

ELEMENTS OF OPTICAL MINERALOGY

AN INTRODUCTION TO MICROSCOPIC PETROGRAPHY

by

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PART II · DESCRIPTIONS OF MINERALS
With Special Reference to Their Optical and Microscopical Characters

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ELEMENTS OF
OPTICAL MINERALOGY



By Alexander N. Winchell

MICROSCOPIC CHARACTERS OF ARTIFICIAL INORGANIC
SOLID SUBSTANCES, OR ARTIFICIAL MINERALS

With a chapter on the universal stage
by Richard C. Emmons • *Second Edition*

ELEMENTS OF OPTICAL MINERALOGY

AN INTRODUCTION TO MICROSCOPIC PETROGRAPHY

Part I • Principles and Methods • Fifth Edition

*Part II • Descriptions of Minerals • With the
collaboration of Horace Winchell • Fourth Edition*

Part III • Determinative Tables • Second Edition

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PREFACE

During the eighteen years since the publication of the third edition of this work, probably the most important development in mineralogy has been derived from the X-ray study of crystals. This has led to an increase in our knowledge of the crystal structure of minerals, a better understanding of the variations in the composition of minerals, and a revision of the classification of minerals.

The X-ray studies of silicates by Bragg¹ and many others led to their classification as first presented in a textbook in the third edition of this work. With slight modifications, including names of divisions as proposed by Strunz² and Fleischer,³ that classification is extended, in this volume, to all silicates, although it is still true that many rare silicates and even some common ones have not yet been studied sufficiently by X-ray methods to obtain full information regarding their structure; in such cases the classification given here is only tentative.

Since X-ray studies of minerals are so important, a very brief statement of the results of such studies has been included in the descriptions, usually under the heading of structure (abbreviated "Struc.").

In preparing this edition the attempt has been made to keep constantly in mind the concept that a mineral is a (crystal) phase found in nature, and that one phase and therefore one mineral is not necessarily constant or simple in composition. In fact, the more minerals are studied the clearer it becomes that most minerals have compositions which cannot be expressed accurately by any simple formulas because of the variations in composition. It is true that some minerals, like diamond and quartz, have definite and simple chemical formulas, but they are exceptions. Even minerals like rutile and sphalerite practically always contain appreciable quantities of elements not shown in the formulas assigned to them. Thus rutile, which is white like pure artificial TiO_2 , is unknown in nature; and natural sphalerite normally contains iron, which may amount to 20 per cent or more. However, very often the variations in composition are not so limited as this, and one

¹ W. L. Bragg: *Zeit. Krist.*, LXXIV, 237 (1932); *The Structure of Silicates*, Second Edition, 1932; *Atomic Structure of Minerals*, 1937.

² H. Strunz: *Mineral. Tabellen*, 1941.

³ M. Fleischer: Some Problems in Nomenclature: *Am. Soc. Test. Mat.*, Preprint 117 (1947).

mineral, like plagioclase, may show continuous variation in composition from one formula ($\text{NaAlSi}_3\text{O}_8$) to a different one ($\text{CaAl}_2\text{Si}_2\text{O}_8$). Or one mineral may vary continuously in composition from one formula to several others—for hornblende there seem to be at least eighteen end-member formulas!

This concept that one mineral may vary in composition is a new one; indeed, at the start of this century most mineralogists believed that any one mineral had one fixed composition, and, therefore, plagioclase was considered to be a group of minerals each of which had a definite composition; for example, albite was Ab_1An_0 , oligoclase was Ab_3An_1 , andesine was Ab_2An_1 , labradorite was Ab_1An_1 , etc. Consequently, mineral names have been given to end-members and sometimes to intermediate types of such variations while the series or system as a whole unit may have remained unnamed. This situation is illustrated by the names enstatite and hypersthene, applied to parts of the orthorhombic pyroxene series from MgSiO_3 to FeSiO_3 ; the name enstenite⁴ has been suggested for the entire series. Accordingly, enstenite is the name of a mineral species, and enstatite and hypersthene are the names of certain varieties or subspecies. The name for a mineral species is a name which applies to all variations in composition which are possible in the given phase; it is a name of a natural unit. The varietal names are applied to portions of such a unit whose limits are arbitrary and artificially determined. Nevertheless, such varietal names are useful and fully justified, at least in some cases, as illustrated in the plagioclase series.

