ENVIRONMENTAL GEOCHEMISTRY OF MINESITE DRAINAGE: PRACTICAL THEORY AND CASE STUDIES, *DIGITAL EDITION*

by:

Kevin A. Morin

and

Nora M. Hutt

Minesite Drainage Assessment Group/
Grupo Estudio del Drenaje de Minas

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Dedicated to:

1) environmentally thoughtful mining in the 21st century

2) *aloha ‘aina*
domoni ni vanua
(love of the environment)

3) future generations,
to show that we managed as best we could
the environmental legacy of our minesites
and of those bequeathed to us

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PREFACE AND ACKNOWLEDGEMENTS

This book has three purposes. First, it is a *guidebook* for the assessment, prediction, and control of minesite-drainage chemistry. The chapters on these tasks emphasize practical, rather than theoretical, concepts. As demonstrated here, the abundant conflicting theories on drainage chemistry are, for the most part, unimportant to the practical requirements of many minesites.

Second, this is a *reference book* containing numerous case studies on various aspects of drainage chemistry. These illustrate the many different views of drainage-chemistry work around the world and are valuable in extrapolating conclusions to other minesites. Case studies are used heavily in this book to illustrate common themes and to highlight atypical findings.

Third, this is a *textbook* to present the state-of-the-art in minesite drainage to fellow students on the topic. The questions at the end of each chapter provoke additional thought and insight into important issues. No matter what level of experience and age, there is something new and informative in this book for every reader.

Based on our work with more than 130 proposed and existing minesites, and on reviews of hundreds of papers and reports by many others, these three ambitious purposes have been attained here in a reasonably compact book. We welcome copies of other papers and reports that readers consider important and valuable to future compilations.

We have noticed there is confusion sometimes between minesite-drainage chemistry and water-quality impacts. The emphasis in this book is on the chemistry of waters draining from various minesite components. In the jargon of hydrologic studies, the focus is on "headwater" chemical effects in and around a minesite. There is little emphasis on "downstream" chemistry in distant rivers and lakes, where regional water-quality and biological impacts are defined by applicable legislation and social expectations. Consistent with this view, "water quality", which implies comparison to some standard, is rarely used here.

A book like this on theory and case studies cannot be created in isolation from other people — no one person could carry out all these studies and interpretations. Therefore, there are many people and publications that we have depended on, and learned from. Obviously, the efforts of all authors listed in the References are important and gratefully recognized. We are especially grateful to the people who provided technical and editorial comments on various chapters of this book:

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Kevin Morin
Nora Hutt
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CHAPTER 1
INTRODUCTION

1.1 Overview and Objectives

Mining and milling (concentrating) of ore has always been a fundamental activity of the human race, supplying the metals, nonmetals, and minerals needed to maintain and advance our standard of living. Therefore, it is no coincidence that mining activity has grown in intensity and complexity as human civilization has grown and expanded. A simple testimony to this symbiotic relationship is human epochs like the Iron and Bronze Ages. Other testimony comes from historical reports of mining.

Documented mining for raw materials reaches back to the Stone Age, with a 20,000-year-old underground flint mine reported in a limestone cave in Australia (James and Thorpe, 1994). Due to the demand for flint axes, several flint mines were operating in Western Europe by 4000 B.C., with hundreds of shafts dug to depths of 9-12 m.

Copper mining was underway at Rudna Glava, Serbia, by 4500 B.C. to depths of 60 feet (James and Thorpe, 1994). By 2600 B.C., Egyptians were mining turquoise and copper in the Negev of northern Sinai with 6-meter-diameter shafts accompanied by a system of underground workings. About the same time, rock with silver and lead was being mined near Athens using underground workings driven up to 330 feet laterally into hillsides. Cisterns for water supply and ore washing (milling) were excavated nearby into rock and lined with cement.

Underground coal mines in China are reported as early as 200 BC while Roman coal mines in Britain are reported around 100 A.D. (James and Thorpe, 1994). Ancient Romans also operated mines for iron, gold, silver, tin, copper, and lead (Thornton, 1996). These included a copper mine at Córdoba, Spain, with a 688-foot-deep shaft and a lead-silver mine at El Centenillo with workings 3500 feet long and 650 feet deep (James and Thorpe, 1994). The Romans apparently developed relatively advanced techniques for excavating, lighting, ventilating, and draining mines, such as a vertically staged series of 15-foot-diameter water wheels.

Due to our relatively short lifespan, it can be easy for people to overlook past lessons and advances. Today, many think of past mining and milling activities, even a hundred years ago, as primitive. However, by the time Agricola (1556) wrote his text on mining and milling centuries ago, these activities were already refined sciences and arts. The refinements continue today and will no doubt continue into the future.

