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Review

Geochemical characteristics of igneous rocks associated with epithermal mineral deposits—A review

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ABSTRACT

Newly synthesized data indicate that the geochemistry of igneous rocks associated with epithermal mineral deposits varies extensively and continuously from subalkaline basaltic to rhyolitic compositions. Trace element and isotopic data for these rocks are consistent with subduction-related magmatism and suggest that the primary source magmas were generated by partial melting of the mantle-wedge above subducting oceanic slabs. Broad geochemical and petrographic diversity of individual igneous rock units associated with epithermal deposits indicate that the associated magmas evolved by open-system processes. Following migration to shallow crustal reservoirs, these magmas evolved by assimilation, recharge, and partial homogenization; these processes contribute to arc magmatism worldwide.

Although epithermal deposits with the largest Au and Ag production are associated with felsic to intermediate composition igneous rocks, demonstrable relationships between magmas having any particular composition and epithermal deposit genesis are completely absent because the composition of igneous rock units associated with epithermal deposits ranges from basalt to rhyolite. Consequently, igneous rock compositions do not constitute effective exploration criteria with respect to identification of terranes prospective for epithermal deposit formation. However, the close spatial and temporal association of igneous rocks and epithermal deposits does suggest a mutual genetic relationship. Igneous systems likely contribute heat and some of the fluids and metals involved in epithermal deposit formation. Accordingly, deposit formation requires optimization of source metal contents, appropriate fluid compositions and characteristics, structural features conducive to hydrothermal fluid flow and confinement, and receptive host rocks, but not magmas with special compositional characteristics.

Contents

1. Introduction

Precious- and base-metal-bearing epithermal mineral deposits are the shallow manifestations of intrusion-centered hydrothermal systems

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and reflect district-scale magmatism (Simmons et al., 2005). Many of these deposits constitute the upper parts of magmatic-hydrothermal systems whose deeper parts form porphyry Cu-Mo-Au deposits (Seedorff et al., 2005). Epithermal deposits are commonly divided into two principal types distinguished by characteristic gangue mineralogy (Simmons et al., 2005). Gangue assemblages for the first type typically include quartz, adularia, calcite, and illite; representative deposits, commonly referred to as the quartz-adularia type, are generally synonymous with the low- to intermediate-sulfidation epithermal deposits of Einaudi et al. (2003). In contrast, gangue assemblages for the second type include quartz, alunite, pyrophyllite, dickite, and kaolinite; representative deposits, commonly described as the quartz-alunite type, are generally synonymous with high-sulfidation epithermal deposits. A third, quite distinct class of epithermal gold-silver ± tellurium deposits occurs in association with distinctly alkaline volcanic rocks. However, because these deposits are relatively limited in their spatial distribution and are associated with a distinctive volcanic rock composition, these deposits are not included in this review article.

Essentially all epithermal deposits are associated with either calc-alkaline subduction-related arc magmatism or calc-alkaline to tholeiitic back-arc continental rift magmatism (Sawkins, 1990; John, 2001; Sillitoe and Hedenquist, 2003; Simmons et al., 2005). Most igneous rocks associated with epithermal mineral deposits are extrusive but some deposits are directly associated with intrusive rocks. Both arc and back-arc continental rift magmatism can persist in appropriate, unchanging tectonic regimes for several to tens of million years; accordingly, associated epithermal deposits can develop at any time during the corresponding, protracted magmatism. Demonstrating that a particular epithermal deposit is genetically related to specific igneous rocks is seldom possible, however, because the igneous rocks that host deposits are not necessarily genetically responsible for deposit formation. Consequently, for this study, all igneous rocks with ages within several million years and located within <10 km of a particular epithermal deposit are considered to have plausibly contributed to deposit genesis.

Subduction-related rocks associated with epithermal deposits form parts of convergent-margin magmatic arcs in both continental and oceanic settings. These rocks form composite stratovolcanoes, exogenous to endogenous lava dome complexes, and, less commonly, ash-flow calderas. These volcanoes coalesce to form essentially continuous chains of eruptive centers along the length of associated magmatic arcs. Back arc volcanic rocks associated with some epithermal deposits represent more widely distributed volcanic centers typical of magmatism in extensional settings.

