same feature(s).

The main aim of this book is to provide such a laboratory handbook to assist the student of geology (undergraduate and amateur) beginning to study igneous rocks in thin section. It is hoped that it may also be useful as a reference work for more advanced students and others interested in the natural history of rocks.

The work is divided into two parts – Part 1 is devoted to descriptions and photographs of textures found in igneous rocks and Part 2 consists of photographs of common (and a few not so common) igneous rocks.

We have selected those rocks and textural types which we believe may be encountered in an undergraduate course in geology but have made no attempt to produce a comprehensive coverage of all igneous rocks which have been given individual names because many of these names reflect only minor mineralogical or textural differences.

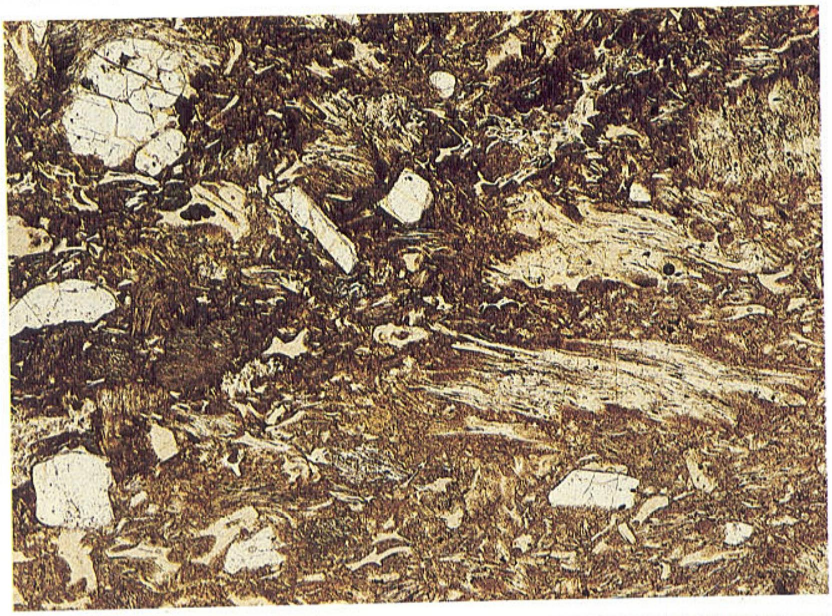
We have tried, as far as possible, to avoid any interpretation of the origin of textures and rocks, although the simple matter of arranging the rocks in some order of presentation is based to some extent on presumed genetic relationships between them.

In a previously published *Atlas of Rock-Forming Minerals* we have illustrated the appearance of the common rock-forming minerals so that here we have not considered it necessary to describe the optical properties in detail. To be able to give a name to the majority of igneous rocks it is only necessary to be familiar with the properties of between twelve and fifteen minerals and we have assumed that the user of this book is already able to recognize these minerals.

Thin sections can be observed under the simplest of microscopes fitted with two pieces of polaroid and a new field of interest is open to the amateur for only a modest financial outlay. Because some amateur geologists may be interested in preparing their own thin sections we have included a brief description of how this may be done.

Many of the photographs show a combination of shapes and colours which have a special beauty of their own, reflecting the fact that while thin section study is of practical importance it can also be of aesthetic satisfaction. A few of the most attractive pictures unashamedly represent the authors' self-indulgence.

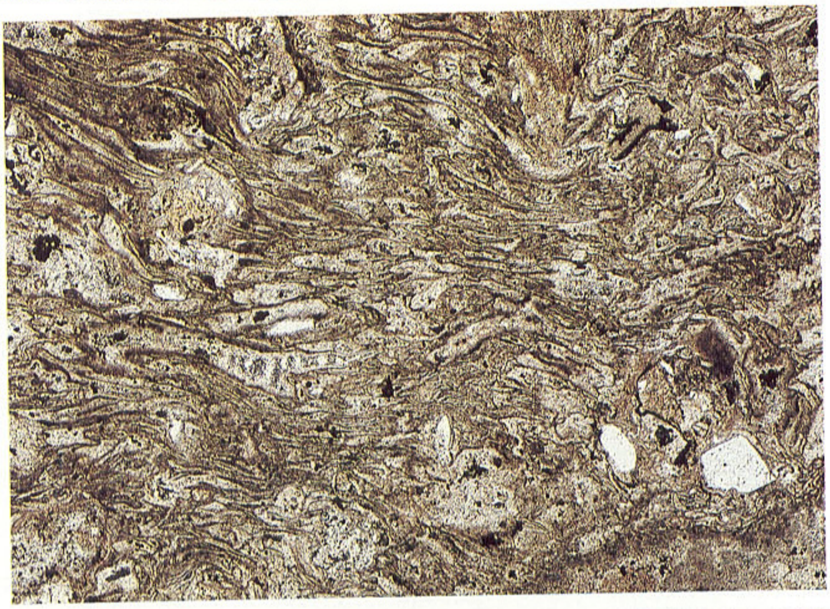
The usual criticism of photomicrographs is that it is very often difficult to determine which feature they are intended to illustrate. For this reason many textbooks are illustrated by drawings in which the required feature may be exaggerated. We have tried to test the usefulness of our photographs by asking our colleagues to identify the mineral assemblage or texture which we have illustrated. We are grateful



8a Glassy unwelded rhyolite tuff

The glassy fragments in this rock, some of which are banded and slightly flattened, are not welded to one another. They and the crystals of quartz and feldspar are embedded in fine glassy particles (ash).

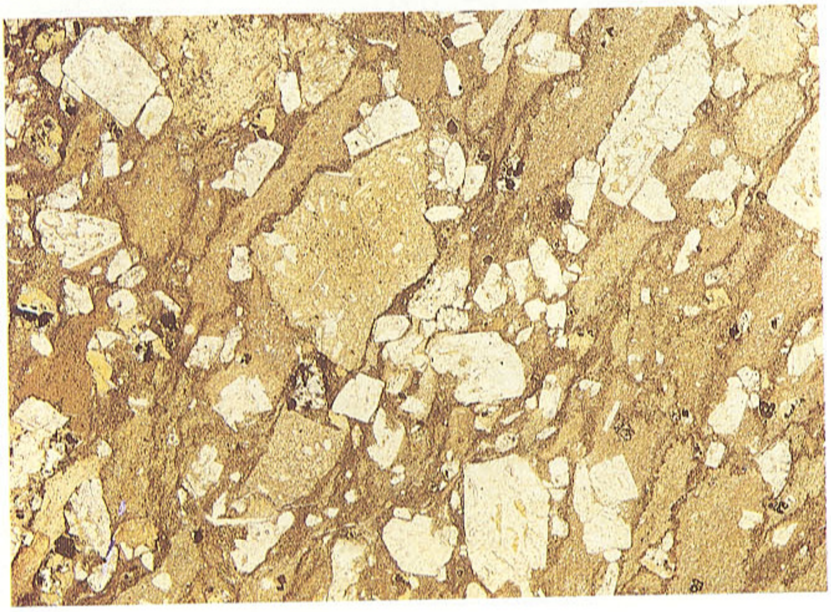
Recent ignimbrite, from Whakatane, North Island, New Zealand; magnification × 46, PPL



8b Glassy welded crystal tuff

The glassy matrix in this rock has an apparent discontinuous lamination caused by extreme compaction and welding of original pumice fragments. The regular alignment of the flattened fragments is known as *eutaxitic texture*.

Welded tuff from Tibchi granite ring-complex, Nigeria; magnification × 36, PPL.



9 Tuff

This fragmental rock consists of crystals of quartz, alkali feldspar and plagioclase of various sizes and shapes, pieces of glassy rhyolite (e.g. centre) and pieces of fine-grained tuff, all enclosed in a fine-grained banded ash matrix which originally may have been glassy. (See also **13**.)

Tuff from Llanellwedd, Wales; magnification × 10, PPL and XPL.

to them for their help in this respect. Most of the photographs were made from thin sections of rocks in the teaching collections of the Geology Departments of Manchester University and St Andrews University. Others were provided by friends and colleagues who made available to us thin sections from their own research collections, and we are most grateful to them for their help in this matter. We are particularly indebted to Dr John Wadsworth and Mr Ian MacKenzie who read and criticized all the descriptions of the textures and rocks. However, any failings in these descriptions are our responsibility alone.

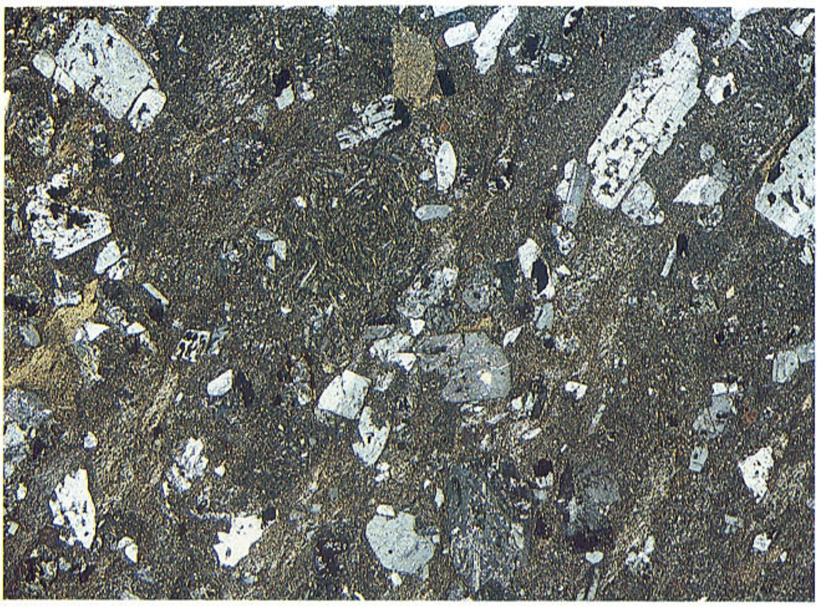
Finally, we caution those using the book not to regard the photographs as representing all the known textures and varieties of igneous rock, or indeed all their guises. These photographs are only an *aid* to recognition of textures and rock types and can never substitute for looking at thin sections under the microscope.

Acknowledgements

We are much indebted to our colleagues and friends who have generously given us thin sections of rocks from which to take photographs: they include the following gentlemen; S. O. Agrell, B. Atkinson, N. Binstead, K. Brooks, F. M. Broadhurst, I.S.E. Carmichael, J. B. Dawson, J. Esson, M. E. Fleet, F. G. F. Gibb, A. Hall, D. L. Hamilton, C. M. B. Henderson, A. M. Hopgood, E. Iki, R. Johnston, I. R. MacKenzie, R. Nesbitt, E. Sapountzis, J. Wadsworth, Rong-shu Zeng and J. Zussman. We have also benefited greatly from having beem able to use the collections of the late Prof. H. I. Drever who was the teacher and friend of both WSM and CHD at St. Andrews University, although 25 years intervened between our time as his students: he and his colleague Mr. R. Johnston were jointly responsible for arousing our interest in igneous rocks early in our careers.

The staff of the publishers have been very patient and helpful and we especially wish to thank them for their consideration and for that quality essential to all publishers – a sense of humour.

Miss Patricia Crook's help both in typing the manuscript and in preparing the index is gratefully acknowledged. We are grateful to Dr Robert Hutchison of the British Museum (Natural History) for permission to photograph thin sections of the Prairie Dog meteorite and the Stannern meteorite, both of which are in the British Museum collections.



Granularity

This property embraces three different concepts: (1) what the aided and unaided eye can or cannot see; (2) absolute crystal sizes (p. 12); and (3) relative crystal sizes (p. 14).

Terms referring to what the aided and unaided eye can or cannot see

Phanerocrystalline (*phaneritic texture* of American petrologists) – all crystals of the principal minerals can be distinguished by the naked eye (see **10**).[1]
Aphanitic – all crystals, other than any phenocrysts present (see p. 14), cannot be distinguished by the naked eye.[2] Two sub-types exist:

(a) *Microcrystalline* – crystals can be identified in thin section with a petrographic microscope (**11**). Crystals only just large enough to show polarization colours (less than 0.01mm) are called *microlites*.
(b) *Cryptocrystalline*[3] – crystals are too small to be identified even with the microscope (**12** and **13**). Globular, rod-like and hair-like crystals which are too small to show polarization colours are known as *crystallites*.

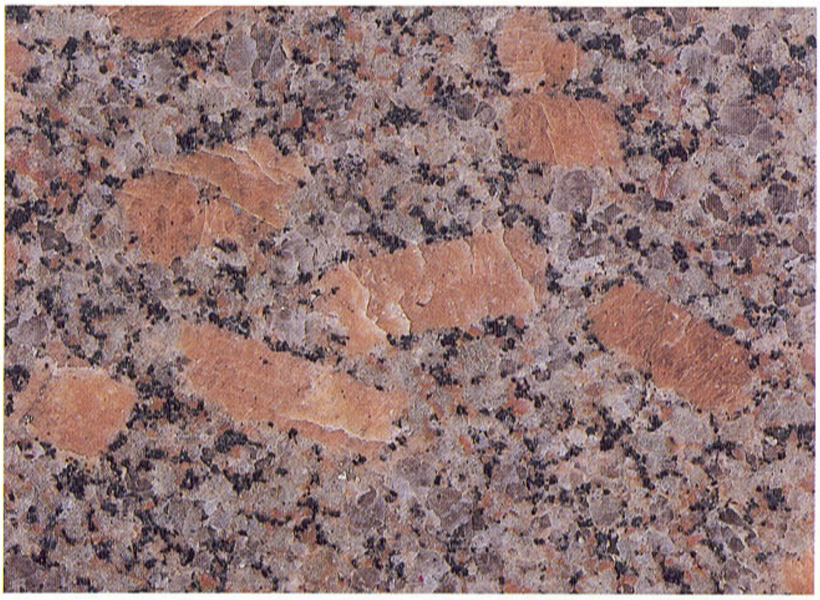
[1]Pegmatitic texture *is a variety of phanerocrystalline in which the crytals are strikingly large, bigger than 1–2 cm, and in rare instances up to many metres.*
[2]*The term* aphyric *is sometimes used for aphanitic rocks which lack phenocrysts* (**eg, 60, 63, 107**).
[3]Felsitic texture *is sometimes applied to siliceous rocks with ill-defined, almost cryptocrystalline, grey-polarizing areas composed of more or less equigranular aggregates of quartz and alkali feldspar. The namé* felsite *is often applied to such rocks, although this is more commonly a field term for fine-grained acid material of uncertain mode off occurrence.*

10 Phanerocrystalline granites

The crystals in the two granites, illustrated here in hand specimen, are clearly visible to the naked eye. Although the rocks contain the same minerals (alkali feldspar, plagioclase feldspar, quartz and biotite) the proportions of the minerals are not the same, and this influences the rock textures. Thus the Shap granite contains two distinct sizes of potassium feldspar crystals (pink), whereas the Eagle Red Granite has only one.

Granite from Shap, England (opposite) and 'Eagle Red' granite, South Africa (next page); both magnifications × 1.

A thin section view of the Shap granite is shown in ***144***

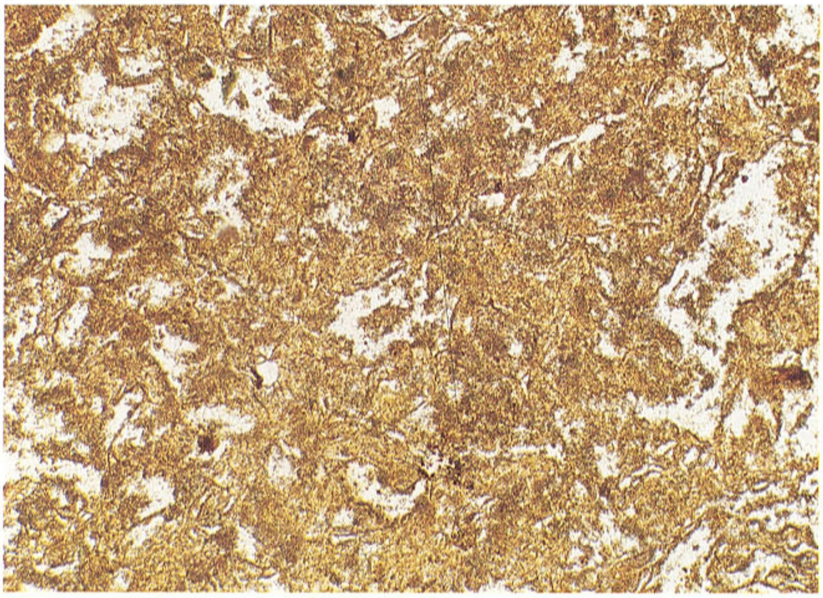


Phanerocrystalline granites (continued)

11 Microcrystalline olivine basalt

This rock consists mainly of plagioclase feldspar, augite and olivine but, without the aid of the microscope, individual crystals would not have been distinguishable. In parts of the photograph the randomly arranged rectangular plagioclases are enclosed by areas showing uniform yellowish interference colours, these are augite crystals.

Olivine basalt from North-west Skye, Scotland; magnification × 11, PPL.

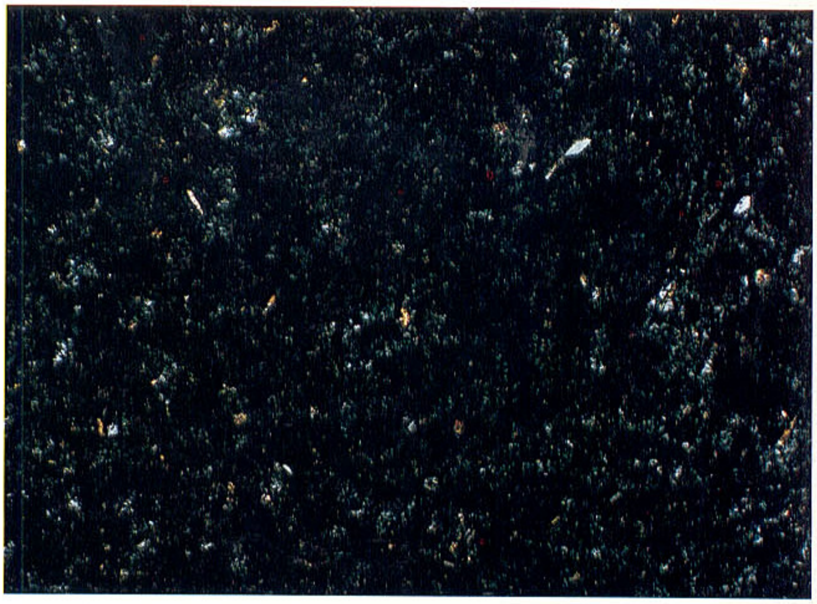


12 Cryptocrystalline rock

Comparison of these two photographs shows that the brown material in the PPL view is birefringent but that the individual crystals are of submicroscopic size. The clear areas in the PPL view are slightly more coarsely crystalline, as can be seen in the XPL view.

Rhyolite from Island of Pantelleria, Italy; magnification × 72, PPL and XPL.

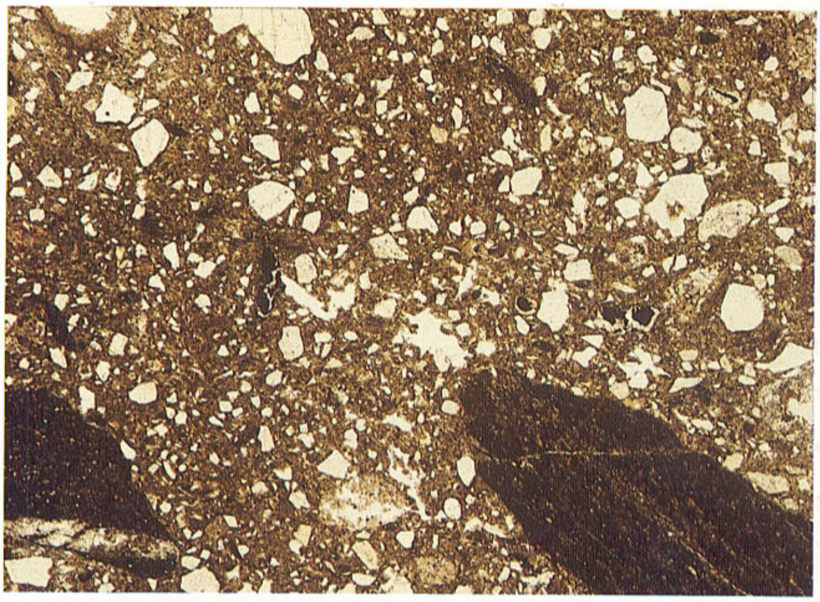
Cryptocrystalline rock (continued)

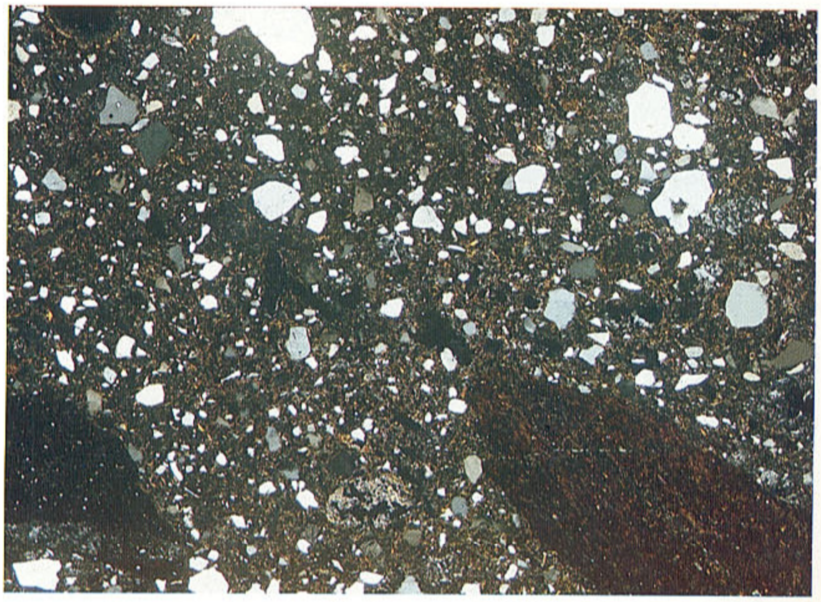


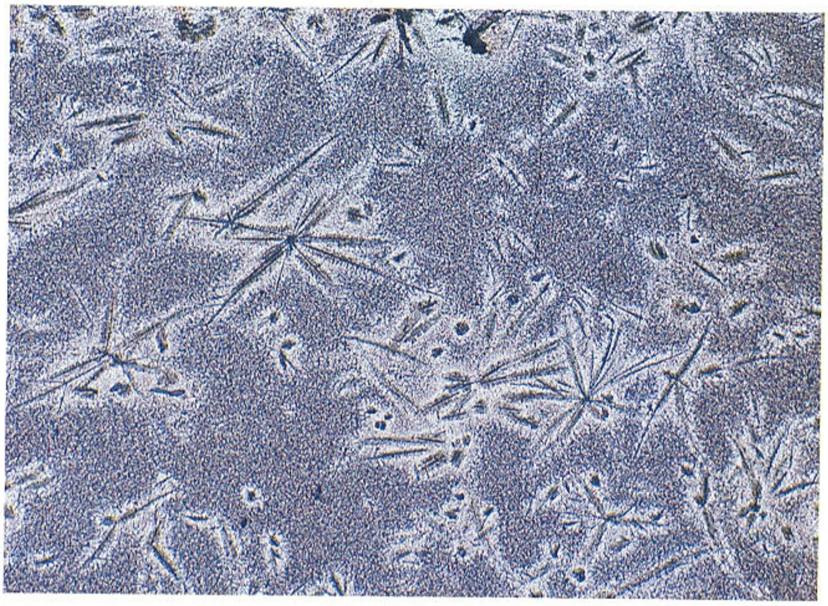
13 Cryptocrystalline matrix in a tuff

Cryptocrystalline texture is common in tuffs (i.e. consolidated ash), as in the matrix of this rock. Here the matrix encloses fragments of shale and quartz crystals. (See also **8** and **9**.)

Tuff from unknown locality; magnification × 16, PPL and XPL.







14 Pitchstone containing crystallites of two sizes

Radiate clusters of crystallites are set here in glass. The bulk of the glass contains even smaller crystallites, causing the grey colour, whereas adjacent to the larger crystallites the smaller ones are absent. This is a higher magnification view of the rock illustrated in **5**.

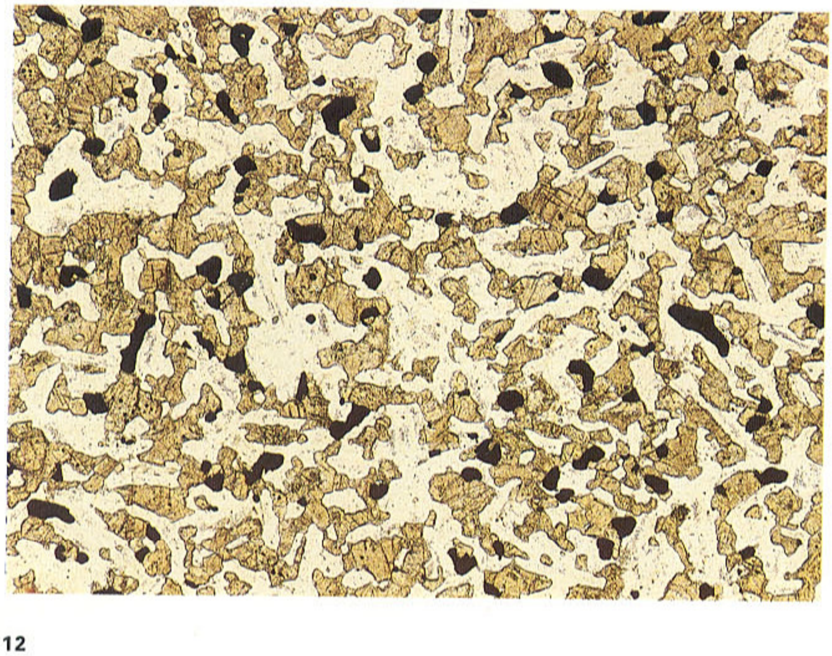
Pitchstone from Arran, Scotland; magnification × 52, PPL.

