ORE GENESIS AND EXPLORATION: 
THE ROLES OF ORGANIC MATTER

CONTENTS

PART I: INTRODUCTION
J.S. Leventhal and T.H. Giordano

PART II: TECHNIQUES
Analytical Techniques for Organic Matter Characterization
B.R.T. Simoneit and A.P. Gize
Ore Deposits
Organic Petrology Applied to Ore Deposits
A.P. Gize
Organic Maturation Modeling Applied to Ore Genesis and Exploration
A.P. Gize, C.A. Kuehn, K.P. Furlong, and J.M. Gaunt

PART III: ORGANIC PROCESSES
Thermodynamic Response of Organic Compounds in Geochemical Processes of Sedimentary Basins
E.L. Shock
Distribution and Origin of Organic Ligands in Subsurface Waters from Sedimentary Basins
Y.K. Kharaka, P.D. Lundegard, and T.H. Giordano
Organic Matter as a Transport Agent in Ore-Forming Systems
T.H. Giordano
Organic Matter: Supergene Enrichment and Dispersion
S.A. Wood

PART IV: ORE SYSTEMS
B.R.T. Simoneit
The Organic Geochemistry of Gold, Platinum, Uranium, and Mercury Deposits
A.P. Gize
Metalliferous Shales and the Role of Organic Matter with Examples from China, Poland, and the United States
R.M. Covney, Jr.
Roles of Organic Matter in Shale- and Carbonate-Hosted Base Metal Deposits
L.M. Pratt and M.C. Warner
The Interaction of Organic Matter and Fluids during the Genesis of Some Precious Metal and Volcanogenic Massive Sulfide Deposits
R.M. Kettler

PART V: APPENDICES
APPENDIX I: Glossary of Chemical Terms
T.H. Giordano
APPENDIX II: Glossary of Organic Compounds
B.R.T. Simoneit and S.A. Wood

Editors
T.H. Giordano, R.M. Kettler, and S.A. Wood

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PREFACE

Organic geochemistry is an important part of many geoscience disciplines, and in this context, organic geochemists have developed a wide range of analytical and experimental techniques to study the nature and evolution of organic matter in soil, sediment, petroleum, and coal. These efforts have evolved into three principal schools of organic geochemistry with their own literary outlets. Each of these three schools can be broadly identified with one of the following areas of study: soil science, petroleum geology and geochemistry, and coal science. For the past 25 years, a core of economic geologists, mostly with geochemical backgrounds, have made significant progress in making organic geochemistry an important component in the study of ore deposits. To accomplish this, it was necessary for these ore-deposit researchers to draw upon the three traditional schools of organic geochemistry for investigative techniques, nomenclature, and classifications, and upon organic geochemists who were willing to devote a part or all of their research efforts to the study of ore deposits.

In the middle to late 1970s, important research on the nature and role of organic matter in ore deposits was being conducted by a small number of organic geochemists and economic geologists. It was not until the 1980s, however, that major conferences were organized with the purpose of creating a forum where scientists from a wide variety of disciplines (economic geologists, physical chemists, microbiologists, geochemists, petroleum geologists, coal and soil scientists) could come together and share their observations and research relevant to the organic geochemistry of ore deposits. In this regard, three particular international-multidisciplinary meetings come to mind: (1) the Conference on the Geochemistry of Organic Matter in Ore Deposits, held November 9–12, 1980, in Warrenton, Virginia, and sponsored by the Geophysical Laboratory of the Carnegie Institution of Washington; (2) the Symposium on Organics and Ore Deposits, held April 25–26, 1985, in Denver, Colorado, and sponsored by the Denver Region Exploration Geologists Society; and (3) the Penrose Conference on Geochemistry of Waters in Deep Sedimentary Basins, held March 15–20, 1987, in Oxnard, California, and sponsored by the Geological Society of America. These meetings, as well as others, were important sources of information and enthusiasm for those studying the nature and role of organic matter in relation to ore deposits. In a sense, the meetings were the springboard that led to the expansion of research efforts in the 1990s.

For the past 15 years, research on the relationship between ore and organic matter has increased significantly. We now know considerably more than we did in the early 1980s concerning the nature and distribution of organic matter in ores, the role of organic matter in the concentration and mobilization of metals, the role of organics in postore-forming processes, and the applications of organic matter to mineral exploration. In the 1990s, much of this research was presented at various regional and national meetings in theme sessions and symposia sponsored by one or more of the following organizations: the Society of Economic Geologists (SEG), the Society for Geology Applied to Mineral Deposits (SGA), the International Association on the Genesis of Ore Deposits (IAGOD), and the International Geological Correlation Project (IGCP) #357-Organics and Mineral Deposits.

