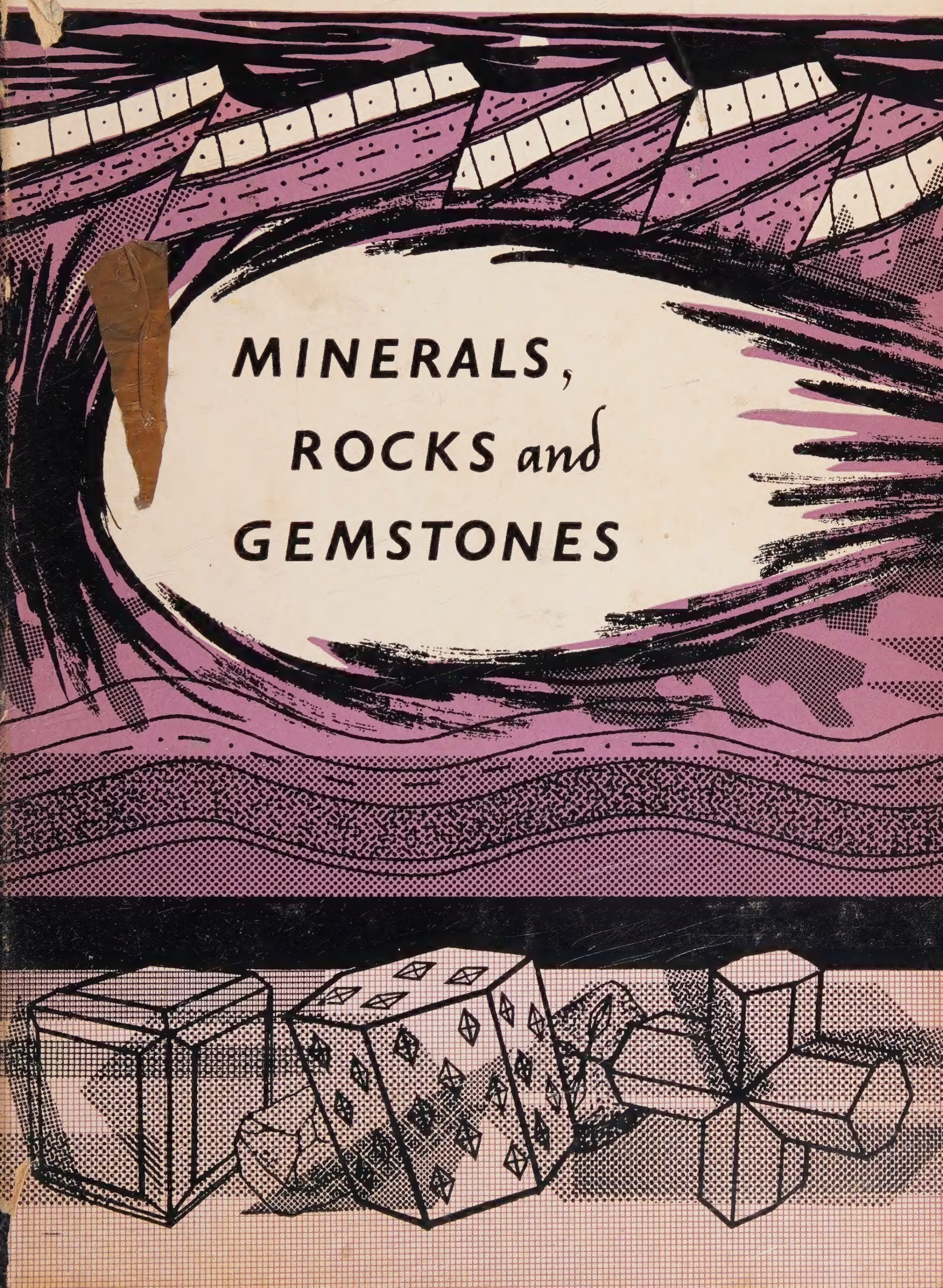
RUDOLF BÖRNER

MINERALS, ROCKS and GEMSTONES



THIS highly practical guide to the identification of minerals, rocks and gemstones is notable for its compactness and ease of reference. It is divided into three parts. The first which deals with minerals contains tables giving the properties, uses, mode of occurrence and localities of nearly 200 minerals. These are first classified by colour and their chief physical characteristics—hardness, streak, lustre, etc.—and their associations and chemical composition are stated. The minerals are then rearranged in another table according to their streak and hardness.

The second section provides an introduction to rocks with special emphasis on their uses and structural properties, and includes a glossary of important rock names and petrographic terms.

The third section gives a fairly detailed account of the properties of over 280 gemstones and ornamental stones with much technical information. In the identification tables the stones are grouped according to their transparency or opacity and their colour.

The book, which is beautifully illustrated, will appeal to university students of geology, jewellers, amateur geologists and gemmologists and to civil engineers.

For this reprint additional plates and references have been added.

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40p

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Translated and edited by
W. MYKURA

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TRANSLATOR'S PREFACE

Dr Börner's book *Welcher Stein ist das?* has had a very wide appeal in the German-speaking world. The novel way in which a wealth of information is simply and explicitly set out has enabled users of the book to track down the names of their mineral, rock, or gemstone specimens, and has at the same time stimulated their interest in various branches of geology.

As the book was written for a German-speaking public, the translator's main task has been to adapt it for use in Great Britain, giving pre-eminence to British localities and adapting the rock classifications, where necessary, to conform with current English usage. It has also been found desirable to give some indication of the uses of the various minerals described in the first part of the book, and to provide a somewhat fuller glossary of rocks and petrographic terms than that given in the German edition.

The translator is greatly indebted to Dr G. H. Mitchell and Dr J. Phemister, who have read through the sections dealing respectively with rocks and gemstones and have made many helpful suggestions. Many thanks are also due to Mr M. J. O'Hara, who has checked the chemical formulae given in the original German text. All responsibility for errors must rest with the translator.

PREFACE

This volume is intended to be a guide to those who, in the course of their profession, or purely as amateurs, come into contact with minerals, rocks or gemstones. It aims to provide an easy and straightforward means of identifying these "stones", without presupposing any detailed technical knowledge or requiring the use of complicated apparatus. The information is set out in such a way that the collector, student or engineer will be able to attempt the identification of his specimens in the "field", using only simple equipment which he can carry in his pocket. For a more detailed and precise identification of minerals, and especially gemstones, it is usually necessary to carry out certain scientific tests with special apparatus. Some of these tests are briefly described in the section dealing with gemstones, where the relevant data are also given.

The book is divided into three parts. The first part deals with minerals and contains tables giving the properties, uses and localities of 200 important minerals. The minerals are arranged according to colour and hardness, their two most readily identifiable characteristics. There are also further tables which assist in the identification of minerals by using the colour of their streak.

The second part contains a general account of the origin, structure and chemical composition of the earth, and provides an introduction to the study of rocks, with special emphasis on their uses and structural properties. It also includes a short glossary of important rocks and petrographic terms.

The third part provides an introduction to the study of gemstones, and contains tables arranged according to colour which set out the salient physical properties of these stones. These are followed by an alphabetical description of the more important gemstones in which additional data about synthetic stones, incorrect names, valuation and occurrence are given.

Sixteen colour plates, portraying some of the minerals, rocks and gemstones, illustrate the book.

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I. MINERALS

Introduction

The term "minerals" in its wider sense is understood to include all the materials which make up the earth's crust. Such varied substances as granite or sandstone, which are essentially of inorganic origin, and coal or chalk, which were formed largely from living organisms, can all be called minerals.

For the geologist and mineralogist, however, the term mineral has a much more restricted meaning. To him it is a substance which possesses a more or less definite chemical composition which can be expressed by a chemical formula. The constituent atoms of a mineral thus defined are often arranged in a definite pattern and its physical properties are as a rule fairly constant. Minerals may be either solids or liquids; substances which are gases at normal temperatures are not usually classed as minerals. The solid minerals have a definite crystalline form, and it is possible to use this as a basis for identifying them. Many, however, occur in more than one shape, and a system relying on crystalline form as the main criterion for their identification would soon run into difficulties. The minerals in the following tables are therefore arranged primarily according to colour.

Rocks may be defined as mineral aggregates composed of one or more minerals. The various ways in which they were formed, as well as the role of the minerals and rocks in relation to the origin and structure of the earth as a whole are discussed in the part of the book which deals with rocks (pp. 129ff). It is worth noting that the dividing line between minerals and rocks is not always well defined. For instance, when a single mineral occurs in great quantity and forms a complete layer or rock mass, the name of the mineral is also given to the rock. It is also common that substances are called minerals in industry which would not be classed as such in science. In gemmology, too, there are gemstones which are not true minerals or are aggregates of several minerals.

Mineral Identification Tables

I. Based primarily on Colour of Mineral

In the following table the minerals are classed according to properties which can be readily determined. They are grouped into sections according to colour, and in these the minerals are arranged in order of increasing hardness. The properties described in the various columns of the tables are hardness, specific gravity, streak, lustre and transparency, fracture, cleavage, characteristic form, and crystalline form. Details of occurrence and localities, mineral associations, and uses are also given.

Hardness. The determination of the hardness of a mineral cannot be carried out very precisely in the field. The scale of hardness (resistance to scratching) called Mohs' scale, has ten grades. The figures 1 to 10 on the scale merely denote an *order* of hardness, and have no quantitative significance, and the difference in hardness between successive grades is in fact very variable. There is, however, the great advantage that most of its grades can be readily determined with the aid of some small easily carried objects. The minerals used as standards for the scale are as follows: 1, talc; 2, gypsum; 3, calcite; 4, fluorspar; 5, apatite; 6, feldspar; 7, quartz; 8, topaz; 9, corundum; 10, diamond. The use of the scale is simple, as most of its grades can be determined by using four everyday objects. A good pocket knife has blades with a hardness of from 5½ to 6, and all minerals of hardness 1 to 5 can be scratched with it. A piece of window glass has hardness 5, a copper coin hardness 3, and a finger nail about hardness 2. With the aid of these, it is possible to determine the intermediate values of 1 (scratched by finger nail), 4 (scratched by glass but not by coin), and 5 (scratched by penknife but scratches glass). These tests are only valid when they are carried out on a fresh unweathered surface of the mineral, as weathered surfaces are usually much softer. With many minerals it is essential to make certain that the individual crystals, which are often very small, are firmly cemented. Quartz, for example, has hardness 7, but a heap of fine sand, consisting entirely of quartz, can readily be parted with a finger. It is thus best to hold the individual crystal during the hardness test.

Specific Gravity. The number below the line in column 3 of the table gives the specific gravity. An accurate balance is necessary for the determination of this property. The actual techniques of the determination will not be elaborated here, as the reader will find them described in all textbooks of elementary physics and elementary mineralogy. These books explain how to use the chemical balance and the specific gravity bottle or pycnometer. Some also discuss the use of heavy liquids with the Westphal Balance, as well as giving other methods. A few examples will serve to give a general idea of the range of specific gravity in minerals. Heavy metals like gold, silver, platinum and mercury have a specific gravity of over 10. Ores are next with a range of from 4 to 7, while the majority of the remaining minerals vary from about 2 to 3. Organic minerals like coal are even lighter, with a specific gravity of up to 1·7.

Streak. The colour of the streak left on an unglazed porcelain tablet is a useful aid in mineral identification. In the field it is often the only way in which otherwise similar minerals can be quickly distinguished from each other. An example is the intensely red arsenic-sulphur mineral called realgar, which, on account of its orange-yellow streak, can easily be distinguished from other red minerals such as ruby silver, cinnabar, and crocoisite. As streak plates are quite small (about 2 in. square) and easily carried, they should always be kept handy when field determinations are being made.

Lustre and Transparency. The next distinguishing features given in the table are lustre and transparency, which are determined directly by observation. Many glassy minerals have a vitreous lustre (abbreviated to vit.), talc has a typical silky lustre (silk.), whereas all metallic minerals have a more or less well defined metallic lustre (met.). Other types of lustre are pearly (pearl.), fatty (fat.), and adamantine or diamond (ad.). The meaning of these terms is self-explanatory.

The three grades of transparency used in this book are transparent (abbreviated to trp.), translucent (trl.), and opaque (op.). Intermediate grades such as sub-translucent (sub-trl.) are occasionally used.

Fracture. The column headed Fracture is used in cases where the mineral is sometimes made up of small crystals or grains, and indicates in what manner such an aggregate tends to break up. We can distinguish even, uneven, brittle, hackly, and conchoidal fracture.

Cleavage. Cleavage is the tendency of certain minerals to split along definite planes which are related to their crystal shape and internal structure. Some minerals cannot be split in any particular direction, while others can be split easily in one or more directions. In the tables, the degree of cleavage is as a rule described by the following terms: perfect, complete, good, distinct, indistinct, or just perceptible. It is important to determine how many cleavage directions a mineral possesses. Mica, for instance, has a perfect cleavage in only one direction and can be split into very thin plates. Rock salt, on the other hand, has a perfect cleavage in three directions, which means that cleavage fragments take on a cubic or rectangular shape. If cleavage is particularly good, the resulting surface is smooth and pearly in appearance, as is the case with rock salt and gypsum. With poor cleavage, small unevennesses are found on the surface and there is little or no lustre.

Occurrence. This column indicates in which kind of rock a particular mineral is most commonly found. Although many minerals are found in both crystalline and sedimentary rocks, it is useful to know with which particular rock the mineral in question is normally associated, as this may be a valuable factor in the sequence of steps leading to its identification.

Localities. Under this heading the occurrences in the British Isles are given first. These are followed by the more important localities in Europe and then by those in other continents. By adopting this system it has not been possible to arrange localities in order of importance, but in certain cases the major producing areas have been specially indicated.

Associated Minerals. Many minerals do not occur alone but are closely associated with a whole group of allied types. The various copper minerals, for instance, are often found in one specimen, and the bright green mineral malachite is frequently found in close association with the deep azure blue azurite (Plate II.12). Another example among ore deposits is the close association of lead and zinc minerals with barytes and native silver.

Name and Formula. This column is self-explanatory. The most recent internationally accepted symbols have been used in the compilation of the chemical formulae. In addition to the scientific name of the mineral, commonly used names and mining names are also shown. Obsolete names have been omitted.

Blowpipe. In some cases the behaviour of a mineral in a blowpipe flame is given. The two main characteristics are the ease of fusion and the colour of the flame. The solubility of minerals in acid or alkaline solutions is also shown.

Uses. This column shows the various purposes for which a particular mineral has been used. For commercial exploitation a mineral has to be found in sufficient quantity, and an ore has to be sufficiently concentrated, to make its extraction worth while. Access, ease of working, and the state of the world market are other factors which have a bearing on the prospects of successful exploitation.

Common Form. The column headed Common Form gives the form or habit in which the mineral usually occurs. A mineral does not necessarily have a crystalline shape. It may, for instance, be amorphous, massive, platy, wiry, or grid-shaped (reticulate). Some minerals are most commonly found as thin encrustations on other minerals. Clear crystals of quartz may, for example, be thinly coated with dark green chlorite. Sometimes minerals are kidney shaped or reniform, like kidney ore, a variety of haematite, the red iron ore. Others, like flint and chert, are nodular. Asbestos and some varieties of gypsum are typical fibrous minerals, while mica is tabular and talc is scaly.

The *Crystalline Form* is the property of a mineral which, next to colour, is most frequently used in its identification. Minerals are either crystalline or amorphous. The latter have no regular shape, and the

PLATE I ORES: 1. IRON ORES AND RELATED ORES

1st Row: 1. Psilomelane, 2. Limonite, 3. Siderite; *2nd Row*: 4. Vanadinite, 5. Cobalt Bloom, 6. Crocoisite, 7. Wolfram, 8. Limonite (concretionary variety); *3rd Row*: 9. Magnetite, 10. Psilomelane, 11. Cobaltite, 12. Scheelite, 13. Chromite; *4th Row*: 14. Micaceous haematite, 15. Haematite, 16. Magnetite, 17. Pyrolusite; *5th Row*: 18. Marcasite, 19. Kupfernickel (Niccolite), 20. Minette; *6th Row*: 21. Rhodocrosite, 22. Siderite, 23. Pyrite, 24. Descloizite.


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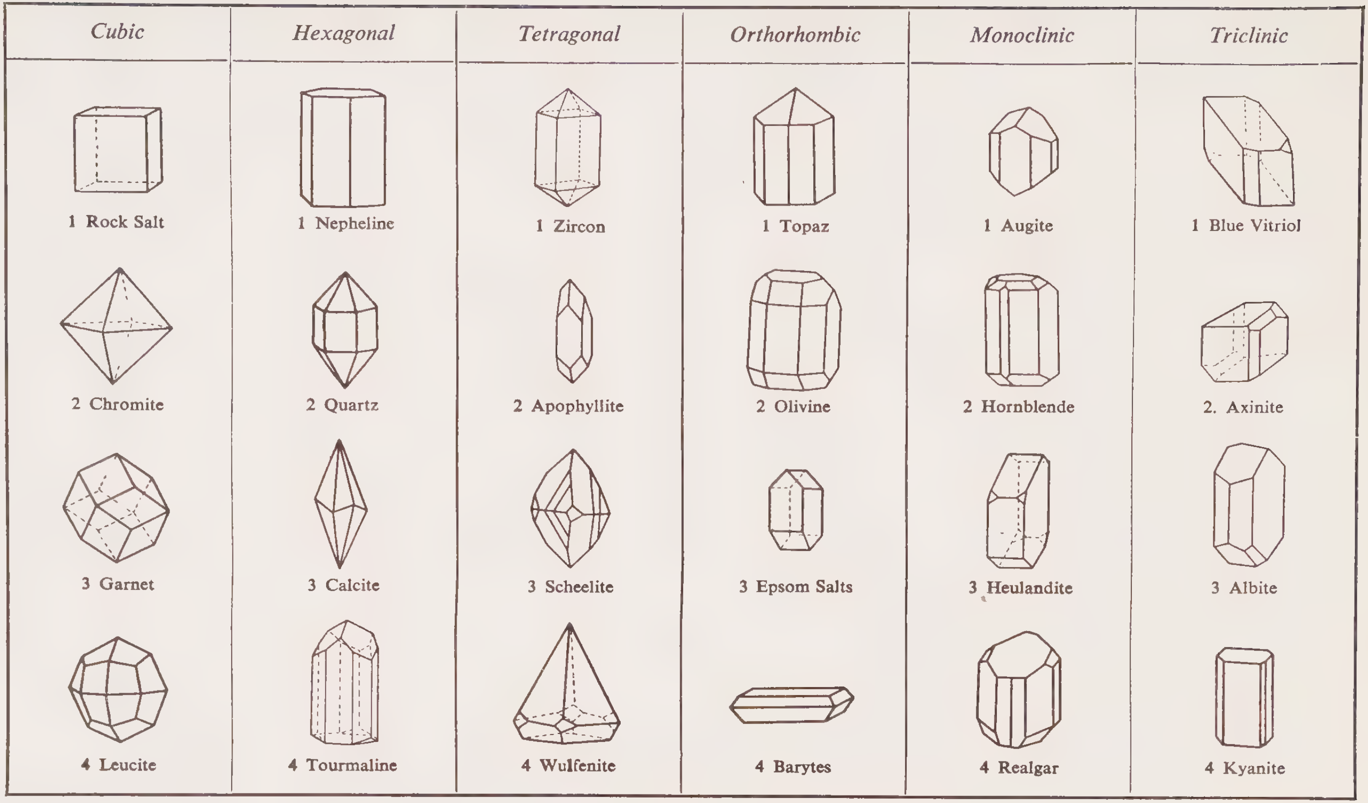


Fig. 1. Characteristic Forms in the various Crystal Systems

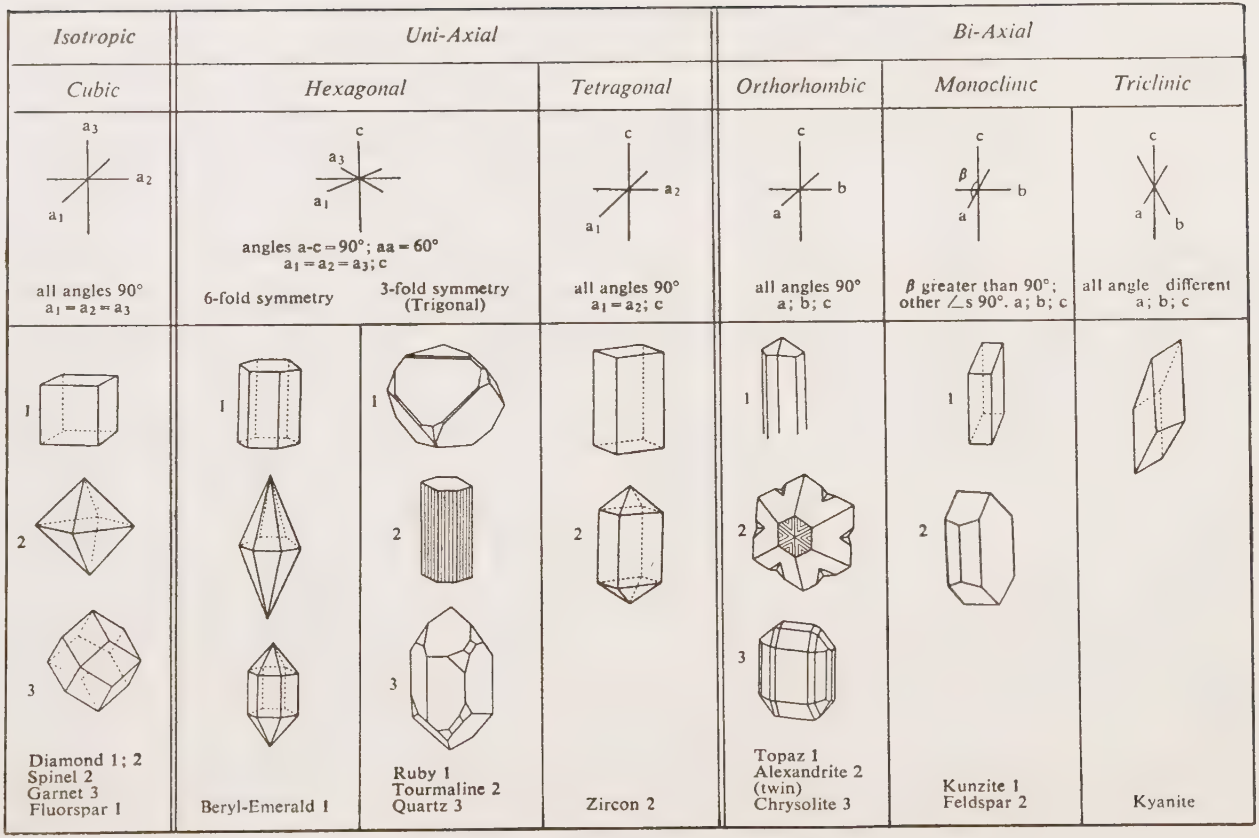


Fig. 2. The Crystal Systems (after G. O. Wild, *Praktikum der Edelsteinkunde*)

internal arrangement of their constituent atoms is irregular (see Opal, Plate XIV.3). The majority of minerals are crystalline, even if this is not always immediately obvious to the naked eye because of the extremely small size of the crystals. In many cases a good hand lens will provide sufficient magnification to identify the crystals, and it may often not be necessary to carry out a closer examination by binocular or petrographic microscope. A lens of good quality is essential, and it is best to get one with a magnification of 8 to 10, as those with larger magnifications usually have a very restricted field of vision and spherical aberration round the edges.

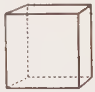
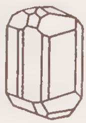
The Crystal Systems. The six crystal systems and some common examples of crystal forms in these systems are shown in Figs. 1 (p. 5) and 2 (p. 6). Under Crystal Form, the crystal system and type to which the mineral belongs are not always given. It is rather intended to give a general description of the form which the crystal most commonly takes, and such self-explanatory terms as cubic (=rock-salt), columnar (=tourmaline) and rhombohedral (=calcite) are used. To supplement this description a diagram illustrating the crystalline form of the mineral is given. In the case of many minerals, a sketch has been purposely omitted; these minerals are mostly microcrystalline; that is, their crystalline character can only be recognised under the microscope.

Many minerals occur in a number of different crystal forms. Thus about 3000 forms of calcite and over 200 forms of epidote are known. Only the most common forms are therefore described in this book.

A list of recommended books dealing in greater detail with the properties and uses of minerals is given at the end of the book.

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
1	indigo-blue to blue-black	1·5 – 2·0 / 4·7	black	fat. / op.	even / perfect (1 direction)	as encrustation or in plates; usually found in zone of secondary enrichment of copper lodes
2	blue (also white, colourless, red, yellow, grey)	2·5 / 2·1 – 2·3	colourless	vit. / trp. – trl.	conch. / perfect cubic (3 directions)	in sedimentary rocks, formed by evaporation of isolated bodies of sea water, salt domes
3	blue	2·5 / 2·2 – 2·3	pale blue	vit. / trl.	conch. / indistinct	in zone of weathering of copper lodes
4	indigo-blue (white when freshly broken, blue when exposed to air)	2·5 / 2·6 – 2·7	bluish-white	vit. – pearl. / trl.	into thin flexible plates / good (1 direction)	with iron and copper ores, in clay and peat, and in fossil bones and shells

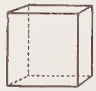
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
esuvius, igoslavia, laska, Iontana J.S.A.), hile	chalcocite (copper glance), chalcopyrite (copper pyrites), weathering products of copper sulphides	**Covelline** Covellite — CuS (66·4% Cu) Blowpipe: easily fused; blue flame	copper ore	finely granular, massive or powdery — small crystals  crystals uncommon, usually as thin hexagonal plates
heshire, tassfurt Germany), alzburg Austria), rance, J.S.A. Michigan, Iew York, ansas, klahoma, exas), aspian Sea, hina, ndia, etc.	gypsum, clay, anhydrite, all other salts (halides)	**Rock Salt** Halite — $NaCl$ Blowpipe: easily fused, yellow flame Plates VI.6, IX.6	glass-making, soap-making; manufacture of sodium carbonate, sodium hydroxide, and chlorine; domestic purposes	crystalline, granular, less frequently fibrous; soluble in water  cube, sometimes with hollow faces
ornwall, Iarz Mts. Germany), io Tinto Spain), Chile	chalcopyrite (copper pyrites), from which it is formed by oxidation	**Chalcanthite** Blue Vitriol — $Cu[SO_4]\cdot 5H_2O$ soluble in water	copper ore (rare)	as encrustation, efflorescence, stalactitic, collumnar, or kidney-shaped (reniform)  crystals very rare and minute
ornwall, Devon, hetland peat swamps), Bavaria Germany), rimea, Bolivia	pyrrhotite, pyrites, often found in or on fossils	**Vivianite** Blue-iron Earth — $Fe_3^{\cdot\cdot}[PO_4]_2\cdot 8H_2O$		long prisms, fibrous, encrusting aggregates, radiating  prismatic crystals (monoclinic)

glas. = glassy res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
5	azure-blue	3·5 – 4·0 / 3·7 – 3·9	cobalt blue	vit. / trl. – op.	conch. / good	in zones of weathering of copper lodes and deposits
6	violet-blue (colourless when pure), also green, yellow, red	4·0 / 3·1 – 3·2	colourless	vit. / trp. (when uncoloured)	conch. to uneven / perfect (3 directions)	in veins and druses in igneous and sedimentary rocks
7	blue, colourless, white, grey	4·5 – 7·0 / 3·5 – 3·7	white	vit. – pearl. / op.	fibrous / very good (in part)	in schists and gneisses, sometimes intergrown with staurolite, also in granite pegmatites
8	azure-blue, dark blue	5·5 / 2·3 – 2·4	pale blue	vit., fat. / op.	conch. / distinct or imperfect	in crystalline limestones near junction with granite usually as compact aggregates

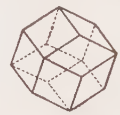
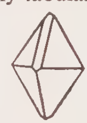
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Redruth Cornwall), Lyon (France), Katanga Congo), U.S.A., Russia, Australia	various other oxidised copper ores, e.g. malachite; sometimes limonite	**Azurite** Blue Carbonate of Copper / $Cu_3[OH\|CO_3]_2$ Blowpipe: easily fused Plate II.12	copper ore	massive, as encrustation, in layers, or botryoidal with enamel-like texture  short prisms or thick plates
Derbyshire, Durham Weardale), Germany, Alps, U.S.A. Kentucky, Illinois)	barytes, galena, blende, quartz	**Fluorspar** Fluorite, Blue John / CaF_2 soluble in H_2SO_4 Plates IV.4, VI.2	manufacture of opaque glass and hydrofluoric acid; flux in steelmaking, ceramic industry, e.g. enamel of baths, vitriolite, etc.	coarsely crystalline, compact, occasionally columnar or earthy  cubes, octahedra, sometimes twinned crystals
igh grade netamorphic ocks of the Scottish Highlands, India (main producer), U.S.A., Brazil	staurolite, sillimanite	**Kyanite** (Disthene) / $Al_2[O\|SiO_4]$ Blowpipe: not fusible	manufacture of refractory cement, toughening glass	long blade-like crystals, radiating rosettes or grains  triclinic system, crystals long prismatic, radially fibrous
Monte Somma Vesuvius), Alban Mts. Rome), Chile, Afghanistan, Lake Baikal U.S.S.R.), Persia	in limestone (calcite); often spangled with iron pyrites	**Lapis Lazuli** (Lazurite) / $(Na,Ca)_8[S,Cl,SO_4)_4(AlSiO_4)_6]$ Blowpipe: easily fused. Decoloured by HCl with evolution of H_2S	ornamental and gemstone, formerly used in manufacture of ultramarine paint	crystals rare, compact aggregates compact compact, massive (amorphous)

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
9	bright blue, also grey	5·5 – 6·0 / 2·3 – 2·4	white	vit., fat. / trp. – trl.	conch. / fairly good	in recent volcanic rocks which are rich in alkalies (nepheline – syenites)
10	sky-blue, dark or pale	5·0 – 6·0 / 3·1	colourless	vit. / trl. (at edges only)	uneven, brittle / none	in quartzite, usually compact
11	blue, colourless, grey, yellowish to white	5·0 – 6·0 / 2·2 – 2·4	white	vit. – fat. / trp. – trl.	conch. / distinct	in soda-rich syenites
12	turquoise blue, bluish-green	5·0 – 6·0 / 2·6 – 2·8	white	waxy / op.	conch. / poor, brittle	particularly common in zone of weathering of aluminium-rich rocks, e.g. trachytes
13	deep blue, bluish-black	6·0 – 6·5 / 3·0 – 3·1	blue-grey	vit. / trl.	rough / perfect prismatic	mica-schist and gneiss (soda-rich varieties)

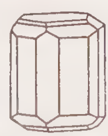
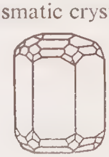
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
Ionte Somma /esuvius), lban Mts. Rome), ifel Germany)		**Hauyne** / $Na_6Ca_2[(SO_4Cl)_2(Al.SiO_4)_6]$ Blowpipe: fused with difficulty		granular aggregates, and as phenocrysts (individual crystals in fine-grained rock)  cubic (octahedra and rhombdodecahedra), twins common
ustria, witzerland, weden, J.S.A., razil		**Lazulite** / $(Fe^{\cdot\cdot},Mg)Al_2[OH\|PO_4]_2$ Blowpipe: not fusible	sometimes used as ornamental stone	usually massive, twins common, crystals rare, pointed pyramids, less commonly tabular  monoclinic, crystals rare
Germany, ortugal, /esuvius, Norway, Greenland, Kola Peninsula U.S.S.R.) olivia	hauyne, lazurite, nepheline, leucite	**Sodalite** / $Na_8[Cl_2\|(AlSiO_4)_6]$ Blowpipe: fuses with difficulty		in irregular grains, massive compact, granular / cubic system, rhombdodecahedral crystals
ersia, Sinai en. (Egypt), J.S.A. (New Iexico), ussia	often found together with limonite or chalcedony	**Turquoise** / $CuAl_6[(OH)PO_4]_4 5H_2O$ Blowpipe: not fusible	gemstone	finely granular, reniform; no crystals / none
are: nglesey, ermatt Switzerland), osta Valley taly), alifornia, New Caledonia	staurolite, soda-rich hornblende	**Glaucophane** (Amphibole Family) / $Na_{2-3}MgFe_3^{\cdot\cdot}Al_2[Si_8O_{22}](OH)_{1-2}$ Blowpipe: fuses to glass		fibrous, massive or granular; columnar, 6-sided prisms / monoclinic system, prismatic crystals, often without basal surface

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
14	pale blue, sapphire blue, clear or opaque	6·5 / 3·7		highly lustrous / op. – trl.	conch., brittle / none	small crystals
15	amethyst-coloured, dark lilac, pink, yellow, emerald green	6·5 – 7·0 / 3·1 – 3·2		vit. / trp.	conch. / good	as large crystals in pegmatite veins in granite and gneiss
16	violet	7·0 / 2·65	white	vit. / trp., trl.	conch. brittle / none	in cavities in many volcanic rocks, as amygdales and veins
17	blue-grey, yellowish	7·0 – 7·5 / 2·6	white	fat. / trp., trl.	conch. / in part distinct	in gneisses, hornfelses, norites and some granites
18	pale blue, sea-green; green, see also emerald (No. 45)	7·5 – 8·0 / 2·7	white	vit. / trp.	conch. uneven / indistinct	in igneous rocks in druses and veins

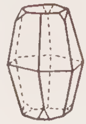
vit. = vitreous silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
nly known n San Benito Mine, California	titanium silicates, natrolite	**Benitoite** / $BaTi[Si_3O_9]$ Blowpipe: fuses to transparent glass	gemstone	intergrown  hexagonal system, double pyramid (maximum length 2 cm.)
eterhead Scotland), Killiney Ireland), Manitoba, outh Dakota, Madagascar, Brazil	beryl, cassiterite, tourmaline	**Spodumene** / $LiAl[Si_2O_6]$ Varieties: pink – kunzite; green – hiddenite Plate XII.8 Blowpipe: fuses with red flame	raw material for manufacture of lithium salts; gemstone	crystal aggregates, twins; resembles diopside No. 36; monoclinic system, very large crystals, resembling diopside
Brazil, Ceylon, Urals	other forms of quartz	**Amethyst** / SiO_2 (see quartz No. 195) Plate XII.10, 13 Blowpipe: not fusible	gemstone	very rarely as single crystals, mainly in druses; see quartz No. 195; hexagonal system prisms with pyramids, radiating aggregates
Scottish Highlands, Cornwall. Gemstones: Ceylon, ndia, Burma, Madagascar	quartz, nepheline	**Cordierite** (Dichroite) / $(MgFe)_2Al_3$ $[AlSi_5O]_{18}$ Blowpipe: Fusible only on edges	gemstone	scaly or massive, sometimes granular  prisms with rounded edges
Mourne Mts. Ireland), Elba, Urals, Brazil, Australia, Madagascar, South Africa	pegmatitic veins of granite	**Aquamarine** (variety of Beryl, No. 45) / $Be_3Al_2[Si_6O_{18}]$ Plate XI.12 Blowpipe: Fusible only on edges	gemstone	long prismatic crystals  hexagonal system, long hexagonal prisms, sometimes intergrown

glas. = glassy, res. = resinous op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
19	blue, watery (see also red = ruby, No. 65)	9·0 / 3·9 – 4·0	white	vit. / trp. – dull	conch., brittle / none, but separation plates parallel to base are common	as pebbles in alluvial deposits; in metamorphosed volcanic rocks

vit. = vitreous, silk. = silky, met. = metallic pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
Ceylon, Burma, Siam, Queensland, Madagascar, also recorded in Mull and Ardnamurchan	chlorite, magnetite, as accessory constituent in gneiss and mica-schist	**Sapphire** (Blue Corundum) / Al_2O_3 Plate XI.1–4 Blowpipe: Not fusible	gemstone	columnar, pyramidal, barrel-shaped, granular, massive  hexagonal system, prisms often very large, also steep-sided bi-pyramids

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
20	pale green, greenish-grey	1·0 / 2·7 – 2·8	colourless – white	pearl. / trp. – op.	brittle, uneven / scaly (fatty)	crystalline schists; altered basic igneous rocks, dolomites
21	apple green, silver-white, yellowish	1·5 / 2·7	white	pearl. / trl.	conch., scaly / partly good, partly flexible	in crystalline schists, quartz veins, granites, etc.
22	leek-green	1·0 – 2·0 / 2·8 – 2·9	greenish-white	glas., pearl. / trl.	brittle / scaly	in low-grade metamorphic rocks, e.g. chlorite schists, phyllites; serpentine
23	blackish-green to blue-green	2·0 / 2·5 – 2·8	greenish-white	glas., fat., pearl. / trl.	brittle, splintery / scaly	chlorite schists, phyllites, filling in amygdales
24	dark green, olive green, bluish-green	2·0 / 2·3		dull / op.	granular – no fracture / none	oceanic sediments

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
yrenees mainly rance), taly, U.S.A., Ianchuria, Jrals	varieties: steatite (soapstone), potstone, rensellerite	**Talc** (Soapstone) / $Mg_3[(OH)_2\|Si_4O_{10}]$ Plates IV.1, VI.5 Blowpipe: almost infusible	ornamental stone, ceramics, filler for paints, rubber, paper, etc., toilet powder, electrical insulators, refractory products	scaly (talc), massive (soapstone); small scales (flat plates); monoclinic system, 6-sided plates
pain, rdennes, ifel, in rystalline chists of wiss Alps, Jrals	quartz, cassiterite, local constituent in schists and granites	**Pyrophyllite** / $Al_2[(OH)_2Si_4O_{10}]$ Blowpipe: fused with difficulty	similar to those of talc, No. 20	radiating foliated aggregates, compact; columnar, 6-sided lamellae; orthorhombic system, tabular crystals
videspread vherever hlorite and erpentine ccur	sphene, etc.	**Prochlorite** (Chlorite Family) / $(MgFe^{\cdot\cdot}Al)_6(OH)_8$ $(AlSi)_4O_{10}$ Plate VII.5 Blowpipe: not fusible		comb-like and irregular aggregates; small distinct crystals; monoclinic system, crystals rare, small 6-sided plates and scales
Iighland chists, Alps, Pennsylvania, tc.	diopside, augite, garnet	**Clinochlore** (Chlorite Family) / $Mg_5Al(OH)_8$ $[AlSi_3O_{10}]$ Blowpipe: fuses into greyish-yellow bead		crystals, compact, scaly aggregates;  monoclinic system, small tabular crystals
Comely Sst. Cambrian of hropshire); Greensand, Chloritic Marl nd Chalk Marl of English Cretaceous; J.S.A.	sandstone, marl	**Glauconite** / $K(MgFeAl)(AlFe)$ $(OH)_2[Al_{0-1}Si_{4-3}$ $O_{10}]$ Blowpipe: fuses to black magnetic glass	locally worked as source of potassium	amorphous earthy aggregates, granular; small rounded grains; grains to diameter of about 3 mm.

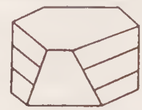
glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
25	green, apple green, bluish	2·5 / 2·6 – 2·8	greenish-white	pearl. / trp. – trl.	rough / scaly	chlorite schists; in druses and cavities; alteration product of micas, amphiboles and pyroxenes
26	apple green	2·5 / 3·0 – 3·1	greenish	/ op.	earthy, no fracture / granular	coating on nickel ores
27	apple green, emerald green	2·0 – 4·0 / 2·2 – 2·7	light green	matt – earthy / op.	conch., earthy / none	in clayey masses formed by lateritic decay of nickeliferous serpentine and in certain veins
28	emerald green, blue-green, sometimes blue	2·0 – 4·0 / 2·0 – 2·2	greenish-white	fat. / op., edges trl.	conch. / none	in zone of weathering of copper lodes and deposits, and in limonite deposits
29	grass-green to blackish-green	3·0 – 3·5 / 3·8	apple green	vit. / trp. – trl.	conch. / complete	in zone of weathering of copper lodes, esp. under desert conditions

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty ad. = adamantine or diamond,

PLATE II ORES: 2

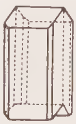
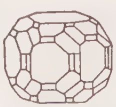
1st Row: 1. Cassiterite, 2. Native Mercury, 3. Stibnite, 4. Bornite; *2nd Row*: 5. Cerussite, 6. Blende, 7. Tetrahedrite; *3rd Row*: 8. Galena, 9. Blende (left), chalcopyrite (right); *4th Row*: 10. Malachite, 11. Chalcopyrite, 12. Malachite with azurite; *5th row*: 13. Blende (botryoidal variety), 14. Barytes.

Localities	Associated Minerals	Name Formula	Uses	Common Forms: Diagram Crystal Form
idespread	olivine-rich rocks, serpentine	**Penninite** (Chlorite Family) $Mg_5(Mg,Al)[(OH)_8|(Al,Si)Si_3O_{10}]$ Blowpipe: fuses into yellow bead		compact, dense aggregates; resembles serpentine  monoclinic system, pseudo-hexagonal crystals, twins
ohemia, ilesia, pain, ntario Canada)	cobalt bloom, chloanthite (white nickel), kupfernickel	**Nickel Bloom** (Annabergite) $Ni_3[AsO_4]_2.8H_2O$ Soluble in acids		earthy coating on minute crystals hair-like needles monoclinic system, crystals rare
'ogtland Germany), Jrals, Ioumea (New Caledonia); iddle Dregon), Vebster North arolina)	serpentines, nickel ores	**Garnierite** (Noumeite) $(NiMg)_6(OH)_8[Si_4O_{10}]$ Blowpipe: not fusible; yields water and blackens when heated in closed tube	valuable nickel ore (local)	massive, dense, stalactitic, often friable massive to earthy, friable gel, hydrated nickel-magnesium-silicate
izard Cornwall), Jrals, atanga Congo), hodesia, hile, Mexico, alifornia	malachite, azurite, tile ore (red copper and iron oxide)	**Chrysocolla** $CuSiO_3.nH_2O$ (cf. No. 34)	copper ore	amorphous, compact and massive, in encrustations or thin seams amorphous, finely fibrous amorphous, botryoidal, stalactitic
t Just Cornwall), tacama esert (Chile), eru, Bolivia, alifornia, outh ustralia	malachite, chrysocolla	**Atacamite** (Remolinite) $CuCl_2.3Cu(OH)_2$ Flame: blue-green to green	copper ore	columnar, radiating, granular or foliaceous aggregates; also as loose sand orthorhombic system, crystals prismatic, spiky

glas. = glassy, res. = resinous; op. = opaque trp. = transparent, trl. = translucent; conch. = conchoidal
c

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
30	shades of green, yellow, veined and spotted with red, white, green, etc.	3·0 – 4·0 / 2·5 – 2·6	white	dull / trl. – op.	conch., brittle / fibrous	alteration product of rocks rich in magnesia; also in schists and limestones
31	blackish-green to emerald green; different shades are often concentrically banded	3·5 – 4·0 / 3·9 – 4·1	light green	vit., silk. dull / trl. – op.	conch. / good in some forms	in zone of oxidation of copper deposits, lodes, etc.
32	leek green to blackish-green, sometimes yellowish-green	3·5 – 4·0 / 3·3 – 3·5	yellowish-green	fat. / op.	uneven / very brittle (granular)	on limonite
33	green, itself colourless, also coloured yellow, blue, pale pink	4·0 – 5·0 / 3·2	white, grey, yellowish-grey	vit. / trl. – op.	conch., uneven, brittle / very poor	in pegmatitic veins and druses; in acid igneous rocks; accessory mineral in igneous rocks and metamorphic limestones

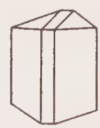
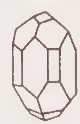
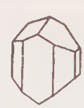
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name Formula	Uses	Common Forms: Diagram Crystal Form
izard, anffshire, outh yrshire, hetlands, astern Canada, astern U.S.A.; idespread in ld crystalline chists	formed by decomposition of olivine, hornblende and augite; magnetite, haematite, dolomite	**Serpentine** $Mg_6(OH)_8Si_4O_{10}$ Plate VII.6 Blowpipe: fuses with difficulty	building stone, ornamental work (mainly interior), asbestos of commerce (fibrous varieties)	lamellar = (antigorite), fibrous = (chrysotile) compact, fibrous dense aggregates
edruth Cornwall), larz Mts. Germany), Chessy France), Jrals, U.S.A., Chile, South ustralia	copper pyrites, atacamite, azurite, brochanthite	**Malachite** $Cu_2[(OH)_2\|CO_3]$ Plate II.10 Blowpipe: fusible	copper ore ornamental stone	massive, in botryoidal aggregate with smooth mammilated surface, also granular and earthy  monoclinic system; long, thin prisms, fibrous, in loose bushels
outhern rance, Germany	limonite	**Dufrenite** $(Fe_2^{\cdots}, Fe_3^{\cdot\cdot})$ $[(OH)_3\|PO_4]$ (?) Blowpipe: fuses to black bead	locally as iron ore	radially fibrous, botryoidal and spherical aggregates crystals very rare and small orthorhombic system; crystals rectangular with rounded edges
pain, Ontario Canada), Kola Peninsula U.S.S.R.), Virginia U.S.A.), Bolivia, Mexico	iron ores, cassiterite, present in many igneous rocks	**Apatite** $Ca_5[(F,OH,Cl)\|(PO_4)_3]$ Fluor-apatite and chlor-apatite are usually both present Blowpipe: edges only fusible	production of phosphorus chemicals, fertiliser	intergrown crystals, often very large; also massive, granular, radiating, fibrous, mammilated  hexagonal system, combination of prism and pyramid; also thick plates and bi-pyramids

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
34	emerald green	5·0 / 3·3	green, greyish-blue	vit. / trp. – trl.	conch. to uneven / good	in calcite veins and cavities; zone of weathering of copper lodes
35	dark green, pale green, white, pale grey	5·0 – 6·0 / 2·9 – 3·1	white	vit. / op.	brittle / good	in impure marble, dolomite and calc-silicate hornfelses; metamorphosed basic igneous rocks, e.g. actinolite schists
36	pale green, colourless, grey, yellow	5·0 – 6·0 / 3·3	white	vit. / trp. – trl.	rough, uneven / good, often lamellar	crystalline schists, metamorphosed limestones and dolomites
37	greenish-grey, black, brownish-black	5·0 – 6·0 / 3·3 – 3·4	whitish-grey	met., brassy / op.	rough / good	very common rock forming mineral in basic intrusive rocks, esp. gabbros

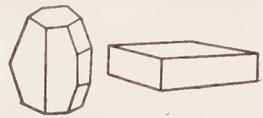
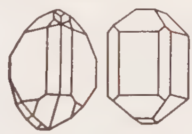
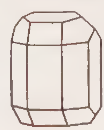
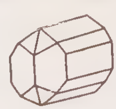
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Otavi (S.W. Africa), French Congo, Katanga (Congo), Peru, Chile, U.S.A., Turkestan	calcite, dolomite	**Dioptase** (Emerald Copper) / $Cu_3[Si_3O_9].3H_2O$ Blowpipe: not fusible	too rare to be of value as copper ore	in druses, small prismatic crystals, hydrated gel = chrysocolla (No. 28)  hexagonal system, rhombohedral; massive = chrysocolla; botryoidal
Scottish Highlands, Alps, S.W. Africa	chlorite, talc, serpentine	**Actinolite** / $Ca_2(FeMg)_5$ $[Si_8O_{22}](OH)_2$ also **Tremolite** (Amphibole Family) Blowpipe: easily fused	form of asbestos, used in wall and boiler insulation, also acid-filtering	parallel and radiating, columnar and fibrous aggregates  monoclinic system, long, slender 6-sided prisms; twins
Scottish Highlands, Alps, Scandinavia, Urals, Vesuvius, U.S.A.	augite, aegirine, chlorite (chrome diopside [bright green is found associated with South African diamonds)	**Diopside** (Pyroxene Family) / $CaMg[Si_2O_6]$ Blowpipe: fuses with difficulty		lamellar, massive, columnar, scaly and granular  monoclinic system, prismatic, crystals with striated surfaces, twins
widespread in areas of basic igneous rock	augite, diopside, serpentine, chlorite (weathers into serpentine)	**Diallage** (lamellar variety of augite) / $Ca(MgFe)Si_2O_6$ Blowpipe: not fusible		lamellar or foliaceous masses in plutonic rocks  monoclinic system

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
38	green, yellowish-green, yellow, colourless or white	6·0 – 6·5 / 2·8 – 3·0	white	vit., waxy, pearl. / trp. – trl.	uneven, brittle / distinct	infilling in cavities, joint spaces, fissures and druses
39	brownish-green, brown, yellow, red-brown	6·5 / 3·3 – 3·5	white	vit., broken surface fat. / trp. – trl.	rough, brittle / none	in impure limestones affected by thermal or regional metamorphism
40	olive green, yellowish-green, dark green, brown	6·5 – 7·0 / 3·3	white	vit. / trp. – trl.	conch. / poor	important constituent of basic igneous rocks, e.g. olivine-basalts and gabbros, main constituent of peridotite and dunite (olivine rock)
41	dark green, bluish-green, blackish-green, red = (withamite)	6·0 – 7·0 / 3·3 – 3·5	grey	vit. / trl. – op.	conch., uneven, brittle / perfect (1 direction)	metamorphic mineral formed by alteration of impure calcareous rocks and igneous rocks rich in Ca-feldspar

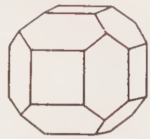
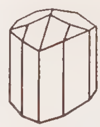
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Scottish Carboniferous lavas, Central Europe, Pyrenees, Africa, U.S.A.	other zeolites, epidote, native copper, analcite, natrolite	**Prehnite** (Zeolite Family) / $Ca_2Al_2[(OH)_2\|Si_3O_{10}]$ Blowpipe: fusible		single crystals rare, usually botryoidal, comb-like or rounded masses with radiating crystalline structure  orthorhombic system; crystals usually tabular
Monte Somma (Vesuvius), Loch Tay limestone (Scotland), South Germany, Bohemia, Urals, U.S.A., Canada	garnet (granular), diopside, wollastonite, scapolite	**Idocrase*** Vesuvianite / $Ca_{10}(Mg,Fe)_2Al_4[(OH_4)\|(SiO_4)_5\|(Si_2O_7)_2]$ resembles Euclase** (gemstone) Blowpipe: fusible	gemstone	crystals, also massive, granular; often radiating or finely granular  ** tetragonal system, short thick prisms, pyramids less common; sometimes long prisms
widespread in areas of basic igneous rocks, Dunite: Bushveld Complex (Transvaal); Peridot: Red Sea, Burma, Brazil	alteration products are limonite (brown), haematite (red), serpentine (green), also iddingsite and bowlingite	**Olivine** (Peridot) (Chrysolite) / $(MgFe)_2[SiO_4]$ Blowpipe: Infusible, decomposed in HCl with gelatinisation	peridot = gemstone	in rounded crystals in rock  orthorhombic system; prism modified by domes and pyramids, also thick tabular crystals
Norway, Alps, Urals, Lake Superior, Arizona	scapolite, garnet, hornblende, augite; resembles tourmaline and idocrase	**Epidote** (Pistacite) / $Ca_2(Al,Fe^{\cdots})_3[OH\|(SiO_4)_3]$ Blowpipe: melts to brown magnetic slag	sometimes used as gemstone	very widespread, elongated needles, many surfaces (over 200 separate forms)  monoclinic system, elongated crystals, twins, radiating groups

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
42	greenish to bluish	7·0 / 2·9 – 3·0	white	vit. / trp. – trl.	conch. / none	weathering product in salt domes, in bedded saline deposits
43	dark green, brown, blue, red, pink, also black. Varieties: green = Tourmaline, indigo-blue = Indicolite, red = Rubellite, brown = Dravite, black = Schorl. See gemstones, pp. 235-7.	7·0 / 3·0 – 3·2	white	vit. / trp. – trl.	conch., uneven, brittle / none or difficult	accessory mineral in acid igneous and metamorphic rocks; in veins and druses
44	olive-green, grey, reddish-yellow	7·0 – 7·5 / 3·1 – 3·2	white	vit. / usually op.	uneven to brittle / poor	metamorphic mineral formed in clayey rocks by high temperature and low stress, accessory mineral in some granites

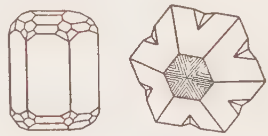
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
tassfurt Germany), nd all other ılt deposits	rock salt, carnallite, gypsum, anhydrite	**Boracite** / $Mg_6[Cl_2\|B_{14}O_{26}]$ Blowpipe: fuses with difficulty, green flame		small intergrown crystals or concretions  cubic system; cubes and tetrahedra or combination of the two
ornish ranites, larz Mts., axony. emstone arieties: ladagascar, razil, olivia, hile, J.S.A., ussia	in granites with feldspar and biotite; in schists, gneisses and metamorphic limestones; cassiterite, opalite, fluorspar, topaz, cobalt minerals	**Tourmaline** / complex borosilicate of aluminium with alkali metals Plate XII.1–7	gemstone (some varieties)	columnar, longitudinally striated; cross sections 3-sided and slightly rounded  hexagonal system (hemimorphic (trigonal); long 3-sided prisms terminated by rhombohedron; numerous faces
ndalusia Spain), Cornwall, lps, Urals, Brazil, California, Nevada U.S.A.), Transvaal	breaks down into muscovite and sericite; kyanite	**Andalusite** / $Al_2[O\|SiO_4]$ Blowpipe: not fusible	refractory porcelain for sparking plugs, and refractory bricks for electric furnace linings, etc.	thick prisms with square cross section; var. chiastolite is columnar and radiating with cruciform markings in cross section  orthorhombic system; simple 4-sided prisms with horizontal basal plane

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
45	green to emerald green, yellow to blue-green. Varieties: rose red = Morganite, green = Emerald, blue = Aquamarine, yellow (opalising) = Heliodor	7·5 – 8·0 / 2·6 – 2·8	white	vit. / trp. – trl.	conch., uneven / none, brittle	pegmatite veins in granite; metamorphic rocks, e.g. mica schist

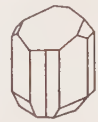
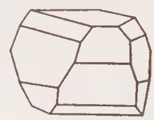
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
olombia, rals, ansvaal, azil, aine .S.A.), so ornwall	quartz, topaz, tourmaline	**Beryl** / $Al_2Be_3[Si_6O_{18}]$ Plate XI.8–11	gemstone if clear and transparent	long prisms, often large, never twinned 
		Emerald / $Be_3AlCr_2[Si_6O_{18}]$		
		Chrysoberyl / $BeAl_2O_4$ Blowpipe: fuses on edges only		hexagonal, long 6-sided prisms, sometimes rounded, almost spherical; numerous faces

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	*Hardness* / *S.G.*	*Streak*	*Lustre* / *Transparency*	*Fracture* / *Cleavage*	*Occurrence*
46	red to orange	1·5 – 2·0 / 3·5 – 3·6	orange-yellow	ad. (like blende) / trl.	conch. / good in 1 direction	in ore veins in volcanic rocks, deposit from hot springs
47	red, scarlet, cochineal red, grey, steel-coloured	2·0 – 2·5 / 8·0 – 8·2	cochineal red	ad. / trp. in thin layers	uneven, brittle / good	in volcanic rocks as impregnations and in veins
48	scarlet, cochineal red (darkens on exposure to light)	2·5 / 5·57	cochineal red	ad. (like blende) / sub-trp. – trl.	conch. / good	in veins, precipitated from hot solutions
49	peach red (becomes pearl grey in air)	2·5 / 2·95	pale red	vit. – ad. / trl.	/ perfect	formed by the weathering of smaltite and cobaltite in the upper parts of ore veins

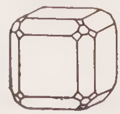
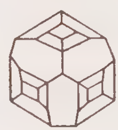
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
Iungary, osnia, Iacedonia, ersia, China, J.S.A.	stibnite, lead arsenic silver and gold ores	**Realgar** AsS Blowpipe: fusible; bluish-white flame	arsenic ore, pigment for lacquers, etc.	short or long prisms or needles; also massive or granular  monoclinic system, prismatic crystals; good crystals rare, usually very small
Almaden Spain), taly, . Russia, Vestern J.S.A., Mexico, China, Turkestan	mercury, pyrites, marcasite, stibnite, quartz, chalcedony; carbonates	**Cinnabar** HgS Blowpipe: yields sublimate of mercury	most important mercury ore	granular, fibrous, dense, massive or impregnating  hexagonal system, thick tabular prisms, rhombohedra
Erzgebirge, Black Forest Germany), Dauphiné France), J.S.A., Chile	pyrargyrite (dark red silver ore)	**Proustite** (Light Red Silver Ore) Ag_3AsS_3 Blowpipe: fuses easily	silver ore (minor importance)	massive, dendritic, impregnating and encrusting usually massive hexagonal system, prismatic crystals
Cornwall, Riesengebirge Saxony), Thuringia, French Morocco	smaltite (tin white cobalt), cobaltite	**Cobalt Bloom** Erythrite $Co_3[AsO_4]_2.8H_2O$ Blowpipe: fusible; red solution in acids	cobalt ore (manufacture of steel and alloys)	globular, reniform, scaly, earthy; occasionally radiating, encrusting crystals too small monoclinic, small needle-like crystals, fibrous

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
50	copper red (darkens when exposed to air)	2·5 – 3·0 / 8·5 – 9·0	copper red, metallic	met. / op.	hackly / none (ductile and malleable)	as hydrothermal deposit near surface, usually near copper-bearing rocks
51	yellowish-red	2·5 – 3·0 / 5·9 – 6·0	orange	ad. (fat.) / trl.	conch., uneven / distinct	in druses, and where lead ores have been acted upon by solutions containing chromium
52	dark red, blue-grey, lead grey to iron black	2·5 – 3·0 / 5·85	cochineal red	met., sometimes dull / op., red trl.	conch., brittle / good	in veins precipitated from hot solutions
53	orange-red, yellow, brown	2·5 – 3·0 / 6·6 – 7·2	pale yellow	fat., res. / trp. – trl.	uneven /	in zone of weathering of lead veins

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
pain, Italy, ake Superior egion, Utah, rizona, Iontana hile, atanga Congo)	cuprite, native silver, calcite, quartz	**Native Copper** / Cu Blowpipe: easily fused	copper ore	massive, impregnating, in thin plates, arborescent, also encrusting / usually massive  cubic system, distorted octahedra, twins
iberia, Jrals, razil, asmania, ast Indies, hilippines	galena, chrome ores	**Crocoisite** Crocoite / $Pb[CrO_4]$ Blowpipe: easily fused to Pb and green Cr_2O_3 readily soluble in acids	not important as ore	impregnating, massive, encrusting  monoclinic system, long crystals, needles or plates
pain, ohemia, Iexico, hile, eru, olivia J.S.A., Ontario	silver minerals, galena, calcite	**Pyrargyrite** (Dark Red Silver Ore) / Ag_3SbS_3 Blowpipe: easily fused to globule of AgS; decomposed by HNO_3	important silver ore	massive and irregular; in druses  hexagonal system, prismatic crystals, many faces
Cheshire, Vanlockhead Scotland), pain, rgentine, J.S.A., .W. Africa	pyromorphite minerals	**Vanadinite** / $Pb_3[Cl\|(VO_4)_3]$ Blowpipe: fusible; soluble in acids	minor ore of lead	small prisms with pointed pyramids, often in parallel groups / small long prisms / hexagonal system, prisms and pyramids resembling apatite

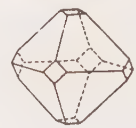
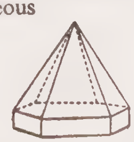
glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
54	flesh to brick red, white, yellow, grey	3·0 – 3·5 / 2·77	colourless, pale pink	fat. / trl.	conch. / good	in saline deposits
55	cochineal red, red-brown, metallic red	3·5 – 4·0 / 5·8 – 6·2	brownish-red	met. / trp. – trl.	conch., uneven / fairly good	in zone of weathering of copper lodes, widespread.
56	rose red, grey, brownish, rarely colourless	4·0 / 3·3 – 3·6	reddish-white	vit. / trl.	conch., uneven / very good	common constituent of ore veins; metasomatic replacement mineral in limestones
57	blood red to hyacinth red	4·5 – 5·0 / 5·4 – 5·7	reddish-yellow	ad. / trl.	conch. / perfect (1 direction)	as bands and lenses in metamorphic limestones

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Plate III Ores: 3

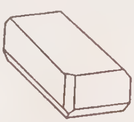
1st Row: 1. Psilomelane, 2. Osmiridium, 3. Native Silver, 4. Native Arsenic; *2nd Row*: 5. Native Gold, 6. Wulfenite, 7. Galena crystals; *3rd Row*: 8. Pyrite, 9. Ilmenite, 10. Stibnite, 11. Galena with Siderite.