Terms indicating absolute ranges of grain size

Coarse-grained – crystal diameters > 5 mm
Medium-grained – crystal diameters 1–5 mm
Fine-grained – crystal diameters < 1 mm[1]

The next six photographs (**15**, **16** and **17**) were all taken at the same magnification (× 27) to indicate how grain size relates to the number of crystals seen in a given field of view (4.2 × 3.1 mm), and hence the extent of the texture visible at that magnification. While the overall texture is recognizable in the fine-grained rock, it is not so in the coarse one and a low-power objective lens would be necessary to examine it adequately. Petrographic microscopes rarely have a sufficiently low-power objective lens for examining the textures of coarse-grained rocks; a hand lens should be used for these, with two sheets of polaroid, if available.

[1] *Some petrologists include another range, < 0.05 mm, which they call* very fine-grained.

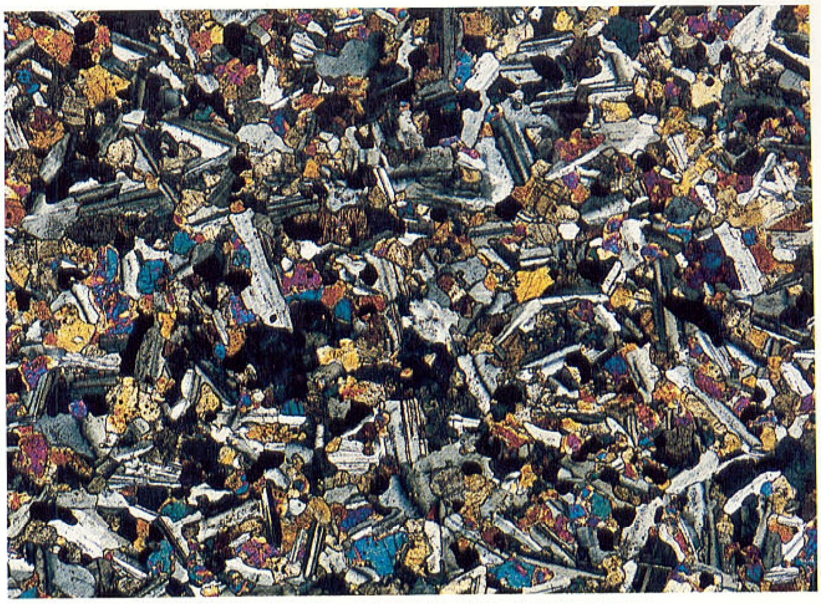


15 Fine-grained gabbro

This rock contains plagioclase, orthopyroxene, augite and magnetite; some of the orthopyroxene crystals (low birefringent mafic mineral) contain narrow lamellae of augite. Although the rock is fine grained, it is called a 'gabbro' because it is from a large intrusion; the fine grain size results from quick cooling at the intrusion margin. Another term that could be used for this rock is *microgabbro* (see p. 78).

Gabbro from chilled margin of the Skaergaard intrusion, East Greenland; magnification × 27, PPL and XPL.

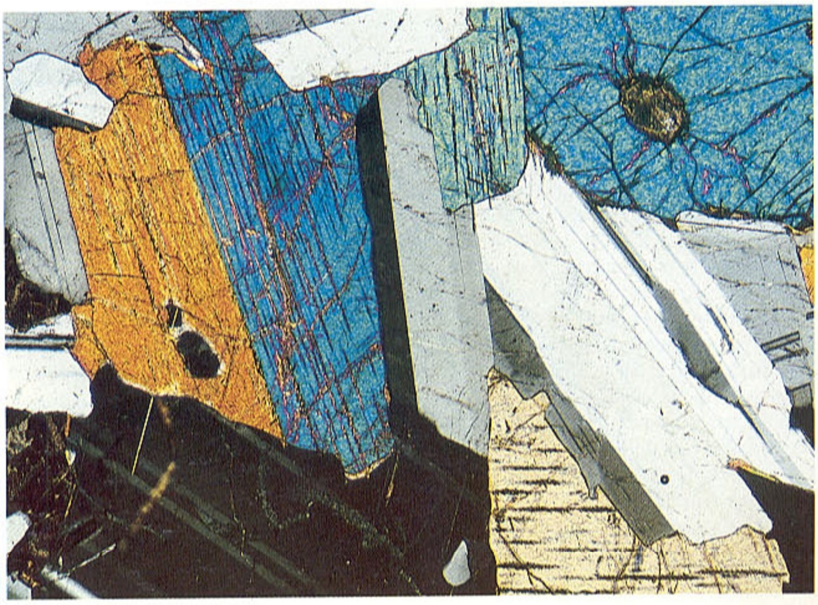
Fine-grained gabbro (continued)

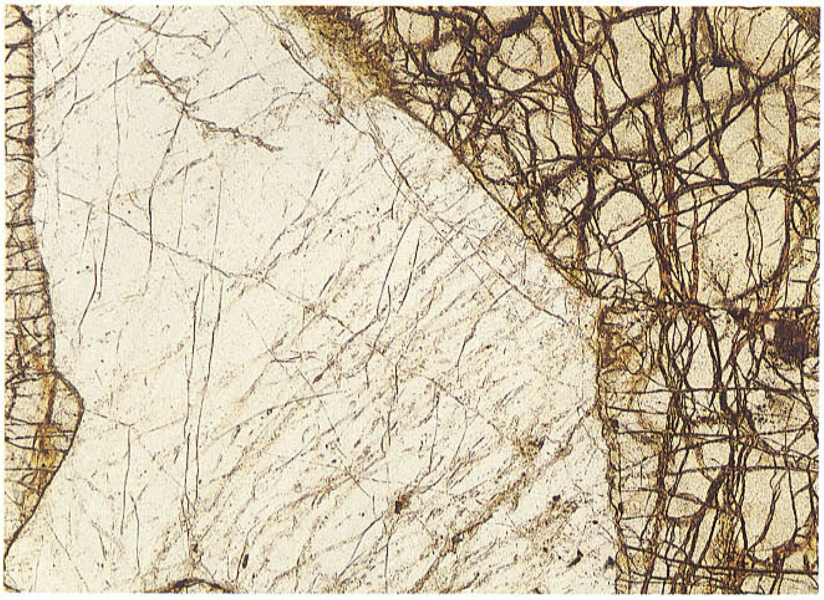


16 Medium-grained olivine gabbro

The spaces between the tabular crystals of plagioclase in this rock are occupied by augite and ilmenite. At the top right of the picture the plagioclase abuts onto an olivine crystal. The augite crystals contain lamellae of orthopyroxene.

Gabbro from Lower Zone b of the Skaergaard intrusion, East Greenland; magnification × 27, PPL and XPL.





17 Coarse-grained olivine gabbro

At this magnification only parts of three large olivines and one plagioclase are visible, such that textural relations are not determinable in this single view.

Gabbro from Rhum, Scotland; magnification × 27, PPL and XPL.

Terms indicating relative size of crystals

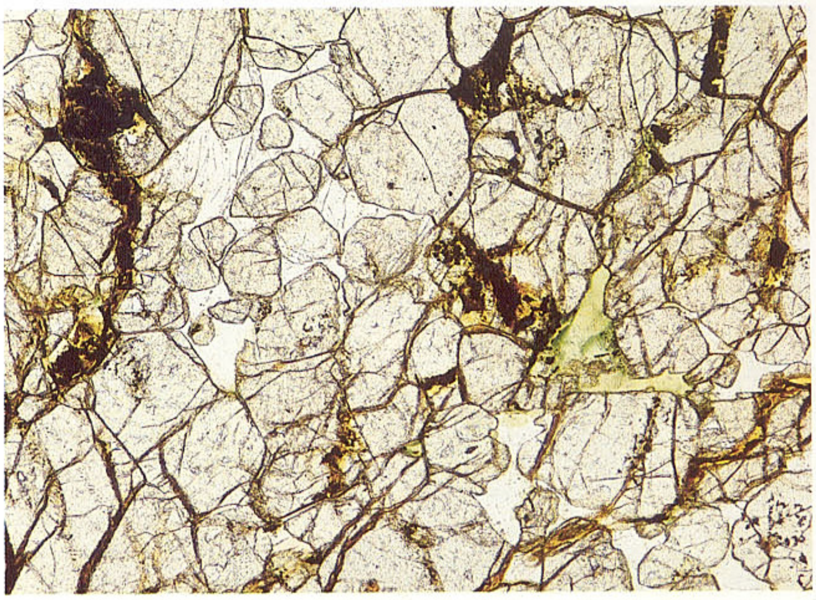
Equigranular – all crystals are of approximately the same size.
Inequigranular – crystals differ substantially in size. A common variety, *porphyritic* texture, involves relatively large crystals (*phenocrysts*[1]) embedded in finer-grained groundmass. (*N.B.* The same mineral may be present as both phenocrysts and groundmass.) In naming a rock with porphyritic texture the minerals present as phenocrysts should be listed and followed by the suffix -phyric, e.g. 'hornblende-pigeonite-phyric andesite'. However, if the groundmass is glassy, the term 'vitrophyre' is used, e.g. an 'olivine vitrophyre' has olivine phenocrysts set in glass; the texture in this case is referred as *vitrophyric* (**3, 142**). *Seriate* texture involves a continuous range in sizes of crystals of the principal minerals; if the crystals show a broken series of sizes, the inequigranular texture is said to be *hiatal.* Caution is necessary in the identification of seriate and hiatal textures, since the dimensions of a crystal in a thin section depend on the attitude of the intersection of the crystal in three dimensions.

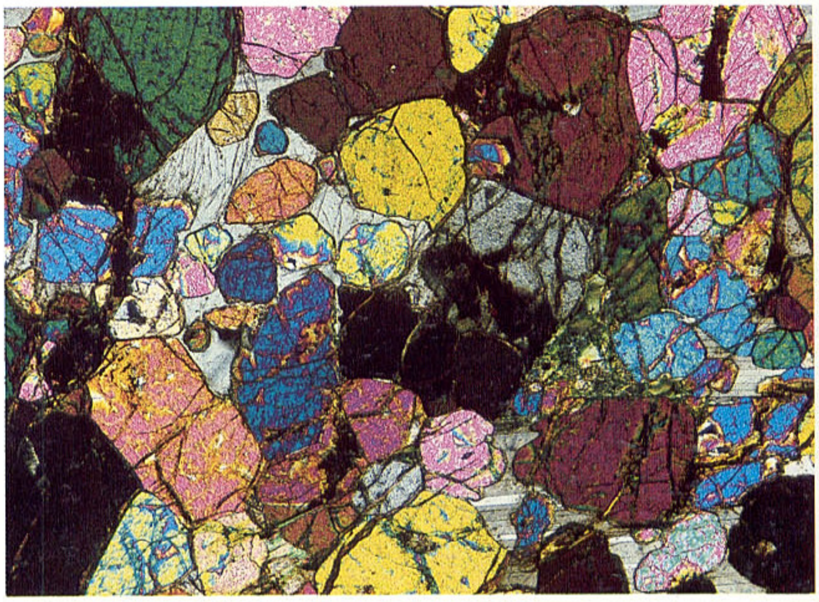
[1] *The prefix* micro- *may be added to* phenocrysts *which have diameters between 0.05 and 0.5 mm (e.g. 'olivine microphenocrysts').*

18 Equigranular peridotite

Uniformly-sized olivine crystals, some of them in clots, form the bulk of this rock, with plagioclase filling the interstices. The black material is microcrystalline haematite formed by oxidation of olivines and the green material is a clay mineral.

Peridotite from the Skaergaard intrusion, East Greenland; magnification × 27, PPL and XPL.
*Additional views of equigranular rocks are shown in **43**, **113**, **117**, **125**, **130** (first photo), **134**, **140** (third photo), **168**.*



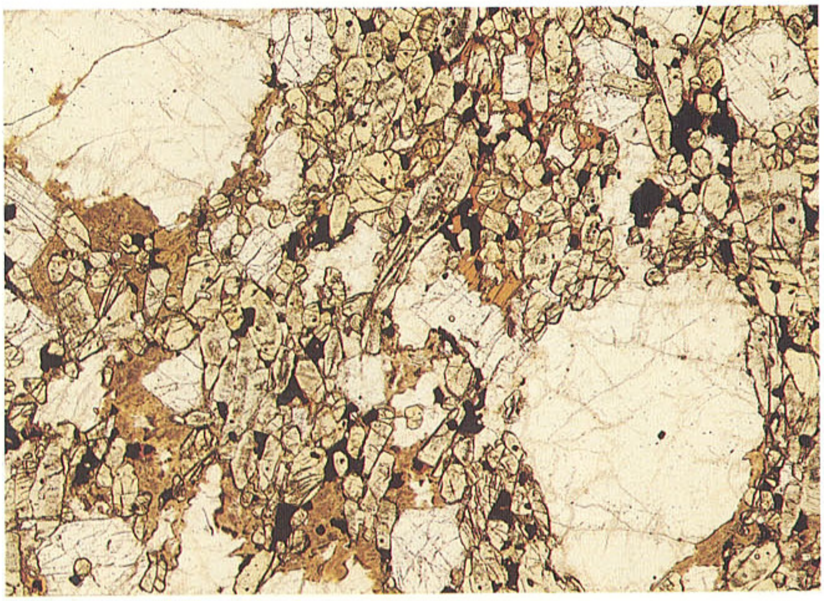


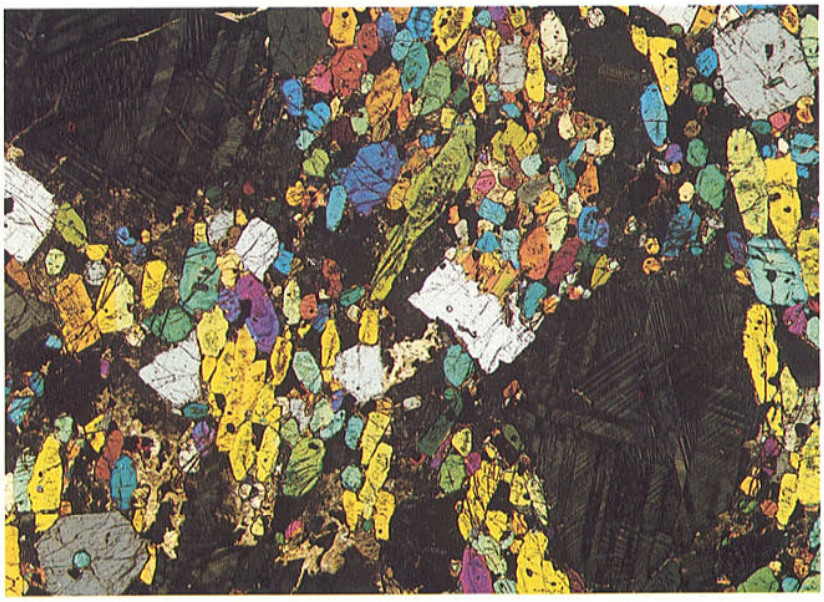
19 Porphyritic andesite

In this rock the phenocrysts (some of them in clots) of plagioclase, hornblende (khaki colour in PPL), augite (pale green in PPL) and magnetite, are surrounded by fine-grained groundmass of plagioclase, magnetite and glass.

Andesite from Siebengebirge, Germany; magnification × 23, PPL and XPL.

Porphyritic andesite (continued)





20 Leucite-phyric micro-ijolite

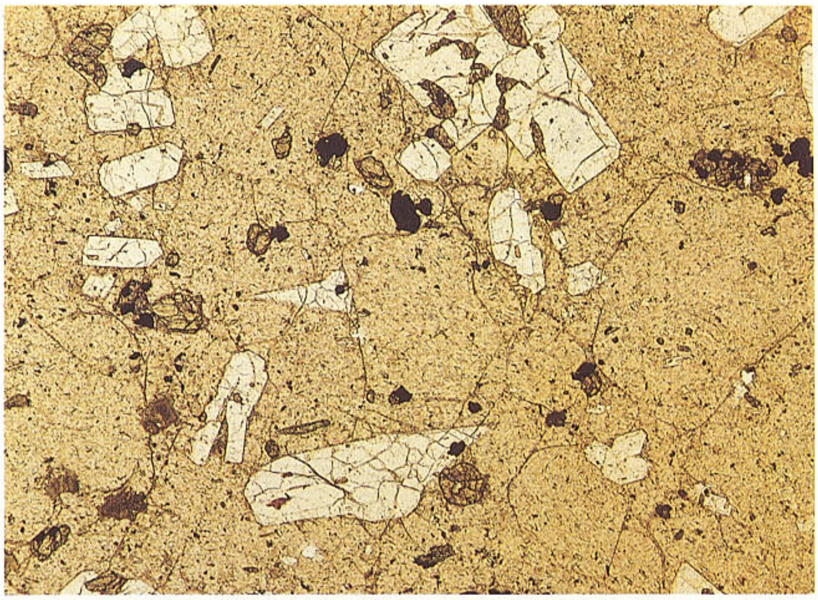
Two, large, shapeless crystals of leucite (very dark and showing multiple twinning in XPL photograph) are here surrounded by an equigranular groundmass consisting of crystals of elongate augite (bright interference colours), equant nepheline (grey in XPL) and interstitial biotite, leucite and magnetite. The amorphous material in the PPL view is a clay mineral.

Micro-ijolite from the Batsberg intrusion, East Greenland; magnification × 11, PPL and XPL.
Many other examples of porphyritic rocks can be seen by leafing through the book.

21 Plagioclase-augite-magnetite vitrophyre

Phenocrysts of the three minerals plagioclase, augite and magnetite, some of them in clots, are set in glass which contains crystallites of plagioclase.

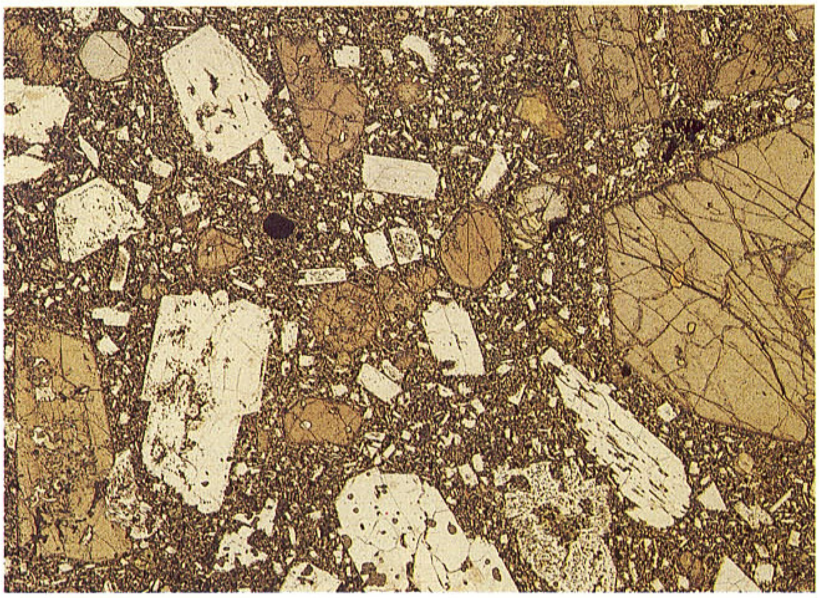
Basalt from Arran, Scotland; magnification × 20, PPL.
See 132 for another example of vitrophyre.

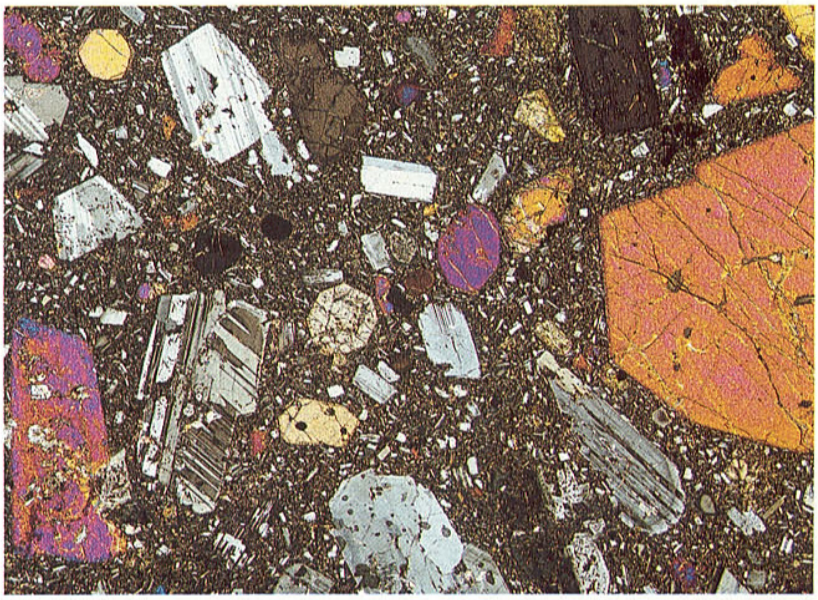


22 Seriate-textured olivine basalt

The crystals of olivine, augite and plagioclase in this basalt all show a wide range of grain size from as small as 0.01 mm up to 4 mm. Note the abundance of groundmass inclusions in some of the crystals, giving them a sponge-like appearance.

Olivine basalt from Arthur's Seat, Edinburgh, Scotland; magnification × 11, PPL and XPL.
See 44 and 137 for other examples of this texture.





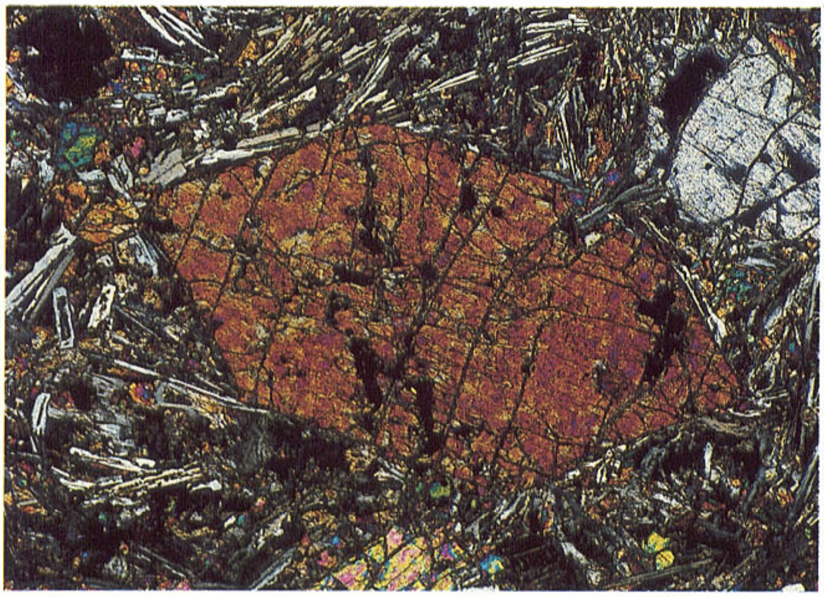
Crystal shapes

Two kinds of term are used to describe crystal shape: (1) those relating to the quality of the development of faces on crystals and (2) those specifying the three-dimensional shapes of individual crystals (p. 19).

Terms indicating the quality of the development of faces on crystals

Regrettably, three sets of words are in use to describe the same ideas, the most commonly used set being that in the first column of the following table.

Preferred terms	Synonymous terms	Synonymous terms	Meaning
Euhedral	Idiomorphic	Automorphic	Crystal completely bounded by its characteristic faces.
Subhedral	Hypidiomorphic	Hypautomorphic	Crystal bounded by only some of its characteristic faces.
Anhedral	Allotriomorphic	Xenomorphic	Crystal lacks any of its characteristic faces.



23 Euhedral olivine in olivine basalt

The photograph shows the characteristic six-sided euhedral shape of olivine in sections through the prism and dome faces. Note the slight enclosure of matrix material by one of the prism faces.

Olivine basalt from Ubekendt Ejland, West Greenland; magnification × 40, XPL.

24 Subhedral olivine in picritic basalt

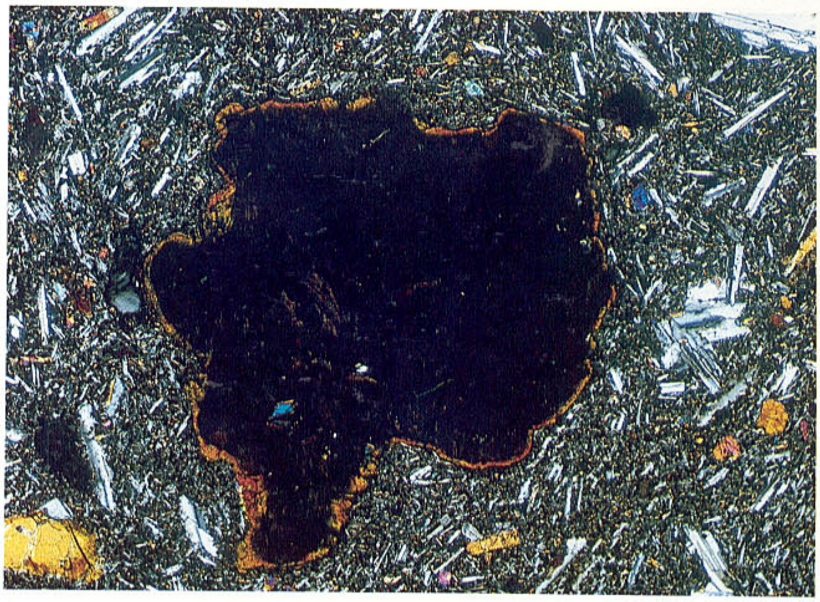
Some of the faces on this equidimensional olivine crystal are flat, planar ones, whereas others are curved and embayed.

Picritic basalt from Ubekendt Ejland, West Greenland; magnification × 72, XPL.

25 Anhedral olivine phenocryst in basalt

The entire perimeter of the large olivine crystal, at extinction in this picture, has an irregular outline and no planar faces are present. (The narrow brown rim on the crystal is 'iddingsite' formed by hydration and oxidation of the olivine.)

Olivine basalt from Mauritius, Indian Ocean; magnification × 32, XPL.