In conjunction with the 1997 Geological Society of America annual meeting, the Society of Economic Geologists sponsored a short course held on the 17th and 18th of October at the University of Utah. The present volume, which represents the printed version of that short course, is divided into four topical sections (introduction, techniques, organic processes, ore systems) and appendices (glossary of chemical terms, glossary of organic compounds). Examples of applications to mineral exploration are embedded in the chapters throughout the volume and were not compiled into a single section. It is our hope that this publication will serve as an introductory text to the topic of ores and organic matter, while also serving as a reference to those seeking more advanced concepts and an up-to-date summary of research and exploration applications. Although each chapter is self-contained, it may be necessary for the reader to brush up on nomenclature and classification terminology by referring to Chapter 1 and the glossaries in the appendices.

The volume editors would like to thank all the authors and reviewers for their timely efforts in making this volume possible.

Thomas H. Giordano
Richard M. Kettler
Scott A. Wood
BIOGRAPHIES

RAYMOND M. COVENEY, JR., chairs the Department of Geosciences, University of Missouri, Kansas City, where he has been a member of the faculty since 1971. He served as interim dean of the College of Arts and Sciences during academic year 1992-1993. After receiving his B.S. degree in geology from Tufts University in 1964, Dr. Coveney served as a lieutenant (junior grade) with the U.S. Navy aboard USS Fremont, home ported in Norfolk. Profs. W.C. Kelly and F.S. Turnearre introduced him to the field of mineral deposits during 1966, his first year of graduate studies at the University of Michigan. He was initiated into the practical field aspects of exploration and mining during 1967 by Frederick T. Fischer, while they were both employed by the New Jersey Zinc Company in Hanover, New Mexico, and in 1968 by Donald R. Dickey at the Oriental mine in Alleghany, California. The research for his Ph.D. dissertation, in which he attributed formation of the high-grade gold ores of the Oriental mine to redox processes associated with serpentization, was supported by the Dickey Exploration Company. Since 1976, Coveney's research has focused on the origins and the economic significance of metalliferous shales. He has written 32 papers on shales and has supervised 10 shale-related M.S. theses and other projects involving field studies in Missouri and other midwestern states, Ireland, Canada, Poland, and China.

KEVIN P. FURLONG is professor of Geosciences at The Pennsylvania State University, and focuses in his research on thermal and deformational processes of plate tectonics. He received B.A. degrees in mathematics and geology from Middlebury College, and a Ph.D. in geophysics from the University of Utah (1981). Prior to joining the faculty at Penn State, he taught for several years at the University of Wyoming. Furlong's research interests are currently aimed at improving our understanding of the nature of plate-boundary processes along major transpressional boundaries and interpreting the geodynamics of sedimentary basins by applying numerical modeling techniques to simulate the geologic evolution of the regions.

JONATHAN M. GAUNT is employed in precious metal and resource evaluation. He graduated with a B.Sc. (Honours) degree in geology from the University of Wales (Swansea) in 1989 and subsequently studied for an M.S. degree in mining geology at Camborne School of Mines (1990). In 1994, he completed a Ph.D. at the University of Manchester, focusing on the relationships between sedimentary basin evolution, petroleum migration, and base metal mineralization.

THOMAS H. GIORDANO is head of the Geological Sciences Department at New Mexico State University, where he held a postdoctoral appointment from 1977 to 1979, conducting geothermal exploration; he has been a member of the faculty since 1980. Giordano graduated in 1972 with a B.A. degree in chemistry from Millersville University (PA) and received his Ph.D. in geochemistry from The Pennsylvania State University in 1978, under the direction of H.L. Barnes. His current research interests include the chemical evolution of sediment-hosted ore deposits, the role of organic matter in natural hydrothermal processes, and thermodynamic properties and speciation of metals in aqueous solutions. He has supervised 14 M.S. theses (6 in the area of ore deposits) and has authored or coauthored over 100 papers and book chapters, primarily dealing with organic matter in sedimentary basins, metal-organic complexes, ore deposits, and paleosols.

