Minerals

Their Constitution and Origin

Second edition

The new edition of this popular textbook once again provides an indispensable guide for the next generation of mineralogists.

Minerals is an authoritative and comprehensive study of modern mineralogy, designed for use on one- or two-semester courses, for undergraduate and graduate students in the fields of geology, materials science, and environmental science.

This second edition has been thoughtfully reorganized, making it more accessible to students, whilst still being suitable for an advanced mineralogy course. Fully updated and revised, important additions include expanded introductions to many chapters, a new introductory chapter on crystal chemistry, revised figures, and an extended color plates section containing beautiful color photographs. Text boxes include historical background and case studies to engage students, and end-of-chapter questions help them reinforce concepts. With new online resources provided to support learning and teaching, including laboratory exercises, PowerPoint slides, useful web links, and mineral identification tables, this is a sound investment for students and a valuable reference for researchers, collectors, and anyone interested in minerals.

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Minerals

Their Constitution and Origin

Second Edition

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Preface

Minerals: Their Constitution and Origin is an introduction to mineralogy for undergraduate and graduate students in the fields of geology, materials science, and environmental science. It has been designed as a textbook for use in a one- or two-semester course but gives students a broader view and covers all aspects of mineralogy in a modern and integrated way. It provides detailed references to important publications on principles of crystallography and mineralogy. The book is not only descriptive but for interested readers derives basic principles such as aspects of symmetry theory, background on stereographic projection, X-ray diffraction and thermodynamics, based on general background from mathematics, physics and chemistry. The overall goal is to emphasize concepts and to minimize nomenclature. The text includes appendices covering identification of hand specimens and optical properties. With the broad approach, the book is not only a textbook for students but also a reference for teachers, researchers, collectors and anyone interested in minerals. The book is written in a modular fashion that permits instructors to select or omit some parts, depending on the level of the course, without compromising the continuity.

Today mineralogy is not just part of a geology curriculum. The importance of mineralogy has broadened to a wide variety of disciplines, from igneous petrology to soils science, from archaeology to cement engineering, from materials science to structural geology. Our book provides an alternative to existing texts by focusing more tightly on concepts, at the expense of completeness, and by integrating geological processes and applications more closely with the discussions of systematic mineralogy.

The book is divided into six parts:

Part I deals with general concepts of crystal chemistry, bonding, chemical formulas, mineral classification and hand specimen identification.

Part II introduces concepts of symmetry expressed in the morphology and structure of crystals. It then explores defects in crystal structures and the diversity of features observed during crystal growth.

Part III centers on the physics of minerals. First it shows how to use X-ray diffraction to determine the structural features introduced in Part II. A chapter on physical properties is optional but is significant for modern mineral physics and geophysics. We introduce optical properties and the use of the petrographic microscope because most mineralogists need to have this background before mineral systems are discussed in detail. The chapter on mineral identification with a microscope relies on access to relevant laboratory equipment. If there is no such access to microscopes, or if a separate course in optical mineralogy is available, chapters on optical mineralogy can be skipped. Part III concludes with a discussion of advanced analytical techniques, introducing equipment that may be encountered in modern mineralogical research laboratories.

Part IV discusses the wide range of mineral formation. It also provides some background in thermodynamics for understanding mineral equilibria in geological environments and phase transformations. Later chapters include applications of thermodynamics to sedimentary, hydrothermal, metamorphic, and igneous processes to demonstrate its relevancy.

Part V is a systematic treatment of mineral groups and about 200 of the most important minerals. Each chapter combines mineral characteristics with a discussion of a mineral-forming environment particularly linked to this mineral group, and information about mineral origin and mineral-forming processes. Part V starts with the most common minerals in the crust, quartz and feldspars, and ends with an overview of rare organic minerals like mellite.

Part VI on applied mineralogy deals with topics such as metal deposits, gems, cement, and human health, and explores how minerals form in the universe and were active components at each stage of the evolution of the Earth. We now have a much better understanding of minerals in the deep Earth, thanks largely to progress in seismology and experiments at ultra-high pressure and temperature. This part is largely independent from the rest of the book and these chapters can be used as reading assignments and form good starting points for term projects. The chapters should illustrate to students that mineralogy is not just complicated formulas, strange names, Miller indices, and point-groups, but has practical significance.

Appendices contain determinative tables and important technical terms are defined in a glossary.

