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Constraints on the sources of ore metals in Mississippi Valley-type deposits in central and east Tennessee, USA, using Pb isotopes

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ABSTRACT

The Mississippi Valley-Type (MVT) Central and East Tennessee (TN) districts contain lead-zinc deposits that occur in the Early Ordovician carbonates of the Knox Group. Although both districts share similar host rock, have similar temperatures of formation, and typically fill open spaces of collapse breccias or replace their host carbonates, previous studies may suggest that these ores did not form from the same mineralizing fluids and may have different Pb sources. Nu Plasma MC-ICP-MS Pb isotopic analyses on sulfides from Central and East TN were conducted and the metal sources evaluated. Pb isotope ratios from the Young Mine in the East TN District plot within ranges defined by other East TN District samples from previous studies. Generally, Pb isotope ratios or ores from the Elmwood Mine in the Central TN District are more radiogenic and plot between samples from the southern Appalachians and Illinois-Kentucky districts. It appears that the thick, black, metal-rich shales of the Appalachian Basin have been the source of the Pb-Zn and ore fluids of MVT deposits that formed the East TN deposits. When East TN Pb data from this study are compared to Central TN Pb data, Central TN Pb is commonly more radiogenic, suggestive of a mineralizing fluid with different compositions. Lead isotopic signature of Central TN ores may imply potential mixing between end-member sources originating from the Southern Appalachians and Illinois basins.
Lead isotopes in MVT and carbonate-hosted base metal deposits in US, South America, and Europe display two basic types of Pb-isotopic signatures. The classic MVT deposits in the mid-continent US (SE and Central Missouri, Illinois-Kentucky, and Upper Mississippi Valley districts) have highly radiogenic Pb-isotopic compositions and they generally display linear Pb-isotopic arrays. In contrast, deposits from Europe (Irish-type, Silesian-type, Alpine-type, and Cévennes region), the Appalachians, and Andean-type deposits have lower Pb-isotopic values. The European deposits (except for the Irish-type) have a restricted range of isotopic ratios, which suggest a single mineralizing event of relatively short duration. It appears that basement rocks or sedimentary rocks derived from the basement contributed Pb to many MVT and carbonate-hosted base-metal deposits worldwide. Hydrothermal leaching of radiogenic Pb from the crystalline basement rocks may have occurred during formation of these ore deposits. High $^{238}U/^{204}Pb$ values for several districts also suggest a supracrustal origin of Pb.

1. Introduction

The largest Mississippi Valley-Type (MVT) deposits are found in North America. Worldwide, they account for 38% of the total Pb and Zn tonnage in sediment-hosted deposits (Leach et al., 2010). A high percentage of these deposits formed during Devonian to Permian time and a smaller proportion during Cretaceous to Tertiary time, related to a series of intense tectonic events during assimilation of Pangea: the Acadian orogeny (Late Devonian – Early Mississippian) generated early mineralization in the Appalachian Mountain region; the Alleghenian-Ouachita orogeny (Pennsylvanian – Permian) caused the mineralization in the Appalachian and the midcontinent regions; the Laramide orogeny (Late Cretaceous – Early Tertiary) generated the mineralization in the Cordilleran region (Leach et al., 2010; Gregg and Shelton, 2012). Well-known deposits and districts in the midcontinent region include the Upper Mississippi Valley, Central Missouri, SE Missouri Lead Belts, Tri-State, and Northern Arkansas districts; major deposits in the Appalachian region include the Central and East Tennessee districts, and the Timberville, Nittany Arch, and Friedensville deposits (Fig. 1). Most MVT deposits are located at the flanks of hydrocarbon-producing sedimentary basins and fluid inclusions of hydrocarbons are often present together with inclusions of saline brine in the ore minerals. This is direct evidence that oil and possibly gas was present in the ore at the time of formation.

The most abundant minerals in MVT deposits are sphalerite and galena (zinc and lead, respectively), in addition to barite, fluorite, calcite

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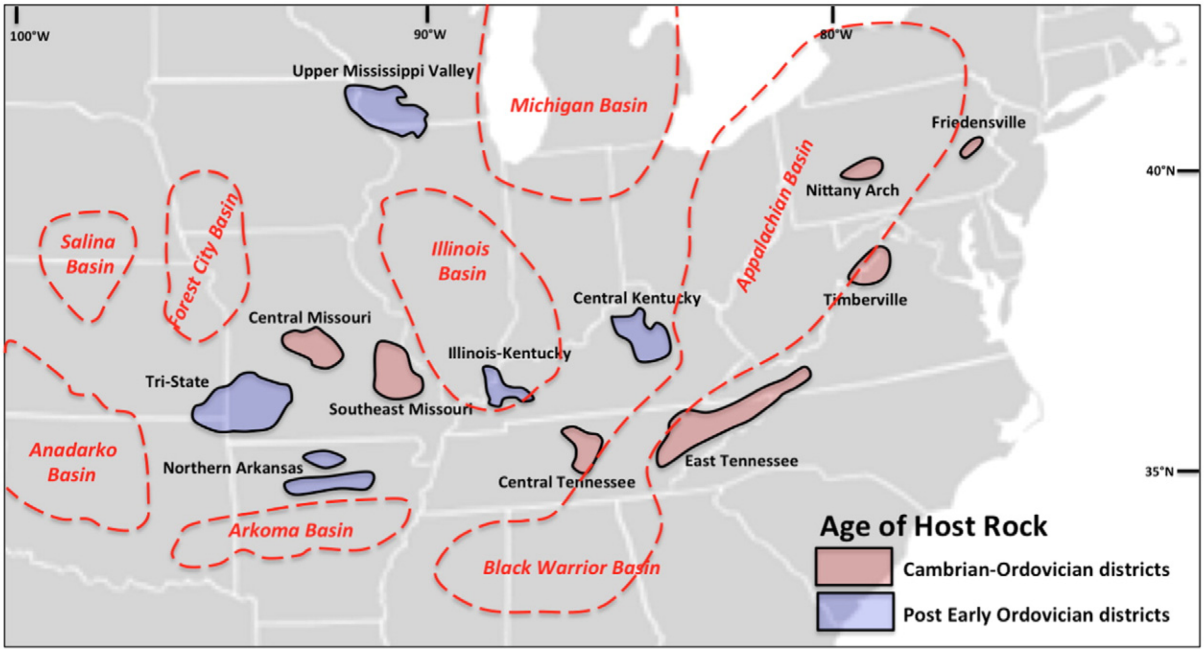