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Permian of N.E. England, Stassfurt (Germany), Alps, Texas	all potassium salts	**Polyhalite** $K_2Ca_2Mg[SO_4]_4 \cdot 2H_2O$ water soluble; lilac flame	source of potash	massive, fibrous, lamellar or rarely columnar triclinic system, elongated prisms
Cornwall, Chessy (S. France), Spain, Chile, Peru, Arizona, Urals	copper carbonates, malachite	**Cuprite** Red Oxide of Copper Cu_2O Blowpipe: fuses to globule of metallic copper; soluble in acids and NH_3	copper ore	massive, granular, capillary  cubic system, octahedra
Germany, Hungary, Spain, U.S.A.	veins of gold, silver, lead, and zinc	**Rhodochrosite** (Dialogite) $MnCO_3$ Blowpipe: not fusible	not very important as manganese ore	massive, botryoidal, dense aggregates, encrusting, globular  hexagonal system, rhombohedral, small crystals, mainly in druses
Italy. New Jersey (U.S.A.), Tasmania	franklinite, willemite, calcite, rhodonite	**Zincite** Red Oxide of Zinc ZnO Blowpipe: not fusible	of only local importance as zinc ore	massive, granular, scaly, foliaceous  hexagonal system, flat 6-sided plates with pyramids

glas. = glassy res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
58	ruby red, yellowish-red	5·0 / 4·0	red to brownish-yellow	ad. / trp.	none, flexible / perfect	frequently covering limonite, also with pyrite
59	pale to copper red, brown, tarnishes easily	5·5 / 7·3 – 7·7	brownish-black	met. / op.	conch., uneven / rarely seen	in hydrothermal veins
60	pale flesh-coloured, red, rose red, also brownish-red	5·5 – 6·5 / 3·4 – 3·68	white	glas., cleavage plane pearl. / trp. – trl.	conch., uneven / perfect	as layers alternating with bands of silica or slate in lead-silver veins
61	red to red-brown	up to 6·5; very variable / 5·2 – 5·3	red, red-brown	dull / op.	rough / none	in veins, layers, or ore beds, usually in limestone

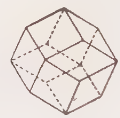
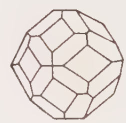
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
n many imonite ore leposits	limonite, goethite, pyrite	**Micaceous Goethite** / γ–FeOOH Blowpipe: fusible; becomes red and magnetic		powdery, mammilated nodules flat plates small plates, rosettes
Cornwall, Erzgebirge, Black Forest Germany), Spain, Argentine, Cobalt Ontario)	nickel ores, barytes, copper and silver ores, galena, chromite	**Kupfernickel** Niccolite / NiAs Blowpipe: fusible; soluble in conc. acids giving red solution	nickel ore	massive, injected in irregular masses, botryoidal, reniform crystals, rare, massive hexagonal system, crystals rare, 6-sided pyramids
Harz Mts. Germany), Spain, Hungary, France, Sweden, Urals, Brazil, Mexico, Broken Hill New South Wales)	crystalline schists; quartz, hausmannite, braunite, magnetite, galena	**Rhodonite** (Manganese Spar) / (Mn,Fe,Ca)[SiO_3] Blowpipe: fuses into black globules	ornamental work; black or violet glaze on stonework, glass colouring (violet)	massive and cleavable, large crystals, granular  triclinic system, tabular, prisms, crystals rare – large and imperfect
North Lancashire, Forest of Dean, Cumberland, Bilbao (Spain), Minnesota, Alabama U.S.A.), Newfoundland	in limestones or porphyries; orthoclase, heulandite, limonite	**Haematite** (red varieties) / Fe_2O_3 see also No. 118 Plate I.15 Blowpipe: not fusible; magnetic	iron ore	massive, dense; fibrous, earthy (reddle), foliaceous (micaceous haematite), also reniform (kidney ore) none (scaly)

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
62	brownish-red, blood red, red-brown, dark green (no blues)	6·0 – 6·5 – 7·0 / 3·4 – 4·6	white	glas., fat. / op.	sub-conch., brittle, rough / poor	common rock-forming mineral in metamorphic rocks formed from clayey sediments, limestones, dolomites and basic igneous rocks; heavy residue in sediments
63	1. pink 2. red, yellow, brown	7·0 / 2·65	1. white	1. vit. 2. vit. / 1. trp. – trl. 2. op.	conch., brittle / very poor	1. in pegmatites 2. in coarse sandstones

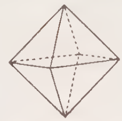
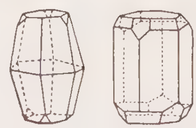
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
common in schists of Scottish Highlands, Germany, Alps, Scandinavia, etc.; commercial garnets from U.S.A. (Adirondacks); gems: Ceylon, Australia, Urals, S. Africa, Brazil, Mexico	schists and gneisses, calcite, wollastonite, epidote, magnetite, hornblende, biotite, diopside, clinochlore, galena, idocrase	**Garnet** / 1. Grossular = hyacinth-red $Ca_3Al_2[SiO_4]_3$ 2. Andradite = brown $Ca_3Fe_2^{\cdots}[SiO_4]_3$ Melanite = black $Ca_3Fe_2^{\cdot\cdot}[SiO_4]_3$ 3. Pyrope = blood-red $Mg_3Al_2[SiO_4]_3$ 4. Almandine = deep red $Fe_3^{\cdot\cdot}Al_2[SiO_4]_3$ 5. Spessartite = brownish-red $Mn_3Al_2[SiO_4]_3$ 6. Uvaronite = emerald green $Ca_3Cr_2^{\cdots}[SiO_4]_3$ Plate XI.18 Blowpipe: 1. fuses – pale green 2. fuses – black 3. difficult to fuse 4. fuses – black 5. fuses	abrasive, gemstone	granular, massive, dense or as phenocrysts   / cubic system, dodecahedra, icositetrahedra, also round grains
1. Bavaria, Finland, Urals, Maine (U.S.A.), Brazil, S.W. Africa 2. As grains in most coarse sediments	1. vein minerals 2. components of coarse sediments	**1. Rose Quartz** / SiO_2 **2. Ferruginous Quartz** / SiO_2 Blowpipe: not fusible	1. gemstone	1. coarsely crystalline 2. usually rounded grains / hexagonal system 1. crystal faces rarely seen 2. no crystal form

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
64	red, blue, black and all colours	8·0 / 3·5 – 4·1	white	vit. / trp. – trl.	conch. / very poor	in contact metamorphosed rocks, accessory mineral in igneous rocks
65	red, blue, brown, grey, black	9·0 / 3·9 – 4·1	white	vit. / trp. – trl. to op.	conch., brittle / none, separation plane on twin plane	in contact metamorphosed rocks, segregation veins in some peridotites, in certain acid igneous rocks and residual sediments

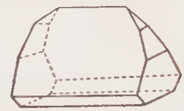
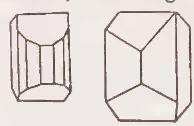
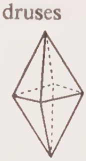
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
gems: Ceylon, Burma, Siam, Afghanistan; also Sweden, U.S.A., Brazil	calcite and dolomite, zircon, garnet, magnetite, chlorite	**Spinel** $MgAl_2O_4$ Blowpipe: not fusible	gemstone (some varieties)	usually small individual grains  cubic system, well-developed octahedra, twins
Naxos (Greece), Transvaal, Turkey, Australia, Canada, U.S.A., Urals. Gemstones: Burma, Ceylon, Siam, U.S.A., Queensland	chlorite, spinel, enstatite, magnetite, muscovite, haematite, quartz	**Corundum** Al_2O_3 Varieties: Sapphire – blue, Ruby – red, Emery – small grains, greyish black Plate V.1–5 Blowpipe: not fusible, insoluble in acids	gemstone (coloured varieties), abrasive	massive, crystalline, granular; crystals barrel-shaped  hexagonal system, rhombohedra, intergrown crystals, large prisms and pyramids

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
66	yellow, pale brown	1·5 – 2·0 / 1·66 – 1·7		vit. / trl.	— / good	peat bogs
67	lemon yellow	1·5 – 2·0 / 3·4 – 3·5	yellow	fat., pearl. / trl.	— / perfect, cleavage surface cross striated, lamellae flexible	as realgar, also weathering product of arsenic minerals, deposit from some hot springs, volcanic sublimate
68	sulphur yellow, brown	2·0 / 1·9 – 2·1	pale yellow	res., ad. / trp. – trl.	conch., uneven / fairly good	craters and crevice of extinct volcanoes, bedded in sediments (near volcanoes)
69	wax yellow, honey-coloured, clouded	2·0 – 2·5 / 1·0 – 1·1	white	res. / trp. – trl.	conch. / brittle	as irregular nodular fragments in late Tertiary strata of estuarine origin

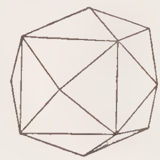
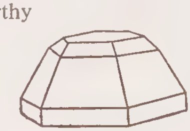
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Germany, Australia, Guiana	organic decomposition products	**Struvite** ——— $NH_4Mg[PO_4].$ $6H_2O$ soluble in acids		crystals with sharp corners  orthorhombic system, crystals sometimes intergrown
Caucasus, Macedonia, taly, Kurdestan Turkey and Persia)	realgar and other arsenic minerals	**Orpiment** ——— As_2S_3 gives reddish- yellow sublimate on heating; Blowpipe: fuses easily, bluish- white flame	arsenic ore (insecticide, weed-killer), also as pigment in lacquer work	crystals rare, small, short prisms, lense-shaped – rounded aggregates, foliaceous, encrusting  monoclinic system, prisms, crystals rarely good
Sicily, Spain, Texas, Louisiana, Japan	among lavas, ashes, tuffs, etc.; gypsum, celestine, calcite, aragonite, sulphates and carbonates	**Native Sulphur** ——— S Blowpipe: fuses easily, oxidised to SO_2, volatile	manufacture of H_2SO_4 gunpowder, vulcanising rubber, bleaching, weed-killers, insecticides	granular, fibrous, radiating floury, encrusting, in nod- ules and druses  orthorhombic system, crys- tals at times large with acute pyramids
Prussian Coast of Baltic, Galicia Poland), Sicily	resins like amber, lignite, sand, clay	**Amber** ——— approx. $C_{40}H_{64}O_4$	ornaments, mouthpieces of pipes, black varnish	reniform, amorphous, grains, plates no crystals amorphous, irregular nodules

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
70	golden yellow, does not tarnish, green in transmitted light	2·5 – 3·0 / 15·5 – 19·3	pale golden yellow	met. / op.	hackly, very ductile / none, soft and malleable	veins (reefs), in sediments, e.g. banket (gold-bearing conglomerates), placer or alluvial deposits
71	honey yellow, orange yellow	3·0 – 3·5 / 4·9 – 5·0	yellow	res., ad. / trl.	/ distinct	weathering product of cadmium–zinc blende
72	orange yellow, lemon yellow, wax yellow, honey-coloured, reddish	3·0 / 6·7 – 6·9	yellowish-white	ad., waxy / trp. – trl.	conch., uneven to brittle / fairly good	weathering product of lead deposits

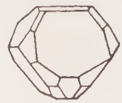
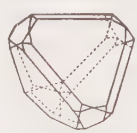
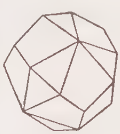
vit. = vitreous, silk. = silky, met. = metallic pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Veins: Austria, Western U.S.A., Victoria, New South Wales, Urals, New Zealand, Mexico; *Old Sediments*: Rand (S. Africa), New South Wales, South Dakota; *Placers*: Urals, India, Ghana, Alaska, U.S.A., S. America, Australia	sulphides, tetrahedrite, silver ores, galena, limonite, quartz, pyrites, arsenopyrite, barytes, calcite, fluorspar, zinc blende	**Native Gold** Au Plate III.5 Blowpipe: easily fused; soluble in aqua regia	precious metal	thin foils, threads, etc., good crystals rare, twinned and often distorted; grains and scales in alluvium, large masses (nuggets) in alluvium or veins  cubic system, cubes with edges and corners rounded
Bishopton (Scotland), Upper Silesia (Czechoslovakia), Pennsylvania, widespread elsewhere	zinc blende	**Greenockite** CdS Blowpipe: not fusible; soluble in HCl	not sufficiently abundant to be worked as cadmium ore	platy pyramidal form, in prisms, encrustations, earthy  hexagonal system, hemimorphic, crystals rare and small
Alps, Czechoslovakia, Hungary, Pennsylvania, Arizona, Utah, French Congo	lead ores, calcite, molybdenum ores	**Wulfenite** $Pb[MoO_4]$ Blowpipe: fusible; soluble in HCl and HNO_3	molybdenum ore (manufacture of special steels, catalysts, pigments)	prismatic, pyramidal, massive, dense, drusy, loose aggregates, crystalline crusts  tetragonal system, pyramids usually set on short prismatic plates

glas. = glassy res. = resinous; op. = opaque, trp. = transparent trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
73	pale yellow, colourless, white	3·5 / 4·3 – 4·5		vit. / trp.	— / perfect	weathering product of zinc ores
74	brass yellow, golden yellow, tarnishes, sometimes irridescent, black	3·5 – 4·0 / 4·1 – 4·3	greenish-black	met. yellow / op.	conch., uneven / rarely distinguishable	in pneumatolitic and hydrothermal veins; with sulphide and skarn minerals at limestone-igneous contacts, in kupferschiefer
75	brass yellow to bronze yellow (often tarnished)	3·5 / 5·3	greenish-black	met. / op.	uneven / perfect	in veins associated with other nickel minerals, never in large quantities; as nodules in clay-ironstone
76	yellow, red, brown, black	3·5 – 4·0 / 3·9 – 4·2	yellowish, white, leather-brown	ad. – res. / trp., trl. – op.	conch., brittle / perfect	metasomatic cavity and joint fillings and disseminations in limestone; hydrothermal vein deposits; in areas of contact metamorphism

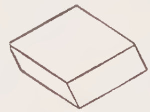
vit. = vitreous, silk = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Greece, Algeria, S.W. Africa (Tsumeb), Utah, Arizona	zinc minerals	**Adamite** $Zn_2[OH\|AsO_4]$ Blowpipe: easily fused; soluble in acids		drusy, aggregates of small grains very small crystals, many faces
Cornwall, Germany (Harz Mts., Mansfeld), Alsace (France), Spain (Rio Tinto), Scandinavia, Japan, Korea, U.S.A. widespread)	tetrahedrite, zinc blende, galena, limonite, malachite, azurite, copper glance, pyrites, blue vitriol	**Chalcopyrite.** Copper Pyrites $CuFeS_2$ Blowpipe: fusible, blue flame, leaving black magnetic grains	principal copper ore	massive, crystals small, in druses, coating, reniform, never fibrous or radiating  tetragonal system, crystals cubic, surfaces usually rough and dull; twins more common than single crystals
Cornwall, Saxony, Pennsylvania, Cobalt (Ontario)	siderite, chalcopyrite and other sulphides, nickel, kupferschiefer and occasionally coal	**Millerite** (Nickel Pyrites) (Capillary Pyrites) NiS Blowpipe: easily fused to magnetic bead; green solution with HNO_3	minor nickel ore	in very fine capillary crystals, in fibrous bushels, rarely massive small hairs hexagonal, rhombohedral, needles, radially fibrous
Cornwall, Cardiganshire, Derbyshire, Cumberland, Bohemia, Westphalia, Mississippi Valley (U.S.A.), New Mexico, Broken Hill (New South Wales), Siberia	galena, quartz, calcite, barytes, fluorspar, siderite, pyrites, chalcopyrite	**Blende** Sphalerite (Black Jack) ZnS Plate II.13 Blowpipe: fusion of edges difficult; soluble in HCl	most important zinc ore	massive, cleavable, granular, frequent twins, radial aggregates; sometimes dense, fibrous, foliaceous, encrusting   cubic system, tetrahedra, crystals frequently distorted and often twinned

glas. = glassy res. = resinous; op. = opaque trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
77	pale yellowish, buff, brownish, grey, brownish-black	4·0 – 4·5 / 3·7 – 3·9	colourless, brownish-black from weathered mineral	vit. / trl. – op.	conch., uneven / perfect rhombohedral	in sediments as ribs and nodules, metasomatic replacement of limestone, in veins associated with cryolite and tin ores
78	bronze-coloured, brownish, reddish, tarnishes on exposure	4·0 / 4·6	greyish-black	met. / op.	sub-conch., uneven / distinct, lamellar	in and near basic igneous rocks, esp. norites; less common in veins
79	yellow, brown, colourless, silver-white, greyish-green	5·0 / 4·3 – 4·5	white	vit., pearl. / trl. – op.	conch., uneven, brittle / perfect rhombohedral	alteration product of zinc blende, metasomatic replacement in limestone or dolomite

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
Cleveland, Northampton-hire, as lay-ironstone hroughout British and other coal-ields; Spain, Germany, Croatia, Connecticut, Greenland	quartz, chalcopyrite, cryolite, tin ores, pyrolusite	**Siderite** Chalybite (Spathose Iron) — $FeCO_3$ Plate I.3, 22 Blowpipe: not fusible; soluble in HCl	oolitic iron ore	massive, cleavable, granular, oolitic, saddle-shaped, mixed with clay minerals in concretions as clay-ironstone  hexagonal system, rhombohedra, faces often curved, lenticular, flat, bent crystals
Cornwall, Devon, Dolgelly (Wales), Norway, Black Forest, Harz, etc. (Germany), Sudbury (Ontario), South Africa	magnetite, pyrite, chalcopyrite, nickel ores, ilmenite	**Pyrrhotite** (Magnetic Pyrites) — FeS (up to 5% Ni) Blowpipe: fuses to black magnetic globule	valuable nickel ore	massive, granular, dense aggregates, foliaceous  hexagonal system, 6-sided tabular prisms, prisms in rosettes
Mendip Hills (Somerset), Matlock (Derbyshire), Alston Moor (Cumberland), Leadhills (Scotland), Germany, Algeria, S.W. Africa, Missouri (U.S.A.), East Asia	calcite, dolomite, blende, hemimorphite, galena	**Smithsonite** (Calamine) — $ZnCO_3$ Blowpipe: not fusible; soluble in HCl	important zinc ore	massive, reniform, botryoidal; in stalactitic or foliaceous masses and crusts; dense, porous, granular; crystals usually too small and indistinct; hexagonal system, rhombohedral; crystals small

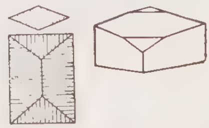
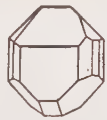
glas. – glassy, res. – resinous; op. – opaque, trp. – transparent, trl. – translucent; conch. – conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
80	yellow, greenish, brown, black, red-brown	5·0 – 5·5 / 3·4 – 3·6	colourless	vit. – ad. / sub-trp. – op.	conch., brittle / fairly good, sometimes lamellar	as accessory mineral in acid igneous rocks; abundant in some lime-rich rocks, e.g. contact altered limestones
81	pale yellow, dark brown	5·0 – 5·5 / 4·8 – 5·3	white	res. / op.	conch., brittle / imperfect, sometimes good	in clefts in silicate rocks, as accessory mineral in granites and gneisses; heavy residue in sediments (monazite sands)
82	brown, green	5·5 / 3·2 – 3·5	white	met. – bronze-like or silk. / trl. – op.	none / sometimes good, lamellar	in the olivine crystals of basalts
83	honey-coloured, brown, blue-black, hyacinth red	5·5 – 6·0 / 3·8 – 3·9	whitish	ad., res., met. / sub-trp. – trl.	none / perfect	veins of hydrothermal origin, weathered igneous rocks, sandstones

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Plate IV Minerals illustrating Mohs' scale of hardness

1st Row: 1. Talc, 2. Gypsum, 3. Calcite; *2nd Row*: 4. Fluorspar, 5. Apatite, 6. Feldspar; *3rd Row*: 7. Quartz, 8. Topaz; *4th Row*: 9. Corundum, 10. Diamond.

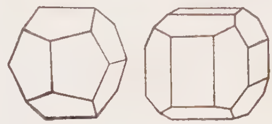
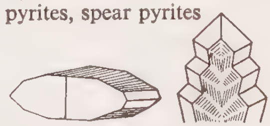
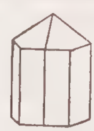
Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Saxony, Austrian Alps, Canada, Massachussets (U.S.A.), worked in Kola Peninsula (U.S.S.R.)	chlorite, albite, adularia, sanidine, hornblende	**Sphene** (Titanite) / $CaTi[O\|SiO_4]$ Blowpipe: fuses with difficulty; decomposed by H_2SO_4	local ore of titanium (white pigment, steel manufacture)	massive, granular, scaly aggregates, envelope-shaped, penetration twins  monoclinic system, wedge- or lozenge-shaped, elongate, twins common
Norway, Travancore (India), East Indies, Brazil, Nigeria	garnet, zircon, chromite, gold, diamond	**Monazite** / $Ce[PO_4]$ (with ThO_2 and SiO_2) Blowpipe: barely fusible; soluble in HCl	source of thorium, cerium and other rare earth metals; electrodes, medical treatment (radio-active)	rolled grains of sand size, thick tabular crystals, massive  monoclinic system, crystals single or grown together
widespread	serpentine	**Bronzite** (Iron-bearing Enstatite) (Pyroxene Family) / $(Mg,Fe)_2[Si_2O_6]$ cf. Augite, No. 137 Blowpipe: Infusible (only edges of fine splinters fused)		fibrous with bronze-like schiller lustre, crystals rare crystals rare orthorhombic system, incompletely formed crystals in rock
Germany, Minas Geraes (Brazil), Colorado, Urals	quartz, rutile	**Anatase** / TiO_2 Blowpipe: not fusible		slender acute pyramids, tabular crystals or roundish  tetragonal system, small crystals

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

E

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
84	pale brass yellow to bronze yellow	6·0 – 6·5 / 5·0 – 5·2	greenish-black	met. / op.	conch., uneven / sometimes good	very common in ore deposits and veins, disseminated in many weathered sedimentary rocks, accessory in igneous rocks
85	yellow, greenish (like pyrites)	6·0 – 6·5 / 4·8 – 4·9	greenish-blackish-grey	met. / op.	uneven, brittle / very poor	in concretions in sedimentary rocks, e.g. chalk; replacement in limestones; in veins
86	yellowish-red, wine yellow, sea blue, green, colourless	8·0 / 3·5 – 3·6	white	vit. / trp. – op.	sub-conch., uneven / perfect	accessory mineral in acid igneous rocks; in zone of contact alteration around granite margins; in pegmatites and tin veins

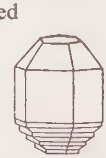
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Rio Tinto (Spain), Portugal, Harz Mts. (Germany), Scandinavia, France, Cyprus, Tasmania, Transvaal, Mexico, Colorado, Pennsylvania	haematite, galena, chalcopyrite, blende, arsenopyrite, pyrrhotite, gold	**Pyrite** Iron Pyrites / FeS_2 Plate I.23 Blowpipe: fuses to black magnetic residue	manufacture of sulphuric acid and alum; manufacture of sulphur	crystals very shiny, smooth, striated in triangles, granular or radially fibrous aggregates, massive, nodular, reniform; fossils frequently preserved in pyrite  / cubic system, cubes and pyritohedra, usually well developed, sometimes distorted, about 60 different shapes
English Chalk, Bohemia, Bolivia	chalcopyrite, pyrite, galena, blende	**Marcasite** (White Iron Pyrites) / FeS_2 Plate I.18 Blowpipe: fuses to black magnetic residue		twig-like tabular, radiating nodular forms; twinned aggregates form cockscomb pyrites, spear pyrites  / orthorhombic system, short prisms, often repeatedly twinned, producing pseudo-hexagonal forms
Mourne Mts. (Ireland), Sweden, Asia Minor, California. Gemstone Urals, Japan, S. Rhodesia, Brazil	granite minerals, cassiterite, fluorspar, tourmaline	**Topaz** / $Al_2[FOH)_2SiO_4]$ Plate XI.14	gemstone	massive, in parallel, radiating or dense aggregates, short and long prisms  / orthorhombic system, prismatic double pyramid, twins

glas. = glassy, res. = resinous; op. = opaque trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
87	brown, yellow, black	1·0 – 5·5 / about 3·8 (variable)	yellowish-brown	sub-met., silk., earthy / op.	conch. / none	alteration product of iron-bearing minerals (common in iron caps); responsible for the yellow and brown coloration of many rocks
88	pinchbeck brown, reddish; tarnishes and becomes irridescent on exposure (Peacock Ore)	3·0 / 4·9 – 5·3	pale greyish-black	met. / op.	conch., uneven / seldom distinct	primary deposit in copper lodes, also in zone of secondary enrichment; associated with magmas as segregation or late magmatic product
89	pale pinchbeck brown, bronze yellow	3·5 – 4·0 / 4·6 – 5·0	black	met. / op.	brittle / good, granular	occurs intergrown with pyrrhotite, same mode of occurrence; also in basic plutonic rocks
90	pale to dark brown	3·5 – 4·0 / 4·0	pale brown	vit. / op.	fibrous, smooth / good	associated with lamellar sphalerite (blende), in which it occurs as radiating bundles

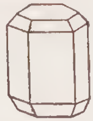
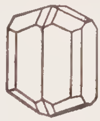
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond.

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
widespread throughout the world; present in some of the Jurassic iron ores of England; "Minette" ores of Alsace-Lorraine	pyrites, siderite	**Limonite** (Brown Haematite) $Fe_2O_3.nH_2O$ Plate I.2 Blowpipe: not fusible	iron ore	dull, earthy, fibrous, oolitic or pisolitic (Pea Iron Ore), reniform, stalactitic, concretionary, often with black glazed coating; Bog Iron Ore: loose, porous, earthy crystals too small amorphous (colloidal origin)
Cornwall (horse-flesh ore), Germany (in Kupferschiefer), Sweden, Namaqualand (S. Africa)	chalcopyrite, chalcocite, zinc blende, galena, magnetite	**Bornite** Erubescite (Variegated Copper Ore) Cu_5FeS_4 Blowpipe: fuses to grey magnetic globule	valuable copper ore	massive, irregular fragments, dense, platy crystals rare cubic system, cube or octahedron with rough surface
Germany, Sweden, Norway, U.S.S.R., Sudbury (Ontario), Transvaal	pyrrhotite, kupfernickel, chalcopyrite	**Pentlandite** $(Fe,Ni)_9S_8$(?) Not soluble in HCl	valuable nickel ore	grains, small to fist size granular aggregates cubic system, usually grains without crystal form
Germany, Bohemia, Silesia, Bolivia	blende	**Wurtzite** ZnS Blowpipe: edges only fusible		massive, usually in lamellar layers, encrusting crystals seldom well developed  hexagonal system, crystals rare, striated; 6-sided prisms with pyramids

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
91	brown, blue, green, honey yellow, orange red, white, colourless; colours often vivid	3·5 – 4·0 / 6·7 – 7·0	whitish	res., ad. / trl.	conch., uneven, brittle / trace or none	with other lead ores in oxidation zone of lead veins
92	black, brown, pale yellow	5·0 – 5·5 / 3·8 – 4·3	brown to brownish-yellow	ad., silk., dull / thin splinters trl.	rough / good (1 direction)	ore formed by weathering near present or fossil land surfaces; disseminated in reddened sedimentary rocks
93	yellowish-brown to red-brown, sometimes black	5·5 – 6·0 / 4·2 – 4·9	yellowish-white to brown	ad. / trp. – trl.	metallic, brittle / poor	in cracks and druses, usually as single crystals; alteration product of other titanium-bearing minerals
94	brownish, reddish-brown, black, greenish	6·0 – 6·5 / 3·5 – 3·55	yellowish-grey to dark green	vit. – res. / op., edges trl.	uneven / distinct	in soda-rich igneous rocks, pegmatite veins

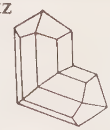
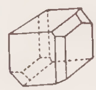
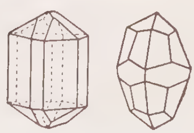
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Cornwall, Derbyshire, Cumberland, Leadhills (Scotland), Saxony, Harz, Bohemia, Rhodesia, Pennsylvania	galena	**Pyromorphite** (Green Lead Ore) $Pb_5[Cl \mid (PO_4)3]$ Blowpipe: fusible; blue-green flame	minor lead ore	reniform, botryoidal, massive, aggregates, encrusting  hexagonal system, prismatic crystals, often barrel-shaped
Cornwall, Saxony, Thuringia, Russia, Michigan	limonite, haematite, turgite	**Goethite** α–FeOOH Blowpipe: fusible		radiating fibrous aggregates massive, powdery, granular  orthorhombic system, double pyramids, prisms, longitudinally striated; capillary or needle-shaped
Tremadoc (North Wales), Alps, Arkansas (U.S.A.)	silicate rocks	**Brookite** TiO_2 Blowpipe: not fusible		single detached crystals  orthorhombic system, tabular crystals vertically striated
Sweden, Norway, Roumania, Portugal, Kola Peninsula (U.S.S.R.), Greenland, Arkansas (U.S.A.), Brazil	augite and hornblende	**Aegirine** (Acmite) (Pyroxene Family) $NaFe^{\cdots}[Si_2O_6]$ Blowpipe: easily fused: yellow flame		ingrowing in druses, capillary and fibrous, twins  monoclinic system, long prisms with pointed terminations (acmite); shorter prisms (aegirine); striated

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
95	brown, black, reddish-brown, blood red	6·0 – 6·5 / 4·2 – 4·3	pale yellow to green	met. / trl. – op.	conch., uneven, brittle / good to poor	accessory mineral in basic igneous rocks, and as large magmatic segregations and veins associated with gabbros and norites, apatite veins, concentrated in some beach sands and other detrital deposits
96	clove brown, smoky-grey, plum-blue, greenish	6·5 – 7·0 / 3·3	white	vit. / trp. – trl.	conch., brittle / fairly distinct	zone of contact metamorphism of igneous rocks in limestones
97	brown, brownish-black	6·0 – 7·0 / 6·8 – 7·1	white to pale yellow	very brilliant on crystal faces, ad. / trl. – op.	conch. / incomplete	veins associated with granites and porphyries; alluvial (placer) deposits; accessory mineral in granites and pegmatites

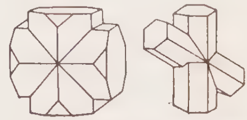
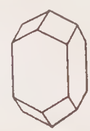
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Norway, Sweden, Quebec, Ontario, Virginia, Georgia, Florida, Arkansas (U.S.A.), Travancore (India), Australia, Tasmania, Senegal	other titanium minerals, apatite, quartz, kyanite	**Rutile** / TiO_2 Blowpipe: not fusible; insoluble in acids	important titanium ore	compact masses, grains, thin hairs and needles in interior of quartz  / tetragonal system, prisms with pyramids, needle-shaped, radially grouped, knee-shaped twins, repeated twinning forming wheel-shaped multiple twins; distorted and longitudinally striated forms
Cornwall, Harz Mts., Saxony, Switzerland, Hungary, Spain, U.S.A. (Pennsylvania, California, New York), Canada	tourmaline, magnetite	**Axinite** / $Ca_2(Mn,Fe)Al_2BH[SiO_4]_4$ Blowpipe: easily fused to green bead	rarely as gemstone	massive, lamellar, columnar, crystalline aggregates  / triclinic system, thin sharp-edged crystals, single or in druses
Cornwall, Malaya, East Indies, Burma, Siam, China, Nigeria, Congo, Bolivia, Australia; also Erzgebirge (Bohemia and Saxony)	quartz, orthoclase, muscovite, rutile, stannine, chalcopyrite, wolfram, scheelite, arsenopyrite, blende, pyrites, galena	**Cassiterite** Tinstone / SnO_2 Blowpipe: not fusible; insoluble in acids	most important tin ore	massive, fibrous, disseminated in small grains  / tetragonal system, very variable, short prisms terminated by pyramids, striated

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
98	red-brown, blackish-brown	7·0 – 7·5 / 3·7 – 3·8	white	vit., also dull / trl. – op.	conch., uneven, brittle / good, interrupted	metamorphic rocks
99	brownish-red, colourless when pure	7·5 / 3·9 – 4·8	white	ad. – res. / trp. – trl., op.	conch. / indistinct	accessory in acid igneous rocks, in decomposed acid pegmatites and in metamorphic rocks; as detrital grains in some sandstones

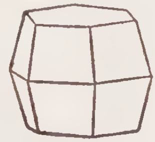
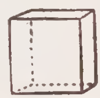
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Scottish Highlands, Switzerland, Austria, Brittany, Russia, U.S.A.	staurolite – mica schists, gneisses, kyanite	**Staurolite** $Fe(OH)_2.2Al_2SiO_5$ *or* $(OH)_2.FeAl_4[Si_2O_{10}]$ Blowpipe: not fusible; insoluble in acids		embedded, prismatic, cross-shaped twins (staurolite twins)  orthorhombic system, long or short 6-sided prismatic crystals
Norway, Ceylon, India, Urals, New South Wales, West Africa, Madagascar, U.S.A.	in granite, quartz-porphyry, trachyte, syenite, sandstones, black sands with rutile and ilmenite	**Zircon** $Zr[SiO_4]$ Plate XI.15 Blowpipe: not fusible; insoluble in acids; gem var.: Hyacinth See Gemstones, p. 237	gemstone, source of zirconium (used in manufacture of refractory crucibles, wireless valves, etc., flashlight powders and metal alloys)	prismatic crystals, never massive, also in rounded detrital grains  tetragonal system, prism and pyramid, twins

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
100	lead grey (vaguely violet)	1·0 – 1·5 / 4·7 – 4·8	dark grey	strongly met. / op.	none, sectile, almost malleable / perfect	granites, pegmatites, quartz veins; also in some contact metamorphic zones; widespread but in small quantities
101	lead grey, black, tarnishes	1·5 / 11·4	grey	dull / op.	none (soft) / none	in ore bodies rich in manganese (very rare)
102	lead grey to tin white, tarnishes with irridescence	2·0 / 6·8 – 7·2	dark lead grey	strongly met. / op.	conch. / very good	in veins associated with tin, silver, cobalt, and other ores
103	lead grey, tarnishes with irridescence	2·0 / 4·6 – 4·7	dark blue-grey	met. – dull, tarnishing / op.	conch. / very good	in veins, mainly associated with quartz

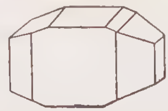
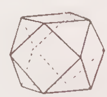
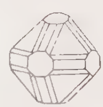
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Norway, Colorado, New Mexico (U.S.A.), Canada, Queensland and New South Wales (Australia), Morocco, China	granites, quartz veins (easily confused with graphite)	**Molybdenite** ——— MoS_2 Blowpipe: not fusible, green flame	chief ore of molybdenum (manufacture of special steel, electrical purposes, pigment)	massive, in foliaceous and scaly aggregates, laminae are flexible  hexagonal system, flat 6-sided plates, crystals rare – short prismatic or barrel-shaped
Sweden, Transylvania, Urals, Altai (U.S.S.R.), Korea, New Jersey, Idaho (U.S.A.)	manganese ores	**Native Lead** ——— Pb Blowpipe: easily fused	rare	capillary, wiry, infilling, loose  cubic system, cubes up to 4 cm., very rare
Cornwall, Cumberland, Saxony, Sweden, Bolivia	antimonite, chalcopyrite	**Bismuthinite** (Bismuth Glance) ——— Bi_2S_3 Blowpipe: fuses easily	bismuth ore (medical, e.g. bismuth meals; cosmetic preparations; glaze on porcelain; low fusion point alloys)	massive, cleavable and columnar aggregates needle-like prisms resembling stibnite, No. 103 orthorhombic system, small needle-like crystals
Cornwall, Germany (Westphalia, Saxony), Auvergne (France), Sardinia, Portugal, Algeria, Russia, Japan, Hunan (China), Bolivia	quartz, bismuthinite, galena, cinnabar, realgar, orpiment	**Stibnite** Antimonite (Antimony Glance) ——— Sb_2S_3 Plate III.10 Fuses with match flame	antimony ore (alloys with lead, paint pigments, etc.)	in thin needles, blades, also massive, fibrous, in masses of radiating crystals  orthorhombic system, crystals elongated and longitudinally striated

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
104	greyish-white, yellowish, dark grey	2·0 – 2·5 / c. 5·0	black	met. / op.	none / good	residual lateritic deposit, forming layers and nodules in the surface clay
105	dark lead grey, iron black	2·0 – 2·5 / 7·0 – 7·3	dark grey, shiny	met., tarnishes / op.	sub-conch., small / indistinct	in veins, mainly with lead ores; generally connected with igneous rocks
106	lead grey, sometimes tarnishes	2·5 / 7·2 – 7·6	greyish-black	met. / op.	flat, even (on cleavage) conch. / perfect cubic	as disseminations, in veins or lodes in limestones and dolomites or sometimes sandstones; sometimes near intrusive igneous rocks

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
India, Minas Geraes (Brazil), Ghana, Transvaal, Arkansas (U.S.A.), Transcaucasia	manganite, psilomelane	**Pyrolusite** / MnO_2 Blowpipe: not fusible	manganese ore (steel manufacture, dry batteries, disinfectants)	radiating, fibrous structures, massive, reniform  orthorhombic system, in radiating crystalline masses; pseudomorphing manganite
Saxony (Germany), Norway, Colorado, Nevada, Utah (U.S.A.), British Columbia, Ontario (Canada), Mexico, South America	silver ores, chalcopyrite	**Argentite** Silver Glance / Ag_2S Blowpipe: fusible; soluble in conc. HNO_3	important silver ore	massive, in plates, reticulated, arborescent; mainly small crystals / cubic system, cube with octahedron
Derbyshire, Flintshire, Cumberland, Isle of Man, etc.; Germany, Bohemia, Sweden, Siberia, Spain, Greece, Idaho, Colorado, Kansas (U.S.A.), Brit. Columbia, Burma, Rhodesia, N.S.W. (Australia)	chalcopyrite, quartz, calcite, barytes, siderite, blende, silver ores; resembles antimonite	**Galena** (Lead Glance) (Blue Lead) / PbS (some AgS usually present) Plate II.8, III.7, 11 Blowpipe: gives off sulphurous fumes, forms yellowish-green encrustation, and fuses to metallic globule (lead); soluble in HNO_3	most important lead ore; silver extracted from "argentiferous galena"	massive, sometimes platy, as coating, coarsely and finely granular, fibrous and sometimes foliated   cubic system, cube often modified by octahedral forms; crystals usually well developed and large, edges rounded

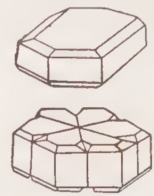
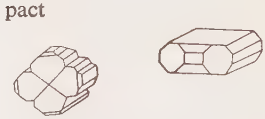
glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
107	dark lead grey	2·5 – 3·0 / 5·7 – 5·8	dark grey, shining	met., strong / op.	conch. – uneven / poor	in zone of secondary enrichment of primary copper ores; formed by action of ground waters; in veins or beds; sometimes as nodules in sandstone
108	dark lead grey	2·5 / 6·2 – 6·8	black	met. / op.	none / fibrous	in hydrothermal veins, siderite veins
109	lead grey to steel grey, iron black	3·0 / 5·5 – 5·9	grey	met. / op.	conch. / distinct	like tetrahedrite (No. 111), with which it is commonly associated
110	steel grey to iron black	3·5 / 4·4	black	met. / op.	brittle / good	in veins with other copper ores

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

PLATE V Rock-forming minerals: 1. Minerals in igneous rocks

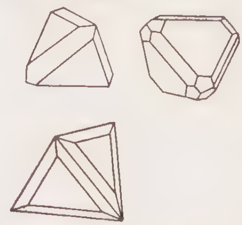
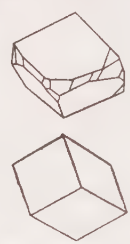
1st Row: 1. Quartz, 2. Orthoclase (Feldspar), 3. Microline (Feldspar); *2nd Row*: 4. Oligoclase (Feldspar), 5. Leucite with black Garnet (Melanite), 6. Garnet; *3rd Row*: 7. Augite, 8. Hornblende, 9. Green Tourmaline, 10. Epidote; *4th Row*: 11. Biotite (Mica), 12. Muscovite (Mica).

Localities	*Associated Minerals*	*Name*	*Uses*	*Common Forms: Diagram*
		Formula		*Crystal Form*
Cornwall, Norway, Germany, Sicily, Spain, S.W. Africa, U.S.A., Mexico	galena, argentite, chalcopyrite, bornite, enargite, tetrahedrite	**Chalcocite** (Copper Glance)	valuable copper ore	massive, cleavable, as coating, tabular, compact 
		Cu_2S Blowpipe: boils and then fuses to globule of copper; forms blue solution in HNO_3 and precipitates sulphur		orthorhombic system, thick plates or prisms, crystals in groups, as twins with stellate grouping of three crystals
Sweden, Austria, Germany, Bohemia, Tuscany, Urals	antimonite, galena, quartz, siderite	**Boulangerite**		massive, finely granular, compact, fibrous, radiating aggregates usually finely crystalline fibrous
		$5PbS.2Sb_2S_3$ Blowpipe: fusible		orthorhombic system, crystals very rare, prismatic
Cornwall, Germany (Harz Mts.), Hungary, Italy, Transylvania, Mexico, Bolivia, Chile, Peru	galena, tetrahedrite, barytes, siderite	**Bournonite** (Wheel Ore)	lead-copper ore	massive, granular to compact 
		$2PbS.Cu_2S.Sb_2S_3$ Blowpipe: fuses easily		orthorhombic system, thick tabular crystals, twinned to form structure like cog wheel
Serbia, Hungary, Spain, Argentine, Chile, Peru, Montana (U.S.A.), Japan, Luzon (Philippines), S.W. Africa	pyrite, chalcocite, bornite, manganite	**Enargite**	copper ore	massive, granular, radiating crystals rare
		Cu_3AsS_4 Soluble in HNO_3		orthorhombic system, prismatic crystals with vertical striations, small

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
111	steel grey, iron black, tarnishes; when coated with chalcopyrite, brass yellow	3·0 – 4·0 / 4·4 – 5·4	black to reddish-brown, grey	met. / op.	sub-conch. – uneven / almost absent	in veins with chalcopyrite
112	greyish-white, yellowish, brownish	3·5 – 4·0 / 2·85 – 2·95	colourless	vit. – pearl. / bright – trl.	conch. / perfect rhombohedral	extensive sedimentary beds, usually formed by replacement of calcite; near joints and fissures in limestone; ore and mineral veins; gypsum beds, chlorite and talc schists
113	steel grey, iron black, bell-metal colour	4·0 / 4·3 – 4·5	black	met. / op.	uneven / indistinct	in cassiterite and tin lodes

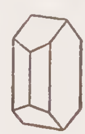
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name*	*Uses*	*Common Forms: Diagram*
		Formula		*Crystal Form*
Cornwall, Harz Mts., Saxony, Bohemia, Hungary, Chile, Peru, Bolivia, Montana (U.S.A.)	pyrite, mispickel, chalcopyrite, galena, chalcocite, blende, bournonite, bornite, enargite, cinnabar	**Tetrahedrite** (Grey Copper) (Fahlerz) ——— $(CuFe)_{12}Sb_4S_{13}$ Vars.: 1. Argentiferous grey copper ore (silver Fahlerz) (CuAg) 2. Arsenic Fahlerz 3. Mercury Fahlerz (Schwartzite) = Cu – Mg – Sb Blowpipe: fusible	copper ore, also produces other metals, e.g. silver	massive, granular, triangular striations  cubic system, tetrahedron, many faces, usually well developed; cubes rare
Magnesian limestone (English Permian), Devonian of Eifel district, etc., Dolomites (Italy); very extensive and widespread	calcite, gypsum, blende, galena, chlorite, talc	**Dolomite** ——— $CaMg[CO_3]_2$ Blowpipe: not fusible; soluble in warm HCl	building stone, furnace linings, preparation of CO_2	crystal faces often curved, saddle-shaped crystals, also massive and granular with saccharoidal texture  hexagonal system, rhombohedra, twins (like calcite)
Cornwall, Erzgebirge (Saxony), Bolivia, Tasmania	cassiterite, blende, pyrites, galena	**Stannine** Tin Pyrites (Bell Metal Ore) ——— Cu_2FeSnS_4 Blowpipe: fuses with difficulty; in HNO_3 forms blue solution	tin ore	massive, disseminated, finely granular, or dense aggregates crystals very rare tetragonal system, small tetrahedra

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
114	steel grey to silver white	4·0 – 4·5 / 14 – 19	white, steel-grey	met. / op.	hackly, ductile / none	disseminated as small grains in basic and ultra-basic igneous rocks; and in larger quantities in magmatic segregation zones in these rocks; in alluvial (placer) deposits
115	steel grey to iron black	4·0 – 5·0 / 7·88	grey, shiny	met. / op.	hackly, ductile / only in artificial crystals	rare on earth; found in meteorites associated with other elements
116	ashy grey to yellowish, greenish-grey	6·0 / 3·23 – 3·38	white	vit. / op.	uneven / perfect	metamorphic rocks, "greenstones," amphibolites, metamorphosed impure limestones; in iron and copper ore lodes
117	glassy grey	6·0 / 2·53 – 2·56	white	vit. – pearl. / trp. – cloudy	conch., uneven, brittle / almost perfect	rock-forming mineral in acid volcanic rocks

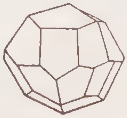
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
ɜushveld South Africa), ᴀbyssinia, ᴄongo, Jrals, Borneo, ᴜdbury Ontario), ᴀlaska, ᴄolombia	platinum minerals, iridium, olivine, chromite; in quartz veins	**Native Platinum** / Pt. Blowpipe: does not fuse; soluble in hot aqua regia	main source of platinum	grains and irregular-shaped or rounded lumps; scaly. usually rounded grains. cubic system, cube, crystals rare
Giant's ᴄauseway ɒasalt Ireland), Greenland, Brit. Columbia, New Zealand	magnetite, associated minerals in meteorites: olivine, enstatite, augite, anorthite	**Native Iron** (Meteoric Iron) / Fe. Blowpipe: not fusible; soluble in acids	quantities too small	granular, scaly, platy. no crystals. cubic system, crystals not found in Native Iron
Scottish Highlands, ᴀlps, etc., Norway, Tennessee U.S.A.)	amphiboles, iron and copper ores	**Zoisite** (Epidote Family) / $Ca_2Al_3[OH(SiO_4)_3]$. Blowpipe: fuses to transparent bead		massive, columnar, longitudinally striated, cleavable, fibrous. long prismatic crystals, striated. orthorhombic system, long prismatic crystals
n most areas of younger rhyolites and trachytes, Vesuvius, Drachenfels (Germany)	other feldspars, quartz	**Sanidine** (glassy variety of orthoclase feldspar) / $K[AlSi_3O_8]$. Blowpipe: only edges fusible		glassy tabular crystals  monoclinic system

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
118	steel grey to iron black, tarnishes	6·5 / 5·2 – 5·3	cherry red to red-brown	met. / op.	conch., rough, brittle / none	very widespread, in pockets replacing limestone, in layers interbedded with sedimentary rocks, in metamorphic rocks, and residual in sediments
119	greyish-yellow, greyish-green, brownish	6·0 – 7·0 / 2·0	white	vit. – fat. / trp. – trl.	uneven / perfect	metamorphic rocks altered by high temperature and moderate stress – both in regional and contact metamorphic areas; gneisses, mica schists, hornfelses, in veins
120	shades of grey, yellowish-brown or black when fresh; usually with white porous coating	7·0 /		dull / trl. – op.	conch. / none	as nodules, irregular concretions or tabular layers in chalk; often takes shape of fossils, esp. echinoids and sponges

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty ad. = adamantine or diamond,

Localities	Associated Minerals	*Name* / *Formula*	Uses	*Common Forms: Diagram* / *Crystal Form*
North Lancashire, Cumberland, Forest of Dean, Elba, Germany, Ukraine, Bilbao (Spain), Lake Superior district, Alabama, Eastern States (U.S.A.), Brazil, Cuba	magnetite, limonite	**Haematite** (Kidney Ore) (Specular Iron) ——— Fe_2O_3 Plate I.15 Blowpipe: not fusible; soluble in HCl	important iron ore	massive, fibrous with reniform shape (kidney ore), foliaceous and scaly (micaceous haematite), crystalline (specular iron), or granular  hexagonal system, with many forms: e.g. pyramidal, cube-like, modified rhombohedral
common in Scottish Highlands; commercial prod.: Assam, Rewa (India)	quartz	**Sillimanite** (Fibrolite) ——— $Al[AlSiO_5]$ Blowpipe: not fusible; not soluble in acids	high grade refractories, esp. refractory porcelain and bricks for electric furnaces	fibrous, wisplike aggregates, columnar, foliaceous, massive thin needles orthorhombic system, very small needle-like crystals
English Chalk outcrops: N. and S. Downs, Chilterns, Yorks. and Lincs. Downs; Antrim (N. Ireland)	chalk, opal	**Flint** ——— SiO_2 Blowpipe: not fusible: scarcely soluble in acids	tube mills, pottery industry; formerly also road-making, building, gun flints, etc.	massive, nodular to flat concretions, sometimes in form of fossils amorphous none, amorphous

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
121	black, brown	range: Wad = 1·0 Psilomelane = 6·0 / 0·2 – 4·3	black, brownish-black	dull, waxy, rarely met. / op.	small, rough / none	residual or lateritic deposit; in sedimentary rocks occurs as beds or layers of nodules associated with other manganese ores; probably originated as colloidal precipitate
122	black, brownish-black, iron black, dark steel grey	1·0 / 2·1 – 2·3	black, shining	met. or dull / op.	uneven / perfect	in metamorphic rocks, as bedded masses in crystalline schists, in veins, disseminated throughout country rock close to a contact with igneous rocks
123	pitch black	1·0 – 2·0 / 1·1 – 1·2	black	res. / op.	conch. / none	in masses (e.g. pitch lakes), in clefts and veins; impregnated in porous sedimentary rock; encrusting crystals of galena and chalcopyrite

vit. = vitreous silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Transvaal, Minas Geraes (Brazil), India, Arkansas (U.S.A.)	other manganese ores	**Psilomelane** related: Wad (Bog Manganese) $BaMn^{\cdot\cdot}Mn_8^{\cdot\cdot}O_{16}(OH)_4$ Plate I.10, III.1 Blowpipe: not fusible	important manganese ore (steel manufacture as deoxidiser and de-sulphuriser; also dry batteries, paints, disinfectants)	botryoidal, nodular, stalactitic (psilomelane); also dendritic, loose, powdery (wad) no crystals
Germany, Austria, Ceylon, Korea, U.S.S.R. (Siberia), Madagascar, Mexico, Ontario (Canada), Arizona (U.S.A.)	in schists and gneisses, pegmatite and quartz veins	**Graphite** (Black Lead) C Plate VII.1 Blowpipe: not fusible	facings in foundries, paint and crucible manufacture, electrodes, lubricants, lead pencils, etc.	1. crystalline (uncommon); 2. massive, granular, in scales or laminae, radiating aggregates, earthy; fatty touch usually massive, crystals rare  hexagonal system, 6-sided scales and laminae
Switzerland, Italy, Sweden, Trinidad, Venezuela, Cuba, Alberta, Dead Sea	no typical mineral association	**Asphalt** Mineral Pitch mixture of hydrocarbons	road and paving materials, insulating, waterproofing, etc.; manufacture of hydrocarbons	massive, impregnating, in irregular masses in veins, platy, botryoidal, reniform amorphous

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
124	black	2·0 – 2·5 / 1·15 – 1·5	black	dull – vit.	conch. / none (in layers)	as seams in strata of various ages, esp. Carboniferous and, less important, Cretaceous
125	black, silver grey, yellowish, brown	2·0 – 3·0 / 2·9 – 3·1	white	pearl. – met. / trl.	none, lamellar / perfect in 1 direction	in granites and gneisses containing tinstone; of pneumatolytic origin
126	black, dark brown, dark green	2·5 – 3·0 / 2·8 – 3·2	white	pearl. – met. / trl. – op.	elastic, flexible / perfect in 1 direction	the most commonly found mica in igneous and metamorphic rocks, also in coarse-grained sediments
127	black (grey on freshly broken surface)	3·0 – 4·0 / 5·4 – 5·9	black	met., dull / op.	uneven and granular / fairly good	as minor constituent in silver and cobalt ore veins

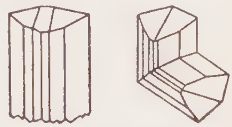
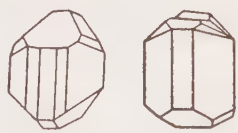
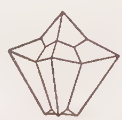
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
ritish coal- elds, Pas de Calais and Nord (France- Belgium), Ruhr Germany- Holland), aar (France- Germany), Poland, Czechoslovakia, J.S.S.R., J.S.A., Canada, Alaska, China, India, Viet Nam, South Africa, Australia	no associated minerals	**Coal** (Bituminous Coal to Anthracite) ——— 74 – 94% C 3 – 20% O 1 – 5% H (See also p. 175)	fuel, coal gas, coke, tar, ammonia, hydrocarbons, etc.; many uses in chemical industry	massive, sometimes banded, in seams none, composed of organic remains
Zinnwald Czecho- lovakia), Cornwall	quartz, cassiterite, scheelite, fluorspar	**Zinnwaldite** (Mica Family) ——— $K(LiFe^{\cdot\cdot})Al$ $[AlSi_3O]_{10}(OH,F)_2$ Blowpipe: easily fused, red flame		lamellar, in radial groups  monoclinic system, lamellae with 6-sided outline
very widespread	mineral assemblages of granite, syenite, porphyry, trachyte	**Biotite** (Mica Family) ——— $K(Mg,Fe,Mn)_3$ $(OH,F)_2[AlSi_3O_{10}]$ Plate V.11 Blowpipe: fuses to black glass	as for muscovite (No. 170), but not usually exploited commercially	thin, tabular, flexible plates  monoclinic system, pseudo-hexagonal, 6-sided lamellae
Harz Mts., Saxony, Bohemia, Chile, Japan	silver and cobalt ores	**Native Arsenic** ——— As Plate III.4 Blowpipe: becomes volatile without fusing, garlic smell		usually massive or reinform, in layers, nodules or grains crystals rare hexagonal, rhombohedral; crystals rare; equi-dimensional or needle-shaped

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
128	blackish-brown	4·0 / 4·3 – 4·4	dark brown	met. (when unweathered) / trl.; splinters, red translucence	uneven / fairly good	rarely found unweathered, in veins associated with pyrolusite
129	velvet black, greenish or brownish-grey	4·0 – 6·0 / 9·0 – 9·7	dark green to brownish	greasy, sub-met., usually dull / op.	conch. /	in veins formed at high temperature; as primary constituent in some granites and pegmatites
130	black, dark brown	5·0 – 5·5 / 7·14 – 7·54	yellowish-brown to black	sub-met. / op.	uneven, brittle / perfect	pneumatolitic veins near granite masses; usually associated with cassiterite
131	iron black, bluish tinge	5·5 / 4·7 – 4·8	chestnut	sub-met. / op. – trl.	uneven / very good	in metamorphic rocks, in veins associated with acid igneous rocks

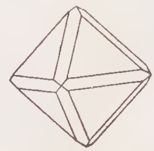
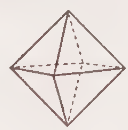
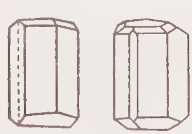
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
ornwall, ermany, ova Scotia	pyrolusite, barytes, calcite	**Manganite** $MnOOH$ Blowpipe: not fusible: soluble in HCl	manganese ore	bundles of crystals, columnar, radial aggregates, rarely granular  orthorhombic system, crystals in druses form long prisms; twins
oachimsthal Bohemia), axony, orway, weden, atanga Congo), Vest Africa, anada, onnecticut, akota J.S.A.)	silver, bismuth, and cobalt ores	**Pitchblende** Uraninite UO_2 Blowpipe: fuses with difficulty; soluble in HNO_3 and H_2SO_4; radioactive	uranium and radium ore	massive, botryoidal, stalactitic, round scales, often colloform gels often amorphous cubic system, crystal cubes only found in pegmatites
t Austells Cornwall), pain, ortugal, hina, Burma, orea, alaya, olivia, razil, olorado J.S.A.), ueensland Australia)	cassiterite, quartz, apatite, tourmaline, molybdenite fluorspar	**Wolfram** Wolframite $(Mn,Fe)[WO_4]$ Blowpipe: fusible; soluble in HCl End members in Fe–Mn range Ferberite $FeWO_4$ Hubnerite $MnWO_4$	chief ore of tungsten (steel manufacture, alloys, filaments in electric bulbs)	tabular, needles, flakes usually striated; also massive, in radiating aggregates  monoclinic system, prismatic crystals, twins common
arz Mts. Germany), weden	magnetite, braunite, calcite, manganite	**Hausmannite** Mn_3O_4 Blowpipe: not fusible; soluble in HCl		massive, crystalline, granular  tetragonal system, pyramidal habit, frequently twinned and intergrown

glas. = glassy res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
132	iron black, brownish-black	5·5 / 5·0 – 5·2	black	met., dull / op.	conch., brittle / poor, octahedral	in most igneous rocks, large deposits are due to magmatic segregation
133	iron black, brownish-black	5·5 / 4·5 – 4·8	brown	sub-met. / op.	uneven – conch. / none	as primary mineral in ultrabasic rocks, associated with nickel and platinum ore deposits
134	black, brownish-black, more rarely greenish	5·0 – 6·0 / 2·9 – 3·4	grey-greenish-brown	vit. / op.	uneven / perfect in 2 directions intersecting at 120°	primary mineral in acid and intermediate igneous rocks; in schists and gneisses, forms major constituent of certain metamorphic rocks, e.g. amphibolite

vit = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	*Name* / *Formula*	Uses	*Common Forms: Diagram* / *Crystal Form*
rals, veden Kiruna, ällivare), nland, ermany, .S.A. New York, yoming, tah), lexico, hile	ilmenite, corundum, spinel, olivine, haematite, chalcopyrite, garnet, lievrite, pyrrhotite	**Magnetite** (Magnetic Iron Ore) ——— Fe_3O_4 Blowpipe: very difficult to fuse; soluble in HCl; strongly attracted by hand magnet	valuable iron ore	small accessory crystals, massive, granular, scaly, dense crystals small  cubic system, octahedra, crystals sometimes distorted, striated and twinned
.S.S.R., reece, ugoslavia, ustria, orway, urkey, Rhodesia, Africa, uba, hilippines	in peridotites, serpentine, nickel and platinum ores	**Chromite** (Chrome Iron Ore) ——— $FeCr_2O_4$ Blowpipe: infusible (magnetic); insoluble in acids	most valuable chrome ore (manufacture of alloys, esp. chrome steel, refractory bricks and cements, chemical industry)	crystals rare, disseminated granular, massive, compact; in irregular masses, grains segregated in nests  crystals very rare, cubic system, octahedra
ery widely stributed	biotite, chlorite, epidote, augite, diallage	**Hornblende** (Amphibole Family) ——— Complex silicate: $(Na,K)_{0\cdot5-2}Ca_{3-4}$ $Mg_{3-8}Fe^{\cdot\cdot}_{2-4}$ $(Al,Fe^{\cdot\cdot\cdot})_2[(OH)_4\|$ $Al_{2-4}Si_{14-12}O_{44}]$ Plate V.8 Blowpipe: fuses easily; decomposed by HCl		crystalline, massive, also long blade-like forms, fibrous, granular  monoclinic system, prismatic habit, often twinned

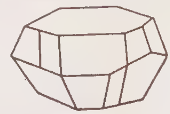
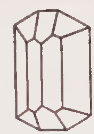
glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
135	iron black, blackish-brown	5·0 – 6·0 / 4·5 – 5·0	black	sub-met. or dull / op. – trl.	conch. / none (apparent in twins)	accessory constituent of basic igneous rocks, often concentrated in magmatic segregations and dyke-like bodies, beach sands
136	black to brownish	5·5 – 6·0 / 4·1	blackish	sub-met. – vit. / op.	uneven / distinct	in zones of contact metamorphism; in crystalline schists
137	pitch black, greenish-black	6·0 / 3·3 – 3·5	grey-green	vit., dull / op.	conch. – uneven / good, 2 sets of cleavage planes meeting at angle of nearly 90°	very widespread and important rock-forming mineral in basic igneous rocks; also in metamorphic rocks

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond

PLATE VI ROCK-FORMING MINERALS: 2

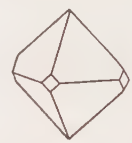
1st Row: 1. Calcite, 2. Fluorspar; *2nd Row*: 3. Anhydrite, 4. Gypsum; *3rd Row*: 5. Talc, 6. Rock Salt (Halite); *4th Row*: 7. Barytes, 8. Glauconite.