ANDREW P. GIZE graduated with a degree in geology from the University of St. Andrews in 1976, earning an M.S. degree in organic geochemistry and coal petrology from Newcastle-upon-Tyne in 1977. He worked with Hu Barnes on the organic geochemistry of Mississippi Valley-type deposits and received a Ph.D. from The Pennsylvania State University in 1984. Following pre- and post-doctoral Fellowships at the Geophysical Laboratory, Carnegie Institution of Washington, he has taught at Southampton and is currently at the University of Manchester. He spent some time doing exploration in Canada and the U.K.; current interests include ore deposits, environmental organic and organo-metallic geochemistry, and analytical development.

RICHARD M. KETTLER received a B.S. degree in geology from the University of Wisconsin-Madison in 1978 and an M.S. degree in geology from the University of California at Los Angeles in 1982. After two years with Gulf Oil Exploration and Production Co., Kettler returned to graduate study at the University of Michigan and was awarded a Ph.D. in 1990. In 1989, he accepted a faculty position in the Department of Geosciences at the University of Nebraska-Lincoln, where he is now an associate professor. His research has included studies of gold mineralization, bitumen generation in diatomaceous sedimentary rocks, and the dissociation and complexing equilibria of carboxylic acids.

YOUSIF K. KARAKA has been a research hydrologist with the U.S. Geological Survey, Menlo Park, California, for more than 20 years. His areas of interest include water-rock interactions in a variety of natural and contaminated systems, especially in sedimentary basins, in geothermal areas, and in major fault systems. Current research covers naturally occurring organics, organic-inorganic interactions, remediation of contaminated agricultural drainage and water produced with petroleum, and the role of fluids on the dynamics of the San Andreas fault system. He has authored or coauthored about 100 scientific papers, reports, and book chapters. He received his Ph.D. from the University of California at Berkeley in 1971. He is an associate editor of both *Applied Geochemistry* and *Geology*, and an executive member of the Working Group on Water-Rock Interaction of IAGC.
CARL A. KUEHN began his career in mineral exploration with a B.A. degree from Amherst College (1976). After apprenticing for a year in Germany with Preussag A.G., he attended The Pennsylvania State University, from which he received an M.S. degree in geology (1984) via a work-study program funded by the Anaconda Copper Company. This research effort was a field mapping and geochemical sampling program in central Nevada that focused on exploration aspects of potential gold mineralization in the central Toiyabe Mountains. This research led to Kuehn’s posing some fundamental questions on the overall geologic setting of sediment-hosted gold mineralization, which subsequently were addressed in a Ph.D. dissertation completed at Penn State in 1989. His doctoral research on the Carlin gold deposit was funded by the National Science Foundation, the U.S. Geological Survey/WMR group, and Penn State. Its primary focus was on attempting to better understand the geology and geochemistry of this type of gold deposit by using the alteration characteristics determined by mapping and core-logging, combined with detailed paragenetic, fluid inclusion, and stable isotope studies to better constrain an understanding of the changing P-T-X conditions at Carlin through time. Since 1988 he has been V.P. Exploration of IMDEX, Inc., a geologic consulting firm based in Tucson, Arizona, that specializes in providing services in Mexico and Latin America. His consulting work specializes in gold deposits and emphasizes combining academic and pragmatic approaches to increase efficiency in applied mineral exploration.

JOEL LEVENTHAL was research geochemist at the U.S. Geological Survey, Denver, Colorado, where he investigated organic matter and ore deposits beginning in 1974. Leventhal received his education from the University of California at Los Angeles and California State University, Los Angeles; he was awarded a Ph.D. by the University of Arizona and conducted postdoctoral research at the University of California at Santa Barbara. Leventhal’s research has also involved using organic, inorganic, and isotopic geochemistry to understand environments of deposition and metal enrichment mechanisms for black shales. More recent work includes methane from coastal marshes and global change, environmental leaching of coal ash, and environmental dispersion of arsenic related to gold mining. He retired from the U.S. Geological Survey in December 1997, and is now an independent consultant in Lake- wood, Colorado.

PAUL D. LUNDEGARD is employed as a principal scientist in the Environmental Technical Support group of the Unocal Corporation, in Brea, California. He received his B.S. degree in geology from the College of William and Mary, an M.S. degree in geology from the University of Cincinnati, and a Ph.D. in geochemistry from The University of Texas at Austin. In the past he has investigated the origin and role of organic acids in sedimentary diagenesis by a combination of field studies, laboratory experiments, and computer simulations. Currently Lundegard’s work in site assessment, remediation, and litigation projects focuses on the identification, transport, and fate of environmental contaminants.

