16. CLASTIC METASEDIMENT-HOSTED VEIN SILVER-LEAD-ZINC

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G. Beaudoin and D.F. Sangster

INTRODUCTION

Silver-lead-zinc vein districts are commonly associated with major fault zones in clastic metasedimentary terranes; individual veins occur in a variety of lithologies ranging in age from Proterozoic to Cenozoic. Silver-lead-zinc veins are a late feature in the tectonic evolution of orogens. Classical examples are the Kokanee Range (British Columbia), Keno Hill (Yukon Territory), Coeur d'Alène (U.S.A.), Přibram (Czechoslovakia), and the Harz Mountains and Freiberg (Germany) (Fig. 16-1).

IMPORTANCE

Silver-lead-zinc veins constitute one of the largest silver resources in the world with the Coeur d'Alène district being the world's largest silver district; in Europe they have been mined since the Middle Ages. In Canada, deposits of this type are of diminishing economic importance.

SIZE AND GRADE OF DEPOSITS

Metal production in a single district ranges up to 30 kt Ag, 7 Mt Pb, and 3 Mt Zn. In terms of contained metals, a large silver-lead-zinc vein district (such as Coeur d'Alène) compares with a large Zn-Pb-Ag sedimentary-exhalative deposit or a large Zn-Pb Mississippi Valley-type district. Grades are highly variable as they may be biased by selective mining methods. Examples follow:

Kokanee Range – district total: 10.4 Mt grading 5.1% Pb, 4.8% Zn, and 251 g/t Ag;
  Silvana: 3.8 kt grading 5.8% Pb, 5.1% Zn, and 515 g/t Ag;
  Bluebell: 4.8 Mt grading 4.8% Pb, 4.8% Zn, and 46 g/t Ag;

Keno Hill – district total: 4.54 Mt grading 6.8% Pb, 4.6% Zn, and 1412 g/t Ag;
  Husky – production to 1984: 3.6 kt grading 3.96% Pb, 0.27% Zn, and 1450 g/t Ag;

Coeur d'Alène – production to 1965: >100 Mt grading 6.2% Pb, 1.9% Zn, and 193 g/t Ag.

Silver-lead-zinc vein districts are characterized by Pb/(Pb+Zn) ratios ranging from 0.51 to 0.72 and (Agx100)/((Agx100)+Pb) ratios ranging from 0.22 to 0.63. In Ag-Pb-Zn space (Fig. 16-2A), lead-zinc skarns are characterized by high Zn contents, whereas porphyry copper and epithermal vein districts have higher Ag, compared with silver-lead-zinc vein districts. In Ag-Pb-Au space, carbonate replacement and manto deposits are enriched in Au relative to Ag-Pb-Zn vein districts (Fig. 16-2B).

GEOLOGICAL FEATURES

Geological setting

The classical silver-lead-zinc vein districts are in two orogens: the Cordilleran Orogen of North America and the Variscan Orogen of Europe (Fig. 16-1). The districts are in metasedimentary terranes typically dominated by thick