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Norway, Sweden, Alps, Travancore (India), Malaya, U.S.A. (Adirondack Mts.), Canada	haematite, magnetite, apatite	**Ilmenite** ——— $FeTiO_3$ Plate III.9 Blowpipe: infusible; barely soluble in acids	titanium ore (white paint pigment, bessemer steel manufacture)	crystalline, radiating, in thin plates or scales, also granular as sand  hexagonal system, tri-rhombohedral habit; tabular, rosettes, twins
Nassau, Silesia, Elba, Tuscany, Greece, Greenland	augite, sodalite, tin ores, zoisite, epidote	**Lievrite** Ilvaite (Yenite) ——— $CaFe_2^{\cdot\cdot}Fe^{\cdot\cdot\cdot}[OH\|(SiO_4)_2]$ Blowpipe: fusible; decomposed by HCl		radiating crystalline aggregates, rarely granular aggregates  orthorhombic system, long prismatic or needle-like crystals; striated longitudinally
widespread	diopside, hornblende, epidote, biotite, chlorite, limonite	**Augite*** (Pyroxene Family) ——— $Ca_{\cdot 8-10}$ $(MgFe^{\cdot\cdot}Fe^{\cdot\cdot\cdot}Al)_{1\cdot 0-1\cdot 2}$ $(AlSi)_2O_6$ Plate IX.7 Blowpipe: fusible **Hypersthene**** ——— Blowpipe: fusible		crystalline; massive, granular, fibrous *  **  monoclinic system, short stumpy 8-sided prisms, twins; other pyroxenes: *a.* Orthorhombic: enstatite, hypersthene, bronzite; *b.* Monoclinic: diopside, hedenbergite, aegirine, spodumene; *c.* Triclinic: wollastonite, rhodonite

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
138	iron black	6·0 – 6·5 / 5·0 – 5·2	dark brown to reddish-brown	met. / op.	brittle, uneven / poor	in metamorphosed crystalline limestones
139	iron-black, brownish-black	6·0 – 6·5 / 4·7 – 4·9	black, brownish	sub-met. / op.	uneven, brittle / poor	in metamorphic rocks, also found as residual mineral in sediments

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
Franklin Furnace, New Jersey (U.S.A.)	zincite, willemite, calcite	**Franklinite** / $ZnFe_2O_4$ Blowpipe: not fusible; soluble in HCl	zinc ore	crystalline, also in rounded grains and lenses; crystals seldom good / cubic system, octahedra, often rounded at edges
Harz Mts., Thuringia, Italy, Sweden, S. Africa, India	granular limestones and dolomites	**Braunite** / $Mn_4^{\cdot\cdot}Mn_3^{\cdot\cdot\cdot\cdot}[O_8\|SiO_4]$ Blowpipe: not fusible	manganese ore	crystalline and massive, granular, aggregates  tetragonal system, octahedral habit, crystals usually small

glas. = glassy, res = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
140	tin-white	— / 13·5 – 13·6		met. / op.		as fluid globules in cinnabar
141	white, yellow, greenish, bluish	1·0 / 2·2 – 2·6	white	pearl. or dull / op.	conch., earthy / perfect	in weathered granites formed by decomposition of feldspars; in groundmass of sediments; in association with some metallic ores
142	snow white, pale yellow	2·0 – 2·5 / 3·2 – 3·8	gleaming	dull / op.	brittle / none	associated with smithsonite ore deposits, formed by oxidation of zinc blende
143	white, greenish, grey	2·0 / 2·93 – 3·0	white	silver white / —	none / fibrous	alteration product of hornblende as cross-fibres in veinlets, traversing massive serpentine

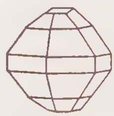
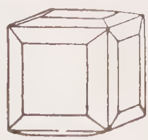
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
Spain (Almaden), Italy (Idria), Peru, U.S.A. (Texas, California)	cinnabar	**Mercury** Hg Blowpipe: volatilises easily	mined with cinnabar; manufacture of drugs and chemicals, mercury vapour lamps, electrical instruments, thermometers, etc.	liquid, in small globules, solidifies at −40° C. liquid rhombohedral when solid
Cornwall and Devon, France (Limoges), Germany, (Saxony, Silesia), Czechoslovakia, Italy, Japan, U.S.A. (Arkansas)	other hydrated aluminium silicates, feldspars, nepheline, leucite, scapolite	**Kaolin** (Kaolinite, China Clay) $Al_4[(OH)_8,Si_4O_{10}]$ Blowpipe: infusible; completely decomposed by H_2SO_4	manufacture of porcelain and china, paint manufacture, filler in paper and rubber	usually soft fine clayey, also scaly, in thin plates or loose aggregates scales monoclinic system, distinct pseudo-hexagonal plates
Austria, Silesia, Spain, U.S.A. (Pennsylvania), Canada, Algeria	smithsonite, aurichalcite, zaratite	**Hydrozincite** $Zn_5[(OH)_3\|CO_3]_2$ Blowpipe: not fusible; soluble in acids	zinc ore (unimportant)	massive, earthy, dense, as encrustation (chalky appearance) amorphous or minute monoclinic crystals (microcrystalline)
Cyprus, Quebec (Canada), Central Urals (U.S.S.R.), Rhodesia, Transvaal	serpentine, actinolite	**Chrysotile** (Fibrous serpentine = Serpentine Asbestos) $(OH)_8Mg_6[Si_4O_{10}]$ Hydrated magnesium silicate Blowpipe: fuses with difficulty (small splinters); soluble in HCl and H_2SO_4	most important form of commercial asbestos (90% of total asbestos)	fibrous, felted, scaly, lamellar fine fibres monoclinic system

glas. = glassy res. = resinous; op. = opaque, trp. = transparent, trl. = translucent: conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
144	silver white, reddish tinge, tarnishes readily	2·0 – 2·5 / 9·7 – 9·8	lead grey with metallic lustre	met. / op.	finely granular, brittle / perfect	in veins associated with ores of tin, nickel and silver, also in intrusive rocks
145	tin white	2·0 – 3·0 / 6·1 – 6·3	white	met. / op.	brittle / fairly good	in ores
146	white, reddish, yellowish, colourless	2·0 / 1·6	white	vit., shining / trp. – trl.	conch. / none	in saline residues, as a late stage precipitate of sea water
147	silver white, yellowish, tarnishes brown	2·5 – 3·0 / 9·6 – 12	silver white, shining	met. / op.	hackly, sectile / none	in strings and veins, with silver sulphides in the upper part of silver sulphide lodes; in cobalt-nickel veins

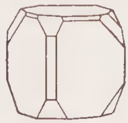
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
ornwall, axony Schneeberg), New South Vales, Queensland, Bolivia	bismuthinite, cobaltite, cassiterite, kupfernickel	**Native Bismuth** — Bi Blowpipe: volatilises completely	bismuth ore (manufacture of fusible alloys, electrical apparatus, "bismuth meals")	crystalline, massive, foliaceous, granular, also feathery, and striped; arborescent crystals rare hexagonal system, rhombohedral, sometimes twinned
ransylvania, J.S.A. Colorado, California), Vestern Australia	gold, selentellurium, sulphur, pyrites	**Native Tellurium** — Te Blowpipe: fuses easily	tellurium ore, limited uses, e.g. in electrolytic processes of magnesium and zinc purification	massive, with cavities massive hexagonal system, rhombohedral, crystals occasionally prismatic
tassfurt N. Germany), Galicia, pain, ersia	potassium salts, rock salt, anhydrite	**Carnallite** — $MgCl_2.KCl.6H_2O$ Blowpipe: fuses easily; bitter taste; soluble in water	important potassium salt; fertilisers	crystalline, in stringers or coarsely granular aggregates  orthorhombic, crystals rare, hexagonal habit
ermany axony, arz), Peru, lexico, .S.A. Nevada, ake Superior), anada Ontario), ustralia Broken Hill, N.S.W.)	galena, silver glance, cerussite	**Native Silver** — Ag Plate III.3 Blowpipe: fuses easily; soluble in HNO_3; coats copper immersed in HNO_3	coinage, plate, jewellery, electroplating, medicine, etc.	crystalline and platy, most commonly massive, distorted, also arborescent, reticulated  cubic system, distorted cubes or octahedra

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
148	white, reddish, brownish	2·5 – 3·0 / 2·95	white	vit. – pearl. / trl.	uneven, brittle / perfect in 1 direction, less good in 2 others	in tin-bearing granites, in granite pegmatite veins
149	white, greyish	3·0 – 3·5 / 6·6 – 6·7	lead grey	met. / op.	uneven, brittle / good	in ore veins
150	silver white	3·0 – 3·5 / 13·7 – 14·8	silver white	met. / op.	conch. /	in cinnabar ore deposits as scattered grains, in oxidation zone of some silver deposits
151	dirty white, grey, yellow, reddish-brown	3·0 (variable) / variable	white	dull / op.	/ none	residual deposit, formed by decay of aluminium-bearing rocks, usually under tropical conditions

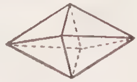
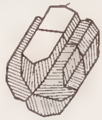
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
West Greenland, U.S.A. (Colorado), Urals	quartz, siderite, pyrites, galena, chalcopyrite, cassiterite	**Cryolite** $Na_3[AlF_6]$ Fusible with lighted match; partly soluble in HCl and H_2SO_4	electrolytic process of extracting aluminium from bauxite; enamel manufacture	crystals rare, massive, platy, cleavable  cubic system, striated cubes, twins
Germany (Harz Mts.), Bohemia, Sweden, Portugal, Australia, Canada	stibnite, silver and arsenic minerals	**Native Antimony** Sb Blowpipe: easily fused; completely volatile	rare antimony ore; metal used in production of alloys	usually massive, lamellar, botryoidal, granular crystals very rare hexagonal, rhombohedral, more rarely cubic or tabular; repeated twins – fourlings and sixlings known
Spain, Sweden, Hungary, Chile	cinnabar	**Native Amalgam** (Silver Amalgam) (HgAg) proportions vary Blowpipe: mercury volatilises leaving globule of silver	rare, silver ore	crystalline, massive, platy, moss-like often massive cubic system, rhombodecahedra (many faces)
Hungary, France, Greece, Italy, Yugoslavia, U.S.S.R., China, India, Ghana, Jamaica, British and Dutch Guiana, Brazil, U.S.A. Minor quantities in Co. Antrim and Ayrshire		**Bauxite** $Al_2O_3.2H_2O$ with impurities including silica, iron, phosphorus, and titanium. Consists largely of the minerals diaspore or gibbsite	main ore of aluminium, abrasive	amorphous, earthy, granular or pisolitic masses amorphous

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
152	silver white to pale yellow	3·5 / 9·4 – 10·0	dark grey	strongly met. / op.	uneven / perfect in 1 direction	in silver and silver-cobalt veins
153	white, clouded, colourless, pale shades of yellow or brown	4·5 / 2·44 – 2·5	white	vit. / trl. – op.	uneven / seen with difficulty	filling cracks, cavities, vesicles, etc., in eruptive rocks, also in ore veins
154	greenish-white, yellowish	4·5 – 5·0 / 5·9 – 6·1	white	ad., res. / trl. – op.	conch., uneven / brittle, sometimes good	in pegmatites and pneumatolytic veins, also at contacts of igneous rocks with limestones
155	white, grey	4·5 – 5·0 / 2·8 – 2·9	white	pearl., vit. / trl.	rough / perfect	contact-metamorphic mineral in impure limestones, in igneous rocks contaminated by limestone

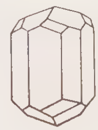
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Spain, Germany (Harz Mts), Black Forest), Chile, Australia (N.S.W.)	silver ores, galena, arsenic and antimony minerals	**Dyscrasite** Ag_3Sb Blowpipe: fuses easily		crystalline, massive, granular, platy, striated  orthorhombic system, pyramids, twins
Germany (Harz Mts.), Bohemia	pyrrhotite	**Harmotome** (Cross-stone) Zeolite Family $(BaK_2)[Al_2Si_5O_{14}].5H_2O$ Blowpipe: crumbles and fuses easily; decomposed by HCl		crystalline  monoclinic system, crystals are always cruciform penetration twins; often occur as fourlings, which may have re-entrant angles, hence "cross-stone"
Cumberland, Cornwall, Erzgebirge Saxony and Bohemia), U.S.A. (California, Nevada, Arizona), Bolivia	quartz, wolfram, fluorspar, cassiterite, barytes	**Scheelite** $Ca[Wo_4]$ Blowpipe: fuses with difficulty; soluble in HCl and HNO_3	important tungsten ore (see No. 130)	crystalline, also massive, encrusting, reniform  tetragonal system, tetragonal pyramids, platy, striated, twins
Sweden, Finland, Mexico, New York, Canada, New South Wales	garnet (grossularite), vesuvianite, diopside, epidote	**Wollastonite** $CaSiO_3$ Blowpipe: fuses with difficulty, easily on edges		crystalline, massive, radiating, columnar, fibrous, lamellar  monoclinic or triclinic system, usually tabular, crystals rarely good

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
156	white, colourless, grey	5·0 – 6·0 / 2·54 – 2·77	white	pearl., res., vit. / op.	conch. / distinct	in metamorphic rocks, e.g. contact altered limestones and regionally metamorphosed amphibolites and gneisses; in igneous rocks as alteration product of plagioclase feldspars
157	tin white, pale grey	5·0 / 6·4 – 6·6	greyish-black	met. / op.	uneven, brittle / poor	in hydrothermal veins
158	white, grey, yellowish-white	5·0 – 5·5 / 2·2 – 2·4	white	vit., silk. / trp. – trl.	conch. / perfect	as secondary mineral in amygdales of basalts and phonolites

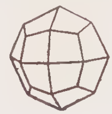
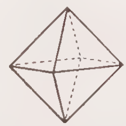
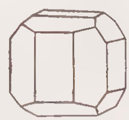
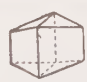
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	*Name* / *Formula*	Uses	*Common Forms: Diagram* / *Crystal Form*
Pyrenees, Switzerland, Scandinavia, U.S.A. (New York, Mass., New Jersey), Brazil	muscovite, biotite, epidote, albite, kaolin, plagioclase	**Scapolite** (Wernerite) ——— isomorphous mixture of two molecules: Marialite $Na_8[Cl_2,SO_4,CO_3,(OH)_2 \mid (AlSi_3O_8)_6]$ and Meionite $Ca_8[(Cl_2,SO_4,CO_3(OH)_2(Al_2Si_2O_8)_6]$ Blowpipe: fuses easily		crystalline, massive, granular, columnar, radiating; dense aggregates  tetragonal system, long prisms terminated by pyramids
Cornwall, Germany, (Saxony, Black Forest), Bohemia (Joachimsthal), France (Dauphiné), Canada (Cobalt, Ontario), Morocco	cobalt bloom, nickel bloom, arsenical nickel, calcite, barytes, quartz	**Smaltite** (Tin White Cobalt) ——— $CoAs_{3-2}$ Blowpipe: fuses to black globule; forms red solution in HNO_3 also **Chloanthite** (White Nickel) ——— $NiAs_{3-2}$ as above, but forms green solution in HNO_3	cobalt and nickel ore	crystalline and massive, granular, dense, reniform, reticulated cubic system, modified octahedron, cube and rhombdodecahedron
Scottish Permo-Carboniferous and Tertiary basalts, Antrim basalts, Iceland, Faeroe Is., Karroo (S. Africa) and and other basalt areas	other zeolites	**Natrolite** (Zeolite Family) ——— $Na_2[Al_2Si_3O_{10}].2H_2O$ Fused by lighted match; decomposed by HCl		crystalline, massive, fibrous, radiating  orthorhombic system, prismatic and in thin needles

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
159	milk white, greyish, colourless	5·5 / 2·2 – 2·3	white	vit. / trp. – nearly op.	conch., uneven / poor	late hydrothermal infilling of cavities in basalt; also primary mineral in certain basic igneous rocks
160	white, reddish tinge	4·5 – 5·5 / 4·8 – 5·8	greyish-black	met. / op.	uneven, brittle / very good	in hydrothermal veins with other sulphide ores
161	silver white, reddish tinge	5·5 / 6·0 – 6·4	grey	met. / op.	conch. / good	in metasomatic contact deposits; in schists, also in hydrothermal veins
162	tin white, pale grey	5·5 – 6·0 / 5·9 – 6·2	black	met. / op.	uneven, brittle / good in 1 direction	in pneumatolitic ore veins, in contact metamorphosed rocks

vit. – vitreous, silk. – silky, met. – metallic, pearl. – pearly, fat. – fatty, ad. – adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
cotland ermo- :arboniferous nd Tertiary olerites and asalts), Germany Harz Mts.), Bohemia, celand, J.S.A., slands of ndian Ocean	in basalts and dolerites; magnetite, nepheline	**Analcite** (Analcime) (Zeolite Family) — $Na[AlSi_2O_6].H_2O$ Blowpipe: fuses easily; decomposed by HCl		crystalline, also massive, granular, earthy  cubic system, icositetrahedron; crystals may be single or in druses, usually small
weden, Northern Rhodesia, Katanga Congo), J.S.A. (Miss., Maryland)	millerite, siderite, chalcopyrite, pyrite	**Linnaeite** — Co_3S_4 Blowpipe: fuses to magnetic bead; soluble in HNO_3	cobalt ore	crystalline, massive, granular, compact  cubic system, cubic or octahedral habit, good crystals (resemble spinel); twins
candinavia, axony, Bohemia, Canada Ontario), Australia	pyrite, pyrrhotite, chalcopyrite, siderite	**Cobaltite** — CoAsS Blowpipe: fusible forms red solution in HNO_3	important cobalt ore; not found in large quantities	crystalline, massive, granular  cubic system, pentagondodecahedra, twins, striated
Cornwall, Devon, Germany Saxony, Harz Mts.), Silesia, Sweden, Canada Ontario)	pyrrhotite, tin ores, gold-quartz veins	**Arsenopyrite** Mispickel (Arsenical Pyrites) — FeAsS Blowpipe: fuses to black bead; soluble in HNO_3	arsenic ore (weed-killer, insecticide)	crystalline, massive, radiating, granular, reniform  orthorhombic system, in druses

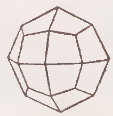
glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
163	white, colourless, pale grey	5·5 – 6·0 / 2·6 – 2·65	white	greasy, vit. / trp. – trl.	conch., uneven / distinct 1 (direction)	original constituent of igneous rocks rich in soda and poor in silica, e.g. phonolites, nepheline basalts, nepheline syenites
164	whitish-grey	5·5 – 6·0 / 2·6	white	vit., greasy / op.	conch., brittle / —	original constituent in recent volcanic rocks rich in potash and poor in silica, e.g. leucite basalt, leucite-phonolite, etc.
165	silver-white	6·0 – 7·0 / 22·6 – 22·8		strong met. / op.	hackly / poor	in crude platinum and gold

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond.

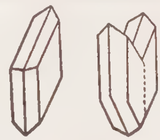
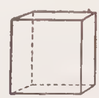
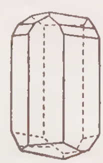
PLATE VII ROCK-FORMING MINERALS AND OTHERS

1st Row: 1. Graphite, 2. Chalcedony; *2nd Row*: 3. Kaolin, 4. Marble; *3rd Row*: 5. Chlorite, 6. Fibrous Serpentine (Asbestos).

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Germany, Norway, Kola Peninsula (U.S.S.R.), Portugal, S.W. Africa	garnet (melanite), hornblende, sanidine	**Nepheline** Nephelite (Eleolite) (Feldspathoid Family) / $Na_3K[AlSiO_4]_4$ Blowpipe: fusible	source of aluminium (in U.S.S.R.)	crystalline, in aggregates  hexagonal system, short prisms, twins
Vesuvius, Germany, Brazil, U.S.A. (Arkansas), British Columbia	nepheline, analcite, orthoclase; muscovite	**Leucite** / $KAlSi_2O_6$ Plate V.5 Blowpipe: almost infusible; decomposed by HCl	source of aluminium, potash, fertiliser	crystalline, disseminated grains  cubic system, trapezohedron and rhombdodecahedron
Russia, East Indies	platinum, osmium (as alloy), gold	**Iridium** / Ir Blowpipe: not fusible; not soluble in acids	dental, jewellery, electrical, thermoelectric thermometers	small round grains cubic system, crystals very rare

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
166	colourless, white, yellowish	1·5 – 2·0 / 2·3 – 2·4	white	pearl. / trp. – op.	conch. / perfect	in saline residues formed by evaporation of sea water; in dolomitised limestones; associated with sulphide ore bodies; in clays and shales formed by decomposition of pyrite near shells, etc.
167	colourless, or variously coloured by impurities	2·0 / 1·9 – 2·0	white	vit. / trl. – clouded	conch., brittle / perfect, cubic	in saline deposits, salt domes, sublimation product of volcanoes
168	colourless, tinge of grey, yellow	2·0 – 2·5 / 1·7 – 1·8	white	res. – earthy / trp.	conch., brittle / distinct	playa deposits, borax marshes and muds; formed by drying of saline seas
169	colourless, white	2·0 – 2·5 / 1·7 – 1·8	white	vit. / trp.	smooth / good	in saline deposits, in zone of weathering of ore deposits, as efflorescent crust on limestone (in caves)

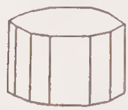
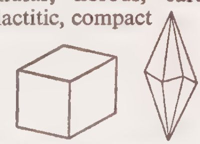
vit. – vitreous, silk. – silky, met. – metallic, pearl. – pearly, fat. – fatty, ad. – adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Great Britain (London Clay, Oxford Clay, etc.), France, Spain, Germany, Italy, U.S.A.	anhydrite, alabaster, galena	**Gypsum** $Ca[SO_4],2H_2O$ Plate IV.2, VI.4 Blowpipe: fuses to white bead	Portland cement, fertiliser, filler in paper, paint, etc., plaster of paris for plaster board, etc.	crystalline, fibrous, scaly, compact masses, lamellar aggregates, granular, earthy  monoclinic system, swallow tail and arrow-head twins, also in interpenetrated stellate groups (rosettes)
see No. 2	anhydrite, gypsum, other halides; in clay, shale	**Rock Salt** (see No. 2) Halite NaCl Plate VI.6, IX.6 Blowpipe: easily fused, burns with yellow flame, deliquescent, water soluble	see No. 2	crystalline, granular, rarely columnar  cubic system, cubes, some rounded faces
Tibet, California, Nevada, Argentine, Bolivia, Chile	rock salt, soda	**Borax** (Tincal) $Na_2B_4O_7.10H_2O$ Blowpipe: fusible	soap and glue manufacture, tanning, preservatives, fluxes, porcelain-enamel, heat-resisting and optical glass, etc.	massive, earthy columns with opaque crust  monoclinic system, short prisms
Germany, British Columbia, Saskatchewan, Siberia	magnesium salts	**Epsomite** Epsom Salts $Mg[SO_4].7H_2O$ Soluble in water; fusible	medicinal, tanning	earthy fibrous aggregates, efflorescence  orthorhombic system, prismatic crystals

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

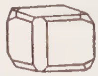
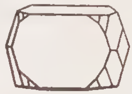
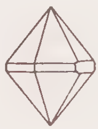
No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
170	colourless, yellowish, brownish	2·0 – 2·5 / 2·78 – 2·88	white	pearl. / trp. – trl.	flexible, foliaceous / perfect, into thin plates	granites, pegmatites, gneisses, mica schists, metamorphic limestones, micaceous sandstones, sandy shales, etc.
171	colourless, white, greenish	2·5 / 2·4	white	vit. – pearl. / trp. – trl.	scaly / perfect	in contact metamorphosed impure limestones (brucite marble); in veins traversing serpentine
172	colourless, white	2·5 – 3·0 / 2·3 – 2·4	white	vit. – pearl. / trl.	/ perfect	in serpentine, talc schist, in bauxite deposits, alteration product of corundum
173	colourless, white, sometimes yellowish, also other tints	3·0 / 2·6 – 2·8	white	vit. / trp. – op.	conch., masked by perfect cleavage / perfect, rhombohedral	very widespread, crystals in druses, cavities and cracks, in ore veins, alteration product in igneous rocks, dominant component of limestone, chalk, marble, etc.

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Scottish Highlands, Alps, Russia (Urals), India, U.S.A. (New Hampshire, N. Carolina), Canada, East Africa	in granite, pegmatite, gneiss, mica schist; albite, adularia	**Muscovite** (Potash Mica) ——— $KAl_2[OH,F)_2\|AlSi_3O_{10}]$ Plate V.12 Blowpipe: fuses with difficulty into grey to yellowish bead	insulation for electrical apparatus, condensers, dynamos, telephones; roofing materials, lubricants, rubber tyres, artificial stone, etc.	large flexible plates ("mica books"), disseminated scales  monoclinic system, 6-sided tabular crystals; good crystals rare
Shetland (Unst), Sutherland (Assynt), Skye, Italy, Ontario, Quebec, Texas, Pennsylvania	talc, gypsum	**Brucite** ——— $Mg(OH)_2$ Blowpipe: not fusible; soluble in acids	magnesium ore	massive, foliaceous, scaly, more rarely fibrous; laminae are thin and flexible tabular crystals, small hexagonal system, rhombohedral, tabular crystals
North Sweden, Germany (Vogelsberg), Urals	natrolite	**Gibbsite** Hydrargillite ——— γ–$Al(OH)_3$ Blowpipe: not fusible		scaly, botryoidal concretions with radial fires  monoclinic system, twins, 6-sided plates or prisms
very widespread	aragonite, barytes, gypsum, dolomite	**Calcite** (Calc Spar, Carbonate of Lime) ——— $CaCO_3$ Plate VI.1 Blowpipe: unfusible; flame: yellowish-red; soluble in dilute HCl with effervescence	manufacture of lime, cement, flux in smelting, fertiliser; Iceland spar used in production of optical instruments	granular, fibrous, earthy, stalactitic, compact  hexagonal, rhombohedral; common forms: Iceland spar, dog-tooth spar, nail-head spar, prismatic and other forms; repeated twins common

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
174	colourless, clear, coloured with various tints of blue, grey, green or yellow	3·0 / 6·3	white	ad., res. / trp. – trl.	conch. / good, but variable	product of weathering of galena in upper parts of lead veins and at surface
175	colourless, white, grey, bluish	3·0 – 4·0 / 2·9 – 3	white, yellowish, greenish	vit. – pearl. / trp.	brittle / perfect in some directions	in many saline residues, hydrothermal veins, in gold-quartz veins, also in cap rock over salt domes
176	colourless, glassy, dull to clouded	3·0 – 3·5 / 2·25 – 2·35	white	vit., pearl. on smooth surface / trl. (op. on exposure)	brittle / perfect	clefts and vesicles in igneous rocks, in gneisses and schists
177	colourless, white, grey, yellow, brown	3·0 – 3·5 / 6·4 – 6·6	white	ad., res. / trp. – trl.	conch., brittle / good, variable	in zone of weathering of lead veins

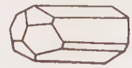
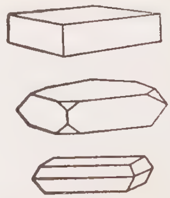
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
nglesey, ornwall, erbyshire, umberland, eadhills Scotland), pain, Russia, New South Vales Broken Hill), J.S.A., New Caledonia	cerussite, siderite, barytes, celestine	**Anglesite** (Lead Vitriol) — $Pb[SO_4]$ Blowpipe: fuses on charcoal; slightly soluble in HNO_3, completely soluble in KOH	valuable lead ore (small quantities)	massive, dense, well-developed single crystals  orthorhombic system, short prismatic or tabular crystals
Northern England, Germany Harz Mts., Hanover), Chile, Western Australia	rock salt, gypsum	**Anhydrite** — $Ca([SO_4]).\frac{1}{2}H_2O$ Blowpipe: fuses with difficulty to white bead	fertiliser, manufacture of sulphates, cement and plaster	compact, granular, fibrous, lamellar, sometimes columnar  orthorhombic system, cube-like crystals, prismatic, often with glide-twin lamellae
cottish avas, Germany, rittany, New Jersey	in gneiss, schist; copper	**Laumontite** (Zeolite Family) — $(CaNa_2)[AlSi_2O_6]_2.4H_2O$ Blowpipe: fuses easily		columnar, fibrous, earthy aggregates  monoclinic system, striated long prismatic crystals; twins
eadhills Scotland), ornwall, erbyshire, urham, ardigan, Germany, ohemia, ardinia, J.S.A. Colorado, rizona), hodesia sumeb Mine S.W. Africa)	galena, anglesite, aragonite	**Cerussite** (White Lead Ore) — $PbCO_3$ Blowpipe: fusible; soluble in HNO_3	valuable lead ore	massive, reniform, stalactitic, in needles, bushel-like aggregates, earthy  orthorhombic system, pyramidal, tabular, single crystals are tabular

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
178	colourless, white, yellowish, sometimes bluish, flesh-coloured, red, violet	3·0 – 3·5 / 3·9 – 4·0	white	vit., pearl. / trp. – trl.	conch., brittle / perfect	in cracks and vesicles in limestones and dolomites; in sediments associated with gypsum, rock salt, and clay; in cap rock of salt domes
179	colourless, tinged with yellow, red, brown or blue by impurities	3·0 – 3·5 / 4·48	white	vit., res. / trp. – trl.	conch., masked by perfect cleavage / perfect	widespread; in veins associated with sulphide ores of lead and zinc, and sometimes fluorspar
180	colourless, white, grey, yellow	3·5 – 4·0 / 2·1 – 2·2	white	pearl. / trp. – trl.	uneven / perfect	in vesicles and cavities in lavas
181	colourless, white, reddish, yellowish	3·5 – 4·0 / 2·7 – 2·8	white	vit. / op.	conch. / good (1 direction)	alteration product of acid lavas, forming pockets and seams

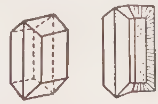
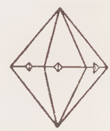
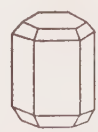
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* *Formula*	*Uses*	*Common Forms: Diagram* *Crystal Form*
Bristol area (Yate), Germany (in Muschelkalk), Italy, Sicily (in sulphur), Egypt, U.S.A.	limestone, dolomite, gypsum, marl, sulphur	**Celestine** Celestite $Sr[SO_4]$ Blowpipe: fusible; flame: red	source of strontium salts (used in beet-sugar manufacture and for fireworks; also pharmaceutical and chemical uses)	massive, lamellar, fibrous, columnar aggregates, granular  orthorhombic system, crystals with many faces
North England, Derbyshire, W. Scotland, Germany, France, U.S.A. (Colorado, Connecticut)	galena, nickel, zinc, cobalt and manganese ores, antimonite	**Barytes** Heavy Spar $Ba[SO_4]$ Plate VI.7 Blowpipe: yellowish-green flame: soluble in hot H_2SO_4	manufacture of paint; filler for paper, textiles and leather; boring mud	comb-like (cockscomb barytes), nodular, reniform and coarsely lamellar aggregates, fibrous, radiating  orthorhombic system, well-developed crystals common, tabular crystals with many faces
Scottish lavas, Antrim, Faeroe Is., Sweden, Transylvania, Alps, India	Iceland spar (calcite), magnetite, pyrite	**Stilbite** (Zeolite Family) $(CaNa_2)[Al_2Si_6O_{16}].6H_2O$ Blowpipe: fusible; decomposed by HCl		divergent and radiating masses  monoclinic system, sheaf-like crystal aggregates
Italy, Hungary, Greece, U.S.A. (Colorado), New South Wales	in trachytes and rhyolites	**Alunite** (Alumstone) $KAl_3[(OH)_6\|(SO_4)_2]$ Blowpipe: crackles and gives sulphurous fumes; soluble in HCl and hot H_2SO_4	source of potassium and aluminium salts	dense earthy granular masses dense mass hexagonal system, rhombohedral, cube-like crystals

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
182	colourless, white, yellowish, grey, sometimes darker	3·5 – 4·0 / 2·95	white to yellowish	vit. / trp. – trl. to op.	conch., brittle / poor	deposit from hot springs; with beds of gypsum and iron ores; upper parts of coral reefs, sometimes in cavities in volcanic rocks
183	colourless, white, greyish, yellowish	3·5 / 4·28 – 4·37	white	vit. – dull / trp. – trl.	uneven / distinct	in veins with galena and barytes
184	colourless, white, grey, yellow	3·5 / 3·7	white	vit. – res. / trp. – trl.	conch., brittle / distinct	in ore veins; as nodules and geodes in limestone
185	colourless, whitish-grey, brownish, copper-red	3·5 – 4·0 / 2·2	white	pearl., also vit. / trp. – trl.	uneven / perfect	in cavities and vesicles in basic volcanic rocks

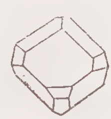
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
widespread, esp. Greenland, Hungary, Spain, Austria, Germany	calcite, siderite, clay, gypsum, sulphur	**Aragonite** $CaCO_3$ Blowpipe: not fusible		massive, fibrous, radiating, columnar  orthorhombic system, repeated twinning common; long needle-like crystals
Northumberland, Durham, Cumberland, North Wales, Austria, U.S.A. (California)	galena, barytes	**Witherite** $BaCO_3$ Blowpipe: fuses easily; flame yellowish-green; soluble in HCl	source of barium salts; pottery	massive, botryoidal, reniform, fibrous aggregates  orthorhombic system, double pyramids similar to quartz, repeated twinning common
Durham, Strontian (Argyll), Germany (Harz Mts.), Austria, U.S.A. (New York)	galena, barytes, celestine	**Strontianite** $SrCO_3$ Blowpipe: edges only fusible; flame: red	source of strontium salts (see No. 178)	massive, fibrous, sheaf-like radiating aggregates  orthorhombic system, prismatic crystals, double pyramid, often acicular (needle-shaped)
Iceland, Faeroe Is., Norway, Germany, Switzerland, Bombay, U.S.A. (New York)	basic volcanic rocks, ore veins	**Heulandite** (Zeolite Family) $(CaNa_2)[Al_2Si_6O_{16}]\cdot 5H_2O$ Blowpipe: fuses to white glass		massive, globular, radiating and lamellar masses  monoclinic system, thick tabular crystals

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
186	colourless, white, yellowish, brown, grey	4·0 – 4·5 / 3·0	white	vit. / trp. – trl.	conch. / perfect	alteration product of dolomite and limestone by solutions from igneous magma, in fractures and irregular veins in serpentine
187	colourless, white, pale green, yellow, brown	5·0 / 3·3 – 3·5	white	vit. / trp. – trl.	conch. – uneven / good, variable	in veins and beds accompanying zinc, iron and lead sulphides
188	colourless, white, reddish, yellowish-white, rose-red	4·5 – 5·0 / 2·3 – 2·4	white	pearl. / trp. – trl.	uneven, brittle / perfect	in cavities and vesicles in basic lavas; in ore deposits
189	colourless, white, reddish, brown	4·5 / 2·1	white	vit. / trp. – trl.	uneven, brittle / fairly distinct	in cavities and vesicles in basic lavas

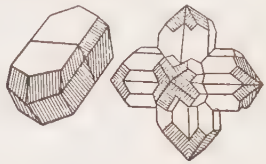
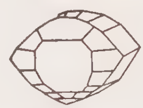
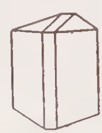
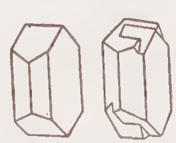
vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Austria, Czecho-slovakia, Urals, Euboea (Greece), U.S.A. (Washington), Quebec, Manchuria	talc, chlorite schist, dolomite, opal, serpentine	**Magnesite** $MgCO_3$ Blowpipe: not fusible	refractory bricks, furnace linings, crucibles, production of CO_2, magnesium and magnesium salts	massive, earthy, nodular, reniform, fibrous; also crystalline like calcite hexagonal system, rhombohedral
Somerset, Derbyshire, Cumberland, Leadhills (Scotland), Germany, Algeria, U.S.A. (Virginia, New Jersey), Mexico	zinc blende, smithsonite	**Hemimorphite** (Calamine, Silicate of Zinc) $Zn_4[(OH)_2\|Si_2O_7].H_2O$ Blowpipe: not fusible; soluble in HCl	zinc ore	reniform, fibrous and nodular masses  orthorhombic system, (hemimorphic), small tabular crystals
Iceland, Sweden, Germany, Bohemia, U.S.A. (New Jersey)	in basic lavas, magnetite	**Apophyllite** (Zeolite Family) $KCa_4[F\|(Si_4O_{10})_2].8H_2O$ Blowpipe: exfoliates and fuses; soluble in HCl		granular, foliaceous masses, striated  tetragonal system, tabular and cube-like crystals, prismatic with pyramids
Scotland, Iceland, Bohemia, Germany, U.S.A. (New York)	in volcanic rocks	**Chabazite** (Zeolite Family) $(Ca,Na_2)[Al_2Si_4O_{12}].6H_2O$ Blowpipe: exfoliates and fuses; soluble in HCl		crystalline  hexagonal system, rhombohedral

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
190	colourless, white, yellow, grey	4·5 / 2·2	white	vit. / trl.	uneven, brittle / poor	in cavities and vesicles in basalt
191	colourless, white, greenish, yellowish	5·0 – 5·5 / 2·9 – 3·0	white	vit. / trp. – trl.	conch., uneven / —	in cracks and cavities in igneous rocks
192	colourless, white, grey, green; see also No. 35	5·5 – 6·0 / 2·9 – 3·1	white	vit. / trp. – trl.	splintery / perfect	in crystalline schists; in metamorphosed basic and ultrabasic rocks; in metamorphosed impure limestone
193	colourless, white, grey, greenish, flesh-coloured	6·0 / 2·53 – 2·56	white	pearl., vit. / trp. – trl. to op.	conch., uneven, splintery / very good in 1 direction less good in 2 others	in acid igneous rocks, gneisses; important rock-forming mineral

vit. = vitreous, silk. = silky, met. = metallic, pear. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
ntrim, eland, ermany, ustria, aly (Sicily, esuvius)	in basalts	**Phillipsite** (Zeolite Family) ——— $(CaK_2)_2[Al_2Si_4O_{12}]_2 \cdot 9H_2O$ Blowpipe: fusible; decomposed by HCl		crystalline, often in radiating aggregates  monoclinic system, short prismatic form, penetrating cruciform twins
ustria 'yrol), ermany larz Mts., lack Forest), ohemia, .S.A. lew Jersey)	in basic igneous rocks	**Datolite** ——— $Ca[OH\|BSiO_4]$ Blowpipe: fuses to black glass; flame: green	sometimes as gemstone	massive, granular aggregates, reniform  monoclinic system, short prismatic crystals
lps, ermany, ungary, weden, .S.S.R. ake Baikal)	talc, serpentine; related minerals: nephrite, uralite	**Tremolite** (Amphibole Family) ——— $Ca_2(Fe_5Mg)_5[Si_8O_{22}](OH)_2$ Blowpipe: fusible	form of asbestos (Italian asbestos), insulating material	crystals long, blade-like, acicular, massive aggregates, fibrous  monoclinic system, well-developed prisms
ommercially xploited in: .S.A., anada, orway, weden (from egmatites), aly (Elba); : Austell Cornwall) nd Scotland . minor uantities	in granite, syenite, porphyry, trachyte, gneiss, crystalline schists	**Orthoclase** (Feldspar Family) ——— $K[AlSi_3O_8]$ Plate IV.6, V.2 Blowpipe: edges only fused with difficulty; decomposed by HNO_3	manufacture of glass and porcelain, earthenware glaze, mild abrasive	crystalline, also massive with granular or lamellar structure  monoclinic system, Carlsbad twins

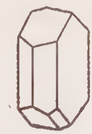
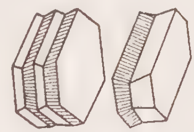
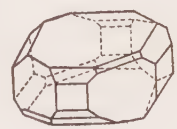
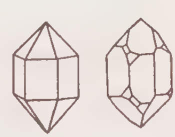
glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
194	colourless, white, green, grey, red, yellow	6·0 – 6·5 / 2·61 – 2·77	white	vit. – pearl. / op.	conch., uneven, brittle / very good in 1 direction, less good in 2 others	rock-forming mineral in igneous and metamorphic rocks, as fragmental grains in arkoses and feldspathic sandstones; very widespread
195	colourless (rock crystal); coloured varieties: purple (amethyst), pale pink (rose quartz), smoky brown (cairngorm, smoky quartz), milk-white (milky quartz)	7·0 / 2·65	white	vit. / trp. – trl.	conch., splintery / poor	common mineral in acid igneous rocks; forms bulk of sandstones and quartzites

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

PLATE VIII PLUTONIC ROCKS

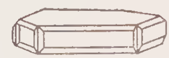
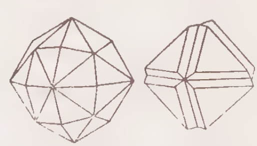
Plutonic Rocks. 1st Row: 1. Syenite, 2. Granite; *2nd Row*: 3. Gabbro, 4. Diorite; *Volcanic Rocks. 3rd Row*: 5. Porphyry, 6. Quartz-porphyry; *4th Row*: 7. Basalt, 8. Andesite.

Localities	Associated Minerals	Name / Formula	Uses	Common Forms: Diagram / Crystal Form
ery idespread	in gabbro, diorite, dolerite, basalt, gneiss	**Plagioclase** (Feldspar Family) / isomorphous mixture of albite $Na[AlSi_3O_8]$ and anorthite $Ca[Al_2Si_2O_8]$ molecules; Members of series are: Albite, less than 10% Anorthite, Oligoclase, 10–30% An, Andesine, 30–50% An, Labradorite, 50–70% An, Bytownite, 70–90% An, Anorthite, more than 90% An Plate V.2–4 Blowpipe: 1. Albite: fuses with difficulty; flame: yellow; 2. Anorthite: fusible; decomposed by acids	soda-rich varieties: see orthoclase (No. 193); labradorite rock used as ornamental building stone	crystalline, also massive as rock-forming mineral    triclinic system, tabular, intergrown crystals, lath-shaped; repeated twinning = albite twins, periclase twins
ommercial uartz crystals: razil, Iadagascar, 'eylon, Jganda; emstones: e pp. 227–31	rock-forming mineral in many varieties of rock	**Quartz** / SiO_2 Plate IV.7, XII.9–14 Blowpipe: not fusible; slightly soluble in HF	manufacture of glass and silica bricks, optical instruments and precision apparatus; used in radio oscillators and radio-telephones; gemstone	crystalline, twins  hexagonal system, long 6-sided prisms with pyramids

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
196	colourless, clear, sometimes milky	6·5 – 7·0 / 2·27	white	vit. / trp. – trl.	/ rarely good, scaly	in acid volcanic rocks, e.g. rhyolite, trachyte; also in cavities in volcanic rocks
197	colourless, pale yellow, pale pink	7·5 – 8·0 / 3·0	white	vit. / trp.	conch. / indistinct	in granitic veins and biotite schists
198	colourless, yellowish, brown, blue, grey, black; black = carbonado; badly coloured = bort	10·0 / 3·50 – 3·52		ad. / trp. – trl.	conch. / perfect	as primary mineral in basic and ultrabasic rocks (often in volcanic vents); in alluvial deposits

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* *Formula*	*Uses*	*Common Forms: Diagram* *Crystal Form*
Antrim, Transylvania, Hungary, Germany, U.S.A. (Washington), Mexico, S. Africa, (Drachenfels trachyte)		**Tridymite** SiO_2 Blowpipe: not fusible; soluble in HF		crystalline  hexagonal system. 6-sided plates; repeated twinning
Norway, Urals (U.S.S.R.), Minas Geraes (Brazil), Colorado (U.S.A.), Tanganyika	emerald, chrysoberyl, apatite, in mica schists	**Phenakite** $Be_2[SiO_4]$ Blowpipe: not fusible; insoluble in acids	gemstone of little importance (often confused with quartz)	crystalline  hexagonal system, (trigonal symmetry), prismatic crystals
Sierra Leone, Congo, Ghana, South and S.W. Africa, Brazil, British Guiana, U.S.S.R.	quartz, gold, platinum; alluvial minerals	**Diamond** C Plate IV.10, XI.6 Blowpipe: not fusible, splinters burn	gemstone, abrasive and cutting agent	aggregates, water-worn grains, splinters, rounded bodies  cubic system, octahedral form, curved faces, striated, crystals often distorted and irregular

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

No.	Colour	Hardness / S.G.	Streak	Lustre / Transparency	Fracture / Cleavage	Occurrence
199	opalescent, internal coloured reflections	5·5 / 2·0 – 2·1	white	sub-vit. / trl. – op.	uneven / none	in or associated with young volcanic rocks, filling cavities in basalt or sandstone, or replacing wood
200	leek green speckled with red	6·5 – 7·0 / 2·5 – 2·6		dull / op.	rough / none	as No. 201
201	intensive colours – red, brown, yellow	7·0 / 2·5 – 2·6		dull / op.	rough, conch. / none	in volcanic rocks, also product of contact metamorphism of clay or shale (Porcelain Jasper)
202	various colours	7·0 / 2·59 – 2·61	white	waxy, dull / trl. – op.	rough, hackly / none	in vesicles and other cavities in volcanic rocks

vit. = vitreous, silk. = silky, met. = metallic, pearl. = pearly, fat. = fatty, ad. = adamantine or diamond,

Localities	*Associated Minerals*	*Name* / *Formula*	*Uses*	*Common Forms: Diagram* / *Crystal Form*
Hungary, Mexico, Australia (N.S.W., Queensland, S. Australia), U.S.A. (Nevada)		**Opal**	gemstone	amorphous
		$SiO_2 + H_2O$ Plate XIV.1–7 Blowpipe: not fusible		none (gel-like)
mainly India	inclusions in volcanic rocks	**Heliotrope** Bloodstone	gemstone	cryptocrystalline (very finely crystalline)
		SiO_2 + impurities		none
India, Egypt	clay inclusions in volcanic rocks; in tuffs	**Jasper**	gemstone	cryptocrystalline (very finely crystalline)
		SiO_2 + impurities **Plasma** = bright green speckled with white		none
very widespread	in basalts, dolerites, etc.	**Chalcedony**	gemstone	cryptocrystalline, i.e. only microscopically determinable as minute fibres or grains
		SiO_2 + impurities and water Plate VII.2 Varieties: **Carnelian**, yellowish red – blood red **Chrysoprase**, apple green **Sard**, brownish (trl.) **Agate**, variegated, composed of different coloured bands		none

glas. = glassy, res. = resinous; op. = opaque, trp. = transparent, trl. = translucent; conch. = conchoidal

Mineral Identification Table

II. Based on Colour of Streak

In the following table the minerals are listed primarily according to the colour of the streak they leave on a porcelain plate, and are further subdivided according to hardness. The table should make it possible to identify minerals in the field with the minimum of equipment. The order of colours is as follows: white, yellow, brown, red, blue, green, grey, and black.