LISA M. PRATT is professor of Geological Sciences and codirector of the Biogeochemical Laboratory at Indiana University. She obtained a B.A. degree in botany from the University of North Carolina, M.S. degrees in botany, from the University of Illinois, and geology, from the University of North Carolina, and a Ph.D. in geology from Princeton University. Her work on sediment-hosted mineralization began when Pratt was a research scientist in the branch of Petroleum Geology of the U.S. Geological Survey, from 1982 through 1987. In 1988, she joined the faculty of Indiana University. Dr. Pratt and her graduate students are involved in molecular and isotopic studies of carbon and sulfur in black shales and organic-rich modern sediment. She has done detailed organic geochemical research on base metal-sulfide ores from the White Pine mine in the Upper Peninsula of Michigan and the Red Dog mine in the Brooks Range of Alaska. Her current research is focused on stable isotopic evidence for living sulfide-oxidizing and sulfate-reducing bacteria in the deep South African gold mines.

EVERETT L. SHOCK received his undergraduate training at the University of California at Santa Cruz and his graduate education at the University of California at Berkeley. He joined the faculty of the Department of Earth and Planetary Sciences at Washington University in St. Louis in 1987, and since 1993 has been chairman of the Environmental Studies Program. His research interests include the transformation of organic compounds in geochemical processes, the interdependence of organic and inorganic reactions during fluid-driven processes, ways in which those processes support microorganisms in groundwater, rivers, hot springs, and the deep subsurface, and geochemical constraints on the emergence of life. These interests have led to studies of sedimentary basin brines, petroleum reservoirs, continental and submarine hydrothermal systems, the lower oceanic crust, hot springs, large North American rivers, carbonaceous meteorites, the Martian crust, and the icy satellites Triton and Europa.

BERND R. T. SIMONEIT is a professor of Organic Geochemistry at Oregon State University. He joined that faculty in 1981 after being on the research staff of the University of California, initially in Berkeley and subsequently in Los Angeles. He received his Ph.D. in organic geochemistry from Bristol University, England, in 1976, and has been involved in academic research since 1966. This research initially dealt with the origin and evolution of life on Earth and the search for evidence of extraterrestrial life (for example, on the moon and in meteorites). Later, it evolved
into studies of the distribution and fate of organic matter in
the geosphere and biosphere (i.e., organic and petroleum
geochemistry, biogeochemistry, and analytical chemistry
applied to pollution and ecology), and currently includes
the geochemistry of organogenic elements and com-
pounds in the lithosphere (i.e., in hydrothermal systems,
fluid inclusions, and organic metamorphism in supercriti-
cal fluids). Simoneit has participated in numerous panels,
advisory groups, field programs, and editorial boards. His
research has been presented at more than 350 meetings
and is published in over 400 papers, book chapters, and
two books.

MATTHEW C. WARNER completed his Ph.D. in geologi-
cal sciences at Indiana University in 1998. His dissertation
research focused on the role of sedimentary organic matter
and migrated petroleum in formation of the Red Dog
zinc-lead deposit in northwestern Alaska. He used ratios of
molecular fossils (biomarkers), isotopic compositions of
organic fractions, and trace element compositions to assess
the degree of hydrothermal alteration in various parts of
the Red Dog deposit and adjacent host shale. Matt worked
as a member of the geologic staff at Red Dog mine for
three summers and served summer internships with Shell
Offshore, Arco Oil and Gas, and Amoco Production com-
panies. He received a B.A. degree in English from the Uni-
versity of Notre Dame in 1984 and an M.A. degree in geol-
ogy from the University of California at Santa Barbara in
1992. Currently, he is employed by Shell Exploration & Pro-
duction Co.

