

This DVD presents the entire contents of the *Economic Geology* anniversary series, including the supplemental appendices that were provided on CD-ROM with the most recent volume. The first of the series, the *Economic Geology 50th Anniversary Volume*, was published in 1955, with Alan M. Bateman as editor. The project was undertaken to commemorate a half-century birthday of the journal, *Economic Geology*, which was founded in 1905. Papers included were authoritative reviews of what were considered at the time to be the most important topics within the field of economic geology. An organizing committee, chaired initially by H.G. Ferguson, worked with other volunteers to edit and see the project through to timely completion.

The *Economic Geology 75th Anniversary Volume*, with Brian J. Skinner as editor and Paul K. Sims as chairman of the organizing committee, was dedicated to Walter S. White. White, as president of the Economic Geology Publishing Company, guided the journal through a time of transition, spearheading the effort to establish the Publishing Company as a non-profit group and re-organizing the journal with the creation of an Editorial Board. The volume recognizes White's efforts and, again, had as its goal the publication of authoritative reviews on the most important topics in economic geology.

The latest addition to the series, the *Economic Geology 100th Anniversary Volume*, also was undertaken with the goal of covering the most important topics in economic geology, an ambitious project in a field that had expanded enormously. The organizing committee helped focus the wide range of topics into what was manageable. Editors Jeffrey W. Hedenquist, John F.H. Thompson, Richard J. Goldfarb, and Jeremy P. Richards, in their thanks to others, offer a suggestion of the tremendous amount of work that went into producing the 2005 volume.

Geology is unique among sciences because much of the work done by pioneers in the field has not become obsolete. Unlike studies in other sciences, such as medicine, where new findings replace old, much that has been written about geology remains as relevant in 2005 as it was in 1955. Because of the pertinence, there is a continuing demand for access to the information found in these anniversary volumes. We have planned the collection to be searchable; we trust that it will prove useful to contemporary economic geologists.

ECONOMIC GEOLOGY

Fiftieth
Anniversary Volume

1905 - 1955

ALAN M. BATEMAN, EDITOR

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1955

The Fiftieth Anniversary Volume

In 1951 the Editor suggested to H. G. Ferguson, President of the Economic Geology Publishing Company, that we should consider the possibility of preparing a special volume to commemorate the fiftieth anniversary of the founding of ECONOMIC GEOLOGY. The idea was discussed informally for a few weeks, and was presented to the Board of Directors of the Publishing Company for approval. The Board then appointed an Organizing Committee of those whose names appear on the title page, with H. G. Ferguson as Chairman. The Organizing Committee concluded that the Volume should consist, not of random papers, but entirely of review articles critically prepared by invited authors on selected subjects. The Organizing Committee discussed the matter with several prospective authors and, finding ready response, drew up a tentative outline of contents and authors, which was presented before a joint meeting of the Organizing Committee and the Directors of the Economic Geology Publishing Company held during the annual meeting of the Society of Economic Geologists at Detroit, in November of 1951. It was then realized that the Committee should be enlarged and broadened so as to be more representative of the various fields of economic geology. This was done and a Fiftieth Anniversary Volume Committee was formed with the next meeting scheduled for the Boston meeting of the Society of Economic Geologists in November of 1952. At this meeting, plans for the Fiftieth Anniversary Volume were matured; Mr. Ferguson's resignation was accepted with regret; and James A. Noble, of the California Institute of Technology, was appointed a member of the Committee, and was elected its Chairman. Chairman Noble called meetings of the Committee to be held at Toronto in November of 1953, and at Los Angeles in November of 1954, during which the contents and authorship were enlarged and arrangements made for the finalization of publication of the Volume. Chairman Noble assembled and helped edit much of the material. The Table of Contents that follows is the result of the efforts of both Committees, and for the contents themselves the Committees, the Economic Geology Publishing Company, and the Editor are grateful to the contributing authors.

YALE UNIVERSITY
NEW HAVEN, CONN.
OCTOBER, 1955

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ECONOMIC GEOLOGY

Seventy-Fifth
Anniversary Volume

1905-1980

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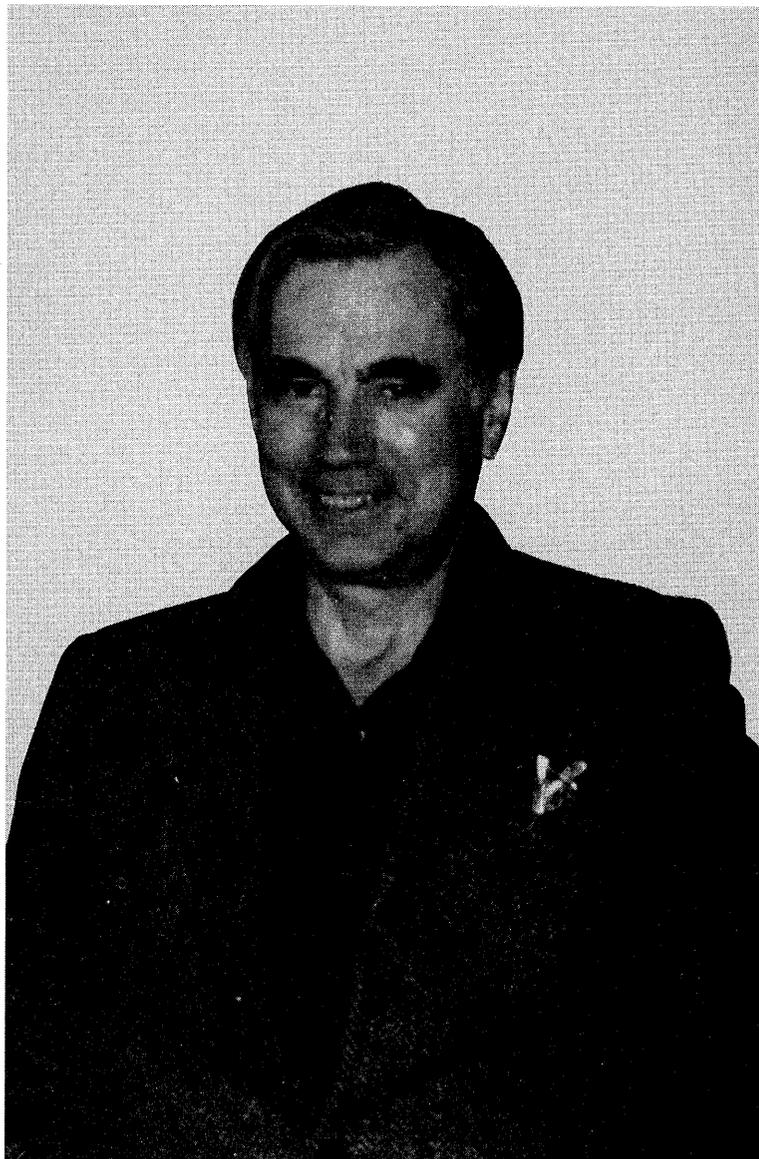
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Dedication to Walter S. White



