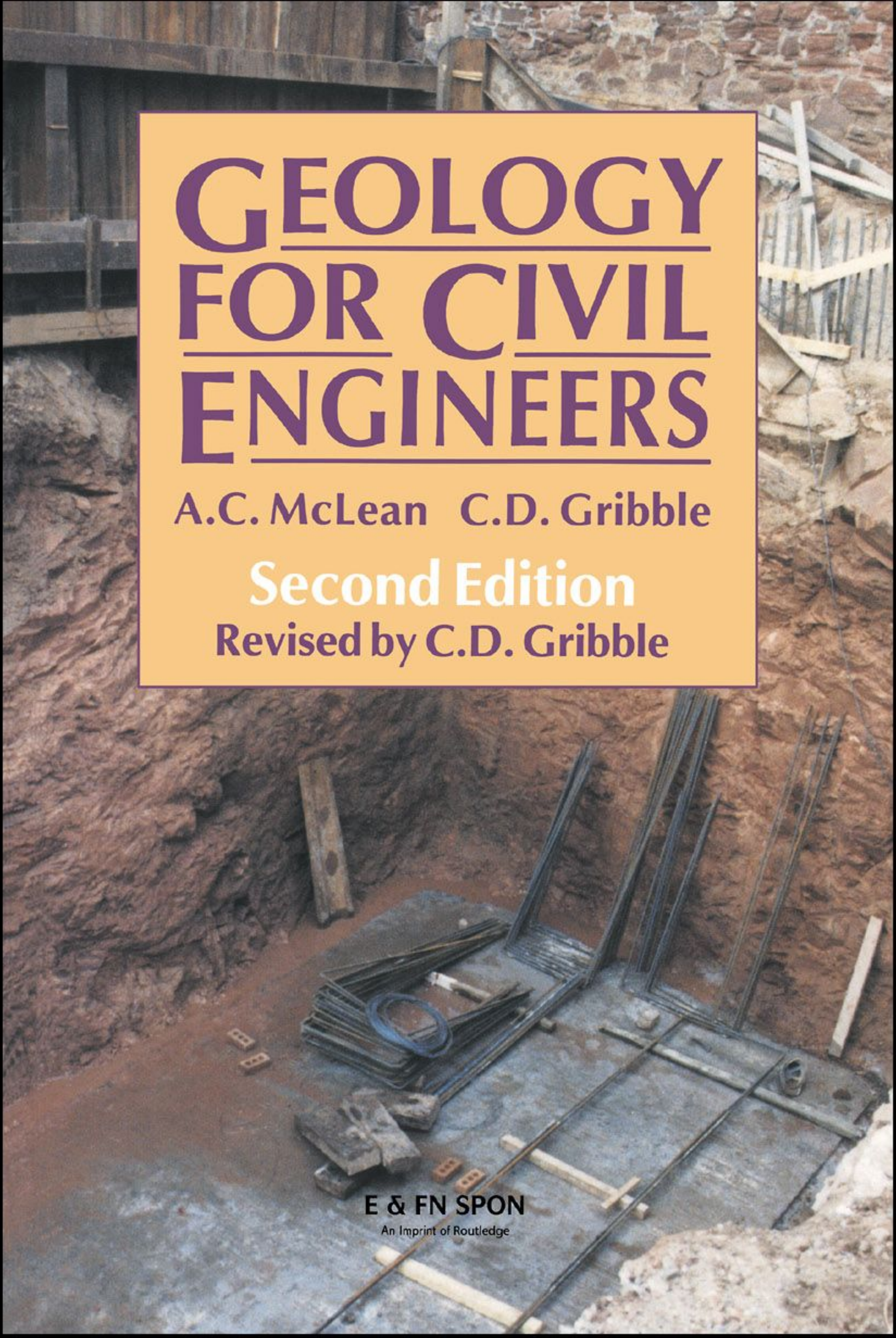

GEOLOGY FOR CIVIL ENGINEERS

A.C. McLean C.D. Gribble

Second Edition

Revised by C.D. Gribble

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GEOLOGY FOR CIVIL ENGINEERS

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This book is
dedicated to the memory of
Dr Adam McLean

Preface to the second edition

Adam McLean and I were asked by Roger Jones of Allen & Unwin to consider producing a second edition of our book after the first edition had been published for a few years. Critical appraisals of the first edition were sought, and I am most grateful to Professor Van Dine and Dr Drummond for their many detailed and helpful comments. I should also particularly like to thank Dr Bill French, who pointed out where corrections were required and also where additions (and subtractions) to the text could gainfully be made without changing the original flavour of our book. I have incorporated most of these helpful suggestions and hope that the text has been improved, but any mistakes and inaccuracies are mine.