Fig. 1. Map of the U.S. midcontinent region showing the locations of major MVT mining districts, sedimentary basins, and the age of rocks hosting the deposits (modified from Heyl et al., 1966; Kendrick et al., 2002).

and dolomite. MVT deposits are characterized by low temperature of formation (50 °C to 200 °C), epigenetic emplacement, and stratabound character (generally restricted to carbonates). The MVT deposits formed from very large hydrothermal systems in which the fluid drive was caused by deformation of foredeeps and uplift of foreland thrust belts during collisional tectonics (Leach and Rowan, 1986; Oliver, 1986; Garven et al., 1993). The model that most accurately describes the regional hydrothermal systems is topographically driven fluid flow in which ground water, recharged in the uplifted orogenic margin of a foredeep, migrates through deep portions of the basin, acquires heat and dissolved components, and discharges along the basin's cratonic flank (Bethke and Marshak, 1990). Reduced sulfur content is the major control on the concentration of metals in MVT ore fluids, therefore low reduced-sulfur sedimentary brines will have greater potential to extract metals from a variety of lithologies; the metals, especially the base metals, are considered to be transported as metal-chloride complexes in MVT ore fluids (Leach et al., 2010). There are multiple precipitation mechanisms that have been proposed to explain the formation of ore-grade sulfides in MVT deposits, including fluid mixing, cooling, changes in pH through wall-rock alteration, and various sulfate reduction processes (Sverjensky, 1981; Viets and Leach, 1990; Anderson and Price, 1991; Plumlee et al., 1994; Goldhaber et al., 1995; Shelton et al., 2009; Appold and Wenz, 2011).

Relatively little research has been done on MVT deposits from the Central and Eastern Tennessee (TN), resulting in a very limited understanding of the origin of the hydrothermal fluid and the sources of ore metals. This study is an attempt to contribute to the overall understanding of the Central and Eastern TN MVT deposits through use of Pb isotope geochemistry. Since Pb is common in ore deposits, either as primary Pb or as minor/trace element, Pb isotopes will be used to establish isotopic ranges for Central and Eastern TN from which the source of the Pb and Zn might be inferred. The use of Pb isotopes to constrain the source(s) of associated metals such as Zn, Cu, Au, and Ag is limited by the assumption that the Pb is derived from the same source, transported, and deposited by the same hydrothermal fluid (Tosdal et al., 1999). However, since Pb, Zn, and Cu have comparable geochemical behavior, this assumption is most likely true, particularly in base metal-rich magmatic hydrothermal systems and Pb-rich deposits in sedimentary settings (Henley et al., 1984).

The current study aims at determining the Pb isotope ratios of sphalerite samples collected from the Elwood Mine (Central TN District) and the Young Mine (Mascot-Jefferson City District in East TN; Fig. 2) and comparing them to previously published Pb isotope ratios of ores from the same area and from other districts in the US midcontinent. This will help constrain the source(s) of the Pb and Zn in MVT ores from the Central and East TN districts. Another objective is to establish the radiogenic nature of the ore: are these samples ordinary or do they contain anomalous amounts of Pb similar to "J-type" (Joplin-type) MVT deposits? Heyl et al. (1966, 1974) summarized that there are two distinct types of lead: common or "ordinary" Pb that followed the hypothetical evolution of Pb through time, as related to the plumbotectonic model described by Doe and Zartman (1979), and anomalous Pb. Common Pb is presumed to have a homogenous source from the mantle or lower crust, which further mixes with the upper crustal leads (Gaylord, 1995) and follows the hypothetical evolution of Pb. Anomalous Pb has isotopic ratios considerably more radiogenic than ordinary Pb and is likely the result of preferential concentration of radiogenic Pb over a long period of time or a consequence of the mixing of radiogenic Pb and common Pb during a much shorter time (Gaylord, 1995).

2. Setting and characteristics of Tennessee Mississippi Valley-type ore districts

2.1. Central Tennessee district

The Central TN District consists of the Gordonsville-Elmwood Mine located in the northeastern corner of the Central Basin (Fig. 2). Structurally, the Central Basin is a broad anticlinal feature known as the Nashville Dome. The deposits in the Central TN district are located along the crest and flanks of the Cincinnati Arch, the anticlinal divide between the Appalachian and Illinois basins (Fig. 2), generated during the Taconic, Acadian, and Alleghenian orogenic events. The burial depth of the Knox Group (zone of ore mineralization) reaches a minimum of about 90 m from the surface (Fig. 3A) at the deeply eroded apex of the