The very existence of these natural units seems to have been overlooked frequently by mineralogists. For example, metallurgists know that gold and silver form a continuous series of mix-crystals; mineralogists seem to overlook the fact that the continuous series is illustrated also in nature, as well shown by the metal produced by the National mine in northern Nevada which contained very nearly equal parts of gold and silver.

The development of our knowledge of the variations in composition possible in one mineral and the consequent variations in physical characters is clearly illustrated by the fact that the first edition of this work (in 1909) contained only two diagrams showing the relations between variations in composition and in physical characters (plagioclase and orthoclase—celsian), whereas the second edition (in 1927) contained thirty-nine such diagrams, the third edition (in 1933) fifty-six, and the present edition (1951) more than one hundred twenty.

⁴ A. N. Winchell: *Am. Jour. Sci.*, VI, 504 (1923).

This book is necessarily based largely on a compilation of all available data. Free use has been made of the standard publications on mineralogy, including especially:

E. S. Dana and W. E. Ford: *System of Mineralogy*, Sixth Edition, with three appendices, 1892–1915.

C. Doelter: *Handbuch der Mineralchemie*, Vols. I–IV, 1912–1931.

P. Groth: *Chemische Krystallographie*, Vols. I–II, 1906 and 1908.

C. Hintze: *Handbuch der Mineralogie*, Vols. I, II, 1897–1938.

A. Lacroix: *Minéralogie de la France*, Vols. I–V, 1893–1913.

C. Palache, H. Berman, and C. Frondel: *Dana's System of Mineralogy*, Seventh Edition, Vol. I, 1944.

The most important source of summaries of recent literature is to be found in *Mineralogical Abstracts*, Vols. I–X, 1920–1949.

For data on optical properties the preceding volumes are of value and also:

T. Barth and H. Berman: *Chem. Erde*, V, 22, (1930)

H. R. Landolt and R. Bornstein: *Physikalisch-chemische Tabellen*, 5 Aufl., 1923–1936.

E. S. Larsen: Microscopic Determination of the Nonopaque Minerals, *U. S. Geol. Surv. Bull.* 679 (1921).

E. S. Larsen and H. Berman: Microscopic Determination of the Nonopaque Minerals, *U. S. Geol. Surv. Bull.* 848 (1934).

For data on X-ray studies of crystal structure one should consult especially: *Strukturbericht*, Vols. I–VII, 1931–1943, and R. W. G. Wyckoff: *Crystal Structures*, 1948.

It is a pleasure to acknowledge the generous assistance received from many mineralogists in the preparation of this book; for example, Professor D. J. Fisher of the University of Chicago made the important suggestion that Schuster's rule for the sign of extinction angles in feldspars should be applied to all monoclinic and triclinic minerals. Helpful suggestions or data have been received from other colleagues including:

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ABBREVIATIONS AND SYMBOLS

(Chemical symbols and names of periodicals are not included.)

- A, B = optic axes of biaxial crystals.
A (in a chemical formula) = one atom of any metallic element.
 a = front and rear coordinate or crystal axis.
 α = angle between the positive directions of the b and c crystal axes.
Alter. = alterations.
B = birefringence.
B (in a chemical formula) = one atom of any element, usually a metal, in oxides, halides, and sulfides, and an acid-forming element in other compounds.
 b = right and left coordinate or crystal axis.
B.P. = boiling point.
Bx = bisectrix.
 β = angle between the positive directions of the a and c crystal axes.
C (after refractive index) = red light ($656\text{ m}\mu$).
 $^{\circ}\text{C}$. = degrees Centigrade.
 c = vertical coordinate or crystal axis.
 γ = angle between the positive directions of the a and b crystal axes.
Char. = characters.
Class. = classification.
Comp. = composition.
D (after refractive index) = yellow light of the D doublet ($589\text{ m}\mu$).
Diag. = diagnostics.
E = extraordinary ray.
2E = the apparent optic axial angle measured in air.
F (after refractive index) = blue light ($486\text{ m}\mu$).
F. = fusibility.
G. = specific gravity.
H. = hardness.
2H = the apparent optic axial angle measured in oil.
Hex. = hexagonal.
Incl. = inclusions.
Inver. = inversion.
Isom. = isometric.
Li (after refractive index) = lithium (red) light ($671\text{ m}\mu$).
 λ = wave length of monochromatic light.
 m = an indefinite number.
 μ = micron; a thousandth of a millimeter.
 $\text{m}\mu$ = millimicron; a millionth of a millimeter.
Max. = maximum.
Mono. = monoclinic.
M.P. = melting point.
N = index of refraction.