WHITE

Hardness	Mineral
1	Sassoline = $B(OH)_3$
	Websterite / Aluminite = $Al_2[(OH)_4\|SO_4].7H_2O$ hydrated Al-sulphate
	Talc = $Mg_6(OH)_4Si_8O_{20}$
	Kaolinite = $Al_4(OH)_8Si_4O_{10}$
1–1·5	Natron = $Na_2CO_3.10H_2O$
	Arsenolite = As_2O_3
	Mirabilite = $Na_2(SO_4).10H_2O$ / Glauber Salt
1–2	Sal Ammoniac = NH_4Cl
	Carnallite = $MgCl_2KCl.6H_2O$
	Native Sulphur = S
	Soda-Nitre = $NaNO_3$
	Gypsum = $CaSO_4.2H_2O$
	Vivianite = $Fe_3^{\cdot\cdot}[PO_4].8H_2O$
	Struvite = $(NH_4)Mg[PO_4].6H_2O$
	Pyrophyllite = $Al_4(OH)_4[Si_8O_{20}]$
1–2·5	Chlorite = $Mg_5Al(OH)_8[AlSi_3O_{10}]$ / Penninite
	Amosite = $Mg_4Al_2[(OH)_8\|Al_2Si_2O_{10}]$
	Antigorite = $Mg_6[(OH)_8\|Si_4O_{10}]$
2	Halite = NaCl
	Sylvine = KCl
	Senarmontite = Sb_2O_3
	Saltpetre = KNO_3
2–2·5	Hydrozincite = $Zn_5[(OH)_3CO_3]_2$ / White Jack
	Borax = $Na_2B_4O_7.10H_2O$
	Epsomite = $MgSO_4.7H_2O$ / Epsom Salts
	Potash alum = $KAl[SO_4]_2.12H_2O$
	Pharmacolite = $CaH[AsO_4].2H_2O$
	Sepiolite = $2MgO.3SiO_2.2H_2O$ / Meerschaum
	Muscovite = $KAl_2[Si_3AlO_{10}](OH)_2$

Hardness	Mineral
2·5	Lepidolite = $[AlLi]_3K[Si_4O_{10}](OH,F)_2$
	Zinnwaldite = $K(LiFe^{\cdot\cdot})Al[AlSi_3O_{10}](OH,F)_2$
	Biotite = $K(MgFe^{\cdot\cdot})_3(OH,F)_2[AlSi_3O_{10}]$
	Phlogopite = $KMg_3[Si_3AlO_{10}](OH,F)_2$
about 2·5	Brucite = $Mg(OH)_2$
	Chalcanthite = $Cu(SO_4).5H_2O$
2–3	Native Tellurium = Te
	Valentinite = Sb_2O_3
2·5–3	Native Silver = Ag
	Cryolite = Na_3AlF_6
	Hydrargillite = $Al(OH)_3$ / Gibbsite
	Phosgenite = $Pb_2[Cl_2CO_3]$
	Glauberite = $CaNa_2(SO_4)_2$
	Caledonite = $Pb_5Cu_2[(OH)_6\|CO_3\|(SO)_4]_3$
	Vanadinite = $Pb_5[Cl(VO_4)_3]$
	Chrysocolla = $CuSiO_3.nH_2O$
about 3	Silver Amalgam = AgHg
	Calcite = $CaCO_3$
	Anglesite = $Pb(SO_4)$
	Kainite = $KCl.MgSO_4.3H_2O$
	Wulfenite = $Pb[MoO_4]$
3–3·5	Cerussite = $PbCO_3$ / White lead ore
	Celestine = $SrSO_4$
	Barytes = $BaSO_4$ / Heavy Spar
	Polyhalite = $K_2SO_4.MgSO_4.2CaSO_4.2H_2O$
	Laumontite = $(CaNa_2)[AlSi_2O_6].4H_2O$

WHITE

Hardness	
3–4	Anhydrite = $Ca[SO_4]$
	Chrysotile (Asbestos) = $(OH)_8Mg_6[Si_4O_{10}]$
3·5–4	Witherite = $BaCO_3$
	Kieserite = $MgSO_4.H_2O$
	Adamite = $Zn_2[OH\|AsO_4]$
	Blende, Sphalerite = ZnS
	Dolomite = $CaMg[CO_3]_2$
	Ankerite = $CaFeMg[CO_3]_2$
	Strontianite = $SrCO_3$
	Alunite = $KAl_3[(OH)_6\|(SO_4)_2]$
	Pyromorphite = $Pb_5[Cl(PO_4)_3]$
	Wavellite = $Al_3(OH)_3(PO_4)_2.5H_2O$
	Mimetite = $Pb_5[Cl(AsO_4)_3]$
	Margarite = $CaAl_2[(OH)_2\|Si_2Al_2O_{10}]$
	Heulandite = $CaNa_2[SiAlO_8]_2.5H_2O$
	Stilbite = $(CaNa_2)[Al_2Si_6O_{16}].6H_2O$
	Bismuth ochre = $Bi_2O_3.3H_2O$
about 4	Fluorspar, Fluorite = CaF_2
	Rhodochrosite, Dialogite = $MnCO_3$
4–4·5	Native Platinum = Pt
	Magnesite = $MgCO_3$
	Siderite = $FeCO_3$
	Alstonite = $n(CaBa)CO_3$
	Kyanite = $Al_2[O\|(SiO_4)]$
	Harmotome = $(BaK_2)_2[Al_4Si_{11}O_{30}].10H_2O$
	Phillipsite = $(CaK_2)_2[Al_2Si_4O_{12}]_29H_2O$
	Chabazite = $CaNa_2[Al_2Si_4O_{12}].6H_2O$
4–5	Xenotime = $Y(PO_4)$
	Variscite = $Al(PO_4).2H_2O$
	Scheelite = $CaWO_4$
4·5–5	Wollastonite = $CaSiO_3$
	Apophyllite = $KCa_4[F\|(Si_4O_{10})_2].8H_2O$
5	Smithsonite (Calamine) = $ZnCO_3$
	Apatite = $Ca_5[F,OH,Cl)\|(PO_4)_3]$
	Hemimorphite = $Zn(OH)_2.SiO_3$
5–5·5	Monazite = $Ce(PO_4)$
	Melilite = $(Ca,Na)_2(AlMg)(Si,Al)_2O_7$
	Sphene, Titanite = $CaTi[(SiO_4\|O)]$
5–5·5	Analcite = $Na[AlSi_2O_6].H_2O$
	Datolite = $Ca[OH.B.SiO_4]$
	Natrolite = $Na_2[Al_2Si_3O_{10}].2H_2O$
	Scolecite = $Ca[Si_3Al_2O_{10}].3H_2O$
about 5·5	Perovskite = $CaTiO_3$
	Lazulite = $(Fe,Mg)Al_2[OH\|PO_4]_2$
5–6	Enstatite = $Mg_2[SiO_6]$
	Bronzite = $(MgFe)_2[SiO_3]$
	Diopside = $CaMg[Si_2O_6]$
	Cancrinite = $(Na_2,Ca)_4[CO_3.(H_2O)_{0-3}.(AlSiO_4)_6]$
	Anthophyllite = $(Mg,Fe)_7(Si_8O_{22})(OH)$
5·5–6	Periclase = MgO
	Opal = hydrated SiO_2
	Hyalite = SiO_2
	Wood Opal, Fire Opal, Green Opal = hydrated SiO_2
	Anatase = TiO_2
	Willemite = $Zn_2(SiO_4)$
	Hauerite = MnS_2
	Rhodonite = $Mn(SiO_3)$
	Tremolite, Actinolite = $Ca_2Mg_5(OH)_2Si_8O_{22}$
	Nepheline = $Na(SiO_4Al)$
	Leucite = $KAlSi_2O_6$
	Sodalite = $Na_8[Cl_2(AlSiO_4)_6]$
	Nosean = $Na_8[(SO_4).(AlSiO_4)_6]$
	Hauyne = $(Na,Ca)_{8-4}[(SO_4)_{2-1}.AlSiO_4)_6]$
about 6	Amblygonite = $LiAl[F,OH).PO_4]$
	Turquoise = $CuAl_6[(OH)_2(PO_4)]_4.4H_2O$
	Zoisite = $Ca_2Al_3[(OH).(SiO_4)_3]$
	Augite = $CaMg[Si_2O_6]$ + Fe,Al,Ti,Na
	Feldspar Family
	Orthoclase, Adularia, Sanidine, Microcline, Amazonite = $K[AlSi_3O_8]$
	Albite = $Na[AlSi_3O_8]$ – (abbr. as Ab)
	Pericline
	Oligoclase, Sunstone = NaCa – Feldspar (Ab 90%–70%)
	Andesine = Na,Ca – Feldspar (Ab 70%–50%)
	Labradorite = CaNa – Feldspar (Ab 50%–30%)
	Bytownite = CaNa – Feldspar (Ab 30%–10%)
	Anorthite = $Ca[Al_2Si_2O_8]$

WHITE

Hardness	
6–7	{ Cassiterite = SnO_2
	{ Tinstone
	Kyanite = $Al_2[O.SiO_4]$
	Prehnite = $(OH)_2Ca_2Al_2(Si_3O_{10})$
	Sillimanite = Al_2SiO_5
about 6·5	Chondrodite = $Mg_5[(OH.F)_2.(SiO_4)_2]$
	Benitoite = $BaTi(Si_3O_9)$
	{ Idocrase = $Ca_{10}(Mg,Fe)_2Al_4.(Si_9O_{34}).(OH)_4$
	{ Vesuvianite
	Jadeite = $NaAlSi_2O_6$
	Diaspore = α–AlOOH
	{ Olivine = $(Mg,Fe)_2SiO_4$
	{ Peridot
	Chrysolite = $(Mg,Fe)_2SiO_4$
	Axinite = $Ca_2(Mn,Fe)Al_2BH(SiO_4)_4$
	{ Spodumene = $AlLi(Si_2O_6)$
	{ Kunzite
	{ Hiddenite
6·5–7	*Garnet Family*
	{ Grossular = $Ca_3Al_2[SiO_4]_3$
	{ Hessonite
	Andradite = $Ca_3Fe_2^{\cdots}[SiO_4]_3$
	Melanite = $Ca_3Fe_2^{\cdots}[SiO_4]_3$ + Ti
	Pyrope = $Mg_3Al_2[SiO_4]_3$
	Almandine = $Fe_3^{\cdot\cdot}Al_2[SiO_4]_3$
	Spessartite = $Mn_3Al_2[SiO_4]_3$
	Uvarovite = $Ca_3Cr_2^{\cdots}[SiO_4]_3$
7	*Quartzes*
	{ Smoky Quartz = SiO_2
	{ Cairngorm
	{ Amethyst
	{ Morion
	{ Rock Crystal
	{ Cat's Eye = SiO_2
	{ Tiger's Eye
	{ Prase
	{ Citrine = SiO_2
	{ Milky Quartz
	{ Chalcedony
	{ Jasper
	{ Ordinary Quartz
	{ Carnelian
	{ Sard = SiO_2
	{ Chrysoprase
	{ Agate
	{ Onyx
	{ Plasma
	{ Heliotrope
	{ Flint
	{ Chert
7	Tridymite = SiO_2
	Boracite = $Mg_6[Cl_2.B_{14}O_{26}]$
7–7·5	{ Tourmaline = $Na(MgFe)_3B_3Al_3(OH)_4(Al_3Si_6O_{27})$
	{ Achroite – pale green tourmaline
	{ Rubellite – red tourmaline
	{ Siberite – red tourmaline
	{ Indicolite – blue tourmaline
	{ Dravite – brown tourmaline
	{ Schorl – black tourmaline
	{ Danburite = $Ca[B_2Si_2O_8]$
7·5	Staurolite = $[Al_4(SiO_4)_2].[Fe^{\cdot\cdot}O_2(OH)_2]$
	Cordierite = $Mg_2Al_4[Si_5O_{18}]$
about 7·5	{ Andalusite = Al_2SiO_5
	{ Chiastolite
	{ Zircon = $Zr(SiO_4)$
	{ Hyacinth
	Euclase = $Al[(OH.BeSiO_4)]$
7·5–8	Phenakite = $Be_2(SiO_4)$
	{ Beryl = $Al_2Be_3(Si_6O_{18})$
	{ Emerald – green beryl
	{ Aquamarine – pale blue beryl
	{ Morganite – rose red beryl
	{ Heliodor – greenish-yellow beryl
about 8	Spinel = $MgAl_2O_4$
	Topaz = $Al_2[(SiO_4.F_2)]$
8·5	{ Chrysoberyl = Al_2BeO_4
	{ Alexandrite
about 9	{ Corundum = Al_2O_3
	{ Sapphire – blue corundum
	{ Ruby – red corundum
	{ Emery
10	{ Diamond = C
	{ Carbonado – black
	{ Bort

YELLOW

Hardness	
1·5–2	Native Sulphur = S
	Realgar = AsS
	Orpiment = As_2S_3
up to 2	Pyrostilpnite = Ag_3SbS_3
up to 2·5	Proustite = Ag_3AsS_3
	Trögerite = $[(UO_2)_3(AsO_4)_2].12H_2O$
	Uranophane = $CaO.2UO_3.2SiO_2.7H_2O$
up to 3	Native Gold = Au
2·5–3	Vanadinite = $Pb_5[(VO_4)_3\|Cl]$
	{Crocoite = $PbCrO_4$ / Crocoisite}
3	Wulfenite = $Pb[MoO_4]$
	Olivenite = $Cu_2[AsO_4.OH]$
up to 3·5	Greenockite = CdS
3–4	{Blende = ZnS / Sphalerite}

Hardness	
3–4	{Pyromorphite = $Pb_5(PO_4)_3Cl$ / Green Lead Ore}
	{Dufrenite = $Fe^{\cdots}[(OH)_3.PO_4]$ / Kraurite}
	Mimetite = $Pb_5(AsO_4)_3Cl$
4	{Zincite = ZnO / Red Oxide of Zinc}
4–5	Xenotime = $Y(PO_4)$
	Triplite = $(Fe,Mn)_2(PO_4F)$
	{Goethite = α–FeO OH / Needle Iron Ore}
	Micaceous Goethite = γ–FeO OH
up to 5·5	Limonite = $Fe_2O_3.1{\cdot}5H_2O$
	Minette = α–FeO OH
	{Wolfram = $(Fe, Mn)\,WO_4$ / Wolframite}
up to 6	Brookite = TiO_2
	Hypersthene = $(Mg,Fe)SiO_3$
up to 6·5	Rutile = TiO_2
	{Acmite = $NaFeSi_2O_6$ / Aegirine}

BROWN

1	Wad = MnO_2 + (variable)
2–2·5	Miargyrite = $AgSbS_2$
up to 3·5	Descloizite = $Pb(Zn,Cu)[OH\|VO_4]_2$
up to 4	{Blende = ZnS / Sphalerite}
	Wurtzite = ZnS
3·5–4	{Cuprite = Cu_2O / Red Copper Oxide}
about 4	Manganite = $MnO(OH)$
	Hauerite = MnS_2
up to 4·5	Siderite = $FeCO_3$
	Sphaerosiderite = $FeCO_3$
up to 5	Xenotime = $Y(PO_4)$
about 5	{Goethite = αFeO OH / Needle Iron Ore}
	Micaceous Goethite = γ–FeO OH
5·5	{Kupfernickel = $NiAs$ / Niccolite}
	{Breithauptite = $NiSb$ / Antimonial Nickel}

5·5	Hausmannite = Mn_3O_4
	{Limonite = $Fe_2O_3.H_2O$ / Brown Haematite}
	Minette = $Fe_2O_3.H_2O$
	{Wolfram = (FeMn)Wo$_4$ / Wolframite}
5–6	Psilomelane = MnO_2 + (variable)
5·5	{Magnetite = Fe_3O_4 / Magnetic Iron Ore}
	{Chromite = $FeO.Cr_2O_4$ / Chrome Iron Ore}
	{Pitchblende = UO_2 / Uraninite}
5·5–6	Brookite = TiO_2
	Amphiboles:
	Anthophyllite = $(Mg,Fe)_2[Si_2O_6]$
	Hornblende = Complex silicate – Al & Fe bearing.
about 6	{Tantalite = $(Fe,Mn)(NbTa)_2O_6$ / Niobite}
up to 6·5	Franklinite = $(Zn,Mn)Fe_2O_4$
	Rutile = TiO_2
	{Haematite = Fe_2O_3 / Specular Iron Ore / Kidney Ore}
6–7	{Cassiterite = SnO_2 / Tinstone}

RED

Hardness	
1·5–2	Realgar = AsS
	Erythrite / Cobalt Bloom = $CO_3[AsO_4]_2.8H_2O$
2	Polybasite = $(Ag,Cu)_{18}Sb_2S_{11}$
	Pyrostilpnite = Ag_3SbS_3
2–2·5	Miargyrite = $AgSbS_2$
	Cinnabar = HgS
	Proustite = Ag_3AsS_3
2·5–3	Native Copper = Cu
	Pyrargyrite = Ag_3SbS_3
	Crocoisite = $PbCrO_4$ / Crocoite
3	Greenockite = CdS
3·5	Polyhalite = $K_2SO_4MgSO_4.2CaSO_4.2H_2O$
3·5–4	Cuprite = Cu_2O / Red Oxide of Copper

Hardness	
about 4	Hauerite = MnS_2
	Rhodochrosite = $MnCO_3$ / Dialogite
up to 4·5	Zincite = ZnO / Red Oxide of Zinc
4·5–5	Thorite = $Th(SiO_4)$
5–5·5	Hausmannite = Mn_3O_4
5·5–6	Rhodonite = $Mn[SiO_3]$ / Manganese Spar
about 6	Niobite = Columbite = $(Fe,Mn)(NbTa)_2O_6$
	Tantalite = $(Fe,Mn)Ta_2O_6$
6·5	Haematite = Fe_2O_3 / Specular Iron Ore / Kidney Ore

BLUE

Hardness	
1·5–2	Vivianite = $Fe_3^{\cdots}[PO_4]_2 8H_2O$ / Blue-iron Earth
2–2·5	Liroconite = $Cu_9Al_4[(OH)_3\|AsO_4]_5.20H_2O$
	Linarite = $PbCu[(OH)_2.\|SO_4]$
2·5–3	Clinoclase = $Cu_3[(OH)_3\|AsO_4]$
3·5–4	Azurite = $Cu_3[(OH)_2\|CO_3)_2]$
5–5·5	Lazurite = $(NaCa)_8[(SO_4,SiCl_2)\|AlSiO_4]_6$ / Lapis Lazuli
6	Glaucophane ≃ $Na_2Al_2Mg_3Si_8O_{22}(OH)_2$
7	Dumortierite ≃ $Al_8BSi_3(OH)O_{19}$

GREEN

Hardness	
1–1·5	Molybdenite = MoS_2
1–2	Glauconite = similar to mica, variable
1–2·5	Chlorite = clinochlore = $Mg_5Al(OH)_8[AlSi_3O_{10}]$
	Amosite = $Mg_4Al_2[(OH)_8\|Al_2Si_2O_{10}]$
	Antigorite = $Mg_6[(OH)_8\|Si_4O_{10}]$
	Penninite = $Mg_5(Mg,Al)(OH)_8\|Si_4O_{10}$
2	Chalcophyllite = $Cu_{18}Al_2(AsO_4)_3(SO_4)_3(OH)_{27}.33H_2O$
2–2·5	Torbernite = $Cu[UO_2\|PO_4]_2.12H_2O$
	Aragonite = $CaCO_3$
	Annabergite = $Ni_3[AsO_4]_2.8H_2O$ / Nickel Bloom
	Pharmacosiderite = $Fe_3[(AsO_4)_2\|(OH)_3].5H_2O$
2·5–3	Caledonite = $Pb_5Cu_2[(OH)_6\|CO_3\|(SO_4)_3]$
	Clinoclase = $Cu_3[(OH)_3\|AsO_4]$
2–4	Chrysocolla = $CuSiO_3.nH_2O$
	Garnierite = $(NiMg).SiO_2.(OH)_2.nH_2O$
	Olivenite = $Cu_2(AsO_4)OH$
	Chamosite = $(Fe^{\cdot\cdot}Mg)_3[Al_2Si_2O_{10}].n(H_2O)$(?)
3·5	Atacamite = $CuCl_2.3Cu(OH)_2$
	Descloizite = $Pb(Zn,Cu)[OH\|VO_4]$
	Euchroite = $Cu_2[OH\|AsO_4].3H_2O$
3–4	Millerite = NiS / Nickel Pyrites

GREEN

Hardness	Mineral
3·5–4	Chalcopyrite = Cu,FeS_2 Copper Pyrites Alabandite = MnS Malachite = $Cu_2[(OH)_2\|CO_3]$ Brochantite = $Cu_4[(OH)_6\|SO_4)]$ Dufrenite = $Fe_3^{\cdots}[(OH)_3\|PO_4]$ Kraurite
4·5–5	Pseudomalachite = $Cu_3[(OH)_3\|PO_4]$
5	Dioptase = $Cu_3[Si_3O_9].3H_2O$
5–6	Hedenbergite = $CaFe[Si_2O_6]$ Diallage = like augite
5·5–6	Pitchblende = UO_2 Uraninite
5·5–6	Allanite = $(Ca,Ce,La,Na)_2.(Al,Fe,Mg)_3[OH\|(SiO_4)_3]$ Orthite Hornblende = Amphibole
6	Augite = $CaMg.Si_2O_3 + (Al,Fe)$
6–6·5	Pyrite = FeS_2 Pyrites Iron Pyrites Aegirine = $NaFeSi_2O_6$ Acmite
6–7	Chloritoid = Ottrelite $Fe_2Al_2(OH)_4Si_2Al_2O_{10}$
6·5–7	Thortveitite = $(Sc,Y)_2.[Si_2O_7]$
7·5–8	Hercynite = $FeO.Al_2O_3$ Iron Spinel

GREY

Hardness	Mineral
1	Graphite = C
1·5	Nagyagite = $AuTe_2.6Pb(S,Te)$ Molybdenite = MoS_2
1–2	Glauconite = similar to mica, variable
1·5–2	Tetradymite = Bi_2Te_2S Sylvanite = $AuAgTe_4$
2	Antimonite = Sb_2S_3 Stibnite Bismuthinite = Bi_2S_3 Bismuth Glance
2–2·5	Native Bismuth = Bi Argentite = Ag_2S Silver Glance
2·5	Argyrodite = $4Ag_2S.GeS_2$ Plagionite = $Pb_{13}Sb_7S_{23}$ Meneghinite = $Pb_{13}Sb_7S_{23}$ Geocronite = $5PbS.Sb_2S_3$
2–3	Calaverite = $(Au,Ag)Te_2$
2·5–3	Chalcocite = Cu_2S Copper Glance Galena = PbS Lead Glance
3	Bornite = Cu_5FeS_4 Erubescite Bournonite = $2Pbs.Cu_2S.Sb_2S$ Wheel Ore
3	Zinckenite = $PbS.Sb_2S_3$ Chamosite = $(Fe^{\cdot\cdot},Mg)_3[Al_2Si_2O_{10}].nH_2O(?)$
3–3·5	Native Antimony = Sb Cerussite = $PbCO_3$ White Lead Ore
3·5	Enargite = Cu_3AsS_4 Dyscrasite = Ag_3Sb
3–4	Native Arsenic = As
3·5–4	Pentlandite = $(Fe,Ni)_9S_8$
4	Pyrrhotite = FeS Magnetic Pyrites
4–5	Native Iron = Fe Triplite = $(Fe,Mn)_2(PO_4F)$
4·5–5	Native Palladium = Pd Safflorite = $CoAs_2$ Cobalt Pyrites = $(Co,Ni)_3S_4$ Linnaeite
5	Ullmannite = $NiSbS$
5·5	Gersdorffite = $NiAsS$ Löllingite = $FeAs_2$
5–5·5	Chloanthite = $NiAs_{2-3}$ White Nickel
5–6	Hedenbergite = $CaFe(Si_2O_6)$ Diallage = like augite

GREY

Hardness

5·5 Cobaltite = $CoAsS$
Smaltite = $CoAs_{2-3}$
Tin White Cobalt
Magnetite = Fe_3O_4
Magnetic Iron Ore
Perovskite = $CaTiO_3$

5·5–6 Rammelsbergite = $NiAs_2$
Orthite = $(Ca,Ce,La,Na)_2(Al,Fe,Mg)_3[OH|(SiO_4)_3]$
Allanite
Arfvedsonite = $Na_5Ca(Fe^{\cdot\cdot},Mg,Ti)_7Fe_3^{\cdot\cdot}[(OH)_4|(Al,Fe^{\cdot\cdot\cdot})_1Si_{15}O_{44}]$
Hypersthene = $(Mg,Fe)_2[Si_2O_6]$
Common Hornblende = Al_2O_3- and Fe_2O_3-bearing amphibole
Basaltic Hornblende

Hardness

6 Glaucophane = $Na_2Al_2Mg_3Si_8O_{22}(OH)_2$

6–6·5 Marcasite = FeS_2
White Iron Pyrites

6–7 Cassiterite = SnO_2
Tinstone
Epidote = $Ca_2(Al,Fe^{\cdot\cdot\cdot})_3[OH(SiO_4)_3]$
Pistacite

6·5–7 Gadolinite = $Y_2Fe[OBeSiO_4]_2$

7·5–8 Hercynite = $FeO.Al_2O_3$
Iron Spinel

8 Gahnite = $ZnO.Al_2O_3$
Zinc Spinel

BLACK

1 Asbolan = Cobalt-bearing psilomelane
Earthy Cobalt

1–1·5 Nagyagite = $AuTe_2.6Pb(S,Te)$
Sternbergite = $AgFe_2S_3$

1·5–2 Covelline = CuS
Covellite

2 Bismuthinite = Bi_2S_3
Bismuth Glance
Polybasite = $9\ (Ag,Cu)_2S.Sb_2S_3$

2–2·5 Pyrolusite = MnO_2

2·5 Argyrodite = $4Ag_2S.GeS_2$
Plagionite = $5PbS.4Sb_2S_3$
Boulangerite = $5PbS.2Sb_2S_3$

3 Bornite = Cu_5FeS_4
Erubescite
Zinckenite = $PbSb_2S_4$

3·5 Enargite = Cu_3AsS_4

3–4 Native Arsenic = As
Millerite = NiS
Nickel Pyrites
Capillary Pyrites

3·5–4 Chalcopyrite = $CuFeS_2$
Copper Pyrites
Tetrahedrite = Cu_3SbS_{3-4} with Ag,Hg,Zn
Fahlerz
Pentlandite = $(Fe,Ni)S$

4 Stannine = Cu_2FeSnS_4
Tin Pyrites
Manganite = $MnO(OH)$

4 Pyrrhotite = FeS
Magnetic Pyrites

4–4·5 Siderite = $FeCO_3$
also Sphaerosiderite

5 Ullmannite = $NiSbS$

5–5·5 Kupfernickel = $NiAs_{2-3}$
Niccolite
Gersdorffite = $NiAsS$
Löllingite = $FeAs_2$
Chloanthite = $NiAs_{2-3}$
White Nickel
Wolfram = $(Fe,Mn)WO_4$
Wolframite

5·5 Pitchblende = UO_2
Uraninite
Magnetite = Fe_3O_4
Magnetic Iron Ore
Cobaltite = $CoAsS$
Smaltite = $CoAs_{2-3}$
Tin White Cobalt

5–6 Psilomelane = MnO_2
Ilmenite = $FeTiO_3$

5·5–6 Rammelsbergite = $NiAs_2$
Mispickel = $FeAsS$
Arsenopyrite

6 Tantalite = $(Fe,Mn)Ta_2O_6$
Niobite = $(Fe,Mn)Nb_2O_6$
Columbite

6–6·5 Pyrite = FeS_2
Pyrites
Iron Pyrites
Braunite = $Mn_4^{\cdot\cdot}Mn_3^{\cdot\cdot\cdot\cdot}(O_8|SiO_4)$

6–7 Sperrylite = $PtAs_2$

II. ROCKS

The Origin and Composition of the Earth

It is quite likely that the exact story of how our planet came to be formed may never be completely and satisfactorily unravelled. Astronomers and geophysicists have advanced various theories about the earth's origin and its subsequent development, but as yet no general agreement appears to have been reached. Most of these theories, though differing in many important aspects regarding the evolution of the solar system, are agreed that the earth started its independent life in the universe as a glowing ball consisting of solid particles (planetesimals) and gas. It is now known that this phase in the earth's development took place at least four and a half thousand million years ago – a span of time difficult to visualise. During this stage in its history the earth gradually cooled, ceased to give out light, and eventually became a liquid ball. It was in this condition that the first separation of its constituent materials took place under the influence of gravity. The heavy components sank to the depths and the lighter ones remained near the surface. This first differentiation was probably fairly crude. There were no sharp boundaries between layers of different density, and much mixing of material between the adjacent layers must have taken place. The first portions of the original crust were formed when, after further continuous loss of heat, the temperature of the outer part of the earth fell to about 1100° to 900° C. Remnants of this original crust are preserved in only a few places on the present surface of the earth, as the greater part of it was altered out of recognition by subsequent sinking and re-melting, and was incorporated in later formed parts of the crust. The age of what are thought to be the remains of the original crust has been estimated by various methods, and is taken to be from three to three and a half thousand million years. As the cooling penetrated inwards, the outer skin of solid rock became gradually thicker. The cooling also brought about a contraction of the outer solid mantle, which, being made of relatively inelastic material, tended to break. In this way the separate crustal blocks were formed. As these were floating on a viscous substratum, they were pushed against each other and were locally broken, folded, raised up or pushed down. These movements led to the formation of wrinkles and folds on the face of the earth, and so the first mountain chains arose. Remnants of these original mountain belts are now preserved in only a few areas, as most of them were greatly altered and even re-melted during later earth movements.

When the earth's surface had cooled to the so-called critical temperature, the water of the primeval oceans was formed by condensation. Some of this water evaporated and passed into the atmosphere, and was thence carried over the land surfaces where it was precipitated as rain and snow. The water and ice were responsible for the mechanical disintegration and chemical solution of the surface rocks, and helped to transport the materials so produced to the plains and the sea. In this way the mountain chains were gradually flattened and eventually reduced to level plains. The process of mountain-building was thus constantly opposed by the destructive forces of denudation, and during the subsequent history of the earth there have been several periods of mountain-building followed by periods of gradual levelling. These processes have gone on without ceasing to the present day.

Composition

By the application of Newton's Law of Gravity it has been possible to calculate the total weight of the earth. As the earth's volume can also be calculated it can be shown that its average density or specific gravity is 5·6. The density of the outer crust of the earth is much less than 5·6; it is between 2·6 and 2·8. To obtain a mean density of 5·6 it must thus be assumed that the specific gravity of the earth's core is considerably greater than this. It is not, of course, possible to determine the density and composition of the core by any direct means, as the deepest bore-holes have reached a depth of only 5 km. (3 miles), which is less than one thousandth of the radius of the earth (6370 km. or 3958 miles). Our knowledge of the internal composition of the earth is based largely on the data obtained from the seismographic records of earthquakes. These indicate that at depths of 6 to 50 km. and 2900 km. (1802 miles) there are well-defined surfaces which reflect earthquake shock waves. These surfaces of discontinuity, as they are called, would seem to separate zones or layers of quite distinct mineralogical composition. The zone below 2900 km. is called the *core*, which has a radius of about 3500 km. (2175 miles) and may be partly or completely liquid. The study of meteorites, which are thought by some to be fragments from shattered stars or planets, suggests that the earth's core, like the meteorites, consists of a mixture of nickel and iron with a density of 8 to 10·3. The layer next to the core, often called the *inner mantle*, lies between 2900 km. and about 1200 km. from the surface, and is thought to be composed of the sulphides and oxides of heavy metals, with a density range of 5·5 to 6·5. This layer grades into the *outer mantle*, whose density at the depth of 50 km. is 3·3. Some people think that the outer mantle consists largely of a magnesium-rich variety of the mineral olivine and has the composition of certain peridotic rocks (see p. 185) exposed in the world's great mountain chains. The outermost

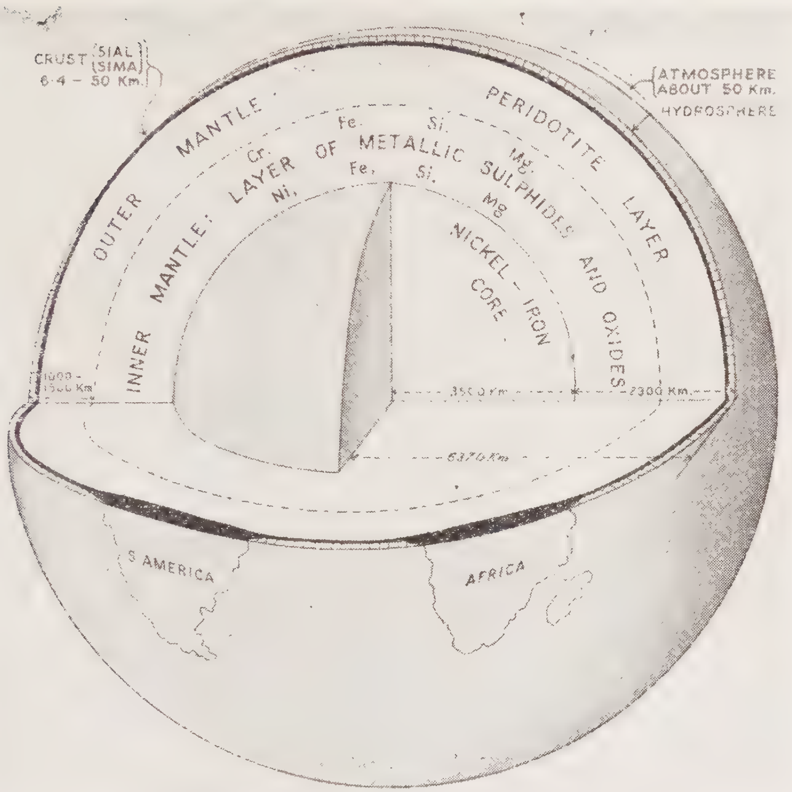
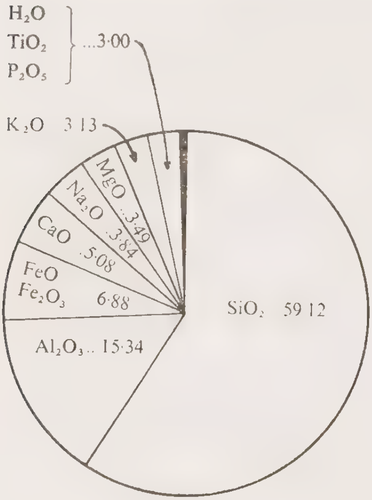


Fig. 3

layer – the *crust* – is separated from the outer mantle by a surface marking a sharp change of physical properties, which is known as the *Mohorovičic Discontinuity*. This surface occurs at a depth of about 6·4 km. below the oceans, and below the continents its depth varies from 20 to 50 km. The lower part of the crust is composed of the minerals which form the heavy rocks rich in iron and magnesium, and is known by the name *Sima* (from *Si*licon – *Ma*gnesium). The thin discontinuous outer skin which overlies the sima is called *Sial* (from *Si*licon – *Al*uminium), and is composed of the lighter rocks rich in aluminium silicates. The thickness of the sial is, according to recent experimental data, about 10-11 km. under the continents. Under the great oceans the sial is completely absent. It thus forms the continental masses, which, according to A. Wegener, the first exponent of the Theory of Continental Drift, are floating on the viscous sima. The irregular but nearly continuous mantle of water covering the lithosphere is called the hydrosphere, and the whole is enveloped by the atmosphere, a layer of gases and vapours about 50 km. thick whose density decreases rapidly outwards.

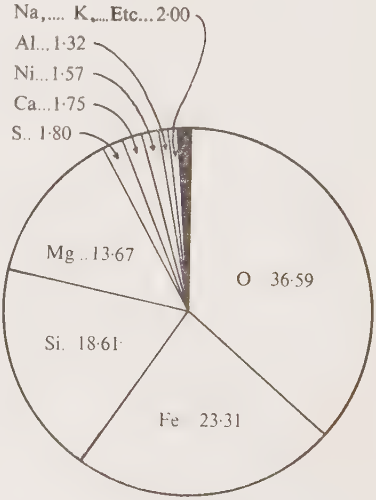
Distribution of Elements

The average composition of the rocks forming the sial and the sima is shown graphically in Figs. 4 and 5. These diagrams show that the sial contains more silica (SiO_2) and considerably more alumina (Al_2O_3) than the sima, which in turn is characterised by its relatively high content of iron (Fe) and magnesium (Mg).



Sial Zone

Fig. 4. Chemical composition of the crystalline rocks by percentage



Sima Zone

Fig. 5. Chemical composition of the stony meteorites by percentage

(after G. Wagner, *Lehrbuch der Geologie und Mineralogie*)

When the chemical composition of the whole earth is considered, it is seen that the 90 or so elements of which it is composed are not distributed evenly throughout, but are separated into groups which are concentrated at certain depths. The greater part of the iron, for instance, is located in the earth's core, which also contains nickel (about 8 per cent.), cobalt, arsenic, gold, and other heavy elements. That, at least, is the composition of the core as suggested by the study of iron meteorites. The mantle surrounding the core appears to be composed largely of elements of intermediate weight, such as copper, zinc, mercury, bismuth, selenium, sulphur, and antimony. In the outermost layer or lithosphere oxygen is combined with such elements as silicon, aluminium, magnesium, calcium, sodium, potassium, and also iron. There is thus a marked zoning of the elements according to depth, but this is, of course, by no means complete. If it were, such elements as iron, nickel, and platinum would not be found at the earth's surface.

As the outer skin of the lithosphere is of direct concern to mankind, it is desirable to consider its chemical composition rather more closely. The average composition of the upper 15 km. of the earth's crust is given in Table I.

Table I

Composition by Weight per cent. of the Earth's Crust – Individual Elements based on Clarke (1924) and Rankama and Sahama (1950)

1.	Oxygen	(O)	49·4	
2.	Silicon	(Si)	25·8	
3.	Aluminium	(Al)	7·5	1. – 4. = 87·4%
4.	Iron	(Fe)	4·7	
5.	Calcium	(Ca)	3·4	
6.	Sodium	(Na)	2·6	
7.	Potassium	(K)	2·4	1. – 8. = 97·8%
8.	Magnesium	(Mg)	2·0	
9.	Hydrogen	(H)	0·9	
10.	Titanium	(Ti)	0·5	
11.	Chlorine	(Cl)	0·2	1. – 12. = 99·5%
12.	Phosphorus	(P)	0·1	

This table shows that almost 50 per cent. of the earth's crust is oxygen, which does not, of course, occur in its elemental state, but is combined with the other elements to form the various minerals. It is thus useful to consider the composition of the earth's crust in terms of the various oxides which form the chemical basis of most minerals (Table II).

Table II

Composition by Weight per cent. of the Earth's Crust – Oxides

1.	SiO_2	61·0	9.	H_2O	1·15
2.	Al_2O_3	15·5	10.	TiO_2	1·05
3.	FeO	3·8	11.	P_2O_5	0·30
4.	Fe_2O_3	3·1	12.	MnO	0·12
5.	CaO	5·1	13.	CO_2	0·10
6.	Na_2O	3·8	14.	BaO	0·05
7.	MgO	3·5	15.	Cr_2O_3	0·05
8.	K_2O	3·1	16.	Cl	0·05

Those over 3% make up 97%, and those under 3% make up 2·87% of the total weight.

It is seen from Tables I and II that over 97 per cent. of the total weight of the earth's crust is made up of only eight elements. The relative abundance of elements in the earth as a whole is very different, as is shown in Table III.

Table III

Percentage Distribution of Elements in the Entire Earth
based on Clarke (1924)

after Anderson		*after Linck*	
1. Iron	40·0	1. Iron	50·0
2. Oxygen	27·5	2. Oxygen	22·0
3. Silicon	14·5	3. Silicon	11·0
4. Magnesium	9·0	4. Magnesium	9·0
5. Nickel	3·2	5. Nickel	6·0
6. Calcium	2·1	6. Calcium	1·0
7. Aluminium	1·8	7. Aluminium	0·6
Total	98·1	Total	99·6

The Main Rock Categories

The percentages given in Tables I to III are average values which have been obtained by taking into account all known rock types. It is quite obvious that the various rocks differ greatly from each other in chemical composition, which is ultimately determined by their mode of origin.

Rocks are grouped into three main categories according to their origin. These are the *igneous* or *eruptive*, *sedimentary*, and *metamorphic* rocks.

1. igneous or eruptive rocks

The rocks in this group were formed by the solidification of molten rock-material called magma. With few exceptions they are crystalline, and the individual minerals of which they are composed can be recognised either with the naked eye or with the aid of a lens or microscope. The exceptions are glassy in texture.

The igneous rocks can again, according to origin, be divided into three groups:

A. *Plutonic Rocks* (after Pluto, god of the underworld)

These, according to orthodox views, were formed by the consolidation of magma masses which did not penetrate to the surface, but remained in the lower part of the crust under a deep cover of older rocks. Here the magma was able to cool slowly and form large crystals during solidification. The plutonic rocks now exposed at the surface are thus coarsely crystalline in texture. Examples are granite, diorite, and gabbro.

It is believed by some that not all plutonic rocks were necessarily derived from liquid magma. Some granite masses, for instance, may have been formed by the alteration of pre-existing rocks by hot solutions without passing through a liquid phase. This alteration, termed granitisation, is thought to take place at great pressure and possibly high temperature, and is thus an extreme form of metamorphism (p. 136).

B. *Hypabyssal Rocks*

Hypabyssal rocks were formed from magma which penetrated through the crust along fissures and other lines of weakness but did not reach the surface. They are normally found in small intrusions, such as dykes, sills, and laccoliths. The magma from which they were formed cooled and crystallised more rapidly than that of plutonic rocks, and they are thus generally more fine-grained. Many hypabyssal rocks of sialic composition contain large crystals set in a fine-grained ground mass. The texture of such rocks is known as porphyritic, and many have been called porphyries, or porphyrites. Examples of hypabyssal rocks are quartz porphyry, micro-diorite, and dolerite.

Differentiated rocks such as lamprophyres form a special class of the hypabyssal rocks. They are closely related to plutonic rocks and are derived from a "residual magma" which may have a somewhat different composition from the parent magma. Lamprophyres occur as veins or dykes in plutonic rocks and as minor intrusions in sedimentary rocks. They are usually fine-grained in texture.

C. *Extrusive or Volcanic Rocks* (after Vulcan, god of fire)

Where magma was able to penetrate to the surface along fissures or volcanic vents it poured out to form lava flows. Such flows are being formed today around the active volcanos. As the lava cools and consolidates rapidly, the extrusive rocks are generally fine grained. Examples are basalt, andesite, and rhyolite.

2. SEDIMENTARY ROCKS

When the igneous or primary rocks mentioned above are exposed at the surface, they are gradually broken down by the physical and chemical agents of weathering. The products of this action are carried away by water, ice, or wind, and are eventually deposited on the sea floor, in lakes, on the flood plains of rivers, and in depressions on the land. Sedimentary rocks are formed by the eventual compaction of these loose deposits or sediments. Other types of sedimentary rocks are produced by the accumulation of shells and other organic remains and by the precipitation of salts from aqueous solution. It is possible to classify sedimentary rocks into several groups according to their origin, as follows:

1. Clastic or mechanical deposits (shale, sandstone, conglomerate).
2. Chemical deposits (salt and gypsum beds and certain limestones).
3. Organic or biogenic deposits (coal, shelly limestones).
4. Residual deposits (laterite, bauxite).

3. METAMORPHIC ROCKS

Both igneous and sedimentary rocks may be involved in earth movements. As a result they may be subjected to shearing stresses near the surface or pushed down into the "root" zones of the mountain belts where, under the influence of high temperatures and pressures, they may be partially or completely melted, mixed, and injected with liquid magma or merely intensely sheared and folded. During these processes, new minerals, which are stable under the prevailing physical conditions, are formed, and the reconstituted rocks usually take on a foliated or schistose appearance. When, after a long period of erosion, such rocks are again exposed at the surface, it is often not possible to recognise their original character. Gneisses, for instance, may result from the alteration of granites, sandstones, shales, or even limestones. Most metamorphic rocks are foliated, and they can usually be described by one of the following names: gneiss, schist, phyllite, slate, quartzite, marble. The gneisses are often subdivided according to origin into ortho-gneisses (derived from igneous rocks) and para-gneisses (derived from sedimentary rocks).

The type of metamorphism described above, which is connected with mountain-building movements, is termed *regional metamorphism.* The more local alteration near the junction of igneous intrusions, which is entirely ascribed to the effect of heat, is called *thermal* or *contact metamorphism.*

DISTRIBUTION OF ROCK TYPES IN THE EARTH'S CRUST

In the upper 16 km. of the crust of the earth the main rock types occur in the following proportions:

1. Igneous rocks (including all plutonic types)		95%
2. Sedimentary rocks (and their metamorphic equivalents)		
(*a*) Shales and schists	4	5%
(*b*) Sandstones	0·75	
(*c*) Limestones	0·25	

Table IV

Average Composition per cent. of Major Rock Types
based on Clarke (1924)

Oxide	*Igneous Rocks*	*Schists*	*Sedimentary Rocks*	
			Sandstones	*Limestones*
SiO_2	**59·12**	**58·11**	**78·31**	5·19
Al_2O_3	**15·34**	**15·40**	4·76	0·81
Fe_2O_3	3·08	4·02	1·08	0·54 (Fe₂O₃ + FeO)
FeO	3·80	2·45	0·30	
MgO	3·49	2·44	1·16	7·89
CaO	**5·08**	3·10	**5·50**	**42·57**
Na_2O	3·84	1·30	0·45	0·05
K_2O	3·13	3·24	1·32	0·33
H_2O	1·15	**4·99**	1·63	0·77
CO_2	0·10	2·63	5·04	**41·54**

PLATE IX SEDIMENTARY ROCKS

1st Row: 1. Breccia, 2. Conglomerate; *2nd Row*: 3. Red Sandstone, 4. Limestone composed of fossil shells; *3rd Row*: 5. Shale, 6. Rock Salt.

The great difference in the composition of various rock types is shown in Table IV, which gives the average composition of some important rocks. The percentage values shown in heavy type indicate that the material in question is present in the minerals which make up the greater part (about four-fifths) of the particular rock type.

Table IV shows that the igneous rocks and crystalline schists contain on average about 60 per cent. silica (SiO_2) and about 15 per cent. alumina (Al_2O_2). The term Sial is thus well founded. In sandstones silica forms nearly 80 per cent. of the total mass and, as the quartz grains are often cemented by calcite, CaO may form as much as 5·5 per cent. of an average sandstone. The preponderance of the $CaO + CO_2$ in limestone is obvious.

It now remains to consider the composition of the earth's crust according to the percentage distribution of its main constituent minerals, quite irrespective of the various rock types in which they are found.

Table V

Percentage Distribution of the Most Common Minerals in the Earth's Crust

based on Clarke (1924)

1. Feldspars (and feldspathoids)	Plagioclase	40·2	57·9
	Orthoclase	17·7	
2. Augite, hornblende, and olivine			16·3
3. Quartz with chalcedony and opal			12·6
4. Magnetite and haematite			3·7
5. Micas (biotite, muscovite, etc.)			3·3
6. Calcite			1·5
7. Clay minerals			1·0
8. Limonite and other hydrated iron minerals			0·3
9. Dolomite			0·1
10. Accessory minerals in *igneous rocks* (apatite, sphene, zircon, pyrrhotite, garnet, etc.)			2·5
11. Accessory minerals in *sedimentary rocks* (pyrite, pyrolusite, garnet, rutile, apatite, zircon, carbonate, etc.)			0·5
		Total	99·7

The above table (Table V) gives an insight into the percentage distribution of the nine groups of rock-forming minerals which together make up a large part of the earth's crust. There are, however, many more minerals which enter into the composition of the rocks found in this outer layer, and for a comprehensive study of these rocks it is necessary to consider a much larger number of minerals. Most rocks found in nature are made up, not of one or two, but of a large number of different minerals.

CRITERIA USED IN ROCK CLASSIFICATION

Both the mineral content and chemical composition (which are closely related) have been used as a basis for the classification of rocks within the major groups, more particularly among the igneous rocks. Chemical data alone, however, are not sufficient to give a comprehensive picture of a rock, and so do not enable us to build up a reasonable classification of the wide range of rock types found within these groups. SiO_2, for instance, might either be in the form of quartz, or be combined with certain metallic oxides thus forming a silicate such as feldspar or mica. Before we can name and classify a rock it is necessary to know not only its exact mineral composition but also something of its structure and texture, which include details of the size of the component grains, the shape and distribution of those grains, the presence or absence of foliation, and so on. In the case of igneous rocks, for example, the rock texture can tell us if the rock in question was consolidated at depth or at the surface. The petrographer is also interested in the shape and field relationships of the body in which the rock is found, and wants to know the geological period during which it was formed. Consideration of all these factors, together with chemical analysis and microscopic examination, are necessary before a rock can be correctly named and classified.

STRUCTURE AND TEXTURE (FABRIC)

The most obvious features of a rock, apart from colour and specific gravity, are its structure and texture. According to the size of the component minerals, the *structure* of an *igneous rock* may be described as glassy, aphanitic (composed of minute embryonic crystals), porphyritic (isolated crystals set in a very fine-grained matrix), or crystalline. Crystalline rocks may be fine to coarse-grained, equigranular, or inequigranular. The *texture* of an igneous rock is determined by the shape and arrangement of the individual crystals, and special terms are used to describe the textural features. Well-developed crystals are thus said to be euhedral (making the rock idiomorphic); shapeless grains are anhedral (allotriomorphic); and those intermediate between the two are subhedral (subidiomorphic). Large crystals enclosing smaller ones are called ophitic, or, if the enclosure is not complete, subophitic. The minerals may have a haphazard orientation within the rock or they may all be aligned in one direction, in which case they exhibit flow structure, which is particularly well developed in certain acid lavas. Another textural feature of an igneous rock is its degree of compaction, which may be described as massive, porous, vesicular, or even scoriaceous, like pumice stone.

In *metamorphic rocks* we may recognise such structural features as slaty cleavage, foliation or schistosity, and gneissose structure. As in the case of igneous rocks, a special nomenclature exists to describe the various microstructures. For instance, when the component minerals are mainly equidimensional and rounded in outline the rock is termed granoblastic; when they are flaky it is lepidoblastic; and when fibrous it is nematoblastic. Other more special structures have been called porphyroblastic (conspicuously large crystals surrounded by smaller ones, as in augen gneiss); poiciloblastic or sieve structure (small mineral inclusions in the large crystals); and diablastic (intergrowth of minerals trending in different directions).

The texture of *sedimentary rocks* is determined by the shape and size of the component particles. If, in the case of clastic sediments, these are coarse and angular, the rock is a breccia; if they are coarse and well rounded, it is a conglomerate. In sandstone the grains are smaller, and in the finest sandstone they are only just visible to the naked eye. The grains may be well rounded, as in desert sandstone, or angular, as in the case of those transported and deposited by water. If the grains can only be distinguished by a lens or microscope, or not at all, the rock is a mudstone or shale. Much statistical work has been done on the grain size of sediments, and many grade scales defining the ranges in particle size of various sediments are in existence. Reference to one of these is made in a later part of this book (p. 158).

The textures of chemical and organic sediments are quite different from those of the clastic sediments. Many chemical deposits are crystalline or fibrous, and their textural features are described by terms originally coined for igneous or metamorphic rocks. Others are oolitic (composed of spherical particles like cod roe), pisolitic, or spherulitic (spherical bodies with radiating internal structure).

The structures of sedimentary rocks are generally best studied at the outcrop. They include the features connected with bedding, such as lamination, current bedding, graded bedding, slump structures, load casts, and ripple markings, as well as secondary features which are due to chemical action that has taken place shortly after deposition. Examples of the latter are nodules and concretions, stylolites and cone-in-cone structures.

AGE RELATIONSHIPS

The relative ages of sedimentary rocks can be accurately established with the aid of the fossils which are found in many formations. In igneous and metamorphic rocks there are no organic remains, and their relative ages can only be determined by more indirect means. Lava flows can be dated fairly easily, as they are usually interbedded with sedimentary rocks. The establishment of the age of intrusive rocks is more complicated. They are younger than the latest formation through which they pass. Many intrusions, however, are found in rocks considerably older than they are, and their ages have to be inferred by comparing them with related igneous rocks found in neighbouring areas.

For most igneous rocks, intrusive and extrusive, were formed during well-defined periods of igneous activity. The volcanic products of such periods, though they may vary greatly in composition and texture, usually have a certain family resemblance, such as, for instance, a relatively high content of alkaline minerals, which can be detected in the chemical or mineralogical composition of most products.

In Britain, there have been four great periods of igneous activity since Pre-Cambrian times. The first of these reached its peak during the Ordovician Period (about 440 to 500 million years ago), when the great lava masses of central and north Wales, Ireland, and the Lake District were formed. The second period was closely connected with the Caledonian Earth Movement, which took place in late Silurian and early Old Red Sandstone times (about 370 to 410 million years ago) and was most intense in the area which is now Scotland and Ireland. At that period the great granite bosses of the Grampian Highlands, the Southern Uplands, Leinster and Donegal were emplaced, and the lavas, which today form the Lorne Plateau east of Oban, the Ochil, Pentland and Cheviot Hills, were poured out. The third episode started early in the Carboniferous Period (350 million years ago) and continued into Permian times (about 270 million years ago). The intrusion of granite masses in Devon, Cornwall, and the Channel Islands, and the extrusion of great piles of lava flows in the Midland Valley of Scotland and to a lesser extent in southern Scotland and central England, were some of the salient features of this episode. Fairly late in the period, great dyke swarms and large sills, such as the Great Whin Sill, were intruded in central Scotland and northern England. The last period of igneous activity started in Tertiary times (about 40 million years ago) and embraced the vast area extending from north-west Scotland and northern Ireland across the North Atlantic to Iceland and Spitzbergen. In Britain, volcanic activity ceased in Tertiary times, but in Iceland it has persisted to the present day. The main products of this last episode are great flows of basalt lava, remnants of which can be seen in Antrim and the Inner Hebrides. Of even greater interest are a series of complex volcanoes connected with intrusions of granite and gabbro, the dissected remains of which may be studied in Skye, Ardnamurchan, Mull, Arran, Northern Ireland and other places. The final phase of Tertiary igneous activity in Britain was the emplacement of great swarms of north-westerly trending dykes which are now exposed in the western parts of Scotland and in Northern Ireland.

The Rock-Forming Minerals

The character of a rock is largely determined by the composition of its constituent minerals, their relative abundance and mutual relationships. These features can best be ascertained by studying a thin section of the rock under a petrographical microscope, but much can nevertheless be seen by examining the hand specimen with a good pocket lens. Apart from the minerals mentioned in Table V (p. 137) there are many others which may be of importance in the identification of a rock. Even quite rare minerals are often essential and even diagnostic constituents of certain groups of rocks.

The minerals which make up the greater part of a rock are called the essential or rock-forming minerals. These may be divided according to colour into light (leucocratic) and dark (melanocratic) minerals. Those minerals which occur in only minor quantities are known as accessory minerals.

The igneous rocks, which crystallised from a magma, contain a rather different set of minerals from the sedimentary rocks, many of which were derived by weathering from pre-existing rock types. A number of minerals, which are resistant to weathering, such as quartz and mica, are found in both.

I. MINERALS CHARACTERISTICALLY FOUND IN IGNEOUS ROCKS

A. *Light-coloured or leucocratic minerals*

1. *Quartz* (SiO_2), usually occurs in massive or granular, more rarely in crystalline form. *Tridymite* and *cristobalite* are crystalline varieties formed at high temperatures. *Chalcedony* and opal are other varieties of rock-forming silica.

2. *Feldspars*

a. Alkali-feldspars include the potassic feldspars ($K[Al_3Si_3O_8]$), sodic feldspars ($Na[AlSi_3O_8]$), and various combinations of the two. The K-feldspars include *orthoclase*, *sanidine* and *microcline*, the most common Na-K-feldspars are *anorthoclase* and *perthite*, and the Na-feldspar is *albite*.

b. Soda-lime feldspars (plagioclase series). These show a gradational variation in composition between the two end members, *albite* ($Na[AlSi_3O_8]$) and *anorthite* ($Ca[Al_2Si_2O_8]$), the minerals of intermediate composition being *oligoclase* (90-70 per cent. albite), *andesine* (70-50 per cent. albite), *labradorite* (50-30 per cent. albite) and *bytownite* (30-10 per cent. albite).

3. *Feldspathoids*, a group of minerals closely related to the feldspars, but notably poor in silica. They are found in rocks somewhat deficient in silica, which are devoid of free quartz.

a. Leucite ($K[AlSi_2O_6]$) forms roundish crystals, resembling analcite.

b. Nepheline ($Na[AlSiO_4]$) occurs in small prisms.

c. The minerals *hauyne*, *nosean*, and *sodalite* consist basically of $Na[AlSiO_4]$ with the addition of $CaSO_4$ in the case of hauyne, Na_2SO_4 in the case of nosean, and NaCl in the case of sodalite.

d. A mineral related to the feldspathoids is *melilite*, which is a mixture of the two end members *akermanite* ($Ca_2(Mg,Fe)Si_2O_7$) and *gehlenite* ($Ca_2Al_2SiO_7$).

4. *Potash mica = muscovite* ($KAl_2[(OH,F_2)|AlSi_3O_{10}]$) occurs in white plates or scales with pearly lustre.

B. *Dark or melanocratic minerals*

1. *Pyroxenes*, dark in colour, usually in stumpy crystals. Orthorhombic forms are *enstatite* ($Mg_2[SiO_6]$), *bronzite* ($(Mg,Fe)_2[Si_2O_6]$), and *hypersthene* ($(Fe,Mg)_2[Si_2O_6]$); monoclinic forms include *augite* ($Ca(Mg,Fe,Al)[(SiAl)_2O_6]$), *diallage* (as augite), *diopside* ($CaMg[Si_2O_6]$),] *aegirine* ($NaFe^{\cdots}[Si_2O_6]$), and *pigeonite* ($(Mg,Fe)[SiO_3]$).

2. *Amphiboles*, black or greenish black in colour, usually occur as short to longish prisms. They include *hornblende* ($Ca_2(Mg,Fe^{\cdot\cdot})_5[Si_8O_{22}](OH)_2$, with Al,$Fe^{\cdots}$ and some Na), *arfvedsonite* (sodic amph.), and *riebeckite* (sodic amph.).

3. *Magnesium mica = biotite* ($K(Mg,Fe,Mn)_3[(OH,F)_2|AlSi_3O_{10}]$), brown or black, platy and easily cleaved.

4. *Olivine* ($(Mg,Fe)_2[SiO_4]$), usually found as deep green or deep black anhedral crystals.

5. *Garnets*, dark red to black, with well-developed crystal shapes. More important in metamorphic rocks.

6. *Tourmaline* (complex boro-silicate), black, very hard, usually prismatic form (also in metamorphic rocks).

7. *Chlorite* ($Mg_5Al(OH)_8[AlSi_3O_{10}]$) a family of soft, dark minerals, which are scaly and dark green to greyish-black in colour; includes *clinochlore*, *penninite*, and *prochlorite*.

8. *Serpentine* ($Mg_6[(OH)_6|Si_4O_{11}].H_2O$), usually green or red, soft with soapy feel; includes *antigorite* and *chrysotile*.

C. *Minerals found in subordinate quantities* (*accessory minerals*)

Rutile, apatite, magnetite, spinel, chromite, pyrrhotite, ilmenite, wollastonite, zircon, chlorite, serpentine, and others.

II. ROCK-FORMING MINERALS IN SEDIMENTARY ROCKS

A. *Mechanical or Clastic sediments*

1. *Quartz* (SiO_2), usually occurring as grains, fragments, or in veins.

2. *Calcite* ($CaCO_3$), *dolomite* ($CaMg[CO_3]_2$), *siderite* ($FeCO_3$).

3. *Clay minerals*, e.g., *kaolinite* ($Al_4[(OH)_8|Si_4O_{10}$), *anauxite*, *dickite*, *nacrite* (kaolin group); and members of the *montmorillonite* (e.g. $(OH)_4Al_4Si_8O_{10}.xH_2O$), *illite* (e.g. $(OH)_4K_{1-1\cdot5}(Al_4Fe_4Mg_{10})Si_{6\cdot5-7}Al_{1-1\cdot5}O_{20}$), and *halloysite* (e.g. $(OH)_{16}Al_4Si_4O_6$) groups.

4. *Muscovite* ($KAl_2[(OH,F)|AlSi_3O_{10}]$).

5. *Iron Oxides*, e.g. *haematite* (Fe_2O_3), *magnetite* (Fe_3O_4); and hydrated iron oxides, e.g., *limonite* ($Fe_2O_3.nH_2O$), *goethite* (α-FeOOH).

B. *Sediments of chemical origin*

1. *Gypsum* ($CaSO_4.2H_2O$). White to reddish in colour; may occur massive as *alabaster* or in fibrous form.

2. *Anhydrite* ($CaSO_4$). Resembles calcite, but is heavier. It is white to bluish in colour.

3. *Rock Salt* (NaCl). Usually occurs as cubes.

