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Volume 2

GEOLOGY AND GEOCHEMISTRY OF EPITHERMAL SYSTEMS

CONTENTS

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B.R. Berger and P.M. Bethke

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Geology and Geochemistry of Epithermal Systems

B.R. Berger and P.M. Bethke, Editors
J.M. Robertson, Series Editor

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FOREWORD

Geology and Geochemistry of Epithermal Systems--Volume 2 of Reviews in Economic Geology--was created to accompany a Society of Economic Geologists (SEG) short course of the same name that was given in October, 1985, prior to the annual meetings of the Geological Society of America and Associated Societies in Orlando, Florida. As was the case with Volume 1, the final published version of Volume 2 unfortunately postdates the short course by some months.

Geology and Geochemistry of Epithermal Systems presents a synthesis of the current understanding of the processes responsible for the concentration of metals (especially gold and silver) in near-surface environments, provides an overview of the systematics of the most important approaches to the study of epithermal ores and processes, and summarizes the geology of both sediment-hosted and volcanic-hosted epithermal precious-metal deposits.

After the volume editors, the most significant contributors to the production of this volume were the members of the Editorial Support Group, Branch of Exploration Geochemistry, U.S. Geological Survey, Denver, Colorado. These ladies, Marilyn A. Billone, Candace A. Vassalluzzo, and especially Pamela S. Detra and Dorothy B. Wesson, accomplished the long, arduous, and often frustrating job of assembling, editing, and formatting the book with a uniformly high level of professionalism and good cheer. Their efforts are gratefully acknowledged. Carol Hjellming of the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) editing staff checked, balanced, and helped interpret the chemical equations; Lynne McNeil (NMBMMR) formatted the cutlines. Lastly, I wish to express my continuing appreciation to the New Mexico Bureau of Mines and Mineral Resources and its Director, Frank Kottlowski, who provide the Series Editor with time, space, and encouragement.

James M. Robertson
Series Editor
Socorro, NM
March, 1986

PREFACE

In a speech on May 10, 1911, before the Geological Society of Washington, Waldemar Lindgren described his systematic classification of all types of mineral deposits. One of his categories included deposits related to intrusive and eruptive igneous rocks that form veins at shallow depths that contain open-cavity filling textures and that have been a primary source of "bonanza" grades of gold and silver--the epithermal deposits. Historically, most of the ores in epithermal systems have been mined from quartz veins, breccias, or disseminations that are associated with non-marine volcanic rocks. Open-space filling textures and structures are common--comb structure, crustification, symmetrical banding, and crystal-lined vugs. Ore minerals include native gold, native silver, electrum, argentite, sulfosalts, tellurides, and selenides and often the common sulfides sphalerite, galena, and chalcopyrite. Common gangue minerals are quartz, adularia, calcite, barite, rhodochrosite, and fluorite. Alteration is commonly widespread in epithermal systems, particularly in the upper portions of the vein systems; among the alteration phases are quartz, adularia, illite, chlorite, alunite, and kaolinite.

Lindgren (1928) recognized the difficulty of developing a rigid subsidiary classification scheme for epithermal deposits; he separated them into six categories:

1. Gold deposits
2. Argentite-gold deposits
3. Argentite deposits
4. Gold selenide deposits
5. Gold telluride deposits
6. Gold telluride deposits with alunite

Nolan (1933) and Ferguson (1929) felt that few of these six characteristics were restricted enough to be diagnostic and proposed only two classes of epithermal systems based on the weight ratio of gold to silver, silver-gold, and gold-silver. Based on his experience with deposits in Nevada, Ferguson (1929) found that there is a bimodal distribution of gold-silver ratios, and Nolan (1933) felt that the bimodality was due to genetic processes.

For the silver-gold deposits, Nolan (1933) noticed that through-going fault fissures control the ore and felt that this implies a deep origin for the source of the metals. Nolan (1933) also noted that the precious-metal ores are very commonly sharply limited above and below by approximately parallel surfaces referred to as the ore "horizon." He suggested that these limits are related to temperature. Base metals tend to increase at and below the base of the lower surface of the precious-metal ore. Figure 1 is a longitudinal, vertical projection of the Last Chance-Confidence silver-gold vein in the Mogollon mining district, New