Despite many studies of epithermal deposits, conducted during many decades, no synoptic compilation or interpretive synthesis of geochemical data for igneous rocks associated with epithermal deposits has been completed. A small compilation (140 samples representing 12 deposits; Arribas, 1995) represents the only attempt to characterize the wide array of igneous rocks associated with these deposits. Simmons et al. (2005) defined a representative subset of epithermal deposits whose characteristics exemplify this broad class of deposits (Fig. 1). This subset, augmented by a few additional, subsequently discovered deposits, constitutes the group of epithermal deposits for which data were compiled (du Bray, 2014). Interpretations presented herein are based on a derivative version of that compilation, which includes data for 1497 samples of essentially unaltered igneous rock associated with about 50 individual epithermal deposits or districts (du Bray, 2014). A series of geochemical filters (du Bray, 2014) were used to identify potentially altered samples; these samples were removed from the interpreted dataset. The absence of altered samples in the interpreted dataset was confirmed using molar element metrics defined by Booden et al. (2011). <2% of samples in the interpreted dataset have values of molar (K + Na + 2Ca)/Al less than the 0.95 limit defined as indicative of altered rock. The majority of samples within this small group have compositions consistent with the data array defined by unaltered magmatic compositions. The primary compilation was modified prior to data interpretation because igneous rocks associated with several epithermal deposits are represented by disproportionately large numbers of samples whose abundances might potentially bias the dataset. Accordingly, random selections of appropriate numbers of samples were made from analyses available for igneous rocks associated with the Bodie, Aurora, Comstock Lode, Martha Hill-Favona-Karangahake-

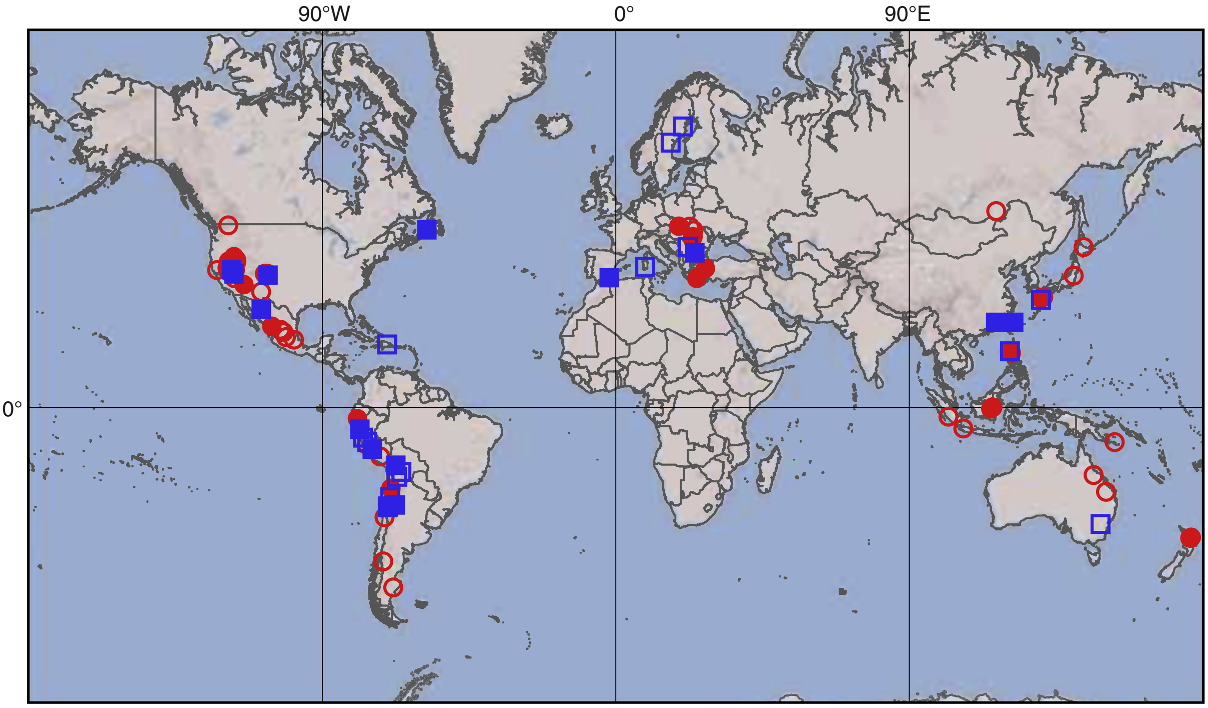

Fig. 1. Map showing the worldwide distribution of representative epithermal mineral deposits. Blue squares, quartz-alunite deposits. Red circles, quartz-adularia deposits. Filled symbols indicate deposits for which geochemical data are available; unfilled symbols represent deposits for which geochemical data are not available.