Walter S. White

It is with great pleasure and appreciation that his friends and colleagues dedicate this 75th Anniversary Volume of *Economic Geology* to Walter S. White. Rarely does an individual who has such a great influence on his profession maintain such a low profile as "Whitie" has managed to do over the last 25 years.

Whitie is a longtime fixture of New England and Lake Superior geology, but we will not deal here with this aspect of his career, nor will we belabor his long

and productive career in the U. S. Geological Survey. Instead, we shall consider the signal service he has performed on behalf of the profession through his participation in the affairs of the Economic Geology Publishing Company.

In 1957 Whitie became Secretary and a Director of the Publishing Company, and in 1966 he succeeded Harold Bannerman as President. For the next seven years, Whitie guided the Publishing Company

through a series of critical maneuvers including: new editorial procedures; a confrontation with its long-time patron, the Society of Economic Geologists; and particularly delicate dealings with stockholders of the Publishing Company and their heirs, regarding a reorganization required by changes in the tax laws. Throughout all this he functioned quietly and effectively, using his quick wit, fine sense of humor, and appreciation for the feelings of others to achieve what those of us around him had deemed well nigh impossible.

In the mid-1960s, *Economic Geology* was facing a crisis. Alan Bateman had served as Editor for almost 50 years and had been operating much of the time almost single-handedly. During those years the journal had increased in size and the science had increased in complexity to the point where no one person, no matter how devoted, could carry the sole editorial burden; yet Alan was unwilling to ask for help beyond his highly qualified, but seldom used, Board of Associate Editors. Moreover, Alan's venerable age and the departure from Yale University of Roy Jensen, raised concern about the immediate continuity should the Editor falter. With tact and respect Whitie persuaded Alan to accept (at first grudgingly, but soon enthusiastically) the hard-working Editorial Board that, under the direction of, first, Bateman and, later, Brian Skinner, has served the journal and profession so well for 15 years.

The reorganization of the Publishing Company is a classic of Whitie's behind-the-scene statesmanship. As originally chartered in 1905, the Publishing Company had 80 shares with a par value of \$25. Most were purchased individually by economic geologists who recognized the need to support the new journal. As the years passed, the Company prospered, but no

dividends were ever paid (none were ever intended); shares for the most part were repurchased (always at the \$25 par value) by the Company and resold to younger geologists. Some shares found their way into the coffers of the Society of Economic Geologists where they remained, and others became part of the estates of deceased shareholders. The Company received bequests and return on investments so that by the mid-1960s a portfolio valued at about a quarter of a million dollars had accumulated. Moreover, times had changed and the Internal Revenue Service began to look on organizations such as the Publishing Company with such covetous eyes that a formal change to a "not-for-profit" organization was needed; but to accomplish this required the unanimous consent of all shareholders. This consent was easy to obtain from the individual professional geologists and from the Society who understood the true nature and function of the organization, but the heirs and administrators of estates viewed each of the shares under their control as a $1/80$ th portion of a quarter million dollars and, thus, of considerably greater value than the \$25 offered for each share. Fortunately, Whitie's persistent and unswerving efforts finally convinced all of the holdouts that the Publishing Company really was a non-profit group so the essential reorganization could come about.

Today we have a strong and productive Economic Geology Publishing Company whose principal publication, *Economic Geology*, is preeminent among all geotechnical journals. This enviable position has come through the long and devoted efforts of many, but without Walter White's catalytic and cohesive role in a time of difficulty, the efforts of others would have gone for naught. Whitie, old chum, we will be forever indebted to you.

Seventy-Fifth Anniversary Volume

Introduction

The first notions of a new journal came to J. E. Spurr during the closing days of 1904. When he shared his thoughts with friends in Washington, D. C., they were so enthusiastic about the suggestion that they formed themselves into an ad-hoc committee to seek ways to implement the idea. The ad-hoc group met informally for several months and by May of the following year was ready to announce the birth of an unusual new publishing company and the journal the company would produce. The first formal meeting of the Economic Geology Publishing Company took place on May 16, 1905. The first issue of the new journal appeared in October of the same year, and the first volume was completed in December 1906. The birthing was not easy, but it was successful because the founders provided much of the financing as well as the first papers. The story of those earliest days and the many struggles of the fledgling journal is engagingly recounted by Alan M. Bateman in an article published in the Fiftieth Anniversary volume.

From inception, management of the *Journal* has differed from the management of most scientific journals. There was no sponsoring society, so the founders raised capital by incorporating and selling shares in the venture. The *Journal* has been owned and published by the Economic Geology Publishing Company ever since. There is no record that the founders experienced difficulties in selling shares in the Company, but they must have had some because the Publishing Company had a goal that other corporations (and presumably many of the investors) would have found difficulty in understanding: the new corporation was committed to keeping the books balanced but not to making a profit.