Terms indicating three-dimensional crystal shape

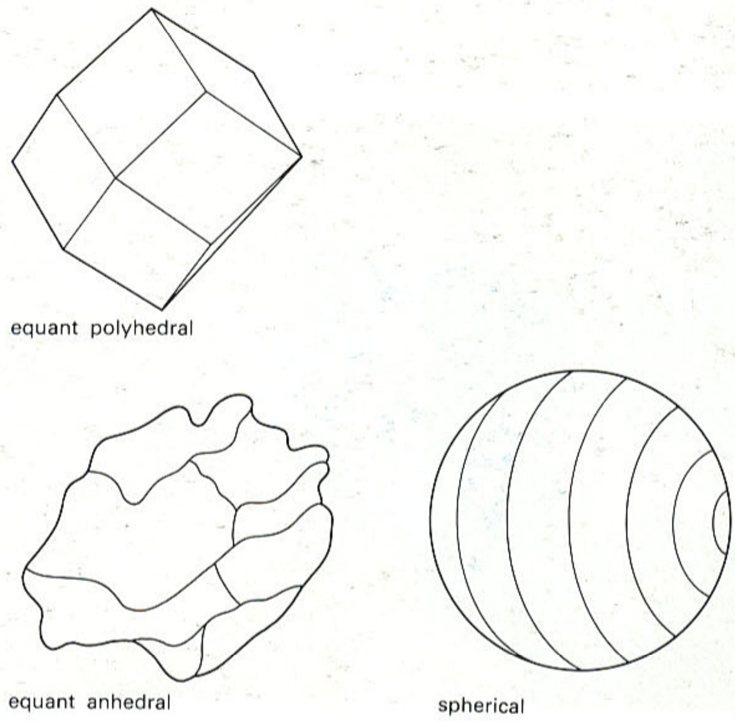
In hand specimens of coarse-grained rocks it is often possible to see the three-dimensional shape of a crystal on a broken surface. For finer-grained rocks, however, the crystals have to be examined in thin sections and the two-dimensional shapes of several crystals of different orientations used to deduce the three-dimensional shapes of the crystals in general.

General three-dimensional terms

The shape may either be an *equidimensional* (syn. *equant*) or an *inequidimensional* one, as illustrated in figs. A and B where the names applied to the various shapes are shown.

Fig. A Examples of equidimensional crystal shapes

The words *grain* and *granule* are often used for equidimensional crystals, and *drop* and *bleb* for particularly small examples.



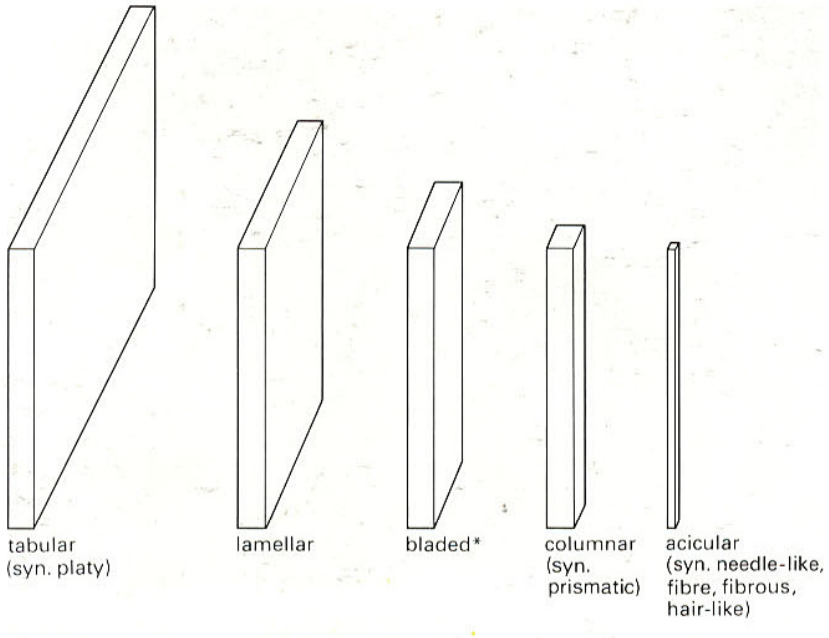


Fig. B Examples of inequidimensional shapes

N.B. Although these are euhedral examples, they could be subhedral or anhedral.

**Bladed feldspar crystals by common usage are frequently described as 'lath-shaped' or as 'laths of feldspar', in allusion to the slats (laths) in a Venetian blind.*

Specific three-dimensional terms

Skeletal, dendritic and embayed crystals

Skeletal crystals are those which have hollows and gaps, possibly regularly developed, and usually with particular crystallographic orientations. In thin section these spaces appear as embayments[1] and holes in the crystal, filled with groundmass crystals or glass. *Dendritic crystals* consist of a regular array of fibres sharing a common optical orientation (i.e. all part of a single crystal) and having a branching pattern resembling that of a tree or the veins in a leaf or a feather. In practice, many crystals can be described as either skeletal or dendritic because they have characteristics of both.

[1] *A common misconception among petrologists is that the terms 'embayment' and 'embayed' imply resorption of a crystal by reaction with liquid. While this may be true of some crystals (e.g.* ***29****), others (e.g.* ***26*** *and* ***27****) have embayments which probably formed during growth.*

26 Skeletal olivines in picritic basalt

All the large crystals in this rock are olivines and each shows a different shape in section; some are complex skeletal crystals (e.g. elongate yellow crystal on the left), others are relatively simple skeletons (e.g. equant orange crystal, middle right) and yet others have only small embayments.

Picritic basalt from Ubekendt Ejland, West Greenland; magnification × 40, XPL.

27 Skeletal olivine

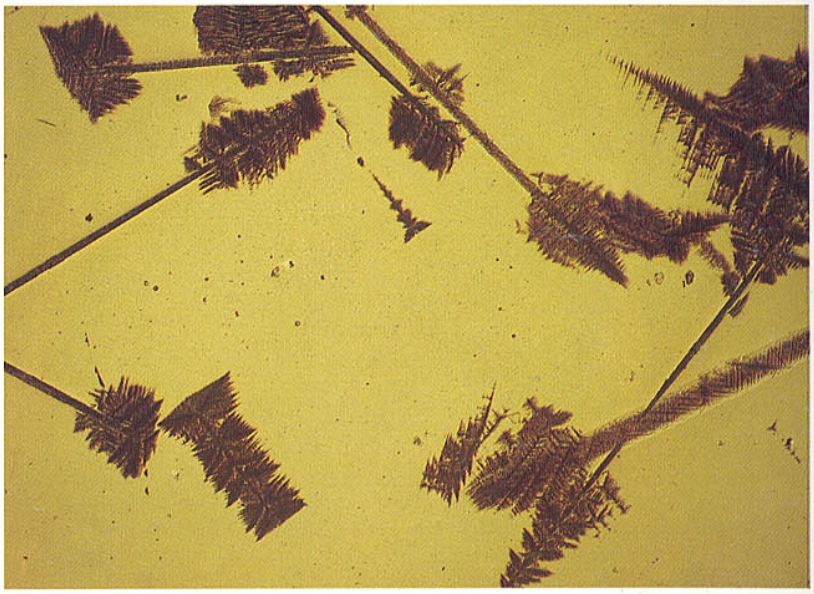
While superficially resembling the euhedral outline of the olivine in **23**, the crystal occupying the bulk of this picture has a complex interior form and incomplete prism and dome faces.

Picritic basalt from Ubekendt Ejland, West Greenland; magnification × 15, PPL.

28 Dendritic olivines

All the delicate, dendritic crystals in this photograph are olivines which formed during exceedingly rapid solidification of the basalt melt, part of which became the yellow glass.

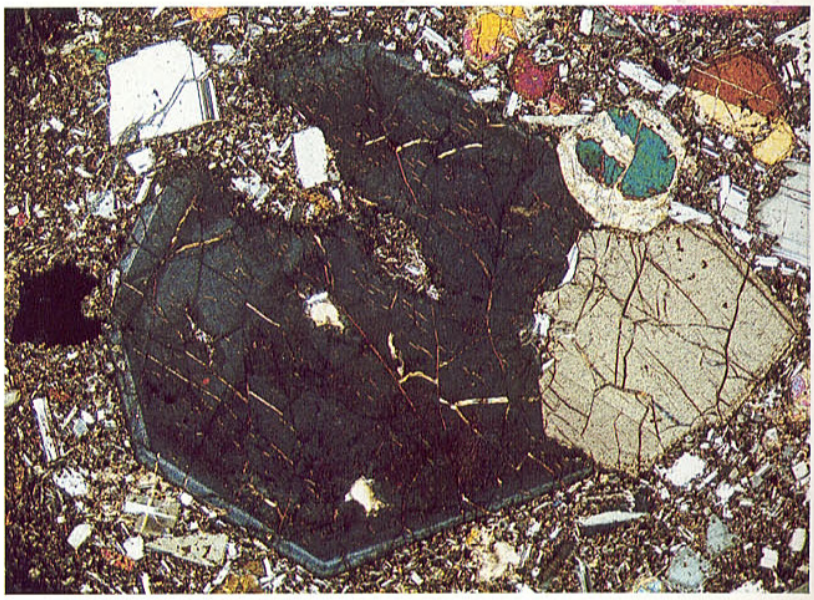
Specimen of olivine basalt melted and then cooled at 1400°/hr in the laboratory; magnification × 40, PPL.

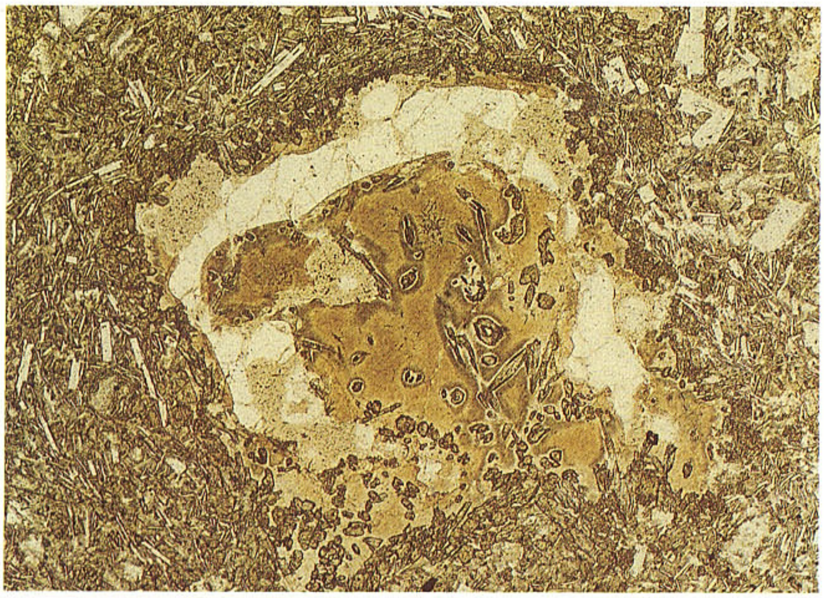


29 Embayment in augite phenocryst

The large augite crystal in this photograph contains a deep embayment filled with the basaltic groundmass. The irregular outline of this embayment distinguishes it from the embayments in the skeletal crystals in **27**. Note also the distinct marginal zoning and the delicate 'patchy zoning' within the crystal.

Olivine basalt from Arthur's Seat, Edinburgh, Scotland; magnification × 23, XPL.





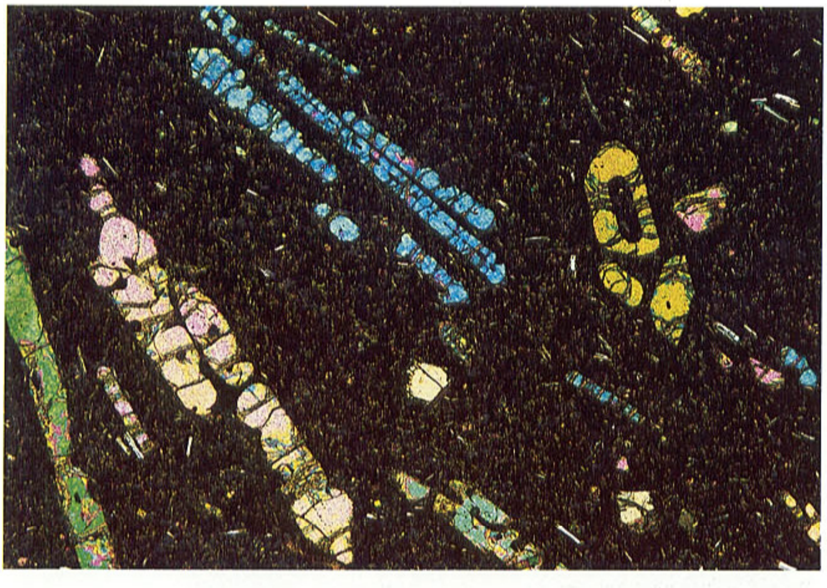
30 Embayed quartz

The deeply embayed quartz crystal in this olivine basalt contains brown glass and small, columnar, skeletal pyroxenes. It is also surrounded by a film of the glass and an aggregate of equant granular augite crystals which separate it from the basaltic groundmass.

Olivine basalt from Lassen Park, USA; magnification × 42, PPL.

Parallel-growth crystals

The term is applied to an aggregate of elongate crystals of the same mineral whose crystallographic axes are mutually parallel, or almost so. Although in thin section the individual parts of the aggregate may be isolated from one another, in the third dimension they are probably connected. A parallel-growth crystal is therefore a single, incomplete crystal formed by a particular style of skeletal growth.



31 Olivine parallel growth

The elongate olivines near the middle of the photograph and showing blue interference colour all have the same crystallographic orientation, and hence represent a single, parallel-growth crystal. The crystal with yellowish-green interference colour shows how the parallel-growth crystal *might* appear, if sectioned at right angles.

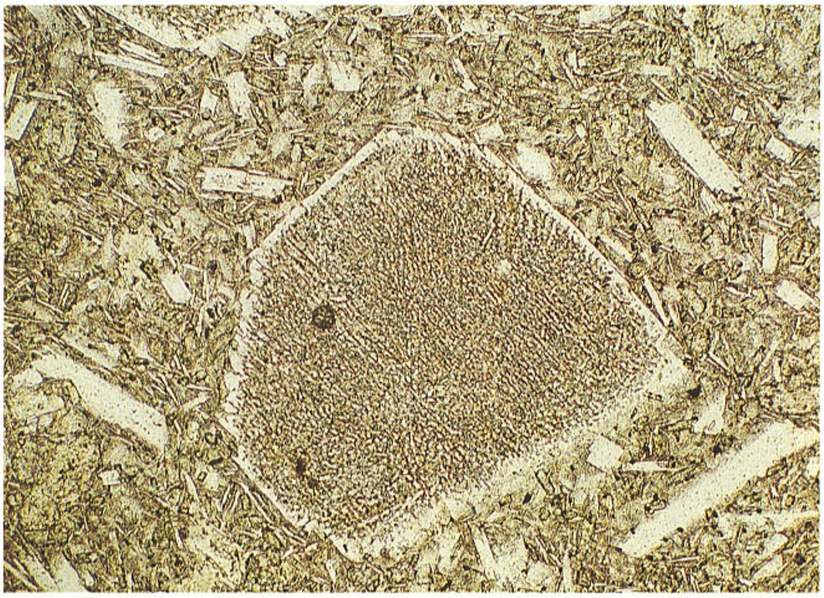
Picritic basalt from Ubekendt Ejland, West Greenland; magnification × 23, XPL.

32 Parallel growth in a very coarse-grained rock

Here the parallel growth is of a very large olivine crystal. The actual width of the field of view is 1.7cm and this shows only a small part of the parallel growth, whose total width is 50cm and height is 150cm. The whole comprises several hundred parallel units like the ones shown here. Plagioclase and augite occupy the 'channels' between the parallel growths. In the XPL picture the polars have been rotated so that the olivine is not in extinction. The slight differences in birefringence of the olivine at the top and bottom of the picture are caused by the section being thinner there. This rock has the special textural name *harrisite*.

Feldspathic peridotite from Rhum, Scotland; magnification ×7, PPL and XPL.

Sieve-textured crystals
These contain abundant, small, interconnected, box-shaped glass inclusions, giving the crystals a spongey, or porous, appearance.



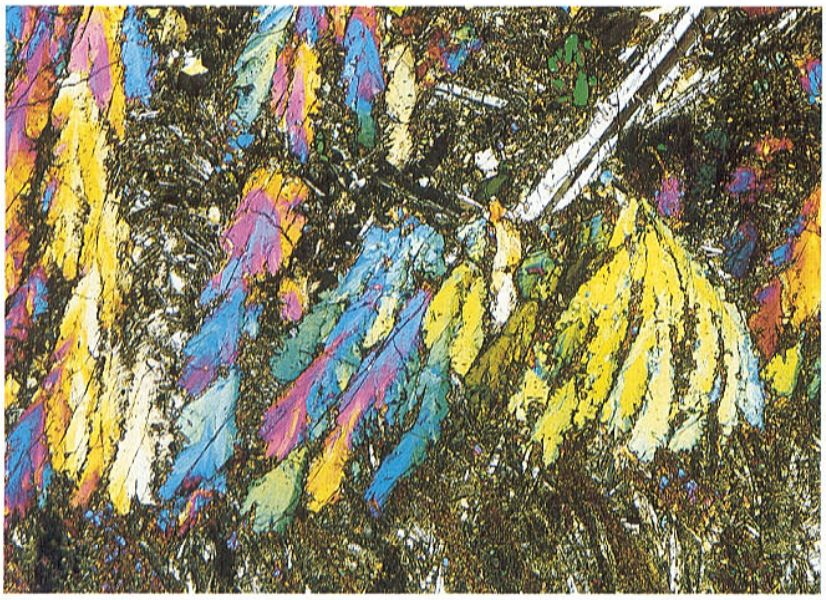
33 Sieve-textured feldspar

The core of this xenocryst consists of glass and alkali feldspar in a fine-mesh-like arrangement; the narrow rim is an overgrowth of plagioclase.

Olivine basalt from Lassen Park, USA; magnification × 62, PPL.

Elongate, curved, branching crystals

These are rarely genuinely bent, rather the curvature is caused by development of branches along the length of the crystal, each branch having a slightly different crystallographic orientation to its neighbours (e.g. **34–36**).



34 Curved branching augite

The highly coloured crystals in this photograph are complex, branching crystals of augite in subparallel alignment. They form part of a pyroxene-rich band in a differentiated dyke. (See also **71**.)

Dolerite from North Skye, Scotland; magnification × 21, XPL.

35 Branching augite in lamprophyre dyke

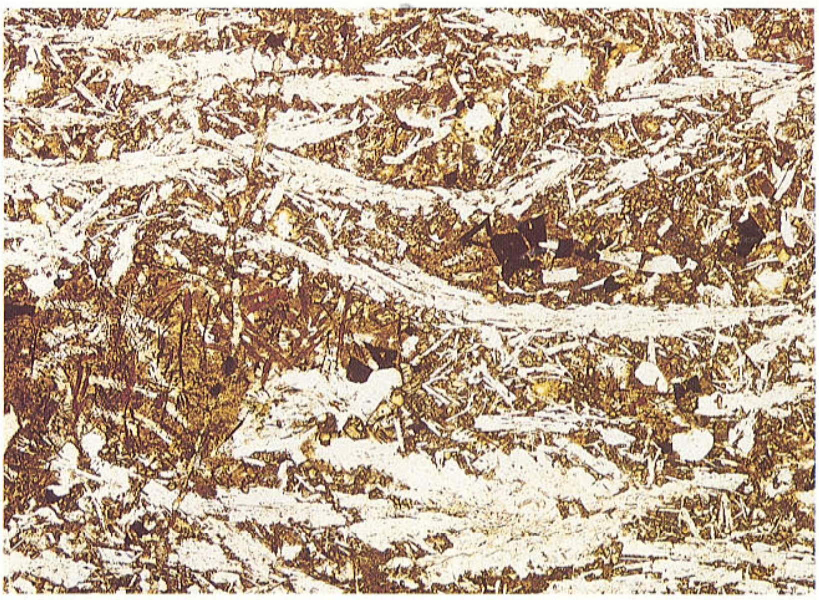
The acicular, aligned phenocrysts in this photograph are all of augite, forming composite, radiating, curved and branching groups. Individual needles can be seen to consist of several straight portions offset slightly from one another, and having very slightly different orientations; this gives each 'needle' its curved appearance. The margin of the dyke lay to the left. (See also **70**.)

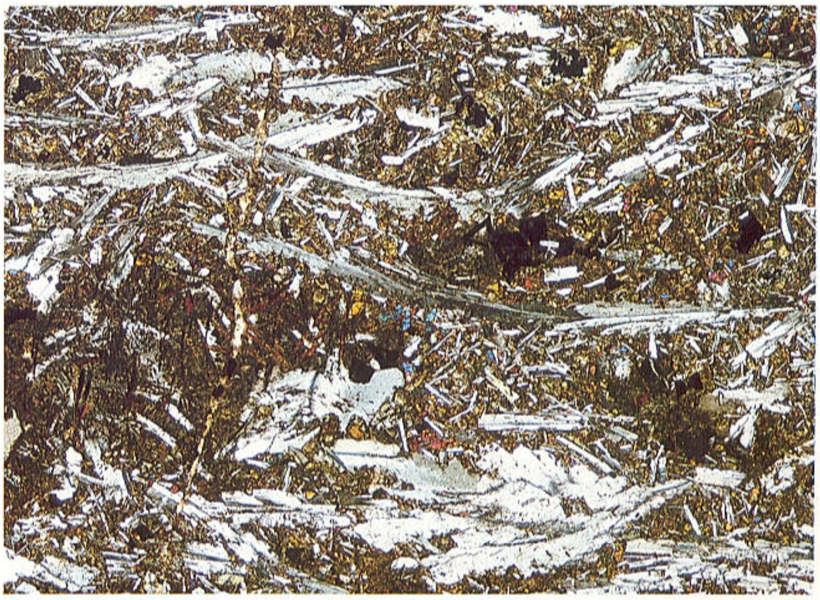
Fourchite from Fiskaenesset area, South-west Greenland; magnification × 20, XPL.

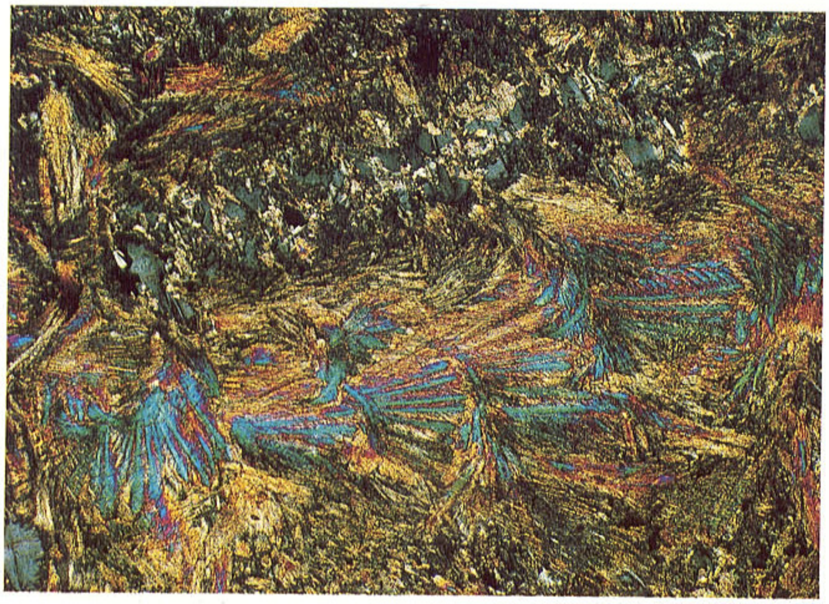
36 Curved and branching plagioclase crystals in dolerite

The large composite plagioclase crystals in this rock are elongate parallel to the *c* crystallographic axis and flattened parallel to (010). From the direction in which they branch, and from that in which the crystal at the bottom widens, it can be deduced that the crystals grew from right to left. The matrix consists of fine-grained plagioclase, olivine, pyroxene, amphibole, devitrified glass and clay minerals.

Feldspathic dolerite, Ubekendt Ejland, West Greenland; magnification × 16, PPL and XPL.







37 Composite branching augite crystal

These photographs illustrate a particularly intriguing shape of branching augite crystal: it consists of groups of slightly diverging needles, subparallel to the length of the crystal, which apparently have grown from curved branching needles oriented approximately at right angles to the crystal length. Despite the uniform interference colour of many of the needles, a sweeping style of extinction occurs when the microscope stage is rotated under crossed polars, indicating that the needles are not all of the same crystallographic orientation.

Peridotitic komatiite from Munro Township, Ontario, Canada; magnification × 52, PPL and XPL.

Pseudomorphs

It may be found that crystals in a thin section, although having the characteristic shape of a particular mineral, prove to be of another mineral, or an aggregate of crystals of another mineral. The name *pseudomorph* is used for such a crystal. If the pseudomorph has the same composition as the original crystal (e.g. 'quartz' in place of tridymite) it is known as a *paramorph*.

38 Carbonate pseudomorphs after olivine

The phenocrysts in this altered basalt show typical sections of skeletal olivine, with inclusions of groundmass in the embayments. However the photograph shows the phenocrysts to be occupied by finely crystallized carbonate, indicating that replacement of olivine has occurred.

Altered basalt from Castleton, Derbyshire, England; magnification × 27, XPL.

Another example of pseudomorphs is shown in ***149****.*

Mutual relations of crystals (and amorphous materials)

The various patterns of crystal arrangement which can exist are conveniently introduced under the following headings: equigranular textures; inequigranular textures; oriented textures; intergrowth textures; radiate textures; overgrowth textures; banded textures; and cavity textures. Particular textures may belong to more than one of these categories and some also belong to the categories of **crystallinity**, **granularity** and **crystal shape**. Thus certain of the textures introduced in this section have already been mentioned and reference is made to photographs of them in previous sections.