Na (after refractive index) = sodium (yellow) light (589 m μ).

N_E = index of refraction for the extraordinary ray.

N_O = index of refraction for the ordinary ray.

N_X = index of refraction for the X ray (fast) = α of German writers and N_p of Parts I and III.

N_Y = index of refraction for the Y ray (intermediate) = β of German writers and N_m of Parts I and III.

N_Z = index of refraction for the Z ray (slow) = γ of German writers and N_g of Parts I and III.

n = an indefinite number.

O = ordinary ray.

Occur. = occurrence.

Opt. = optic.

Orth. = orthorhombic.

p = an indefinite number.

Phys. = physical.

Prop. = properties.

r = red (light).

r > *v* (or *r* < *v*) (after optic axial angle) means that the optic axial angle in red light is greater than (or less than) the optic axial angle in violet light.

Rhom. = rhombohedral.

Struc. = structure.

Tetr. = tetragonal.

Tl (after refractive index) = thallium (green) light (535 m μ).

Tric. = triclinic.

Trig. = trigonal.

U.C. = unit cell; U.C. 4 means that the unit cell contains 4 times the formula atoms.

2V = the true angle between the optic axes, or the optic axial angle.

v = violet (light).

X (in a chemical formula) = one atom of an element like S, O, Cl, F (also OH).

X = the vibration direction of the fast ray; also that ray.

X > Y (or X < Z), etc. = absorption greater (or less) for the fast ray than for the the intermediate (Y) or slow (Z) ray.

Y = the vibration direction of the intermediate ray; also that ray.

Z = the vibration direction of the slow ray; also that ray.

\wedge = angle; for example, Z \wedge *c* = the angle between Z and *c*.

> = is greater than.

< = is less than.

100, 010, 001, 110, etc. = Miller symbols of one or more crystal planes (or faces).

{100}, {010}, {001}, {110}, etc. = Miller symbols of crystal forms.

\perp = normal to.

|| = parallel; this is often omitted, as in the statement: "the optic plane is 010"; or it is replaced by an equals sign, as in "X = *a*."

(+) or (−) before 2V (or 2E or 2H) means that the optic sign of the mineral is plus or minus.

SPECIAL NOTICE

Since this is the first time certain symbols have been used in any volume of this work on optical mineralogy, it is important to emphasize, by repetition, the fact that N_g , N_m , N_p , N_o , and N_z of Parts I and III are replaced in this edition of this volume by N_Z , N_Y , N_X , N_O , and N_E . Furthermore, in Parts I and III, and in previous editions of this volume, the sign of the extinction angle in monoclinic and triclinic minerals (except feldspars) has been considered to be positive if it was measured in the obtuse angle between a and c , or b and c , and negative if measured in the acute angle. Schuster's rule, which is accepted very generally for feldspars, reverses this, since it requires that, when viewing a section from the direction of the positive octant ($+a$, $+b$, $+c$) toward the negative octant ($-a$, $-b$, $-c$), angles measured by rotating the section clockwise from the extinction position with the slow Z ray (if possible) north-south to the position with the cleavage, twinning, or crystal edge north-south shall be considered positive and those measured by rotating the section anticlockwise shall be considered negative. In this volume Schuster's rule has been applied to the extinction angles of all minerals. Accordingly, the sign of the extinction angle in this book is given as positive ¹ if it is measured to a position in the acute angle between a and c (or b and c) and negative if it is measured in the obtuse angle.