4. *Calcite* ($CaCO_3$), soft, white to yellowish, with perfect rhombohedral cleavage.

5. *Aragonite* ($CaCO_3$), very similar to calcite, but different crystal form (orthorhombic system).

6. *Dolomite* ($CaMg(CO_3)_2$), resembles calcite but slightly harder and often with curved faces.

7. *Limonite* ($Fe_2O_3.nH_2O$), brown iron ore.

8. *Bauxite* ($Al_2O_3.2H_2O$), greyish to yellow-brown, amorphous or granular mass.

9. *Salt* deposits, which, apart from rock salt, contain such minerals as *sylvine* (KCl), *carnallite* ($MgCl_2.KCl.6H_2O$), *kieserite* ($MgSO_4.H_2O$) and *polyhalite* ($K_2Ca_2Mg[SO_4]_4.2H_2O$).

10. *Chlorite minerals*, such as chamosite and thuringite.

11. *Glauconite*, a hydrated Mg-Fe-Al silicate, olive-green to grey, amorphous, granular or earthy.

12. *Coal, lignite, peat.*

III. METAMORPHIC MINERALS

Metamorphic minerals are formed by the alteration of sedimentary and igneous rocks through the action of heat, pressure, and at times migrating fluids. As a result the old minerals are either altered into forms which are stable at the new temperatures and pressures or are completely re-formed into new minerals by the combination of several mineral species or the influx of material from outside.

1. In metamorphosed clayey sediments the newly-formed minerals are chlorite $Mg_5Al(OH)_8[AlSi_3O_{10}]$, sericite ($KAl_2[(OH,F_2)|AlSi_3O_1]$), biotite, garnet, staurolite ($Al_4[Fe^{\cdot\cdot}O_2(OH)_2(SiO_4)_2]$), kyanite ($Al_2SiO_5$), cordierite $Mg_2Al_3[AlSi_5O_{18}]$, andalusite ($Al_2[O.SiO_4]$), chiastolite ($Al_2[O.SiO_4]$), and sillimanite ($Al[AlSiO_5]$), according to metamorphic grade (see p. 184).

2. In metamorphosed impure limestones, calc-aluminium-silicate minerals such as epidote ($Ca_2(Al,Fe^{\cdots})_3[OH|(SiO_4)_3]$), idocrase ($Ca_{10}(Mg,Fe)_2Al_4[(OH)_4|(SiO_4)_5|(Si_2O_7)_2]$), and wollastonite ($CaSi_3O_9$), and aluminium minerals such as spinel ($MgAl_2O_4$) and corundum (Al_2O_3) are developed; also tremolite (amphibole) and diopside ($CaMg[Si_2O_6]$).

3. In dolomitic limestones newly developed minerals are forsterite (Mg_2SiO_4), diopside, and tremolite, together with some of the minerals mentioned under 2.

4. In pure sandstones no new minerals are developed, but in the more impure sandstones biotite, muscovite, and garnet are formed.

5. Basic igneous rocks and related rocks give rise to such minerals as hornblende, epidote, albite, iron ore (magnetite), garnet, and omphacite; ultrabasic rocks produce talc, serpentine, and certain amphiboles.

6. In metamorphosed acid igneous rocks new minerals are less common.

The mineral associations produced by the action of heat (thermal metamorphism) are different from those produced during dynamic (stress) and regional metamorphism.

Table VI

Specific Gravity of the Rock-Forming Minerals

1·60	Carnallite	3·00–3·02	Actinolite
1·95	Sylvine	3·00–3·03	Biotite
2·10	Sulphur	3·12–3·14	Tourmaline
2·15	Rock Salt	3·14–3·16	Apatite
2·00–2·20	Opal	3·16–3·18	Fluorspar
2·20–2·25	Graphite	3·18–3·20	Andalusite
2·20–3·30	Analcite	3·20–3·22	Hornblende
2·30	Glauconite	3·30–3·31	Diopside
2·31	Gypsum	3·30–3·33	Diallage
2·45	Hauyne	3·35–3·40	Augite
2·47	Leucite	3·40–3·42	Epidote
2·55	Nepheline	3·40–3·44	Idocrase (Vesuvianite)
2·56	Sanidine	3·41–3·45	Olivine
2·56	Orthoclase	3·46–3·48	Sphene
2·58	Microcline	3·50–3·52	Topaz
2·55–2·60	Chalcedony	3·58–3·67	Staurolite
2·56–2·67	Cordierite	3·56–3·67	Kyanite
2·62	Serpentine	3·60–3·64	Spinel
2·63	Albite	3·70–3·75	Garnet (pyrope)
2·65	Quartz	3·77–3·80	Limonite
2·68	Scapolite	3·88–3·90	Siderite
2·70	Talc	3·94–3·95	Corundum
2·71–2·72	Calcite	4·20–4·22	Chalcopyrite
2·73–2·75	Chlorite	4·28–4·30	Garnet (andradite)
2·76	Anorthite	4·46–4·50	Rutile
2·83	Wollastonite	4·52–4·55	Zircon
2·85	Muscovite	4·58–4·60	Pyrrhotite
2·90	Dolomite	4·62–4·65	Chromite
2·95	Anhydrite	4·68–4·74	Ilmenite
3·00–3·02	Magnesite	4·85–4·92	Marcasite
3·00–3·04	Glaucophane	5·16–5·22	Pyrite
3·00	Tremolite	5·20–5·22	Magnetite

PLATE X METAMORPHIC ROCKS

1st Row: 1. Phyllite, 2. Marble; *2nd Row*: 3. Gneiss, 4. Garnetiferous Mica Schist; *3rd Row*: 5. White Carrara Marble, 6. Sericite Schist.

Table VII

Hardness of Rock-Forming Minerals (Mohs' Scale)

1. *Talc*, graphite, kaolin (and all other clay minerals, which are normally earthy and can be broken up by hand), chlorite, reddle (earthy weathering product of haematite), ochre (weathering product of limonite and some limestones).
2. *Gypsum*, rock salt, sylvine, carnallite, sulphur, biotite, muscovite and other members of the mica family, gold, glauconite, hornblende aggregates, serpentine-asbestos.
3. *Calcite*, dolomite, anhydrite, serpentine, chalcopyrite.
4. *Fluorspar*, magnesite, siderite (softer when partly weathered), pyrrhotite, kyanite (only when scratched parallel to prism edges).
5. *Apatite*, augite, hornblende, andalusite (when surface is weathered), diallage, scapolite, sodalite, enstatite-hypersthene, analcite, actinolite, diopside, nepheline, hauyne, leucite, tremolite, chromite, magnetite, sphene, limonite.
6. *Feldspar*, epidote, marcasite, pyrite, ilmenite, olivine, garnet, opal (sometimes softer), haematite, glaucophane, zoisite, rutile, idocrase, sometimes leucite and nepheline.
7. *Quartz*, andalusite, tourmaline, garnet, kyanite (when scratched at right angles to prism edges), cordierite, staurolite, zircon.
8. *Topaz*, spinel.
9. *Corundum* (ruby, sapphire).
10. *Diamond*.

Table VIII

The Most Important Characteristics used in the Identification of some Rock-Forming Minerals

Based on P. Niggli (1946)

I. Pale Minerals

Quartz

Very hard (Hardness 7); conchoidal fracture, usually fresh and unweathered (chemically very stable); vitreous to fatty lustre; transparent; shape usually irregular, often occurring in rock as shapeless mass; as grains in sediment.

Feldspars

(i) *Plagioclase*: Hardness 6; cleavage surfaces intersect at right angles; cleavage faces have high lustre, pearly in case of labradorite; colour grey to reddish; tendency to twinning; occurs either in thick plates or in prisms; very common in igneous rocks, but is readily decomposed and does not often occur in original state in sediments.

(ii) *Potash- and alkali-feldspars*: White, grey, or flesh-coloured; usually tabular or lath shaped; simple twins; sanidine is glassy or whitish.

Leucite

Rounded shape; easily weathered into white kaolin-like mass; colour white to ashy grey; similar minerals are hauyne (bluish) and analcite (reddish).

Nepheline
No particular shape; superficially resembles quartz; fracture surfaces have fatty lustre; colour white to yellowish; cross section six-sided.

Muscovite
Silver-white flexible plates with pearly lustre; sometimes occurs in fine scales. Found in granites, gneisses, mica schists and in sandy and silty clastic sediments.

Soda-mica (paragonite) is yellowish, lithium-mica (lepidolite) is reddish.

Sericite
Silky lustre; fine scales; occurs in metamorphic rocks.

Calcite
White to yellowish; perfect rhombohedral cleavage; Hardness 3; often occurs in cleavage rhombs; forms limestone, chalk, marble, and is present in calcareous tuffs; also found as large crystals in druses, cavities and veins; effervesces with dilute HCl.

Aragonite
Is an unstable variety of $CaCo_3$ formed by crystallisation from aqueous solution, and found in animal skeletons, esp. corals and algae.

Dolomite
Has the same crystal structure as calcite, but is harder, slightly heavier, effervesces only with warm concentrated HCl, and shows no twinning.

Anhydrite
Aggregates resemble calcite, but cleavage is different and less perfect; no reaction with HCl.

II. Dark (Coloured) Minerals

Augite (pyroxene family)
Usually deep black to brownish-black; this distinguishes it from diopside (whitish-green) and omphacite (green); form is stumpy, short prismatic with 4- or 8-sided cross sections; diallage is highly cleaved with metallic lustre on cleavage surfaces; in basalt augite is pitch black, diallage brownish-black; diallage is common in gabbros, augite in basalts.

Hornblende (amphibole family)
Usually forms more elongated prisms than augite; two cleavage planes intersect at about 120° (augite 90°); more pronounced lustre than augite; cross sections six-sided; colour, green; the brown variety is basaltic hornblende, which occurs in basic lavas; pargasite is a green mineral allied to hornblende found in contact metamorphosed rocks.

Fibrous amphiboles: actinolite, slender prisms with cleavage intersecting at 124°, green in colour; and tremolite, white or dark grey, both common in metamorphosed basic and ultrabasic rocks; also uralite, an alteration product of pyroxene.

Olivine
Greenish to olive coloured, also greenish-black; form, rounded crystals; cleavage usually poor; often altered to serpentine, iddingsite or iron oxide forming reddish-brown or rust-coloured patches in basic igneous rocks.

Garnet

Dark red, reddish-brown to black; usually has good crystal shapes with various habits in cubic system; very hard. Varieties: pyrope (Mg-garnet) deep red, grossularite (Ca-garnet) green, almandine (Fe-garnet) red, spessartite (Mn-garnet) orange, andradite (Fe···-Ca-garnet) brown to green. Usually occurs in metamorphic and contact altered rocks, more rarely in igneous and sedimentary rocks.

Staurolite

Resembles garnet in colour, but crystals are more elongate (orthorhombic system); occasional twins; hardness 7; conchoidal fracture; occurs with garnet and kyanite in metamorphic rocks.

Tourmaline

Pitch black; prismatic habit; conchoidal fracture; sections 3- or 6-sided with rounded edges; crystals striated lengthwise. Colour varieties: red = rubellite, black = schorl. Often found in metamorphic contact zones. Hardness 7.

Biotite

The mica usually found in plutonic rocks; occurs in easily cleaved elastic plates, often with hexagonal outline; very soft; colour, brownish-black to black, may range into deep green due to surface alteration to chlorite; often reddish-brown due to weathering; occurs in igneous and metamorphic rocks.

Chlorite

Small green to greyish-black scales; hardness $1\frac{1}{2}$ to 2 (very soft); easily cleaved, but cleavage flakes are small and not elastic like mica; occurs in metamorphic rocks and as an alteration product of other dark minerals.

Table IX provides a general picture of the mineralogical and genetic relationship of the main groups of igneous rocks. The rocks grouped together in the horizontal rows are closely related chemically and mineralogically. They are subdivided into plutonic, extrusive, and hypabyssal rocks. The lamprophyric types are treated separately in the last column. The vertical rows are divided according to mineral content into five rock groups, which range in composition from acid (high silica content) to ultrabasic (low silica content). In the case of the plutonic and extrusive rocks, the calc-alkaline (calcium rich) and alkaline (sodium, etc. rich) rock types are treated separately. It should, however, be noted that the rocks classed in the table as extrusive rocks may also occur as minor intrusions, and some of the "plutonic" types may occasionally be of hypabyssal character.

Table
Igneous

Essential Minerals	*Silica per cent.*	*Temperature of Crystallisation*	*S.G.*	*Plutonic Rocks*	
				Calc-alkali types	*Alkali-rich types*
1. *quartz, feldspar* (*orthoclase* & sometimes subordinate plagioclase), *biotite* and sometimes hornblende augite or other pyroxene	80 to 70	1000° C.	2·5–2·7	granite (Q., Or., Bi.) adamellite (Or.≃Pl.) granodiorite (Pl.>Or.)	alkali-granite (+Q.) alkali-syenite (−Q.)
2. No quartz, feldspar (*orthoclase* and subordinate plagioclase), *hornblende*, sometimes pyroxene or mica	60	1100° C.	2·6–2·8	syenite (laurvigite)	alkali-syenite (nordmarkite) (pulaskite)
3. *feldspar* (*plagioclase*), *hornblende*, sometimes pyroxene or mica	55	1200° C.	2·7–2·8	monzonite (Or.≃Pl.) quartz diorite (Q.) (tonalite) diorite	nepheline-syenite (+N.) leucite-syenite (+L.)
4. *feldspar* (*plagioclase*), *augite*, sometimes olivine, hornblende; magnetite	50 to 45	1250° C.	2·9–3·0	gabbro (Pl.+Au.+Ol.) norite (Pl.+Hyp.+Ol.)	essexite (Pl.+Or.+Ol. +Au.+N.+Anal. teschenite (Pl.+Au.+Anal. theralite (Pl.+Au.+N.) shonkinite (Au.+Or.+Ol.+ Bi.+Anal.+N.)
5. No feldspar; olivine, augite, magnetite, sometimes hornblende	45 to 38	1400° to 1500° C.	3·3	peridotite (olivine rock) picrite (Ol.+Au.+ Pl. (small amount)) pyroxenite (various pyroxenes)	

l = leucocratic (light rocks), m = melanocratic (dark rocks), Au. = Augite, Alb. = Albite, Anal. = Analcite, Bi. = Biotite, Ho. = Hornblende

X

Rocks

Extrusive Rocks		*Hypabyssal Rocks*	*Pegmatites and Lamprophyres*	
Calc-alkali types	*Alkali-rich types*			
hyolite bsidian (glassy) itchstone partly glassy) lacite (Pl.> Or.)	alkali-rhyolite (pantellerite) (quartz-keratophyre)	quartz-porphyry felsite granophyre	pegmatite (l. – coarse-grd.) aplite (l. – fine-grd.) minette (m) vogesite (m)	ACID (high SiO_2 content, pale rocks, low S.G.)
rachyte	alkali-trachyte (keratophyre)	micro-syenite or "porphyry"	syenite-aplite (l) bostonite (l)	INTERMEDIATE
{trachy-andesite (O. ≃ Pl.)}	phonolite (+N.) leucitophrye (+L.)	micro-diorite or "porphyrite"	kersantite (m) nepheline-aplite (l) spessartite (m) nepheline-pegmatite (l)	
andesite			malchite (l) camptonite (m) diorite-aplite (l) monchiquite (m)	
basalt	tephrite (Pl. + Au. + (L., N. or Anal.)) basanite (Pl. + Au. + Ol. + (L., N. or Anal.))	quartz dolerite (+Q.) **dolerite**	 gabbro-pegmatite	BASIC (low SiO_2 content, dark rocks, high S.G.)
imburgite (Au. + O.)				ULTRABASIC
ugitite (Au.)				

Hyp. = Hypersthene, L. = Leucite, N. = Nepheline, Ol. = Olivine, Or. = Orthoclase, Pl. = Plagioclase, Q. = Quartz

L

Table

Some Important

PLUTONIC ROCKS

Name / *Colour*	*Varieties*	*Mineral Composition* — *Rock-Forming Minerals*	*Accessory Minerals*
1 **Granite** whitish-grey, grey, reddish-grey, flesh-coloured to red, black and white, yellowish, more rarely greenish or blue	*a.* Alkali granites (Or. or Alb.): biotite-granite lepidolite-granite hornblende-granite riebeckite-granite hypersthene-granite =(charnockite) diopside-granite aegirine-granite *b.* adamellite (Or.≃Pl.) *c.* granodiorite (Pl.> Or.)	quartz, feldspar (orthoclase with subordinate plagioclase), mica (biotite, muscovite, lepidolite); sometimes various amphiboles or pyroxenes; colour is usually determined by the feldspar	apatite, zircon, magnetite; sometimes sphene, topaz tourmaline. name: Lat. *granum* = grain, i.e. granular rock
2 **Syenite** *a.* Syenite grey to dark grey, sometimes reddish	hornblende-syenite, biotite-syenite, pyroxene-syenite, monzonite (Or.≃Pl. [oligoclase-andesine]), laurvigite (feldspar is anorthoclase)	feldspar (orthoclase with subordinate plagioclase), mica (biotite), amphibole, pyroxene, no quartz	apatite, sphene, zircon, iron ores; name: Syene (Aswan) in Egypt is the locality from which Pliny derived the name
b. Nepheline-Syenite	foyaite (N., feldspar and subordinate dark minerals), sodalite-syenite, cancrinite-syenite	nepheline, orthoclase, biotite, amphibole, pyroxene	apatite, sphene, zircon, iron ores, sodalite, cancrinite
c. Leucite-Syenite		leucite, orthoclase, diopside	apatite, sphene, magnetite, nepheline, melanite (garnet)

l = leucocratic (light rocks), m = melanocratic (dark rocks), Au. = Augite, Alb. = Albite, Anal. = Analcite, Bi. = Biotite, Ho. = Hornblende

x

Rocks

Texture	*Properties* *Specific Gravity* *Crushing Strength*	*Uses* *Building and* *Civil Engineering*	*Localities* *Britain: World*
coarsely crystalline, crystals often occur as shapeless inter-locking grains; also fine-grained types: microgranite and granophyre – with graphic intergrowth of quartz and feldspar	usually very hard and resistant to weathering, polishes well, but difficult to shape manually; weathering more rapid if mica content is high; S.G., 2·6–2·8; Cr. Str., 14,000–43,000 lb./sq. in.; not structurally sound at high temperatures, cracks with rapid heating and cooling	important building stone, facings of buildings, foundations, tomb stones, plaques, road metal (chips), kerbstones, viaducts, retaining walls, etc.	Cornwall, Devon, Channel Islands, Shap Fell, Skiddaw etc. (Westmorland), Cheviots; Criffel, Cairnsmore of Fleet, Loch Doon (Southern Uplands), Glen Etive, Moor of Rannoch, Strontian etc. (Argyll), Cairngorms, Peterhead, Aberdeen, Skye, Arran, Donegal, Galway, Leinster, Newry, Mourne Mts. (Ireland), St. Kilda. Scandinavia, Pyrenees, Alps; U.S.A., Canada; India Granophyre: Lake District (Ennerdale); Mull, Rhum; Slieve Gullion (Ireland).
coarsely crystalline, resembling granite	very hard and resistant to weathering; polishes well, but difficult to shape manually; S.G., 2·6–2·8; Cr. Str., 21,000–35,000 lb./sq. in.	similar to granite, particularly suitable for underground and underwater structures; road metal; laurvigite is used as ornamental building stone because of "schiller" lustre on polished surface	Ben Loyal (Sutherland), Loch Borolan (Sutherland) ——— Laurvigite: Norway Monzonite: Predazzo, Italy Loch Borolan (Sutherland) ——— Kola Peninsula (Russia), Scandinavia, Brazil, U.S.A.

Hyp. = Hypersthene, L. = Leucite, N. = Nepheline, Ol. = Olivine, Or. = Orthoclase, Pl. = Plagioclase, Q. = Quartz

Name / Colour	Varieties	Mineral Composition: Rock-Forming Minerals	Mineral Composition: Accessory Minerals
3 **Diorite** black and white, black and grey	trondhjemite (quartz, feldspar [oligoclase-andesine], biotite), tonalite or quartz diorite (quartz as minor constituent, <10%), true diorites: hornblende-diorite, biotite-diorite; meladiorites (feldspar – poor), e.g. appinite (hornblende – rich)	plagioclase feldspar (oligoclase-andesine), hornblende, biotite, pyroxene; rare quartz in some varieties, but absent in true diorite	apatite, iron ore, sphene, zircon
4 **Gabbro** dark grey and black, brownish to greenish, rarely reddish	hornblende-gabbro, biotite-gabbro, norite (pyroxene is hypersthene); related rocks: troctolite (Pl. + Ol.), eucrite (Pl. + Au. + Hyp. + Ol.); with feldspathoids: essexite (N. + Anal.), teschenite (Anal.), theralite (N.) anorthosite = labradorite rock (sometimes classed with diorites)	plagioclase feldspar (labradorite to anorthite), augite or diallage; often olivine; sometimes hornblende	apatite, ilmenite, spinel, magnetite

PEGMATITES AND LAMPROPHYRES

Name / Colour	Varieties	Rock-Forming Minerals	Accessory Minerals
5 **Aplite and Pegmatite** variable colour	granite-aplite and pegmatite, syenite-aplite, and pegmatite, diorite-aplite and pegmatite, gabbro-aplite and pegmatite, norite-aplite and pegmatite, essexite tinguaite-aplite and pegmatite	same as those of the corresponding plutonic rocks, but with very variable content of leucocratic (light) minerals	same as those of plutonic rocks plus rare minerals containing rare elements

l = leucocratic (light rocks), m = melanocratic (dark rocks), Au. = Augite, Alb. = Albite, Anal. = Analcite, Bi. = Biotite, Ho. = Hornblende

Texture	*Properties Specific Gravity Crushing Strength*	*Uses Building and Civil Engineering*	*Localities Britain: World*
oarsely crystalline, often finer than ranite, crystals sually in shapeless nterlocking grains	very hard and tough, difficult to shape, polishes well; S.G., 2·8–3·0; Cr. Str., 21,000–25,000 lb./sq. in.	similar to granite; much used as road metal, concrete aggregate, foundations	Loch Awe, Ben Nevis = tonalite; Garabal Hill (S.W. Scotland), Leicestershire (Charnwood Forest), Anglesey, Channel Islands (meladiorites)
oarsely crystalline; rystals usually in hapeless inter-ocking grains	very hard, difficult to shape; S.G., 2·8–3·1; Cr. Str., 25,000 lb./sq. in.	similar to granite when not too coarse grained; mainly used as road metal	Lizard (Cornwall), Carrock Fell (Cumberland); St David's (Pembroke); Skye, Rhum, Mull, Ardnamurchan (N.W. Scotland), Huntly, Insch, Haddo (Aberdeenshire and Banffshire – mainly norites); Slieve Gullion, Carlingford Mts. (N.E. Ireland) ——— Silesia, Alps, Scandinavia, Greenland Norite: India, Sudbury (Canada), Bushveldt (S. Africa). Anorthosite: Quebec, Labrador (E. Canada)
plitic: relatively ne grained with nicro-granitic exture; egmatitic: very oarse grained, ften with perfect rystals	very variable physical properties	similar to corresponding plutonic rock; but rarely found in large quantities	found in all plutonic rocks; well developed in Cornwall, Scottish Highlands ——— Brazil (important commercial source of pegmatites)

Hyp. = Hypersthene, L. = Leucite N. = Nepheline, Ol. = Olivine, Or. = Orthoclase, Pl. = Plagioclase, Q. = Quartz

Name / Colour	Varieties	Mineral Composition: Rock-Forming Minerals	Mineral Composition: Accessory Minerals
6 **Lamprophyre** variable colour	minette (Or. + Bi. + [Au.]), kersantite (Pl. + Bi. + [Au.]), vogesite (Or. + Ho.), spessartite (Pl. + Ho.), camptonite (barkevikite amphibole + Pl.), monchiquite (Ol., Au., amphibole, Bi., Anal., *no* feldspar)	feldspar, biotite, amphibole, pyroxene	apatite, iron ore, olivine
FINE-GRAINED (EXTRUSIVE AND HYPABYSSAL ROCKS)			
7 **Rhyolite** grey, reddish-grey, pink, yellowish, blue-green, brown	potassic rhyolite, sodic rhyolite; textural varieties: pitchstone (partly glassy), obsidian (glassy); allied type: dacite (Pl. > Or.)	quartz, feldspar (orthoclase with subordinate plagioclase), biotite, sometimes pyroxene, amphibole	apatite, zircon, magnetite
and **Quartz Porphyry**	quartz porphyry, felsite		
8 **Trachyte** pale colours, grey, yellowish, reddish-mauve	keratophyre (albite, little orthoclase), quartz-trachyte (with some quartz), biotite-trachyte, augite-trachyte, hornblende-trachyte; related type: trachy-andesite (Or. ≃ Pl., plagioclase is oligoclase-andesine)	orthoclase (often as sanidine), plagioclase (albite), biotite, amphibole, pyroxene	apatite, iron ore, zircon, sphene
and **"Porphyry"**	"porphyry", feldspar-porphyry, rhomb-porphyry (sodic variety)		

l = leucocratic (light rocks), m = melanocratic (dark rocks), Au. = Augite, Alb. = Albite, Anal. = Analcite, Bi. = Biotite, Ho. = Hornblende

Texture	*Properties* *Specific Gravity* *Crushing Strength*	*Uses* *Building and* *Civil Engineering*	*Localities* *Britain: World*
trongly porphyritic vith large, well-ormed crystals of ark minerals, e.g. nica or hornblende, n a ground-mass of eldspar	very variable physical properties which may change completely within a short distance	similar to parent rock, but little used	Northern England (Shap, Windermere); Southern Uplands, Scottish Highlands (wide distribution as dykes and sills)
orphyritic (large rystals in finely rystalline ground-nass) to finely rystalline, often vith parallel (flow) anding; glassy arieties have pherulitic and erlitic structures	hard, durable, takes good polish when fresh; resistant to weathering; S.G., 2·5–2·6; Cr. Str., 21,000–40,000 lb./sq. in.	external and internal walls, monuments, road metal	*Rhyolite*: 1. *Pre-Cambrian*: Shropshire (Wrekin), Malvern Hills, Channel Islands; 2. *Lower Palaeozoic*: Lake District, C. and N. Wales, Co. Waterford; 3. *Old Red Sandstone*: Glen Coe, Pentland Hills (Midlothian); 4. *Tertiary*: Skye, Arran (Pitchstones), Co. Antrim. *Quartz porphyries* and *felsites* are common in minor intrusions in Scotland, and in lavas in Ireland
			Iceland, Hungary, Germany, Roumania
orphyritic, to nely crystalline, ften with parallel lignment of minute eldspar laths rachytic texture), arthy texture	less resistant to weathering than most other igneous rocks; lower crushing strength; usually rough and porous, not easily polished; S.G., 2·4–2·8; Cr. Str., only 7,000–10,000 lb./sq. in.	road metal, concrete aggregate; rarely as building stone	1. *Pre-Cambrian*: Malvern Hills; 2. *Lower Palaeozoic*: Girvan (S.W. Scotland) – keratophyre, N. and S. Wales; 3. *Old Red Sandstone*: Pentland Hills, Cheviots; 4. *Carboniferous*: East Lothian, Eildon Hills (Roxburgh); 5. *Tertiary*: Mull.
			France, Germany, Hungary; rhomb-porphyry in Oslo district, Norway

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Name / Colour	Varieties	Mineral Composition: Rock-Forming Minerals	Mineral Composition: Accessory Minerals
9 **Andesite** dark grey, purplish-grey	pyroxene-andesite, e.g. hypersthene-andesite; biotite-andesite; hornblende-andesite	plagioclase (oligoclase to andesine), biotite, hornblende (lamprobolite), pyroxene	apatite, iron ore
10 **"Porphyrite"** or **Porphyritic Microdiorite**	pyroxene-microdiorite, hornblende-microdiorite, biotite-microdiorite, markfieldite (groundmass of intergrown quartz and orthoclase feldspar)	plagioclase (oligoclase to andesine), biotite, hornblende, pyroxene; quartz rare	apatite, iron ore
11 **Basalt** and related types dark grey, black		plagioclase (usually labradorite), augite, olivine; some varieties have leucite, nepheline, melilite and glass	magnetite, biotite, apatite, hauyne, hornblende, zeolites, perovskite
	a. without feldspathoids:		
	olivine-basalt	labradorite, augite, olivine	
	mugearite	oligoclase, augite, olivine	
	tachylite (basalt glass)	glassy	
	b. with feldspathoids:		
	(i) with olivine		
	nepheline-basanite	feldspar, nepheline, olivine, augite	
	leucite-basanite	feldspar, leucite, olivine, augite	
	(ii) without olivine		
	nepheline-tephrite	feldspar, nepheline, pyroxene	
	leucite-tephrite	feldspar, leucite, pyroxene	
	nephelinite	nepheline, pyroxene	
	leucitite	leucite, pyroxene	

l = leucocratic (light rocks), m = melanocratic (dark rocks). Au. = Augite Alb. = Albite, Anal. = Analcite, Bi. = Biotite, Ho. = Hornblende

Texture	*Properties Specific Gravity Crushing Strength*	*Uses Building and Civil Engineering*	*Localities* Britain: World
usually porphyritic with fine matrix (frequently found in altered condition)	S.G., 2·5–2·8; Cr. Str., comparatively low	road metal, little used as building stone	1. *Lower Palaeozoic*: N. and S. Wales, Shropshire, Lake District, Mendips, Central Ireland; 2. *Old Red Sandstone*: Pentlands, Ochils, Sidlaws, and Cheviots, Ayrshire, Lorne Plateau, Glen Coe
			Very important in Western American mountain regions, esp. Andes; Java, Japan
porphyritic, usually coarser grained than andesite	S.G., 2·56–2·85; Cr. Str., 15,000–34,000 lb./sq. in.	of only local importance	occurs in minor intrusions Penmaenmawr, Harlech District (N. Wales), Cheviot Hills, Southern Scotland, Glen Coe – Ben Nevis area, Charnwood Forest (markfieldite)
fine grained porphyritic or aphanitic (small crystals – only visible by microscope), commonly shows columnar jointing	very hard and tough, resistant to weathering, difficult to shape, easily polished; S.G., 2·8–3·3; Cr. Str., 35,000–55,000 lb./sq. in.	road metal, concrete aggregate	1. *Lower Palaeozoic*: N. and C. Wales, Ireland; 2. *Old Red Sandstone*: Ochils, Sidlaws, Pentlands, Ayrshire, Ben Nevis, Devon and Cornwall; 3. *Carboniferous*: Clyde Plateau, Campsies, West-, Mid- and East Lothian, Ayrshire, Derbyshire, Shropshire, Devon and Cornwall; 4. *Permian*: Devon; 5. *Tertiary*: Inner Hebrides Ardnamurchan, Co. Antrim Also common in dykes in Scotland and Ireland
			Very important in Deccan (India), Hawaii, Iceland

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Name / Colour	Varieties	Mineral Composition: Rock-Forming Minerals	Mineral Composition: Accessory Minerals
12 **Dolerite** dark grey, black, greenish	quartz-dolerite, olivine-dolerite, teschenitic dolerite [with anal.] tholeiite (quartz glass in spaces between crystals)	plagioclase feldspar (labradorite), augite, sometimes olivine; some varieties have feldspathoids [nepheline, analcite, etc.], rare quartz	apatite, ilmenite, sometimes hornblende, quartz

SEDIMENTARY ROCKS

Name / Colour	Varieties	Mineral Composition: Rock-Forming Minerals	Mineral Composition: Accessory Minerals
13 **Conglomerate** and **Breccia** (Rudaceous Rocks or Psephites) variable	*a.* Conglomerate (rounded fragments) *b.* Breccia (angular fragments) *c.* Tillite (ancient boulder clay)	variable, depending on source of material; pebbles may be of quartzite, quartz, greywacke, chert, lava, or other igneous rocks, or any other hard rock type	variable

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Texture	*Properties* *Specific Gravity* *Crushing Strength*	*Uses* *Building and* *Civil Engineering*	*Localities* *Britain: World*
crystalline, medium grained, finer than gabbro	very strong when fresh, often badly weathered near surface; S.G., 2·8–3·3	road metal, concrete aggregate	very widespread in sills esp.: Central Valley of Scotland, N. England (Great Whin Sill), Central England, N.E. Ireland
			Important examples: Karroo (South Africa), Pallisades Sill (New York)
clastic rocks containing fragments over 4 mm. in diameter; matrix may be sandy as in a. and *b*., or clayey as in *c*.; diameter of of the larger components (Wentworth Scale):[1] boulder> 256 mm. cobble 64–256 mm. pebble 4–64 mm.	hardness variable pebbles often detachable from matrix; worked with difficulty; S.G. varies according to pebble content		*a*. Torridonian (Scotland) Old Red Sandstone (Scotland), Trias, e.g. Bunter Pebble Bed (Central England) and other formations
			Flysh (Alps), Banket (S. Africa), Trias (Eastern U.S.A.) *b*. Upper Carboniferous and Permian Rocks of North and Central England (e.g. Brockram, Clent and Haffield Breccias) *c*. Dwyka Tillite (S. Africa), Talchir Boulder Bed (India) [Upper Carboniferous]; Canada, S. Africa [Pre-Cambrian]; also Schiehallion Boulder Bed (Perthshire) [Dalradian]

[1] There are a number of scales which attempt to define the range of grain size in the clastic sedimentary rocks. As the Wentworth Scale has been recommended by the Committee on Sedimentation, U.S. Council of National Research, and is being increasingly used in Britain, it has been used throughout this book.

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Name / Colour	Varieties	Mineral Composition: Rock-Forming Minerals	Mineral Composition: Accessory Minerals
14 **Sandstone** (Arenaceous Rocks or Psammites) white, pale grey, grey, buff, yellowish, red, brownish, sometimes green	*a.* quartzose sandstone orthoquartzite	quartz grains with clayey, siliceous, limy or irony cement	variable, depending on source of sediments, e.g. muscovite, feldspar, glauconite, garnet, etc.
	b. arkose	quartz, feldspar, (> 25%); derived from weathering of acid igneous rocks	
	c. greywacke	quartz, feldspar (15–50%) plus variable amount of minerals derived from weathering of basic igneous rocks, slates and other dark rocks, no cement in matrix	
	d. sub-greywacke	quartz, little feldspar and some dark minerals	
	e. grit (with large angular grains)	quartz and other mineral grains, variable	
	f. quartzite	quartz grains fused with quartz cement	
15 **Shale, Mudstone,** etc. (Argillaceous Rocks, Lutites or Pelites) pale grey, grey, bluish-grey, black, purple, red, green	*a.* shale – laminated, fissile *b.* mudstone – unlaminated *c.* marl – soft limy mudstone also: carbonaceous shale – black, well laminated; oil shale – bituminous; alum shale – with alum crystals; siltstone (grain size $\frac{1}{256}$–$\frac{1}{16}$ mm.) is intermediate between mudstone and sandstone; slate – lowly metamorphosed shale, tough and fissile	kaolin and other clay minerals	variable, include quartz, muscovite, calcite, zircon, rutile, bitumen and other carbonaceous material

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Texture	*Properties Specific Gravity Crushing Strength*	*Uses Building and Civil Engineering*	*Localities* Britain: *World*
astic – coarse, edium- to fine-rained; grains nge in size from mm. to 2 mm. Ventworth Scale): rains are sub-ngular (water eposited) or ounded (wind eposited); rit: angular grains; uartzite: fused rains	sandstone: hardness varies according to cement, which also determines ease of weathering; may split easily into blocks (freestone) or slabs (flagstone); not polishable; S.G., 2–2·5; Cr. Str. varies according to cement up to 38,000 lb./sq. in. greywacke: often hard and brittle, difficult to shape	*a.* and *d.* most important building stone; still used for stone facings, steps, monuments, etc. *c.* only local building stone, road metal *f.* road metal	*a.* and *d.* widespread in all geological formations, esp.: Old Red Sandstone (South Wales, Welsh Border, Scotland, Ireland); Carboniferous, particularly Millstone Grit – in all coal-fields; Permian and Triassic – Central to N.W. England, Scotland *b.* Torridonian Sandstone (N.W. Scotland), also Sparagmite (Scandinavia); *c.* in lower Palaeozoic Rocks of Wales, Southern Scotland, and Ireland *e.* widespread in Carboniferous and Old Red Sandstone in Britain *f.* Basal Cambrian rocks of N.W. Scotland, Shropshire (Stiperstones), Warwicks. and Worcs. (Lickey Hills, Nuneaton), Eastern Ireland; also common in Dalradian Rocks of Scottish Highlands and Ireland
astic, hardened ggregate of clay inerals; grain ze $<\frac{1}{256}$ mm. Ventworth Scale); ay be finely minated and ssile or nlaminated	hardness very variable; their use for building purposes depends on fissility, resistance to weathering, imperviousness to water and chemical composition, e.g. slate: good cleavage and resistance to weathering; fireclay: high alumina, low iron and magnesium content is responsible for refractory properties	shales, etc.: brick and tile manufacture; fireclay: refractory bricks; slate: roofing and pavement slabs	shale and mudstone are common in many geological formations; *marl*: Chalk Marl (Cretaceous) in S.E. England, Tertiary (Isle of Wight), also locally in Upper Carboniferous, e.g. Ruabon Marl, Manchester Marl; the Keuper Marl (Triassic) is not a true marl *oil shale*: West and Mid Lothian (Scotland) *slate*: Ffestiniog – Dolgelly area (Central Wales), Llanberis – Nantlle area (North Wales), Skiddaw, etc. (Lake District), Ballachulish (Argyll), Cornwall, Tipperary, Cork

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Name / Colour	Varieties	Mineral Composition: Rock-Forming Minerals	Mineral Composition: Accessory Minerals
16 **Limestone** (Calcareous Rocks) pale to dark grey, white, pale brown, yellowish, reddish	crystalline limestone, shelly limestone, reef limestone (coral, bryozoan, etc.), oolitic limestone, chalk; *magnesian varieties*: magnesian limestone (5–10% dolomite), dolomitic limestone (10–50% dolomite), calcitic dolomite (50–90% dolomite), dolomite (> 90% dolomite); *impure varieties*: cementstone, cornstone, marl (see No. 15)	calcite; sometimes aragonite, dolomite	clay, sand, iron oxide, bituminous materials; chert or flint as nodules
17 **Pyroclastic Rocks** volcanic breccia, agglomerate, tuff; variable in colour, often grey, yellowish, reddish, greenish	*classified* *a. according to origin*: (i) essential (tuff, etc.) – composed of fragments of erupting lava; (ii) accessory – composed of debris of earlier lavas ejected from volcanic vent; (iii) accidental – composed of sediments, etc., ejected from choked-up vent or torn from rocks through which vent was drilled; *b. according to contents*: (i) crystal tuff (etc.) – composed of crystal detritus; (ii) vitric tuff (etc.) – composed of volcanic glass fragments; (iii) lithic tuff (etc.) – composed of rock fragments; *named according to composition*: e.g. rhyolitic tuff, andesitic tuff, basaltic tuff; also – tuffaceous sandstone, shale, etc. (if a normal sediment is mixed with igneous fragments)		vary according to origin; calcite or zeolites often developed as secondary minerals

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Texture	*Properties Specific Gravity Crushing Strength*	*Uses Building and Civil Engineering*	*Localities* *Britain: World*
ystalline, massive fissile; composed fossil detritus; litic or pisolitic; so loose and rous (travertine, fa)	hardness variable, easily worked, usually resistant to weathering; S.G., 2·6–2·8; Cr. Str., 2,800–25,000 lb./sq. in.	much used building and ornamental stone, e.g. Portland Stone, Cotswold Stone, Bath Stone; raw material for Portland Cement, road metal	present in most formations, esp. Cambrian, e.g. Durness Limestone (N.W. Highlands); Silurian: Wenlock and Aymestry Limestone (Welsh Border and Midlands); Devonian: South Devon; Carboniferous Limestone: e.g. Pennines, Bristol District and Mendips, South- and North-East Wales, Ireland; Permian: Magnesian Limestone (N.E. England to Nottingham); Jurassic: Oolitic Limestone (Cotswolds, Lincs., Yorks.), Portland Stone (Dorset); Cretaceous: Chalk (Chilterns, N. and S. Downs, N.E. Ireland)
arse to fine ained, often strati- d; large fragments ten embedded in atrix of finer bris; generally gular fragments; xtural classifi- tion: Particle Size glo- erate / lcanic eccia } > 32 mm. pilli tuff 4–32 mm. ff < 4 mm.	hardness very variable, often loose, porous and soft, sometimes hard and indurated; often resistant to weathering, easily worked and shaped; hardness increases on exposure; deadens sound and insulates against heat; S.G., 0·8–3·0; Cr. Str., 14,000–21,000 lb./sq. in., though often lower	locally used as building stone, occasionally as road stone	rhyolitic tuff: Snowdonia, Central and S.W. Wales, Ireland andesitic tuff: Lake District, Cader Idris (North Wales), Lorne Plateau (Argyll), Ireland basaltic tuff: St David's (S. Wales), Central Scotland

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Name / Colour	Varieties	Mineral Composition: Rock-Forming Minerals	Mineral Composition: Accessory Minerals
METAMORPHIC ROCKS			
18 **Gneiss** colour like that of the varieties of granite	*a. according to origin*: (i) ortho-gneiss, derived from igneous rocks, (ii) para-gneiss, derived from sedimentary rocks; *b. textural varieties*: augen-gneiss granite-gneiss *c. mineralogical varieties*: sillimanite-gneiss andalusite-gneiss cordierite-gneiss pyroxene-gneiss hornblende-gneiss garnet-gneiss, etc.	*essential minerals*: quartz, orthoclase, plagioclase, biotite, muscovite, pyroxene; also andalusite, cordierite, sillimanite, epidote, garnet according to variety	apatite, rutile, zircon, iron ore
19 **Granulite**	kyanite-granulite biotite-granulite pyroxene-granulite garnet-granulite	quartz, orthoclase, plagioclase, garnet, pyroxene	apatite, zircon, rutile, kyanite, biotite, epidote, hercynite (iron-spinel)
20 **Schist** pale colours, often grey	muscovite-schist (mica-schist) garnetiferous mica-schist staurolite-schist calcareous schist graphite-schist sericite-schist paragonite-schist	essential: quartz, muscovite, biotite, paragonite; variable: garnet, staurolite, albite, epidote, calcite, kyanite, graphite	rutile
21 **Phyllite** dark grey, greenish	sericite-phyllite chlorite-sericite-phyllite	sericite, chlorite, quartz	rutile, tourmaline, magnetite, albite, ottrelite

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Texture	*Properties* *Specific Gravity* *Crushing Strength*	*Uses* *Building and* *Civil Engineering*	*Localities* *Britain: World*
oliated, micaceous ayers alternate with ands or lenticles of ranitic texture nd composition	tends to cleave into irregular plates; S.G., 2·55–3·0; Cr. Str., 22,500-25,000 lb./sq. in.	road metal, pavements, stone steps	North-West Highlands and Outer Hebrides [Lewisian Gneiss], Northern and Grampian Highlands (in vicinity of large granitic masses); also Malvern Hills, Anglesey
omposed of welded nterlocking grains granoblastic exture); not markedly fissile, ut with flaggy artings	similar to gneiss	road metal	Scottish Highlands, esp. north of Great Glen Fault
oliated, due to arallel alignment of laty and elongated minerals; foliation urfaces may be lane, wavy or ontorted	very easily cleaved, soft	of little use as building material; sometimes used for paving slabs	Scottish Highlands (the "pelitic rocks" of the Moine Series), many formations in Dalradian Series of Scotland and Ireland
oliated with perfect chistosity and lossy sheen on urface of splitting; oliation often wavy	easily cleaved, but thin plates are not usually as tough as slate	locally as roofing slate	among low grade metamorphic rocks of Scottish Highlands, especially close to Highland Boundary Fault; also Arran, Ireland, Cornwall

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Name / Colour	Varieties	Mineral Composition: Rock-Forming Minerals	Mineral Composition: Accessory Minerals
22 **Amphibole Rocks** green, dark green	amphibolite plagioclase-amphibolite garnet-amphibolite zoisite-amphibolite hornblende-schist anthophyllite-schist tremolite-schist glaucophone-schist "epidiorite" = epidote-zoisite amphibolite or plagioclase amphibolite	hornblende, sometimes actinolite, tremolite or glaucophane	albite, quartz, garnet, apatite, iron ores, sphene, rutile, epidote, zoisite, chlorite
23 **Serpentinite** (Serpentine Rock) bright green, blackish green, streaked and blotched with red	chrysotile-serpentinite, tremolite-serpentinite } asbestos garnet-serpentinite bronzite-serpentinite bastite-serpentinite	serpentine (alteration product of olivine)	garnet, bronzite, tremolite, talc
24 **Marble** white to yellowish, bluish, green, black, flesh coloured, red and white patches	calcite-marble dolomite-marble	calcite, dolomite	quartz, mica, talc, zoisite, brucite, grossularite, idocrase, diopside

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Texture	Properties Specific Gravity Crushing Strength	Uses Building and Civil Engineering	Localities Britain: World
foliated with interlacing fibres, also massive	occasionally hard and massive, very variable	locally as road metal, concrete aggregate	Scottish Highlands (in Lewisian, Moinian and Dalradian formations), Lizard (Cornwall), Anglesey, N.W. Ireland
massive with soapy feel, fibrous (asbestos), foliated	usually not resistant to weathering; S.G., 2·6–2·75; Cr. Str., (massive form): 20,000–35,000 lb./sq. in.	ornamental stone; internal decorations, shop fronts, fire-places; asbestos: fire-resistant sheeting	Lizard (South Cornwall), Anglesey, Girvan-Ballantrae district (South Ayrshire), Stonehaven to Loch Lomond (along Highland Boundary Fault), Portsoy (Banffshire)
massive, granular, fibrous	granular marble is easily worked and polished, resistant to weathering; S.G., 2·65–2·85; Cr. Str., 11,400–25,000 lb./sq. in.	decorative building stone, internal facings, statues, ornaments	most British marbles are impure, e.g. Durness "Limestone" (N.W. Scotland), Loch Tay "Limestone" (Perthshire), N. Ireland; pure marble: Tiree (Hebrides) ——— pure marbles of commercial importance: Carrara (Italy), Paros (Greece)

Hyp. = Hypersthene, L. = Leucite, N. = Nepheline, Ol. = Olivine, Or. = Orthoclase, P. = Plagioclase, Q. = Quartz

Alphabetical Description of Rocks and Petrographic Terms

Accessory Minerals. Minerals present in minor quantities in a rock.

Acid Rocks. Igneous rocks containing a high percentage of silica (+65 per cent.) and 10 per cent. or more of free quartz. Examples are granite, quartz porphyry and rhyolite.

Agglomerate. A coarse-grained consolidated deposit consisting chiefly of large bombs and fragments of lava embedded in a matrix of finer tuffaceous material. It was formed as a result of volcanic explosion, and is found in or near volcanic vents.

Amygdaloidal Rock. A lava or other igneous rock in which ovoid or elongated cavities, which were formed during consolidation by the expansion of gases within the lava, are filled by minerals such as calcite, chalcedony or zeolite. The individual mineral-filled cavities are termed amygdules (or amygdales).

Andesite. A fine-grained intermediate igneous rock occurring normally in lava flows, but also found in minor intrusions, especially dykes. Corresponds to diorite mineralogically, and consists essentially of plagioclase feldspar (oligoclase-andesine) associated with one or more of the coloured minerals biotite, hornblende or pyroxene. According to the dominant coloured mineral it is possible to distinguish three main varieties: augite- or hypersthene-andesite; biotite-andesite; and hornblende-andesite. Andesitic types containing a considerable quantity of free primary quartz are termed dacites.

Andesite is distinguished from trachyte by the absence of alkali feldspar (i.e. orthoclase) which is an essential constituent of the latter, and from basalt by the type of feldspar (andesine-oligoclase in andesite, labradorite-anorthite in basalt), the lower percentage of coloured minerals and the absence of olivine.

The division between andesite and microdiorite, the coarser-grained rock type of the same mineralogical composition, is drawn at the point where the grains of the groundmass can no longer be distinguished with the naked eye.

Anhydrite. A chemical sediment and mineral ($CaSO_4$), precipitated from solution by evaporation of marine and inland waters. Also formed by replacement of gypsum ($CaSO_4.2H_2O$). Used for manufacture of fertiliser and sulphuric acid.

Aplite. A fine-grained igneous rock occurring in small veins in granitic rocks and formed by crystallisation of the residual magma of the parent rock. Aplite is a light-coloured rock, and its component minerals are essentially feldspar and quartz. Aplites and pegmatites are often found in close association within a vein, and it is likely that the former were derived from "dry", and the latter from "wet" or volatile-rich, portions of the residual magmas.

Basalt. A fine-grained basic igneous rock occurring mainly as lava flows but also in minor intrusions. It is usually black when fresh, and consists of a minutely crystalline groundmass sometimes containing larger crystals (phenocrysts) of olive-green olivine, black augite, and, more rarely, colourless plagioclase feldspars (usually bytownite). The groundmass is normally composed of plagioclase feldspar (labradorite-anorthite) and pyroxene, and contains accessory minerals, especially magnetite. The term basalt in its widest sense includes a range of rock types which fall into two main groups:

A. Calc-alkali types, containing essentially plagioclase, augite, and olivine, and

B. Alkali basalts which include

1. *Tephrite* (containing augite, nepheline or leucite, together with plagioclase),
2. *Basanite* (as tephrite but including olivine),
3. *Trachy-basalt* (containing both orthoclase and plagioclase),
4. *Nephelinite* and *leucitite* (containing nepheline or leucite respectively instead of plagioclase),
5. *Limburgite* (containing olivine and augite in glassy base), and several other types.

In texture basalts may be dense and massive, as in centres of lava flows and in dykes, or slaggy and porous, as at the tops and bottoms of lava flows. Basalt is frequently jointed to form long polygonal columns, most of which are six-sided. These are well displayed at the Giant's Causeway in Antrim and at Fingal's Cave in Staffa. Massive basalt is difficult to work and shape, but is not too brittle for use in the building of walls and reservoirs. At present it is extensively used for road metal and the manufacture of glass wool.

Basic Rocks. Igneous rocks containing a relatively low percentage of silica ($<$55 per cent.) and having no free quartz and a high proportion of dark minerals. Examples are gabbro, dolerite and basalt.

Batholith (Bathylith). A large deep-seated intrusive mass of plutonic rock, usually of granite, normally occurring in orogenic belts. It is often elongated parallel to the fold axes of the surrounding rock, and has an irregular dome-shaped roof and very steep walls.

Biogenic Sediments. Organic sediments (see Sedimentary Rocks).

Boss. An intrusion of plutonic rock, roughly circular in plan and smaller than a batholith.

Breccia. A coarse clastic sediment containing angular fragments. Apart from sedimentary breccia (i.e. cemented scree) it is possible to distinguish fault- or crush-breccia and volcanic breccia according to mode of origin.

Building Stones and Materials: Properties. Igneous and sedimentary rocks will be treated separately. Metamorphic rocks are of only local importance and of limited use.

A. *Igneous Rocks.* Most igneous rocks are relatively impervious to water, a property which makes them particularly resistant to the action of frost. Their low porosity also gives them a high resistance to chemical weathering, though this is not the case with certain lime-rich basalts and dolerites, which are corroded by acids. All igneous rocks are capable of withstanding heat to a greater or lesser extent, and a sudden cooling by water usually affects only the surface.

Dressing. All hard igneous rocks can be easily worked and shaped by mechanical means. Medium-grained rocks can be dressed more evenly than coarse-grained varieties. The jointing of the rock determines the size of the blocks available, and a closely jointed rock is unsuitable for building. Even such relatively soft and porous rock types as trachyte and porphyrite can be readily prepared, and can even to some extent be polished.

Road Metal. All fresh igneous rocks are suitable for road metal and concrete aggregate. Dolerites and diorites are most suitable for road making, as they bind well with bitumen, while acid igneous rocks are particularly suitable for top dressings.

The properties of *volcanic tuffs* are intermediate between those of igneous and sedimentary rocks. Some of the more indurated types are, after suitable preparation, used as ornamental stones, mainly on account of their variable colour. Certain cleaved tuffs have been used as roofing slates. Both of these are, however, exceptions, and most tuffs can only be used in a crushed state for concrete aggregates and possibly road metal.

B. *Sedimentary Rocks*

1. *Clayey sediments.* These are, to a large extent, the end products of the chemical weathering of feldspars. They consist of minute particles of clay minerals, often in a colloidal state, together with a variable admixture of other minerals. Their role in soil mechanics and their use as raw materials in the building industry depend on their grain size and chemical composition. The following are the limits of grain size of the fine-grained sediments as defined by the Wentworth Scale:[1] clay $< \frac{1}{256}$ mm., silt $\frac{1}{256}$ mm. to $\frac{1}{16}$ mm. ($> \frac{1}{16}$ mm. = sand).

Of the sediments in the clay grade, clay (usually unconsolidated) and sometimes shale and mudstone are used in brick making. Their suitability for this purpose depends on the amount of shrinkage on drying

[1] See footnote on p. 159.

(unsuitable if more than 30 per cent. of original volume) and their freedom from excessive sulphur and carbon.

Slate is formed from mudstone, shale or fine volcanic ash that has been subjected to intense pressure at moderate temperature. During this process a reorientation of constituent particles and crystallisation of new mica minerals perpendicular to the direction of pressure took place, and slaty cleavage was formed. A slate can thus be split into thin coherent sheets which make ideal roofing slates. The best slates, as, for example, those quarried in North and Central Wales, are fine-grained with perfect cleavage, and are relatively free from pyrites.

2. *Sandstones.* The suitability of sandstones for building purposes is largely dependent on the cement which binds the individual sand grains. Four distinct types of cement can be recognised:

a. Clay: clayey sandstone is soft and friable, therefore not suitable for building.

b. Calcite: calcareous sandstone is hard and compact but is prone to chemical weathering.

c. Silica: siliceous sandstones have rather variable resistance to weathering. If the clay and calcite components in the cement are small, the sandstone is very durable.

d. Iron compounds: several iron minerals, e.g. siderite, chamosite and haematite, may form cement in sandstone. Ferruginous sandstones are durable but difficult to work.

The spacing of bedding planes and joints control both the quarrying and dressing of sandstone. Sandstones that have no marked current bedding and are easily cut into blocks are termed freestones, and those that split easily into slabs along the bedding planes are flagstones. Quartzites, the re-crystallised sandstones, are often suitable for top dressings on tarmac roads.

3. *Limestones.* These can, for building purposes, be divided into two main groups:

a. Massive limestones, which are largely composed of organic remains and are frequently oolitic, are the most common. They are compact and very resistant to weathering and have made excellent building stones. Some Lower Carboniferous limestones are sufficiently strong to make road aggregates. Few limestones are suitable for structures that have to bear great mechanical stress, such as viaducts and bridges.

b. Bedded limestones which can be split into thin or thick plates are suitable for internal work if they do not contain too high a proportion of clayey material. The famous Solenhofen "slates" come into this category.

At the present day the most important use of limestone in connection with building and engineering is the manufacture of Portland Cement.

Table

Some Physical

Major Rock Group	*Rock Type*	*S.G.*	*Water absorption (absorbtivity) (weight per cent)*	*Porosity (volume per cent)*
Igneous Rocks	1. Granite, Syenite	2·60–2·80	0·2–0·5	0·4–1·5
	2. Diorite, Gabbro	2·80–3·00	0·2–0·4	0·5–1·2
	3. Quartz-porphyry, Porphyry	2·55–2·80	0·2–0·7	0·4–1·8
	Andesite			
	4. Basalt	2·95–3·00	0·1–0·3	0·2–0·8
	5. Dolerite	2·80–3·00	0·1–0·4	0·3–1·0
Sedimentary Rocks	1. Siliceous Rocks, etc.			
	(*a*) Quartzite, Greywacke, Vein-quartz	2·60–2·65	0·2–0·5	0·4–1·3
	(*b*) Quartzose sandstone	2·60–2·65	0·2–0·5	0·4–1·3
	(*c*) Other sandstones	2·00–2·65	0·2–9	0·5–24
	2. Calcareous Rocks			
	(*a*) Massive limestone, Dolomite, Marble	2·65–2·85	0·2–0·6	0·4–1·8
	(*b*) Loose limestone, Limestone conglomerate	1·70–2·60	0·2–10	0·5–25
	(*c*) Calcareous sinter (e.g. travertine)	2·40–2·50	2–5	4–10
	3. Volcanic tuff	1·80–2·00	6–15	12–30
Metamorphic Rocks	Gneiss and Granulite	2·65–3·00	0·1–0·6	0·3–1·8
	Serpentine	2·60–2·75	0·1–0·7	0·3–1·8
	Schist	2·70–2·80	0·5–0·6	1·4–1·8

XI

Properties of Rocks

Crushing strength of dry rock (lb./sq. in.)	*Bending stress (lb./sq. in.)*	*Elasticity (Dynamic modulus of elasticity = E in lb./sq. in.) (tens of thousands)*	*Lime Content (Percentage CaO by weight)*
22750–34150	1400–2850	Granite 2100–10000	Granite: 0–1 Syenite: 0–4
24200–26500	1400–3100		Diorite: 3–7 Gabbro: 8–10
25600–42650	2150–2850	Porphyry 8100–9700	
35550–56900	2150–3550	7100–14300	Basalt: 10–12
25600–35550	2150–3550	10000–11400	Dolerite: 8–11
21350–42650	1850–3550	Quartzite 9200–11400	Quartzite: traces Greywacke: very low
17050–28450	1700–2850	600–5700	traces or none
4250–25600	450–2150	600–5700	up to 20
11400–25600	850–2150	Limestone 3600–10000	Limestone: 38–56 Dolomite: 20–36 Marble: 56
2850–12800	700–1150	——	——
2850–8550	550–1400		
2850–4250	300–8500		
22750–25600	4–10	1850–5120	
19900–35550	8–18		
7100–11400	——		Slate: 2–3

This is made from two-thirds ground-up limestone or chalk and one-third clay. Impure limestones, such as the Chalk Marl and the Liassic Limestones, are also used for this purpose.

c. Other limestones used in building:

(i) Travertine, a recent deposit, formed most commonly by hot springs in volcanic areas, is used for internal decorative work.