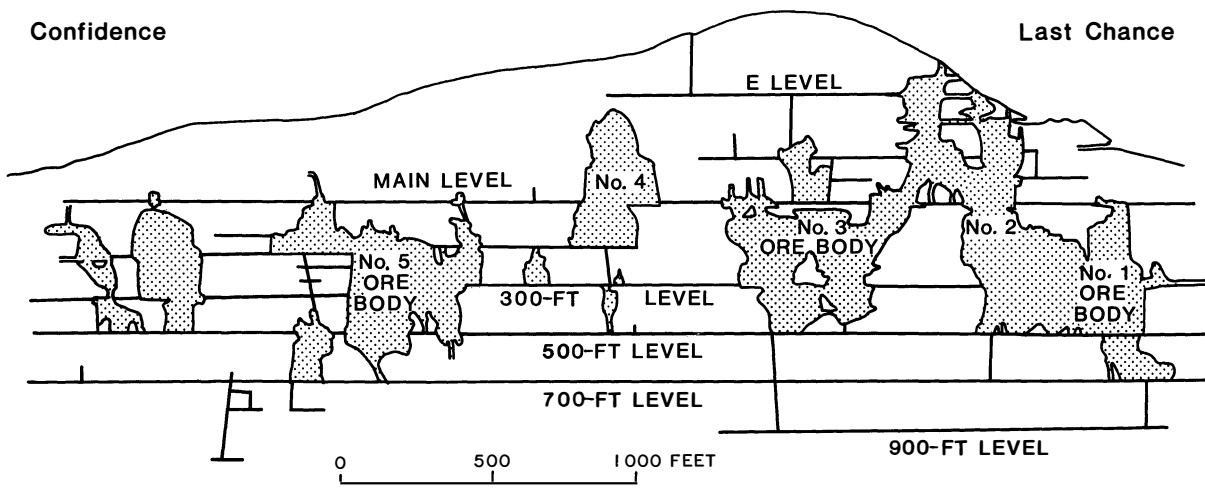
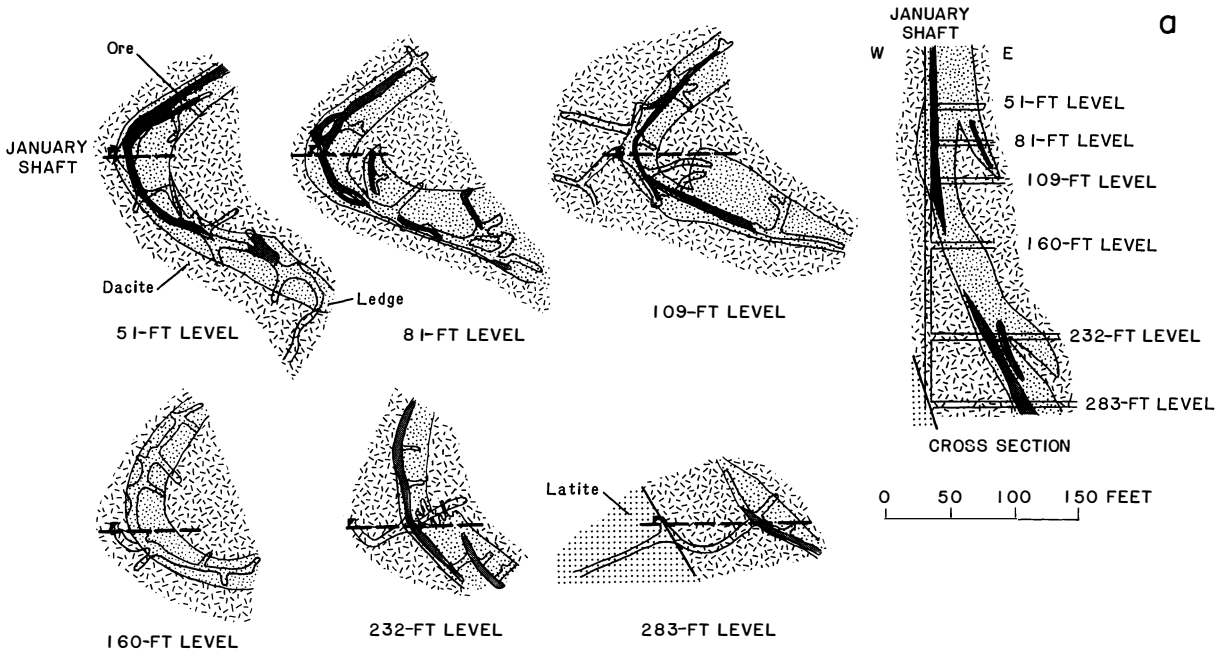


Figure P.1. Vertical, longitudinal projection of the Confidence-Last Chance vein in the Mogollon mining district, New Mexico (Ferguson, 1927). Banded quartz vein is continuous along strike with ore grade material occurring in specific masses (stippled areas) in the vein. The tops and bottoms of the silver-rich ore bodies describe near parallel surfaces referred to as the "ore horizon."

Mexico (Ferguson, 1927) illustrating the ore horizons, the shape of ore bodies, and the typical distribution of ore grades within a continuous banded quartz-adularia-sericite vein. Burbank (1933) reported that base metals appear to be more abundant in silver-gold deposits in regions of sedimentary rocks with overlying volcanic rocks and in thick, volcanic sequences with a long history of volcanic activity. In contrast to the silver-gold deposits, Nolan (1933) noted that gold-silver deposits are commonly within or close to small, shallow intrusive bodies and that the ore-controlling fracture systems are frequently more discontinuous than those associated with silver-gold deposits. The gold-silver ores are also more irregular in distribution than the silver-gold ores. Nolan felt that this irregularity may be related to the complex thermal regimes in these types of systems due to the shallow intrusive activity. Figure 2a shows a series of plan views of the January mine, Goldfield mining distrct, Nevada and a cross section through the January shaft (Ransome, 1909) showing the relationships of ore to quartz-alunite-kaolinite replaced wallrock ("ledge matter") and the host rocks. Figure 2b shows two cross sections from Ransome (1909, p. 154) of the Combination mine in Goldfield illustrating the irregular vertical distribution of bonanza-grade ore masses within the "ledge matter." Also, the ore bodies were not persistent along strike.