Initially incorporated in the District of Columbia, the Publishing Company was reincorporated in 1970 as a nonprofit membership corporation in Delaware. The modification in corporate status came in response to a suggestion made by the Internal Revenue Service.

The affairs of the Publishing Company are controlled by a Board of Directors, and the *Journal* is sold to the public by direct subscription. Day-to-day operations of paper selection, review, and printing are in the hands of the Editor, while business matters, such

as subscriptions and advertising, are in the hands of the Business Editor.

The one tie the Publishing Company has with a society was instituted many years after the *Journal* was founded—with the Society of Economic Geologists. When the Society was founded in 1920 it first considered publishing its own bulletin. Because the venture seemed financially questionable, and the coffers of the new society were bare, an arrangement was reached whereby members of the Society first received offprints of papers written by its members and eventually *Economic Geology* as part of the membership fee. The arrangement is a straight-forward financial one, but it has led to sixty years of close and effective cooperation between the two organizations. But even though most Directors of the Publishing Company also have been Society members and five Directors are now appointed to the Board of the Publishing Company to represent Society interests, the organizations remain separate and independent. At the present time only 30 percent of those who receive *Economic Geology* do so through membership in the Society of Economic Geologists—the great majority of the approximately 8,000 subscribers purchase the *Journal* directly from the Economic Geology Publishing Company.

The founders of the *Journal* were of two minds when it came to choosing a name for the new publication. Their original choice was *Journal of Applied Geology*, but during the organizing meetings of 1905 Applied Geology was changed to Economic Geology. The name has led some to be confused about the purposes of the *Journal*, thinking, apparently, that economic geology means the economics of geology. But there was no confusion in the minds of the founders. They knew exactly what they meant when they used the term economic geology. The subject was defined in their original statement of purpose—a statement that has guided the *Journal* to the present day. The *Journal*, they said,

“will be devoted primarily to the broad application of geological principles to mineral deposits of economic value, to the scientific description of such deposits, and particularly to the chemical,

physical and structural problems bearing on their genesis. With the engineering and commercial aspects of mining, *Economic Geology* will not be directly concerned . . .”

They intended the emphasis to be mineral deposits and so it has remained to the present day—but not all mineral deposits. The deposits of special interest are those in which are found the ore minerals, that small group of minerals and mineral substances for which we find uses in our technological society.

Papers in *Economic Geology* have ranged widely in scope. Prior to the formation of the American Association of Petroleum Geologists in 1920 and publication of their *Bulletin*, *Economic Geology* was the preferred site for many of the early classics in petroleum geology. For many years, too, papers dealing with ground water appeared frequently in the pages of the *Journal*, as did papers on coal geology, certain aspects of engineering geology, and geophysics. The balance and range of papers submitted at any given time reflected the prevailing interests of the profession at that time. Although the number of papers submitted on topics in coal geology and ground water has declined over the past 25 to 30 years, they continue to be welcome in the *Journal*.

Most of the papers that appear in *Economic Geology* concern metallic and nonmetallic mineral deposits. The pattern has changed little since publication of the first issue, and as a result the fascinating evolution of ideas concerning how, where, and when the different kinds of mineral deposits formed is recorded in the pages of the seventy-five volumes of *Economic Geology*. No other record of the subject is so complete or so extensive. By the time fifty volumes had been printed—in 1955—the record was 42,000 pages long, and the Directors of the Publishing Company decided to print a Fiftieth Anniversary Volume containing 25 papers in which were reviewed the most important topics of economic geology as then perceived. The volume was a great success and had a major influence on students in the decade that followed its appearance. Some of the fine papers in the volume are still referred to in current research literature—a remarkably long referral history for a scientific paper of any kind.

Economic Geology's third quarter century—1955–1980—has been a period of great change and development in all sciences. Thirty-five thousand *Journal* pages were printed during the period, and because the page size was increased approximately 40 percent with Volume 63 in 1968, more papers were published in the 25-year period than during the first 50 years. The growth reflects and records a science that is changing almost issue by issue. The reasons for change are not difficult to discern. One reason is the increasing use of laboratory experiment through

which the chemistry of rock types, of wall-rock alterations, and of ore mineral assemblages can be simulated and studied under controlled conditions. Multiple hypotheses can be pared down to a very few possibilities and this narrowing and focusing of ideas has led, in turn, to major advances in our knowledge of the physical and chemical conditions under which mineral deposits form. As the body of data from experimental geochemistry grew, there developed another reason for change. Experiments are limited, but through thermochemical calculations it is possible to be quantitative and to calculate conditions of formation that cannot be simulated in the laboratory or directly measured from information preserved in the ore and gangue minerals. The move toward quantification and calculation continues apace and will probably be one of the major areas for advance during the next 25 years. Yet another reason has come through refinements to mass spectrometers, which has led in turn to systematic studies of isotopic fractionations, especially the stable isotopes of hydrogen, carbon, oxygen, and sulfur. The chemistry of the fluids that transported the ore constituents can finally be tested because isotopic signatures offer an opportunity to identify sources of materials. Many long-held beliefs have finally been tested, and some of the answers have proved to be very surprising. These and many other advances in geochemistry have recently been admirably reviewed in the second edition (1979) of the *Geochemistry of Hydrothermal Ore Deposits* edited by H. L. Barnes.

Not all of the advances in economic geology have come through geochemistry. The enormous growth in demand for mineral resources has led to a period of unprecedented, worldwide mineral exploration. As a result, classes of deposits that were unknown in 1955 are now represented by several examples, and the number of examples in some long-recognized classes—such as porphyry coppers—have been multiplied many-fold. With a greatly increased sample size and with the much deeper understanding of tectonic settings that has come through the realization of plate tectonics, it is apparent that certain types of deposits occur in specific tectonic settings. Furthermore, we can now prove through radiometric dating that the frequency with which certain classes of deposits formed varied through geological ages. Changing ideas concerning time and tectonic setting have inevitably refined the skills of those who seek to discover new deposits and those same ideas now hold out the promise that eventually we may be able to estimate, with some degree of certainty, the frequency of mineral deposits in the crust.