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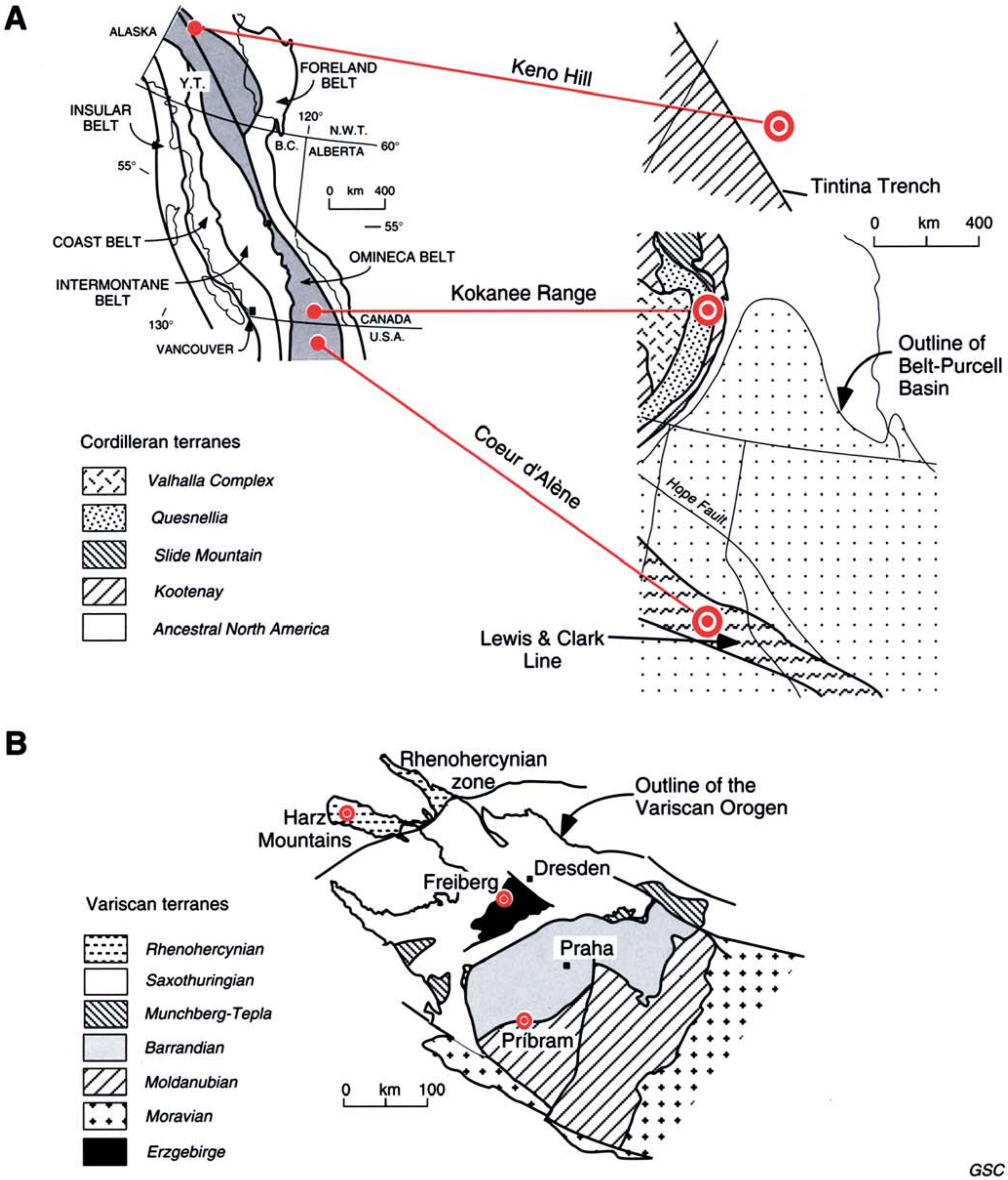

Figure 16-1. Location of six classical silver-lead-zinc vein districts in: **A)** the Cordilleran Orogen of North America; **B)** the Variscan Orogen of Europe (from Beaudoin and Sangster, 1992; reproduced from Economic Geology, 1992, v. 87, p. 1007).

and monotonous sequences of fine- to medium-grained clastic rocks with minor carbonate, mafic volcanic, and tuff units. The sedimentary basins, initiated as epicratonic embayments on passive margins, or in continental, oceanic, or back-arc marginal basins, are commonly part of large Pb-Zn metallogenic provinces containing large sedimentary-exhalative deposits (e.g. Selwyn Basin and Belt-Purcell Basin). These basins have typically been deformed, metamorphosed, and intruded by igneous rocks. The latter comprise zoned monzonitic to syenitic plutons (Coeur d'Alène), syn- to late orogenic granodioritic batholiths (Kokanee Range, Příbram), gabbronorite (Harz Mountains), and postorogenic dioritic to granitic plutons (Harz Mountains, Keno Hill). The intrusions can be classified as I, S, and within-plate types with alkaline to calc-alkaline affinities (Beaudoin and Sangster, 1992).

Age of host rocks and mineralization

Silver-lead-zinc veins are found in sedimentary, volcanic, or plutonic rocks ranging in age from Proterozoic to Eocene. Although the veins, traditionally, have been genetically related to the intrusion of granitic plutons or batholiths, recent geochronological data have demonstrated a significant age difference between intrusion and mineralization. The latter has been shown (Beaudoin and Sangster, 1992) to be younger(-) or older(+) than those intrusions which, traditionally, have been considered to be genetically related to mineralization: ~-110 Ma (Kokanee Range); ~-170 Ma (Harz Mountains); >+770 Ma (Coeur d'Alène). These large differences in ages have resulted in a re-assessment of the relationship between intrusions and Ag-Pb-Zn veins.