At the beginning of the revision Adam McLean became ill, and the illness got progressively worse until, in March 1983, he died. In memory of all the enjoyment we had with the first edition, I should like to dedicate the second edition to Adam with my respect.

Colin Gribble
Glasgow, September 1983

Preface to the first edition

The impulse to write this book stemmed from a course of geology given by us to engineering undergraduates at the University of Glasgow. The course has changed, and we hope improved, during the twenty years since one of us was first involved with it. It was essentially a scaled-down version of an introductory course to science undergraduates; it is now radically different both in content and in the mode of teaching it. Our main thought, as we gradually reshaped it, was to meet the special interests and professional needs of budding civil engineers. It is a matter for serious debate as to whether time should be found within an engineering course for classes of a broad cultural nature. Our experience in teaching indicates that the relevance of subject matter to the vocation of those taught usually increases their interest and enthusiasm. Furthermore, in engineering curricula which are being crowded by new and professionally useful topics, we doubt whether a place would have been found for a general course on geology which discussed, for example, the evolution of the vertebrates or the genetic relationship of the various basic plutonic rocks. On the other side of the scale, we have firm beliefs that educated men and women should be aware of the Theory of Natural Selection and its support from the fossil record, and should be aware of other major scientific concepts such as plate tectonics. We have found some space for both of these in our book. Other apparent digressions from what is obviously relevant may serve a professional purpose. For example, civil engineers must have an insight into how geologists reach conclusions in making a geological map, in order to evaluate the finished map. Similarly, they should appreciate how and why geologists differentiate between (say) gabbro and diorite, not because these differences are important for most engineering purposes but so that they can read a geological report sensibly and with the ability to sift the relevant from the irrelevant information.

Our course and this book are essentially an introduction to geology for civil engineers, which is adequate for the needs of their later careers, and on which further courses of engineering geology, soil mechanics or rock mechanics can be based. They are not conceived as a course and text on engineering geology. We have, however, extended the scope of the book beyond what is geology in the strict sense to include engineering applications of geology. This is partly to demonstrate the relevance of geology to engineering, and partly in the expectation that the book, with its appendices, will also serve as a useful handbook of facts and methods for qualified engineers and other professionals who use geology. The reactions of the majority of those who reviewed our first draft reassured us that our ideas were not peculiar to ourselves, and that we were not the only teachers of geology who felt the need for a textbook tailored to them. Other views ranged from a preference for altering the book to make it a comprehensive account of the whole of geology largely devoid of material on engineering, to a preference for a more radical change along the lines we were following, which would have produced an introductory text in engineering geology rather than geology. The balance of opinion seemed reasonably close to our own prescription, though we are grateful for the many constructive suggestions that have led to major changes of content and arrangement as well as minor amendments. If we have not ended at the centre of the many opinions that colleagues and friends have kindly given us, it is because at the end of the day we have special interests and views ourselves, and it is our book. We hope that you will find it useful and readable.