When the Board of Directors of the Economic Geology Publishing Company, under the leadership of President George Becraft, decided in 1978 to publish a Seventy-Fifth Anniversary Volume, their goal was

the same as that of their predecessors for the Fiftieth Anniversary Volume—to publish authoritative reviews of the most important topics in economic geology today. The appearance in 1979 of *Geochemistry of Hydrothermal Ore Deposits* filled the need for reviews of most topics in geochemistry. What was clearly needed in addition was a volume that brought together the many new ideas concerning time and place of mineral deposition, of exploration for new deposits, and of the assessment of undiscovered mineral potential in untested ground.

Detailed planning for the Seventy-Fifth Anniversary volume together with selection of topics and invitations to authors was entrusted to a committee appointed by the Board of Directors of the Publishing Company in consultation with the Executive Committee of the Society of Economic Geologists. Committee members were P. B. Barton, Jr., George E. Becraft, DeVerle Harris, Peter F. Howard, V. E. McKelvey, A. J. Naldrett, E. L. Ohle, D. A. Prentorius, W. C. Prinz, Brian J. Skinner, Tatsuo Tatsumi, John C. Wilson, and Paul K. Sims, Chairman.

The papers that make up this volume are grouped under three general headings: Geology of major classes of mineral deposits; Application of geology, geophysics, and geochemistry to mineral exploration; and Economic and social factors that affect exploration and development of mineral deposits. The papers on geology are arranged generally so as to emphasize changes in the nature and type of mineral deposits through geologic time. Coverage of major deposit types is by no means complete because in some cases completeness would have led to duplication. For example, the volume contains no papers on iron ores because that will be the subject of a publication arising from the ICGP's large project, *Iron-Formations of*

the Hamersley Basin and Analogous Basins of Iron-Formation Deposition.

More than forty hardworking volunteers provided formal reviews of the papers and an even larger number of people helped with informal reviews. Without their help, hard work, good judgment, and sound advice the volume could not have reached its high standard of scholarship. Paul K. Sims served as editor for the volume and was assisted by DeVerle Harris and John C. Wilson in seeking reviews of manuscripts in their special fields of knowledge. Louise Taylor of the U. S. Geological Survey provided indispensable record-keeping and clerical assistance. For the enormous task of copy editing former Editorial Assistants Betty Weinman and Virginia Lee Fisk got back into harness and together with Catherine Wilder and present Editorial Assistants Nancy Ahlstrom and Mabel Peterson the task was completed without disrupting the production of regular issues of *Economic Geology*. We are greatly in debt to all who helped in this complex undertaking.

The real merits of the volume rest, of course, on the tireless efforts of those who authored the 29 papers. All members of the profession and those who will join the profession in the years ahead, stand in their debt. The Committee for the Seventy-Fifth Anniversary Volume speaks for everyone in thanking the authors for their hard work and dedication.

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ECONOMIC GEOLOGY

One Hundredth
Anniversary Volume

1905–2005

Jeffrey W. Hedenquist, John F. H. Thompson, Richard J. Goldfarb,
and Jeremy P. Richards, Editors



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O. Tomurtogoo, G. Badarch, and V. A. Buryak*

[Herrington]

Mineral Deposits of the Urals and Links to
Geodynamic Evolution *Richard J. Herrington, Victor V. Zaykov,
Valery V. Maslennikov, Dennis Brown, and Victor N. Puchkov*



Preface

One hundred years of research and opinion in economic geology have been published in the pages of *Economic Geology* since October 1905. Despite many changes with time, including a large number of deposits discovered worldwide, deposit types unknown a century ago, and new analytical methods employed in the study of deposits, some of the basic questions of 100 years ago remain: how do certain kinds of ore deposits form, what are the ultimate sources, pathways, and depositional mechanisms of the metals, and can we better explore for the resources on which the future of a healthy and sustainable society depends? In addition, how have ore processes changed with the evolving Earth, and how do ore deposits reflect and record this evolution?

During the annual meeting of the Geological Society of America in 2001, Brian Skinner, Chairman of the Publications Board of the Society of Economic Geologists, established an ad hoc committee to discuss plans for the 100th anniversary of the journal. Early the following year this ad hoc group evolved into the Organizing Committee, with members listed below who came from a wide range of backgrounds and locations around the world. The Board approved the three different publications proposed by the Committee: this *One Hundredth Anniversary Volume*, a series of forward-looking Special Papers commissioned for the regular issues of the journal during the centenary period, and a Special Publication to coincide with a meeting in 2006 on the topic of “Wealth Creation in the Minerals Industry.” Papers in the Special Publication will cover a variety of issues related to the business of the minerals industry, from exploration through to mine closure, all to be managed for a sustainable future.

The goal of this Anniversary volume, as it was with the predecessor 50th and 75th Anniversary volumes, is to meet the needs and interests of economic geologists in industry, government, and academia, both professional and student, for concise and up-to-date overview papers that provide a synthesis of important topics in economic geology. The Organizing Committee started with a wide range of material to be considered, and over time the Anniversary volume became focused on the topics covered here.

This volume includes three types of papers: Earth environments and processes, to introduce and summarize many of the other papers; ore deposit types; and regional metallogeny. Authors were asked to review the history of each topic, outline fundamental aspects, synthesize insight on ore genesis, provide observations useful for exploration, and offer an assessment of the questions they perceive will be studied in the century ahead. The editors inserted cross references to other papers in the volume where appropriate, as many of the papers deal with topics that are linked to one another. Some authors have tabulated large compilations of basic information on the deposit types discussed in their papers; this material, together with any additional figures and other supplementary information, is recorded in an electronic Appendix on a CD-ROM at the back of the volume. This was done to aid the reader in searching for data and to keep the printed volume at a manageable length.