There are many excellent mineralogy textbooks, ranging from the early Niggli (1920) monograph (which still contains much of the information that is needed), to modern books such as Hibbard (2002), Klein and Dutrow (2007), Nesse (2011) and Klein and Philpotts (2012). Our book has a different emphasis. The goal is to be selective in including material rather than all inclusive, yet trying to remain quantitative, scientifically sound, and avoiding superficiality. It is well known that many students are frightened of mathematical expressions. We are using some equations here and there, but they can be skipped, without losing the thread, if students do not have the necessary background. But since most geology programs require mathematics and physics courses, it seems only reasonable to show students that this material is useful and to show some quantitative relationships; for example, how trigonometry can be used to calculate interfacial angles; how X-ray diffraction patterns are linked to lattice parameters; basic thermodynamics to understand a boundary in a phase diagram; simple linear algebra to appreciate why a second-rank tensor, such as the optical indicatrix, has the shape of an ellipsoid; or how complex numbers can be used to add waves more easily analytically than graphically to obtain diffraction intensities. We also have not shied away from referring to important references, including the classic studies of von Laue (1913) on X-ray diffraction, van't Hoff (1912) on the geochemistry of salt deposits, Bowen (1915) on experimental petrology, and also recent discoveries such as the structure of the lower mantle (e.g. Lekic *et al.*, 2012), mineral identification on Mars (e.g. Bish *et al.*, 2013) or isotope analyses at the atomic scale (e.g. Valley *et al.*, 2014). This provides links to follow up on details about some of the milestones in mineralogy for readers who are interested.

The origin of this book goes back to 1993, when Dasha Sinitsyna, a student from (then) Leningrad, visited Berkeley on an exchange program and brought a little red book on mineralogy, written by her professor, Andrey Bulakh (1989), which caught Rudy Wenk's attention because it was an inspiring brief introduction to mineralogy. Over the following years we established further contact, in part through the exchange of another student, Anton Chakmouradyan. After reciprocal visits to St Petersburg and Berkeley, sponsored by the University of California Education Abroad Program, the authors decided to attempt to produce an English mineralogy book, in the spirit of the Russian version but expanded it considerably.

The different backgrounds of the authors guarantee a broad view: Andrey Bulakh is a specialist on alkaline rocks and minerals and geochemistry and has written several books that are widely used at Russian universities, including the latest (Bulakh, 2011). Rudy Wenk's earlier research focused on metamorphic rocks, deformation fabrics, and investigations of microstructures in feldspars and carbonates with electron microscopes. More recently it has emphasized minerals at high pressure, stress and temperature with aspects such as anisotropy in the deep Earth (see http://eps.berkeley.edu/people/hans-rudolf-wenk). Both have taught introductory mineralogy at major universities for a long time. In this book we have tried to unite our expertise.

The first edition was published 12 years ago. Why have we prepared a new edition? The basic concepts of mineralogy and crystallography have not changed and a lot still relies on investigations with the petrographic microscope, introduced almost 200 years ago, and X-ray diffraction, celebrating in 2014 its hundredth anniversary with the UNESCO Year of Crystallography. But in 12 years a few things have happened: 1000 new minerals were added to the 4000 in 2002, but none of those are the subject of the book. Important is the shift in mineral production. South Africa is no longer the leading supplier of diamonds and China has become by far the main producer of steel. Particularly it manufactures a whopping 60% of the world's cement.

In 12 years the internet has also made profound changes. If you want to know the density of olivine, or the price of gold, you no longer go to a library but to Wikipedia. The new edition takes this into account by referring not only to books for "Further reading" but also recommends webpages with important mineral information. Appendices on mineral properties are provided not only in printed format but as digital files as well. And we added digital materials that may be useful for instructors: PowerPoint files from which teachers can select slides, and sample laboratory exercises based on a one-semester Berkeley mineralogy course. A Kindle edition is also available.

Compared with the first edition we have reorganized the content to make it easier to use for teaching. Part I starts with crystal chemistry and connects students with what they learnt in chemistry lectures, then links it to mineral classification which is mainly based on chemical composition, and introduces hand-specimen identification to bring students early in contact with actual minerals. With such a background it makes it easier to advance in Part II to the more abstract but important concepts of symmetry principles as well as graphic representations of crystal forms such as the stereographic projection. In Part V we have added a brief chapter on organic minerals, though rare but very interesting to make readers aware of different types of bonding and crystal structures.

The book has benefited from the help of many colleagues. Some generously contributed illustrations, others reviewed parts of the manuscript and provided valuable input in discussions. Foremost our thanks go to students who, over many years, taught us what for them is important in mineralogy, made us appreciate the difficult subjects, and guided us to topics of most interest.

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Last but not least we are grateful to the staff at Cambridge University Press for their dedication and patience. Of course blame for all remaining deficiencies, omissions, and errors in content rests with the authors and we continue to appreciate the input from readers who suggest corrections. We can make corrections in future printings and do not have to wait for another edition; so do not hesitate to contact us to report errors and make suggestions. We dedicate the book to our wives, Julia Wenk and Victoria Kondratieva.

H.-R. Wenk
A. Bulakh

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