ADAM McLEAN
COLIN GRIBBLE
Glasgow, August 1978

Acknowledgements

We wish to thank the friends and colleagues who assisted us generously and patiently by their advice, by their critical reading of our text and by their encouragement. We considered carefully all the points that they made, and many significant improvements from our original draft are witness to this, just as any persistent failings, and any errors, are our own responsibility. A special thank you is due to Professor W.Dearman of the University of Newcastle, Professor P.McL.Duff of the University of Strathclyde, Dr I.Hamilton of Paisley College of Technology, Dr D. Wilson of the University of Liverpool, and Professor Boyd of the University of Adelaide, for reading critically the entire text and making a host of useful comments. We were fortunate in being able to discuss particular sections of the book with friends, whose specialised knowledge was a source of expert opinion and information, and we thank all of them sincerely. They include Mr R.Eden, Assistant Director BGS; Mr N. Dron of Ritchies Equipment Limited, Stirling; Mr C.I.Wilson, Dunblane; and Dr G.Maxwell of the University of Strathclyde. We are grateful to Professor B.E.Leake of our own department at the University of Glasgow for help and encouragement; to other colleagues there, particularly Dr J. Hall, Dr B.J.Bluck and Dr W.D.I.Rolfe; to the two typists, Mrs D.Rae and Mrs D.MacCormick, who prepared the draft copy; and to the wife of one of us, Mrs Beatrice McLean, who did most of the preparation of the Index-Glossary as well as offering help at all stages. Last, but not least, we acknowledge the courteous shepherding of Mr Roger Jones of George Allen & Unwin from the start of it all, to this point.

The second edition could not have been produced without the very great help and guidance I received from Roger Jones and Geoffrey Palmer of George Allen & Unwin. I also wish to thank Mary Sayers, whose careful editing of the revised text unquestionably improved the final product, and Beatrice McLean who helped with the Index-Glossary for this edition. Finally I should like to thank Professor Bernard Leake of my own department for his help and encouragement at a particularly difficult time, Dr Brian Bluck for his guidance on sedimentary rocks and processes, the secretaries of Glasgow University Geology Department—Irene Wells, Dorothy Rae, Irene Elder and Mary Fortune—who typed the entire book a second time, and my sister, Elizabeth, who proof read the entire book.

C.D.G.

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Introduction

1.1 Role of the engineer in the systematic exploration of a site

The investigation of the suitability and characteristics of sites as they affect the design and construction of civil engineering works and the security of neighbouring structures is laid out in British Standard Code of Practice for site investigations (BS 5930:1981, formerly CP 2001). The sections on geology and site exploration define the minimum that a professional engineer should know.

The systematic exploration and investigation of a new site *may* involve five stages of procedure. These stages are:

(1) *preliminary investigation* using published information and other existing data;
(2) *a detailed geological survey* of the site, possibly with a photogeology study;
(3) *applied geophysical surveys* to provide information about the subsurface geology;
(4) *boring, drilling and excavation* to provide confirmation of the previous results, and quantitative detail, at critical points on the site; and
(5) *testing of soils and rocks* to assess their suitability, particularly their mechanical properties (**soil mechanics** and **rock mechanics**), either *in situ* or from samples.

In a major engineering project, each of these stages might be carried out and reported on by a consultant specialising in geology, geophysics or engineering (with a detailed knowledge of soil or rock mechanics). However, even where the services of a specialist consultant are employed, an engineer will have overall supervision and responsibility for the project. The engineer must therefore have enough understanding of geology to know how and when to use the expert knowledge of consultants, and to be able to read their reports intelligently, judge their reliability, and appreciate how the conditions described might affect the project. In some cases the engineer can recognise common rock types and simple geological structures, and knows where he can obtain geological information for his preliminary investigation. When reading reports, or studying geological maps, he must have a complete understanding of the meaning of geological terms and be able to grasp geological concepts and arguments. For example, a site described in a geological report as being underlain by clastic sedimentary rocks might be considered by a civil engineer to consist entirely of sandstones. However, clastic sedimentary rocks include a variety of different rock types, such as conglomerates, sandstones and shales or mudstones. Indeed it would not be unusual to find that the site under development contained sequences of some of these different rock types—say, intercalated beds of sandstone and shale, or sandstone with conglomerate layers. Each of these rock types has different engineering properties, which could affect many aspects of the development work such as core drilling into, and excavation of, the rock mass, and deep piling into the underlying strata.