We thank members of the Publications Board, chaired successively by Brian Skinner, Samuel Adams, and John Thoms, for their support and direction throughout the four-year process of planning, writing, editing, and production, and Mark Hannington, Editor of *Economic Geology*, and Steve Kesler for their sage advice. We thank all members of the Organizing Committee for their input to the structure and breadth of the volume. Reviewers of the papers, listed below, helped to maintain the quality expected of *Economic Geology*, and we thank them for their timely efforts. We acknowledge Alice Bouley, Managing Editor of SEG Publications, in Littleton, Colorado, and her collaborators, for copyediting and production of the volume, and Bernadette Lancaster, Editorial Assistant, *Economic Geology*, in Ottawa, Canada, for her assistance. Finally, we thank all of the authors for providing papers that we believe will be important to the science of economic geology for many years to come.

In closing, we acknowledge the sponsors of the volume for their generous financial contributions; they are listed below. Their support has allowed the Society to keep the price of this large volume at an affordable level for all.

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ECONOMIC GEOLOGY ONE HUNDREDTH ANNIVERSARY VOLUME



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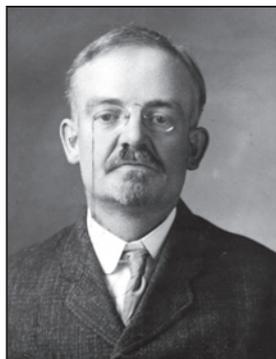


The Founders of *Economic Geology*

Twelve individuals played a major role in founding the journal. Their photos appear below .

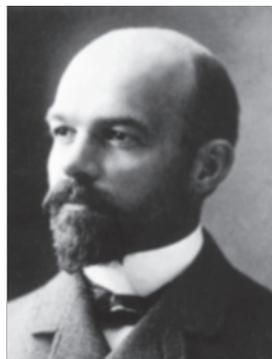


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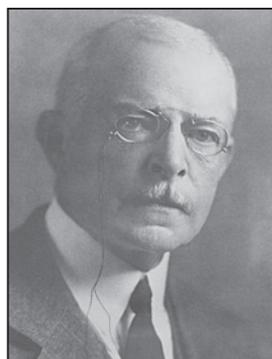
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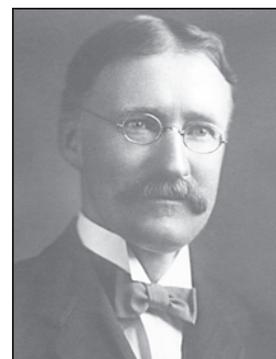
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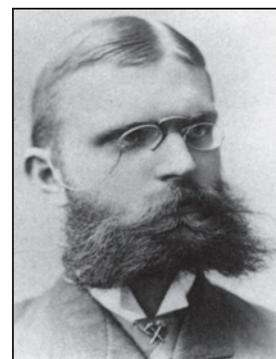


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The Editors of *Economic Geology*
1905 – 2005

During the first 100 years of the journal, five individuals have served as its Editor .
Below are their photos with years of service indicated.



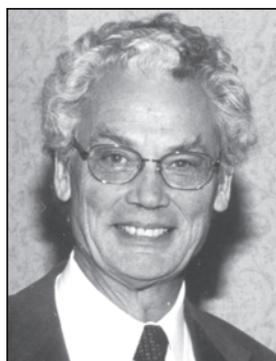
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2001–



Introduction: A Century of Excellence

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From the first issue in 1905 onward, *Economic Geology* has been the main publication for those who study mineral deposits; indeed, it is now difficult to imagine economic geology without *Economic Geology*. It is interesting to ask, therefore, *Who were the farsighted people who founded the journal, and Why did they think a specialized publication devoted to mineral deposits was needed?*

Who Were the Founders?

Let us first address the question, *Who were the founders?* They were the 12 men who collectively decided a new publication was needed, who then planned the financial structure to support the venture, and who served as the original editorial group. All were employed by, or associated with, the U.S. Geological Survey. Josiah Edward Spurr suggested the need for a journal sometime in November or December 1904. After informal discussions, nine of the founders met in the office of Waldemar Lindgren in the headquarters of the U.S. Geological Survey in Washington, D.C., on May 16, 1905, and founded the Economic Geology Publishing Company. The sole purpose of the company was the publication of a journal "...devoted primarily to the broad application of geologic principles to mineral deposits of economic value, and to the scientific description of such deposits, and particularly to the chemical, physical, and structural problems bearing on their genesis." Initial financing for the new company was raised by the sale of 80 shares at a cost of \$25 per share.

Eight of the men at the founding meeting formed the first board of directors; Spurr was president, Frederick L. Ransome, secretary, and George O. Smith, treasurer. Other members were Arthur H. Brooks, Marius R. Campbell, Walter H. Weed, Waldemar Lindgren, and a young academic from Lehigh University in Pennsylvania, John D. Irving. The ninth man at the meeting was H. Foster Bain. Irving was appointed editor. Lindgren, Ransome, and Campbell from the U.S. Geological Survey, together with three academics, James F. Kemp of Columbia University, Heinrich Ries of Cornell University, and Charles K. Leith of the University of Wisconsin, were appointed associate editors. The initial board members, the editor, and associate editors are the people we now recognize as the founders of *Economic Geology*. Two others, Frank D. Adams, of McGill University in Canada, and John W. Gregory, of Glasgow University in Scotland, were subsequently added as associate editors, and a third person, W. S. Bayley of the University of Illinois, was appointed as business editor, but they are not known to have played any role in founding the journal. It is interesting to note the ages of the founders in 1905. Marius Campbell, at 47, was the eldest, followed by Kemp, aged 46, Lindgren, aged 45, and Weed, aged 43. All the rest were in their 30's. The launching of *Economic Geology* was a venture by a group of young men near the peaks of their productive careers.

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Why a Journal?