(ii) Dolomitic Limestone, a limestone containing a high proportion of the mineral dolomite, is also suitable for a building stone. Its resistance to weathering should, however, be ascertained before use, as some types are badly affected by sulphurous fumes in industrial areas.

(iii) Marble, a well-crystallised limestone, which has been metamorphosed by heat and pressure, is much used for internal decorative work on account of its attractive appearance, which is largely due to colour patterns formed by impurities. These are well seen on polished surfaces. Pure marbles, such as the fine-grained white marbles of Paros (Greece) and Carrara (Italy), are used for sculpture.

Building Stones: Testing. Technical data giving properties of more important building stones are given in Table XI (pp. 172-3).

Building Stones: Choice for specific purposes. For *underground structures* such as foundations, cellars, and water reservoirs only dense hard rock types which are not chemically affected by ground water are suitable. The most suitable are granite, syenite, diorite, basalt, and quartzite. For *structures above ground level* rather softer and more porous varieties which are none the less resistant to weathering can be used. Sandstones, limestones, and very compact argillaceous rocks as well as compact tuffs, trachytes, and porphyrites are thus quite suitable. *Pavement slabs* and *stone steps* can be made from all compact, well-cemented rocks. Among igneous rocks, granites, diorites, porphyries, trachytes, and basalts are most used; among sedimentary rocks, sandstones, massive limestones, and marbles are suitable. Compact slates have been much used. For *internal structures*, such as walls and floors, limestones, which are here protected from atmospheric weathering, are particularly suitable. Marble and travertine are much used for decorative purposes. The most common natural *roofing material* is slate, and less frequently phyllite. Certain thinly bedded sandy limestones, such as the Stonesfield and Collyweston "slates" of Gloucester, Oxford, and Northampton, and flagstones, such as the "grey slates" of Yorkshire and Lancashire, have been locally used for roofing. *Stone setts* formerly used for roads were made of rocks particularly resistant to abrasion and weathering. Fine grain was a disadvantage, as this led to a smoothly polished surface. Medium-grained rocks were most suitable. Granites, syenites, gabbros, porphyries, and dolerites, as well as compact sediments such as greywackes have been used. *Kerbstones* are made of very strong, massive rocks such as granite, greywacke, basalt, and quartzose sandstones. All compact rocks resistant to abrasion and weathering are suitable for *road metal.* Igneous rocks are generally preferred, and dolerites, diorites, and gabbros are most reliable.

Bysmalith. An intrusion which has the shape of a cylinder or an inverted cone, and has either penetrated to the surface or has a domed top. It is usually separated from the surrounding strata by a ring fault. Bysmaliths are often associated with cauldron subsidence.

Carbonatite. A hypabyssal intrusive rock consisting largely of calcium carbonate and other carbonates, together with some rare minerals. Usually associated with nepheline-syenite complexes.

Cement. The material which binds together the particles of clastic rocks. Common cementing materials are clay, calcite, silica, and iron oxide.

Chalk. A soft white limestone composed of almost pure calcium carbonate. It is made up largely of the remains of foraminifera, and contains other marine fossils such as sea urchins and molluscs.

Chert. A fairly pure siliceous rock occurring either as distinct beds or as nodular concretions in limestones older than the chalk. It consists mainly of chalcedony, which may be fibrous, and contains silicified remains of organisms such as radiolaria and sponge spicules. Chert is light grey to black when fresh and weathers to shades of yellow and brown.

Clay. A relatively unconsolidated sediment composed mainly of finely divided clay minerals often in a colloidal state. Grain size does not usually exceed ·002 mm. Apart from clay minerals, finely divided particles of quartz, lime, and magnesia are often present.

Coal. A black or brown mineral substance formed by the partial decomposition of vegetable matter in a waterlogged environment free from direct contact with air. This vegetable matter was subsequently compressed and consolidated by the weight of overlying sediment and chemically altered by the ensuing rise in temperature. Coal is composed of carbon together with hydrogen, oxygen, some nitrogen and sulphur, as well as a variable amount of moisture and inorganic mineral matter.

A. Coals formed from the remains of land and swamp plants, often by decomposition *in situ,* are called *humic coals.* In these, plant structures are often sufficiently intact to be recognisable under the microscope. They are classified according to rank. Rank is determined by the degree of coalification, which involves the progressive elimination of moisture and the volatile constituents accompanied by a proportionate increase in the percentage of carbon. The following ranks are recognised:

1. *Peat*, containing up to 57 per cent. C, at least 34 per cent. O, and 6·5 per cent. H (dry weight); the first stage in the transformation of vegetable matter into coal.

2. *Lignite*, with 70 per cent. C, 23 per cent. O, and 6·6 per cent. H; a brown coal with the woody structure still prominent, which cracks on drying and burns with a smoky flame.

3. *Sub-bituminous coal*, an intermediate type between lignite and bituminous coal.

4. *Bituminous coal*, containing about 85 per cent. C, 7 per cent. O, and 5·5 per cent. H; the ordinary household coal, which is black and banded with bright and dull layers.

5. *Semi-bituminous coal*, intermediate between bituminous and anthracitic coal; very suitable as a steam coal.

6. *Semi-anthracite.*

7. *Anthracite*, the highest rank of coal, with about 94 per cent. C, 1·5 per cent. O, and 3·5 per cent. H; it is hard, clean to handle, has a bright lustre, breaks with conchoidal fracture and burns with a smokeless flame.

B. Coals made up largely of finely divided plant debris, spores, or algae are termed *sapropelic coals*. These include *cannel coal*, a dull, lustreless, unlaminated coal, which breaks with a conchoidal fracture and burns with a luminous flame, and *torbanite* or *boghead cannel*, a tough, brown or dull black, oil-bearing substance composed mainly of the remains of algae.

Coal Petrology. The common household coal is banded, and dull and bright layers can easily be seen with the naked eye. Each layer is made up of one or more of the four distinct substances found in coal. These are:

1. *Vitrain*, the bright, glossy material which is clean to the touch and breaks with conchoidal fracture.
2. *Clarain*, bright coal with silky lustre, breaking with a smooth fracture.
3. *Durain*, dull coal with matt, earthy lustre and a close firm texture.
4. *Fusain*, the friable, porous substance which readily stains the hands; resembles charcoal.

These four coal types are in turn composed of one or more of a number of distinct and more or less homogeneous constituents, which are comparable to the minerals in inorganic rocks, and are termed *macerals* (coal minerals). The more important macerals are defined below:

1. *Vitrinite*, composed of woody tissues showing cellular structure; the dominant constituent of vitrain and clarain. Consists of two substances called collinite and tellinite.

2. *Fusinite*, or fossil charcoal, showing cellular structures with carbonised cell walls and hollow cavities; forms most of fusain.

3. *Micrinite*, a completely structureless jellified coal substance; present in durain.

4. *Exinite*, translucent yellow in colour, composed of the remains of spores and cuticles, and forming the greater part of durain.

5. *Resinite*, the fossil remains of plant resins, which form yellow oval bodies; found mainly in vitrain.

Cone Sheet. A minor intrusion, shaped like the wall of an inverted cone. Found in Tertiary volcanic centres such as Skye and Ardnamurchan.

Conglomerate. A cemented clastic sediment composed of rounded pebbles or cobbles embedded in a finer sandy matrix. (Contrast with breccia – angular pebbles.)

Contact Metamorphism. The alteration of rocks, mainly by heat, in the proximity of igneous intrusions. The zone of altered rocks surrounding an intrusion is known as the metamorphic aureole. New minerals developed during contact metamorphism are different from those developed during regional or dynamic metamorphism. They include andalusite, cordierite, lime garnet (grossularite), manganese garnet (spessartite), diopside, and feldspars, which are all stable at high temperature but unstable at great pressure.

Crystalline Schists. A general term describing foliated rocks formed by the effects of pressure, heat, and possibly migrating fluids during regional metamorphism. They include phyllites, mica schists and gneisses. (See Metamorphic Zones.)

Dacite. A fine-grained volcanic rock resembling andesite, but containing quartz and potassic feldspar as well as plagioclase. Dacites are the fine-grained equivalents of the granodiorites.

Diabase. The American term for dolerite. In Britain the name diabase is used for a rock of doleritic composition which has been altered to such an extent that hardly any of the original minerals have survived.

Diagenesis. The physical and chemical alteration which may take place in sediments during and after their deposition but before their consolidation. This excludes all metamorphic changes engendered by heat from igneous rocks or by mountain-building movements. Examples of diagenesis are the reduction of ferric oxides by organic matter in mud, the decomposition of some silicate minerals and formation of new (authigenic) minerals, as well as the formation of nodules by the concentration of cementing materials such as silica or siderite.

Diorite. A coarse-grained igneous rock of granitic texture composed of up to 75 per cent. plagioclase feldspar (within the oligoclase-andesine range) together with hornblende, biotite, or augite. Hornblende is the most characteristic dark mineral. Quartz is rare or absent. A wide range of rock types is included in the diorite clan. Among these are:

1. Granodiorite (contains $>$ 10 per cent. quartz; plagioclase and orthoclase).
2. Trondhjemite (a granodiorite in which alkali-feldspar is absent).
3. Tonalite, or quartz diorite (contains $<$ 10 per cent. quartz; plagioclase in excess of orthoclase; and hornblende).
4. True diorite (quartz-free).
5. Meladiorites, which have a relatively high content of dark minerals, e.g. appinite (hornblende-rich).
6. Lamprophyric diorites, e.g. kersantite and malchite (see p. 154).

Dolerite. A medium-grained igneous rock of gabbroic composition, occurring in sills, dykes and laccoliths. The mineral content is plagioclase feldspar (usually labradorite), augite or titan-augite, and iron ores. When olivine is present the rock becomes olivine-dolerite, and when quartz is present it becomes quartz-dolerite.

Dolomite. A mineral consisting of calcium and magnesium carbonate, $CaCO_3 : MgCO_3$, in equimolecular proportions. The rock dolomite is a limestone containing more than 50 per cent. of the mineral dolomite. Most dolomite limestones originated as calcite limestones in which part of the calcite was subsequently replaced by dolomite.

Dolomitic Limestone. A limestone consisting chiefly of calcium carbonate, but containing from 10 to 50 per cent. of the mineral dolomite.

Dyke. A sheet-like minor intrusion of igneous rock which is inclined at a high angle to the bedding of the strata it traverses. Most dykes are thus more or less vertical.

Eruptive Rocks. See igneous rocks.

Extrusive Rocks. Igneous rocks which consolidated from magma flowing over the surface of the ground. They are usually fine-grained or glassy, and may have flow texture. The extrusive rocks of granitic composition are rhyolite, felsite, and sometimes quartz porphyry; those of syenitic composition are trachyte and "porphyry"; the extrusive equivalents of diorite are andesite and "porphyrite"; and those of gabbro are basalt and sometimes dolerite. (See Lava, p. 182.)

Felsite. A mainly hypabyssal igneous rock of rhyolitic composition, consisting essentially of a crypto-crystalline (minutely crystalline) aggregate of quartz and orthoclase feldspar. Phenocrysts of quartz or orthoclase may be present.

Fireclay. A fine-grained clayey sediment which contains a high percentage of alumina and silica, and is relatively free from iron and magnesium. Often found as a seat-earth of some coal seams, and may contain carbonaceous streaks which are the remnants of rootlets.

Refractory at high temperatures and used in the manufacture of firebricks, etc.

Flint. A siliceous rock consisting mainly of granular chalcedony with some opal-like silica. Occurs as nodules, ribs, and veins in chalk. It is dark grey in colour when fresh, and has a white porous crust on weathered surfaces. Flint breaks with a conchoidal fracture.

Gabbro. A basic, coarse-grained plutonic rock, composed essentially of plagioclase feldspar (labradorite to anorthite) and augite (diallage). Accessory minerals are magnetite, ilmenite, apatite, sphene, pyrite, and garnet. If hypersthene occurs instead of augite, the rock is called *norite.* (the parent rock of the nickel ores at Sudbury, Canada). When olivine is present, the rock is called *olivine-gabbro,* and if olivine is the only dark mineral, it is termed *troctolite.* A rock composed largely of labradorite-feldspar is called *anorthosite.* Basic plutonic rocks which are rich in alkalis differ from true gabbros in that they contain feldspathoids such as nepheline and analcite. The most important of these are:

1. *Essexite* (containing small amounts of nepheline and/or analcite in the interstices between feldspar crystals, as well as some orthoclase feldspar).
2. *Teschenite* (containing analcite both as individual crystals and in the interstices).
3. *Theralite* (containing nepheline both as crystals and in the interstices).

Ganister. A fine-grained compact siliceous sandstone, usually pale grey in colour, occurring in Carboniferous strata as the seat-earth of some coal seams. It consists almost entirely of silica, and its freedom from fluxing constituents such as iron and magnesium makes it refractory at high temperatures. Used for furnace linings.

Glassy Rocks. Igneous rocks which were formed by the rapid cooling and consolidation of magma. They are most commonly lavas of rhyolitic composition. *Obsidian* and *pitchstone* are examples. The chilled edges of minor intrusions may also be glassy, and the glassy form of basalt is called *tachylite.*

Gneiss. A foliated rock in which highly micaceous layers alternate with bands or lenticles of granitic texture and composition. It is formed by the alteration of rocks under the influence of high temperature and great pressure, as well as by the influx of migrating fluids. Gneisses may pass laterally into granodiorites or granites. According to origin, gneisses can be subdivided into ortho-gneisses (formed from igneous rocks) and para-gneisses (formed from sedimentary rocks). The variation in composition and texture of gneiss is great, and the number of accessory minerals is large. According to the characteristic mineral present, it is possible to distinguish such types as biotite-gneiss, muscovite-gneiss, hornblende-gneiss, sillimanite-gneiss, andalusite-gneiss, etc.

Granite. The most important and widespread plutonic rock, present in almost all geological formations from pre-Cambrian to Tertiary.

Mineral Composition: Feldspar, usually orthoclase with subordinate plagioclase (albite-oligoclase range), quartz, and mica (biotite or muscovite). Hornblende or augite are sometimes present in small quantities. Accessory minerals are apatite, magnetite, ilmenite, haematite, zircon, pyrite, monazite, sphene; and more rarely tourmaline, rutile, fluorspar, topaz, garnet, cordierite, and lithium-mica.

Colour: As the dominant component is orthoclase feldspar, granite is usually light in colour, either white, grey, bluish-grey, reddish to flesh-coloured, or pale greenish.

Chemical Composition: SiO_2 60-75 per cent., Al_2O_3 15-18 per cent., alkalis 7-10 per cent. (K usually exceeds Na). Percentage mineral composition: feldspars, up to 60 per cent., quartz 30-35 per cent.

Nomenclature: Granites are usually named after the dominant dark mineral, e.g., biotite-granite, hornblende-granite, augite-granite.

Related Rock Types:

1. *Sodic granite*, containing sodic pyroxene or amphibole, e.g. aegirine or riebeckite; *rockallite* is a dark facies of aegirine-riebeckite-granite.
2. *Charnockite*, composed of quartz (full of rutile needles), microcline, oligoclase, hypersthene, and biotite. It is a member of a hypersthene-bearing group of rocks occurring in India and Uganda.
3. *Greisen*, a pneumatolytic modification of granite near quartz and mineral veins. In this, feldspars are altered to aggregates of lithium-mica, fluorite, zinnwaldite, and sometimes topaz.
4. *Rapakivi granite*, a hornblende-biotite-granite with crystals of flesh-coloured potassic feldspar mantled with green or grey oligoclase. Rapakivi granites are well known in Finland, but some types of Shap and Dartmoor granites are in the same category.
5. *Adamellite*, a granite containing potassic feldspar and plagioclase (andesine to oligoclase) in roughly equal proportions (e.g. Shap granite).
6. *Granodiorite*, see under diorite.

Origin: Whereas the greater proportion of the plutonic rocks in the earth's crust is of granitic composition, the extrusive rocks are predominantly basaltic. It is unlikely that all plutonic rocks were derived from a common parent magma by the process of magmatic differentiation, as during differentiation the basaltic minerals crystallise out first, and one would expect to find at least as many gabbros as granites. As granitic rocks occur only in continental areas, where the sialic layer is present, and are most common in orogenic belts, it has been suggested that granitic magma originated through local fusion (palingenesis) of the sial. Another widely-held concept is that certain granites were formed directly from pre-existing rocks of greatly varying composition without passing through the liquid state. This process is known as granitisation, and is thought to be brought about by the percolation of hot aqueous solutions (or even by "dry ionic migration") through the country rock. The solutions are said to carry new minerals in ionic form into the pre-existing rock, which is changed first into a migmatite (mixed rock) and finally into a granite. It is possible to recognise granite masses of both "magmatic" and "migmatic" origin, and it has been shown that in some granitic complexes parts of the material undergoing granitisation were softened and ultimately liquified, thus behaving as intrusive masses.

Granophyre. A hypabyssal intrusive rock of granitic composition, in which the quartz and orthoclase feldspar are intergrown to form crystals. When seen in thin section, the quartz in these crystals has the shape of Runic or Semitic hieroglyphics (graphic texture).

Granulite. A metamorphic rock composed of roughly equidimensional interlocking mineral grains which are mainly quartz and feldspar. Mica occurs only in scattered flakes and the rock is never markedly fissile, though the alternation of bands of slightly different mineral composition may give it a banded structure. Granulites may be formed by the metamorphism of feldspathic sandstone, in which case biotite and garnet are developed; or from acid igneous rocks, in which case biotite, sillimanite, or hercynite are formed.

Greywacke. A type of sandstone composed of angular to sub-rounded grains of quartz and feldspar together with minerals and rock fragments derived from the disintegration of basic igneous and other dark-coloured rocks. It is generally dark greyish-brown in colour and strongly compacted. Greywackes are common in the Lower Palaeozoic rocks of Wales and the Southern Uplands of Scotland.

Hornfels. A metamorphosed rock which has been completely reconstructed by the action of intense heat. It is tough, compact, and granular in appearance, and the component minerals are stumpy and arranged in a criss-cross pattern (decussate structure). New minerals developed in hornfels include andalusite, cordierite, enstatite, diopside, wollastonite, anorthite, and grossularite. Quartz, feldspar, and mica are usually present.

Hypabyssal Rocks. Igneous rocks of intermediate grain size which consolidated in small intrusions such as dykes and sills. They frequently have well-developed porphyritic texture.

Igneous Rocks (Eruptive Rocks). These have been defined as rocks formed by consolidation from liquid magma, and are grouped into plutonic, hypabyssal, and extrusive rocks. There is, however, some doubt if all plutonic rocks have passed through a "magmatic" or liquid condition, and it is possible that in certain cases these represent the final stages in the process of metamorphism.

Intermediate Rocks. Igneous rocks intermediate in composition between the acid (granitic) and basic (basaltic) rocks, and containing between 55 and 65 per cent. silica. Examples are syenite, trachyte, diorite, and andesite.

Kaolin. A whitish clay formed by the chemical weathering of igneous rocks rich in feldspar. It contains a high proportion of the mineral kaolinite. Raw material for the manufacture of porcelain.

Keratophyre. An ancient extrusive rock, with the chemical composition of albitic trachyte, in which the coloured minerals are so altered that it is not possible to determine their original nature.

Laccolith. A minor intrusion of igneous rock which has been intruded along a bedding plane or other plane of weakness in such a way that the overlying beds have been arched up into the form of a dome. Laccoliths are usually round or elliptical in plan, with a flat base and arched top. It is possible that they are fed by a central pipe, but some may be local modifications of sills. Laccoliths may be multiple and may lie one above the other, as in the case of cedar-tree laccoliths.

Lava. Molten rock material (magma) which has reached the surface through a vent or through fissures and has spread over the ground. Lava flows may be formed on dry land or under the sea. The term lava is also applied to rocks of all ages which originated as lava flows.

Limestone. A sedimentary rock consisting largely of calcium carbonate (calcite or aragonite), and which sometimes has an admixture of dolomite. Limestones may be of organic, chemical, or clastic origin, though more usually they are formed by the combination of two or all three of these factors. The texture may be porous, oolitic, or massive, or the limestone may consist entirely of cemented shell or animal fragments or of reefs of coral, bryozoan, or algal colonies with an admixture of other organisms. The impurities of limestone include a great variety of substances, and these may impart varied colours to the rock. Limestone has been widely used as building material, the massive form for walls and the platy form for internal polished surfaces. It is also used in the steel industry, for artificial fertiliser, and in the manufacture of Portland cement. Pure limestone which has been subjected to metamorphism by heat and pressure forms marble, used as a decorative building material.

Loam. An iron-rich clay with an admixture of silty material, used in brick-making and pottery.

Loess. A fine-grained clayey or silty sediment transported by the action of wind and accumulated in thick unstratified deposits. It is soft and friable, yellow in colour and rich in lime, and forms extensive belts of fertile country extending from Central Europe through the steppes of Asia to China.

Lopolith. A large concordant igneous intrusion, which is lenticular and convex downwards, having a saucer-like structure. Many lopoliths are of a composite character, consisting of several layers of different rocks (though mainly gabbroic), the ultrabasic ones being at the bottom and the granitic ones at the top.

Magma. The fluid raw material from which igneous rocks are consolidated. It is composed of molten rock material (a mixture of complex silicates and oxides) charged with water vapour and other volatile constituents, such as carbon dioxide, sulphur dioxide, nitrogen, and chlorine.

Magnesian Limestone. A limestone containing a small proportion of magnesium carbonate (5-15 per cent.) not in the form of dolomite, but in solid solution in calcite crystals. The Magnesian Limestone formation in the Permian System of Northern England contains some magnesian limestone, but consists mainly of dolomitic limestone (see p. 178).

Marl. A clayey sediment rich in lime, including every gradation between calcareous clay and clayey limestone. Marls may contain between 25 and 75 per cent. of clay. They are usually fairly soft; and the more consolidated deposits of this type are sometimes termed marlstone.

Metamorphic Rocks. Rocks formed from pre-existing rocks by alteration due to intense heat, pressure, or shearing stress, or by a combination of these. (See Contact Metamorphism, p. 177; Metamorphic Zones, below.

Metamorphic Zones. Metamorphic rocks in an area of regional metamorphism, such as the Scottish Highlands, range from relatively little altered rocks such as slates and phyllites to highly altered types such as augen-gneiss. There are thus very different grades of metamorphism, but the relationship between these grades is of a gradual, orderly kind which is related to the region as a whole. The physical conditions controlling the grade of metamorphism are taken to be temperature, pressure, and shearing stress. It has been suggested by the German geologist Grubenmann that the degree of metamorphism is determined by the depth within the earth's crust at which the rocks were metamorphosed, and he recognised the zones shown in the following table:

Zone	*Depth*	*Minerals formed*
1. Epi-zone	Shallow depth	Serizite, talc, serpentine, chlorite, hornblende.
2. Meso-zone	Intermediate depth	Muscovite, Na-pyroxene, Na-amphibole, tremolite.
3. Kata-zone	Great depth	Sillimanite, cordierite, diopside, wollastonite, corundum, idocrase, olivine feldspar, graphite.

In the Scottish Highlands it has been shown that the grades of metamorphism are related to the great granitic masses of the Central Grampians and Northern Highlands, and that the degree of metamorphism becomes progressively less away from these intrusions. The metamorphic grades thus appear to be related mainly to temperature, pressure and shearing stress being of less importance; and the zones of metamorphism can be delineated by isothermal lines, or *isograds* = lines of equal grade. The following zones, named after a characteristic newly developed mineral, have been worked out for metamorphosed clayey sediments.

Low temperature, fairly high stress.

Metamorphic Zone (Named after Index Mineral)	*Rock Types*
0. Clastic Micas	Slate.
1. Chlorite	Chlorite-sericite-schist, phyllite.
2. Biotite	Biotite-schist, chloritoid-schist.
3. Garnet (almandine)	Garnetiferous mica-schist, garnetiferous phyllite.
4. Staurolite	Staurolite-garnet-mica-schist, staurolite-gneiss.
5. Kyanite	Kyanite-garnet-mica-schist, kyanite-gneiss. (These two zones cannot always be separated out.)
6. Sillimanite	Sillimanite-gneiss, cordierite-gneiss, garnet-gneiss.

High temperature, high stress.

Similar metamorphic zones have been worked out in the case of other metamorphosed sedimentary and igneous rocks, and the mineral associations characterising the various temperature zones have been established.

Metasomatism. The process of replacement of one mineral by another as a result of the introduction of material from external sources. The outline of the original mineral is often retained by the new one. Examples of metasomatism are the replacement of calcite by dolomite or siderite in many limestones, the replacement of gypsum by anhydrite in saline deposits (evaporites), and the formation of chert in limestones. The formation of granite from pre-existing rocks may also be a form of metasomatism.

Mudstone. A sedimentary rock composed mainly of particles of clay size, without lamination and non-fissile.

Obsidian. A glassy volcanic rock of rhyolitic composition, usually with marked conchoidal fracture. It is rarely completely free from crystalline material and often contains minute scattered incipient crystals, termed crystallites. Obsidian often has perlitic structure, which is a series of roundish cracks produced by contraction during cooling.

Oolite. A rock, usually a limestone, made up of an aggregate of spherical bodies termed ooliths, which are usually less than 1 mm. in diameter. It resembles the roe of a fish. Individual ooliths are composed of concentric shells of aragonite, calcite, or iron carbonate. The Jurassic oolitic limestones of England have provided valuable building stones such as Portland stone, Bath stone, and Ancaster stone.

Organic Sediments. Sedimentary deposits formed from the remains of living organisms. (See Sedimentary Rocks.)

Ortho-gneiss (also ortho-schist). A metamorphic rock which was formed by the alteration of an igneous rock.

Para-gneiss (also para-schist). A metamorphic rock which was formed by the alteration of a sedimentary rock.

Pegmatite. A very coarsely crystalline igneous rock occurring in veins or small irregular masses in or near to bodies of plutonic rock, usually granite. It consists mainly of the minerals quartz and potassic feldspar which often display characteristic graphic intergrowth. It may also contain tourmaline, topaz, and fluorspar, as well as the minerals of rare elements. Pegmatite is formed by the crystallisation at a low temperature of the residual magma of the parent rock. This magma is rich in water and other volatile constituents.

Peridotite. An ultrabasic coarse-grained igneous rock, dark in colour and of high specific gravity. It consists chiefly of olivine and may contain variable amounts of pyroxene, hornblende, or biotite. It is often an important source of chromium and platinum ores.

Phenocrysts. Large crystals, often of perfect crystalline shape, which occur in a finer-grained groundmass in igneous rocks.

Phonolite. A fine-grained igneous rock, grey-green or brownish in colour, with a characteristic ring when struck by a hammer. Mineralogically, it is the fine-grained equivalent of nepheline-syenite, consisting of orthoclase feldspar (usually sanidine), nepheline, leucite, and sodic pyroxene (i.e. aegirine) or amphibole (i.e. riebeckite). Varieties of phonolite contain nosean, sodalite, or leucite instead of nepheline.

Phyllite. A metamorphic rock formed by the dynamic metamorphism of clayey sediments. It is usually perfectly foliated with a silky sheen on the surface of splitting, and the foliation is often slightly wavy or rumpled. The platy mineral along the foliation surface is sericite. (See Metamorphic Zones, p. 183.)

Picrite. An ultrabasic medium- to coarse-grained igneous rock, dark in colour, and consisting of olivine plus augite or orthopyroxene (enstatite) or hornblende, together with a small amount of plagioclase feldspar. According to the mineral association it is possible to distinguish augite- or hornblende-picrite.

Pisolite. A type of limestone made up of more or less spherical bodies about the size of peas. The individual grains consist of concentric shells of calcium carbonate or related minerals. Modern pisolites composed of aragonite are found in the deposits of hot springs.

Pitchstone. A semi-glassy (sub-vitreous) extrusive rock of rhyolitic composition, containing many minute and imperfectly developed crystalline growths. Perlitic structure is common. (See Obsidian, p. 184.)

Plutonic Rocks. A major group of igneous rocks which are coarse-grained and which crystallised at great depth. They can be divided according to composition into four main groups: 1. Granites; 2. Syenites; 3. Diorites; 4. Gabbros. (See also Granite (origin), p. 180.)

Porphyrite, Porphyry. Terms formerly used for various hypabyssal rock types of intermediate composition which almost invariably display porphyritic texture. The term porphyry, or syenitic porphyry, has been used for porphyritic micro-syenite, and the term porphyrite for porphyritic micro-diorite. The mineral content of these rocks is similar to that of their coarse-grained relatives, and they are often named according to the dominant porphyritic mineral, e.g. feldspar-porphyry, augite-porphyrite, hornblende-porphyrite. Rhomb porphyry is a sodic micro-syenite from Norway containing porphyritic feldspars with a rhombic cross-section.

Porphyritic Texture. A porphyritic rock is an igneous rock which contains large often well-developed crystals embedded in a finer-grained crystalline or glassy groundmass.

Pumice Stone. A very vesicular (frothy) lava associated with recent volcanoes. The pumice used commercially is pale-coloured with a somewhat pearly lustre, and is rhyolitic in composition.

Pyroclastic Rocks. Consolidated rocks consisting of detritus ejected from volcanoes. They include volcanic breccia or agglomerate which contain large fragments (bombs and blocks) over 32 mm. in diameter; lapilli tuff, containing fragments up to 32 mm. in diameter; and tuff, which is composed of particles up to 4 mm. in diameter. The term "ash" has been used to denote fine tuff, but its use should be restricted to the unconsolidated material from which tuff is made.

Quartzite. A compact siliceous rock consisting of detrital quartz grains with the interstices filled with quartz cement. It is usually formed by the alteration of quartzose sandstone through heat and pressure, which led to the fusion of adjacent particles, the quartz cement being a crystalline outgrowth from the sand grains.

Quartz-Porphyry. A fine-grained hypabyssal rock of granitic composition with porphyritic crystals of quartz and orthoclase feldspar. The groundmass consists of feldspar (orthoclase and plagioclase) and quartz together with subordinate biotite or hornblende.

Regional Metamorphism. See Metamorphic Rocks, Metamorphic Zones (p. 183).

Rhyolite. A fine-grained acid extrusive rock of granitic composition, usually pale in colour and often with marked flow banding. It consists of orthoclase feldspar (sanidine), some albite, quartz (the high temperature forms, β-quartz or tridymite), and subordinate mica or pyroxene. Hornblende is rare. Sodic rhyolites contain more albite than orthoclase, and have aegirine or riebeckite instead of augite or hornblende. Rhyolites which are glassy are termed obsidian, and partly crystalline types are pitchstones.

Ring Dyke. A minor intrusion with a roughly circular outcrop normally dipping outward at a high angle from the centre. Ring complexes, as in Mull and Ardnamurchan, often contain several concentric ring dykes which are associated with ring faulting or cauldron subsidence.

Sandstone. A sedimentary rock composed of rounded or angular clastic grains, usually of quartz, cemented with quartz, calcite, clay, or iron oxide. It is the most important building stone. (See Sedimentary Rocks.)

Schist. A foliated rock formed by the action of heat and pressure during regional metamorphism. It is composed of mica and a variable number of other minerals such as quartz, garnet, epidote, or zoisite, depending on the character of the original rock and the degree of metamorphism. The foliation, which may be plane or contorted, is largely due to the parallel alignment of the mica flakes.

Sedimentary Rocks. Rocks composed of material which was laid down by various agencies either in water or on land. The term sediment includes both loose (unconsolidated) and compact (consolidated) deposits. Sediments can be conveniently divided into the following groups:

A. *Clastic or detrital deposits*

1. *Rudaceous sediments* or *psephites*: Coarse-grained with fragments over 2mm.[1] in size. Unconsolidated types are gravel and scree. Consolidated types are conglomerate (rounded pebbles) and breccia (angular pebbles).

2. *Arenaceous sediments* or *psammites*: Composed of grains of medium size, ranging from $\frac{1}{16}$ mm. to 2 mm. They include sand (unconsolidated), sandstone, arkose, and greywacke (consolidated).

3. *Argillaceous sediments* or *pelites*: These comprise the finest-grained sediments, e.g. mud, clay, silt, loess (unconsolidated), and shale, mudstone, siltstone (intermediate grain size), and marl (consolidated).

[1] Grain sizes according to Wentworth Scale.

B. *Chemical and organic deposits*

1. *Inorganic deposits* (*hydroliths*): Deposited by precipitation from aqueous solution, e.g. gypsum, anhydrite, rock salt, bog iron ore, siliceous sinter, and tufa.

2. *Biogenic* or *organic deposits* (*bioliths*): Formed largely from remains of living organisms.

a. Calcareous: Limestones and dolomites (from remains of algae, foraminifera, corals, bryozoa, molluscs, etc.).
b. Carbonaceous: Formed from remains of plants or planktonic organisms, e.g. coal, anthracite, lignite, crude oil, bitumen, asphalt.
c. Ferruginous: Usually formed by the action of bacteria, e.g. organic limonite.
d. Siliceous: Formed from minute siliceous skeletons, e.g. radiolarian ooze.
e. Phosphatic: e.g. guano.

C. *Residual deposits*

Soils, terra rossa, laterite, and bauxite.

Serpentinite (Serpentine rock). A rock composed almost entirely of the mineral serpentine. It is a compact or fibrous rock variously coloured and easily polished; worked as ornamental stone.

Shale. A sedimentary rock composed mainly of particles of clay size ($<\frac{1}{256}$ mm.); it is laminated and fissile. Fissile sediments containing both silt ($\frac{1}{256}$ mm.–$\frac{1}{16}$ mm.) and clay particles may also be termed shale.

Siliceous Sediments. Sediments composed essentially of quartz. Consolidated types are quartzite, siliceous sandstone, chert, and flint. Unconsolidated types are kieselguhr (= siliceous earth or diatomaceous earth), siliceous oolite, and siliceous sinter.

Sill. An intrusion of igneous rock formed by the consolidation of magma which has forced its way between adjacent beds of a bedded rock, or was emplaced as a more or less horizontal sheet in an unbedded rock. Sills may vary in thickness from a few inches to several hundred feet and they have often a very wide lateral extent.

Siltstone. A sedimentary rock composed mainly of particles of silt size ($\frac{1}{256}$ mm. - $\frac{1}{16}$ mm.), which has no lamination and is not fissile. A laminated rock of this grain size is often called shale, but should preferably be termed laminated siltstone.

Slate. A fine-grained clayey rock with marked cleavage along which it can be split into thin cohesive plates. Slaty cleavage is not related to the original bedding plane, but was formed during compression of the rock, when the flaky minerals were rotated and came to lie with their long axes perpendicular to the direction of compression.

Spilite. A basic lava with less than 50 per cent silica, but with feldspars consisting entirely of albite; generally amygdaloidal. In most spilites the coloured minerals are altered to chlorite, serpentine, etc., and it has been suggested that the albite was formed by the alteration and leaching of calcium-rich plagioclase. Spilites were poured out under the sea and usually exhibit pillow structure.

Syenite. An acid-intermediate plutonic rock with granitic texture composed of about 70 per cent. potassic feldspar with subordinate albite; coloured minerals (about 25 per cent.), i.e. hornblende, biotite, or augite; and free quartz (0-10 per cent.). Syenite is often named according to the dominant dark mineral, e.g. hornblende-syenite, augite-syenite, mica-syenite or alkali-syenite, the latter containing sodic-pyroxene or sodic-amphibole. Syenites containing feldspathoids (e.g. nepheline-syenite, leucite-syenite) usually have albite instead of orthoclase, possess no free quartz, and have a higher percentage of coloured minerals than normal syenites.

Thermal metamorphism. See Contact Metamorphism (p. 177).

Trachyte. A fine-grained extrusive igneous rock of acid-intermediate composition, which corresponds in mineral content to syenite; pale grey to purplish in colour, somewhat porous and light in weight. Most trachytes are porphyritic and the crystals of the groundmass often show parallel alignment due to lava flowing in the viscous state (called trachytic texture).

Travertine or **Calcareous Sinter.** A recent calcareous deposit formed in lakes, in limestone caverns and in the vicinity of hot springs by the evaporation of lime-rich waters. It contains various banded, botryoidal, and oolitic structures, and has locally (in Italy) been used as a decorative building stone. (Not resistant to weathering.)

Tufa. A recent calcareous deposit, usually spongy or porous in texture, formed near lime-rich springs and sometimes in rivers.

Tuff. A consolidated deposit of materials ejected from a volcanic vent. Tuff particles (ash) are normally less than 4 mm. in size, and may be composed of fragments of lava expelled during the eruption. These fragments may be glassy, crystalline or detached crystals. Tuffs may also contain or consist of debris which choked up the volcanic vent before the eruption or which formed the country rock through which the volcanic orifice was drilled.

Ultrabasic Rocks. Igneous rocks which have a very low silica content, and consist almost entirely of the magnesium-iron silicate minerals olivine, pyroxene or hornblende. Examples are peridotite, picrite, pyroxenite and eclogite (containing garnets).

Volcanic Rocks. See Extrusive Rocks (p. 178).

III. GEMSTONES

Introduction

Gemstones are rare minerals possessing certain special properties which are not usually found in other minerals and which make them suitable for cutting into gems and ornaments. The most important of these properties are their exceptional hardness, their sparkle or "fire," their superb transparency, and in certain cases, their colour and lustre. Hardness is perhaps their most obvious characteristic, and many precious stones are harder than quartz (Hardness 7). It has, in fact, been customary to make a distinction between "precious stones," and "semi-precious stones," which was based mainly on hardness. Such a grouping, however, has little real significance, and the term "semi-precious stones" is no longer generally used. The transparent stones derive their attraction and value from their special optical properties, which are responsible for the "fire," lustre, and nuances of colour seen to perfection in the cut gem. The opaque stones, on the other hand, are characterised either by their fine, often variable, colouring, or by the iridescent sheen or lustre produced by polished surfaces.

The identification of gemstones is based on the determination of certain physical properties, such as specific gravity (Table XII), hardness, refractive index, and other optical values. The tables on the succeeding pages set out the necessary data. As the examination of gemstones is not usually carried out in the field, the tables have been made sufficiently comprehensive to allow them to be used in the laboratory or workshop, where optical instruments are available.

Many imitation and synthetic gemstones are now being made, and in some cases these are remarkably like the natural stone. Special emphasis is therefore given to the characteristics which distinguish natural stones from the man-made product.

Table XII

Specific Gravity of Gemstones

4·90–5·30	Haematite	3·16–3·23	Apatite
±4·80–4·90	Marcasite	3·10–3·20	Andalusite
	Zircon	3·10–3·25	Fluorite
4·75	red-brown = hyacinth	3·05–3·10	Orthoclase
4·70	blue	3·10	Euclase
4·33	green	2·94–3·16	Tourmaline

TABLE XII (contd.)

3·90–4·20	Almandine (garnet)
	Corundum =
±4·00	sapphire
3·90–4·10	ruby
3·70–4·00	Malachite
3·80–3·85	Demantoid (garnet)
3·65–3·80	Pyrope (garnet)
	Chrysoberyl =
3·65–3·75	alexandrite
3·65–3·77	Staurolite
3·60–3·70	Grossular (garnet)
3·56–3·67	Kyanite
(3·40)–3·65	Benitoite
3·52–3·65	Pleonaste
3·60–3·63	Hessonite
	Spinel
3·52–3·71	red
3·60–3·65	others
3·61–3·76	synthetic
3·50–3·58	Topaz
3·51–3·53	Diamond
3·40–3·70	Rhodonite
3·29–3·47	Idocrase = vesuvianite
3·30–3·57	Olivine = chrysolite
3·28–3·53	Epidote = pistacite
3·28–3·36	Dioptase
3·30–3·35	Jadeite
3·15–3·20	Kunzite
2·94–3·06	Nephrite
2·96–3·00	Phenakite
2·70–2·89	Morganite = pink beryl
2·60–2·82	Turquoise
2·66–2·76	Beryl
2·69–2·72	Labradorite
2·66–2·70	Emerald
2·68–2·70	Scapolite
	Quartz
2·65	citrine, amethyst, rock crystal, rose quartz
2·60–2·65	Chalcedony
2·60–2·65	Agate
2·60–2·65	Chrysoprase
2·56–2·76	Jasper
2·45–2·90	Lapis Lazuli
2·57–2·66	Cordierite
2·50–2·60	Obsidian
2·54–2·57	Amazonite
2·55–2·58	Adularia = moonstone
2·36	Moldavite
2·20	Chrysocolla
2·00–2·22	Opal
2·00	Fire Opal
1·00–1·10	Amber

Hardness Tests of Minerals and Gemstones

A number of improvements in the hardness scale and in the technique of hardness testing, which have been introduced from time to time, will now be briefly mentioned. The scale of hardness introduced by Mohs has ten grades. This scale was first enlarged to twelve grades by Breithaupt, who used the same standard minerals as Mohs (i.e. talc to diamond), and it was later extended to form a "technical scale" with fifteen grades. As it has been found that the range and precision of these hardness scales is not sufficiently great for some purposes, a test purporting to give absolute values of hardness with a quantitative significance was introduced by Auerbach and Herz. In this test the hardness of any particular mineral is measured by determining the amount of pressure which must be applied to the centre of a spherical segment of the mineral until it reaches the limit of elastic yield. A similar method evolved by Brinell is used to determine the hardness of metals and other materials where, for technical purposes, precise data of hardness are required. Finally, there is a hardness test introduced by Rosiwal-Toula, which measures the degree of abrasion suffered by a mineral when it is treated by abrasives under standard conditions. The various scales are compared in Table XIII.

Table XIII

The various scales used to show the hardness of minerals and gemstones

Mineral	*Scale after Mohs* (1–10)	*Scale after Breithaupt* (1–12)	*Scale after Auerbach*	*Technical Scale*[1] (1–15)	*Scale after Rosiwal*	*Hardness Difference*
Talc	1	1	14	1	$\frac{1}{33}$	
Gypsum or						0·22
Rock Salt	2	2	20	2	$\frac{1}{4}$	3·25
Mica	—	3	—	—	—	
Calcite	3	4	92	3	4½	0·5
Fluorspar	4	5	110	4	5	1·5
Apatite	5	6	237	5	6½	
Hornblende	—	7	—	—	—	
Feldspar						30·5
(Orthoclase)	6	8	253	6	37	
Quartz	7	9	308	7 (pure quartz-glass)	120	83
						55
Topaz	8	10	525	8 (quartz)	175	
						825
Corundum	9	11	1150	9 (topaz)	1000	
						139,000
Diamond	10	12	—	10 (garnet)	140,000	
				11 (fused zircon)		
				12 (corundum)		
				13 (silicon-carbide)		
				14 (boron carbide)		
				15 (diamond)		

[1] The "technical scale" as set out in this column tries to avoid the extremely large ranges in actual hardness between the higher grades of Mohs' Scale by introducing a number of additional grades which are more equally spaced in terms of true hardness.

In spite of the various attempts to produce a more precise hardness scale, Mohs' scale is usually quite adequate and is still generally used by mineralogists. In Table XIV the more important gemstones are arranged in order of hardness. This table brings out the fact that, with certain exceptions, such as amber, lapis, and fluorspar, gemstones are relatively hard minerals whose value is partly due to their durability and resistance to abrasion.

Table XIV

Hardness of Gemstones and Ornamental Stones according to Mohs' Scale

10·0	Diamond	6·0–6·5	Rhodonite
9·0	Corundum (=ruby, sapphire)	6·0–6·5	Prehnite
		6·0–6·5	Marcasite
8·5	Chrysoberyl (=alexandrite, cymophane)	6·25–6·35	Marialite
		6·0–6·5	Franklinite
8·0	Topaz (blue, gold, red, pink)	5·5–6·5	Scapolite
		5·5–6·5	Haematite
8·0	Spinel (ceylonite, pleonaste)	5·8–6·5	Pyrite
		5·5–6·5	Opal
7·6–8·0	Euclase	5·5–6·5	Kyanite
7·5–8·0	Phenakite	6·0	Orthoclase
7·5–8·0	Beryl (emerald, aquamarine, heliodor)	6·0	Adularia = moonstone
		5·5–6·0	Turquoise
7·0–7·5	Zircon (hyacinth, blue, brown, yellow, green red)	5·8–6·0	Sunstone (feldspar)
		5·5–6·0	Labradorite
		5·15–6·0	Lapis Lazuli
7·25–7·5	Cordierite (dichroite)	5·5–6·0	Magnetite
7·25–7·5	Pyrope garnet	5·5–6·0	Leucite
7·0–7·5	Andalusite, Chiastolite	5·8–6·0	Amazonite
7·0–7·5	Staurolite	5·5–6·0	Lazulite
7·0–7·25	Tourmaline (achroite, indicolite)	5·0–6·0	Ilmenite
		5·5–6·0	Chromite
6·5–7·5	Garnet (almandine = 7·25)	5·5–6·0	Aventurine (feldspar)
		5·0–6·0	Hypersthene
6·5–7·1	Andradite garnet	5·5–6·0	Nephrite (hornblende)
7·0	Quartz (amethyst, rock crystal, citrine, morion, smoky quartz, rose quartz, cairngorm)	5·0–6·0	Actinolite
		4·5–5·0–6·0	Diopside
		5·0–5·5	Natrolite
		5·0–5·5	Moldavite
		5·0–5·5	Limonite
6·75	Olivine (chrysolite)	3·5–5·5	Crocoite
6·5–7·0	Idocrase (=vesuvianite)	up to 5·5	Sodalite (hauyne, nosean)
6·5–7·0	Chalcedony		
6·5–7·0	Jadeite	4·8–5·0	Apatite
6·5–7·0	Hiddenite	up to 5·0	Dioptase
6·5–7·0	Kunzite (spodumene)	4·0–5·0	Bronzite
6·5–7·0	Epidote (=pistacite)	4·0–5·0	Variscite
6·5–7·0	Sillimanite	4·0–4·5	Crocidolite
6·5–7·0	Axinite	3·0–4·0	Serpentine
6·5–7·0	Obsidian	3·5–4·0	Malachite
6·0–6·5	Rutile	3·5–4·0	Fluorspar
5·5–6·5	Nephrite	2·5–4·0	Azurite
6·25–6·5	Benitoite	2·0–2·5	Amber

Optical Properties of Gemstones

Minerals are either crystalline, or without crystalline structure, in which case they are amorphous. The atoms forming a crystalline mineral are arranged in a definite pattern which determines the structure and symmetry of the crystal. There are six main crystal systems and these can be defined by the relative lengths and angular relationships of their crystallographic axes, as summarised in the following table:

Crystal System	*Axes*
1. Cubic	3 axes of equal length intersecting at right angles.
2. Tetragonal	3 axes; vertical axis of different length from the two horizontal axes; all at right angles.
3. Hexagonal	4 axes; three equal and horizontal, making angles of 120° with each other; vertical axis at right angle to the plane of the horizontal axes and of different length.
4. Orthorhombic	3 axes; all unequal and all at right angles.
5. Monoclinic	3 axes; all unequal; one axis at right angles to the vertical axis, the third set at an oblique angle to the other two.
6. Triclinic	3 axes; all unequal and none at right angles.

The crystallographic axes are shown graphically in Fig. 2 (p. 6). In a system where all three axes are unequal the vertical axis is called c, that running from left to right is b, and that running from front to back is a. In the crystal system where two or three axes are of the same length, the equal axes are all a. The angle between axes b and c is α, that between a and c is β, and that between a and b is γ.

DOUBLE REFRACTION

From the point of view of optical properties, minerals are classed as isotropic (cubic system) and anisotropic (all other crystal systems). In the case of isotropic minerals, the properties of light rays refracted by the crystal are not altered, but in the anisotropic minerals the refracted light is broken up into two rays vibrating at right angles and travelling at different velocities. The latter are thus said to be doubly refracting.

Crystals belonging to the tetragonal and hexagonal systems possess one direction in which light may travel without being doubly refracted. This is the direction of the optic axis which coincides with the axis of prismatic elongation, or c-axis, of the crystal. Such crystals are called optically uniaxial. In orthorhombic, monoclinic, and triclinic crystals there are two directions along which light is not doubly refracted, and these crystals are thus said to be optically bi-axial.

It has already been stated that the two rays produced by double refraction in anisotropic uniaxial crystals travel at different velocities, which means that they also possess different indices of refraction. The two rays, which are called the ordinary ray (ω) and the extraordinary ray (ϵ), are polarised (i.e. they vibrate) at right angles to each other. The ordinary ray vibrates in a direction at right angles to the optic axis and the extraordinary ray in a plane through the optic axis of the mineral. The difference between the refractive index (R.I.) of ϵ and ω is called the birefringence, which is constant for any given mineral. If the birefringence (i.e. R.I. of $\epsilon -$ R.I. of ω) is positive, the crystal is optically positive, and if it is negative, the crystal is optically negative.

In a crystal the light ray which travels at the smallest velocity but has the largest refractive index is termed γ, and that with the maximum velocity and minimum R.I. is termed α; $\gamma - \alpha$ is thus the measure of the birefringence. With biaxial crystals there is a third direction at which light travels at an intermediate velocity and thus has an intermediate refractive index. This third ray is termed β, and it is perpendicular to the other two. In the case of uniaxial minerals the crystal is optically negative (e.g. apatite) when the *c*-axis coincides with ϵ and α, and optically positive (e.g. quartz) when it coincides with ϵ and γ.

The optical properties of a mineral can be determined with the aid of a microscope equipped with a polariser and analyser. The determination of the refractive index and birefringence of gemstones is, however, usually carried out with the aid of a refractometer,[1] which is both accurate and simple to use. The optical properties of the more important gemstones are set out in Table XV.

Table XV

Refractive Indices of Gemstones

1. Isotropic (singly refractive) Minerals

Mineral	*Variety*	*Refractive Index*
Diamond		2·42–2·43
Garnet	*a.* Almandine	1·78–1·82
	b. Pyrope	1·74–1·75
	c. Hessonite	1·74
Spinel		1·72
Glass	(Imitation gemstones)	1·50–1·67
Opal		1·44–1·46
Fluorspar		1·43

Note: No important singly refractive (isotropic) gemstone has a refractive index falling within the range of that of glass. This is a useful feature in the detection of "paste" imitations.

[1] For a detailed description of the refractometer see B. W. Anderson, *Gem Testing*, 6th edn., London 1958.

Table XV (contd.)

2. Optically Uniaxial Minerals

Mineral	*Variety*	*Birefringence*	*Refractive Indices* ε	ω	*Optical Sign*
Smithsonite		0·200	1·618	1·818	–
Calcite		0·172	1·486	1·648	–
Zircon	Hyacinth	0·062	1·99	1·93	+
Dioptase		0·053	1·697	1·644	+
Benitoite		0·047	1·804	1·757	+
Tourmaline	many varieties	0·035	1·620	1·655	–
Tourmaline	Achroite, Dravite	0·020	1·657	1·677	–
Scapolite	Marialite	0·018	1·54	1·56	–
Phenakite		0·016	1·670	1·654	+
Corundum	Ruby, Sapphire	0·009	1·760	1·769	–
Quartz	Amethyst, Rock Crystal, Citrine	0·009	1·553	1·544	+
Beryl	Emerald, Aquamarine	0·006	1·575	1·581	–
Idocrase		0·005	1·716	1·721	–

3. Optically Biaxial Minerals

Mineral	*Variety*	*Birefringence*	*Refractive Indices* α	γ	*Optical Sign*
Crocoite		0·370	2·29	2·66	+
Realgar		0·150	2·46	2·61	–
Sphene		0·134	1·90	2·034	+
Epidote	Pistacite	0·039	1·729	1·768	–
Olivine	Chrysolite, Peridot	0·036	1·661	1·697	+
Pyroxene	Diallage	0·029	1·650	1·679	+
Spodumene	Kunzite	0·016	1·660	1·676	+
Andalusite		0·011	1·632	1·643	–
Chrysoberyl	Alexandrite	0·009	1·747	1·756	+
Cordierite	Dichroite	0·009	1·590	1·599	±
Topaz		0·008	1·619	1·627	+

Note: The above figures may vary slightly in accordance with variations in the chemical composition of the mineral. The optical sign, and even the number of optic axes, may vary in exceptional cases.

DICHROISM

Coloured minerals which are not isotropic may be dichroic, that is they may appear in slightly or completely different colours when seen from different directions. Dichroism is due to the fact that the colours are absorbed to an unequal extent in the two vibration directions of the mineral which therefore appears to be of different shades when viewed from different angles. In the case of optically biaxial minerals, colours may be unequally absorbed along all three vibration directions and three distinct tints or colours may be produced. This latter property is known as pleochroism (many colours).

Dichroism or pleochroism is best seen in polarised light, either with a polarising microscope or with a dichroscope. With a microscope the colour changes in the mineral under examination are seen when the lower polar (polariser) is rotated. During this procedure the upper polar (analyser) is not in position. In the dichroscope two of the colours can be seen side by side at the same time. The latter instrument consists of a tube with a square window at one end and a lens or eyepiece at the other. The tube contains a cleavage rhomb of calcite mounted in such a way that it causes two images of the window to appear side by side when viewed through the eyepiece. The light forming the two images is vibrating in two planes at right angles to each other, one plane for each image. Thus, when a coloured mineral is placed in front of the window, the light from the two polarised rays of the stone is separated and the two colours can be seen in adjacent images.

Table XVI

Dichroism of Gemstones

I

The following examples show the use that can be made of dichroism in distinguishing between otherwise similar minerals:

Blue Stones

Dichroism helps to distinguish sapphire from kyanite, which it resembles in appearance. When the dichroscope shows a blue and a colourless or yellowish image, the stone is a sapphire; but when it produces two bluish images, one paler than the other, the stone is the optically biaxial kyanite. In a similar way, blue tourmaline with marked dichroism can be distinguished from blue spinel which is not dichroic.

Green Stones

If the two images are green and yellowish-green, the stone is an emerald, but if they are pale brown and dark green, it is a tourmaline.

Red Stones

If of the two images in the dichroscope one is red and the other violet, the stone is a ruby, but if the two images are of identical shades of red it is the less valuable red spinel. When the gemstone under observation produces one image with pale pink and deep red colour contrasts and the other of reddish-violet colour, it is a red tourmaline called rubellite, which is also less valuable than a ruby. Similarly, it is possible to distinguish a red garnet (almandine) from ruby by the absence of pleochroism in the former, which, like spinel, belongs to the cubic system.

II

In order to enable the reader to distinguish gemstones by their dichroism, the most common colour ranges of the more important stones are given here.

Red Stones

a. Pleochroic: Corundum (ruby), pale and dark red; tourmaline, pink and dark red; zircon, red and reddish.

b. Non-pleochroic: Spinel, almandine-garnet; opal (fire-opal); diamond.

Pink to Carmine Stones

a. Pleochroic: Topaz, violet and yellowish red; spodumene (kunzite), pink and lilac; corundum (ruby), pale and dark red; tourmaline, pinkish red and yellowish; beryl, golden yellow and yellow; zircon, red and reddish (poor).

b. Non-pleochroic: Spinel; diamond.

Red-Brown to Brown Stones

a. Pleochroic: Topaz, yellowish red and brown; tourmaline, pale and dark brown; axinite, brown and green; andalusite, deep red and olive green; zircon, reddish and yellowish; staurolite, red and yellowish; smoky quartz, dark and pale brown; idocrase, brownish and reddish.

b. Non-pleochroic: Diamond; fire-opal; garnet (hessonite).

Yellow Stones

a. Pleochroic: Golden beryl (heliodor), golden yellow and yellowish green; topaz, pale and dark yellow; tourmaline, pale and dark yellow; quartz (citrine), very weak pleochroism; corundum, yellow, very weak pl.; zircon, weak pl.

b. Non-pleochroic: Diamond only.

Yellowish-Green Stones

a. Pleochroic: Epidote, green-yellow-brown; tourmaline, yellow and green; andalusite, yellow and green; topaz, pale yellow and pale green; spodumene (hiddenite), pale and dark green; beryl (aquamarine), pale bluish and yellowish green; chrysoberyl, yellowish and greenish; chrysolite, green and yellowish green; zircon, very weak pl.

b. Non-pleochroic: Garnet (demantoid).

Green Stones

a. Pleochroic: Chrysoberyl (alexandrite), dark green and yellowish red; tourmaline, yellow and green; epidote, green-yellow-brown; olivine (peridot and chrysolite), green and yellowish green; andalusite, yellow-green-red; spodumene (hiddenite), pale and dark green; green corundum, green and brown; beryl (emerald), dark green and bluish green; idocrase, green and yellow; zircon, very weak pl.

b. Non-pleochroic: Diamond; andradite-garnet (demantoid).

Greenish-Blue Stones

a. Pleochroic: Benitoite, bluish and colourless; kyanite, dark and pale blue; tourmaline (indicolite), bluish green and yellowish; blue topaz, greenish blue and colourless; beryl (aquamarine), bluish and yellowish; corundum (sapphire), poor pl.

b. Non-pleochroic: none.