Equigranular textures

Depending on the general shape of the crystals, three textures can be distinguished in which crystals of the principal minerals in a rock are of roughly uniform grain size:

name	synonyms	definition
euhedral granular	panidiomorphic granular	bulk of the crystals are euhedral and of uniform size
subhedral granular	hypidiomorphic granular	bulk of the crystals are subhedral and of uniform size
(anhedral)[1] granular	allotriomorphic granular (granitic and granitoid textures apply to siliceous rocks only)	bulk of the crystals are anhedral and of uniform size

Boundaries between these categories are not sharply defined and consequently the terms are applied very subjectively. Furthermore a rock may not fit neatly into a single category, thus one in which ~50% of the crystals are euhedral and ~50% anhedral might best be described as having a mixed euhedral and anhedral granular texture.

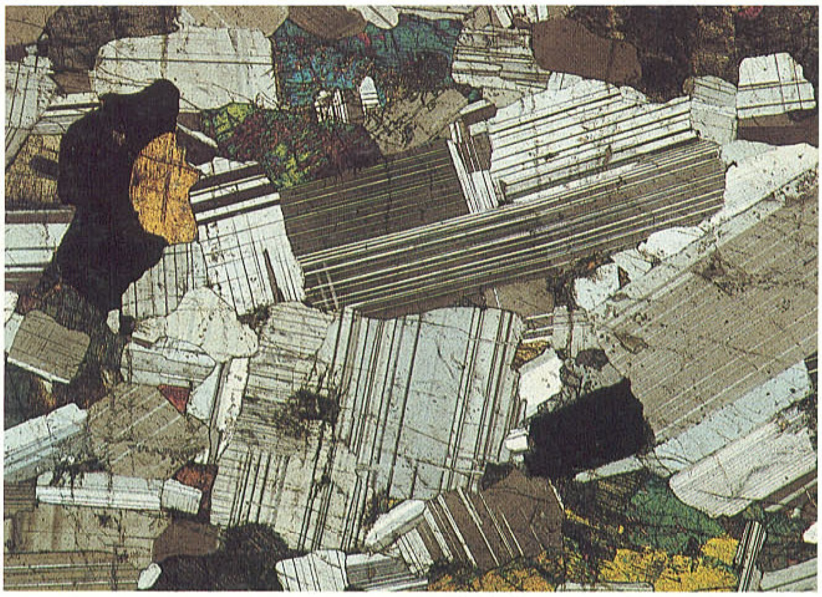
In addition to the examples of these textures in **39–43**, others may be found in **18**, **111**, **113**, **117**, **125**, **130**, **134**, **140** and **168**.

[1] *This adjective is commonly omitted from this textural name.*

39 Euhedral granular hornblendite

Rocks possessing truly euhedral granular textures are very rare. The one in this figure is a good example of a more common situation in which only some of the crystals of the principal mineral, hornblende, are euhedral and some strictly are subhedral. In contrast to **40**, there are a higher proportion of crystals with faces and the term 'euhedral granular' is therefore suggested as most appropriate. It should be appreciated, however, that another petrologist might prefer 'subhedral granular'.

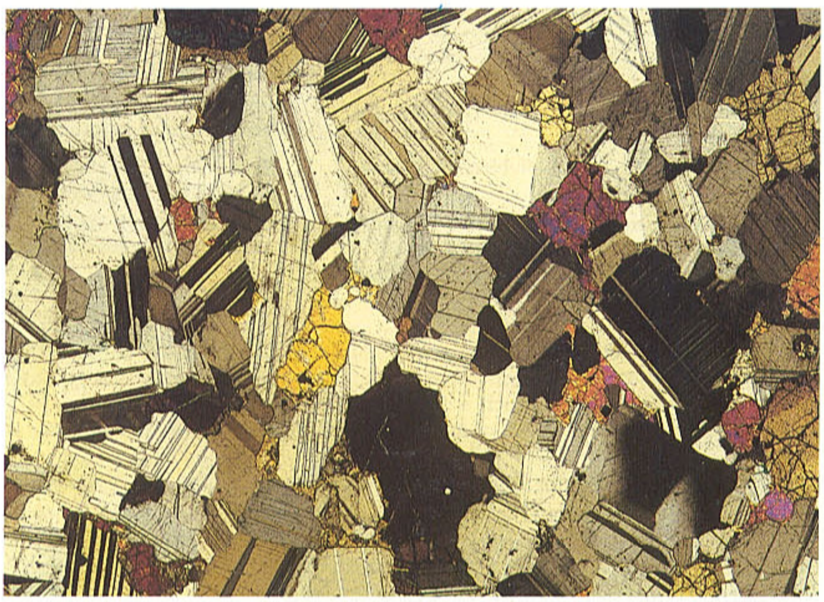
Hornblendite from Ardsheal Hill, Scotland; magnification ×7, XPL.



40 Subhedral granular gabbro

The stout prismatic plagioclase feldspar crystals which dominate this rock are mostly subhedral. The anhedral interstitial crystals are of orthopyroxene, augite and magnetite.

Gabbro from Middle Zone of the Skaergaard intrusion, East Greenland; magnification × 20, XPL.



41 (Anhedral) granular troctolite

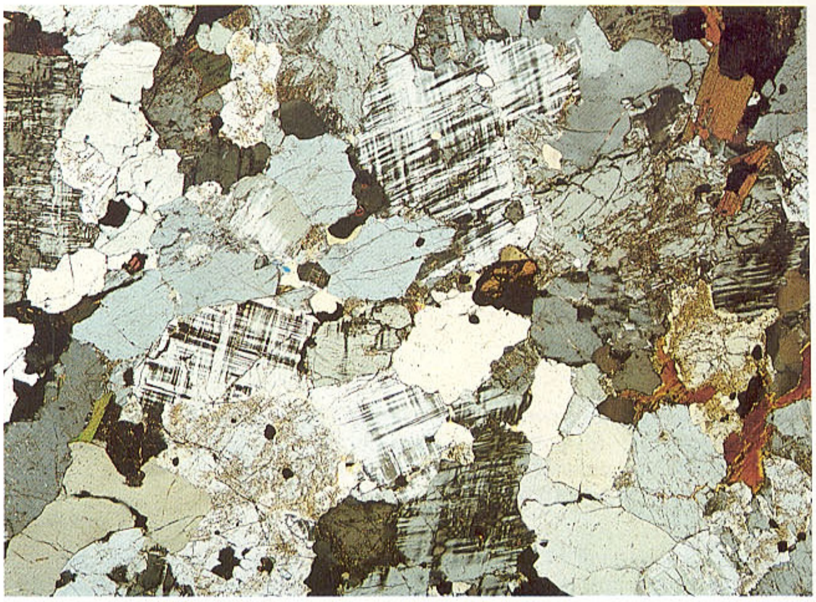
Only a few of the plagioclases in this equigranular rock possess a face and none of the olivines do. The crystals are therefore predominantly anhedral and the 'mosaic' texture is granular.

Troctolite from Garbh Bheinn intrusion, Skye, Scotland; magnification × 17, XPL.

42 Granular granite

Excepting the scarce biotite crystals, the quartz, microcline and albite crystals which make up the bulk of the rock are anhedral and have slightly interdigitating boundaries (i.e. *consertal texture* – see p. 45).

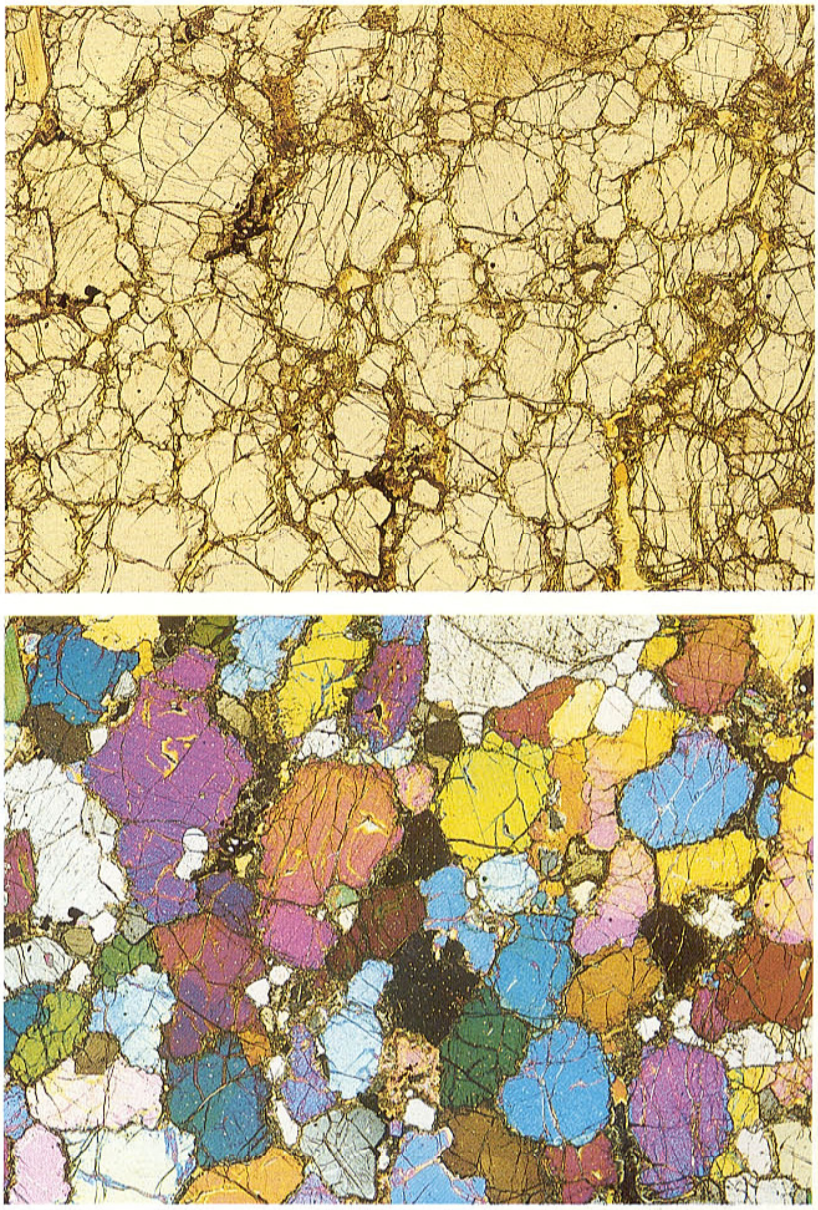
Granite from Madagascar; magnification × 13, XPL.



43 Granular lherzolite

The crystals of olivine (colourless in PPL), and pyroxenes (pale brown in PPL) which make up 95% of this rock, lack any crystal faces.

Lherzolite xenolith from the Matsoku kimberlite pipe, Lesotho; magnification × 16, PPL and XPL.



Inequigranular textures

This category includes seven kinds of texture: (a) seriate; (b) porphyritic; (c) glomeroporphyritic; (d) poikilitic; (e) ophitic; (f) subophitic; and (g) interstitial (intersertal and intergranular). It is not uncommon for a single thin section to display more than one of these textures.

Seriate texture

Crystals of the principal minerals show a continuous range of sizes. (See also p. 14.)

44 Seriate-textured basalt

This basalt, consisting of just plagioclase, augite and a small proportion of magnetite, shows a range in sizes of plagioclase and augite crystals from <0.01–0.5 mm.

Basalt from Island of Mauritius; magnification × 43, PPL and XPL.

*See **22** and **137** for other seriate-textured rocks.*

Porphyritic texture

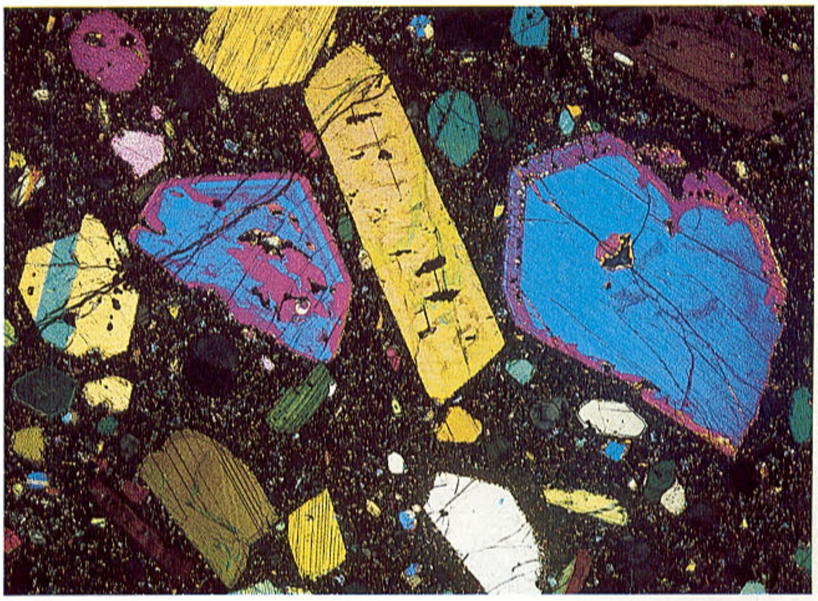
Relatively large crystals (phenocrysts) are surrounded by finer-grained crystals of the groundmass. (See also p. 14.)

45 Augite-olivine-leucite-phyric melilitite

Augite (greyish-green and green in PPL) is present in three generations in this sample – large euhedral phenocrysts, subhedral microphenocrysts and minute groundmass crystals. The leucite occurs as colourless, equant euhedral microphenocrysts, most easily identified by their very low birefringence in the XPL picture, and the olivine as faint-grey, euhedral, columnar microphenocrysts. Note the complicated zoning pattern in one of the augite phenocrysts, the prominent marginal zoning and the line of small inclusions of groundmass crystals in another. Melilite is confined to the fine-grained granular groundmass and cannot easily be seen in these photographs.

Melilitite from Malawa, Celebes; magnification × 11, PPL and XPL.

Many more examples of porphyritic texture may be found by leafing through the book.



Glomeroporphyritic texture

A variety of porphyritic texture in which the phenocrysts are bunched, or clustered, in aggregates or clots called *glomerocrysts*. (A minority of petrologists maintain that the term applies only to monomineralic clots and for polymineralic clots they use the term *cumulophyric texture*.) *Glomerophyric* is usually used synonymously with *glomeroporphyritic*, though the former term strictly should be reserved for clusters of equant crystals (Johannsen, 1931). (*Synneusis texture* also describes crystal clots but includes the genetic implication that the crystals 'swam together' and is therefore best avoided.)

46 Glomeroporphyritic tholeiitic basalt

The photograph shows crystal clots of different sizes composed of plagioclase, augite and olivine crystals, enclosed by fine-grained intergranular- and intersertal textured groundmass.

Basalt from unknown locality; magnification × 11, XPL.

47 Glomeroporphyritic hawaiite

Discrete phenocrysts of plagioclase and olivine, and clots consisting of a few crystals of the same minerals, are set in a fine-grained groundmass, in places showing slight alignment of plagioclase needles. Some plagioclases in individual clots are aligned – this arrangement is common in plagioclase glomerocrysts.

Hawaiite from plateau lavas of North Skye, Scotland; magnification × 11, XPL.

*Additional views of glomeroporphyritic texture may be seen in **122**, **127**, **154** and **158**.*

Poikilitic texture

Relatively large crystals of one mineral enclose numerous smaller crystals of one, or more, other minerals which are randomly oriented and generally, but not necessarily, uniformly distributed. The host crystal is known as an *oikocryst* (or *enclosing crystal*) and the enclosed crystals as *chadacrysts*. Although *chadacrysts* are generally equant, or nearly so, they need not be uniform in size; sometimes they display progressive change in size from the interior to the margin of an oikocryst, indicating differences in extent of chadacryst growth at the time of enclosure. It is not customary to apply *poikilitic texture* to the arrangement in which scarce minute crystals of accessory minerals are embedded in a crystal, nor to that in which the enclosing mineral is approximately the same size as that included.

48 Poikilitic enclosure of olivine crystals by augite

In this photograph approximately 100 crystals of olivine of fairly uniform size are enclosed by a single augite crystal (at extinction).

Peridotite from Quarsut, West Greenland; magnification ×22, XPL.

49 Plagioclase chadacrysts enclosed by augite

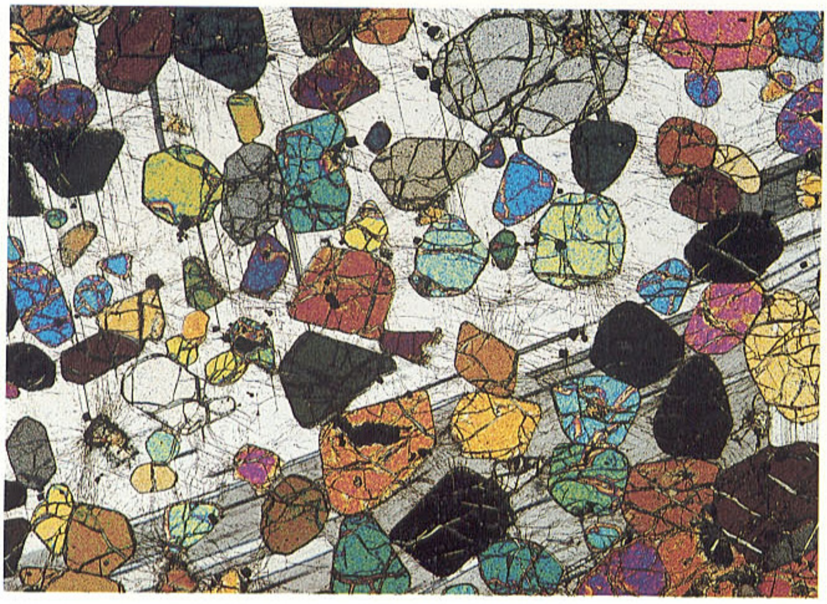
Part of a single augite crystal (yellow colour), exceeding 30mm in size, is shown here enclosing plagioclase crystals, some of which form clots. The orange crystal at upper right is olivine and the crystal almost at extinction is another augite crystal.

Gabbro from North Skye, Scotland; magnification ×7, XPL.

50 Olivine gabbro containing poikilitic domains

Large plagioclases, enclosing or partially enclosing, round olivines at their margins provide a framework to this rock, the interstices of which are occupied by large augites also enclosing round olivines and small stubby crystals of plagioclase.

Olivine gabbro from Middle Border Group of the Skaergaard intrusion, East Greenland; magnification × 12, XPL.



51 Olivines enclosed by plagioclase oikocryst

Subhedral, equant olivine crystals here are enclosed in a single large plagioclase crystal.

Feldspar peridotite from Rhum, Scotland; magnification × 21, XPL.

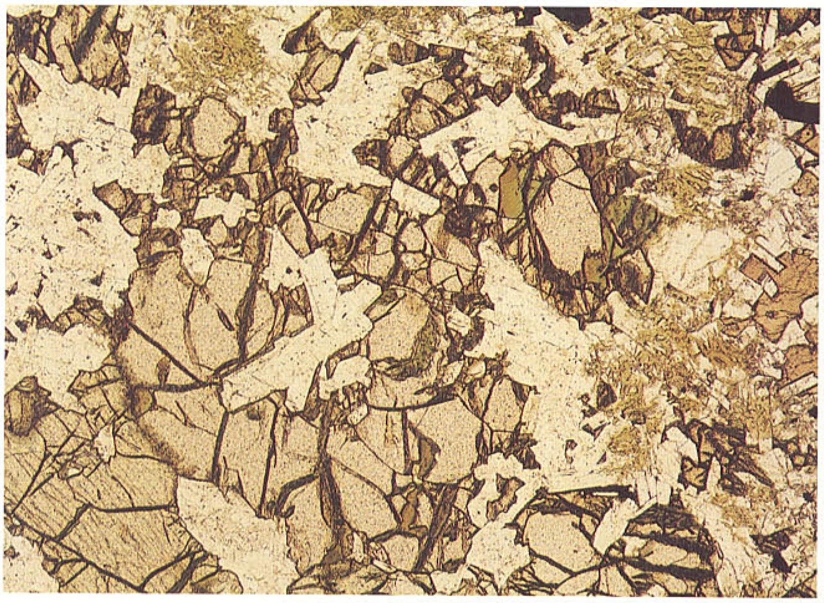
Additional views of poikilitic texture may be found in ***111, 114*** *and* ***167.***

Ophitic texture

This is a variant of *poikilitic texture* in which the randomly arranged chadacrysts are elongate and are wholly, or partly, enclosed by the oikocryst. The commonest occurrence is of bladed crystals of plagioclase surrounded by subequant augite crystals in dolerite (sometimes referred to as *doleritic texture*); however the texture is not confined to dolerites, nor to plagioclase and augite as the participating minerals.

Some petrologists distinguish the arrangement in which the elongate chadacrysts are completely enclosed (*poikilophitic texture*) from that in which they are partially enclosed and therefore penetrate the oikocrysts (*subophitic texture*). *Poikilophitic texture* could also be used when oikocrysts surround elongate chadacrysts of one mineral and equant chadacrysts of another.

Fine- and medium-grained rocks made up of many small oikocrysts have a patchy appearance, sometimes described as *ophimottled*.



54 Subophitic alkali olivine dolerite

In this view plagioclase laths are embedded in olivine rather than pyroxene. One olivine crystal is at extinction in the XPL photograph and another shows orange interference colour. The other mafic mineral in the pictures is augite showing a purple interference colour.

Olivine dolerite from Shiant Isles sill, Scotland; magnification × 26, PPL and XPL.

*See **121**, **126**, **128** and **164** for additional examples of subophitic texture; **121** is particularly interesting because here the pyroxene is subophitically enclosed by plagioclase, and in **164** pyroxene is subophitically enclosed by kalsilite.*

55 Poikilophitic texture in olivine gabbro

For the texture shown here the term poikilophitic is preferable to ophitic because (a) the large augite encloses some equant olivines in addition to plagioclases, and (b) many of the plagioclases are not markedly elongate.

Olivine gabbro from Lower Zone a of the Skaergaard intrusion, East Greenland; magnification × 10, XPL.

56 Ophimottled texture in olivine basalt

Approximately fifty augite crystals are shown here enclosing bladed plagioclases and giving the rock a mottled or speckled appearance.

Olivine basalt from Isle of Mull, Scotland; magnification ×14, XPL.

57 Feldspar-olivine-phyric ophimottled basalt

Phenocrysts of plagioclase and olivine, some in clots, are set in fine-grained ophimottled groundmass.

Olivine basalt from Skye, Scotland; magnification ×12, XPL.

Interstitial textures

Two varieties are recognized on the basis of the material occupying the angular spaces between feldspar laths:

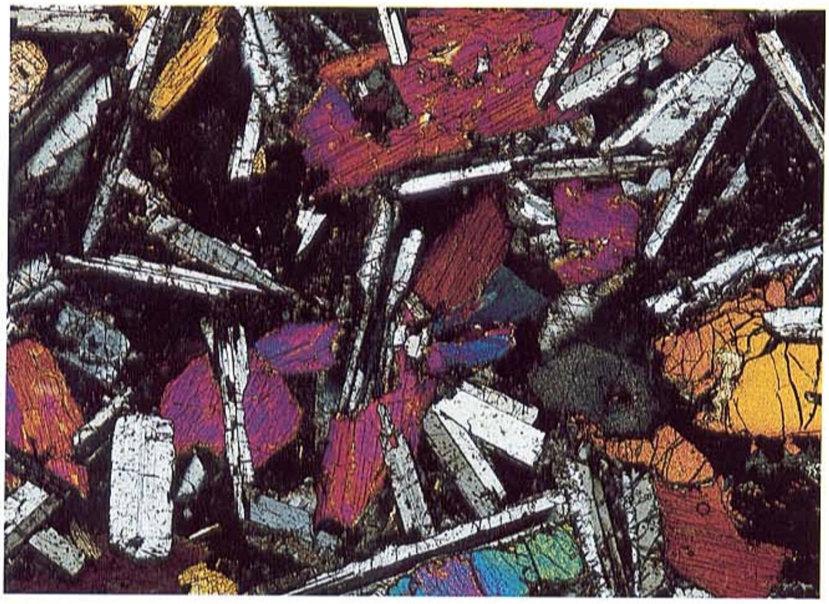
1. *Intersertal texture* – glass or hypocrystalline material wholly, or partly, occupies the wedge-shaped interstices between plagioclase laths. The glass may be fresh or have been altered to palagonite, chlorite, analcite or clay minerals, or it may have devitrified. If a patch of glass is sufficiently large and continuous to enclose a number of plagioclases, some petrologists would describe the texture as *hyalophitic*. (See also *hyalopilitic* texture, p. 41.)
2. *Intergranular texture* – the spaces between plagioclase laths are occupied by one, or more, grains of pyroxene (±olivine and opaque minerals). Unlike ophitic texture, adjacent interstices are not in optical continuity and hence are discrete small crystals. The feldspars may be in diverse, subradial or subparallel arrangement (see also *pilotaxitic* and *felty* textures, p. 41).

As shown by some of the photographs illustrating these textures, a single thin section may contain both types of interstitial texture in separate, but contiguous, textural domains.

58 Intersertal (hyalophitic) texture in tholeiitic basalt

Certain parts of this photograph show lath-shaped plagioclases enclosed in pools of devitrified, deep-brown glass. Other plagioclases are surrounded by augite in a subophitic manner.

Oceanic tholeiite from Leg 34 of the Deep Sea Drilling Project; magnification × 65, PPL.



59 Intersertal texture in alkali dolerite

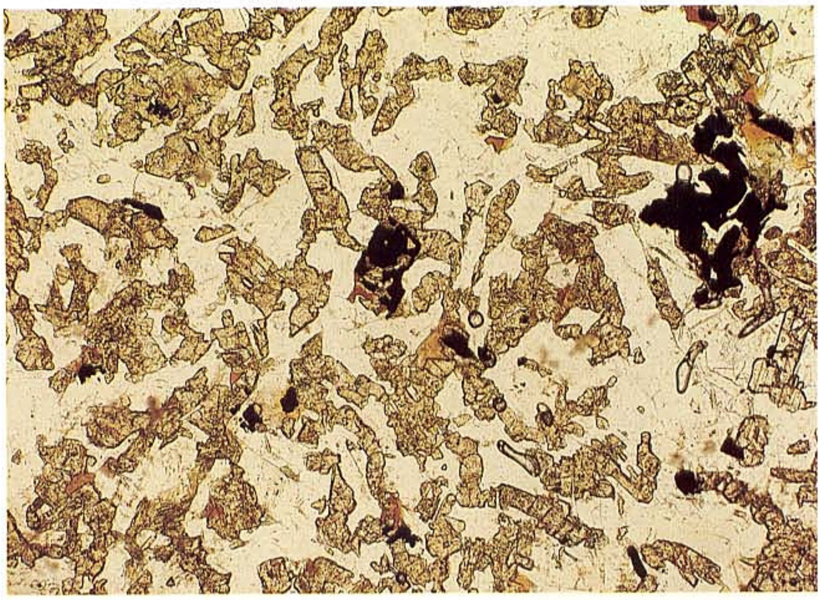
The intersertal texture in this dolerite consists of plagioclase crystals embedded in analcite (colourless in PPL and isotropic in XPL). Other plagioclases are partially enclosed by pyroxene in a subophitic manner. A crystal of olivine can be seen at the right-hand edge of the view in PPL.