Now to the second question, *Why a journal devoted to mineral deposits?* The answer lies in the science of mineral deposits at the dawn of the twentieth century. Although rich mineral deposits had been discovered around the world, throughout the nineteenth century, critical thinking concerning the genesis of deposits came mainly from Europe. Late in the nineteenth century, after a few young North American geologists had studied at European mining schools, things began to change. European ideas and European ways of thinking about the origins of deposits came westward across the ocean. Three of the founders—Kemp, Ries, and Lindgren—had studied in Europe and were bearers of European ideas.

An important player in the events leading to the founding of the journal, though not himself a founder, was Samuel Franklin Emmons. Emmons had trained in Europe and, as leader of the Metals Division of the U.S. Geological Survey, was the supervisor of the founders who worked for the Survey. Emmons, who was 65 years old in 1905, had studied with Gabriel Auguste Daubr e and  lie de Beaumont at the  cole des Mines in Paris and with Carl Bernhardt von Cotta at the Bergakademie in Freiberg, Saxony. On his return, he was employed by the Geological Exploration of the Fortieth Parallel under the leadership of Clarence King. When the U.S. Geological Survey was founded in 1879, King, the first director, appointed Emmons as Geologist in Charge of the Rocky Mountain Division. In this position, Emmons completed a classic study of the Leadville district in 1886 that was published as Monograph 12 of the Survey. This work became the standard against which subsequent Survey monographs and professional papers on mineral deposits were measured. When Emmons delivered his presidential address to the Geological Society of America in 1904, he explained why the U.S. Geological Survey considered monographic studies to be so important: "It was the expectation of those who planned this work that when all the important mining districts of the United States had been thus exhaustively studied, a sufficient store of well ascertained facts regarding ore deposits would have been accumulated to admit of the formulation of a new theory more firmly grounded on a basis of well established fact than any that had yet been presented."

All of the founders published Survey monographs or professional papers and most of them are now recognized as classics. In addition, Kemp published *The Ore Deposits of the United States and Canada*, a lengthy volume that ran through several editions and provided the first comprehensive summary of mineralization in the continent, and Ries published the first detailed economic geology text in North America.

Textbooks, monographs, and professional papers are great for summarizing and recording, but they are not convenient for ongoing scientific debates. The answer to "Why a journal?"

lies in those weighty tomes. *Economic Geology* was founded to meet the needs of a community of young geologists who wished to present evidence, summarize ideas, discuss points of view, and sharpen developing hypotheses.

Why 1905?

Why 1905 rather than 1895, or 1915? The time was right in 1905 because by that time many young North American geologists had come to realize that European concepts were not always in agreement with the new evidence being discovered in North America. Two publications served to focus attention on trans-Atlantic disparities between concepts and evidence. The first, “The Genesis of Ore Deposits,” was a paper delivered at the annual meeting of the AIME in 1893 by a famous European economic geologist, Franz Posepny. The second was the 1904 Presidential address to the Geological Society of America, by Emmons, on “Theories of Ore Deposition Historically Considered.” Emmons posited that many mineral deposits formed as a result of meteoric waters circulating extensively in the crust, picking up mineralizing components, and depositing them by reactions in favorable rocks. Posepny, on the other hand, advocated mineralization from below, the source of the metals being the “barysphere,” a poorly defined but metal-rich region, deep in the Earth. The young founders had their own ideas—some rather extreme, such as Spurr’s idea that quartz veins had been injected as ore magmas. *Economic Geology* was to be the medium in which such disparate ideas could be presented and discussed.

After the Founding

The community of economic geologists was small in 1905, and it was centered in government surveys and, to a lesser extent, in academic institutions. Burgeoning demand for mineral supplies in the years immediately following World War I brought a considerable change to the employment structure. In particular, the number of geologists employed by the mining industry began to increase markedly. By 1920 the change in professional demographics led J. E. Spurr—the same man who had been the first president of the Economic Geology Publishing Company—to suggest that the time was right to form a professional society for the growing community. Thus was formed the Society of Economic Geologists. The Economic Geology Publishing Company and the Society continued as separate but closely related and cooperating entities until they were finally merged in 2001. The history of *Economic Geology* from 1920 onward is not just the history of a scientific journal but also the history of a society and a profession.

It is interesting to ask, “*What effect did the founding of Economic Geology have on the field of economic geology?*” First and most obviously, the journal gave the field its name. The term economic geology had been coined in the early years of the nineteenth century but had fallen into disuse and been replaced by names such as “applied geology” and “mining geology.” Indeed, one of the first issues the founders had to settle was the choice of a name for the new journal; some argued for applied geology, others for economic geology. The same argument arose at the time the Society was founded; economic geology won the day on both occasions.

A second effect arising from the founding of the journal was the separation of economic geology from mining engineering.

As a result, economic geology became an essential component in the scientific fabric of geology. Prior to the founding of *Economic Geology* most papers on mineral deposits were published in mining journals. In the first paper of issue number 1 of *Economic Geology*, Ransome addressed the publication problem and argued the need for a journal that

provides a place where the results of investigations of scientific character, recorded in the concise and accurate phraseology of science and addressed to readers who need no concessions to their knowledge or intelligence, may appropriately be assembled, and where questions of interpretation or theory may be freely discussed. If this idea is steadfastly adhered to, there can be little doubt that the journal will not only be a potent means of maintaining the dignity and influence of one of the most important branches of geology but will be of the greatest ultimate service to both mining engineers and to general geologists.

Ransome’s words need no explanations or additions. The journal has served the purposes he outlined. It has more than fulfilled the hopes and visions of the founders. It is still the principal place for the leading scientists to record their original ideas about how, why, and where mineral deposits form.

Growth of the Discipline

The history of the first century of *Economic Geology* is coincident with the history of economic geology in the twentieth century. One period of massive change stands out. Just as World War II caused massive societal changes, so too did it bring major scientific advances to economic geology. The advances were in part due to new techniques and new discoveries from other sciences, but equally they were due to a rapidly growing world population that led to a boom in mineral exploration and a flood of new field observations.