One rapidly growing refinement is the incorporation of environmental maintenance into the economics and engineering of mining. This is a reasonable consequence of increasing environmental awareness and the increasing intensity and cumulative extent of mining. Some statistics illustrate this best. By the Year 2000, Merrington and Alloway (1994) expect that approximately 240,000 km^2 of the earth's surface will have been disturbed by mining activity. In the Canadian Province of Ontario, there are more than 6000 abandoned minesites with varying degrees of environmental, safety, and health concerns (Mitchell and Mackasey, 1995). In the USA, 17,000 abandoned mines are documented in the State of Utah alone (Vance et al., 1995). Also in the USA, aquatic life has been decimated in 4100 km of 88,000 km of streams within the Commonwealth of Pennsylvania by acidic mine drainage (Scheetz et al., 1995). The Chinese mining industry generates an estimated 2.5×10^9 m^3/yr of polluted water (Chen and Huang, 1995) and Chinese coal mining alone generates 150×10^6 t of waste a year (Hu, 1995). This intense industrial activity around the world must be accompanied by environmental protection or restoration.

In the past, mining and milling were sometimes considered sufficiently important to dismiss legally corporate responsibility for adverse effects on the local environment and health (Vranesh, 1979). It is interesting to read Weingart (1982), an ex-hardline miner, publicly confessing his “sins” and accepting environmental responsibility. There is no longer any doubt that many mining companies place major emphasis on environmental protection. For example, Robertson (1994a) reports that his company will not mine sulfide-bearing ore if the subsequent acid generation cannot be properly prevented or controlled.

Blight (1979) summarized the mining-environment issue well:

> "It is well to concede at this point that any mining or industrial activity will inevitably cause some environmental damage. The overall benefit to the country must be offset against this damage. It must also be recognized that whatever control measures are instituted, due regard must be paid to local conditions and current circumstances. The costs of the waste disposal operation in relation to the revenue-producing operation that must pay for it, the practicability of the environmental protection measures proposed, and the short and long-term consequences of these measures, both for the safety of the public and for their quality of life, must all receive careful and due consideration."

This is reflected in the current international movement for sustainable development.

There are some who oppose efforts to return the environment at old minesites as close as possible to pre-mining conditions. For example, an international organization suggests that millions of bats have been lost by closing and sealing underground mines (Taylor, 1995). Also, Banks et al. (1996) argue that minesite drainages with elevated concentrations of some metals and lower concentrations of others have historically played a beneficial roles. They have provided or augmented surface-water base flows, drinking-water supplies, water treatment, spa waters, and secondary minerals for paints and industrial processes. Nevertheless, this opposition to restoration represents a minority today.

Mining operations can have physical, chemical, and biological effects on the local environment, which consists of soil and rock (solid phase), groundwater and surface waters (liquid phase), and air and pore gases (gaseous phase). Any detailed discussion of one effect or one phase alone can fill, and has filled, several proceedings and books. In this book, the focus is primarily on the chemistry of surface and ground waters draining from minesite components.

In the fields of environmental geochemistry and environmental hydrogeology, sufficient literature on many types of mining now exists to allow a compilation of data to identify similarities and highlight site-specific differences. This, in turn, provides an opportunity to understand mining and milling operations on a large scale in order to (1) remediate closed minesites, (2) guide environmental studies at existing operations, and (3) design improved minesites for the future. The compilation of data and the conceptual chemical models of mining are the primary objectives of this book.

1.2 Organization of This Book

The next chapter, Chapter 2, describes the various minesite components whose physical and chemical characteristics affect the chemistry of their drainages. Chapter 2 also introduces the terminology used in this book. While most technical words are used consistently around the world, other terms vary widely in their meaning and usage. Therefore, clearer communication requires well-defined terminology. For example, the word *mine* is used here as a specific component (open pit or underground working), whereas *minesite* refers here to a set of components. A Glossary is provided in Appendix A to standardize technical meanings in this book.

Chapter 3 provides a brief explanation of how water drains through and from minesite components. This drainage occurs as surface and ground waters. Consequently, Chapter 3 provides the physical framework of water movement, onto which chemistry is superimposed.

The remaining chapters are dedicated to the chemistry of drainage waters. Chapter 4 describes drainage chemistry through in-field case studies of various minesite components. Chapter 5 then explains and illustrates methods for predicting drainage chemistry, and thus provides important theoretical background of a practical nature.

Chapter 6 discusses the geochemical aspects of various methods for controlling the chemistry of drainage waters. The appendices provide supporting information for these chapters.

1.3 Questions

1-1. Many metals and minerals are obtained by mining. How many objects have you encountered in your life that were not derived from, or affected by, mining? (Keep in mind that even a smooth piece of wood may have been cut or trimmed by a metallic instrument fashioned from mined metal.) Over the next 24 hours, note how few non-mining-related objects you encounter.

1-2. What would be the effect on our standard of living if various types of mining, like gold, copper, and potash mining, were halted?

1-3. What percentage of your country's economic production is derived from mining or mineral processing?

1-4. In your community and country, do most people recognize the contribution that mining makes to the economy and their standard of living?

1-5. How much would you limit mining to protect the environment near your home?