Although Waldemar Lindgren (1928) recognized the correlation between epithermal systems and active geothermal systems, it was Donald E. White (1955, 1981) who championed the detailed study of active systems and the application of the results and concepts derived from these studies to epithermal ore deposits. The impact of White's leadership in the study of hydrothermal systems, in general, and epithermal systems, in particular, was recognized by the Society of Economic Geologists when it held a symposium in



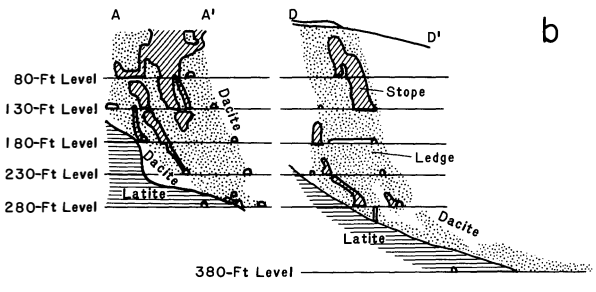


Figure P.2. a). Plan views of the January mine at selected mining levels and a cross section through the January shaft Goldfield mining district, Nevada (Ransome, 1909). Bonanza-grade gold ores occur in replaced dacite referred to as "ledge matter." The ore bodies are not persistent either down-dip or along strike, and occur both on the hanging wall side of the ledge and on the foot wall side. b). Two cross sections from Ransome (1909, p. 154) of the Combination mine in the Goldfield district. Bonanza-grade gold ores occur in irregular, discontinuous masses within the ledge. The ledge follows a lithologic contact and flattens with depth.

his honor in February, 1984 entitled: Geothermal Systems and Ore Deposits. It clearly emphasized the value of using active geothermal areas as models of fossil, ore-forming hydrothermal systems.

Thus, the evolution of understanding of the geology and genesis of epithermal precious-metal deposits has followed a pathway from the early, vividly descriptive studies of mining districts such as the Comstock Lode, Nevada (Becker, 1882), Cripple Creek, Colorado (Lindgren and Ransome, 1906), and Waihi, New Zealand (Bell and Fraser, 1912) to the later, topical studies on structure (Wisser, 1960), alteration (Hemley and Jones, 1964), stable isotopes (Taylor, 1973), and fluid chemistry (Barton et al., 1977). The most recent research on epithermal deposits has built on these past studies and has emphasized the thermal and compositional roles of volcanic rock terranes; the genesis, significance, and pattern of alteration mineralogies; the sources of the geothermal fluids and the paleohydrology of the systems; and, the chemical conditions surrounding the deposition of the ore minerals.

The present volume is an attempt to provide a synthesis of the current state of geological and geochemical knowledge of epithermal precious-metal systems. It follows on, and should be used in conjunction with, the first volume in this series: Mineral-Fluid Equilibria in Hydrothermal Systems by Henley et al. (1984). In the present volume we have attempted to provide a framework for understanding the systematics of controls on fluid compositions and of metal and gangue transport and deposition. The structure, dynamics, and transport properties of active geothermal systems are used as a starting point. With active systems as a reference, the evolution of fluid compositions and the constraints on metal and gangue transport and deposition in the epithermal environment are explored. The systematics of fluid inclusion and light stable-isotope applications is developed because these two approaches have been so useful in the development of our understanding of epithermal processes. The importance of boiling, cooling, and oxidation in transport properties of epithermal systems is evaluated through a numerical modelling approach. With the foregoing as background, the observational base and its interpretation for epithermal ore deposits in continental volcanic and sedimentary terranes is explored through summaries of the geologic, mineralogical, and geochemical characteristis of, and trace-element distributions in, some well-studied epithermal ore deposits. The final chapter is devoted to the use of our understanding of epithermal systems in the development of exploration strategies.

This volume does not attempt to be the final word on epithermal ore deposits, nor does it claim comprehensive treatment. The absence of a chapter on the hydrology of epithermal systems documents the fact that our current understanding of this aspect is woefully inadequate. It does not reflect a lack of recognition of the importance of hydrologic controls. Similarly, this volume focuses on volcanic- and sediment-hosted epithermal deposits in the cordillera of western North America, particularly the United States. It does not treat aspects of alkaline- or basaltic-rock related deposits such as Cripple Creek, Colorado, and Vatacoula, Fiji, nor does it treat the relationship of epithermal systems to deeper hydrothermal systems responsible for the formation of porphyry-type deposits. Again our reason is the lack of an adequate observational base. Our primary purpose in organizing this volume and the related Short Course has been to stimulate critical studies to improve our current understanding of epithermal deposits and processes rather than to document it. Perhaps our omissions will serve this purpose equally as well as our inclusions.

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