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A TEXT-BOOK
OF
MINERALOGY

WITH AN EXTENDED TREATISE ON
CRYSTALLOGRAPHY AND PHYSICAL MINERALOGY

BY
EDWARD SALISBURY DANA
*Professor Emeritus of Physics and Curator of Mineralogy
Yale University*

THIRD EDITION, REVISED AND ENLARGED

BY
WILLIAM E. FORD
*Professor of Mineralogy, Sheffield Scientific School of
Yale University*

TOTAL ISSUE, TWENTY-SEVEN THOUSAND

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PREFACE TO THE THIRD EDITION

The first edition of this book appeared in 1877 and approximately twenty years later (1898) the second and revised edition was published. Now, again after more than twenty years, comes the third edition. The changes involved in the present edition are chiefly those of addition, the general character and form of the book having been retained unchanged. In the section on Crystallography the important change consists in the introduction of the methods employed in the use of the stereographic and gnomonic projections. A considerable portion of the section on the Optical Characters of Minerals has been rewritten in the endeavor to make this portion of the book simpler and more readily understood by the student. In the section on Descriptive Mineralogy all species described since the previous edition have been briefly mentioned in their proper places. Numerous other changes and corrections have, of course, been made in order to embody the results of mineral investigation during the last two decades. Only minor changes have been made in the order of classification of the mineral species. It was felt that as this book is so closely related to the System of Mineralogy it was unwise to attempt any revision of the chemical classification until a new edition of that work should appear. The description of the methods of Crystal Drawing given in Appendix A has been largely rewritten. A new table has been added to Appendix B in which the minerals have been grouped into lists according to their important basic elements. Throughout the book the endeavor has been to present in a clear and concise way all the information needed by the elementary and advanced student of the science.

The editor of this edition is indebted especially to the published and unpublished writings of the late Professor Samuel L. Penfield for much material and many figures that have been used in the sections of Crystallography and The Optical Character of Minerals. He also acknowledges the cordial support and constant assistance given him by Professor Edward S. Dana.

WILLIAM E. FORD

NEW HAVEN, CONN., Dec. 1, 1921.

PREFACE TO THE SECOND EDITION

THE remarkable advance in the Science of Mineralogy, during the years that have elapsed since this Text-Book was first issued in 1877, has made it necessary, in the preparation of a new edition, to rewrite the whole as well as to add much new matter and many new illustrations.

The work being designed chiefly to meet the wants of class or private instruction, this object has at once determined the choice of topics discussed, the order and fullness of treatment and the method of presentation.

In the chapter on Crystallography, the different types of crystal forms are described under the now accepted thirty-two groups classed according to their symmetry. The names given to these groups are based, so far as possible, upon the characteristic form of each, and are intended also to suggest the terms formerly applied in accordance with the principles of hemihedrism. The order adopted is that which alone seems suited to the demands of the elementary student, the special and mathematically simple groups of the isometric system being described first. Especial prominence is given to the "normal group" under the successive systems, that is, to the group which is relatively of most common occurrence and which shows the highest degree of symmetry. The methods of Miller are followed as regards the indices of the different forms and the mathematical calculations.

In the chapters on Physical and Chemical Mineralogy, the plan of the former edition is retained of presenting somewhat fully the elementary principles of the science upon which the mineral characters depend; this is particularly true in the department of Optics. The effort has been made to give the student the means of becoming practically familiar with all the modern methods of investigation now commonly applied. Especial attention is, therefore, given to the optical properties of crystals as revealed by the microscope. Further, frequent references are introduced to important papers on the different subjects discussed, in order to direct the student's attention to the original literature.

The Descriptive part of the volume is essentially an abridgment of the Sixth Edition of Dana's System of Mineralogy, prepared by the author (1892). To this work (and future Appendices) the student is, therefore, referred for fuller descriptions of the crystallographic and optical properties of species, for analyses, lists of localities, etc.; also for the authorities for data here quoted. In certain directions, however, the work has been expanded when the interests

of the student have seemed to demand it; for example, in the statement of the characters of the various isomorphous groups. Attention is also called to the paragraph headed "Diff.," in the description of each common species, in which are given the distinguishing characters, particularly those which serve to separate it from other species with which it might be easily confounded.

