Minerals Engineering 22 (2009) 402–408

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Research in quantitative mineralogy: Examples from diverse applications

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ARTICLE INFO

Article history:
Received 6 October 2008
Accepted 6 November 2008
Available online 27 December 2008

Keywords:
Quantitative mineralogy
Research
Geology
Geomet
Ores

ABSTRACT

Developed for the mining industry and applied to oil and gas projects, quantitative mineralogy also has enormous potential as a research tool. The Advanced Mineralogy Research Center at Colorado School of Mines was developed for this purpose, and several representative ongoing research projects using QEMSCAN® techniques are described herein. Geomet applications relate mineralogy and geology to potential processing attributes such as hardness and grind characteristics. For kimberlite exploration and development, and diamond petrogenesis, quantitative mineralogy reveals the complex secondary silicate mineralogy in volcanic and mantle materials, and provides a means of viewing garnets from exploration samples. In Carlin-type gold deposits, the distribution of arsenian-pyrite can serve as a proxy for the distribution of gold. Monzonites from porphyry copper deposits reveal pervasive potassic alteration and quartz veining, which may impact the behavior of the materials during processing. A new view of feldspar zoning in granites not only has broad implications for understanding the petrogenetic evolution of magmatic systems, but is of relevance in processing feldspar-bearing materials. Environmental and biological applications include soil mineralogy, the effect of soil chemistry on vegetation, and studies of mammalian tissues. These examples illustrate how automated mineralogy allows researchers a means of quantifying mineralogical relationships in a wide variety of materials.

1. Introduction

The Advanced Mineralogy Research Center at Colorado School of Mines (Mines) is dedicated to research and new applications development in quantitative mineralogy. Mines is unique among universities in the world, with expertise in a wide variety of resource-related areas as well as in pure science and engineering. In part, a result of this diversity of available technical capabilities, the AMRC opened its doors in April with some 20 research projects already in development. Projects in the resources sector make up the bulk of initial activities and range from geometallurgy and copper and gold mining to oil shales and petroleum reservoir characterization. Developing research projects in geological, environmental, biological, and planetary sciences also are in progress. Interdisciplinary research is important, with emphasis on communication across key areas to provide for new insights into mineral characterization in a wide variety of sciences. In contrast to common departmental research initiatives, the diversity of projects in quantitative mineralogy enables cross-pollination of ideas among mining, energy, and environmental sciences. Individual sample challenges, identification of complex mineral associations, difficult ore horizons or processing development issues that may not be resolved in an industry setting can be better handled in a dedicated research environment. This interdisciplinary environment presents challenges as well, such as developing training programs on an on-call basis that depend on the level of participation by the researcher.

2. Analytical methods

This paper provides an overview of some current research applications in quantitative mineralogy using QEMSCAN® technology, a scanning electron microscope platform with four energy dispersive X-ray spectrometers, allowing for fast acquisition of X-ray signals to determine mineral abundances in dust- to rock-size samples. Mining applications include examination of the distribution of economic minerals in surrounding materials and the determination of their optimum recovery methods based on mineralogy. Beyond mining, quantitative mineralogy is also being applied to the oil and gas sector in the examination of oil shales and pore throat mineralogy, as well as to coal, environmental, planetary, medical, and other applications where mineralogy is a key factor in material characterization. iDiscover® software accommodate queries and new views of materials.

The QEMSCAN® system combines a fully automated Carl Zeiss EVO50 scanning electron microscope platform with four Bruker silicon-drift energy dispersive (EDS) X-ray detectors, a four-quadrant

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doi:10.1016/j.mineng.2008.11.003