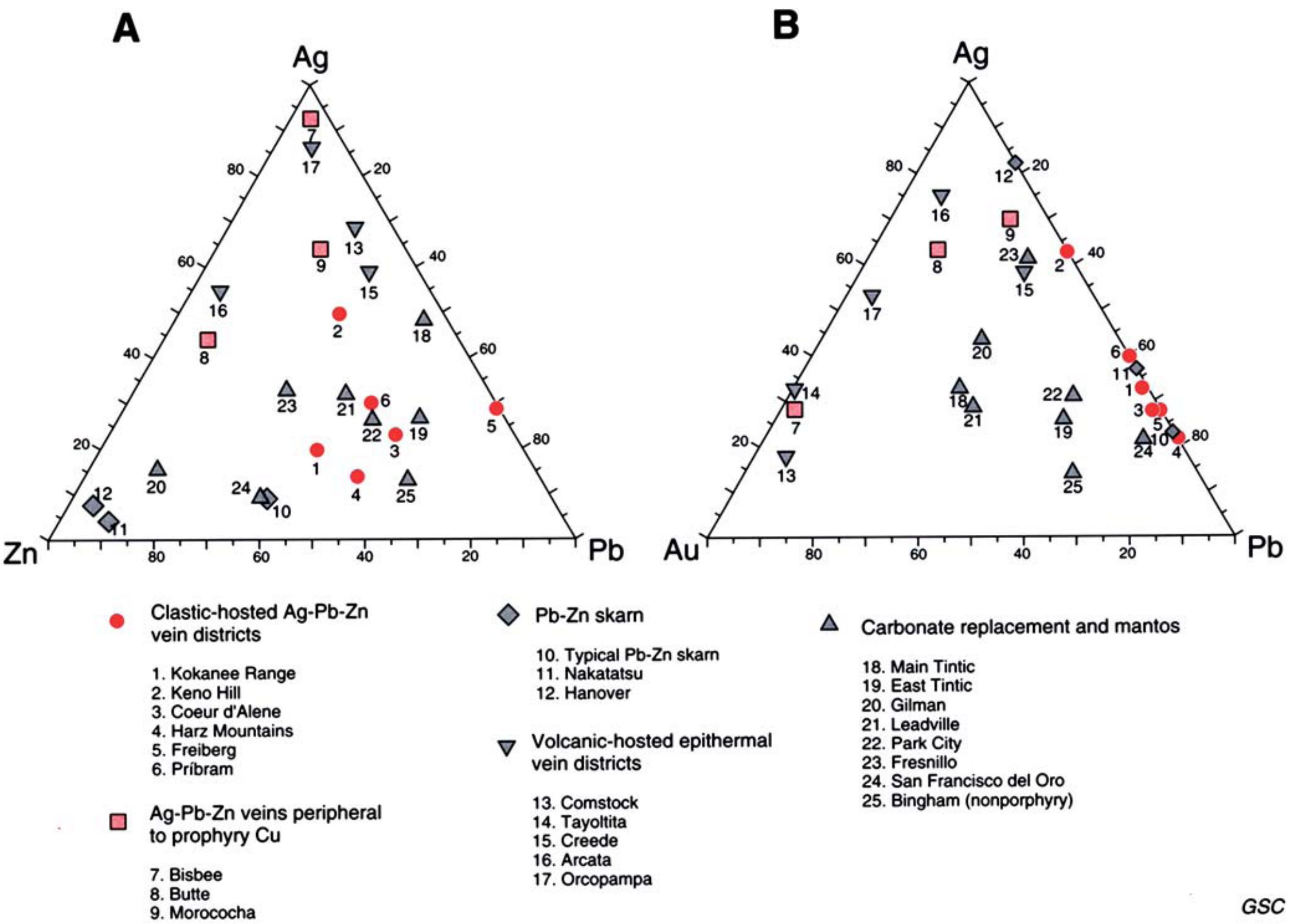

Figure 16-2. Comparison of the metal ratios for silver-lead-zinc vein districts with those of other types of deposits mined for Ag, Pb, or Zn; **A)** Ag-Pb-Zn ternary space; note Tayoltita (14) not plotted on A, zinc data not available; **B)** Ag-Pb-Au ternary space (from Beaudoin and Sangster, 1992; reproduced from Economic Geology, 1992, v. 87, p. 1009).