Blue Stones

a. Pleochroic: Benitoite, blue and colourless; cordierite (dichroite), yellow and bluish; tourmaline (indicolite), dark and pale blue; corundum (sapphire), dark and greenish blue; kyanite, dark and pale blue.

b. Non-pleochroic: Spinel (gahnospinel); diamond.

Pale Blue Stones

a. Pleochroic: Cordierite, yellow and bluish; benitoite, blue and colourless; topaz, pale blue-green and pale pink; beryl (aquamarine), azure blue and yellowish green; kyanite, dark and pale blue; tourmaline (indicolite), dark and pale blue; corundum (sapphire), dark and greenish blue.

b. Non-pleochroic: Spinel (gahnospinel); diamond.

Violet Stones

a. Pleochroic: Benitoite, blue and colourless; axinite, brownish and greenish; violet corundum, violet and pale red; spodumene (kunzite), lilac and pale pink; quartz (amethyst), very poor pl.

b. Non-pleochroic: Almandine-Garnet: spinel.

Gemstones can be classed, according to the way in which they refract light, into the following groups:

A. *Single Refracting (Isotropic) Gemstones*

All of these, except obsidian, chalcedony and opal, which are amorphous, belong to the cubic system. These stones are not pleochroic, and show no variation in colour when viewed through the dichroscope.

a. All varieties of *Garnet*, e.g. purplish red = almandine; reddish brown = spessartite; jade green or greenish grey = grossularite; orange to red-brown = "hyacinth" garnet; brown = andradite; yellowish green to green = demantoid; olive green = "olivine" garnet; emerald green = uvarovite; and black = melanite.

b. All varieties of *Spinel*, i.e. red = "almandine spinel"; pink = "balas ruby"; dark red = "ceylonite"; rose spinel or rubicelle; carmine spinel or rubin-spinel.

c. All coloured and colourless varieties of *diamond.*

d. *Fluorite*, colourless, white, blue, amethyst, yellow, or green.

e. *Obsidian*, a natural glass, coloured black, grey, red, green, or mottled.

f. *Opal* and *Chalcedony*, amorphous varieties of silica (opal is hydrated).

B. *Double Refracting, or Birefringent Gemstones*

These stones are dichroic, and produce the variations in colour shown in Table XVI.

1. *Optically uniaxial stones with negative birefringence*

a. All varieties of *Tourmaline*, including colourless achroite, red rubellite, indigo-blue indicolite, violet-red siberite, brown dravite, green tourmaline, and black schorl.

b. All varieties of *Beryl*, including emerald (green), aquamarine (pale blue), golden beryl or heliodor, and pink beryl or morganite.

c. *Corundum*, which includes ruby (red), sapphire (blue), and such varieties as violet sapphire, star sapphire, olive-green corundum (="oriental chrysolite"), white sapphire or white corundum, green corundum (="oriental emerald"), and yellow sapphire (="oriental topaz").

d. *Idocrase* (=vesuvianite), usually transparent brown, yellow or green, including also the massive green semi-opaque variety called californite.

2. *Optically uniaxial stones with positive birefringence*

a. All gemstone varieties of *quartz* such as amethyst (purple), cairngorm (brown), morion (smoky brown), and citrine (yellow).

b. The red-brown *zircon* called hyacinth.

3. *Optically biaxial gemstones include the following*

a. *Topaz* and all its varieties.

b. *Chrysoberyl*, e.g. alexandrite.

c. *Staurolite* (brown to red-brown and orange).

d. *Spodumene*, including kunzite (pink) and hiddenite (green).

e. *Axinite*, which is clove brown, grey, or violet in colour.

f. *Kyanite*, whose basic colour is blue (dark azure-blue to bluish-green).

g. *Andalusite*, coloured olive-green to deep red.

h. *Cordierite* (=dichroite or iolite), usually coloured smoky-blue to indigo with marked pleochroism.

i. *Chrysolite* (yellowish green) and *Peridot* (olive green), varieties of olivine.

j. *Moonstone*, a variety of feldspar with blue to silver schiller lustre.

k. *Epidote*, or pistacite, with a yellowish-green shade similar to that of the pistachio nut.

DISPERSION

The so-called "fire" of the diamond or zircon is due to the dispersion of light in the gemstone. Light is dispersed by all transparent solid and liquid substances, and the greater the dispersion the more colourful and "fiery" is the light emitted by these. Dispersion is caused by the difference in the refractive index of the mineral for light of different wavelengths, red light being refracted less than violet light. As the amount of dispersion is a constant and measurable property of any mineral, it can be expressed quantitatively as the difference in the refractive index of light (within the dispersing medium) in the red part (6870 Å) and that of light in the violet part (4308 Å) of the spectrum. The bands chosen for this purpose correspond to the Fraunhofer lines B and G of the solar spectrum. The dispersion values of some gemstones are given in Table XVII.

PLATE XI GEMSTONES: 1 – Blue

1st Row: 1. Aquamarine, Brazil; 2. Chalcedony, S.W. Africa; 3. Turquoise matrix, Iran; *2nd Row*: 4. Aquamarine, Brazil; 5. Zircon, Thailand; *3rd Row*: 6. Sapphire, Kashmir; 7. Spinel, Ceylon; 8. Cordierite, Ceylon; *4th Row*: 9. Lapis Lazuli, Afghanistan; 10. Amethyst, Brazil; 11. Tourmaline, Brazil; *Extreme right*: 12. Tourmaline, Brazil.

Table XVII

Colour Dispersion of Gemstones (B – G)

Mineral	*Variety*	*Amount*
arnet	Demantoid	0·057
phene	—	0·051
iamond	—	0·044
ircon	Hyacinth	0·038
pidote	Pistacite, Piedmondite, Manganese-epidote	0·028
arnet	Hessonite	0·028
	Pyrope	0·027
	Almandine	0·024
enitoite	—	0·022
livine	Peridot, Chrysolite	0·020
capolite	Marialite, Meionite	0·020
pinel	Transparent varieties	0·020
orundum	Ruby and Sapphire	0·018
yroxene group	Spodumene	0·017
ourmaline	Achroite, Dravite, Indicolite, Rubellite	0·017

Mineral	*Variety*	*Amount*
Pyroxene group	Diopside	0·016
Axinite	—	0·015
Chrysoberyl	Alexandrite, Chrysoberyl	0·015
Beryl	Emerald, Aquamarine, Morganite, Golden Beryl	0·014
Dioptase	"Copper Emerald"	0·014
Cordierite	Dichroite	0·014
Phenakite	—	0·014
Andalusite	—	0·013
Euclase	—	0·013
Quartz	Amethyst, Citrine, Rock Crystal, Cairngorm, Smoky Quartz	0·013
Feldspar	Moonstone	0·012
Fluorspar	—	0·010

Absorption Spectra of Important Gemstones[1]

In the earlier German editions of this book the description of the use of the spectroscope was purposely omitted as this was usually considered an advanced instrument beyond the scope of the beginner. Small spectroscopes, which are not expensive, are, however, being increasingly used by jewellers, and as their use provides a precise and rapid method of identifying many gemstones, no apology is necessary for this account. By means of spectroscopic analysis it is possible to distinguish quite definitely between such minerals as ruby, red tourmaline, garnet, and spinel which have external colour resemblances.

Two types of instrument are used for spectroscopic work. The first is a simple pocket spectroscope which consists of a tube containing either a diffraction grating or a three-component prism by means of

[1] After B. W. Anderson (1958). See Bibliography.

which a beam of light is resolved into its component wavelengths. The light enters the instrument by a slit, in front of which the gemstone to be examined is placed, and the absorption lines can be seen and read off on a graduated scale through the ocular. This simple instrument is only good enough for rough qualitative tests, for which it has proved very valuable. To obtain more precise data it is necessary to use a spectroscope which has a scale of wavelengths and produces a wide spectral separation. Such an instrument is capable of giving very accurate readings. If such results are to be obtained, it is, however, essential to be well versed in the theory and technique of its use, and the prospective user is advised to consult B. W. Anderson's book *Gem Testing*.

A brief account of the theory of absorption spectra is given below.

First, a few remarks about the laws governing the behaviour of light. The term "absorption of light" usually implies a weakening of the intensity of light as it passes from one medium into another (e.g. from air into a transparent mineral). Now when a beam of white light passes through a glass prism whose surface it strikes at an oblique angle, it is bent (i.e. refracted) both when entering and leaving the prism. During this process of refraction the white light is resolved into its component wavelengths by dispersion. The emitted light thus consists of a wide band of colour in which the six spectral colours – red, orange, yellow, green, blue, and violet – are seen. A band of light containing all six basic colours is called a spectrum, which, as we have seen, is produced by the dispersion of white light, and from which, conversely, white light can be produced.

The various colours of the spectrum have different wavelengths and each shade of colour can be precisely defined by its wavelength, which is measured in Ångström units (abbreviated Å), where 1 Å is ·0000001 millimeters. The range of the wavelengths of the spectral colours is as follows:

Red	7800 Å – 6400 Å	Green	5700 Å – 5000 Å
Orange	6400 Å – 5950 Å	Blue	5000 Å – 4500 Å
Yellow	5950 Å – 5700 Å	Violet	4500 Å – 3800 Å

When white light passes through a colourless stone, all wavelengths of the incident light are reduced in intensity, and the light passing out of the crystal is again white light, though with a somewhat reduced order of brightness. The situation is quite different when white light is passed through a coloured stone. For when light transmitted by the latter is dispersed by a prism or grating to produce a spectrum, the spectrum is seen to contain dark lines or even complete gaps in certain colour ranges. Such an incomplete spectrum is known as an absorption spectrum, as it shows the wavelengths of light which are completely or partially absorbed during their passage through the stone. The number

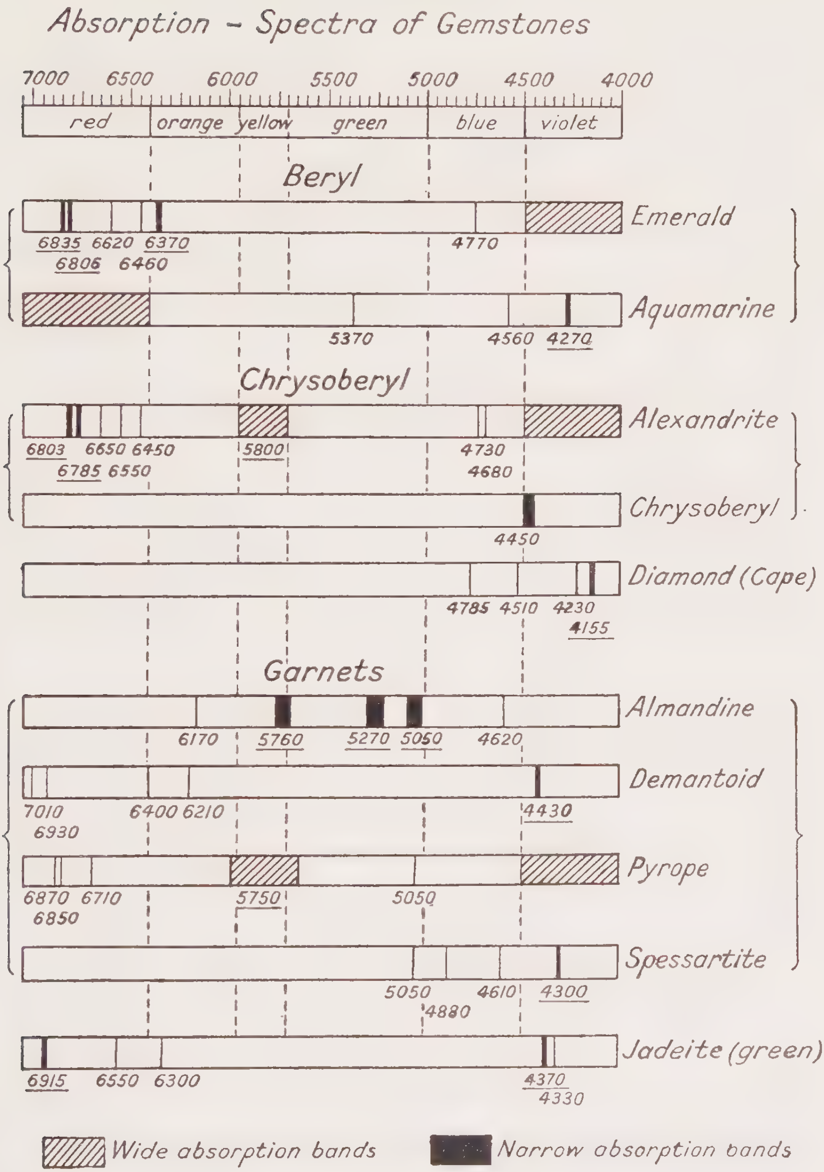
Absorption - Spectra of Gemstones
7000 6500 6000 5500 5000 4500 4000
red orange yellow green blue violet
Beryl
Emerald
6835 6620 6370
6806 6460
4770
Aquamarine
5370
4560 4270
Chrysoberyl
Alexandrite
6803 6650 6450
6785 6550
5800
4730
4680
Chrysoberyl
4450
Diamond (Cape)
4785 4510 4230
4155
Garnets
Almandine
6170 5760 5270 5050 4620
Demantoid
7010
6930
6400 6210
4430
Pyrope
6870 6710
6850
5750
5050
Spessartite
5050
4880
4610 4300
Jadeite (green)
6915 6550 6300
4370
4330
Wide absorption bands
Narrow absorption bands

Fig. 6

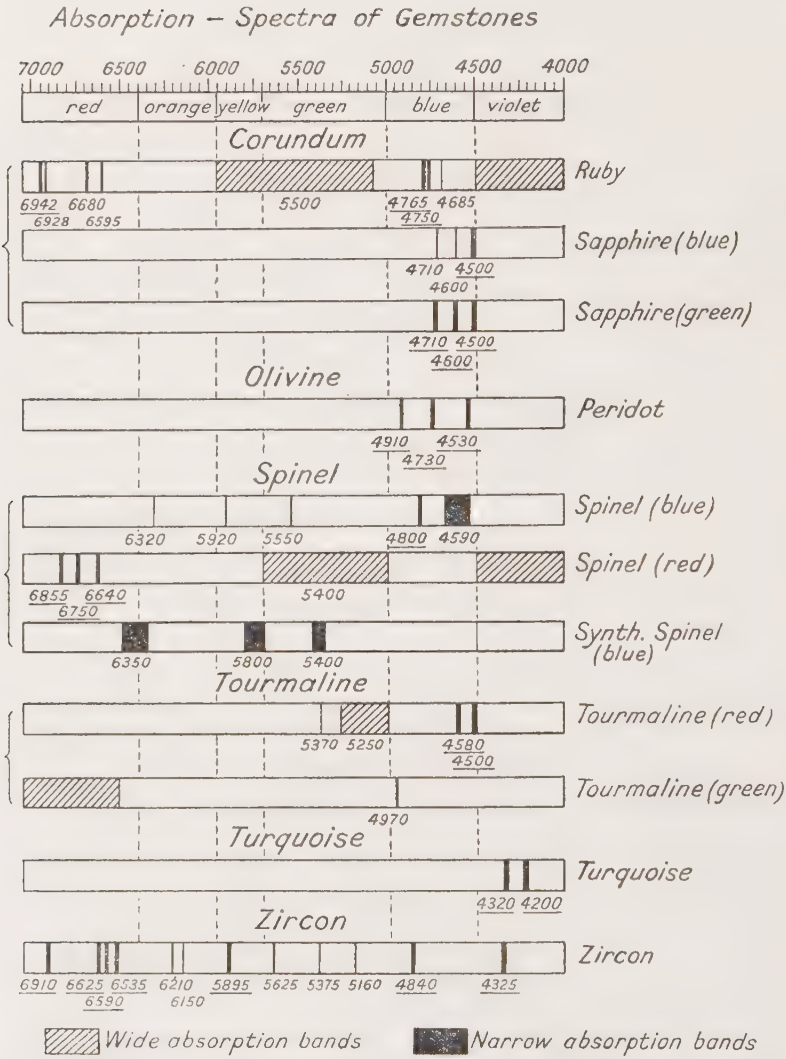

Fig. 7

and range of wavelengths absorbed by any particular crystal is a characteristic feature of that mineral; or, to put it in another way, absorption lines and bands provide an unerring way of identifying a gemstone. This statement has to be qualified with the provisos, (*a*) that the external colouration of the stone, as seen by the eye, is uniform and (*b*) that the specimen is undamaged. If these conditions are fulfilled the method is the most foolproof means of identification available, as the absorption bands of different minerals occur in widely different portions of the spectrum and mistakes are practically impossible. The following examples will illustrate this point. A deep red stone may be a pyrope garnet, a tourmaline, spinel, or ruby. Pyrope, the deep red garnet, and red spinel have many properties which are at least superficially similar and may cause some difficulties in their identification. If the two stones are, however, examined by spectroscope, it becomes a very simple matter to distinguish between them, as red spinel has a wide and unmistakable absorption band extending through practically the entire green part of the spectrum from 5000 Å to 5700 Å (red spinel only), whereas pyrope garnet produces a marked absorption band in the yellow range of the spectrum between 5650 Å and 5950 Å. Two other red stones which are not readily distinguished by ordinary means are red almandine and red spinel. The first has two wide and well-defined absorption bands at 5050 Å and 5270 Å in the green part of the spectrum, leaving the remainder of the green range clearly visible; so there is no chance of confusion with the absorption spectrum of spinel, in which the whole of the green range is completely extinguished.

The absorption spectra of certain gemstones are shown schematically on the accompanying diagrams (Figs. 6 and 7), which have been drawn from data given in B. W. Anderson's book (pp. 110-11) to which the student is again referred.

The Inclusions in Gemstones and their Use as Additional Evidence in Identification

It has long been known that nearly all gemstones, even the purest and most expensive, contain inclusions, but these have until recently not received sufficient attention. As they are practically invisible to the naked eye they have not affected the commercial value of the gemstones and have therefore not been deeply investigated. During the last two decades, however, the study of mineral inclusions has developed into an important branch of the science of gemmology, and has now many interesting and valuable applications.

The inclusions can be examined with any simple microscope which provides low or medium magnification. In the case of many gemstones the inclusions provide certain clues as to the mode of origin of the stones. In the same way as fossils can often tell us the exact age of the formation in which they are found and can thus be used as markers in the search for economically valuable deposits such as oil or coal, the study of diagnostic inclusions can tell the expert gemmologist if a stone – say, a "Montana sapphire" – is natural or synthetic in origin. The inclusions are so characteristic that mistakes are practically impossible. The author's long experience of this work, during which very high magnifications were sometimes employed, has shown him that for all practical purposes inclusions can be studied with magnifications as low as ×20 to ×75, and only very rarely are magnifications as high as ×100 to ×175 required. A simple student's microscope is therefore perfectly adequate for this study.

What is the nature of the inclusions? They may be composed of the same material as the host mineral, or of quite unrelated substances; they may be solid or liquid or even partially gaseous. The substances were enclosed by the crystal during its growth, and can therefore give us some clues about the phases in the development of the crystal. They also help us to distinguish between internal structures of the mineral which were formed by segregation during crystal growth, and those formed by recrystallisation after the mineral itself had crystallised. Original or later-formed cavities, structural anomalies, and other abnormalities which may be indications of earlier phases of crystal growth, as well as all sorts of cracks in the crystal, may be classed with the inclusions. We can thus draw various conclusions about the development of the crystal before and after its solidification, and can distinguish three types of inclusions according to when they were formed in relation to the growth of the crystal, as follows:

a. Pre-existing inclusions, which were already present as completely formed objects before crystallisation commenced.

b. Contemporaneous inclusions, which were formed while crystallisation of the host mineral was taking place.

c. Subsequent inclusions, among which can be classed the various infillings of cracks. If for some reason cracks arise in the crystal during its formation, they may be filled with the residual liquid from the parent fluid. The original cracks can then only be recognised by the presence of small pockets of liquid inclusions.

The study of the age relationships between inclusions and crystals is more the concern of the mineralogists and the geochemists who are working on phases in the crystallisation of rock melts. For those concerned with the simple determination of gemstones it is sufficient to be able to differentiate between solid, liquid, and gaseous inclusions and to recognise their distinctive characteristics.

1. *The Gaseous Inclusions* are of particular importance in the identification of a natural gemstone, as it is commonly found that these are not in direct contact with the crystal, but occur as bubbles within a liquid inclusion. The presence of liquid inclusions in which there are gas bubbles is thus an excellent criterion for distinguishing a natural stone from a synthetic one. There are, however, certain exceptions, especially among the natural glasses: but the gas bubbles in obsidian or moldavite can be fairly readily distinguished by their appearance from those of artificial glasses. The artificial glasses have either large needle-shaped or flag-like inclusions of gas, and occasionally the gas inclusions occur as cloud-like forms, resembling the cirrus clouds of

meteorology. A solitary exception among the precious stones is the diamond, which contains minute bubbles or needle-shaped inclusions of gas barely visible under a microscope and often closely associated with dense cloud structures. These gas inclusions usually cause slight distortions and cracks in their immediate vicinity, which can be easily recognised when examined under polarised light.

2. *The Liquid Inclusions* are even more diagnostic than the gaseous ones, for, with the exception of synthetic emerald, they occur exclusively in natural crystals. These liquid inclusions are very variable in appearance, and they may occur in a large number of different shapes. They are most commonly small residual portions of the solution from which the stone crystallised, but they may also consist of water and sometimes of liquid carbon dioxide. The liquid inclusions originated in cavities which appeared during the growth of the crystal and which were never subsequently completely obliterated. Cracks and infillings of cleavages are examples. Quite often liquid inclusions have the exact shape of a particular crystal and are then called "negative" crystals. By rotating the crystal on the microscope stage, it may frequently be seen that a liquid inclusion contains several immiscible liquids whose boundaries appear as fine lines. An inclusion consisting of a single liquid has only one prominent black boundary. If particularly large drop-like inclusions are present, as is the case with beryls and sapphires (Ceylon sapphire), it is common to find two or three distinct liquids. Often inclusions occur as minute droplets arranged in linear patterns, which always follow certain planes of weakness such as cleavage planes, growth planes, or tension cracks within the crystal. Frequently a crack is healed up so that the linear pattern of inclusions can no longer be seen, and the original plane can only be recognised by a faint line which runs along a structural plane in the crystal.

3. *The Solid Inclusions* can be divided into those composed of the same material as the crystal and those composed of quite unrelated material. They may have been enclosed during the growth of the crystal or they may have crystallised out from the mother liquor at the same time as the crystal. The inclusions of unrelated materials may be of use in identifying natural stones, and their shapes, though often imperfect and broken, may make the actual identification of the included mineral possible. Unrelated minerals which were included during crystal formation were formed earlier than the host crystal, and their orientation thus bears no relation to the structural lines of the latter. The case is quite different with included crystals which were formed from the same mother liquor as the host mineral; their orientation is always closely related to the directional trends of the host's crystal lattice.

It has been stated that many gemstones contain inclusions which possess definite crystalline shapes and are recognisable as belonging to minerals other than the host. The following list names the minerals which are known to occur as inclusions, and gives the shapes in which they are usually found:

Actinolite: elongated prisms.
Anatase: well-developed crystals (p. 53).
Asbestos: long fibres.
Augite: well-developed crystals (p. 85).
Calcite: well-developed rhombohedra (p. 105).
Corundum: well-developed crystals (p. 43).
Diamond: good crystals (p. 119).
Diopside: rounded crystals.
Garnet: rounded crystals.
Haematite: plates and small rosettes.
Hornblende: well-developed crystals (p. 83).
Ilmenite: small plates and bushy rosettes.
Magnetite: well-developed octahedra.
Mica: small plates or "books" of biotite, muscovite, and fuchsite.
Pyrites: well-developed but very small crystals.
Quartz: typical well-developed quartz crystals (p. 117).
Rutile: typical fine rutile needles, usually orientated in the direction of the *c*-axis of the host.
Sillimanite: good crystal shapes.
Tourmaline: well-developed crystals.
Zircon: clearly developed crystals (p. 63).

Of particular interest is the fact that the needles of rutile are characteristic inclusions in corundum, and the star structure of star rubies and star sapphires is due to the presence of minute rutile needles. Rutile needles may also be present in quartz, where they occur as bushels, often visible to the naked eye. As inclusions of rutile are radioactive they can impart a measurable radioactivity to the host crystal, and this may be used as a test for the authenticity of a corundum. Radioactivity can further be used to narrow down the original source of the corundum, as only certain deposits are known to be radioactive, whereas others are completely inert.

Apart from the inclusions whose shapes can be seen, there are also diffuse inclusions which appear as a general cloudiness in the stone. These are almost characteristic of such gemstones as corundum (Siam ruby), sapphire, the garnet hessonite, the quartzes citrine and amethyst, and emerald. They are also common in fluorite.

Traces of irregular growth, which produces zoning, are commonly seen in the corundums and zircons, sometimes in the beryls, and very occasionally in the tourmalines. Other abnormalities of growth, such as twinning, either simple or repeated, occur in some crystals; and twinning is quite common in diamond, corundum (especially ruby), and moonstone.


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GEMSTONE IDENTIFICATION TABLE

1. TRANSPARENT GEMSTONES AND ORNAMENTAL STONES

OLOURLESS, CLEAR

ame as Gemstone	*Name as Mineral*	*S.G.*	*Hardness (Mohs' Scale)*	*R.I.*	*Chemical Formula*
.chroite	Tourmaline	2·94–3·1	7–7·5	1·62–1·66	complex boro-silicate
.dularia (Moonstone)	Feldspar (Orthoclase)	2·50–2·6	6–6·5	1·52–1·53	$K[AlSi_3O_8]$
.patite	Apatite	3·2	5	1·63–1·64	$Ca_5[(F,OH,Cl)\|(PO_4)_3]$
eryl	Beryl	2·63–2·76	7·5–8	1·56–1·58	$Al_2Be_3[Si_6O_{18}]$
eryllonite	Beryllonite	2·85	5·5–6	1·55–1·58	$NaBe[PO_4]$
anburite	Danburite	2·97–3·02	7	1·63	$Ca[B_2Si_2O_8]$
iamond	Diamond	3·52	10	2·41–2·42	C
uclase	Euclase	3·09–3·1	7·5–8	1·65–1·7	$Al(OHBeSiO_4)$
rossular	Garnet	3·5	6–7·5	1·74	$Ca_3Al_2[SiO_4]_3$
yalite	Opal	2·2	5–6·5	1·44–1·45	hydrated SiO_2
Jargoon"	Zircon	4·20–4·65	7·5	1·92–1·98	$Zr[SiO_4]$
eucite	Leucite	2·45–2·5	5·5–6	1·508	$K[AlSi_2O_6]$
arialite	Scapolite	2·64–2·66	6·25–6·5	1·54–1·55	$Na_4(Al_3Cl)Si_9O_{24}$
onticellite	Monticellite	3·10–3·25	5–5·5	1·79–1·84	$CaMg[SiO_4]$
oonstone	Feldspar (Orthoclase)	2·54–2·56	6–6·5	1·52–1·525	$K[AlSi_3O_8]$
atrolite	Natrolite	2·20–2·25	5–5·5	1·48–1·49	$Na_2[Al_2Si_3O_{10}].2H_2O$
ligoclase	Feldspar (Oligoclase)	2·6	6–6·5	1·54–1·55	mixture of albite and anorthite
henakite	Phenakite	2·96–3·0	7·5–8	1·65–1·67	$Be_2[SiO_4]$
ock Crystal	Quartz	2·64–2·66	7	1·54–1·55	SiO_2
illimanite	Sillimanite	3·23–3·24	6·5–7	1·63–1·65	$(Al,O)AlSiO_5$
pinel	Spinel	3·52–4	8	1·72	$MgO.Al_2O_3$
podumene	Pyroxene (Spodumene)	3·2	6·5–7	1·66–1·67	$AlLi[Si_2O_6]$
opaz	Topaz	3·56–3·6	8	1·62–1·63	$Al_2[SiO_4\|F_2]$
ourmaline	Tourmaline	3·08–3·10	7·5	1·61–1·64	complex boro-silicate
hite Corundum	Corundum	3·98–4·0	9	1·76–1·77	Al_2O_3
ircon ("Matura diamond")	Zircon	4·0–4·3	7·5	1·93–1·99	$Zr(SiO_4)$
unyite	Zunyite	2·88	7	1·59	$[Al(OH,F,Cl)_2]_6 Al_2(SiO_4)_3$

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lmandine	Garnet	3·70–4·20	7·25–7·5	1·78–1·83	$Fe^{\cdot\cdot}{}_3Al_2[SiO_4]_3$
mber	Amber	1·05–1·09	2–2·5	1·54	organic
natase	Anatase	3·82–3·95	5–6	2·48–2·56	TiO_2
patite	Apatite	3·17–3·23	5	1·63–1·65	$Ca_5[(F,OH,Cl)\|(PO_4)_3$
eryl	Beryl	2·64–2·67	7·5	1·58–1·59	$Al_2Be_3[Si_6O_{18}]$
itrine	Quartz	2·65–2·69	7	1·54–1·55	SiO_2
iamond	Diamond	3·32–3·54	10	2·41–2·42	C
re Opal	Opal	2·10–2·2	5·5–6	1·44	hydrated SiO_2

op. = opaque, trl. = translucent, trp. = transparent

PLATE XII GEMSTONES: 2 – Red

1st Row: 1. Corundum, Tanganyika; 2. Coral, Italy; *2nd Row*: 3. Ruby, Thailand; 4. Carnelian, Brazil; 5. Spinel, Ceylon; 6. Garnet (uncut), India; 7. Garnet, India; *3rd Row*: 8. Jasper, India; 9. Coral, Italy; *Above*: 10. Fire Opal, Mexico; 11. Rose Quartz, Brazil; 12. Tourmaline, Brazil; *Below*: 13. Jasper, India; 14. Kunzite, Brazil; *Below*: 15. (concentrically banded) Rhodochrosite, Argentine; 16. (columnar) Tourmaline, Mozambique; *Bottom Row*: 17. Rose Quartz, Brazil; 18. Tourmaline (cross section), Brazil; 19. Rhodochrosite, Argentine.

Name as Gemstone	*Name as Mineral*	*S.G.*	*Hardness (Mohs' Scale)*	*R.I.*	*Chemical Formula*
Fluorite	Fluorspar	3·01–3·25	4	1·43	CaF_2
Grossular	Garnet	3·5–3·7	6·5–7	1·77–1·81	$Ca_3Al_2[SiO_4]_3$
Hessonite	Garnet	3·65–3·9	7·25	1·75–1·77	$(FeCa)_3Al_2[SiO_4]_3$
Kunzite	Spodumene (Kunzite)	3·2	6·5–7	1·66–1·67	$LiAl(Si_2O_6)$
Morganite (Pink Beryl)	Beryl	2·8–2·87	7·5	1·58–1·59	$Al_2Be_3[Si_6O_{18}]$
Pink Topaz	Topaz	3·53–3·54	8	1·6–1·63	$Al_2[SiO_4\|F_2]$
Pyrope	Garnet	3·65–3·90	7·25	1·75–1·77	$Mg_3Al_2[SiO_4]_3$
Realgar	Realgar	3·5–3·6	1·5–2	2·46–2·61	AsS
Red Spinel	Spinel	3·53–3·56	8	1·72	$MgO.Al_2O_3$
Red Topaz	Topaz	3·53–3·55	8	1·6–1·61	$Al_2[SiO_4\|F_2]$
Red Zircon	Zircon	4·00–4·63	7·5	1·92–1·98	$Zr[SiO_4]$
Rhodonite	Rhodonite	3·5–3·67	6–6·5	1·66–1·67	$Mn[SiO_3]$
Rose Quartz	Quartz	2·6–2·7	7	1·54–1·55	SiO_2
Ruby	Corundum	3·9–4·14	9	1·76–1·77	Al_2O_3
Spessartite	Garnet	4·0–4·3	7·5	1·79–1·82	$Mn_3Al_2[SiO_4]_3$
Sphene	Sphene	3·4–3·6	5–5·5	1·92–2·05	$CaTi[SiO_4\|O]$
Staurolite	Staurolite	3·65–3·78	7–7·5	1·63–1·65	$[Al_4(SiO_4)]_2\cdot[Fe^{\cdot\cdot}O_2(OH)_2]$
Thulite	Zoisite	3·45–3·48	6–7	1·75–1·78	$Ca_2(Al,Fe^{\cdot\cdot\cdot})_3[OH(SiO_4)_3]$
Topaz	Topaz	3·53–3·55	8	1·6–1·63	$Al_2[SiO_4\|F_2]$
Tourmaline (Rubellite)	Tourmaline	3·09–3·15	7–7·25	1·62–1·65	complex boro-silicate
Vesuvianite	Idocrase	3·35–3·50	6·5	1·71–1·72	$Ca_{10}[(MgFe)_2\|Al_4][Si_9O_{34}](OH)_4$
Zircon	Zircon	4·0–4·65	7·5	1·92–1·98	$Zr[SiO_4]$
BLUE					
Apatite	Apatite	3·15–3·23	5	1·63–1·65	$Ca_5[(F,OH,Cl)\|(PO_4)_3]$
Aquamarine	Beryl	2·67–2·71	7·25–7·5	1·57–1·58	$Al_2Be_3[Si_6O_{18}]$
Axinite	Axinite	3·27–3·29	6·5–7	1·67–1·68	$Ca_2(Mn,Fe)Al_2BH(SiO_4)_4$
Benitoite	Benitoite	3·64–3·67	6–6·5	1·75–1·8	$BaTi[Si_3O_9]$
Beryl	Beryl, see Aquamarine, Morganite, Emerald, Heliodor.				
Blue Spinel	Spinel	3·65–3·72	8	1·72	$MgO.Al_2O_3$
Blue Topaz	Topaz	3·5–3·52	8	1·6–1·62	$Al_2[SiO_4\|F_2]$
Blue Zircon	Zircon	4·6–4·7	7·5	1·92–1·98	$Zr[SiO_4]$
Cordierite (Iolite)	Cordierite	2·57–2·66	7–7·5	1·54–1·55	$Mg_2Al_4[Si_5O_{18}]$
Cyprine	Idocrase	3·3–3·5	6·5	1·71–1·72	$Ca_{10}[(Mg,Fe)_2\|Al_4][Si_9O_{34}](OH)_4$
Diamond	Diamond	3·32–3·54	10	2·41–2·42	C
Dumortierite	Dumortierite	3·24–3·28	7	1·66–1·68	$Al_8BSi_3(OH)O_{19}$
Euclase	Euclase	3·1–3·13	7·5–8	1·64–1·67	$Al(OHBeSiO_4)$
Fire Opal	Opal	2·005	5·5	1·44	hydrated SiO_2
Fluorite	Fluorspar	3·01–3·25	4	1·43	CaF_2
Hauyne	Sodalite	2·28–2·35	5·5	1·49	$(CaNa)_{4-8}(SiAlO_4)_6(SO_4)_2$

op. = opaque, trl. = translucent, trp. = transparent

ame as Gemstone	Name as Mineral	S.G.	Hardness (Mohs' Scale)	R.I.	Chemical Formula
ndicolite	Tourmaline	3·1–3·12	7·5	1·62–1·64	complex boro-silicate
yanite	Kyanite	3·56–3·67	4–7	1·71–1·73	$Al_2[O\|SiO_4]$
azulite	Lazulite	2·96–3·09	5–6	1·6–1·64	$(Fe,Mg)Al_2[OH\|PO_4]_2$
Ioonstone	Feldspar (Orthoclase)	2·54–2·56	6–6·5	1·52–1·525	$K[AlSi_3O_8]$
apphire	Corundum	4·01–4·09	9	1·76–1·77	Al_2O_3
mithsonite	Smithsonite	4·3	4·5	1·81–1·84	$Zn[CO_3]$
aafite (lilac, mauve)	Taafite	3·60–3·61	8	1·717–1·723	$Be_4Mg_4Al_{16}O_{32}$
esuvianite, see Cyprine					
opaz, Blue	Topaz	3·5–3·52	8	1·6–1·62	$Al_2[SiO_4\|F_2]$
ircon, Blue	Zircon	4·6–4·7	7·5	1·92–1·98	$Zr[SiO_4]$

ROWN (RED-BROWN TO ORANGE)

lexandrite	Chrysoberyl	3·65	8·5	1·74–1·75	Al_2BeO_4
lmandine	Garnet	3·7–4·2	7·25–7·5	1·78–1·83	$Fe^{\cdot\cdot}Al_2[SiO_4]_3$
mber	Amber	1·05–1·09	2–2·5	1·54	organic
ndalusite	Andalusite	3·22–3·29	7·5	1·64–1·65	$Al_2[O\|SiO_4]$
xinite	Axinite	3·25–3·29	6·5–7·1	1·67–1·68	$Ca_2(Mn, Fe)Al_2BH(SiO_4)_4$
urnt Amethyst	Quartz	2·64–2·66	7	1·54–1·55	SiO_2
rocoite	Crocoite	5·09–6·01	2·5–3	2·31–2·66	$Pb[CrO_4]$
udialyte	Eudialyte	2·84–3·1	5–5·5	1·61	$(Na,Ca,Fe)_6Zr[(OH)Cl\|(Si_3O_9)_2]$
ire Opal	Opal	2·005	5·5	1·44	hydrated SiO_2
owlerite	Pyroxene	3·63–3·67	5·5	1·66–1·67	$SiO_3(Mn,Fe,Ca,Zn)$
rossular	Garnet	3·05–3·07	6·5–7	1·77–1·81	$Ca_3Al_2[SiO_4]_3$
eliodor	Beryl	2·72–2·73	7·5	1·57–1·58	$Al_2Be_3[Si_6O_{18}]$
essonite	Garnet	3·62–3·67	7	1·56	$Ca_3Al_2[SiO_4]_3$
yacinth	Zircon	4·4–4·82	7·5	1·92–1·98	$Zr[SiO_4]$
anganese Epidote	Epidote	3·25–3·5	7	1·75–1·81	$Ca_2(Al,Fe^{\cdots})_3[OH(SiO_4)_3]$
range coloured Spinel	Spinel	3·53–3·56	8	1·72	$MgO.Al_2O_3$
adparadscha	Corundum	3·89–3·95	9	1·76–1·77	Al_2O_3
yrope	Garnet	3·65–3·9	7·25	1·75–1·77	$Mg_3Al_2[SiO_4]_3$
ealgar	Realgar	3·5–3·6	1·5–2	2·46–2·61	AsS
ubellite	Tourmaline	3·09–3·15	7–7·25	1·62–1·65	complex boro-silicate
uby	Corundum	3·97–4·1	9	1·76–1·77	Al_2O_3
moky Quartz	Quartz	2·65	7	1·54–1·55	$SiO_2 + FeO$
pessartite	Garnet	4·0–4·3	7·5	1·79–1·82	$Mn_3Al_2[(SiO_4)_3]$
aurolite	Staurolite	3·65–3·78	7–7·5	1·73–1·74	$[Al_4(SiO_4)]_2.[Fe^{\cdots}O_2(OH)_2]$
opaz (Golden)	Topaz	3·58	8	1·6–1·63	$Al_2[(SiO_4\|F_2)]$
esuvianite	Idocrase	3·35–3·45	6·5	1·71–1·72	$Ca_{10}[(Mg,Fe)_2Al_4][Si_9O_{34}].(OH)_4$
ircon	Zircon	4·4–4·7	7·5	1·92–1·98	$Zr[SiO_4]$

op. = opaque, trl. = translucent, trp. = transparent

BROWN (YELLOWISH-BROWN TO BROWNISH-YELLOW)

Name as Gemstone	*Name as Mineral*	*S.G.*	*Hardness (Mohs' Scale)*	*R.I.*	*Chemical Formula*
Amber	Amber	1·05–1·09	2–2·5	1·54	organic
Axinite	Axinite	3·27–3·29	6·5–7	1·67–1·68	$Ca_2(Mn,Fe)Al_2BH(SiO_4)_4$
Brown Corundum	Corundum	4–4·01	9	1·76–1·77	Al_2O_3
Brown Spinel	Spinel	3·53–3·56	8	1·72	$MgO.Al_2O_3$
Brown Tourmaline	Tourmaline	3·05–3·12	7·25	1·62–1·66	complex boro-silicate
Brown Zircon	Zircon	4·4–4·7	7·5	1·92–1·98	$Zr[SiO_4]$
Burnt Amethyst	Quartz	2·64–2·66	7	1·54–1·55	SiO_2
Chrysoberyl	Chrysoberyl	3·5–3·84	8·5	1·72–1·75	$Al_2[BeO_4]$
Chrysolite	Olivine	3·27–3·42	6·5–7	1·65–1·69	$(Mg,Fe)_2SiO_4$
Citrine	Quartz	2·65–2·69	7	1·54–1·55	SiO_2
Danburite	Danburite	2·97–3·02	7	1·63	$CaB_2[Si_2O_8]$
Diamond	Diamond	3·32–3·54	10	2·41–2·42	C
Dravite	Tourmaline	3·05–3·15	7·25	1·61–1·63	complex boro-silicate
Epidote	Epidote (Piedmontite)	3·25–3·5	7	1·75–1·81	$Ca_2(Al,Fe^{\cdots})_3[OH(SiO_4)_3]$
Fluorite	Fluorspar	3·01–3·25	4	1·43	CaF_2
Heliodor	Beryl	2·72–2·73	7·5	1·57–1·58	$Al_2Be_3[Si_6O_{18}]$
Hessonite	Garnet	3·62–3·67	7	1·76	$Ca_3Al_2[SiO_4]_3$
Obsidian	Glassy Lava	2·5–2·6	5–5·5	1·5	——
Sinhalite	Sinhalite	3·47–3·50	6–7	1·67–1·71	$MgAlBO_4$
Smoky Quartz	Quartz	2·65	7	1·54–1·55	SiO_2
Titanite	Sphene	3·4–3·6	5–5·5	1·92–2·05	$CaTi[(SiO_4\|O)]$
Topaz (Golden)	Topaz	3·53–3·54	8	1·6–1·63	$Al_2[SiO_4\|F_2]$
Vesuvianite	Idocrase	3·35–3·45	6·5	1·71–1·72	$Ca_{10}[(Mg,Fe)_2]Al_4[Si_9O_{34}](OH)_4$

YELLOW

Amber	Amber	1·05–1·09	2–2·5	1·54	organic
Beryllonite	Beryllonite	2·71–2·73	7·5	1·57–1·58	$NaBe[PO_4]$
Chrysoberyl (Golden)	Chrysoberyl	3·5–3·84	8·5	1·74–1·75	$Al_2[BeO_4]$
Chrysolite	Olivine	3·27–3·42	6·5–7	1·65–1·67	$(Mg,Fe)_2SiO_4$
Citrine	Quartz	2·65–2·69	7	1·54–1·55	SiO_2
Corundum	Corundum	4·0–4·09	9	1·76–1·77	Al_2O_3
Danburite	Danburite	2·97–3·02	7	1·63	$Ca[B_2Si_2O_8]$
Diamond	Diamond	3·32–3·54	10	2·41–2·42	C
Epidote	Epidote	3·25–3·5	7	1·75–1·81	$Ca_2(Al,Fe^{\cdots})_3[OH(SiO_4)_3]$
Euclase	Euclase	3·1–3·12	7·5–8	1·64–1·67	$Al[(OHBeSiO_4)]$
Fire Opal	Opal	2·005	5·5	1·44	hydrated SiO_2
Fluorite	Fluorspar	3·01–3·25	4	1·43	CaF_2
Gold Topaz	Topaz	3·53–3·54	8	1·6–1·63	$Al_2[(SiO_4\|F_2)]$
Heliodor	Beryl	2·72–2·73	7·5	1·57–1·58	$Al_2Be_3[Si_6O_{18}]$
Hiddenite	Pyroxene (Spodumene)	3·2	6·5–7	1·66–1·67	$Li[Al(Si_2O_6)]$
"Jargoon"	Zircon	4·2–4·7	7·5	1·92–1·98	$Zr[SiO_4]$
Phenakite	Phenakite	3·0	7·5–8	1·65–1·67	$Be_2[SiO_4]$

op. = opaque, trl. = translucent, trp. = transparent

ame as Gemstone	Name as Mineral	S.G.	Hardness (Mohs' Scale)	R.I.	Chemical Formula
capolite	Scapolite (Marialite)	2·67–2·7	6·5	1·55–1·57	$Na_4Al_3Si_9O_{24}.Cl$
opaz	Topaz	3·53	8	1·6–1·63	$Al_2[(SiO_4\|F_2)]$
Oriental Topaz", Corundum (yellow), see p. 212					
Topazolite"	Andradite Garnet	3·85–4·0	6·5–7	1·84–1·89	$Ca_3Fe_2(Si_4O)_3$
ourmaline	Tourmaline	3·05–3·12	7·25	1·62–1·66	complex boro-silicate
ellow Corundum	Corundum	4·0–4·09	9	1·76–1·77	Al_2O_3
ellow Spinel	Spinel	3·52–3·55	8	1·72	$MgO.Al_2O_3$
ellow Zircon	Zircon	4·2–4·7	7·5	1·92–1·98	$Zr[SiO_4]$
esuvianite	Idocrase	3·4–3·5	6·5	1·71–1·72	$Ca_{10}[(Mg,Fe)_2\|Al_4][Si_9O_{34}](OH)_4$
REEN					
lexandrite	Chrysoberyl	3·65	8·5	1·74–1·75	$BeO[Al_2O_3]$
ndalusite	Andalusite	3·12–3·18	7·5	1·63–1·64	$Al_2[O\|SiO_4]$
patite	Apatite	3·17–3·23	5	1·64–1·65	$Ca_5[(F,OH,Cl)\|(PO_4)_3]$
onamite	Smithsonite	4·1–4·5	4·5–5	1·81–1·84	$ZnCO_3$
hrysoberyl	Chrysoberyl	3·65	8·5	1·74–1·75	$Al_2[BeO_4]$
hrysolite	Olivine	3·27–3·42	6·5–7	1·65–1·69	$(Mg,Fe)_2SiO_4$
atolite	Datolite	3·0	5	1·62–1·67	$Ca[OH\|BSiO_4]$
emantoid	Andradite Garnet	3·83–3·96	6·5–7	1·78–1·83	$Ca_3(FeCr)_2[SiO_4]_3$
iamond	Diamond	3·32–3·54	10	2·41–2·42	C
iopside	Pyroxene (Diopside)	3·25–3·4	5·5	1·65–1·7	$CaMg[Si_2O_6]$
ioptase	Dioptase	3·27–3·35	5	1·64–1·70	$Cu_3[Si_3O_9].3H_2O$
umortierite	Dumortierite	3·24–3·28	7	1·66–1·68	$Al_8BSi_3(OH)O_{19}$
merald	Beryl	2·64–2·73	7·5	1·58–1·59	$(Al,Cr)_2.Be_3.(Si_6O_{18})$
pidote	Epidote (Pistacite)	3·25–3·5	7	1·72–1·78	$Ca_2(Al,Fe^{\cdots})_3[OH(SiO_4)_3]$
uchroite	Euchroite	3·3–3·4	3–3·5	1·69–1·73	$Cu_2[OH\|AsO_4].3H_2O$
uclase	Euclase	3·11–3·14	7·5–8	1·64–1·67	$Al[(OHBeSiO_4)]$
luorite	Fluorspar	3·01–3·25	4	1·435	CaF_2
arnet, see Andradite, Grossular, Uvarovite, Demantoid					
reen Beryl (Emerald)	Beryl	2·64–2·73	7·5	1·58–1·59	$(Al,Cr)_2.Be_3.(Si_6O_{18})$
reen Corundum	Corundum	4·11–4·12	9	1·76–1·77	Al_2O_3
reen Spinel	Spinel	3·53–3·59	8	1·72	$MgO.Al_2O_3$
reen Topaz	Topaz	3·5–3·52	8	1·6–1·63	$Al_2[(SiO_4\|F_2)]$
reen Zircon	Zircon	4·00–4·65	7·5	1·80–1·86	$Zr[SiO_4]$
rossular	Garnet	3·5–3·7	6·5–7	1·74–1·81	$Ca_3Al_2[SiO_4]_3$
edenbergite	Pyroxene (Hedenbergite)	3·3–3·4	5–6	1·65–1·75	$CaFe[Si_2O_6]$
iddenite	Spodumene	3·2	6·5–7	1·60–1·67	$Li[Al(Si_2O_6)]$
docrase	Idocrase (=Vesuvianite)	3·35–3·45	6·5	1·71–1·72	$Ca_{10}(Mg,Fe)_2Al_4.(Si_9O_{34}).(OH)_4$
oldavite	Moldavite	2·30–2·36	5·5	1·49	——
bsidian (Glassy Lava)		2·5–2·6	5–5·5	1·5	——
ericlase	Periclase	3·75–3·9	6	1·73	MgO
rehnite	Prehnite	2·9	6–6·5	1·61–1·65	$OH_2Ca_2Al_2(Si_3O_{10})$

op. = opaque, trl. = translucent, trp. = transparent

Name as Gemstone	*Name as Mineral*	*S.G.*	*Hardness (Mohs' Scale)*	*R.I.*	*Chemical Formula*
Sphene	Sphene	3·4–3·6	5–5·5	1·92–2·05	$CaTi(SiO_4\|O)$
Spodumene	Spodumene (var. Hiddenite)	3·2	6·5–7	1·66–1·67	$AlLi[(Si_2O_6)]$
Topaz (greenish-blue)	Topaz	3·5–3·52	8	1·6–1·63	$Al_2[(SiO_4\|F_2)]$
Tourmaline	Tourmaline	3·06–3·115	7–7·5	1·62–1·65	complex boro-silicate
Uvarovite	Uvarovite Garnet	3·4–3·5	7	1·79–1·83	$Ca_3Cr_2^{\cdots}[SiO_4]_3$
Vesuvianite	(*a*) Californite, dark green; (*b*) Egeran, yellowish-green; (*c*) Idocrase, olive-green	3·25–3·45	6·5	1·71–1·72	$Ca_{10}[(Mg,Fe)_2\|Al_4][Si_9O_{34}](OH)_4$
Zircon	Zircon	4·00–4·65	7·5	1·80–1·86	$Zr[SiO_4]$

GREY

Name as Gemstone	*Name as Mineral*	*S.G.*	*Hardness (Mohs' Scale)*	*R.I.*	*Chemical Formula*
Andalusite	Andalusite	3·22–3·29	7·5	1·46–1·47	$Al_2[O\|SiO_4]$
Axinite	Axinite	3·27–3·29	6·5–7	1·67–1·68	$Ca_2(Mn,Fe)Al_2B_2H(SiO_4)_4$
Diamond	Diamond	3·32–3·54	10	2·41–2·42	C
Dravite	Tourmaline	3·05–3·15	7·25	1·61–1·63	complex boro-silicate
Epidote	Epidote	3·25–3·5	7	1·75–1·81	$Ca_2(Al,Fe^{\cdots})_3[OH(SiO_4)_3]$
Morion	Quartz (brownish-black)	2·65–2·66	7	1·54–1·55	SiO_2
Smoky Quartz	Quartz	2·65	7	1·54–1·55	SiO_2
Tourmaline	Tourmaline (see Dravite)				
Vesuvianite	Idocrase (= Vesuvianite)	3·35–3·45	6·5	1·71–1·72	$Ca_{10}(Mg,Fe)_2[Al_4][Si_9O_{34}](OH)_4$
Zircon	Zircon	4·00–4·60	7·5	1·92–1·98	$Zr[SiO_4]$

2. TRANSLUCENT AND OPAQUE GEMSTONES AND ORNAMENTAL STONES

WHITE TO PALE GREY

Name as Gemstone	*Name as Mineral*	*S.G.*	*Hardness (Mohs' Scale)*	*R.I.*	*Chemical Formula*
Agate (various colours)	Chalcedony	2·5–2·8	6·5–7	op.	SiO_2
Alabaster (dense aggregates)	Gypsum	2·3	2	op.	$Ca[SO_4].2H_2O$
Aragonite	Aragonite	2·94	4	1·53–1·69	$CaCO_3$
Chalcedony	Chalcedony	2·5–2·8	7	1·54–1·55	SiO_2
Fibrous Gypsum (iridescent lustre)	Gypsum	2·31–2·33	1·5–2	1·52–1·53	$Ca[SO_4].2H_2O$

op. = opaque, trl. = translucent, trp. = transparent

ame as Gemstone	Name as Mineral	S.G.	Hardness (Mohs' Scale)	R.I.	Chemical Formula
deite (white to greenish-white)	Pyroxene (Jadeite)	3·3–3·5	6·5–7	1·65–1·68	$NaAl[Si_2O_6]$
eerschaum (white, yellowish to pink)	Sepiolite	2·0	1·5–2·5	op.	$2MgO.3SiO.2_2H_2O$
ilky Quartz (white, cloudy)	Quartz	2·65–2·69	7	1·54–1·57	SiO_2
ephrite (pale to light green)	Amphibole (Nephrite)	2·9–3·1	5–6	1·62–1·65	$Na_2Ca_4(Mg,Fe)_{10}[(OH)_2O_2\|Si_{16}O_{44}]$
pal (Hyalite = colourless)	Opal	2·0	5·5	1·44	hydrated SiO_2
hite Opal (pale, bluish-white, iridescent)	Opal	1·85–2·0	5·5–6	op.	hydrated SiO_2
LUE					
gate (concentric coloured layers)	Chalcedony	2·50–2·80	6·5–7	op.	SiO_2
zurite (sky-blue)	Azurite	3·8–3·83	3·5–4	1·73–1·83	$Cu_3[OH\|CO_3]_2$
zurite-Malachite (green and blue mottled)	Azurite	3·8–3·83	3·5–4	op.	$Cu_3[OH\|CO_3]_2$
rysocolla	Chrysocolla	2·0–2·42	2–4	op.	$CuSiO_3.nH_2O$
sper (dense, fine-grained aggregate)	Chalcedony	2·5–2·8	6·5–7	op.	SiO_2
pis Lazuli	Lapis Lazuli (Lazurite)	2·38–2·45	5·5	op.	$(NaCa)_8[SO_4,Cl,S)_2\|(AlSiO_4)6]$
zulite	Lazulite	2·96–3·05	5–6	1·60–1·64	$(Fe,Mg)Al_2[OH\|PO_4]_2$
nithsonite	Smithsonite	4·1–4·4	4·5–5	1·81–1·84	$Zn[CO_3]$
rquoise	Turquoise	2·6–2·8	6	op.	$CuAl_6[(OH)_2\|(PO_4)_4].4H_2O$

dontolite or Bone Turquoise, composed of fossil bones and teeth, coloured deep blue or green.

ED					
rneol (blood-red)	Chalcedony	2·5–2·8	6·5–7	op.	SiO_2
re Opal (trl. to op. variety)	Opal	2·005	5·5	trl. – op.	hydrated SiO_2
sper (fine-grained aggregate)	Chalcedony	2·5–2·8	6·5–7	op.	SiO_2
pidolite (reddish-purple)	Lithium-Mica (Lepidolite)	2·8–2·9	2–2·5	op.	$KLi_2Al[Si_4O_{10}(OH,F)_2]$
argarite (pale pink)	Calcium-Mica (Margarite)	3·0–3·1	3·5–4·5	op.	$CaAl_2[(OH)_2\|Si_2Al_2O_{10}]$
ed Coral (Blood Coral)	Natural organic product			op.	——

op. = opaque, trl. = translucent, trp. = transparent

Name as Gemstone	*Name as Mineral*	*S.G.*	*Hardness (Mohs' Scale)*	*R.I.*	*Chemical Formula*
Rhodonite (brownish-red)	Rhodonite	3·5–3·6	6–6·5	op.	$Mn[SiO_3]$
Rose-Quartz (rose-red to pink)	Quartz	2·6–2·7	7	op.	SiO_2
Sardonyx (red and white banded agate)	Chalcedony	2·5–2·8	6·5–7	op.	SiO_2
Thulite (pink aggregate)	Zoisite	3·45–4·8	6–7	op.	$Ca_2(Al,Fe^{\cdots})_3[OH(SiO_4)_3]$
YELLOW AND BROWN					
Agalmatolite (brownish)	? Muscovite	2·7–3·1	2–3	trl. – op.	$KAl_2[Si_3AlO_{10}\|(OH)F_2]$
Amber	Amber (fossil resin)	1·05–1·09	2–2·5	trl. (1·54)	——
Carneol (blood-red to yellowish-brown)	Chalcedony	2·5–2·8	6·5–7	trl. – op.	SiO_2
Fire Opal (golden-yellow variety)	Opal	2·005	5·5	trp. – trl.	hydrated SiO_2
Jasper (dense aggregate)	Chalcedony	2·5–2·8	6·5–7	trl. – op.	SiO_2
Marcasite (pale bronze-yellow)	Marcasite	4·65–4·82	6–6·5	op.	FeS_2
Sard (orange to dark brown)	Chalcedony	2·5–2·8	6·5–7	trl. – op.	SiO_2
Travertine (yellowish-brown, porous)	Calcite	2·63	3	op.	$CaCO_3$
Wood Opal (brown to yellowish, woody, fibrous)	Opal	1·85–2·48	5–6·5	op.	hydrated SiO_2
GREEN					
Amazonite	Feldspar	2·54–2·69	6–6·5	op.	$KAlSi_3O_8$
Azurite-Malachite (green and blue mottled)	Azurite	3·8–3·83	3·5–4	op.	$Cu_3[OH\|CO_3]_2$
Californite (yellowish-green to green, fibrous)	Idocrase (Vesuvianite)	3·35–3·45	6·5	sub-trl. – op.	$Ca_{10}[(Mg,Fe)_2\|Al_4].[Si_9O_{34}](OH)_4$
Ceylonite (dark green to black [Pleonaste])	Spinel	3·65–3·72	8	op.	$MgO.Al_2O_3$

op. = opaque, trl. = translucent, trp. = transparent

PLATE XIII GEMSTONES: 3 – Green

1st Row: 1. Fluorite, S.W. Africa; 2. Alexandrite (uncut), Southern Rhodesia; 3. Malachite, S.W. Africa; *2nd Row*: 4. Euclase, Brazil; 5. Beryl (uncut), Brazil; 6. Grossularite (garnet), South Africa; 7. Aventurine, India; 8. (prism) Diopside, S.W. Africa; *3rd Row*: 9. Dioptase, Congo; 10. (extreme right) Euclase (uncut), Minas Geraes, Brazil; *4th Row*: 11. Malachite, Congo; 12. (ring) Nephrite, New Zealand; *Within ring*: 13. (top) Chrysoprase, Silesia; 14. (bottom left) Peridot, Egypt; 15. (bottom right) Demantoid (garnet), Urals; *Right of ring*: 16. Beryl, Brazil; *Bottom Row*: 17. Tourmaline, Brazil; 18. Emerald, Columbia; 19. Fluorspar, S.W. Africa.