SCOTT A. WOOD is professor of Geochemistry at the
University of Idaho. He was an assistant-associate professor
at McGill University for seven years prior to joining the fac-
ulty at the University of Idaho in 1992. He received a B.A.
degree in both geology and chemistry from Hamilton Col-
lege in Clinton, NY, and an M.A. degree and Ph.D. in geo-
chemistry at Princeton University. For 10 years he has been
an associate editor of the journal Geochimica et Cosmochimica
Acta. He has published more than 50 journal articles deal-
ing with mineral solubility, phase equilibria, and the trans-
port of metals in hydrothermal solutions and surficial
waters. Much of his research has been devoted to the plat-
inum group and rare earth elements. The main areas of
application of his work have been economic geology and
environmental geochemistry.
## CONTENTS

### PART I: INTRODUCTION

*Joel S. Leventhal & Thomas H. Giordano*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Nomenclature and Classification</td>
<td>2</td>
</tr>
<tr>
<td>Ore Deposits and the Organic Carbon Cycle</td>
<td>3</td>
</tr>
<tr>
<td>Roles of Organic Matter in Ore Deposits</td>
<td>7</td>
</tr>
<tr>
<td>Exploration Strategies</td>
<td>11</td>
</tr>
<tr>
<td>Carbon and Sulfur Relationships</td>
<td>12</td>
</tr>
<tr>
<td>Examples of Organic Matter and Their Roles in Ore Deposits</td>
<td>13</td>
</tr>
<tr>
<td>Conclusions and Summary</td>
<td>20</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>21</td>
</tr>
<tr>
<td>References</td>
<td>22</td>
</tr>
<tr>
<td>Appendix</td>
<td>26</td>
</tr>
</tbody>
</table>

### PART II: TECHNIQUES

Chapter 2—Analytical Techniques for Organic Matter Characterization in Ore Deposits
*Bernd R. T. Simoneit & Andrew P. Giö*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>27</td>
</tr>
<tr>
<td>Sample Preparation</td>
<td>29</td>
</tr>
<tr>
<td>Elemental Analysis</td>
<td>31</td>
</tr>
<tr>
<td>Rock-Eval Pyrolysis</td>
<td>34</td>
</tr>
<tr>
<td>Carbon Bonding</td>
<td>34</td>
</tr>
<tr>
<td>Spectroscopy</td>
<td>35</td>
</tr>
<tr>
<td>Stereochemistry</td>
<td>40</td>
</tr>
<tr>
<td>Mass Spectrometry</td>
<td>41</td>
</tr>
<tr>
<td>Chromatography and Ancillary Techniques</td>
<td>42</td>
</tr>
<tr>
<td>Gas Chromatography-Mass Spectrometry</td>
<td>43</td>
</tr>
<tr>
<td>Applications</td>
<td>45</td>
</tr>
<tr>
<td>Conclusions</td>
<td>55</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>56</td>
</tr>
<tr>
<td>References</td>
<td>56</td>
</tr>
<tr>
<td>Appendix</td>
<td>61</td>
</tr>
</tbody>
</table>

Chapter 3—Organic Petrology Applied to Ore Deposits
*Andrew P. Giö*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>63</td>
</tr>
<tr>
<td>Kerogen and Bitumen</td>
<td>63</td>
</tr>
<tr>
<td>The Macerals Concept</td>
<td>65</td>
</tr>
<tr>
<td>Techniques</td>
<td>68</td>
</tr>
<tr>
<td>Applications</td>
<td>74</td>
</tr>
<tr>
<td>Conclusions</td>
<td>79</td>
</tr>
<tr>
<td>Historical Footnote</td>
<td>80</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>80</td>
</tr>
<tr>
<td>References</td>
<td>80</td>
</tr>
</tbody>
</table>

### PART III: ORGANIC PROCESSES

Chapter 5—Thermodynamic Response of Organic Compounds in Geochemical Processes of Sedimentary Basins
*Everett L. Shock*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>105</td>
</tr>
<tr>
<td>Homogeneous Equilibrium: Metal-Organic Complexes</td>
<td>107</td>
</tr>
<tr>
<td>Heterogeneous Equilibrium: Hydrocarbon Solubilities in Aqueous Solutions</td>
<td>108</td>
</tr>
<tr>
<td>Stable Redox Equilibria</td>
<td>109</td>
</tr>
<tr>
<td>Metastable Redox Equilibria</td>
<td>110</td>
</tr>
<tr>
<td>Concluding Remarks</td>
<td>115</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>116</td>
</tr>
<tr>
<td>References</td>
<td>116</td>
</tr>
</tbody>
</table>