Contents

Associated structures

Vein districts were formed late in the tectonic evolution of their orogens and three of these districts are located at terrane boundaries (Beaudoin and Sangster, 1992). The Kokanee Range is in the upper plate of the Valhalla metamorphic core complex, which was unroofed during Eocene extension of the Cordilleran Orogen (Parrish et al., 1988). The Erzgebirge gneiss hosting the Freiberg district forms the lower plate of a low angle extensional shear zone with the veins occurring in a conjugate set of shear and tension fractures cutting the gneiss dome (Matte et al., 1990). Mineralization in the Příbram district is in structures subsidiary to the Central Bohemian shear zone, a major, dextral transpression fault zone at the boundary between the Barrandian and Moldanubian terranes (Zák and Dobeš, 1991).

In the Selwyn Basin, mineralized faults are conjugate to the Mayo Lake shear zone, a dextral transcurrent fault zone (Lynch, 1989a). Mineralization in the Harz Mountains is in sets of parallel and wedge-shaped oblique, dextral strike-slip, and normal faults cutting late Carboniferous Variscan thrusts and isoclinal folds (Hannak, 1981). The Coeur d'Alène district is contained within the Lewis and Clark line, a major intracontinental plate boundary that was initiated as Early Proterozoic synsedimentary faults that remained active to the Holocene, including a major event of dextral strike-slip deformation in the Late Cretaceous (Wallace et al., 1990).

Form of deposits

The veins occur as massive lenticular bodies as much as several metres thick in fractures or in fault zones, or occur as stockwork structures up to 80 m wide in shear zones. The structures containing the veins range from small tension fractures to large fault zones with several kilometres of strike length. Mineralization in an individual district can occur within a large vertical interval ranging from 350 m in Keno Hill to 2300 m in Coeur d'Alène.

Mineralogy and ore textures

Galena and sphalerite are commonly associated with minor pyrite, chalcopyrite, and a diverse and complex suite of sulphosalt minerals, mainly tetrahedrite but also including minor amounts of pyrargyrite, stephanite, bournonite, acanthite, and native silver. Gangue is typically composed of siderite and/or quartz, and lesser amounts of dolomite or calcite. Textures are typically coarse grained and drusy; sphalerite may be characterized by rhythmic banding. In the Kokanee Range and Keno Hill districts, calcite and/or dolomite are typically late stage minerals associated with flooding of the hydrothermal system by meteoric water. Postmineralization deformation, shearing, and brecciation in some districts has obliterated most primary textures.

Silver-lead-zinc veins have long been the subject of mineralogical zoning studies. In some cases, the mineral zones were formed by multiple hydrothermal events or a telescoped single event, rather than by regular zoning about a single point (Kutina, 1963). In the Keno Hill district, Lynch (1989b) documented a mineralogical zonation similar to classical zoning models.

Alteration

Typically, hydrothermal alteration is restricted to the vicinity of the veins and extends as much as a few metres into the wall rocks. The alteration is commonly phyllic, characterized by sericitization, silicification, and pyritization of the wall rocks. In the Coeur d'Alène district, however, large zones of hydrothermal bleaching are typical.

Geochemistry

The following is summarized from a literature review of the six classical metasediment-hosted silver-lead-zinc vein districts (Beaudoin and Sangster, 1992).

Hydrothermal fluids are characterized by temperatures near 250-300°C and salinities ranging from 0 to 26 wt.% NaCl equivalent; CO_2 is abundant in fluid inclusions in some districts. As many as three hydrothermal fluids have been identified, in some districts, from oxygen and hydrogen isotopic studies: 1) a deep-seated fluid of metamorphic origin characterized by high temperature isotopic exchange with crustal rocks; 2) a second fluid which may originally have been of meteoric origin, but which has undergone a long history of isotope exchange with upper crustal rocks; and 3) meteoric water that commonly dominates the waning stage of the hydrothermal system.

Sulphur isotope compositions are usually zoned and correlate with the local country rocks. Carbon isotope compositions in carbonates may be either heterogeneous ($-14<\delta^{13}C<0$), reflecting a variety of local carbon sources, or homogeneous ($-8<\delta^{13}C<-5$), reflecting deep-seated carbon sources. Lead isotope compositions typically form linear arrays and identify primarily upper crustal sources for the lead. Other minor lead sources comprise depleted upper mantle and lower crustal Pb reservoirs.