The years from 1905 to 1955

In recognition of the first 50 years of publication, the Economic Geology Publishing Company commissioned the *Fiftieth Anniversary Volume of Economic Geology* in 1955. This 1,130-page publication summarized the advances and accumulated thinking of the previous 50 years. When the journal was founded in 1905, those involved held very broad views of the field of economic geology. All mineral-based resources save soil were included. The first volume contains papers on petroleum, coal, water, clays, and other resources in addition to metallic mineral deposits. Over the next 50 years the mix slowly shifted toward metallic minerals, but it was still an unbalanced mix in 1955. Reflecting the balance of papers in the journal, the *Fiftieth Anniversary Volume* included papers that summarized advances in petroleum geology, coal geology, properties of calcium and magnesium carbonates, groundwater studies, and clay mineral technology. Metallic minerals were treated in detail. Interestingly, some of the topics are the same as those discussed in papers in volume one, half a century earlier: examples are secondary enrichment, zonation in deposits, and classification of deposits. All papers in the volume record advances, but in many cases the advances were not what we might now, in hindsight, call major.

What, then, were the major advances of the first 50 years?² I suggest that six topic areas in the *Fiftieth Anniversary Volume* cover the main advances of the previous half-century.

1. Metallogenic provinces and epochs, as addressed by F. S. Turneure. Global tectonics was not a concept in 1955, but Turneure perceptively combined a wealth of data on structural patterns, deposit types, and timing of mineralization in ways that, 30 years later, could simply be dropped into place in a plate tectonic framework. The pattern had been recognized but the explanation was wanting.

2. An extraordinary amount of work had been done on the chemistry of hot-spring waters and hot-spring mineralization. The relationship between hot springs and certain kinds of mineralization had been recognized in antiquity, but only in the twentieth century was the concept tested in detail. An intriguing paper by D. E. White pulled a mass of data together and made the case that hydrothermal solutions can have several possible origins; they can evolve from magmatic, meteoric, or even connate saline solutions.

3. Detailed structural analyses of complexly deformed orebodies had been carried out starting in the 1920s. A number of groundbreaking structural studies had been done in places such as Hollinger in Canada, Homestake in the United States, Kalgoorlie and Broken Hill in Australia, leading to the discovery of new orebodies in old fields. An intriguing and beautifully written paper by one of those involved in some of the studies, H. E. McKinstry, describes the advances.

4. The fact that large volumes of altered rock commonly surround cores of mineralization was known in the time of Agricola and probably much earlier. Detailed mineralogical studies of hydrothermal alteration began to advance rapidly in the first half of the twentieth century. Indeed, the first monograph published by the Economic Geology Publishing Company, *Rock Alteration as a Guide to Ore, East Tintic District, Utah*, by T. S. Lovering and others, appeared in 1949. In the *Fiftieth Anniversary Volume*, G. M. Schwartz summarized advances in alteration mineralogy.

5. As a consequence of World War II, a previously minor metal, uranium, rose to major status. Over a 15-year period there was a massive advance in the understanding of uranium geochemistry and in the formative processes of uranium deposits. The work was summarized in an elegant paper by V. E. McKelvey, D.L. Everhart, and R. M. Garrels.

6. The last example is an advance based on improvements in analytical equipment and techniques. Trace element distributions had long been recognized as an indicator of mineral zoning, and also as offering potential clues to the genesis of deposits, but precision of measurement tended to restrict confident use of trace element data. M. Fleischer pulled together the massive body of quantitative spectroscopic data that had been obtained on trace elements in sulfide minerals. Fleischer's compilation was a harbinger of things to come; in the second half of the twentieth century quantitative trace-element studies became important components of studies of compositional zoning of deposits, and also began to play a role in mineral exploration.

The years from 1955 to 1980

Hints that major changes lay ahead began to appear in *Economic Geology* as the first 50 years came to a close.

Fluid inclusions in minerals had been observed and commented on for more than a century. When Lindgren reported his classic study of the Clifton-Morenci district in Arizona (U.S. Geological Survey Professional Paper 43, 1905), he noted the presence of salt crystals in fluid inclusions in quartz and concluded that hydrothermal solutions must be saline. Despite such intriguing observations, fluid inclusions were not objects of study in *Economic Geology* until a paper by H. S. Scott, involving the determination of inclusion-filling temperatures using the decrepitating method, appeared in volume 43, 1948. Six years later, in volume 49, 1954, F. G. Smith published the first paper dealing quantitatively with the compositions of fluid inclusions. The first paper discussing stable isotopes in ore deposits was published by M. L. Jensen in volume 48, 1953, and three years later, J. L. Kulp and others published the first paper demonstrating the potential uses of fractionations between the isotopes of sulfur. Today almost every issue of the journal carries papers in which data and interpretations are derived from fluid inclusion and stable isotope analyses.

The quarter century beginning in 1955 was a time when startling geochemical discoveries began to change geology, economic geology included. An indication that the long-standing puzzle of the transport of ore minerals in hydrothermal solutions was about to yield came with an important paper by J. J. Hemley on the solubility of galena in saline solutions, published in volume 43, 1948. But the path to understanding hydrothermal chemistry really started to widen with papers by P. B. Barton, Jr., in volume 52, 1957, and by H. D. Holland in volume 54, 1959. Terms such as chemical potential (first used in the journal by McKinstry and Kennedy in 1957) and fugacity (first used by Holland in his 1959 paper) started to appear frequently.