The systematic testing of the engineering properties of soils and rocks lies between classical geology and the older disciplines of engineering, such as structures. It has attracted the interest of, and contributions from, people with a first training in either geology or engineering, but has developed largely within departments of civil and mining engineering and is usually taught by staff there. These tests, and the advice about design or remedial treatment arising from them, are more naturally the province of the engineer, and fall largely outside the scope of this book. The reasons for this lie in the traditional habits and practices of both fields. The engineer's training gives him a firm grounding in expressing his conclusions and decisions in figures, and in conforming to a code of practice. He also has an understanding of the constructional stage of engineering projects, and can better assess the relevance of his results to the actual problem.

These reasons for the traditional divisions of practice between geology and engineering must be qualified, however, by mentioning important developments during the last decade. An upsurge of undergraduate and postgraduate courses, specialist publications and services in engineering geology, initiated or sponsored by departments of geology or by bodies such as the Geological Society of London, has reflected an awakened interest in meeting fully the geological needs of engineers and in closing the gaps that exist between the two disciplines.

1.2 Relevance of geology to civil engineering

Most civil engineering projects involve some excavation of soils and rocks, or involve loading the Earth by building on it. In some cases, the excavated rocks may be used as constructional material, and in others, rocks may form a major part of the finished product, such as a motorway cutting or the site f or a reservoir. The feasibility, the planning and design, the construction and costing, and the safety of a project may depend critically on the geological conditions where the construction will take place. This is especially the case in extended 'greenfield' sites, where the area affected by the project stretches for kilometres, across comparatively undeveloped ground. Examples include the Channel Tunnel project and the construction of motorways. In a section of the M9 motorway linking Edinburgh and Stirling that crosses abandoned oil-shale workings, realignment of the road, on the advice of government geologists, led to a substantial saving. In modest projects, or in those involving the redevelopment of a limited site, the demands on the geological knowledge of the engineer or the need for geological advice will be less, but are never negligible. Site investigation by boring and by testing samples may be an adequate preliminary to construction in such cases.

1.3 The science of geology

Geology is the study of the solid Earth. It includes the investigation of the rocks f forming the Earth **(petrology)** and of how they are distributed (their **structure**), and their constituents (**mineralogy** and **crystallography**). **Geochemistry** is a study of the chemistry of rocks and the distribution of major and trace elements in rocks, rock suites, and minerals. This can lead to an understanding of how a particular rock has originated **(petro genesis), and also, in the broadest sense, to a knowledge of the chemistry of the upper layers of the Earth.**

The distribution of rocks at the Earth’s surface is found by making a **geological survey** (that is, by **geological mapping**) and is recorded on **geological maps**. This information about rocks is superimposed on a topographic base map. Knowledge of the nature and physical conditions of the deeper levels of the planet can be gained only by the special methods of **geophysics,** the twin science of geology; the term ‘Earth sciences’ embraces both. From the theory and methods of geophysics, a set of techniques **(applied geophysics)** has been evolved for exploring the distribution of rocks of shallower levels where the interests of geologists and geophysicists are most intertwined.

Knowledge of the Earth at the present time raises questions about the processes that have formed it in the past: that is, about its history. The interpretation of rock layers as Earth history is called **stratigraphy,** and a study of the processes leading to the formation of sedimentary rocks is called **sedimentology**. The study of fossils **(palaeontology)** is closely linked to Earth history, and from both has come the understanding of the development of life on our planet. The insight thus gained, into expanses of time stretching back over thousands of millions of years, into the origins of life and into the evolution of man, is geology’s main contribution to scientific philosophy and to the ideas of educated men and women.

1.4 The aims and organisation of this book

This book defines essential terms, explains concepts, phenomena and methods of argument, and shows how to reach conclusions about the geology of a site and to appreciate its relevance to an engineering project. It is envisaged as a text to accompany an introductory course for engineering undergraduates. It also contains additional information that will be of use to students who intend carrying their study of applied geology beyond a basic course. At the same time, the book is intended to be more than a narrow professional manual, and it is hoped that it will advance the general scientific education of students by presenting, for example, the nature and use of inductive reasoning in science.

The book is arranged so that first the rocks and soils that form the Earth are described, followed by the factors that control their distribution within it. Next it shows how their distribution at one place may be determined, and finally it discusses the relative importance of geological factors in some types of engineering project.