DEFINITIVE CHARACTERISTICS

Silver-lead-zinc veins are characterized by their mineralogy, metal ratios, and local phyllic alteration. The veins are in faults and fractures that are commonly associated with deep crustal breaks at terrane boundaries and are hosted by monotonous sequences of clastic rocks deposited in basins within various tectonic settings and which have been intruded by granitic to gabbroic plutonic rocks. Mineralization occurs late in the tectonic evolution of an orogen and may be associated with the extensional collapse of the orogen.

GENETIC MODEL

Three genetic models have been recently proposed for the formation of metasediment-hosted silver-lead-zinc veins. The magmatic differentiation model (Tischendorf and Förster, 1990) holds that chacophile elements such as Pb, Zn, and Ag, concentrated in the intercumulate fluid phase of an accumulating crystal pile, are expelled, along with mafic and ultrapotassic magmas, to form coeval silver-lead-zinc veins and dykes.

The magmatic-hydrothermal model proposes that heat, derived from coeval crystallizing intrusions, drives the hydrothermal system at temperatures between 250° to 300°C (Möller et al., 1984; Lynch et al., 1990; Criss and Fleck, 1990). Mineralogical, isotope, and other zonations are developed around the intrusion. In the Keno Hill district, Lynch et al. (1990) considered graphitic-rich host rocks to be an important genetic feature, buffering hydrothermal fluids to high CO_2 partial pressures and providing an important metal source.

A third, and our preferred, genetic model involves deep-seated, metamorphic hydrothermal fluids that are channelled along deep crustal faults to higher crustal levels where mineral precipitation takes place as a result of mixing with upper crustal hydrothermal fluids and local boiling. The deep crustal faults are first-order fluid channels which directed fluids from deep-seated sources into subsidiary related structures. Mineralization occurred in these secondary structures, from dilute to saline fluids, at depths as great as 6 km and at temperatures around 250° to 300°C (Beaudoin and Sangster, 1992).

RELATED DEPOSIT TYPES

Silver-lead-zinc veins share several geological characteristics with Ag-Pb-Zn carbonate replacement and manto deposits. Replacement of limestone by massive sulphide bodies along fractures exists in some silver-lead-zinc vein districts. A genetic link between carbonate replacement and manto deposits and nearby intrusions has been suggested, based on zonation from skarn to chimneys, spatial association, and geochemical data (Haynes and Kesler, 1988; Megaw et al., 1988). Carbonate replacement and manto deposits formed at shallow depths, under pressures ranging from 0.3 to 0.8 kbar (Megaw et al., 1988), compared with silver-lead-zinc veins (6 km and 1.6 kbar). Silver-lead-zinc veins appear to be a type of ore deposit distinct from carbonate replacement and manto deposits, but no single deposit scale feature is distinctive; a district scale comparison is required.

EXPLORATION GUIDES

All six classical Ag-Pb-Zn vein districts (Fig. 16-1) were discovered centuries or decades ago in surface outcrop, thereby precluding good examples of recent exploration guides. Development in these areas has been largely directed toward extension of known ore veins. However, in spite of these limitations, some suggested guidelines follow:

1. Regions containing a late, major crustal fault cutting a clastic metasedimentary terrane would be regarded as favourable for vein silver-lead-zinc deposits.
2. A favourable metasedimentary terrane should be part of a Pb-Zn metallogenic province containing sedimentary-exhalative Pb-Zn deposits.
3. Subsidiary faults to the major crustal fault commonly host ore shoots.
4. Boyle (1965) reported that, in the Keno Hill area, analyses of residual soil along traverses across known mineralized vein faults gave broad anomalies with strong contrast for Ag, Pb, Zn, Sb, As, and Mn. Subsequent experience, however, showed that ore shoots in the area yield poor soil geochemical expressions (Watson, 1986).
5. Because Ag-Pb-Zn veins occur in clastic sedimentary rocks commonly containing abundant graphite and/or disseminated pyrite, electromagnetic surveys have had limited success in locating new veins. Faults are well located using EM surveys, but oreshoots give a poor response.
6. In the Keno Hill area, Watson (1986) reported that drilling fences across suspected faults or segments of known faults has been the most successful exploration tool and is credited with the discovery of several deposits. The drill used was of the rotary percussion-type; cuttings were recovered using an air-flush system.

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Author's addresses

G. Beaudoin
Département de géologie et de
génie géologique
Université Laval
Québec, Québec
G1K 7P4

D.F. Sangster
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario
K1A 0E8

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