The list of American localities of minerals, which appeared as an Appendix in the earlier edition, has been omitted, since in its present expanded form it requires more space than could well be given to it; further, its reproduction here is unnecessary since it is accessible to all interested not only in the System of Mineralogy but also in separate form. A full topical Index has been added, besides the usual Index of Species.

The obligations of the present volume to well-known works of other authors — particularly to those of Groth and Rosenbusch — are too obvious to require special mention. The author must, however, express his gratitude to his colleague, Prof. L. V. Pirsson, who has given him material aid in the part of the work dealing with the optical properties of minerals as examined under the microscope. He is also indebted to Prof. S. L. Penfield of New Haven and to Prof. H. A. Miers of Oxford, England, for various valuable suggestions.

EDWARD SALISBURY DANA

NEW HAVEN, CONN., Aug. 1, 1898.

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INTRODUCTION

1. THE SCIENCE OF MINERALOGY treats of those inorganic species called *minerals*, which together in rock masses or in isolated form make up the material of the crust of the earth, and of other bodies in the universe so far as it is possible to study them in the form of meteorites.

2. **Definition of a Mineral.**— *A Mineral is a body produced by the processes of inorganic nature, having a definite chemical composition and, if formed under favorable conditions, a certain characteristic molecular structure which is exhibited in its crystalline form and other physical properties.*

This definition calls for some further explanation.

First of all, a mineral must be a *homogeneous* substance, even when minutely examined by the microscope; further, it must have a *definite chemical composition*, capable of being expressed by a chemical formula. Thus, much basalt appears to be homogeneous to the eye, but when examined under the microscope in thin sections it is seen to be made up of different substances, each having characters of its own. Again, obsidian, or volcanic glass, though it may be essentially homogeneous, has not a definite composition corresponding to a specific chemical formula, and is hence classed as a rock, not as a mineral species. Further, several substances, as tachylyte, hyalomelane, etc., which at one time passed as minerals, have been relegated to petrology, because it has been shown that they are only local forms of basalt, retaining an apparently homogeneous form due to rapid cooling.

Again, a mineral has in all cases a *definite molecular structure*, unless the conditions of formation have been such as to prevent this, which is rarely true. This molecular structure, as will be shown later, manifests itself in the physical characters and especially in the external crystalline form.

It is customary, as a matter of convenience, to limit the name mineral to those compounds which have been formed by the processes of nature alone, while compounds made in the laboratory or the smelting-furnace are at most called artificial minerals. Further, mineral substances which have been produced through the agency of organic life are not included among minerals, as the pearl of an oyster, the opal-silica (tabasheer) secreted by the bamboo, etc. Finally, mineral species are, as a rule, limited to *solid substances*; the only liquids included being metallic mercury and water. Petroleum, or mineral oil, is not properly a homogeneous substance, consisting rather of several hydrocarbon compounds; it is hence not a mineral species.

It is obvious from the above that minerals, in the somewhat restricted sense usually adopted, constitute only a part of what is often called the Mineral Kingdom.

3. **Scope of Mineralogy.**— In the following pages, the general subject of mineralogy is treated under the following heads:

(1) *Crystallography.*— This comprises a discussion of crystals in general and especially of the crystalline forms of mineral species.

(2) *Physical Mineralogy*.— This includes a discussion of the physical characters of minerals, that is, those depending upon cohesion and elasticity, density, light, heat, electricity, and so on.

(3) *Chemical Mineralogy*.— Under this head are presented briefly the general principles of chemistry as applied to mineral species; their characters as chemical compounds are described, also the methods of investigating them from the chemical side by the blowpipe and other means.

(4) *Descriptive Mineralogy*.— This includes the classification of minerals and the description of each species with its varieties, especially in its relations to closely allied species, as regards crystalline form, physical and chemical characters, occurrence in nature, and other points.