Alkali dolerite from Howford Bridge sill, Ayrshire, Scotland; magnification × 23, PPL and XPL.
*See also **126** and **127**.*

60 Intergranular dolerite

Anhedral equant crystals of augite and pigeonite occupy the spaces between plagioclase crystals in this sample.

Dolerite from near the lower margin of Palisades sill, New Jersey, USA; magnification × 60, PPL and XPL.



61 Intergranular olivine gabbro

In this example of intergranular texture the rock is coarse-grained and the plagioclases have a subparallel arrangement. Note that the interstitial augites are anhedral against the euhedral plagioclases.

Olivine gabbro from Lower Zone b of the Skaergaard intrusion, East Greenland; magnification × 15, XPL.

62 Tholeiitic basalt with two types of interstitial texture

In this photograph patches between some of the plagioclases are occupied by brown glass (partly devitrified) and between others by clots of small augite crystals without any glass present, i.e. domains of both intersertal and intergranular texture are present.

Tholeiitic basalt from Ubekendt Ejland, West Greenland; magnification × 27, PPL and XPL.

63 Intersertal, intergranular and subophitic textures in dolerite

All three of these textures co-exist in this rock.

Dolerite from Whin sill, Northumberland, England; magnification × 26, PPL and XPL.

Intersertal, intergranular and subophitic textures in dolerite (continued).

Oriented, aligned and directed textures

Several classes of this textural type exist: (a) trachytic texture; (b) trachytoid texture; (c) parallel-growth texture; (d) comb texture; and (e) orbicular texture.

Trachytic texture

A subparallel arrangement of microcrystalline lath-shaped feldspars in the groundmass of a holocrystalline or hypocrystalline rock.

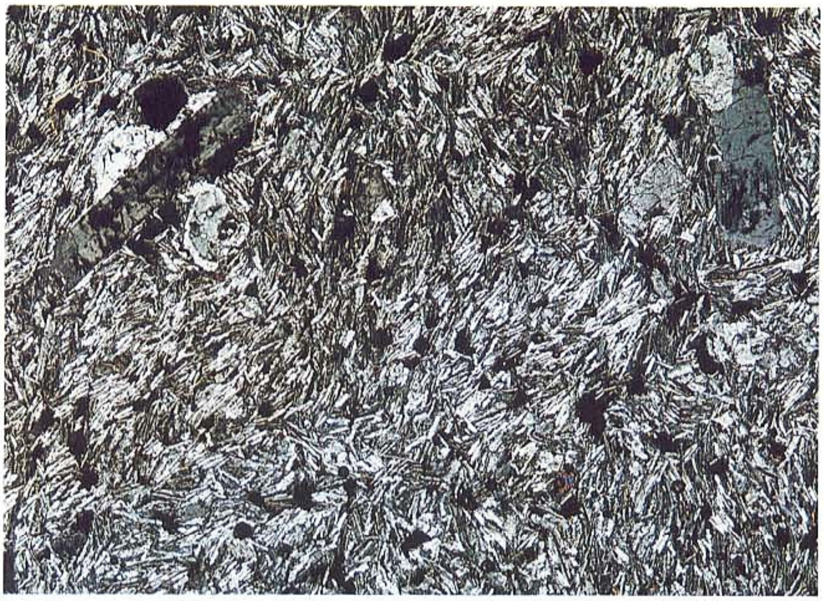
N.B. the term is not restricted in use to rocks of trachyte composition (e.g. see groundmass of **47**).

Some petrologists subdivide trachytic texture with microlite-sized feldspars into *pilotaxitic texture* and *hyalopilitic texture*, depending on whether the material between the feldspars is crystalline or glassy.[1] Strictly, however, the microlites in these textures may be more or less aligned. (For a pilotaxitic texture in which the microlites are essentially randomly arranged the term *felty texture* exists.)

Trachytoid texture

A subparallel arrangement of tabular, bladed or prismatic crystals which are visible to the naked eye (Holmes, 1921). While the term is usually applied to crystals of feldspar, Johannsen (1931) states that it may equally well be used for oriented crystals of any other mineral.

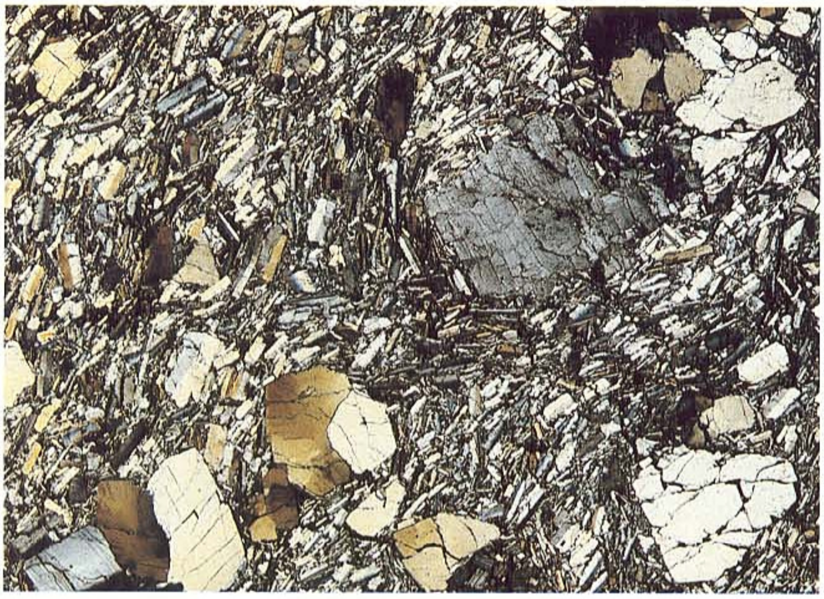
The terms *flow* and *fluxion texture* are sometimes used as synonyms for trachytic and trachytoid textures, however they should be avoided on account of their genetic implications.



64 Trachytic texture in a trachyte

This rock illustrates trachytic texture with no glass between the small, aligned alkali feldspars (i.e. pilotaxitic variety). Note that, rather than there being a single universal alignment direction, there are several domains in the photograph, each having its own preferred direction of feldspar alignment.

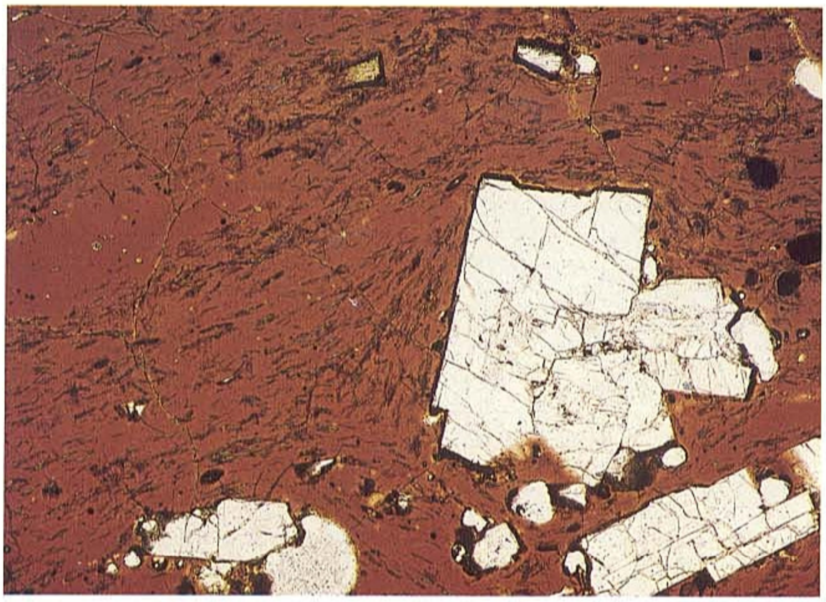
Trachyte from unknown Czechoslovakian locality; magnification × 16, XPL.



65 Trachytic texture in trachyte

The somewhat stumpy groundmass alkali feldspars in this rock display a subparallel alignment which is particularly noticeable where they follow the outline of the phenocrysts.

Trachyte from unknown German locality; magnification × 15, XPL.



66 Hyalopilitic texture in rhyolitic pitchstone

The feldspar microlites in this glassy rock have a preferred elongation direction from lower left to upper right; near the feldspar phenocrysts and opaque crystals the orientation of the microlites follows the outline of these crystals. Note the tendency for the microlites to be arranged in bands.

Pitchstone from Ischia, Bay of Naples; magnification × 20, PPL.

67 Trachytoid diorite

This medium-grained rock contains aligned columnar plagioclases. The cloudy appearance to the plagioclases results from very small inclusions of iron ore and mica.

Diorite from Comrie, Scotland; magnification × 16, PPL.

68 Trachytoid gabbro

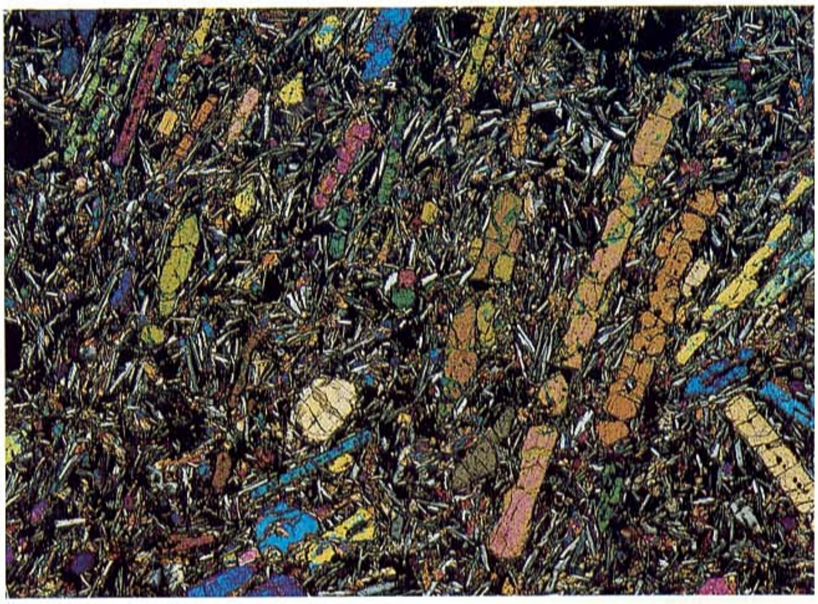
This trachytoid texture consists of platy plagioclases, here seen edge on, stacked upon one another. Note that when this rock is sectioned parallel to the plane of the flattening, the crystal alignment would not be evident.

Gabbro from Lower Zone b of the Skaergaard intrusion, East Greenland; magnification × 12, XPL.

69 Olivines in trachytoid arrangement in olivine dolerite

In this view, large columnar phenocrysts of olivine, some of skeletal type, are aligned, and embedded in intergranular-textured plagioclase and augite.

Olivine dolerite from Isle of Skye, Scotland; magnification × 21, XPL.



Parallel-growth texture

A single elongate skeletal crystal which in thin section appears to consist of a clot of crystals having the same elongation direction and the same optical orientation. (For illustrations see **31** and **32**.) In rocks with trachytoid texture it is not uncommon for neighbouring parallel-growth crystals to be aligned (see **31**).

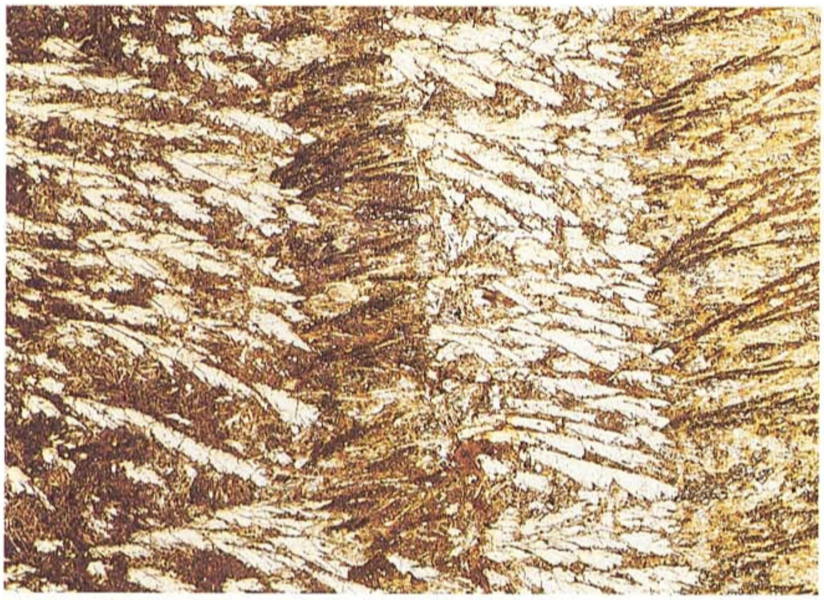
Comb texture (comb layering)

Elongate, possibly curved, branching crystals sharing the same direction of elongation. The crystals typically form a band, layer, or fringe with the elongation direction of the crystals inclined at 60–90° to the plane of the layering. (Synonyms are *Willow-Lake layering* and *crescumulate layering*, though the latter is a genetic term and, hence, should be avoided.)

70 Pyroxene comb layer in a thin lamprophyre (fourchite) dyke

Long branching augite crystals are aligned at right angles to the boundary between the comb-layered rock (below) and pyroxene-phyric rock (above). The V of the branching widens in the direction of growth, which is away from the dyke wall. (See also **35**.)

Lamprophyre dyke from Fiskaenesset area, South-west Greenland; magnification × *8, XPL.*



71 Comb layers in dolerite dyke

Two types of comb-textured layer are present in these photographs: the first and third bands from the right consist of elongate branching olivine (now largely serpentinized) and plagioclase crystals; the second and fourth bands are pyroxenite dominated by complex, elongate, branching augite crystals with scarce plagioclase crystals in between. The margin of the dyke lies to the left. (See also **34**.)

Dolerite from North-west Skye, Scotland; magnification × *8, PPL and XPL.*

Comb layers in dolerite dyke (continued)

Orbicular texture (orbicular layering)

See p. 69 for definition and illustration. In connection with the group of textures being considered here, note that in some orbicules the concentric shells have elongate crystals *aligned* radially about the centre of the orbicule.

Intergrowth textures

In thin section the junction between two crystals may appear as a straight line, a simple curve, or a complex curve; in the third case the crystals interdigitate or interlock, possibly so intimately that they appear[1] to be embedded in one another. These interpenetrative patterns are all examples of *intergrowth textures*. Usually the crystals concerned are anhedral but one or both may be skeletal, dendritic or radiate. Seven varieties are distinguished here: (a) consertal texture; (b) micrographic texture; (c) granophyric texture; (d) myrmekitic texture; (e) intrafasciculate texture; (f) lamellar and blebby intergrowths; and (g) symplectite texture.

Consertal texture

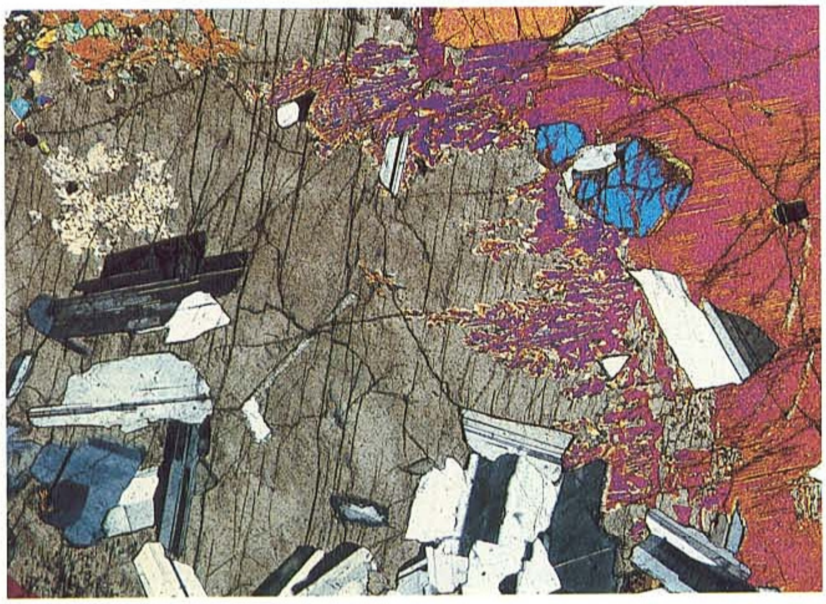
The boundary between two crystals involves interdigitations and hence appears to be notched or serrated in section (Iddings, 1909; Niggli, 1954).

[1] *The appearance of an interdigitating boundary between two crystals, A and B, depends on the extent of interpenetration and the direction in which the boundary is sectioned: some intersections may show the crystals meeting in a complex curve; others may show crystal A enclosed in B; others may show the converse; and yet others may show each enclosing the other.*

72 Consertal texture in granodiorite

This photograph of a quartz-rich portion of the rock shows several quartz crystals with intergrown boundaries. (See also **42**.)

Granodiorite from unknown source; magnification × 43, XPL.



73 Consertal intergrowth texture in gabbro

This picture illustrates an extreme example of intergrown boundaries between crystals; the participating crystals are all augites (purple, pale yellow, grey and orange).

Gabbro from Lower Zone a of the Skaergaard intrusion, East Greenland; magnification × 25, XPL.

Micrographic texture (or graphic, if visible with the naked eye)

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. (A micrographic intergrowth of quartz and alkali feldspar is also known as *micropegmatitic texture*.) A graphic intergrowth of pyroxene and nepheline is shown in **100**.

Granophyric texture

A variety of micrographic intergrowth of quartz and alkali feldspar which is either crudely radiate or is less regular than micrographic texture.

74 Graphic granite

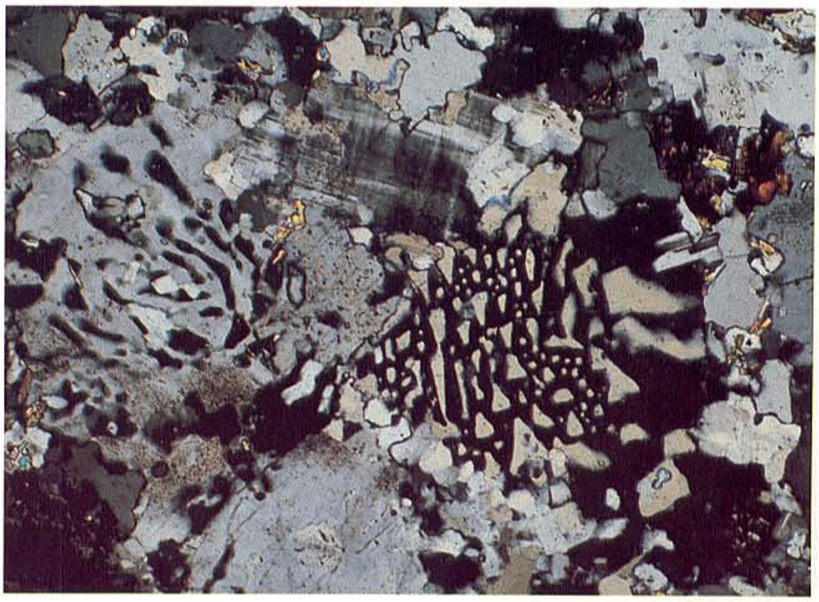
Photograph of a polished hand specimen of graphic-textured granite in which the dark material is smoky quartz and the light material is alkali feldspar.

Graphic granite from unknown locality; magnification × 3.

75 Micrographic texture in aplite

Two of the crystals in this view show an intimate micrographic intergrowth of quartz and alkali feldspar. In one (middle right of XPL photograph), the alkali feldspar is at extinction, and in the other (middle left) the quartz is at extinction. (The PPL photograph is deliberately defocussed to show the Becke line in the higher-relief mineral (quartz) when the objective lens is 'raised'.)

Micro-granite from Worcester, Massachusetts, USA; magnification × 60, PPL and XPL.



76 Micrographic and granophyric textures in microgranite

The photographs show several units of intergrown quartz and alkali feldspar; most are of micrographic type but some have a radiate arrangement (granophyric texture) at their margins. In the Scottish Hebridean igneous province, rocks like this one were formerly known as *granophyres* in allusion to their distinctive textures.

Microgranite from Eastern Red Hills of Skye, Scotland; magnification × 20, PPL and XPL.

77 Granophyric texture

In this rock, radiate intergrowths of quartz and alkali feldspar are arranged about euhedral, equant plagioclase crystals.

Microgranite from Skaergaard intrusion, East Greenland; magnification × 37, PPL and XPL.

Granophyric texture (continued)

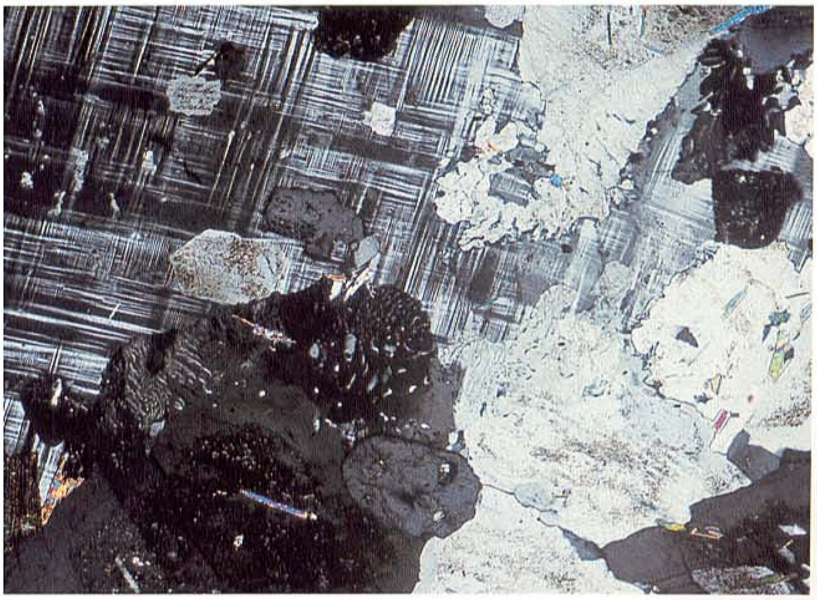
Myrmekitic texture

Patches of plagioclase intergrown with vermicular quartz. The intergrowth is often wart-like in shape and is commonly to be found at the margin of a plagioclase crystal, where it penetrates an alkali feldspar crystal. The texture could be regarded as a variety of symplectite texture (see p. 53).

78 Myrmekitic texture in granite

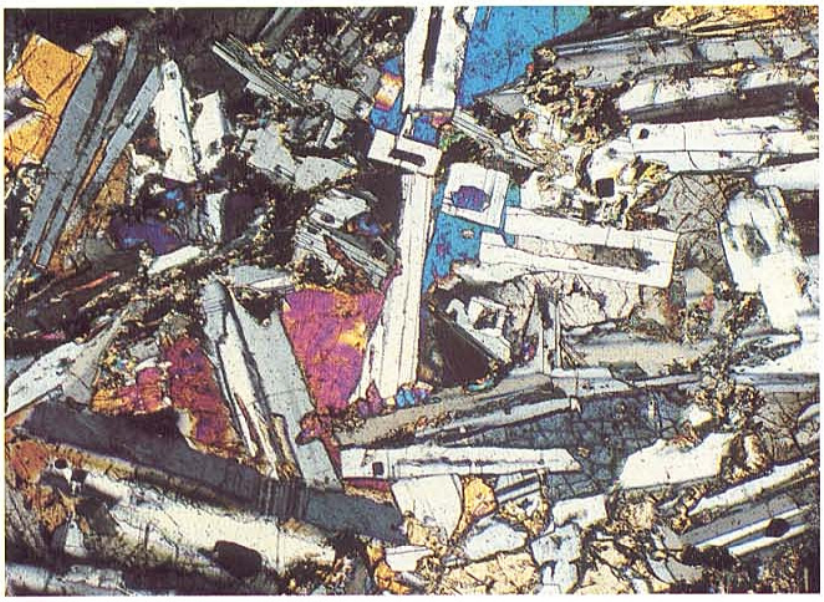
Much of the lower part of this photograph is occupied by an intergrowth of quartz and plagioclase: this forms embayments in the microcline crystal which occupies most of the upper part of the field of view.

Granite from Rubislaw quarry, Aberdeen, Scotland; magnification × 30, XPL.



Intrafasciculate texture

Hollow, columnar plagioclase crystals filled with pyroxene.



79 Intrafasciculate texture in dolerite

This medium-grained rock has an intergrowth texture in which the gaps in the columnar plagioclase crystals are occupied by augite.

Dolerite from Garbh Bheinn intrusion, Isle of Skye, Scotland; magnification × 72, XPL.

Lamellar and bleb-like intergrowths

Parallel lamellae, or trains of blebs, of one mineral, and all of the same optical orientation, are enclosed in a single 'host' crystal of another mineral. Well-known examples involve lamellae or blebs of sodium-rich feldspar in a host of potassium-rich feldspar (*perthitic texture*); the converse (*antiperthitic texture*); and lamellae or blebs of one pyroxene in a host of another (e.g. augite in orthopyroxene or *vice versa*, and pigeonite in augite or *vice versa*). Other examples include: ilmenite lamellae in (ulvöspinel-magnetite) solid-solution crystals; metallic iron rods, and blebs in lunar plagioclases; plagioclase lamellae in pyroxene; amphibole lamellae in pyroxene; and chrome-magnetite lamellae in olivine. Careful examination may reveal lamellae of more than one orientation and scale and sometimes even fine lamellae within coarse lamellae, i.e. multiple generations of lamellae.