The wording is as succinct as possible. Academic geologists have manufactured words in abundance to describe their science, and applied geologists have not only added to the vocabulary but have also acquired a jargon—sometimes only local in use—from their contacts with miners. Since the development of an ability to read geological reports is an aim of the book, it would be contradictory to omit ruthlessly every geological term that seems inessential to the concept or general argument under discussion, however tempting such drastic editing may be. To guide the student in acquiring a basic geological vocabulary, the important terms are printed in bold type, usually at their first occurrence. In addition they are listed in the index, which therefore also serves as a glossary. Again, since the book is meant to serve the double purpose of reading and later reference, there are appendices of some factual details that might otherwise have clogged the text. With much of this information, it is enough that the engineer should understand, for example, how and why properties vary among the common rock types, with only a sense of the order of magnitude of numerical values.

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2
Minerals and rocks

2.1 The common rock-forming minerals

2.1.1 The properties of minerals

A mineral is a naturally occurring inorganic substance which has a definite chemical composition, normally uniform throughout its volume. In contrast, rocks are collections of one or more minerals. In order to understand how rocks vary in composition and properties, it is necessary to know the variety of minerals that commonly occur in them, and to identify a rock it is necessary to know which minerals are present in it. Two techniques are employed to identify minerals:

(a) *the study of a hand specimen* of the mineral, or the rock in which it occurs, using a hand lens (×8 or ×10) and observing diagnostic features; and
(b) *the examination of a thin slice* of the mineral, ground down to a thickness of 0.03 mm, using a microscope, the rock slice being mounted in transparent resin on a glass slide.

The former method is by far the most useful to an engineer, since proficiency in the use of a microscope requires an amount of study out of proportion to its future benefit, except for the specialist engineering geologist. However, examination of rocks in thin section will provide excellent details of rock textures, some of which are difficult to see in the hand specimen. In hand-specimen identification, some features are purely visual (for example, the colour of the mineral) but others, such as hardness, have to be assessed by simple tests. (If the mineral grains are large enough, and an accurate value is needed, they may be removed from the rock and measured in a laboratory.)

A mineral specimen can be an object of beauty in those occasional circumstances where it forms a single crystal or cluster of crystals. The requirements are that the mineral has been free to grow outwards into the solution or melt from which it formed, not obstructed by other solid matter, nor hindered anywhere around it by a shortage of the constituents needed for growth. In such an environment, it develops a regular pattern of faces and angles between the faces, which is characteristic of a particular mineral. The study of this regularity of f form, and of the internal structure of the mineral to which it is related, is called **crystallography**. In most mineral specimens, the local conditions have hindered or prevented some of the faces from developing, or the surface of the mineral is formed simply from the fractures along which it was broken off when collected. Even in these specimens, there is the same regular internal arrangement of atoms as in a perfect crystal of the same mineral. The specimen is **crystalline** even though it is not a crystal. Furthermore, in an imperfect crystal, where some faces have developed more than others to produce a distorted external form, the angles between the faces are still the same as in a perfect crystal.

A study of the regularity of crystal forms, including the values of interfacial angles, shows that all crystals possess certain **elements of symmetry**. These elements include:

(a) **a centre of symmetry,** which a crystal possesses when all its faces occur in parallel pairs on opposite sides of the crystal. A cube, for example, possesses a centre of symmetry but a tetrahedron does not.
(b) an **axis of symmetry,** which is a line through a crystal such that a complete rotation of 360° about it produces more than one identical view. There are four types of axis of symmetry: a **diad** axis, when the same view is seen twice (every 180°); a **triad** axis, when the same view is seen three times (every 120°); a **tetrad** axis (four times—every 90°), and finally a **hexad** axis (six times—every 60°).
(c) a **plane of symmetry,** which divides the crystal into halves, each of which is a mirror image of the other without rotation.

On the basis of the number and type of symmetry elements present in naturally formed crystals, seven **crystal systems** have been proposed, to which *all* minerals can be assigned.

T**winning** in crystals occurs where one part of a crystal has grown or has been deformed such that its atomic structure is rotated or reversed compared with the other part. Multiple twinning occurs and is a diagnostic property in the plagioclase feldspars (see Section 2.1.3).