4. Literature.— Reference is made to the Introduction to the Sixth Edition of Dana's System of Mineralogy, pp. xlv–lxi, for an extended list of independent works on Mineralogy up to 1892 and to its Appendices I, II and III for works published up to 1915; the names are also given of the many scientific periodicals which contain original memoirs on mineralogical subjects. For the convenience of the student the titles of a few works, mostly of a general character, are given here. Further references to the literature of Mineralogy are introduced through the first half of this work, particularly at the end of the sections dealing with special subjects.

Crystallography and Physical Mineralogy

EARLY WORKS * include those of Romé de l'Isle, 1772; Haüy, 1822; Neumann, *Krystallogonomie*, 1823, and *Krystallographie*, 1825; Kupffer, 1825; Grassmann, *Krystallogonomie*, 1829; Naumann, 1829 and later; Quenstedt, 1846 (also 1873); Miller, 1839 and 1863; Grailich, 1856; Kopp, 1862; von Lang, 1866; Bravais, *Études Crist.*, Paris, 1866 (1849); Schrauf, 1866–68; Rose-Sadebeck, 1873.

RECENT WORKS include the following:

Bayley. *Elementary Crystallography*, 1910.

Beale. *Introduction to Crystallography*, 1915.

Beckenkamp. *Statische und kinetische Kristalltheorien*, 1913–.

Bruhns. *Elemente der Krystallographie*, 1902.

Goldschmidt. *Index der Krystallformen der Mineralien*; 3 vols., 1886–91. Also *Anwendung der Linearprojection zum Berechnen der Krystalle*, 1887. *Atlas der Krystallformen*, 1913–.

Gossner. *Krystallberechnung und Kristallzeichnung*, 1914.

Groth. *Physikalische Krystallographie und Einleitung in die krystallographische Kenntniss der wichtigeren Substanzen*, 1905.

Klein. *Einleitung in die Krystallberechnung*, 1876

Lewis. *Crystallography*, 1899.

Liebisch. *Geometrische Krystallographie*, 1881. *Physikalische Krystallographie*, 1891.

Mallard. *Traité de Cristallographie géométrique et physique*; vol. 1, 1879; vol. 2, 1884.

Moses. *Characters of Crystals*, 1899.

Reeks. *Hints for Crystal Drawing*, 1908.

Sadebeck. *Angewandte Krystallographie* (Rose's *Krystallographie*, II. Band), 1876.

Sohncke. *Entwicklung einer Theorie der Krystallstruktur*, 1879.

Sommerfeldt. *Physikalische Krystallographie*, 1907; *Die Krystallgruppe*, 1911.

Story-Maskelyne. *Crystallography: the Morphology of Crystals*, 1895.

Tutton. *Crystalline Structure and Chemical Constitution*, 1910; *Crystallography and Practical Crystal Measurement*, 1911.

Viola. *Grundzüge der Krystallographie*, 1904.

Walker. *Crystallography*, 1914.

* The full titles of many of these are given in pp. li–lxi of Dana's System of Mineralogy, 1892.

- Wallerant.** *Cristallographie*, 1909.
Websky. *Anwendung der Linearprojection zum Berechnen der Krystalle* (Rose's *Krystallographie* III. Band), 1887.
Williams. *Elements of Crystallography*, 1890.
Wülfing. *Die 32 krystallographischen Symmetrieklassen und ihre einfachen Formen*, 1914.
- In *PHYSICAL MINERALOGY* the most important general works are those of Schrauf (1868), Mallard (1884), Liebisch (1891), mentioned in the above list; also Rosenbusch, *Mikr. Physiographie*, etc. (1892). Important later works include the following.
- Davy-Farnham.** *Microscopic Examination of the Ore Minerals*, 1920.
Duparc and Pearce. *Traité de Technique Minéralogique et Pétrographique*, 1907.
Groth. *Physikalische Krystallographie*, 1905.
Groth-Jackson. *Optical Properties of Crystals*, 1910.
Johannsen. *Determination of Rock-Forming Minerals*, 1908. *Manual of Petrographic Methods*, 1914.
Murdoch. *Microscopical Determination of the Opaque Minerals*, 1916.
Nikitin, translated into French by Duparc and de Dervies. *La Methode Universelle de Fedoroff*, 1914.
Winchell. *Elements of Optical Mineralogy*, 1909.
Wright. *The Methods of Petrographic-Microscopic Research*, 1911.