Lamellar and bleb-like intergrowths are often attributed to exsolution of the lamellae and blebs from the host crystal (i.e. solid-state reaction) and the genetic term *exsolution texture* is often therefore applied to them. However, laboratory experiments in which antiperthite formed from a melt as a result of co-crystallization of two feldspars, and others in which ilmenite lamellae formed in pyroxene during co-crystallization of the two phases from the melt, highlight the danger of uncritical use of the term *exsolution texture*.

80 Microperthitic textures

Three examples of perthites are represented here.
The first photograph shows fairly broad sinuous lamellae of albite traversing the tartan twinning of a microcline crystal.

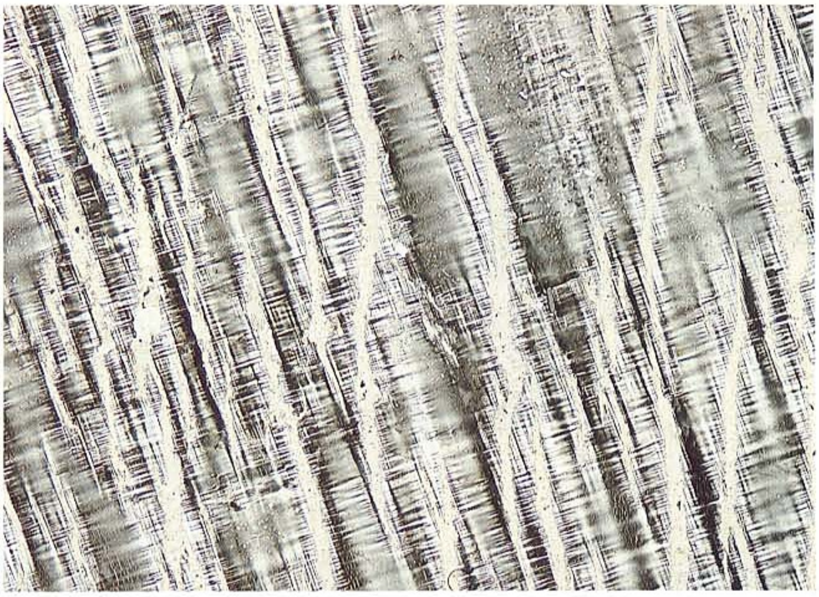
Specimen from pegmatite, Topsham, Maine, USA; magnification × 16, XPL.

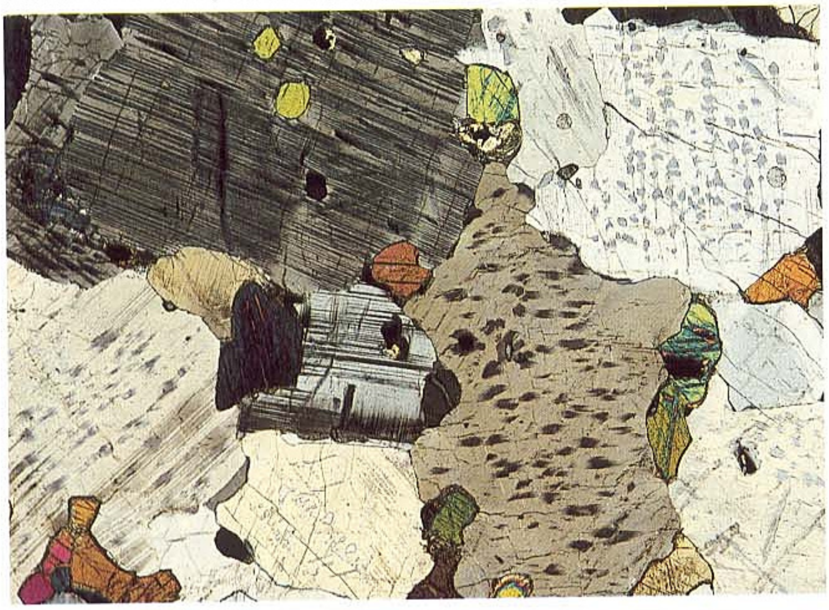
The second photograph shows narrow albite lamellae forming a braided pattern in an orthoclase host (upper centre).

Specimen from granite, Ratagan, Scotland; magnification × 34, XPL.

The third photograph shows two large areas of the field of view with different orientations of crystals consisting of an intimate intergrowth of a potassium-rich feldspar and a sodium-rich feldspar. In each case the darker grey colour represents the potassium-rich feldspar. The proportions of the two materials are approximately equal so that neither is clearly the host – in this case the feldspar intergrowth is known as a *mesoperthite*.

Specimen of nepheline syenite from Langesund fjord, Norway; magnification × 32, XPL.





81 Antiperthitic texture in tonalitic gneiss

The poorly aligned, bleb-like inclusions in the plagioclases in this rock are potassium-rich feldspar of intermediate structural state (i.e. orthoclase). It is likely that the texture formed in this rock during prolonged high-grade regional metamorphism rather than during crystallization of magma.

Tonalitic gneiss from Scourie, North-west Scotland; magnification × 20, XPL.

82 Lamellar intergrowths of two pyroxenes in gabbro

The host crystal to the lamellae is an orthopyroxene (close to extinction); it contains two kinds of lamellae – relatively broad and continuous ones of augite, and narrower discontinuous ones of augite, inclined to the broad variety.

Gabbro from Bushveld intrusion, South Africa; magnification × 9, XPL.

83 Bleb-like intergrowth of augite in orthopyroxene in olivine gabbro

In this sample blebs of augite are embedded in an orthopyroxene host, forming an 'emulsion-like' texture. Though the blebs are irregular in shape they have a common elongation direction and the same optical orientation.

Olivine gabbro from Lower Zone b of the Skaergaard intrusion, East Greenland; magnification × 27, XPL.

Symplectite texture

An intimate intergrowth of two minerals in which one mineral has a vermicular (wormlike) habit.

84 Symplectite of iron ore and orthopyroxene

Iron ore (probably ilmenite) and a small crystal of orthopyroxene are intimately intergrown in a vermicular fashion in the spaces between plagioclase, augite and ilmenite crystals.

Olivine gabbro from Lower Zone b of the Skaergaard intrusion, East Greenland; magnification × 72, PPL.

85 Fayalite-quartz symplectite

Between the opaque mineral (ilmenite) and the silicate minerals in this rock, there exists a complex boundary consisting of a narrow rim of fayalite immediately adjacent to the opaque mineral, which in places abuts onto a symplectite intergrowth of fayalite and quartz. The fayalite in the intergrowth and that which rims the ilmenite have the same optical orientation.

Ferrogabbro from Upper Zone b of Skaergaard intrusion, East Greenland; magnification × 32, PPL and XPL.

Fayalite-quartz symplectite (continued)

Radiate textures

Radiate textures are those in which elongate crystals diverge from a common nucleus. They are most frequently found in fine-grained rocks, but not exclusively; for example, **34**, **35**, **36**, **70** and **71** show large branching pyroxene, plagioclase and olivine crystals in fan-shaped radiate arrangements. A remarkably large number of terms exists to describe the various patterns, including: fan, plume, spray, bow-tie, spherical, sheaf-like, radiate, radial, axiolitic, spherulitic and variolitic. All except the last three (which are defined and illustrated here), are of self-evident meaning.

Spherulitic texture

Spherulites are approximately spheroidal bodies in a rock: they are composed of an aggregate of fibrous crystals of one or more minerals radiating from a nucleus, with glass or crystals in between. The acicular crystals may be either single, simple fibres or each may have branches along its length; any branches may or may not share the same optical orientations as their parents. 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, resulting in an intergrowth texture. Should the spherulite have a hollow centre it is known as a *hollow spherulite*, and if it comprises a series of concentric, partially hollow shells, the term *lithophysa* is used.

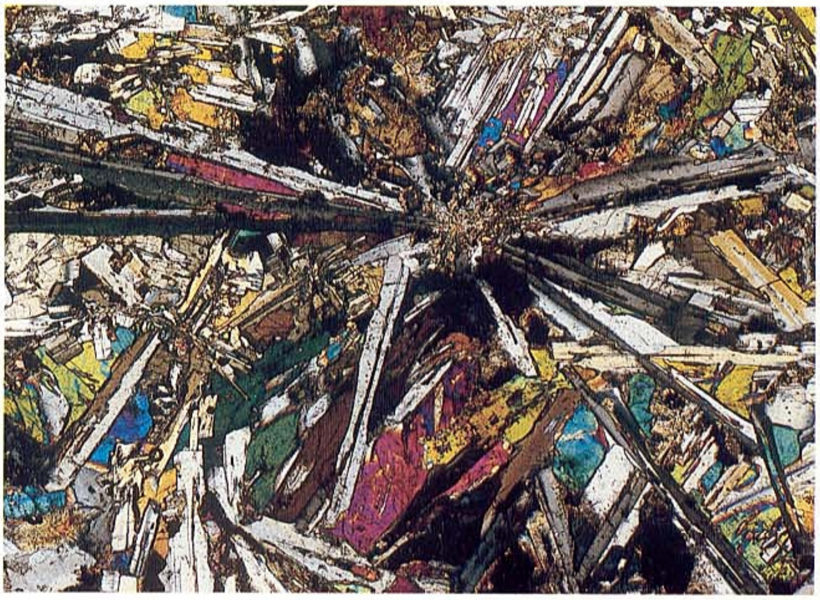
Axiolites differ from spherulites in that radiating fibres extend from either end of a linear nucleus (i.e. from a small acicular crystal) rather than a point. They could be regarded as a variety of overgrowth texture (p. 58), as indeed could those spherulites which grow about visible crystals rather than on submicroscopic nuclei (e.g. **88**).

86 Plagioclase spherulite in dolerite

This spherulite comprises approximately twenty elongate crystals of plagioclase, each having a different optical orientation. It is an 'open' spherulite, in the sense that there is much space between individual plagioclase crystals; the spaces are occupied by coarse augite, columnar plagioclases not related to the spherulite, and smaller spherulites.

Dolerite from Garbh Bheinn intrusion, Skye, Scotland; magnification × 32, PPL and XPL.

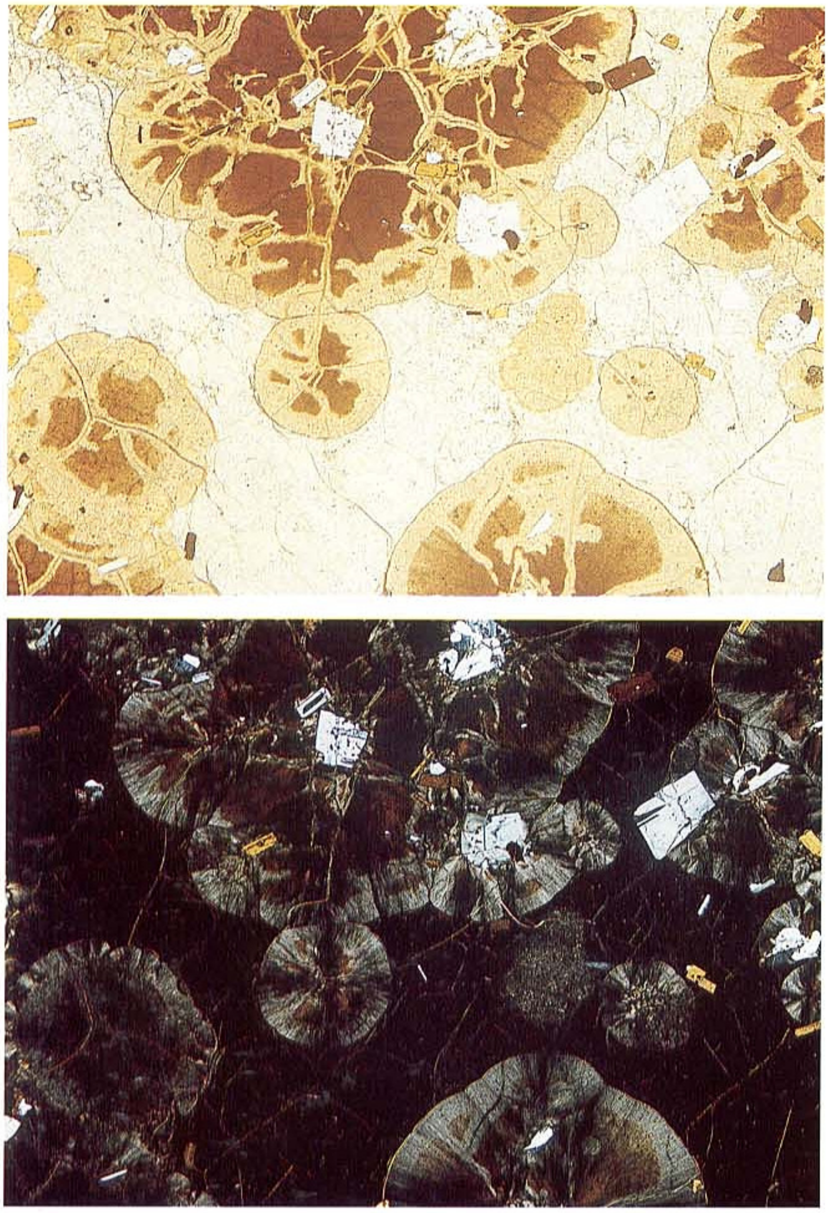
See 126 for a similar example.



87 Spherulite in rhyolite

The spherulite at the centre of this photograph consists of a dense mass of very fine intergrown needles of both quartz and alkali feldspar radiating from a common nucleus. Above and below, the spherulite abuts onto others, whereas to left and right there is glass.

Rhyolite from Hlinik, Hungary; magnification × 27, XPL.



88 Compound spherulites in rhyolite

Both single and compound, or clumped, spherulites are surrounded by glass in this photograph. The spherulites enclose microphenocrysts of plagioclase and biotite. The colour variation in the spherulites is caused by variations in density of fibres.

Rhyolite from Glashutte, Hungary; magnification × 12, *PPL and XPL.*

Variolitic texture

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 ore. This texture differs from spherulitic in that no discrete spherical bodies are identifiable; in fact, each fan as seen in thin section is a slice through a conical bundle of acicular crystals.

89 Variolitic olivine dolerite

The olivine phenocrysts in this sample are set in a groundmass consisting of many fans of diverging plagioclase needles with augite crystals in the interstices. Note how all the fans diverge from lower right to upper left, indicating progressive solidification in this direction. Note also the branching character of some of the plagioclase fibres.

Olivine dolerite from Skye, Scotland; magnification × 27, PPL and XPL.

90 Radiate intergrowth of plagioclase and augite in dolerite

This unusual radiate texture occupying the centre of the view consists of two, mutually perpendicular, columnar, plagioclase crystals, the elongate gaps in which have a radiate distribution; these gaps are occupied by a *single* augite crystal, rather than by many crystals. This kind of radiate texture differs from a spherulite; it is more akin to skeletal growth (p. 20).

Dolerite from Ingia intrusion, West Greenland; magnification × 27, PPL and XPL.

Radiate intergrowth of plagioclase and augite in dolerite (continued)

Overgrowth textures

This term applies to textures in which a single crystal has been overgrown either by material of the same composition, or by material of the same mineral species but different solid-solution composition, or by an unrelated mineral. There are three types: (a) skeletal and dendritic overgrowths; (b) corona texture; and (c) crystal zoning.

Skeletal or dendritic overgrowths

Porphyritic rocks with a glassy or very fine-grained groundmass may show delicate fibres or plates extending from the corners or edges of the phenocrysts. The overgrowth and the phenocryst need not be the same mineral.

91 Overgrowth textures in rhyolitic pitchstone

The faces of the phenocrysts of alkali feldspar and magnetite in this glassy rock have acted as locations for nucleation of dendritic overgrowths of (?) alkali feldspar. Dendritic crystallites are also present in the glassy groundmass.

Pitchstone from Arran, Scotland; magnification × 31, PPL.

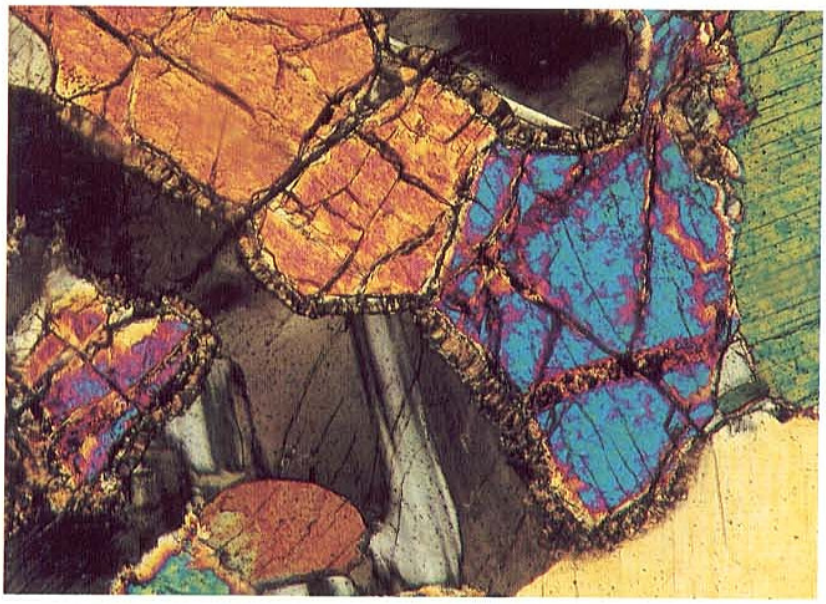
Corona texture

A crystal of one mineral is surrounded by a rim, or 'mantle', of one or more crystals of another mineral, e.g. olivine surrounded by orthopyroxene, or biotite surrounding hornblende. Such relationships are often presumed to result from incomplete reaction of the inner mineral with melt or fluid to produce the outer one and for this reason the equivalent genetic terms *reaction rim* and *reaction corona* are frequently used. The special term *Rapakivi texture* is used to describe an overgrowth by sodic plagioclase on large, usually round, potassium-feldspar crystals, and *kelyphitic texture* is used for a microcrystalline overgrowth of fibrous pyroxene or hornblende on olivine or garnet.

92 Corona texture

In the centre of the photographs a twinned and zoned augite crystal is mantled by green hornblende of non-uniform width.

Quartz diorite from Mull of Galloway, Scotland; magnification × 43, PPL and XPL.



93 Corona texture

Between olivine and plagioclase crystals in this rock there is a 0.02–0.06 mm wide corona which consists of either one or two zones: (1) radially oriented, fibrous, brown hornblende; or (2) colourless pyroxene (see middle of photograph) surrounded by radially oriented, fibrous, brown hornblende. Analysis of the pyroxene suggests that it is a submicroscopic intergrowth of augite and orthopyroxene.

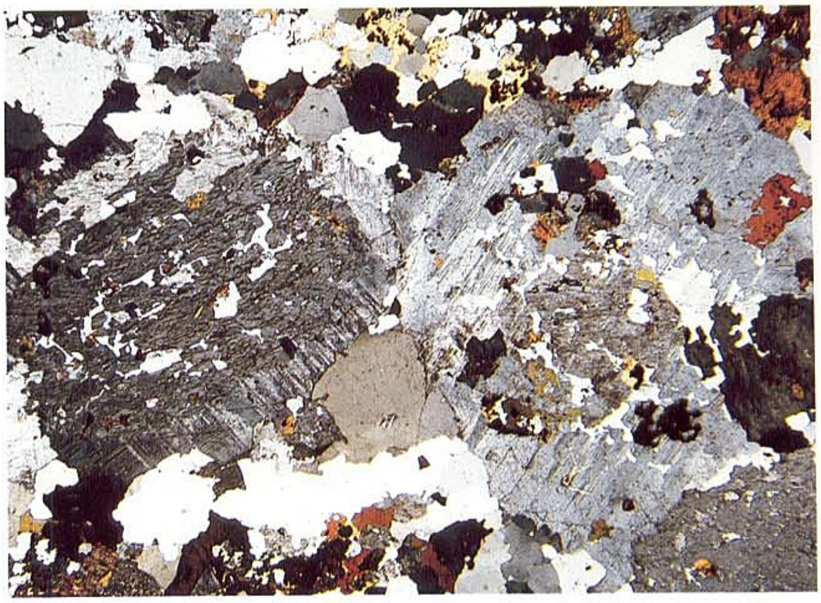
Olivine gabbro from Thessaloniki, North Greece; magnification × 100, PPL and XPL.

94 Rapikivi texture

The texture is of large, round potassic feldspars, some of which are mantled by sodic plagioclase rims, others have no plagioclase rims. In the first photograph, which is of a polished hand specimen, the plagioclase rims have a greenish colour contrasting with the pink potassic feldspar. The second photograph is of a thin section of the same rock.

Granite from Eastern Finland; magnification × 2 (first photo); × 3, XPL (second photo).

Rapakivi texture (continued)



Crystal zoning

One or more concentric bands in a single crystal are picked out by lines of inclusions (**95**) or by gradual or abrupt changes in solid-solution composition of the crystal. As regards the latter type of zoning, a large number of patterns are possible, the commoner ones being illustrated graphically and named below, using plagioclase as an example.

Normal versus reverse zoning
These terms specify the general trend of solid-solution composition from core to rim. 'Normal' indicates high-temperature component→low-temperature component (e.g. An-rich plagioclase→Ab-rich plagioclase, see Fig. C) and 'reverse' indicates the opposite.

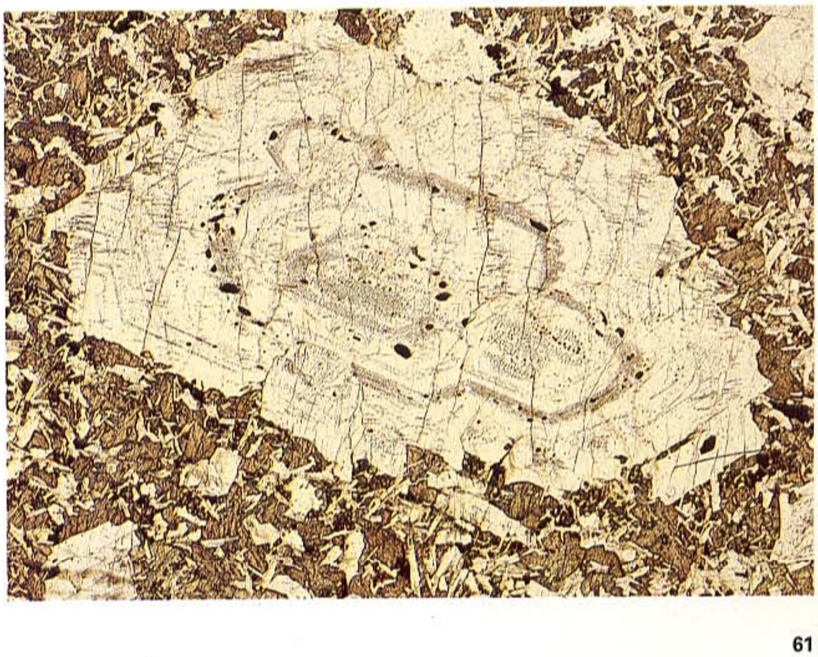
Continuous[1] *versus discontinuous*[1] *zoning*
These terms indicate respectively a gradual or an abrupt change in composition. Figure C shows examples of *continuous normal zoning* and Fig. D an example of *discontinuous normal zoning*. Continuous and discontinuous zoning may alternate (Fig. E).

[1] *These terms are not the same as* continuous reaction *and* discontinuous reaction *of crystals with melt.*

95 Zonal arrangement of melt inclusions in plagioclase

Several stages in the growth of this plagioclase crystal can be picked out by the bands of minute melt inclusions. (See also **45**.)

Feldspar-phyric dolerite from Isle of Skye, Scotland; magnification × 9, PPL.



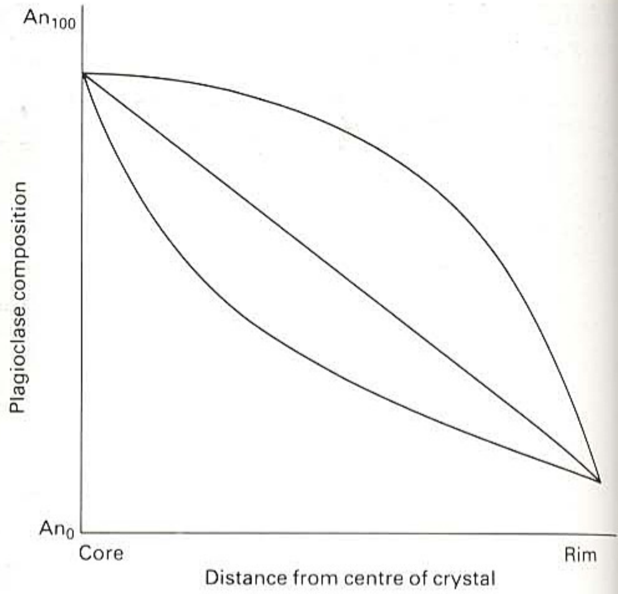


Fig. C Three examples of continuous normal zoning represented on a sketch graph

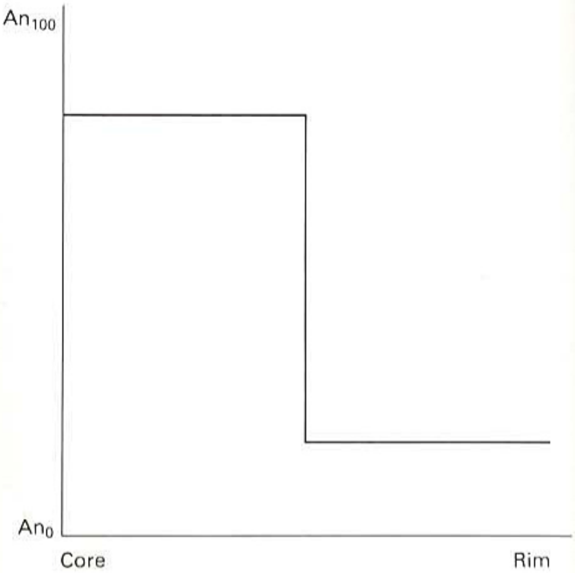


Fig. D Discontinuous normal zoning

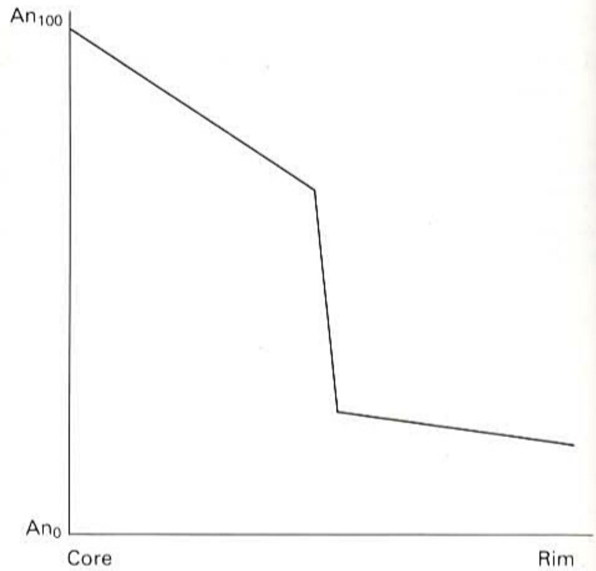


Fig. E Combined continuous and discontinuous normal zoning

96 Zoned plagioclase

The central plagioclase phenocryst in this photograph is discontinuously zoned, having a homogeneous core mantled by a more sodic rim; the rim has continuous normal zoning resulting in variation of the extinction position on rotation of the microscope stage. The crystal is thus partly discontinuously and partly continuously zoned.