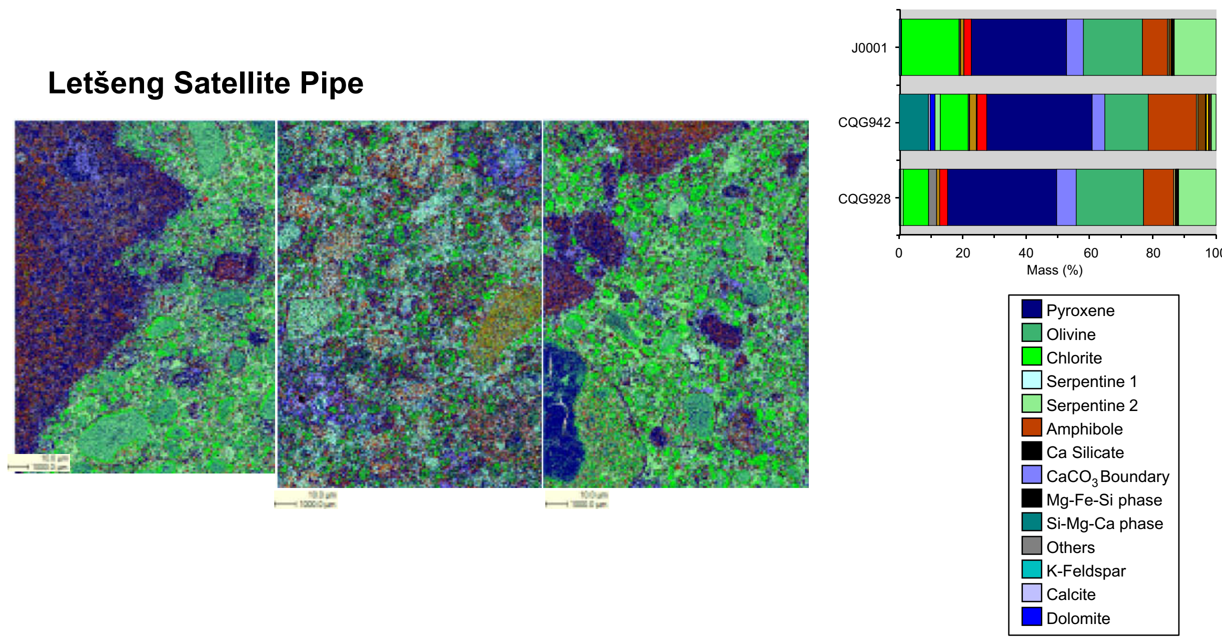

Fig. 1. False-colored images, modal abundances, and mineral list for three samples of Letšeng Satellite Pipe, Lesotho kimberlites. The samples define a distinct population defined by the modal assemblage.

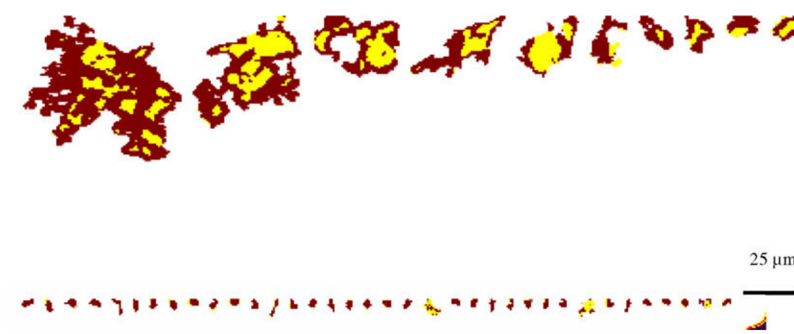

Fig. 2. False-colored digital images of pyrite grains (light, centers) with arsenian rims (darker) from the Chukar Forrwall deposit, Nevada. Sub-micron-sized gold occurs in arsenian-pyrite rims within Carlin-type systems. Identification of arsenian-pyrite can be used as a proxy for gold mineralization.

solid-state backscatter electron detector, and a secondary electron detector (Fig. 2). The system further uses an energy resolution of 133 eV (Mn Kα), peltier cooling (no liquid nitrogen), an accelerating voltage of 25 kV, a specimen current of 5 nA on the Faraday Cup, a working distance of ~24 mm, and a stage *Z* distance of 18 mm. The beam diameter is typically 0.25–0.5 μm. The four EDS-detector array allows for fast acquisition of data (commonly 150 analyses per second) and enables the automated analysis of large sample populations for delivering statistically reliable data sets. iDiscover software automates the stepping of the electron beam across samples at a user-defined pixel resolution, typically 520 μm and down to 12 μm resolution (Fig. 3). At each pixel, the system collects a BSE signal and EDS spectrum and correlates them with predefined mineral definitions developed for the system and for the material. These definitions and correlations are assessed quite closely by the scientist to ensure data quality and accurate representation of the materials. The product is a false-colored image of the material with a large dataset of digital information that can then be queried and displayed in many applications.

3. Research project overviews

Three of the studies presented below fall into the area of geomet, examining mineral characterization for potential process development impacts. The fourth study presented below is a vivid illustration of carefully fine-tuning the technique to provide important compositional variation information. The fifth study illustrates and environmental application in the field of medical geology and environmental science.

3.1. Geomet and diamond deposits

Geomet investigations require thorough mineral characterization of geological and ore materials during process development (Hoal, 2008; Hoal et al., 2006). This includes developing an understanding of the field relationships in a deposit and the distribution of ore and gangue minerals throughout domains that are defined on the basis of process attributes. Quantitative mineralogy is increasingly applied in this context to metal deposits, where the improved understanding of the mineralogy has benefits for liberation studies, comminution behavior, and flotation dynamics, among other aspects of a mining operation. Benvie (2007) demonstrated how automated mineralogy analysis can be applied to kimberlites, the most common lithological host of primary diamond deposits. Diamond ores are highly variable in composition, mineralogy, grain and fragment size, and grade within a deposit. In addition, kimberlites are typically porous and friable materials to handle and analyze. Nevertheless, diamond projects are prime examples of the diverse ways