General Mineralogy

Of the many works, a knowledge of which is needed by one who wishes a full acquaintance with the historical development of Mineralogy, the following are particularly important. Very early works include those of Theophrastus, Pliny, Linnæus, Wallerius, Cronstedt, Werner, Bergmann, Klaproth.

Within the nineteenth century: Haüy's *Treatise*, 1801, 1822; Jameson, 1816, 1820; Werner's *Letztes Mineral-System*, 1817; Cleaveland's *Mineralogy*, 1816, 1822; Leonhard's *Handbuch*, 1821, 1826; Mohs's *Min.*, 1822; Haidinger's translation of Mohs, 1824; Breithaupt's *Charakteristik*, 1820, 1823, 1832; Beudant's *Treatise*, 1824, 1832; Phillips's *Min.*, 1823, 1837; Shepard's *Min.*, 1832-35, and later editions; von Kobell's *Grundzüge*, 1838; Mohs's *Min.*, 1839; Breithaupt's *Min.*, 1836-1847; Haidinger's *Handbuch*, 1845; Naumann's *Min.*, 1846 and later; Hausmann's *Handbuch*, 1847; Dufrenoy's *Min.*, 1844-1847 (also 1856-1859); Brooke & Miller, 1852; J. D. Dana's *System of 1837*, 1844, 1850, 1854, 1868.

More RECENT WORKS are the following:

- Bauer.** *Lehrbuch der Mineralogie*, 1904.
Bauerman. *Text-Book of Descriptive Mineralogy*, 1884.
Baumbauer. *Das Reich der Krystalle*, 1889.
Bayley. *Descriptive Mineralogy*, 1917.
Blum. *Lehrbuch der Mineralogie*, 4th ed., 1873-1874.
Brauns. *Das Mineralreich*, 1903. English, translation by Spencer, 1912.
Clarke. *The Data of Geochemistry*, 1916.
Dana, E. S. *Dana's System of Mineralogy*, 6th ed., New York, 1892. Appendix I, 1899; II, 1909; III, 1915. Also (elementary) *Minerals and How to study them*, New York, 1895.
Dana-Ford. *Manual of Mineralogy*, 1912.
Des Cloizeaux. *Manuel de Minéralogie*; vol. 1, 1862; vol. 2, 1er Fasc., 1874; 2me, 1893.
Groth. *Tabellarische Uebersicht der Mineralien*, 1898.
Hintze. *Handbuch der Mineralogie*, 1889-1915.
Iddings. *Rock Minerals*, 1906.
Kraus. *Descriptive Mineralogy*, 1911.
Lacroix. *Minéralogie de la France et de ses Colonies*, 5 vols., 1893-1913.
Miers. *Mineralogy*, 1902.
Moses and Parsons. *Mineralogy, Crystallography and Blowpipe Analysis*, 1916.
Merrill. *The Non-metallic Minerals*, 1904.
Phillips. *Mineralogy*, 1912.
Rogers. *Study of Minerals*, 1912.
Schrauf. *Atlas der Krystall-Formen des Mineralreiches*, 4to, vol. 1, A-C, 1865-1877.
Tschermak. *Lehrbuch der Mineralogie*, 1884; 5th ed., 1897.

Weisbach. Synopsis Mineralogica, systematische Uebersicht des Mineralreiches, 1875.

Zirkel. 13th edition of Naumann's Mineralogy, Leipzig, 1897.

Wülfing. Die Meteoriten in Sammlungen, etc., 1897 (earlier works on related subjects, see Dana's System, p. 32).

For a catalogue of localities of minerals in the United States and Canada see the volume (51 pp.) reprinted from Dana's System, 6th ed. See also the volumes on the Mineral Resources of the United States published (since 1882) under the auspices of the U. S. Geological Survey.

Chemical and Determinative Mineralogy

Bischoff. Lehrbuch der chemischen und physikalischen Geologie, 1847-54; 2d ed., 1863-66. (Also an English edition.)