As well as crystallography (form) and twinning, other important properties are used to identify minerals in hand specimens, as follows:

COLOUR AND STREAK

The **colour** of a mineral is that seen on its surface by the naked eye. It may depend on the impurities present in light-coloured minerals, and one mineral specimen may even show gradation of colour or different colours. For these reasons, colour is usually a general rather than specific guide to which mineral is present. Iridescence is a play of colours characteristic of certain minerals. The **streak** is the colour of the powdered mineral. This is most readily seen by scraping the mineral across a plate of unglazed hard porcelain and observing the colour of any mark left. It is a diagnostic property of many ore minerals. For example, the lead ore, galena, has a metallic grey colour but a black streak.

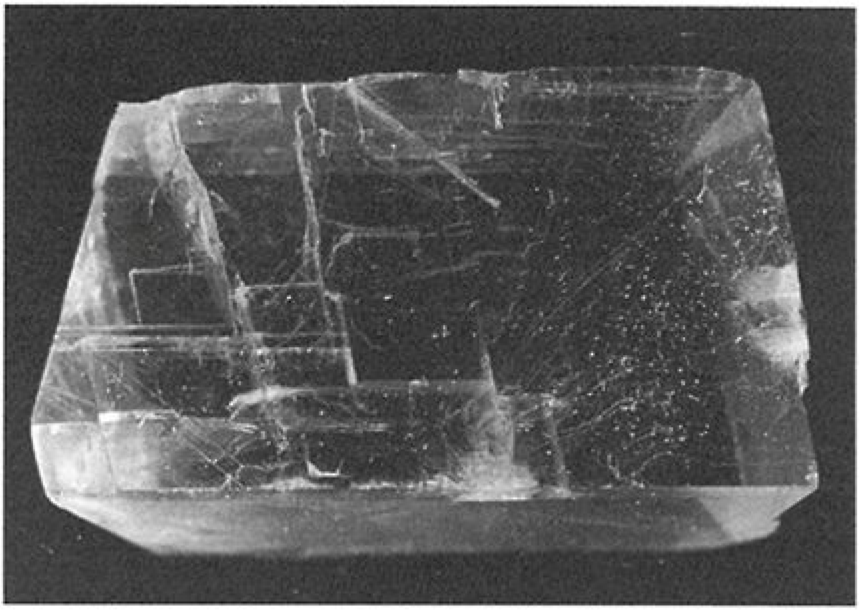


Figure 2.1 A crystal of calcite showing cleavage.

CLEAVAGE

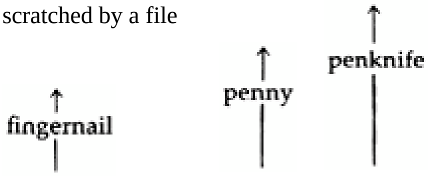
Most minerals can be cleaved along certain specific crystallographic directions which are related to planes of weakness in the atomic structure of the mineral (see Fig. 2.1). These **cleavage directions** are usually, but not always, parallel to one of the crystal faces. Some minerals, such as quartz and garnet, possess no cleavages, whereas others may have one (micas), two (pyroxenes and amphiboles), three (galena) or four (fluorite). When a cleavage is poorly developed it is called a **parting**.

A surface formed by breaking the mineral along a direction which is not a cleavage is called a **fracture** and is usually more irregular than a cleavage plane. A fracture may also occur, for example, in a specimen which is either an aggregate of tiny crystals or glassy (that is, non-crystalline). A curved, rippled fracture is termed **conchoidal** (shell-like).

HARDNESS

The relative hardness (H) of two minerals is defined by scratching each with the other and seeing which one is gouged. It is defined by an arbitrary scale of ten standard minerals, arranged in **Mohs' scale of hardness,** and numbered in degrees of increasing hardness from 1 to 10 (Table 2.1). The hardnesses of items commonly available are also shown, and these may be used to assess hardness within the lower part of the range. The only common mineral that has a hardness greater than 7 is garnet. Most others are semi-precious or precious stones.

Table 2.1 Mohs' scale of hardness.