Chapter 6—Distribution and Origin of Organic Ligands in Subsurface Waters from Sedimentary Basins
*Yousif K. Kharaka, Paul D. Lundegard, & Thomas H. Giordano*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>119</td>
</tr>
<tr>
<td>Nature and Distribution of Organic Ligands</td>
<td>120</td>
</tr>
<tr>
<td>Origin of Major Reactive Species</td>
<td>126</td>
</tr>
<tr>
<td>Destruction of Organic Ligands</td>
<td>126</td>
</tr>
<tr>
<td>Ore Fluid Chemical Models</td>
<td>128</td>
</tr>
<tr>
<td>Summary</td>
<td>128</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>129</td>
</tr>
<tr>
<td>References</td>
<td>129</td>
</tr>
</tbody>
</table>

Chapter 7—Organic Matter as a Transport Agent in Ore-Forming Systems
*Thomas H. Giordano*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>133</td>
</tr>
<tr>
<td>Aqueous-Phase Transport</td>
<td>133</td>
</tr>
<tr>
<td>Petroleum-Phase Transport</td>
<td>145</td>
</tr>
<tr>
<td>Conclusions</td>
<td>151</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>152</td>
</tr>
<tr>
<td>References</td>
<td>152</td>
</tr>
</tbody>
</table>
Chapter 8—Organic Matter: Supergene Enrichment and Dispersion  
Scott A. Wood

Introduction ........................................ 157
Types and Concentrations of Dissolved Organic Matter in Natural Waters .... 157
Interactions of Metals with Humic Substances ...................... 161
Interactions of Metals with Simple Carboxylic Acids .................... 180
Humic Substances versus Simple Carboxylates ........................ 184
Conclusions ............................................ 184
References ........................................... 185

PART IV: ORE SYSTEMS

Bernd R.T. Simoneit

Introduction ........................................ 193
Geologic Locales with Hydrothermal Petroleum Products .................. 199
Hydrothermal Petroleum Expulsion-Extraction-Migration .................. 207
Fluid Interactions ..................................... 207
Implications .......................................... 208
Summary ............................................. 209
Acknowledgments ...................................... 210
References ........................................... 210
Appendix ............................................. 215

Chapter 10—The Organic Geochemistry of Gold, Platinum, Uranium, and Mercury  
Andrew P. Gîze

Deposits .............................................. 217
Introduction .......................................... 217
Organometallic Species ................................ 217
Gold .................................................. 218
Platinum ............................................. 229
Uranium .............................................. 254
Mercury .............................................. 240
Organosulfur Compounds ................................ 241
Organonitrogen Compounds ................................ 242
Reduction ............................................ 242
Discussion ........................................... 243
Conclusions .......................................... 245
Acknowledgments ...................................... 245
References ........................................... 245

Chapter 11—Metalliferous Shales and the Role of Organic Matter with Examples from China, Poland, and the United States  
Raymond M. Coveney, jr.

Introduction ........................................ 251
Definition of a Metalliferous Shale ................................ 251
Concentrations of Metals in Shales ................................ 252
Siting of Metals ...................................... 253
Sources of Metals and Origins of Metalliferous Shales .................. 260
General Significance of Organic Matter ............................... 261
Selected Field Examples ................................ 264
Summary ............................................. 271
Acknowledgments ...................................... 274
References ........................................... 274

Chapter 12—Roles of Organic Matter in Shale- and Carbonate-Hosted Base Metal Deposits  
Lisa M. Pratt & Matthew C. Warner

Introduction ........................................ 281
Carbonate-Hosted Lead-Zinc-Barium Deposits ......................... 282
Shale-Hosted Zinc-Lead Deposits ................................ 286
Shale-Hosted Copper Deposits ................................ 293
Conclusions .......................................... 298
Acknowledgments ...................................... 298
References ........................................... 298

Chapter 13—The Interaction of Organic Matter and Fluids during the Genesis of Some Precious Metal and Volcanogenic Massive Sulfide Deposits  
Richard M. Kettler

Introduction ........................................ 301
Organic Matter as a Reductant of Ore-Forming Fluids .................. 301
Fe-C-S Diagenesis and Gold Mineralization ........................... 305
Preservation of Organic Matter and Sulfide ........................... 309
Acknowledgments ...................................... 311
References ........................................... 312

PART V: APPENDICES

APPENDIX 1:  
Thomas H. Giordano
Glossary of Chemical Terms ................................... 315

APPENDIX 2:  
Bernd R.T. Simoneit & Scott A. Wood
Glossary of Organic Compounds .................................. 321