Experience suggests that students using Part III should be reminded that many minerals vary in composition and therefore in physical properties; for this reason, such minerals cannot be represented in the refringence tables by any single value but must be represented by a range of values. Each mineral with such a variation of refractive index is entered in the tables at the minimum and also at the maximum value of its refractive index, and the continuous variation between these values is indicated by a line connecting the two. This leads to the condition illustrated on many pages of the tables that a single value of the refractive index (N_Y or N_O) may be found to belong to any one of a score, or more, of minerals. For example, if an unknown mineral is found to have an index (N_O or N_Y) of 1.502, reference to Table IVB, on page 145, will show that it might be antigorite (if optically positive) but it might be phillipsite since one of the vertical lines passing 1.502 shows that phillipsite has an index varying from 1.48 to 1.509, and it might be stilbite, for which N_Y varies from 1.498 to 1.504, and it might be paraffin, for which N_Y varies from 1.478 to 1.503; finally, reference to supplementary Table IVB, on page 192, shows that it might be ungemachite. Similarly, if the unknown mineral has an index (N_O or N_Y) of 1.626, reference to page 161 will show that it might be bazzite, but also the vertical lines lead to twenty-two other minerals having an index range which includes 1.626.

Attention should also be called to the fact that diagrams showing the relations between composition and properties are only approximations; in fact, some of the diagrams are based on such scanty and poor data that they must be considered

¹ Of course, there is the very rare exception that the sign is positive when measured clockwise from c to a position beyond a and therefore in the obtuse angle.

rather crude approximations. However, even the most accurate diagrams should be used with caution. For example, the diagram for the forsterite-fayalite series of olivine is relatively very accurate, but such an olivine may contain some manganese or zinc, which would modify its properties. Again diagrams for plagioclase are rather accurate, but an error of 3-4 per cent in the composition indicated should not be considered unreasonable, partly because the diagrams are not perfect and partly because they assume that potassium and sodium affect the properties in exactly the same way, an assumption which is only an approximation as to indices and extinction angles and apparently all wrong, in some cases, as to the optic angle.

The sign of elongation of crystals is positive if Z (the vibration direction of the slow ray) is parallel with, or less than 45° from, the direction of elongation (assuming elongation in one direction); it is negative if X is in this place; and it is plus in some positions of the crystal and minus in other positions if Y is in this place—this is expressed as plus-or-minus (\pm) elongation. In the case of elongation or extension parallel to a plane, the sign of elongation is positive if X is normal to the plane or less than 45° from this position; it is negative if Z occupies this position; it is plus-or-minus (\pm) if Y occupies this position.

The orientation rule, $b > a$, is adopted generally for orthorhombic and triclinic minerals, especially for new or rare species. But it seems undesirable to apply it to minerals, like anglesite, of well-established orientation, even though X-ray study indicates that the a axis of goniometry should be doubled.

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INTRODUCTION

DRAWINGS, PROJECTIONS, AND DIAGRAMS

It will be assumed that ordinary drawings of crystals in clinographic or orthographic projection or true perspective will be understood by those who use this book, since they are simple and are fully explained in nearly any textbook of mineralogy.

Certain other types of projection need some explanation, because they do not give a picture of the actual crystal, but they are very useful since they present a graphic expression of symmetry and of all the angular relations of the crystal much more clearly and exactly than any picture.

SPHERICAL PROJECTION. In spherical projection the crystal is supposed to have its center at the center of an enclosing sphere, as in Fig. 1. From the common center a line is drawn normal to each crystal face, and this line is continued until it meets the surface of the enclosing sphere. This point of intersection is known as the pole of the given crystal face. The poles of all faces in one zone (that is, parallel to one line in the crystal) are on one great circle on the sphere. Conversely, all faces whose poles are on one great circle belong to one zone in the crystal. A face whose pole falls at the intersection of two or more great circles belongs to two or more zones in the crystal. The angular relations between the faces are retained exactly on the sphere; the angles on the sphere, being the angles between normals to the faces, are the supplements of the actual interior angles between the faces of the crystals. These angles between the normals to the faces are the "normal interfacial angles" commonly recorded in all the literature on the subject.

It is customary to place the crystal so that the vertical axis is normal to the equatorial plane of the sphere; then an orthorhombic crystal is turned so that the *b* axis extends right and left. In that position it will have the pole of 001 at the north pole of the sphere, the pole of 010 at the right side, and the pole of 100 at the front of the sphere, the last two poles, as well as those of all faces of the vertical zone (100, 110, 120, 010,