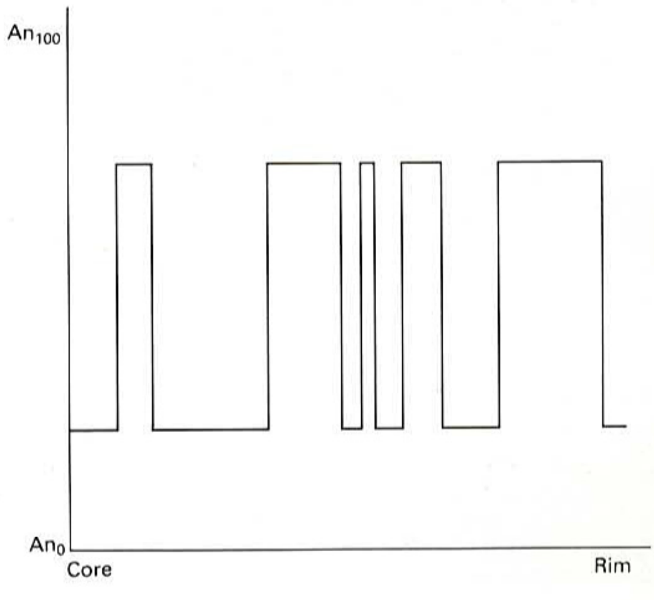
Dolerite from Isle of Skye, Scotland; magnification × 43, XPL.

Multiple zoning

This term is used for crystals having repeated discontinuous zones. If the zones show a rhythmic repetition of width, the pattern is known as *oscillatory zoning*. The overall compositional trend of the multiple zoning may be *normal* or *reverse* or *even* (in which there is no general trend from core to rim). Individual zones may be of uniform or variable composition, such that the zoning pattern on a composition-distance graph is square wave, step-like, saw-tooth, curved saw-tooth, or some combination of these (see Figs. H–J). However, these are details which only *very* careful and lengthy optical examination or electron-probe microanalysis would reveal.

The reader should appreciate that the sketches in figs. C–J are all idealized and that in real crystals the oscillations will be less uniform; furthermore multiple or oscillatory zoning may only occupy part of a crystal, the remainder perhaps being homogeneous or continuously zoned.

Fig. F Multiple, even zoning



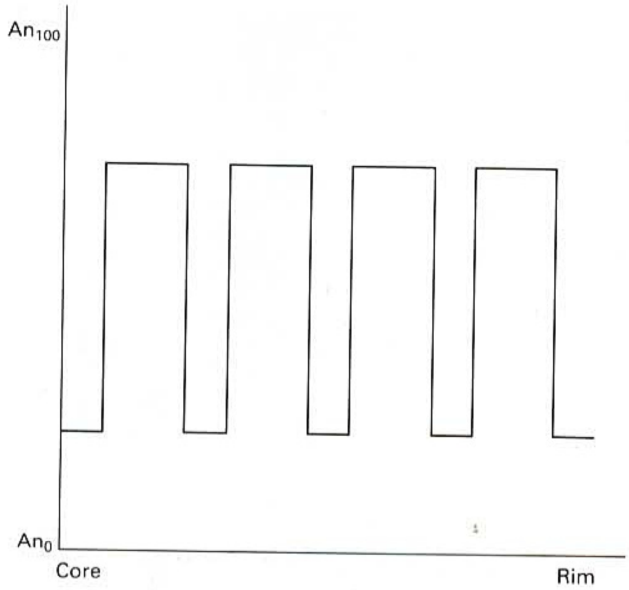


Fig. G Oscillatory, even zoning

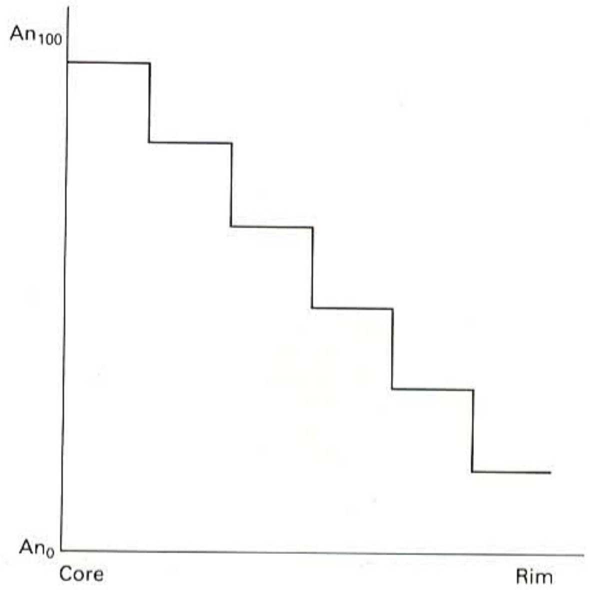


Fig. H Oscillatory, normal zoning: step-like

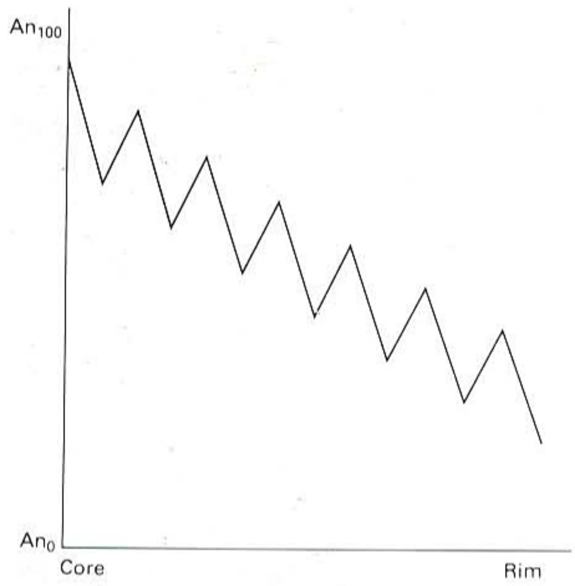
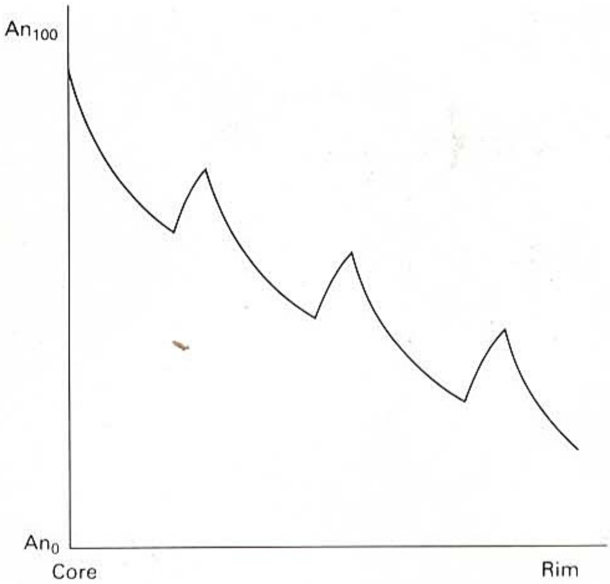


Fig. I Oscillatory, normal zoning: saw-tooth

Fig. J Oscillatory, normal zoning: curved saw-tooth

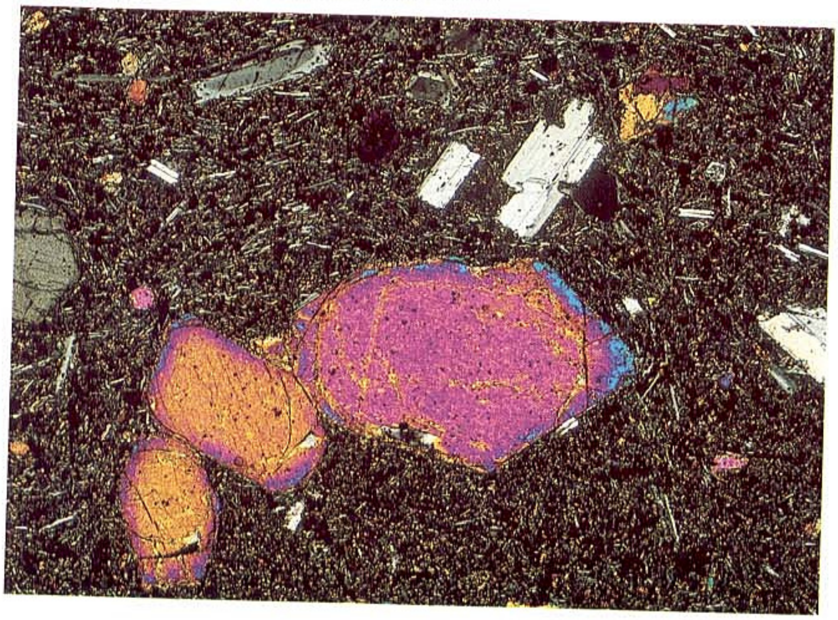


Convolute zoning
This is a variety of multiple zoning in which some of the zones are erratic and have non-uniform thickness (see **97**).

97 Zoned plagioclases

This photograph illustrates several styles of zoning in the two plagioclases comprising the glomerocryst. Combinations of discontinuous, oscillatory and convolute zoning are present, together with zoning picked out by a band of melt inclusions near the margins of both crystals.

Porphyritic andesite from Hakone volcano, Japan; magnification × 24, XPL.



98 Zoned olivines

Zoning is not confined to feldspar crystals. Here, each of the three olivine phenocrysts in the cluster has a homogeneous core surrounded by a continuously normal-zoned mantle, as indicated by the variation in interference colours.

Ankaramite from Mauna Kea, Hawaii; magnification ×43, XPL.

Sector (or hourglass) zoning

As seen in thin section, this ideally takes the form of four triangular segments (sectors) with a common apex (Fig. K(b)). Opposite sectors are chemically identical, whereas adjacent ones differ in composition (though possibly only slightly) and hence in optical properties. Each sector may be homogeneous or show continuous or discontinuous or oscillatory, normal or reverse or even zoning. In three dimensions the sectors are pyramid shaped (Fig. K(a)), and, depending on the orientation of the crystal with respect to the plane of a thin section, a variety of patterns may be seen in thin section (Fig. K(b)–(f)). If the sector boundaries are curved, the pattern can resemble that of an hourglass (Fig. K(g)). Sector zoning is a common feature of pyroxenes in alkali-rich basic and ultrabasic rocks. It has also been seen in plagioclases in a few quickly cooled basalts.

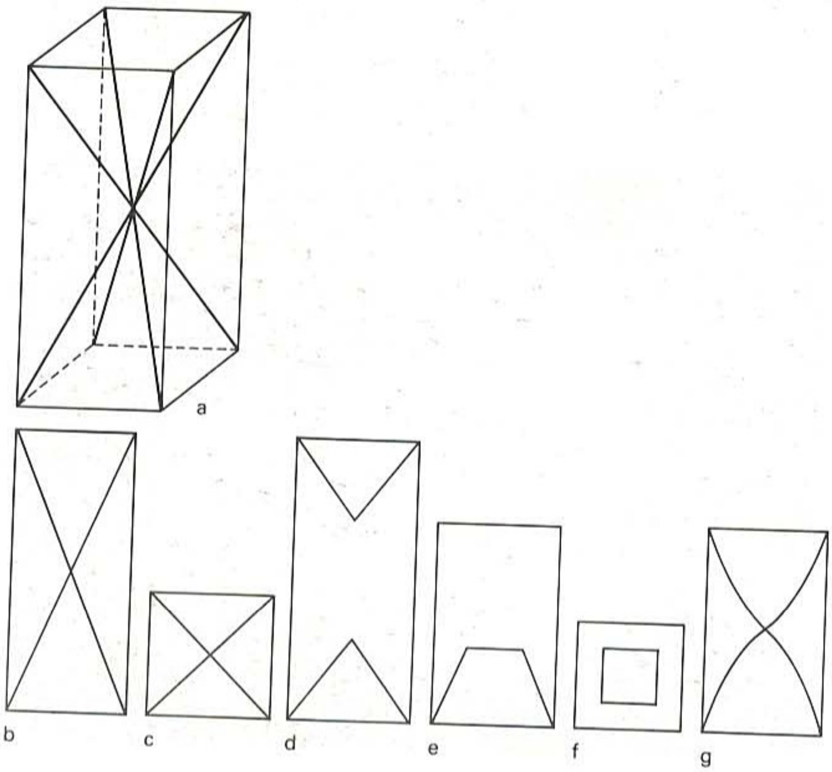
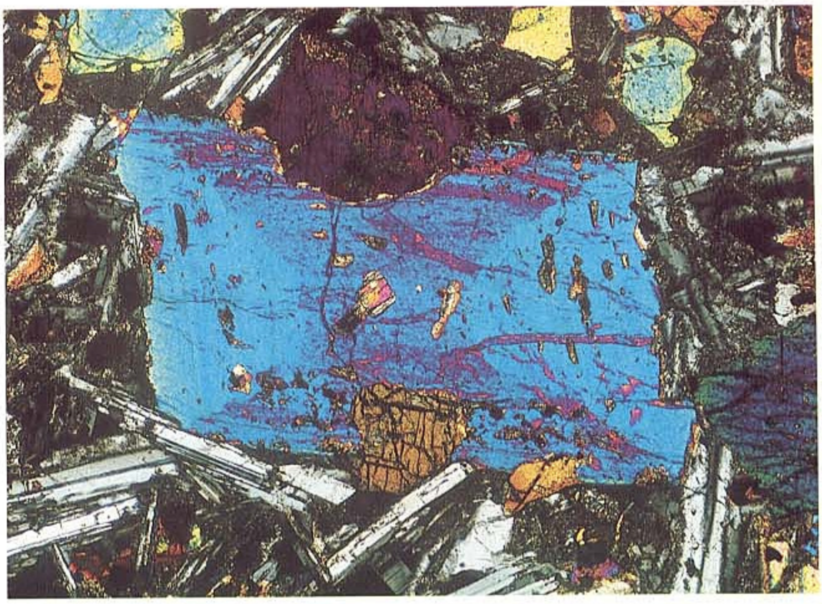


Fig. K Schematic representations of sector zoning

99 Sector-zoned augite

The picture shows a simple sector-zoned augite phenocryst containing elongate melt inclusions; the crystals partially enclosed by two of the sectors are olivines.

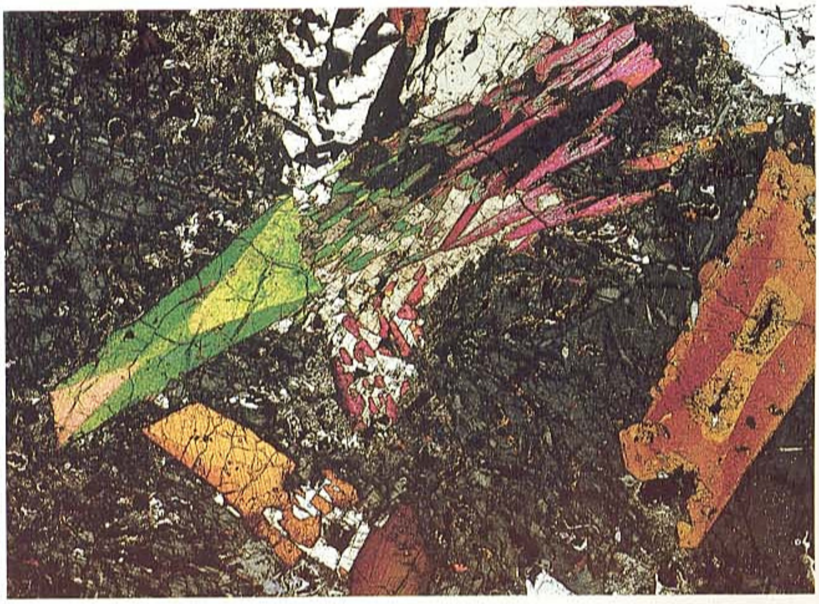
Essexite from Crawfordjohn, Scotland; magnification × 40, XPL.

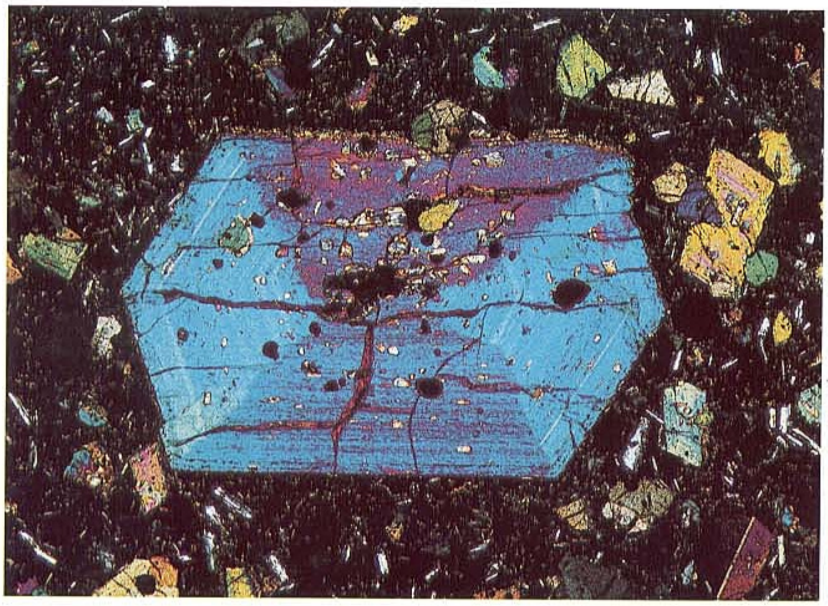


100 Sector-zoned pyroxenes

Two sector-zoned titanaugite crystals are illustrated in these photographs; that on the left is complicated by forming at one end a graphic intergrowth with nepheline and leucite; the other crystal has an intriguing figure-8-shaped core, with a discontinuous, sector-zoned mantle.

Melanocratic nepheline microsyenite from Vogelsberg, West Germany; magnification × 7, PPL and XPL.

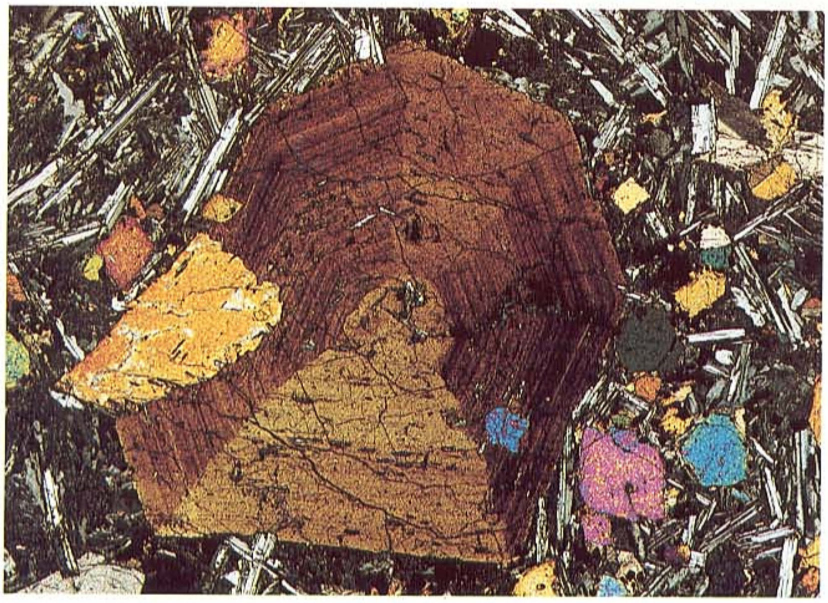




101 Oscillatory- and sector-zoned, inclusio bearing pyroxene

The augite phenocryst occupying most of this photog is sector-zoned and each sector displays oscillatory zon Inclusions of nepheline, augite and magnetite are ranged in trains parallel to the oscillatory zones.

Tephrite from Monte Vulturi, Malfi, Italy; magnifica × 27, XPL.



102 Oscillatory- and sector-zoned pyroxene

Unlike the pyroxenes in **99 and 100**, this sector-zon pyroxene has some sectors bounded by more than o face, e.g. the sector on the right is terminated by t faces, and that on the left by three faces. The crystal e closes plagioclase laths, an olivine (blue colour) and pyroxene crystal (orange colour).

Essexite from Crawfordjohn, Scotland; magnification × 2 XPL.

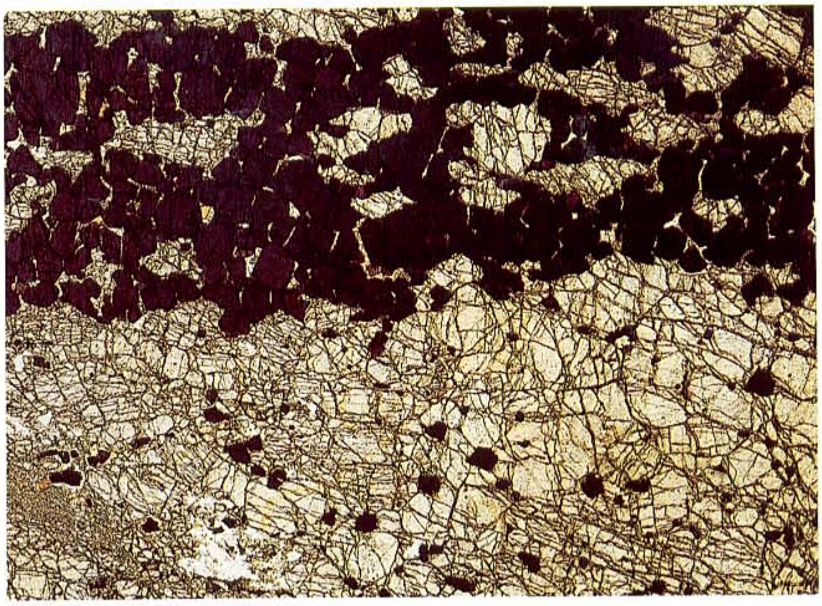
Banded textures (banding)

Textures of this type involve two, or more, narrow (up to a few centimetres), sub-parallel bands in a rock which are distinguishable by differences in texture, and/or colour and/or mineral proportions. The term *layering* is also used by petrologists; while it includes banded texture, it is also used for larger scale stratification. An example of banded texture due to textural differences is illustrated in **5**, and **103** and **104** show examples resulting from extreme differences in mineral proportions.

103 Olivine and chrome-spinel banding (or layering)

The photograph shows two bands, one rich in olivine, with scarce disseminated chrome-spinel crystals, and the other rich in equant chrome-spinel crystals with scarce interstitial olivine.

Banded dunite-chromitite from Skye, Scotland; magnification × 11, PPL.



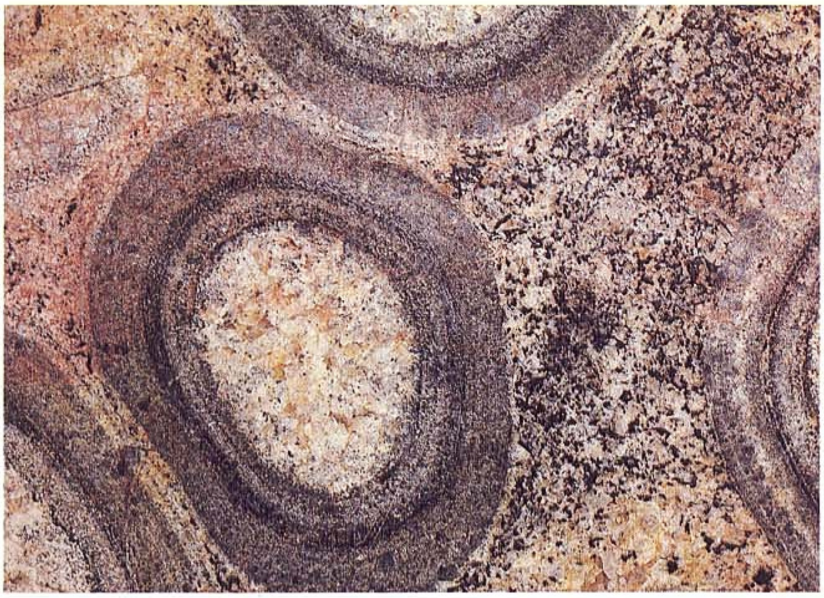
104 Anorthosite-chromitite banding (or layering)

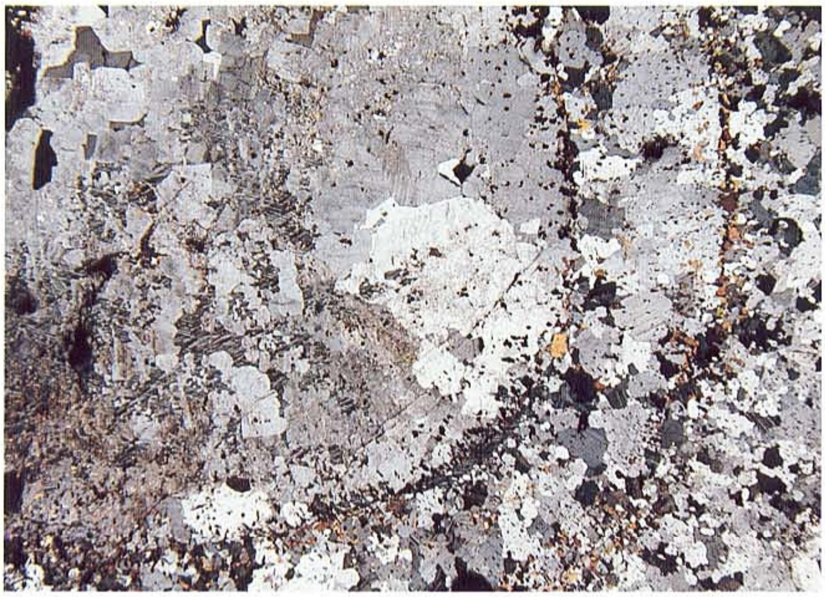
This hand-specimen photograph shows alternating bands of anorthosite (white) and chromitite (black). The yellowish-brown crystals in the anorthosite are enstatite and the black particles are single crystals and glomerocrysts of chromite.