Blum. Die Pseudomorphosen des Mineralreichs, 1843. With 4 Nachträge, 1847-1879.

Brush-Penfield. Manual of Determinative Mineralogy, with an Introduction on Blowpipe Analysis, 1896.

Doelter. Allgemeine chemische Mineralogie, Leipzig, 1890. Handbuch der Mineralchemie, 1912-.

Duparc and Monnier. Traité de Technique Minéralogique et Pétrographique, 1913.

Eakle. Mineral Tables for the Determination of Minerals by their Physical Properties, 1904.

Endlich. Manual of Qualitative Blowpipe Analysis, New York, 1892.

Kobell, F. von. Tafeln zur Bestimmung der Mineralien mittheilung einfacher chemischer Versuche auf trockenem und nassem Wege, 11te Auflage, 1878.

Kraus and Hunt. Tables for the Determination of Minerals, 1911.

Lewis. Determinative Mineralogy, 1915.

Rammelsberg. Handbuch der kristallographisch-physikalischen Chemie, Leipzig, 1881-82. Handbuch der Mineralchemie, 2d ed., 1875. Ergänzungsheft, 1, 1886; 2, 1895.

Roth. Allgemeine und chemische Geologie; vol. 1, Bildung u. Umbildung der Mineralien, etc., 1879; 2, Petrographie, 1887-1890.

Websky. Die Mineral Species nach den für das spezifische Gewicht derselben angenommenen und gefundenen Werthen, Breslau, 1868.

Weisbach. Tabellen zur Bestimmung der Mineralien nach äusseren Kennzeichen, 3te Auflage, 1886. Also founded on Weisbach's work, **Frazer's** Tables for the determination of minerals, 4th ed., 1897.

Artificial Formation of Minerals

Dittler. Mineralsynthetisches Praktikum, 1915.

Gurit. Uebersicht der pyrogeneten künstlichen Mineralien, namentlich der kristallisierten Hüttenerzeugnisse, 1857.

Fuchs. Die künstlich dargestellten Mineralien, 1872.

Daubrée. Études synthétique de Géologie expérimentale, Paris, 1879.

Fouqué and M. Lévy. Synthèse des Minéraux et des Roches, 1882.

Bourgeois. Réproduction artificielle des Minéraux, 1884.

Meunier. Les méthodes de synthèse en Minéralogie.

Vogt. Die Silikatschmelzlösungen, 1903-1904.

Mineralogical Journals

The following Journals are largely devoted to original papers on Mineralogy:

Amer. Min. The American Mineralogist, 1916.

Bull. Soc. Min. Bulletin de la Société Française de Minéralogie, 1878-.

Centralbl. Min. Centralblatt für Mineralogie, Geologie und Paläontologie, 1900-.

Fortschr. Min. Fortschritte der Mineralogie, Kristallographie und Petrographie, 1911-.

Jb. Min. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, etc., from 1833.

Min. Mag. The Mineralogical Magazine and Journal of the Mineralogical Society of Gt. Britain, 1876-.

Min. Mitth. Mineralogische und petrographische Mittheilungen, 1878-; Earlier, from 1871, Mineralogische Mittheilungen gesammelt von G. Tschermak.

Riv. Min. Rivista di Mineralogia e Crystallografia, 1887-.

Zs. Kr. Zeitschrift für Kristallographie und Mineralogie. 1877-.

ABBREVIATIONS

Ax. pl.	Plane of the optic axes.	H.	Hardness.
B_x, B_x_a.	Acute bisectrix (p. 277).	Obs.	Observations on occurrence, etc.
B_x_o.	Obtuse bisectrix (p. 277).	O.F.	Oxidizing Flame (p. 331).
B.B.	Before the Blowpipe (p. 330).	Pyr.	Pyrognostics or blowpipe and allied characters.
Comp.	Composition.	R.F.	Reducing Flame (p. 331).
Diff.	Differences, or distinctive characters.	Var.	Varieties.
G.	Specific Gravity.		

The sign \wedge is used to indicate the angle between two faces of a crystal, as *am* (100 \wedge 110) = 44° 30'.