10	diamond	carbon	
9	corundum	alumina	
8	topaz	aluminium silicate	
7	quartz	silica	scratches glass
6	feldspar	alkali silicate	scratched by a file
5	apatite	calcium phosphate	
4	fluorspar	calcium fluoride	
3	calcite	calcium carbonate	
2	gypsum	hydrated calcium sulphate	
1	talc	hydrated magnesium silicate	

LUSTRE

Light is reflected from the surface of a mineral, the amount of light depending on physical qualities of the surface (such as its smoothness and transparency). This property is called the **lustre** of the mineral, and is described according to the degree of brightness from 'splendent' to 'dull'. The terms to describe lustre are given in Table 2.2.

Table 2.2 Descriptive terms for the lustre of minerals.

metallic	like polished metal	mainly used in describing mineral ores and opaque minerals
submetallic	less brilliant	
dull		
vitreous	like broken glass	mainly for silicate minerals
resinous	oily sheen	
silky	like strands of fibre parallel to surface	
dull		

CRYSTAL HABIT

The development of an individual crystal, or an aggregate of crystals, to produce a particular external shape depends on the temperature and pressure during their formation. One such environment may give long needle-like crystals and another may give short platy crystals, both with the same symmetry. Since the mode of formation of a mineral is sometimes a clue to what it is, this shape or **crystal habit** is of use in the identification of some minerals. The terms used to describe crystal habit are given in Table 2.3.

Table 2.3 Descriptive terms for crystal habit.

Individual crystals	
platy	broad, flat crystal
tabular	elongate crystal which is also flat
prismatic	crystal is elongated in one direction
acicular	crystal is very long and needle-like
fibrous	long crystals—like fibres
Crystal aggregates (amorphous minerals often assume this form)	
dendritic	crystals diverge from each other like branches
reniform	kidney-shaped
botryoidal	like a bunch of grapes
amygdaloidal	infilling of steam vesicles or holes in lavas by salts carried in solution
drusy	crystals found lining a cavity

Aggregations of minerals may also show some internal structure formed by the relationship of the crystals to each other. For example, in columnar structure, the crystals lie in columns parallel to each other. In granular structure, the minerals are interlocking grains similar in appearance to the crystals in sugar lumps. In massive structure, the crystal grains cannot be seen by the naked eye.

SPECIFIC GRAVITY

The **specific gravity** or **density** of a mineral can be measured easily in a laboratory, provided the crystal is not too small. The specific gravity (sp. gr.) is given by the relation:

$$\text{sp. gr.} = W_1/(W_1 - W_2)$$

where W_1 is the weight of the mineral grain in air, and W_2 is the weight in water. A steelyard apparatus such as the Walker Balance is commonly used. In the field such a means of precision is not available, and the specific gravity of a mineral is estimated as low, medium or high by the examiner. It is important to know which minerals have comparable specific gravities:

(a) low specific gravity minerals include silicates, carbonates, sulphates and halides, with specific gravities ranging between 2.2 and 4.0;
(b) medium specific gravity minerals include metallic ores such as sulphides and oxides, with specific gravities between 4.5 and 7.5;
(c) high specific gravity minerals include native metallic elements such as pure copper, gold and silver; but these are rare minerals and are very unlikely to be encountered.

TRANSPARENCY

Transparency is a measure of how clearly an object can be seen through a crystal. The different degrees of transparency are given in Table 2.4.

Table 2.4 Degrees of transparency.

transparent	an object is seen clearly through the crystal
subtransparent	an object is seen with difficulty
translucent	an object cannot be seen, but light is transmitted through the crystal
subtranslucent	light is transmitted only by the edges of a crystal
opaque	no light is transmitted; this includes all metallic minerals

REACTION WITH ACID

When a drop of cold 10% dilute hydrochloric acid is put on certain minerals, a reaction takes place. In calcite ($CaCO_3$), bubbles of carbon dioxide make the acid froth, and in some sulphide ores, hydrogen sulphide is produced.

TENACITY

Tenacity is a measure of how the mineral deforms when it is crushed or bent. The terms used to describe it are given in Table 2.5.

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