Banded anorthosite-chromitite from Critical Zone of the Bushveld intrusion, South Africa; magnification × 2.

Comb layering, orbicular texture, ocellar texture and eutaxitic texture

Comb layering (see p. 44, **70** and **71**) and *orbicular texture* (**105**) are particularly exotic kinds of banding. In the latter, 'orbs' consist of concentric shells of rhythmically alternating mineral constitution. Within the shells the texture may either be granular or elongate crystals may be radially arranged. 'Orbs' may reach a few tens of centimetres in diameter. A further variety of banded texture, *eutaxitic*, occurs in some tuffs and ignimbrites and consists of a regular alignment of flattened glassy fragments (**8b**).





105 Orbicular monzodiorite

The first photograph shows the texture in a hand specimen. The arrangement of the concentric darker bands about the lighter coloured, homogeneous nuclei is well displayed. The second photograph shows the core and a few inner bands of one orbicule in thin section. The bands can be seen to differ from one another in their contents of biotite and alkali feldspar, and in their grain size.

Monzodiorite from the Island of Suuri Lintusaari, Ruokolahti, S.E. Finland; magnification × 1 (first photo) × 3, and XPL (second photo).

Cavity textures

These are a collection of textures which feature either holes in the rock or likely former holes which are now partly or completely filled with crystals.

Vesicular texture

Round, ovoid, or elongate irregular holes (vesicles) formed by expansion of gas, in a magma.

Amygdaloidal texture

Former vesicles are here occupied, or partially occupied, by late-stage magmatic and/or post-magmatic minerals, such as carbonate, zeolites, quartz, chalcedony, analcite, chlorite, and/or, rarely, glass or fine groundmass. The filled holes are known as amygdales or amygdules.

Ocellar texture

Certain spherical or ellipsoidal leucocratic patches enclosed in a more mafic host are known as ocelli (singular ocellus). Unlike amygdales, the minerals filling an ocellus can normally all be found in the host rock; they may include any of: nepheline, analcite, zeolites, calcite, leucite, potassium feldspar, sodium feldspar, quartz, chlorite, biotite, hornblende and pyroxene, or even glass, and the minerals are commonly distributed in a zonal arrangement (**109a**). Often, platy and acicular crystals in the host bordering an ocellus are tangentially arranged (as in **109b**) but sometimes project into the ocellus. Ocelli are normally less than 5 mm in diameter but may reach 2 cm. Their origin has been ascribed on the one hand to separation of droplets of immiscible liquid from magma, and on the other hand to seepage of residual liquid or fluid into vesicles.

Miarolitic texture

These are irregularly shaped cavities (druses) in plutonic and hypabyssal rocks into which euhedral crystals of the rock project.

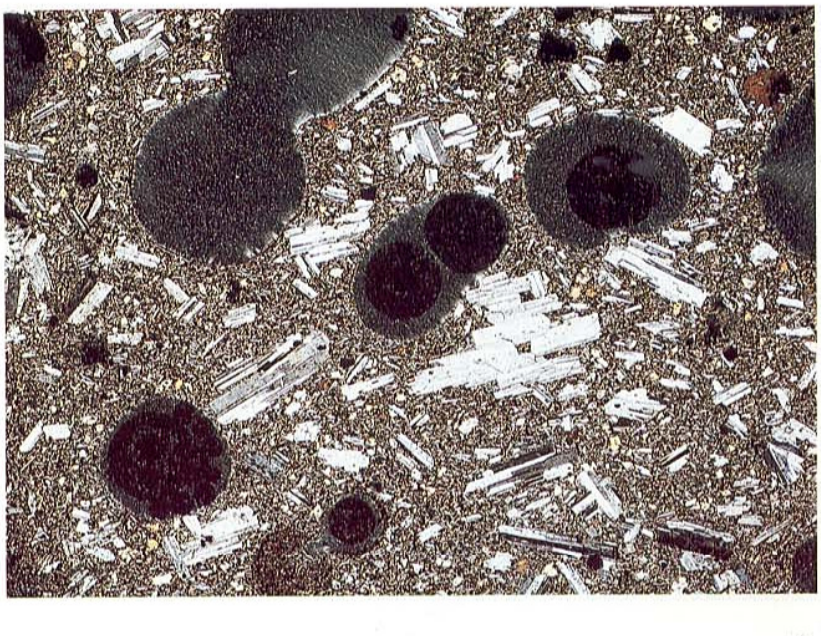
Lithophysa (or stone-ball)

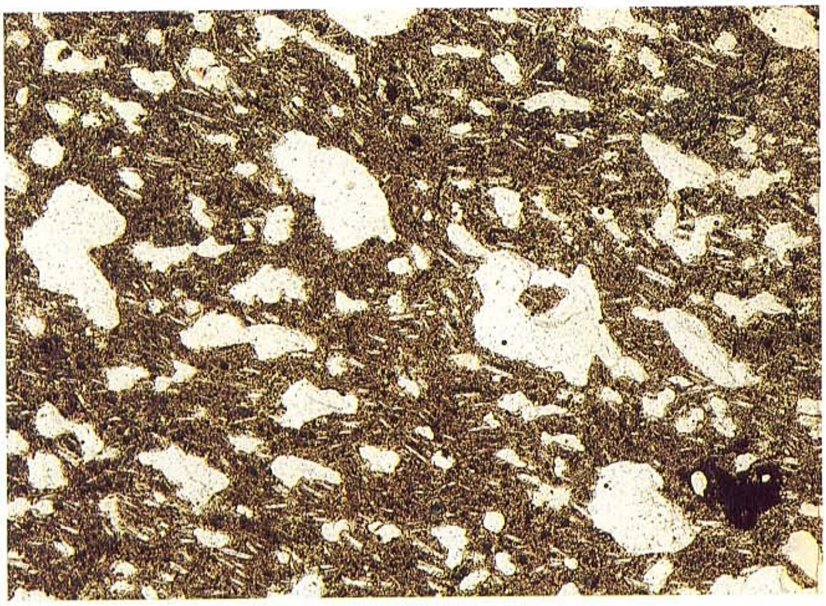
This is the term given to a sphere consisting of concentric shells with hollow interspaces.

106 Vesicular feldspar-phyric basalt

Large subspherical gas cavities are randomly distributed in this volcanic rock. Note the two vesicles at the top left which have coalesced.

Basalt from Mount Fuji, Japan; magnification × 7, PPL and XPL.





107 Vesicular trachyte

Irregularly shaped, elongate vesicles are streaked out through this trachyte; the columnar feldspars show a weak alignment in the same direction.

Trachyte from the Auvergne, France; magnification × 12, PPL.

108 Amygdaloidal basalt

The original vesicles in this volcanic rock are now filled with an aggregate of small calcite crystals; calcite is also present as pseudomorphs after olivine in the groundmass. Pyroxene and glass in the rock are altered to clay minerals.

Basalt from Matlock, Derbyshire, England; magnification × 11, PPL and XPL.
124 shows another amygdaloidal rock.

109 Ocellar texture

The upper photograph shows three ocelli in an olivine dolerite sill. Each ocellus is outlined by a more or less complete veneer of tiny magnetite crystals. At the base of the two largest ocelli the groundmass outside the ocelli extends across the magnetite veneer, except that olivine is absent inside the ocelli. The remainder of each ocellus comprises clear zeolite, turbid, very fine-grained zeolite and scarce magnetite. The left-hand ocellus also contains three elongate pyroxenes on the left side.

Non-porphyritic facies of an olivine dolerite sill, Igdlorssuit, Ubekendt Ejland, West Greenland; magnification × 12, PPL.

The second picture shows two ocelli, occupied by calcite, alkali feldspar, chlorite and fine-grained patches of clay (possibly altered glass). Laths of biotite are arranged tangentially about each ocellus.

Minette from Westmorland, England; magnification × 16, PPL.

The third photograph shows miarolitic (or drusy) cavity in granite. The slightly angular cavity shown in this hand specimen is occupied by crystals of alkali feldspar, quartz and biotite, some up to seven times larger than crystals of the same minerals in the rest of the granite.

Granite from Beinn an Dhubaich, Skye, Scotland; magnification × 1.5.

Introduction

In this Part are defined and illustrated many of the more common igneous rock types. For most types plane-polarized light and crossed-polarized light views are shown. In a few cases more than one example of the rock type is illustrated and in some we have used more than one magnification to show a particular feature of a rock. In addition, reference is made to Part 1 on textures where other examples of a specific rock type are illustrated. Thus, although gabbro may be represented by only two photographs in Part 2, we have noted where other photographs of gabbros appear in Part 1.

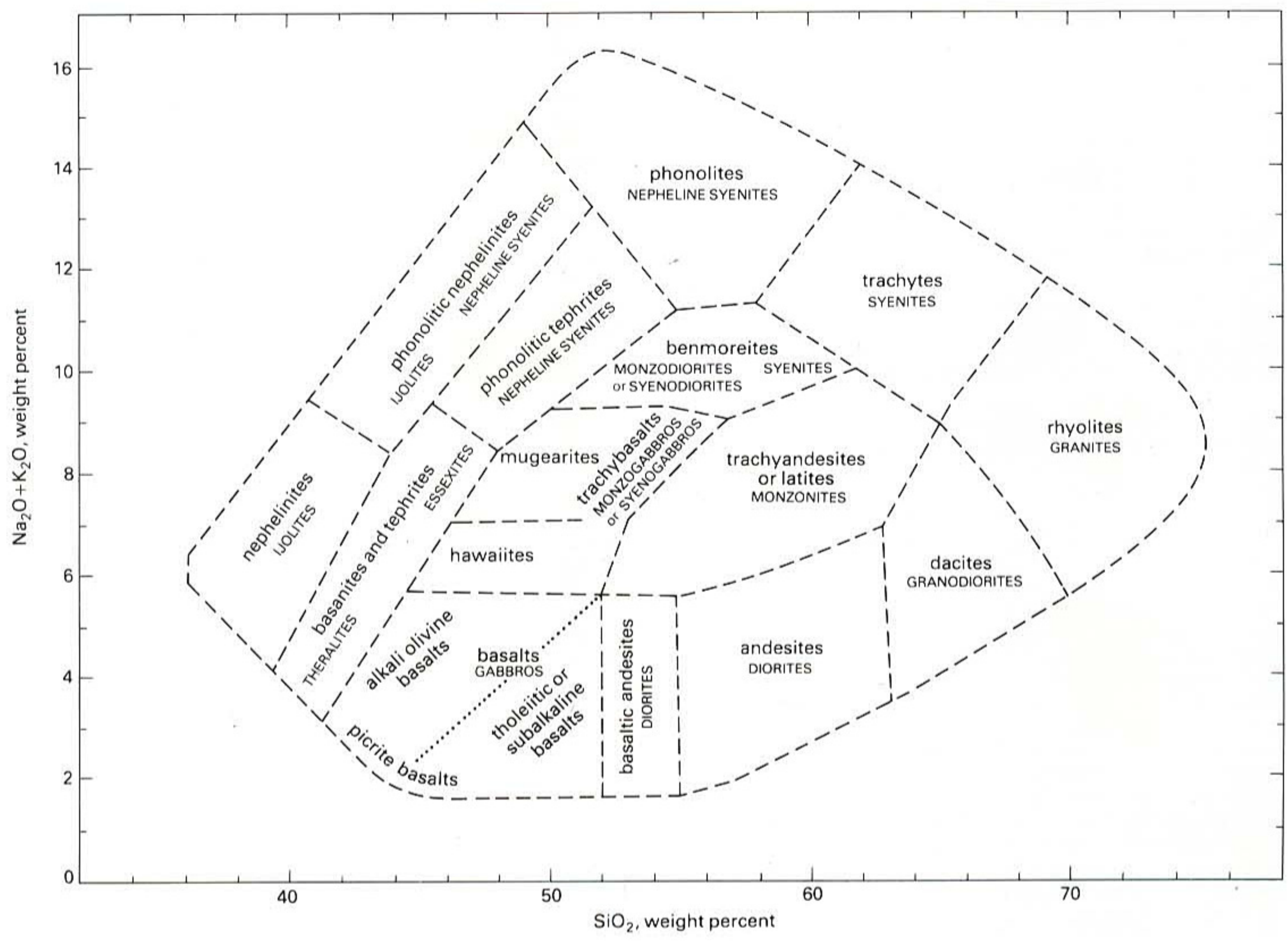
No two igneous rocks are identical in every respect but many are sufficiently alike that they can be illustrated by a few typical specimens. Thus, an olivine gabbro from one locality may be very similar to a large number of olivine gabbros from different parts of the world. We have therefore selected thin sections which are fairly typical of the rock type being illustrated.

The choice of which rocks to include has not been easy and undoubtedly we have omitted somebody's favourite. In Johannsen's *Descriptive Petrography of the Igneous Rocks* more than 540 different names for igneous rocks are listed in the index, not counting those names which have a prefix indicating the presence of a particular mineral or texture, thus we have counted *diorite* as one name rather than the eighteen varieties of diorite listed by Johannsen. Holmes listed about 340 different igneous rocks in his *Nomenclature of Petrology* but probably less than 150 of these are now in common use. We have selected about sixty of these names as rocks which the student may expect to see in an undergraduate course in geology. Certain rock types cannot be distinguished by a cursory examination of a thin section, much less from one or two photographs. Thus, for example, because *mugearites* and *hawaiites* cannot readily be distinguished from *alkali basalts* without a determination of the plagioclase composition, photographs of these rocks in thin section have not been included.

For each rock illustrated we have given what we consider to be the definition of

Fig. L Nomenclature of the commoner igneous rocks based on their silica and alkali contents.

Names of fine grained rocks are shown in small letters and those of coarse-grained rocks in capital letters (modified from Cox, Bell and Pankhurst, 1979)



the name and this is followed by a brief description of what is visible in the field of view of the photomicrographs. In addition to defining the rock illustrated, we have also defined, though not necessarily illustrated, the names of others which are subtypes and whose names are still in use (e.g. *granophyre* as a variety of *microgranite*). Agreement among petrologists on the characteristics of individual rock types is improving but will always be open to some differences of opinion. The names used and defined here are as near to consensus opinion as we can sense it, using the text of Holmes (1920), Johannsen (1931), Hatch *et al.* (1972), and Nockolds *et al.* (1978), the paper of Wilkinson (1968), and our own experience. In most of the definitions we have refrained from stating ranges for the amounts of the essential minerals, since agreement amongst petrologists on this is generally poor. On the other hand, the photographs give the reader an indication of whether a particular mineral is abundant or scarce in the rock.

The photograph descriptions are deliberately short because they are only of those features which can be seen in the photomicrographs. The complete petrographic description of a rock requires a careful examination of the whole slide at different magnifications and the student is likely to see much more than can be illustrated in one view at one magnification.

We have not set out a system for the classification of igneous rocks because this is beyond the scope of this book. The sequence in which the rocks are arranged is broadly ultrabasic and basic rocks first, followed by intermediate and then acid rocks, leaving the alkali-rich rocks to the end. Among the alkali-rich rocks are included a number of rare rock types, simply because they are rare and because the photographs are visually attractive. In any treatment of petrography those rocks traditionally grouped together under the name *lamprophyres* pose a problem because of their diverse characters. Although we have defined some of them, we have illustrated only three – *minette*, *alnöite* and *fourchite*.

While we have avoided a formal classification scheme of rocks, it is nonetheless helpful to have in the mind's eye a series of pigeon holes in which to locate rock names with respect to one another; otherwise the brain tends to succumb to the weight of names and refuses to accept more than a few of them. Figure L (p. 77), modified from Cox, Bell and Pankhurst (1979), is a chemical diagram on which many rock compositions may be plotted. The outermost line encloses most known volcanic rocks and the bounded area has been subdivided and the names of fine-grained and coarse-grained varieties of rocks indicated. The exact positions of the dividing lines and the names in each area are open to debate but, in general, most petrologists would accept this classification. While a great many of the rock types illustrated here are shown on Fig. L, a small proportion are not – e.g. the names on the figure apply to the chemical condition in which Na is less than K. Other names are used for rocks with the much less common condition of K greater than Na (e.g. *leucitite* instead of *nephelinite*).

In the photograph descriptions a number of terms are used which are worthy of definition here:

Essential minerals: those which are necessary to the naming of the rock. They need not be major constituents, e.g. a *crinanite* contains only a small percentage of essential analcite.

Accessory minerals: those which are present in such small amounts in a rock that they are disregarded in its definition, e.g. a small percentage of quartz in a gabbro. However, it may be useful in the name to note the presence of a particular accessory mineral in a rock and this can be done by adding the mineral name as a prefix, e.g. *quartz gabbro*.

Melanocratic, mesocratic and leucocratic (synonymous with *dark-*, *medium-*, and *light-coloured*): terms to indicate the colour index of a rock and hence the relative proportions of dark- to light-coloured minerals. The boundaries are at 66% and 33% dark minerals respectively. *Mafic* and *felsic* may be applied to rocks which are composed predominantly of mafic minerals (olivine, pyroxenes, amphiboles, biotite, opaque minerals) or of felsic minerals (quartz, feldspar and feldspathoid), respectively. They are thus less precise than the colour index terms. The term *ultramafic* is used for rocks with trivial amounts of, or no, felsic minerals. The rarely-used colour index term *hypermelanic* (90–100% dark minerals) is more or less equivalent to ultramafic.

Ultrabasic, basic, intermediate and acid: chemical terms to designate rocks with less than 45%, 45–52%, 52–66% and more than 66% by weight of SiO_2 respectively. Since a large SiO_2 content is reflected in a large amount of light-coloured minerals, these terms correspond approximately to the colour index ones.

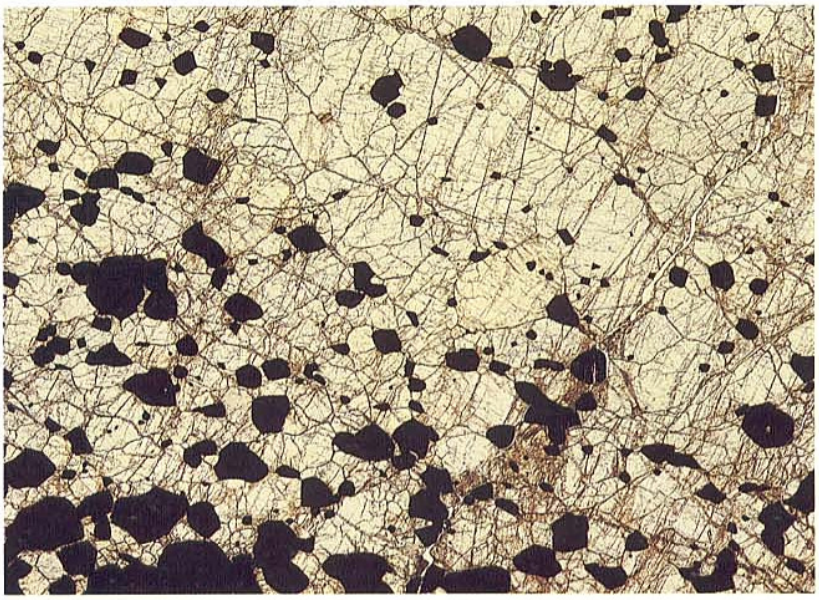
Micro as a prefix: most igneous rocks have fine-, medium-, and coarse-grained varieties. The fine- and coarse-grained varieties always have different names (e.g. basalt and gabbro). Medium-grained varieties may also have a distinct name (e.g. dolerite), or more often these days, the name for the coarse-grained rock is used and prefixed by *micro* (e.g. microgranite, microsyenite or even microgabbro).

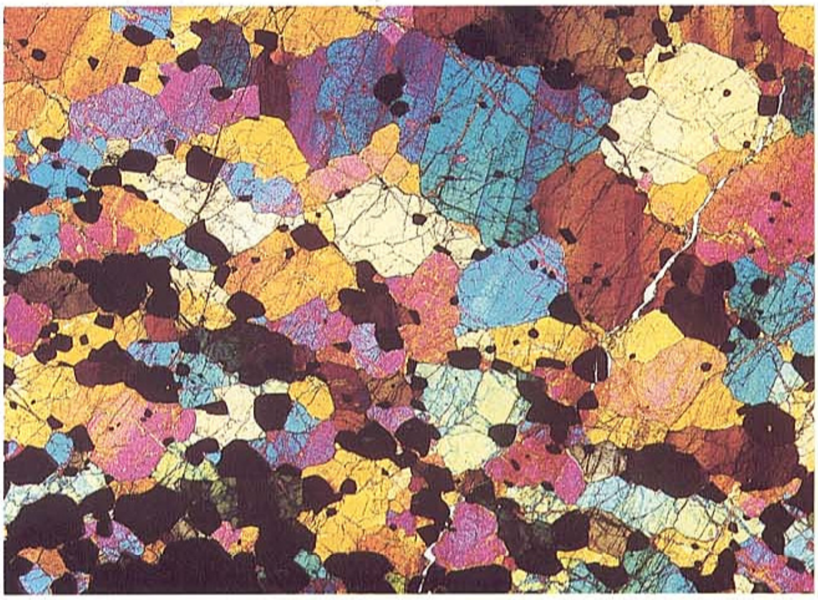
110
Dunite

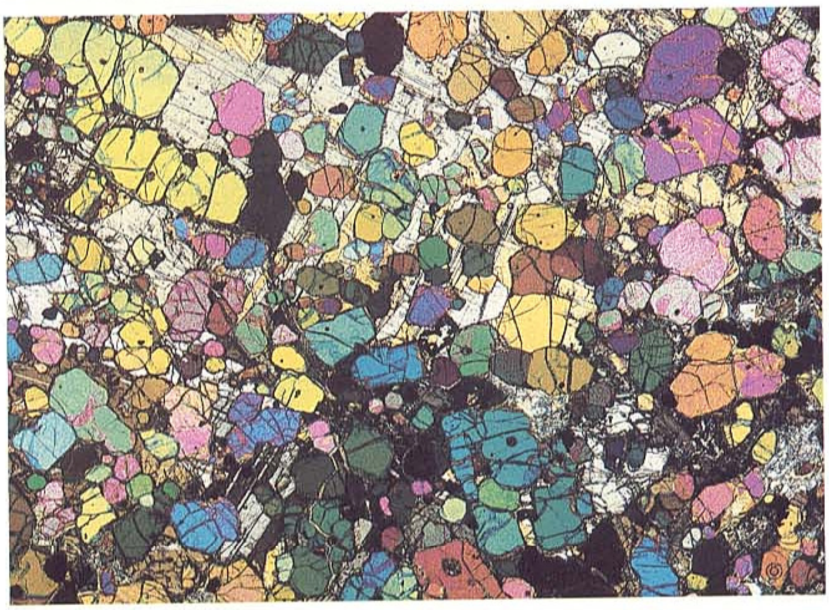
This is the name used for an ultramafic rock which consists almost entirely of olivine, often accompanied by accessory chrome spinel.

The granular-textured sample we have illustrated consists of only two minerals, olivine and a chromium-rich spinel. The spinel appears opaque in the PPL view but, with a more intense light than can be used for photography, it can be seen to have a deep brown colour. A banded structure is visible in the large crystal showing a blue interference colour to the right and slightly up from the centre of the photograph, and in two of the crystals showing brown interference colours to the right of the crystal showing blue. Above the blue crystal a crystal shows irregular extinction. These features indicate that the olivines are strained.

Dunite from Mount Dun, New Zealand; magnification × 16, PPL and XPL. Another dunite is illustrated in ***103***.







111

Peridotite

This term is used for coarse-grained olivine-rich rocks in which olivine is the dominant mineral but is less than 90% of the rock. Textbooks usually state that the accessory minerals are all ferromagnesians and that olivine-rich rocks containing plagioclase and pyroxene should be called *picrites* (or *troctolite*, if olivine and plagioclase only) (**41**, **51**). However, picrite is not much used now, and modern usage allows for plagioclase to be present in peridotite, as can be indicated by the terms *plagioclase* or *feldspathic peridotite* as in **51**. Peridotites containing both orthopyroxene and clinopyroxene (**113**) are often called *lherzolites*. If clinopyroxene is present and orthopyroxene in a minor amount or absent, *wehrlite* is used, and *harzburgite* for the converse.

We have chosen to illustrate this rock by two different samples.

The upper and middle photographs show a poikilitic textured peridotite in which, in the lower left part of the field, a number of round crystals of olivine are embedded in two clinopyroxene crystals, and elsewhere the olivines are enclosed by plagioclase crystals. In the centre of the field, one elongated olivine crystal is surrounded by plagioclase feldspar. The small opaque crystals are chromite. The differences in colour and relief between the plagioclase and the pyroxene are also obvious in the PPL view: stray polarization produces the pale greenish and pink colours in this view.

The lower photograph shows an XPL view of a peridotite in which numerous olivine crystals are poikilitically enclosed in a basic plagioclase feldspar. Only a small proportion of pyroxene is present in this rock.

First and second photographs: Peridotite from Rhum, Scotland; magnification × 12, PPL and XPL.
Third photograph: Peridotite from the Shiant Isles, Scotland; magnification × 15, XPL.
*Other peridotites are illustrated in **18** and **48**.*