The rapidity of advances in geochemistry exceeded the capacity of *Economic Geology* to publish all papers and to some extent challenged the capacity of the readership to absorb all the new findings. In response, a group of young geologists, all of whom looked to *Economic Geology* as their main vehicle of publication, repeated, in essence, the action taken by the founders 60 years earlier—they founded a new publication. Instead of a new journal, the group, led by H. L. Barnes, published a multi-authored review volume titled *Geochemistry of Hydrothermal Ore Deposits*. Three editions of this seminal publication, each edited by Barnes, have now appeared—in 1967, 1979, and 1997. The influence on the science of economic geology has been immense. Every issue of the journal today shows the impact of the three volumes and the geochemical advances in techniques and interpretations that they chronicled.

Leaving aside the dramatic changes produced by geochemistry in the years 1955 to 1980, *What were the other major advances of the time?*³ This was the question pondered by the Organizing Committee and the editor of the *Seventy-Fifth Anniversary Volume* of *Economic Geology*. Five topics stand out above the others:

1. Through the power of radiometric dating, time bounds of certain deposit-forming processes were determined sufficiently precisely to convince even the staunchest skeptics of their validity. A prescient and explicitly convincing paper by

Charles Meyer laid out the case. Certain kinds of mineralization clearly have evolved through geologic time.

2. The plate tectonics paradigm was changing all of geology by 1980. There is no specific paper on the topic in the *Seventy-Fifth Anniversary Volume*, but evidence of a new way of thinking engendered by plate tectonics is evident throughout. At least half of the papers in the volume relate either deposit types or ore-forming process to tectonic locations controlled or influenced by the motions of tectonic plates.

3. For many years, evidence had been gathering to support the hypothesis that Precambrian climates and atmospheres had differed greatly from climates and atmospheres of the Phanerozoic. Two papers addressed some of the consequences for mineralization: Pretorius discussed gold and uranium in Paleoproterozoic quartz-pebble conglomerates, and Button and Tyler discussed the importance of Precambrian paleoweathering and erosion surfaces in southern Africa.

4. Two classes of mineral deposits had received much attention over the 25-year span. Porphyry coppers were not a new class of deposit, but by 1980 so many had been discovered, explored, and studied, that a detailed understanding of their tectonic locations and internal variations of mineralization and alteration was emerging. A seminal paper by Titley and Beane pulled all the findings together.

The second class of deposit to be studied in great detail was volcanic-hosted massive sulfide deposits, reviewed exhaustively by Franklin, Sangster, and Lydon. These fascinating deposits had been known and mined from antiquity, but only in the twentieth century did it become apparent they had been formed on ancient sea floors. Oceanographic explorations of the sea floor in the years following World War II had yielded tantalizing hints of mineralization at places along the modern mid-ocean ridge, but few geologists, if any, thought that modern deposits might be discovered forming on the sea floor today. But discovered they were, first on the East Pacific Rise at 21 degrees north in the late spring of 1979, and then at many other places along both spreading and subduction plate edges.

The years from 1980 onward

The papers that accompany this introduction to the *One Hundredth Anniversary Volume* record many of the advances of the last quarter century. It is always dangerous to decide the importance of topics while the issues are still being studied. You, the reader, can decide for yourself. Articulated with the help of Stephen Kesler and Jeffrey Hedenquist, the following are suggestions for the major advances of the past quarter century:

1. The important role of global tectonics in the formation and distribution of mineral deposits has become firmly established. Evidence of the linkage is principally Phanerozoic in age, the time when Pangea was assembled and then fragmented. It is still unclear to what extent Phanerozoic tectonic models can be safely applied to Proterozoic circumstances and even less clear that Phanerozoic models can be used for the Archean. Despite such uncertainties, the recognition and application of global-scale tectonics in explaining the location of mineralization has had a huge impact on the study of mineral deposits.

2. The extraordinary expansion in the number of discovered diamondiferous pipes is an advance of major proportions. Discoveries are still being reported at a remarkable rate. The science behind the discoveries lies in the vast amount of research on the petrology of mafic and ultramafic rocks and the application of that research to the prospecting for new deposits.

3. When the second edition of *Geochemistry of Hydrothermal Ore Deposits* was published in 1979, the point was made that one of the major unanswered questions concerning hydrothermal systems was their magnitude. Historically they had been thought to be rather localized systems. The 11.7-km hole drilled in the Kola peninsula by Soviet scientists was the first clear indication that our thinking was incorrect. It was discovered that fluid pressures in the hole remained hydrostatic, or nearly so, all the way to the bottom—the crust has to be more permeable than previously thought and widespread circulation may well extend to depths of 20 km or more. At the same time computer modeling has shown that fluid flow, especially in sedimentary basins, can cover distances that are continental in scale.

4. Submarine hydrothermal systems and associated mineralization were discovered just as the *Seventy-Fifth Anniversary Volume* was published. The extraordinary intensity of marine research that followed the breathtaking discoveries has rapidly built our understanding of submarine mineralization, both in the present and the past, to such an extent that ore deposition in the submarine environment is arguably now one of the most clearly understood of all mineralizing environments.

5. The search for alternatives to carbon-based energy sources has sparked intensive investigations into land-based geothermal systems, leading to important insights about meteoric and magmatic hydrothermal systems. Direct analyses of fluids in active hydrothermal systems, both terrestrial and submarine, have refined interpretations of fluid inclusion data from ore deposits, and have allowed numerical models of chemical and physical processes to be tested and refined.

6. So many ore deposits have been discovered over the past half century, and collaborations between industrial, academic, and governmental geologists has been so extensive, that realistic deposit models have now been developed for many of the major classes of mineral deposits; a few examples are epithermal gold, porphyry copper, and immiscible sulfide nickel-copper deposits.

The century past has been an extraordinary one for science in general, and economic geology is no exception. One might reasonably ask, *What is the major challenge that economic geology will face in the century ahead?* My answer, which is hardly controversial, is that the accumulated understandings of deposit-forming processes and the wealth of data now being codified into robust deposit models need to be developed into an exploration philosophy by which geologists can prospect the half of the continental crust that is covered by barren rocks. That is where the great mineral deposits of the future await discovery, but so far we are only starting to develop ways to find them.