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Name as Gemstone	*Name as Mineral*	*S.G.*	*Hardness (Mohs' Scale)*	*R.I.*	*Chemical Formula*
Chloromelanite (dark green, white patches, fibrous)	Jadeite	3·3–3·5	6·5–7	trl. – sub-trp.	$NaAl[Si_2O_6]$
Chrysocolla (blue-green to green)	Chrysocolla	2–2·45	2–4	op.	$Cu[SiO_3]$ + water
Chrysopal (apple-green)	Opal	2·15	6	trp.	hydrated SiO_2 with Ni
Chrysoprase (apple-green)	Chalcedony	2·58–2·65	7	op.	SiO_2
Fuchsite	Chromium Mica (Fuchsite)	2·8–2·9	2	1·59, sub-trp.	——
Garnierite (emerald-green to apple-green)	Garnierite	2·27	1–1·5	op.	$(NiMg_6Si_4O_{11})(OH)_6.H_2O$
Heliotrope (dark green jasper speckled with red)	Chalcedony	2·5–2·8	6·5–7	op.	SiO_2
Jadeite (greenish to whitish-green)	Pyroxene (Jadeite)	3·3–3·5	6·5–7	op.	$Na(AlSi_2O_6)$
Jasper (fine-grained dense aggregate, greenish)	Chalcedony	2·5–2·8	6·5–7	op.	SiO_2
Malachite (concentric layers of pale and dark green)	Malachite	3·8–4·1	3·5–4	op.	$Cu_2[(OH)_2\|CO_3]$
Nephrite (pale emerald-green)	Amphibole (Actinolite)	2·9–3·1	5–6	op.	$Na_2Ca_4(MgFe)_{10}[OH_2O_2Si_{16}O_{44}]$
Plasma (leek-green with yellowish-white patches)	Chalcedony	2·5–2·8	6·5–7	trl. – op.	SiO_2
Prase (leek-green to grass-green with included actinolite needles)	Quartz	2·60–2·66	7	trl. – op.	SiO_2
Prehnite	Prehnite	2·9	6–6·5	trl. – op.	$OH_2Ca_2Al_2(Si_3O_{10})$
Serpentine (green, finely fibrous)	Serpentine	2·5–2·7	3–4	trl. – op.	$Mg_6(OH)_8(Si_4O_{10})$
Turquoise (greenish-blue massive)	Turquoise	2·6–2·83	6	op.	$CuAl_6[(OH)_2\|(PO_4)_4].4H_2O$
Utahlite = Variscite (bluish-green to pale emerald-green)	Variscite	2·3–2·4	4–5	op.	$Al[PO_4].2H_2O$

op. = opaque, trl. = translucent, trp. = transparent

3. Gemstones with Sheen and Iridescent Lustre

A. *Stones with star effect seen by reflected light* (*asterism*)

1. *Star Sapphire* = Corundum. Translucent to opaque. A six-rayed star is seen on the basal surface of the stone. This effect is due to included rutile needles or to minute hollow elongated channels.
S.G., 4·01-4·09; Hardness, 9; R.I., 1·76-1·77; Chem. Comp., Al_2O_3.

2. *Star Ruby* = Corundum. A six-rayed star is formed by included rutile needles which lie parallel to the edges of the six-sided prism.
S.G., 3·96-3·99; Hardness, 9; R.I., 1·76-1·77; Chem. Comp., Al_2O_3.

3. *Star Almandine* = Garnet. This shows a series of faint four-rayed stars, which are produced by translucent inclusions lying parallel to the four main crystal edges.
S.G., 3·7-4·2; Hardness, 7·25-7·5; R.I., 1·78-1·83; Chem. Comp., $Fe_3Al_2[SiO_4]_3$.

B. *Stones with silky sheen* (*schiller lustre*), *or bands of light reflected from fibres or channels within* (*chatoyant effect*)

1. *Adularia* and *Moonstone* = Feldspar. Iridescent bluish pearly sheen in milky translucent groundmass.

2. *Amazonite* = Feldspar. Greenish silky lustre produced by very closely spaced twin lamellae. Spherical surfaces give reflection, flat surfaces have an even silky lustre.

3. *Apatite*. Sheen is seen on finely fibrous apatite.

4. *Calcite*. Fibrous calcite has an iridescent sheen on a rounded surface.

5. *Beryl Cat's Eye*. Silver-grey sheen, due to inclusions of fine needle-shaped crystals in parallel alignment.

6. *Cymophane* or *Cat's Eye Chrysoberyl*. The chatoyance is due to minute parallel channels near the upper surface of the stone. The reflection of light from these channels produces a silky whitish-grey or yellow band of light running at right angles to the inclusions.

7. *Falcon's Eye*, *Tiger's Eye*. Quartz containing fine parallel fibres of crocidolite (an amphibole). The reflection from these fibres gives a silky sheen, which is pale blue to greenish blue (falcon's eye) or golden brown (tiger's eye).

8. *Cat's Eye Quartz*. With sheen produced by inclusions of fibrous amphibole needles. The basic colour is variable, usually yellow, brownish-grey to blue. The ray of light produced is yellowish.

9. *Labradorite*. See 1. above.

10. *Opal*. Opalescent amorphous form of silica; various colours.

11. *Pearl*. Silvery sheen.

C. *Gemstones with lustrous inclusions*

1. *Aventurine Quartz*. Colourless quartz with numerous evenly distributed inclusions of mica or haematite. These give the quartz a

red-brown colour and produce a reddish-golden sheen. Flaky inclusions of the mineral fuchsite give the quartz a green colour.

2. *Aventurine Feldspar* (*Sunstone*). Semi-transparent and translucent almost white to cream-coloured feldspar containing minute flake-like crystals of haematite. These give the stone a reddish colour and produce a spangled effect.

3. *Bronzite* = pyroxene. Brownish black, green, brown, or greenish brown pyroxene containing small scales of ilmenite. These produce a bronze-yellow sheen on the cleavage surfaces.

4. *Diallage* = pyroxene. Same as bronzite, but the colours are grey, green, or dark brown.

5. *Hypersthene* = pyroxene. Same as bronzite; colours are brownish black and blackish green, with greenish-brown or yellowish-brown sheen.

6. *Lapis Lazuli* = Lazurite. Blue to greenish-blue stone containing numerous grains of pyrites of variable size. These were at one time thought to be gold.

Alphabetical Description of Gemstones

with descriptions of colour, chemical composition, properties, chief localities, imitations and synthetic stones, use and value. Names in French, German, and Italian are given.

Adularia. (Related type is Moonstone.)

Fr: *Adulaire*; Ger: *Adular*; It: *Adularia*. Belongs to feldspar family. (Plate XVI, 10, p. 238.)

Colour: Colourless, white to bluish with characteristic iridescent sheen, to which its use as gemstone can be attributed.

Properties: Hardness, 6; S.G., 2·54–2·75; R.I. of transparent stones, 1·52–1·53; Chem. Comp., $K[AlSi_3O_8]$.

Localities: Ceylon, Burma, Brazil.

Incorrect Name: Ceylon Opal.

Imitation: Bluish chalcedony as blue moonstone.

Value: Relatively small.

Amazonite. Fr: *Amazonite*; Ger: *Amazonit*; It: *Amazzonite*. Belongs to feldspar family, mineralogically a microcline.

Colour: Whitish-green, opaque.

Properties: Hardness, 6; S.G., 2·54–2·58; Chem. Comp., $(K,Na)AlSi_3O_8$.

Localities: U.S.A. (Colorado), Russia (Lake Ilmen).

Incorrect Name: Colorado Jade.

Use: Little used as gemstone outside producing countries.

Beryl. Fr: *Beryl* (Pl. XIII, 5, 16, p. 216, and Pl. XIV, 2, p. 235); Ger: *Beryll*; It: *Berillo.*

Occurs in three colour varieties: (*a*) Emerald (green), (*b*) Aquamarine (pale blue), (*c*) Golden Beryl (yellow).

Properties: Hardness, 7·5; S.G., 2·65–2·75; R.I., 1·57–1·58; Chem. Comp., $Al_2Be_3[Si_6O_{18}]$; Opt. Props., uniaxial, negative birefringence; Crystal System, hexagonal.

a. **Emerald** (green). Fr: *Emeraude*; Ger: *Smaragd*; It: *Smeraldo.* (Pl. XIII, 18, p. 216.)

Crystalline Form: Usually 6-sided prism; easily cut and polished.

Dichroism: Very marked, pale yellowish green and bluish green.

Localities: The most valuable forms occur in Colombia (S. America); also Urals, Austria, Norway, North Carolina (U.S.A.).

Imitations: Much attempted; synthetic emerald is sometimes known as igmerald (see Synthetic Stones).

Incorrect Names: Green sapphire called Oriental emerald; green tourmaline called Brazilian emerald; hiddenite called Lithium emerald; dioptase called Copper emerald; demantoid-garnet called Uralian emerald; prehnite called Cape emerald; fluorspar called African emerald.

b. **Aquamarine** (pale blue). Fr: *Aigue-marine*; Ger: *Aquamarin*; It: *Aqua-Marina.* (Pl. XI, 1, 4, p. 200.)

Dichroism: Only the dark varieties have strong dichroism, usually pale yellow and pale sky-blue.

Localities: Much more widespread than emerald, therefore less valuable.

Incorrect Names: Green-blue sapphire called Oriental Aquamarine; blue zircon called Siam Aquamarine.

Value: Depends on fashion; formerly the very dark varieties were popular, now the pale water-clear ones are preferred.

c. **Golden Beryl** or **Heliodor** yell(ow). (Pl. XIV, 2, p. 225.)

Dichroism: Two distinct colours, golden yellow and yellowish green.

Localities: Rarer than aquamarine, but more common than emerald, esp. Elba, Urals, also Brazil.

d. **Other Varieties.** Rose-pink beryl = morganite. Also colourless beryls. (These cannot be used as substitutes for diamonds as they have a low refractive index.)

Chrysoberyl. Two varieties, (*a*) Alexandrite, and (*b*) Cymophane.

Properties: Hardness, 8·5 (the third hardest mineral among the gemstones, surpassed only by corundum with 9 and diamond with 10); S.G., 3·68–3·8; R.I., 1·74–1·75; Chem. Comp., Al_2BeO_4; Opt. Props., birefringent, biaxial positive.

a. **Alexandrite.** Fr: *Alexandrite*; Ger: *Alexandrit*; It: *Alessandrite.* (Pl. XIII, 2, p. 216.)

Colour: In daylight, dull green; by artificial light, blood red. The variation in colour is due to differential absorption of the two kinds of light.

Dichroism: Very marked and distinctive; dark to bluish green, and violet- to rose-red.

Occurrence: Very rare, Urals, Connecticut (U.S.A.), Brazil, Moravia.

Alexandrite is the more valuable of the two varieties of chrysoberyl. Attempts to produce synthetic alexandrite have not been entirely successful. Raw materials used are aluminium silicate with addition of vanadium.

b. **Cymophane (Cat's Eye).** Fr: *Cymophane*; Ger: *Cymophan*; It: *Cimofano.*

Colour: Yellowish green or brownish yellow. Shows a narrow silky ray when cut *en cabochon* (cat's eye effect).

Dichroism: Yellowish and greenish.

Incorrect Names: Oriental Chrysolite. The term Cat's Eye alone without qualification should only be used for the cymophane variety of chrysoberyl, and not for Cat's Eye quartz. Cymophane is often called Oriental Cat's Eye.

Coral. Fr: *Corail*; Ger: *Korallen*; It: *Corallo.* (Pl. XII, 2, 9, p. 209.)

Skeleton of coral polyps, marine animals belonging to the phylum Coelenterata. Found in warm seas, esp. Australasia, Pacific and Indian Oceans. Locally very valuable, but its demand for ornamental use has recently declined.

Corundum. Fr: *Corindon*; Ger: *Korund*; It: *Corindone.*

Two colour varieties: (*a*) Ruby (red), and (*b*) Sapphire (blue).

Chem. Comp.: Al_2O_3 (approx. 53 per cent. Al, 47 per cent. O); red coloration due to presence of chromic oxide; blue coloration due to iron and titanium.

a. **Ruby.** Fr: *Rubis*; Ger: *Rubin*; It: *Rubino.* (Pl. XII, 3, p. 209.)

Properties: Hardness, 9 (next to diamond, the hardest gemstone); S.G., 3·94–4·1; R.I., 1·76–1·77; Opt. Props., optically uniaxial, negative birefringence; Pleochroism, very strong; the two images in dichroscope are violet to dark red and paler red with a touch of yellow; Crystal System, hexagonal, hexagonal prisms.

Varieties: Apart from normal rubies there are asterias or star-stones, in which a star consisting of six rays intersecting at 120° is seen. (This structure is better developed in star sapphires than in star rubies.)

Localities: Ceylon, Burma, Siam, Brazil.

Incorrect Names: Spinel called Balas ruby, spinel-ruby or rubicelle; rose topaz called Brazilian ruby (optically biaxial, S.G. lower); red tourmaline called Siberian ruby (S.G. and R.I. smaller); garnet varieties called Ceylon ruby, Colorado ruby, Arizona ruby and Cape ruby (no dichroism).

Synthetic Rubies: Made from alumina with small additions of K_2CO_3, CaF_2, and $K_2Cr_2O_7$ at very high temperatures in a gas combustion chamber. Very good synthetic rubies are now being made. See Synthetic Gemstones: Corundum.

b. **Sapphire.** Fr: *Saphir*; Ger: *Saphir*; It: *Zaffiro.*

The blue variety of corundum. (Pl. XI, 6, p. 200.)

Properties: Hardness, 9; S.G., 3·94–4·1; R.I., 1·76–1·77; Opt. Props., optically uniaxial, negative birefringence; Pleochroism, stronger than in ruby, two colours in dichroscope – clear blue and greenish-blue; Crystal System, hexagonal, crystals are usually pointed six-sided double pyramids.

Varieties: Star sapphires are often well developed.

Localities: Ceylon, Montana (U.S.A.), Burma, Australia, Kashmir (India). Largest star sapphire ever found: Star of India (3–4 cm. in diameter), now in Museum of Natural History, New York.

Incorrect Names: Cordierite (dichroite) called sapphire (optically biaxial); cordierite (iolite) called lynx sapphire or water sapphire (optically biaxial); blue tourmaline called Brazilian sapphire.

Comparison with similar blue uniaxial gemstones:

	Tourmaline	*Beryl*	*Sapphire*
S.G.	2·94–3·24	2·62–2·77	3·9 –4·1 (higher)
R.I.	1·64	1·57	1·76–1·77 (higher)

c. **Other Varieties of Corundum.**

Water-clear corundum is called Leucosapphire. Purple corundum, or purple sapphire, is sometimes called Oriental Amethyst. Reddish or flesh-coloured corundum is called Padparadscha.

Localities: Padparadscha and violet corundum – Ceylon.

Incorrect Names for variously coloured corundums: Greenish-blue called Oriental aquamarine; green called Oriental emerald; yellow called Oriental topaz; rose-pink called Oriental hyacinth.

Diamond. Fr: *Diamant*; Ger: *Diamant*; It: *Diamante.* (Pl. XVI, 9, 11, p. 238.)

The most valuable gemstone of all, which, unlike any other, consists of a single element, pure crystalline carbon (C). It is thus made of the same substance as graphite and coal, and it attained the crystalline form of diamond by being subjected to tremendous pressure and heat. It had not been possible until recently to synthesise a true diamond on a commercial scale (see Synthetic Gemstones: Synthetic Diamonds, p. 234).

The outstanding properties of diamond are:

(i) The greatest hardness of all gemstones; Mohs' 10, Breithaupt 12, and Rossiwal 140,000 (p. 192).

(ii) Very high refractive index: 2·42–2·43.

(iii) Very great light dispersion. B – G = 0·044.

(iv) Angle of total reflexion (critical angle) is small – only 24°. S.G., 3·5–3·57.

The "brilliant-cut" diamond disperses white light into a wide spectral band and thus produces the brilliant flashes of spectral colours known as "fire". The purer the crystal the better is its "fire".

Colours: The known colour varieties are bluish-white, white, yellow, brown, red, green, blue, black.

Localities: (*a*) Often found in extinct volcanic vents (pipes) as in South Africa (e.g. Blue Ground, Kimberley), East Africa, South-West Africa, and India.

(*b*) In secondary (alluvial) deposits: West Africa (Sierra Leone, Liberia, Congo), Brazil (Minas Geraes), Southern India, (e.g. Koh-i-nur diamond), Russia (Urals), Australia, Indonesia,

Incorrect Names: White zircon called Ceylon diamond; white topaz called Saxony diamond; rock crystal called Alaska diamond or Arkansas diamond.

Value: This is mainly according to colour, purity and "fire". Three grades are recognised: (*a*) First water, no flaws; (*b*) Second water, apparently water-clear, but with slight turbid patches; (*c*) Third water, coloured and possibly containing the flaws of group (*b*).

The value of the cut diamond (brilliant) depends on the type and cleanness of cut, and a further factor is its weight and therefore its size. The standard measure of weight for all precious stones is the carat (1 carat = $\frac{1}{5}$ gm.). Very large specially cut diamonds are termed "solitaires" or "nonpareils". The following are particularly large and famous diamonds:

(i) Koh-i-nur diamond (now in the British Crown Jewels), formerly 186 carat, after recutting only 106 carat.

(ii) Orlov diamond, 194 carat; formerly in the Russian Crown Jewels.

(iii) Pitt or Regent diamond, 136 carat; now in French National Collection at the Louvre, Paris.

(iv) Florentine diamond, 133 carat; in former Austro-Hungarian Crown Jewels.

(v) Star of the South, formerly 254 carat, now 128; in America.

(vi) Excelsior diamond, rough weight 971 carat; was cut into 10 large brilliants and some smaller ones with a total weight of only 340 carat.

(vii) Cullinan or Star of Africa; the largest diamond yet found, original size about 10×6 cm. (3024 carat), roughly rectangular in shape; cut into two very large brilliants named Cullinan I (615 carat) and Cullinan II (309 carat); in British Crown Jewels.

Imitations: Colourless white sapphire (optical properties and specific gravity different); white zircon or topaz (optical properties and specific gravity different); silicon carbide – until recently the nearest approach to synthetic diamond (see Synthetic Diamonds, p. 234).

Feldspar Group. See Adularia (Moonstone), Amazonite, and Labradorite; also **Aventurine feldspar (Sunstone).** A variety of orthoclase. (Pl. XIV, 7, p. 225.)

Colour: Whitish to red-brown, with metallic inclusions, giving internal reflections and producing a spangled effect (cf. aventurine-quartz).

Properties: Hardness, 6; S.G., 2·66; R.I., 1·52–1·53.

Imitations: Artificial glass made to resemble aventurine or sunstone.

Garnet. Fr: *Granat*; Ger: *Granat*; It: *Granato*. (Pl. XII, 6, 7, p. 209, Pl. XIII, 6, 15, p. 216, Pl. XV, 6, p. 235.)

Properties: Chem. Comp., silicates of the metals Fe, Al, Cr, Ca and Mg. The metallic radicals determine the colour of the stones; Crystal System and dichroism, cubic system, therefore not dichroic; crystals are usually rhomb dodecahedra.

Table XIX

The main varieties of garnet

Name	*Colour*	*Hardness*	*R.I.*	*Chem. Comp.*	*S.G.*
Almandine	purplish-red	7·5–8	1·78–1·82	$Fe^{\cdot\cdot}{}_3Al_2[SiO_4]_3$	3·83–4·20
Andradite	brown to brownish-green	6·5–7	1·89	$Ca_3Fe^{\cdot\cdot\cdot}{}_2[SiO_4]_3$	3·80–3·90
Demantoid	green	6·5–7	1·88–1·89	$Ca_3Fe^{\cdot\cdot\cdot}{}_2[SiO_4]_3$	3·80–3·85
Grossular	pale olive-green	7–7·5	1·74–1·76	$Ca_3Al_2[SiO_4]_3$	3·60–3·70
Hessonite	orange-brown	6	1·74–1·76	$Ca_3Al_2[SiO_4]_3$	3·5–3·7
Melanite	black	6·5	1·8–2	$TiCa_3(Fe,Ti,Al)_2[SiO_4]_3$	3·83–3·86
Pyrope	deep red	7–7·5	1·74–1·75	$Mg_3Al_2[SiO_4]_3$	3·65–3·80
Spessartite	brownish-red to orange	6	1·80–1·81	$Mn_3Al_2[SiO_4]_3$	3·98–4·25
Uvarovite	emerald-green	7	1·84	$Ca_3Cr^{\cdot\cdot\cdot}{}_2[SiO_4]_3$	3·41–3·55
Range:		6·5–7·5	1·7–1·9		3·4–4·3

Unusual Types: Wiluite – green garnet from Siberia (the name is sometimes also applied to green idocrase); Rhodolite – rose-red or pale violet garnet; Topazolite – yellow calcium-iron-garnet; Succinite – amber-coloured garnet.

Main Localities: Almandine – India, Ceylon; pyrope – Bohemia, Madagascar, South Africa, U.S.A., India; demantoid – Russia (Urals); grossular – South Africa, Ceylon; rhodolite – Madagascar, North Carolina; spessartite – Ceylon, Brazil, U.S.A., Australia.

Incorrect Names: Almandine called Ceylon ruby, sometimes Arizona spinel; pyrope called American, Arizona, Adelaide, Colorado, or Cape ruby; hessonite called Transvaal jade; demantoid called Ural olivine, Siberian chrysolite, Ural emerald, or Ural chrysolite.

Use: Garnets were much used as gemstones in the past, but their use is greatly influenced by the whims of fashion and they are much less in evidence in Europe today. The place of garnets has to a large extent been taken by aquamarine. Garnet is also an important abrasive.

Haematite. Fr: *Hématite*; Ger: *Hämatit*; It: *Ematite*. (Pl. XVI, 8, p. 238.)

Colour: Bluish black to dark steel-grey, opaque with steely lustre.

PLATE XIV GEMSTONES: 4 – Yellow

1st Row: 1. Apatite, Mexico; 2. Beryl, Brazil; 3. Topaz, Brazil; 4. (below) Topaz, Brazil; *2nd Row*: 5. Chrysoberyl, Brazil; 6. Citrine, Brazil; 7. Orthoclase (feldspar), Madagascar; *3rd Row*: 8. Chrysoberyl (uncut), Brazil; 9. Amber, East Prussia; 10. Yellow Corundum, Ceylon; *4th Row*: 11. Amber, East Prussia; 12. Pyrite, Spain; 13. Brazilianite, Brazil.

Properties: Hardness, 6; S.G., 4·90–5·30; Chem. Comp., Fe_2O_3; Streak, brownish red; Structure, reniform shape, fibrous.

Localities: Cumberland, Spain (Bilbao) and other iron ore deposits.

Use as gemstone: Signet rings, tie-pins (imitation black pearls), cuff links.

Jadeite. Fr: *Jadéite*; Ger: *Jadeit*; It: *Giadeite.* (Pyroxene Family.)

Colour: Green, whitish with emerald-green patches, opaque to translucent.

Properties: Hardness, 6·5–7; S.G., 3·2–3·5; Chem. Comp., $Na(AlSi_2O_6)$; R.I., 1·66–1·68 (when observable).

Similar Mineral: Jadeite is easily confused with the similar but less valuable nephrite. The two are, however, readily distinguished by the following tests:

(*a*) Heated by bunsen flame: jadeite fuses, nephrite infusible.
(*b*) Flame test: jadeite produces yellow flame, nephrite colourless.
(*c*) Nephrite has hardness 6–6·5 and S.G., 2·9–3·1.

Localities: Burma; probably also China and Tibet.

Uses: Carved into ornaments. Was used for axes and weapons by the ancient Mexican and South American civilisations. Former jade cultures are also known in India and China. At the present day, the greatest part of world output goes to China.

Commercial Names: The pale green varieties are known as nephrite and the dark green to leek green are called jade.

Incorrect Names: Serpentine called Jade, Korea jade, or Chinese jade; green garnet (grossularite) called Transvaal jade; green idocrase called American jade; Californite called Californian jade.

Variety: Chloromelanite is a variety of jadeite. It has identical physical properties but differs from jadeite in its colour, which is dark green with white patches and is opaque to translucent. Jadeite is light chrome-green and translucent.

Labradorite. Fr: *Labradorite*; Ger: *Labrador*; It: *Labradorite.* A variety of plagioclase feldspar.

Colour: Iridescent play of colour ("schiller") in green, bluish, and azure blue; pearly lustre.

Properties: Hardness, up to 6; S.G., 2·62–2·76; Chem. Comp., mixture of albite ($Na[AlSi_3O_8]$) and anorthite ($Ca[AlSi_2O_8]$) molecules, containing 50 to 70 per cent. anorthite.

Localities: Labrador, N. Quebec, Ukraine, Madagascar (translucent variety).

Lapis Lazuli. Fr: *Lapis-lazuli*; Ger: *Lapis-lazuli*; It: *Lapis lazzuli.* (Lazurite). (Pl. XI, 9, p. 200.)

Colour: Though the overall colour is deep azure blue, the stone has a greyish groundmass in which small, deep ultramarine crystals are embedded. These inclusions give lapis lazuli its attractive colour. Inclusions of pyrite produce metallic yellowish patches.

Properties: Hardness, 5·5–5·75; S.G., varies from 2·4 to 2·8 or even 2·95 according to the number of inclusions; Crystal system, cubic; Chem. Comp., $(Na,Ca)_8[(SO_4,S,Cl)_2(AlSiO_4)_6]$.

Localities: Formerly largely from U.S.S.R. (Lake Baikal); at present the main producer is Afghanistan; also from Chile and China (Tibet).

Imitations: Chalcedony stained blue is known as German lapis; ultramarine-coloured serpentine from India is also called lapis lazuli.

Malachite. Fr: *Malachite*; Ger: *Malachit*; It: *Malachite*. (Pl. XIII, 3, 11, p. 216.)

Colour: Green, veined, mottled, or banded; opaque.

Properties: Hardness, 3·5–4; S.G., 3·7–4·0; R.I., where determinable, 1·88; Chem. Comp., $Cu_2[(OH)_2|CO_3]$.

Form and Texture: Crystalline system, monoclinic; crystals rare; usually occurs in shapeless masses, in nodular or reniform concretions, and commonly has concentric layers.

Localities: U.S.S.R. (Siberia, Urals), Congo, South-West Africa (Tsumeb Mine), U.S.A. (Arizona).

Uses: Used extensively for ornaments, e.g. vases and figures; also for signet rings, etc.

Variety: Azure malachite, a mixture of blue azurite and green malachite. Hardness, 3·5–4; S.G., 3·7–3·8; R.I., 1·73–1·83.

Nephrite. Fr: *Nephrite*; Ger: *Nephrit*; It: *Nephrite*. (Amphibole Family.) (Pl. XIII, 12, p. 216.)

Colour: Green to white, either in one colour or mottled; subtranslucent to opaque.

Properties: Hardness, 6–6·5; S.G., 2·9–3·1; R.I., 1·61–1·63.

Imitations: Serpentine as nephrite; green garnet as Transvaal nephrite.

Commercial Names: Greenstone; Jade (see Jadeite).

Olivine. Fr: *Olivine*; Ger: *Olivin*; It: *Olivina*. (Pl. XIII, 14, p. 216.)

Varieties: Peridot (green), Chrysolite (yellowish green), Forsterite, Fayalite.

Colour: Ranging through pale green, bottle green, olive green, yellowish (forsterite), brown to black (fayalite).

Properties: Hardness, 6–7; S.G., 3·3–3·37, Chem. Comp., $(Mg,Fe)_2[SiO_4]$; R.I., range 1·645–1·690; Crystal system, orthorhombic; Opt. Props., biaxial, positive birefringence; Dichroism, faint, green and yellowish green (peridot and chrysolite).

Localities: Red Sea island Zebirget (produced most of the peridot used in jewellery), Norway, Burma, Queensland, Minas Geraes (Brazil).

Incorrect Names: Demantoid (green garnet) from Urals called olivine; yellowish-green sapphire and chrysoberyl called oriental chrysolite;

chrysoberyl called Brazilian chrysolite; beryl called aquamarine chrysolite.

Similar Mineral: Brown specimens of olivine are rare, and most brown stones which were formerly thought to be olivine are now known to belong to the mineral species *sinhalite* ($MgAlBO_4$). The properties of sinhalite are very similar to those of olivine, but the distinguishing features are its higher specific gravity (3·47–3·50) and higher refractive index range (1·67–1·71).

Value: Relatively low.

Quartz and other forms of Silica.

Fr: *Quartz*; Ger: *Quarz*; It: *Quarzo*.

The group of gemstones with the largest number of varieties. Silica may occur in crystalline, crypto-crystalline, or amorphous form.

1. Crystalline Silica (Quartz) includes:
   - *a.* Rock Crystal, colourless, often with included needles of rutile.
   - *b.* Amethyst, purple.
   - *c.* Citrine, or "Quartz Topaz" (incorrect), pale to golden yellow.
   - *d.* Cairngorm and Smoky Quartz, smoky-grey to brown.
   - *e.* Morion, nearly black.

2. Finely Crystalline (crypto-crystalline) Silica. This shows no obvious crystal structure. It usually occurs massive or porous and often has a minutely radiating fibrous or granular structure.
   - *a.* Common Chalcedony, greyish-blue, unbanded.
   - *b.* Jasper, impure, often red, but very variable.
   - *c.* Heliotrope (Bloodstone), green speckled with red.
   - *d.* Carnelian (Carneol), red.
   - *e.* Plasma, bright green.
   - *f.* Chrysoprase, apple-green.
   - *g.* Agate, concentric bands, varied.
   - *h.* Onyx, flat bands.

3. Coarsely granular (massive quartzes).
   - *a.* Aventurine, golden or greenish spangled.
   - *b.* Quartz Cat's Eye, pale brown, chatoyant.
   - *c.* Tiger's Eye, golden-brown, chatoyant.
   - *d.* Falcon's Eye, bluish, chatoyant.
   - *e.* Prase, leek-green.
   - *f.* Rose Quartz, pink, cloudy.
   - *g.* Sapphire Quartz and Amethyst Quartz, bluish violet.

4. Amorphous Silica (Opals).
   - *a.* Opal.

5. Synthetic Quartz (see Synthetic Gemstones, p. 234).

1. *a.* **Rock Crystal.** Fr: *Cristal de Roche*; Ger: *Bergkristall*; It: *Cristallo di rocca.* (Pl. XVI, 1, 3, p. 238.)

Colour: Colourless, clear and transparent; often slightly cloudy or tinged with pale colour.

Properties: Hardness, 7; S.G., 2·65; Chem. Comp., SiO_2; R.I., 1·54–1·55; Crystal System, hexagonal; Opt. Props., not pleochroic, uniaxial, positive birefringence.

Localities: Brazil, Madagascar, French and Swiss Alps, Arkansas (U.S.A.), etc.

Incorrect Names: The name "Diamond" combined with that of various localities, e.g. Alaska diamond, Arkansas diamond, Bohemian diamond, Marmaros diamond, Bristol diamond, Cornish diamond.

Imitations: Glasses of various sorts called crystal glass, e.g. lead crystal.

1. *b.* **Amethyst.** Fr. *Améthyste*; Ger: *Amethyst*; It: *Ametista.* (Pl. XI, 10, p. 200.)

Colour: Transparent crystalline quartz, usually purple, but sometimes reddish purple with velvet tone.

Properties: Same as rock crystal, but with distinct pleochroism giving two colours in dichroscope: reddish-purple and bluish-purple.

Localities: Brazil, Ceylon, Urals, Madagascar, Uruguay, Germany.

Incorrect Names: Violet sapphire and violet spinel wrongly called Oriental amethyst.

Special Type: Burnt amethyst has a brown colour resembling that of topaz; sometimes called topaz quartz. (The name topaz is incorrect and must not be used for this mineral.)

1. *c.* **Citrine.** Fr: *Citrine*; Ger: *Citrin*; It: *Citrina.* (Pl. XIV, 6, p. 225.)

Colour: Ranges from pale yellow to brownish yellow. (If the colours are stronger the stone is probably a burnt amethyst, which has been given a golden-yellow to deep brownish colour by the application of heat. This can usually be recognised by its lamellar structure, which is typical of amethysts.)

Properties: Same as rock crystal; pleochroism very weak, usually two shades of yellow.

Localities: Brazil, Madagascar.

Incorrect Names: Citrine is often called topaz by jewellers, who distinguish the true topaz by the prefix Brazilian. Deep yellow to orange-yellow varieties of citrine have been (incorrectly) called Madeira topaz.

1. *d.* **Smoky Quartz,** also **Cairngorm.** Fr: *Quartz fumé*; Ger: *Rauchquarz*; It: *Quarzo affumicato.*

Colour: Cairngorm is smoky yellow to brownish; smoky quartz, smoky brown; very dark brown to black varieties are called morion.

Properties: Same as rock crystal; pleochroism good; colours in dichroscope: pale grey and yellowish-brown.

Localities: Brazil, Madagascar, Urals, Alps. Cairngorms were formerly plentiful in the Cairngorm Mountains of Scotland, but are now less frequently found. Fine cairngorms have also been found in Colorado (U.S.A.) and in Manchuria.

2. **Chalcedony Group.** Fr: *Calcédoine*; Ger: *Chalcedon*; It: *Calcedonia.*

Two main groups of chalcedony can be distinguished:

(i) Unstriped chalcedonies, including common chalcedony, carnelian, heliotrope, jasper, plasma, and chrysoprase.

(ii) Striped chalcedonies, including the important varieties onyx and agate.

2. *a.* **Common Chalcedony.**

Colour: Greyish-blue.

Common chalcedony is only used as a gemstone when it contains particular inclusions, such as dentritic growths of iron oxide (e.g. in moss agate or mocha stone).

2. *b.* **Jasper.** Fr: *Jaspe*; Ger: *Jaspis*; It: *Diaspor.* (Pl. XII, 8, 13, p. 209.)

An impure, opaque form of silica, coloured according to the impurities present. Thus the colour of red jasper is due to the presence of ferric oxide, that of yellow jasper to hydrated ferric oxide (limonite) and that of brownish jasper to manganese oxide.

2. *c.* **Heliotrope.** Fr: *Héliotrope*; Ger: *Heliotrop*; It: *Eliotropo* (Pl. XIV.8, p. 225.)

Colour: Dark green jasper speckled with red (due to ferric oxide).

Properties: Hardness, 6·5–7; S.G., 2·65.

Incorrect names: Haematite, bloodstone.

2. *d.* **Carnelian** or **Carneol.** Fr: *Carnéol* (=Cornaline); Ger: *Karneol*; It: *Carnolia.* (Pl. XII, 4, p. 209.)

A form of chalcedony coloured reddish-brown by ferric oxide.

Use: Formerly much used for cameos; signet rings.

2. *e.* **Plasma.** Fr: and Ger: *Plasma.*

Colour: Green like heliotrope, but no red inclusions. The green colour is due to ferrous oxide and hydroxide.

2. *f.* **Chrysoprase.** Fr: *Crysoprase*; Ger: *Chrysopras*; It: *Chrysoprasa.*

Colour: Apple-green chalcedony, not deep green like heliotrope or plasma. Colour due to presence of nickel hydroxide. (Pl. XIII, 13, p. 216.)

Properties: Those of the other dense forms of silica.

Localities: Germany, U.S.A.

Use: A popular ornamental stone.

2. *g.* **Agate.** Fr: *Agate*; Ger: *Achat*; It: *Agata.* (Pl. XVI, 2, 4, 12, p. 238), and **Onyx.** Fr: *Onyx*; Ger: *Onyx*; It: *Onice.* (Pl. XVI, 6, p. 238.)

Banded varieties of chalcedony. Agate usually has two, three, or more parallel bands of variously coloured material, often arranged concentrically. Onyx usually has only black and white bands. Red and white or brown and white banded onyx is called *sardonyx*.

Properties are those of chalcedony, i.e. Hardness, 6·5–7; S.G., 2·59–2·67; R.I., 1·54–1·55.

Varieties: Moss agate is a milky variety with dentritic (tree-shaped) inclusions which are often green.

Localities: Brazil, India, Madagascar, Germany, also Scotland.

Imitations: Chalcedony is artificially coloured in a wide range of colours and patterns so as to resemble natural agate. Some of the dyes used are not stable and fade on exposure to sunlight, but the "burnt" varieties are stable in light.

3. *a.* **Aventurine.** Fr: *Avanturine*; Ger: *Aventurinquarz*; It: *Avanturina.* (Pl. XIII, 7, p. 216.)

Colour: Golden or greenish, spangled ("schiller") due to small inclusions of mica. The matrix is brownish and a metallic sheen is produced by the inclusions. There are two varieties:

(i) With inclusions of chrome-mica (green),

(ii) With inclusions consisting of small flakes of ferric oxide (red). These have no great value as gemstones.

Localities: Genuine aventurine occurs in India and the Urals.

Imitations: A very similar substance is produced from glass with small included crystals of copper.

3. *b.* **Quartz Cat's Eye.** Fr: *Oeil de Chat*; Ger: *Quarzkatzenauge*; It: *Occio di Gatto.*

Massive quartz enclosing light-coloured fibrous asbestos (mineralogically an amphibole-asbestos). When cut *en cabochon* it produces a typically undulating light reflection known as a "chatoyant" effect. Quartz cat's eye does not have the opalescence of true cat's eye (see chrysoberyl, p. 220). In tiger's eye and falcon's eye the chatoyant effect is caused by the mineral crocidolite (amphibole family).

3. *c.* **Tiger's Eye.** Fr: *Oeil de Tigre*; Ger: *Tigerauge*; It: *Occio de Tigro.*

Identical in structure to cat's eye, but the chatoyant effect is produced by inclusions of crocidolite which has been oxidised to a golden-brown colour.

3. *d.* **Falcon's Eye.**

The structure is identical to that of cat's eye and tiger's eye. The included mineral is crocidolite which has not been oxidised and is blue in colour.

3. *e.* **Prase.** Fr: *Prase*; Ger: *Prasem*; It: *Prasio.*

A fibrous quartz similar in structure to the cat's eye stones, but the included fibres in this case are actinolite (a green member of the amphibole family), which give the stone a leek-green colour.

3. *f.* **Rose Quartz.** Fr: *Quartz rose*; Ger: *Rosenquarz*; It: *Quarzo rosa.* (Pl. XII, 11, 17, p. 209.)

A coarsely granular quartz, pale pink in colour, often cloudy. Much used for ornaments. Pleochroism: Pale whitish and rose red. Asterism (star structure) is well seen in stones cut into roundish (semispherical) shapes.

3. *g.* **Sapphire Quartz and Amethyst Quartz.**

Varieties with inclusions of blue or purple crocidolite fibres. (Both types can more suitably be called falcon's eye.)

4. *a.* **Opal.** Fr: *Opale*; Ger: *Opal*; It: *Opale.* (Pl. XII, 10, p. 209; Pl. XVI, 5, 13-14, p. 238.)

Colour: Play of rainbow colours on milky-white background.

Properties: Hardness, 5–6·5; S.G., 1·9–2·3; R.I., 1·44–1·46. Chem. Comp., $SiO_2.nH_2O$ (about 90 per cent. SiO_2 and 10 per cent. H_2O); Crystalline State: amorphous substance without any particular structure; Opt. Props., behaves as an isotropic substance and is therefore singly refractive and non-pleochroic.

Localities: Mainly Mexico and Australia; formerly also Hungary.

Varieties: (i) Fire-red to brownish-red: Fire opal or Gold opal. (ii) Colourless stone with play of colours: Water opal. (iii) Black with opalescent specks: Black opal. (iv) Wood petrified by opal: Wood opal. (v) When opal occurs as the groundmass in a rock, it is known as opal matrix.

Incorrect Name: Moonstone called Ceylon opal.

Ruby, see **Corundum** (p. 221).

Spinel. Fr: *Spinelle*; Ger: *Spinell*; It: *Spinello.* (Pl. XI, 7, p. 200; Pl. XII, 5, p. 209; Pl. XV, 2, p. 235.)

Colour: Occurs in all colours; the most common are red, red-brown, dark greyish-blue, yellow, purple; also greenish, blue to brownish black. Pure green spinels are rare.

Variations in colour are due to presence of FeO, Fe_2O_3 or Cr_2O_3 which are respectively responsible for the pale green, red, and blue varieties.

Properties: Hardness, 8; Chem. Comp., $MgAl_2O_4$; R.I., high, 1·72; Crystal System, cubic, usually occurs in octahedra, sometimes twinned;

Opt. Props., isotropic, therefore non-pleochroic, and dichroscope images are identical.

Localities: Ceylon and India are most important.

Imitations and Incorrect Names: Green and red garnets as Arizona spinel; almandine garnet as Almandine spinel.

Incorrect Names (Spinels): Dark red spinel called ruby or ruby-spinel (a common misnomer to be guarded against); rose-coloured spinel called Balas ruby; orange spinel called rubicelle; red-brown spinel called hyacinth; violet spinel called oriental amethyst; blue to greenish spinel called sapphire spinel.

Blue spinel is being produced synthetically, and could be confused with sapphire; but the lack of double refraction (birefringence) of spinel is diagnostic.

Value: Variable, depending on purity of colour, freedom from faults, lustre and size of stone. Crystals are usually very small.

Spodumene. Fr: *Spodumen*; Ger: *Spodumen*; It: *Spodumeno.*

Colour: There are two varieties:

a. Hiddenite – yellowish green to bluish green.

b. Kunzite – pink, lilac to purple.

Properties: Hardness, 6·5–7; S.G., 3·13–3·2; R.I., 1·65–1·68; Chem. Comp., $AlLi(Si_2O_6)$; Crystalline System, monoclinic; Pleochroism, good, the two colours in the dichroscope being green and yellowish green (hiddenite), or rose-lilac and pale purple (kunzite).

Localities: Both varieties are found in U.S.A., Brazil, and Madagascar. Hiddenite occurs in North Carolina, kunzite in California, and yellowish-brown kunzite in Minas Geraes (Brazil).

Distinguishing features:

a. Hiddenite is distinguished from emerald by its dichroism:
   Hiddenite: green and yellowish green.
   Emerald: green and bluish green.

b. Kunzite differs from the superficially similar amethyst in having a higher specific gravity; also kunzite is biaxial, amethyst uniaxial.

Synthetic Gemstones.

It has not yet been possible in the case of all important gemstones to produce synthetic stones whose properties are identical to those of their natural equivalents. The most important gemstones which have been produced synthetically for a number of years are described below.

1. **Synthetic Corundum**, produced as red (ruby), blue (sapphire), yellow, pink, brownish-red (padparadscha), and colourless varieties.

   a. **Ruby:** Cut natural rubies can be distinguished from synthetic rubies by their lack of dichroism in the dichroscope. This is due to the fact that the table facet of the natural stone is cut at right angles to the optic axis. In synthetic rubies the table facet is cut at an oblique angle to the optic axis on account of the presence of cleavage planes, and the stone is therefore dichroic. Synthetic star rubies have for some years been produced by the Linde Air Products Company (U.S.A.). These are very similar to the natural stone, but can now be distinguished from the latter microscopically.

b. **Sapphire:** Both ordinary and star sapphires are being produced artificially. The latter are not of the same quality as the star rubies mentioned above. A close examination of a synthetic star sapphire reveals that its star does not, as in the case of its natural equivalent, extend to the base of the cabochon. A simple test is to cover the base of the stone with methyline iodide and to examine the stone carefully through the globule of moisture. If the star is no longer visible the star sapphire is an artificial one.

c. **Corundum:** Synthetic corundums are often made in colours which are not found in natural stones. The most common is a green corundum which closely resembles alexandrite, the green variety of chrysoberyl, and is therefore called synthetic alexandrite. The resemblance even applies to the difference in colour when seen in daylight (deep green) and artificial light (red), which is found in alexandrite.

2. **Synthetic Spinels** are known to exist in practically every colour, but as the synthesis of spinels is not a paying proposition, very few are actually made. The following are the most common synthetic types:
   a. Blue zircon-coloured spinel.
   b. Green alexandrite-coloured spinel.
   c. Pale blue aquamarine-coloured spinel.

   These can be distinguished from the natural stones they are meant to imitate by the following properties:
   a. The spinel is isotropic and not doubly refractive, as is zircon. Further, zircon is dichroic (deep blue and pale washed out blue) and spinel is not.
   b. The spinels lack the dichroism of natural alexandrite.
   c. Natural aquamarine is doubly refractive, which the aquamarine-coloured spinel is not. The spectroscope provides a further means of distinguishing between synthetic spinel and aquamarine. The former absorbs the yellow range of the spectrum and lets through the red range completely, whereas in the case of the latter the exact opposite applies.

3. **Synthetic Emeralds** were produced before the war in Germany (called Igmerald, from the name of the producers, I.G. Farben). Since the war they have been made by C. F. Chatham of San Francisco, U.S.A. The latter have produced large numbers of synthetic stones up to $\frac{3}{4}$ carat in weight. These can be distinguished from natural emerald by their lower refractive index and birefringence.

4. **Synthetic Diamonds** had until recently not been produced commercially. They are now being produced by the General Electric Company of America, and a specimen is on exhibition in the British Museum of Natural History. The substance called β-silicon carbide has many physical properties which are similar to those of diamond, as is shown by the following comparisons:

	Diamond = C	Silicon carbide = Si_3C
Refractive Index	2·417	2·667 (even higher than diamond, c.f. white zircon 1·938, and white sapphire 1·773)
Specific Refraction	0·402	0·526 (zircon 0·137, sapphire 0·193)
Dispersion	0·044	0·103 (zircon 0·038, sapphire 0·018)

Silicon carbide has greater "fire" than diamond, is considerably cheaper and can be produced in unlimited quantities.

5. **Synthetic Quartz.** The manufacture of synthetic quartz crystals is relatively simple, and the crystals are much used in the radio industry. They are produced from an aqueous alkaline solution in a steel bomb. The crystal is formed at a pressure of 15,000 lb. per sq. in. at a temperature of about 750° F. It takes about one month to grow a quartz crystal 1 inch long.

6. **Synthetic Rutile**, sometimes called Titania, was first produced commercially in 1948 by an American firm. Most synthetic rutiles used in jewellery are almost colourless, though with a slight yellow tinge. Other colours, such as yellow, red, orange, or blue, are only rarely seen. Rutile owes its attraction to the exceptionally high colour dispersion, which is about six times higher than that of diamond and gives the stone tremendous "fire". It is, however, relatively soft (hardness 6–6½), and does not form a durable gemstone.

   Natural rutile is not normally used as a gemstone, so the only natural stone with which this synthetic product might be confused is diamond. The stupendous fire of rutile, which causes it to flash with colour like water opal, together with its high double refraction (0·287) which is responsible for a doubling of the rear facets when viewed through the front of the stone, are, however, simple distinguishing features. Colourless rutile is never free from a yellowish tinge, and has a greasy body lustre which is quite unlike the lustre of diamond.

7. **Strontium Titanate.** A synthetic stone with the composition of strontium titanate ($SrTiO_3$) has recently been produced. It closely

Plate XV Gemstones: 5 – Brown

1st Row: 1. Staurolite, Switzerland; 2. Spinel, Ceylon; 3. Topaz, Brazil; *2nd Row*: 4. Hessonite, Madagascar; 5. Hyacinth, Thailand; 6. Spessartite (garnet), Madagascar; *3rd Row*: 7. (left above) Topaz, Brazil; 8. (left below) Topaz, Brazil; 9. Jasper, India.

resembles diamond both in appearance and in optical properties. It is colourless and, like diamond, it is isotropic. Its refractive index is 2·41 (diamond, 2·417), but its dispersion is about four times that of diamond, which gives it greater fire and thus a more marked display of colours. Strontium titanate is, however, a relatively soft mineral (hardness $5\frac{1}{2}$) and can be readily distinguished from diamond as it may be scratched with a steel needle.

Topaz. Fr: *Topaze*; Ger: *Topas*; It: *Topazio*. (Pl. XIV, 3, 4, p. 225; Pl. XV, 3, 7, 8, p. 235.)

Properties: Hardness, 8; S.G., 3·5–3·56; R.I., 1·61–1·62; Chem. Comp., $Al_2[(SiO_4|F_2)]$; Crystalline System, orthorhombic; Pleochroism, good, the two colours in the dichroscope being as follows:

a. Colourless topaz – very pale yellow and pale pink.
b. Pale yellow topaz – colourless and greyish yellow.
c. Deep yellow topaz – dark wine-yellow and pale yellow.
d. Pale blue topaz – pale bluish-green and pale pink.
e. Pink topaz – purple and yellowish-red.
f. Pale green topaz – pale green and pale yellow.

Localities: Germany, Brazil (Minas Geraes), U.S.S.R., Australia, Ceylon, South-West Africa, etc.

Incorrect Names, imitations and their distinguishing features:

1. Aquamarine (sometimes called Brazilian aquamarine) used as incorrect name for bluish-green topaz. Distinguishing features: optical properties and specific gravity.
2. Brazilian topaz, a natural topaz from Brazil (correct name).
3. Brazilian ruby, incorrect name for red topaz from Brazil.
4. Indian topaz, incorrect name for yellow corundum. Distinguishing features: topaz is orthorhombic, corundum is hexagonal.
5. King topaz, incorrect name for reddish corundum (padparadscha) from Ceylon.
6. Hyacinth topaz. incorrect name for hyacinth (brownish-red zircon). Distinguishing features: zircon is tetragonal, topaz is orthorhombic; S.G.: zircon 4·70, topaz 3·53.
7. Occidental topaz, incorrect name for citrine. Distinguishing features: citrine, being quartz, is optically uniaxial; has a much smaller S.G.; hardness is two grades lower; and the refractive index is smaller.
8. Oriental topaz, incorrect name for deep-yellow sapphire. Distinguishing features: same as (4) above.
9. Quartz topaz, incorrect name for citrine.
10. Spanish topaz, incorrect name for pale citrine or burnt amethyst.
11. Scottish topaz, incorrect name for cairngorm.
12. Topaz quartz, incorrect name for ordinary citrine.

Tourmaline. Fr: *Tourmaline*; Ger: *Turmalin*; It: *Turmaline*. (Pl. XI, 11, 12, p. 200; Pl. XII, 12, 16, 18, p. 209; Pl. XIII, 17, p. 216.)

Colour: Tourmaline occurs in almost all colours. The most common are: deep green, deep red, blue (=indicolite), colourless (=achroite), rose-red to carmine (=rubellite), brown to black (=schorl).

Properties: Hardness, 7–7·5; S.G., 2·94–3·24; R.I., 1·62–1·65; Chem. Comp., complex boro-silicate of Al, Mg, Fe, alkalis, etc.; Pleochroism, very strong; the three main colour varieties show the following colours in the dichroscope:

a. deep green and olive green,
b. dark green and bluish green,
c. deep red and yellowish green;

Opt. props., optically uniaxial, negative; Crystalline System, hexagonal.

Main Varieties:

a. Rose red to carmine = rubellite (incorrect name, Siberian ruby).

b. Yellowish-green (incorrect name, Brazilian emerald).

c. Pale to dark green (incorrect names, Brazilian emerald, Ceylon chrysolite, Ceylon peridot, and Brazilian peridot).

d. Blue to greenish-blue = indicolite (incorrect name, Brazilian sapphire).

e. Colourless = achroite.

f. Brown to black = schorl.

Distinguishing Features:

1. Rubellite is distinguished from true ruby by its lower refractive index (rubellite, 1·64; ruby, 1·76), inferior hardness (7·25 as against 9), and lower specific gravity (3·15 as against approx. 4).

It is distinguished from pink topaz by its slightly higher refractive index (1·64 as compared with 1·61), its inferior hardness (topaz = 8), and its lower specific gravity (topaz = 3·5–3·56).

Red spinel differs from rubellite in being isotropic (singly refractive), and in having no dichroism. The dichroism of rubellite is very strong, giving a rose-red and yellow image in the dichroscope.

2. Indicolite is distinguished from pale sapphire in the same manner as rubellite is distinguished from ruby, (i.e. tourmaline as distinguished from corundum).

Other minerals resembling indicolite are kyanite (optically biaxial), and blue cordierite (optically biaxial). Indicolite is markedly dichroic, giving blue-grey and pale blue colours in the dichroscope.

3. Green tourmaline is distinguished from emerald (beryl) by its higher refractive index (emerald = 1·57), higher specific gravity (emerald 2·65–2·75) and stronger dichroism.

Green chrysolite (=olivine) is optically biaxial and is readily distinguished from olive-green tourmaline (uniaxial) by this property.

Tourmaline of all colours can be electrically charged by rubbing and will then attract small scraps of paper.

Localities: Brazil (Minas Geraes), South-West Africa, Rhodesia, Madagascar, Ceylon, U.S.A. (Maine, California, Massachusetts), Siberia, Siam, Elba.

Value: Deep-green stones of good quality are valuable.

Turquoise. Fr: *Turquoise*; Ger: *Türkis*; It: *Turchese*. (Pl. XI, 3, p. 200.)

Colour: Sky blue, blue, bluish green, greenish, sometimes yellowish.

Properties: Hardness, 5·5–6; S.G., 2·5–2·9, varies according to composition; Chem. Comp., $CuAl_6[(OH)_8|(PO_4)_4].5H_2O$. The mineral is very finely crystalline (cryptocrystalline), and occurs in large, often reniform, nodules. These are traversed by minute veinlets and cracks. Turquoise is transparent, and the refractive index is 1·6–1·65 (when determinable). For practical purposes turquoise can be classed as amorphous.

Localities: Mainly Persia, Sinai Peninsula, and Turkey. Also U.S.A. (Nevada, California, New Mexico, Texas, etc.).

Imitations: Dyed agate is called agate turquoise, dyed serpentine is called turquoise. Imitation turquoise is made from compressed aluminium phosphates coloured blue by copper oleate. Synthetic turquoise is easily fused by the blowpipe, whereas genuine turquoise may change colour and splinter but does not fuse.

Zircon. Fr: *Zirkon*; Ger: *Zirkon*; It: *Zirkone*. Gemstone: **Hyacinth.** Fr: *Hyacinth-Jargon*; Ger: *Hyazinth-Jargon*; It: *Giacinto*. (Pl. XI, 5, p. 200; Pl. XV, 5, p. 235; Pl. XVI, 7, p. 238.)

Colour: Colourless and all other colours, esp. blue, green, red-brown (hyacinth), yellowish, purple.

Properties: Hardness, 7–7·5; S.G., 4·33–4·75; Chem. Comp., $Zr(SiO_4)$; Crystalline System, tetragonal, crystals have a square basal section; R.I., 1·99 and 1·93, the highest R.I. next to diamond; optically positive.

Distinguishing Features: Hyacinth (red-brown zircon) is distinguished from brownish-red garnet by its birefringence (garnet is isotropic), higher refractive index, and marked dichroism (red and yellow images).

Some varieties of hyacinth resemble diamond, and the refractive index of the two minerals is similar. Hyacinth is birefringent (uniaxial) while diamond is isotropic. Diamond also has a lower S.G. (3·5–3·57).

Localities: Ceylon, Siberia, India, Siam, Burma, Urals, Australia (New South Wales), North America.

Special Names: Red-brown zircon = hyacinth; blue zircon from U.S.A. sometimes called starlight or starlite; pale yellow zircon formerly called jargoon; brown zircon formerly called zirconite.

Incorrect Names: White zircon called Matura or Matara diamond; bluish-green zircon called Siam aquamarine.

Other Stones: Hyacinth-coloured sapphire called oriental hyacinth.

Plate XVI Gemstones: 6 – Black, White

1st Row: 1. Rock Crystal, Madagascar; 2. Moss Agate, India; 3. Rock Crystal Madagascar; *2nd Row*: 4. Agate (banded), Brazil; 5. Milky Opal, Brazil; 6. Onyx Brazil; 7. Zircon, Thailand; *3rd Row*: 8. Haematite, England; 9. Diamond, South Africa; 10. Moonstone, Ceylon; *Below*: 11. Diamond (crystal), South Africa; 12 Moss Agate, India; *Bottom Row*: 13. Opal (uncut), Australia; 14. Opal, Australia

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W. J. ARKELL

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