

Mineral Resources, Economics and the Environment

Written for students and professionals, this revised textbook surveys the mineral industry from a geological, environmental, and economic perspective. Thoroughly updated, the text equips readers with the skills they need to contribute to the energy and mineral questions currently facing society, including issues regarding oil pipelines, nuclear power plants, water availability, resource tax policy, and new mining locations.

Key features

- A new chapter on metals used in the technology industry is included as well as separate chapters on mineral economics and environmental geochemistry.
- Topics of special interest are highlighted in boxes, technical terms are highlighted when first used, and references are included to allow students to delve more deeply into areas of interest.
- Carefully designed figures simplify difficult concepts and show the location of important deposits and trade patterns, emphasizing the true global nature of mineral resources.

Stephen E. Kesler is an Emeritus Professor in the Earth and Environmental Sciences department at the University of Michigan, and a leading expert in the field of mineral resources. He has taught economic geology for almost 50 years, and worked with numerous exploration, mining, and energy companies worldwide. His research interests include geology and geochemistry of ore deposits, and mineral exploration and economics.

Adam C. Simon is an Associate Professor in the Earth and Environmental Sciences department at the University of Michigan, specializing in economic geology, igneous petrology, and geochemistry. He combines field, laboratory, and experimental work to investigate the physical and chemical evolution of magmatic systems and the formation of ore deposits.

“Stephen Kesler and Adam Simon have done a remarkably good job at presenting a wealth of information about mineral resources along with a balanced view of their economic, environmental and political context that should be easy to understand by technical and non-technical readers alike. They have made particularly good use of text boxes to highlight relevant information and to draw attention to some rather provocative topics that deserve discussion and debate. I strongly recommend this book as a necessary reference to all who are serious about understanding the role of mineral resources in societies today.”

Dr. M. Stephen Enders, *Colorado School of Mines*

“I have been encouraging development of this revised edition for some time, as *Mineral Resources, Economics and the Environment* includes the ideal mix of topics for a course that I teach on global issues in Earth resources. In addition to the coverage of major energy, metallic, and industrial mineral commodities, the new chapter on technology elements is particularly timely. The new pedagogic insets are an excellent means to guide critical thinking on the complex interplay of societal mineral resources demand and its consequences. This revised edition should continue to be a leading textbook on Earth resources, as well as a useful reference for the non-specialist.”

Professor J. Richard Kyle, *University of Texas at Austin*

“This book will be an ideal text for senior undergraduates and postgraduate students. The information is up-to-date, informative and well-illustrated and will allow readers to make valued decisions on the relevance and importance of mineral resources and energy to our civilization. In addition, this book will be of great interest to the general public wanting to learn about mineral resources, economics and the environment.”

Professor Bruce Gemmell, *University of Tasmania*

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To Elias, Kai, and Torsten – the next generation of mineral consumers
Steve Kesler

To Alicia, Abigail, James, Laura, and Ethan – for everything
Adam Simon

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PREFACE

As we move into the twenty-first century, mineral supplies have become a truly global concern. For most of human history, developed countries have consumed far more than their per capita share of world mineral production. Everyone talked about the day when the rest of the world might want its share of the pie, but it was largely an abstract notion. Now, they are at the door. In fact, China has become the world's largest consumer of mineral resources, and India is not far behind. This momentous change poses two threats. First, there is the possibility that we will run out of the minerals even sooner than we thought. Second, there is the increased pollution caused by their extraction and consumption, which has already destroyed the environment in some areas.

These threats have generated a wide range of opinions about mineral resources and the environment. At one end of the spectrum are those who advocate a dramatic reduction in new mineral production with recycling and conservation providing for the future. At the other end are those who feel that vigorous exploration will always find new minerals and that they can be produced safely with minimal attention to the environment. Both camps are on perilous ground. Many mineral commodities, such as oil and fertilizers, cannot be recycled and the growing demand from developing countries will consume any minerals that are conserved by developed countries. To make matters worse, numerous studies have shown that Earth's storehouse of mineral deposits is indeed finite and that substitutes for important mineral commodities are scarce. Finally, we cannot ignore the environmental catastrophes that have been caused by past mineral production or the impending problems likely to be caused by increasing global mineral consumption.

Unless we are willing to make a dramatic reduction in our standard of living, however, we must find a way to produce and consume the enormous volumes of minerals that we need without significant degradation of the environment. In other words, we must find a middle ground in these arguments, and this means compromise. Unfortunately, compromise is impossible if the parties involved do not understand the problem. That is where this book comes in. It provides an

introduction to the geologic, engineering, economic, and environmental factors that govern the production and consumption of mineral resources. This sort of comprehensive information is required if we are to understand all sides of an argument and, hopefully, find a solution.

The book is intended largely for use as a college text, although it can also be used as a primer for anyone with an interest in mineral resources. Mineral professionals who seek a broader view of their field will also find it useful. Because this audience has such a wide range of backgrounds, an effort has been made to make the book a self-contained document, in which all terms and concepts are explained. A basic high school education is all that is needed to read this book. Introductory material on geology, chemistry, engineering, economics, and accounting have been included, along with a glossary of terms, which appear in bold in the text on first mention. Appendices with information on elements, minerals, rocks, mineral commodities, units of weight and measure (including useful conversion factors), and mineral reserves and resources, have also been included, as have references to recent literature. In keeping with their wide use throughout the world, metric (SI) units are used as much as possible in this book, including the term tonne for metric ton, although the (US) short ton, or more simply ton, and (British) long ton are used in some cases where data were reported in these units. Other units, such as flasks and troy ounces, are also employed where dictated by convention.

This book deals with controversial subjects and we have expressed opinions about some of them. We have tried to do this on a case-by-case basis, without following any specific agenda or point of view. It is encouraging in that respect that the book has been cited as too "industry oriented" by some and too "environmentally oriented" by others. Hopefully, each camp will find much that is familiar and friendly, but also much that challenges assumptions and encourages factual debate intended to solve problems and produce a consensus. We will all find many areas in which more data are needed before final decisions can be reached.

Although this book has two authors, it is the product of many minds. We are very grateful to the numerous geologists, mining and petroleum engineers, metallurgists, mineral economists, and other professionals who have allowed access to their projects or operations over the years, and to the many environmentalists who have discussed their research and concerns with us. We are equally

grateful to the many students, particularly those in GS/ES380 at the University of Michigan, who have been a constant source of new information and challenging questions. We are grateful to Dale Austin and Marc Gellote for invaluable assistance with the figures, to Hannah Sherman for help with the references, and to Zoë Lewin for especially careful review of the entire manuscript.