Coeur d'Alene Mining District: product of preconcentrated source deposits and tectonism within the Lewis and Clark line

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ABSTRACT

The Lewis and Clark line (LCL) is a 50 km-wide, structurally and topographically defined lineament that crosses the Mesoproterozoic Belt Supergroup and extends for at least 300 km. No single style of tectonism is predominantly responsible for the line; the LCL is the product of diverse, recurrent tectonism controlled by some underlying, crustal-scale structure at least as old as the Belt rocks themselves, which has been reactivated at various times in response to new stress conditions. Most structures that define the LCL resulted from Cretaceous and Tertiary tectonism that was concentrated and intensified within the line. A particular tectonic event with a distinctive structural style involving formation of reverse faults and dip-slip metamorphic shear zones is associated with formation of the silver-lead-zinc vein ore bodies of the Coeur d'Alene Mining District.

Despite the great length of the LCL, the major concentration of silver-lead-zinc veins of the Coeur d'Alene district are limited to a short portion of the line. A reasonable explanation for this concentration is that it results from the intersection of the LCL with a second long-lived tectonic lineament, here called the Noxon line. During Belt sedimentation, the Noxon line was an arch that separated the Belt basin into two separate subbasins. During early Belt sedimentation, basement structures that controlled the Noxon arch probably localized Sullivan-type, syngenetic zinc-lead-silver deposits. Later, Revett-type, stratabound, copper-silver deposits in the Ravalli Group were also concentrated within the Noxon arch. Redistribution of metals from these two separate sources during Late Cretaceous or early Tertiary tectonism within the LCL is a plausible explanation for the concentration of silver, lead, and zinc that form the veins of the Coeur d'Alene district.

INTRODUCTION

The Coeur d'Alene Mining District is the second largest silver-producing district in the world (after Potosi, Bolivia), as well as a major producer of lead and zinc. Yet, despite its importance and abundant opportunities to view its features in underground mines, a solid understanding of its geology and origin has been elusive.

The mesothermal-vein ore bodies of the Coeur d'Alene district are found in minor reverse faults within the Lewis and Clark line (LCL), a major tectonic lineament of regional proportions. Complex fold and fault structures are present, and pronounced facies and thickness changes in the Mesoproterozoic Belt sedimentary host strata suggest that tectonism affecting the district had an early inception. Conditions leading to formation of the ore deposits were obviously unusual, so an origin related to the complex tectonic history is a common speculation. This paper considers aspects of the tectonic and sedimentary history of the region that are believed to bear on the origin of this remarkable district.

LEWIS AND CLARK LINE

The LCL is a 50-km-wide, structurally and topographically defined lineament that extends more than 300 km across the middle Proterozoic Belt Supergroup (Harrison et al., 1974; Wallace et al., 1990) (Figure 1). The line is regarded by many as a long-lived, recurrently activated tectonic lineament (e.g., Harrison et al., 1974; White, 1998b).[1] As a result of the location of the Coeur d'Alene Mining District within the LCL and the coincidence of most veins with the structural trend of the line, most geologists concur that the rich silver-lead-zinc veins of the district resulted from tectonism controlled by the LCL.

Various authors have proposed that the LCL (or structures approximating parts of the line) was active during Belt sedimentation (Hobbs et al., 1965; Harrison et al., 1974; Winston et al., 1986a, 1986b). However, faults that define the LCL include those with strike-slip, normal, and reverse offsets. Historically, strike slip in the LCL has been emphasized, especially by Hobbs and others (1965). Relatively minor right-lateral offsets of intersecting structures (Hobbs et al., 1965; Harrison et al., 1992) and facies and thickness changes (White et al., this volume) confirm right-lateral

[1]I endorse the familiar concept of the LCL as discussed by Harrison and others (1974) and Wallace and others (1990). However, note that Winston (this volume) emphasizes a significantly different interpretation of structures in this part of Montana and Idaho.

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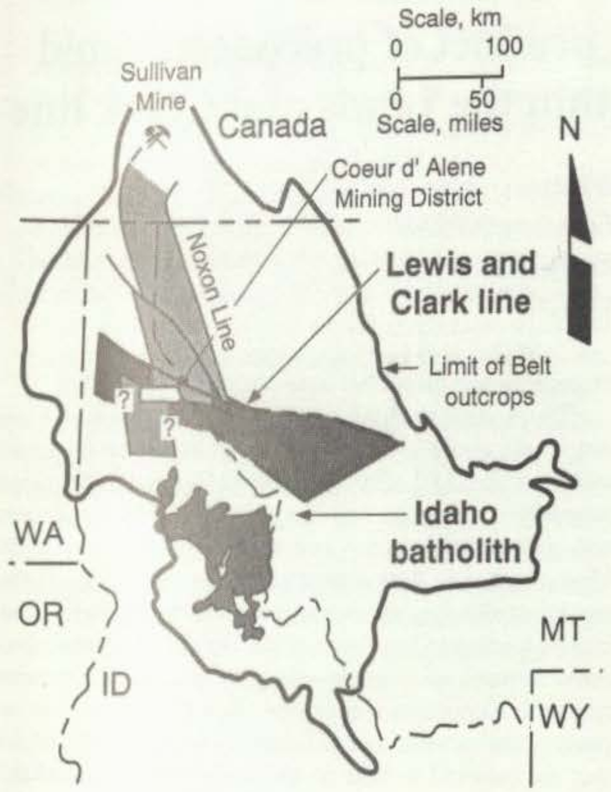

Figure 1. Generalized geologic map showing the Lewis and Clark line (after Wallace and others, 1990), the Noxon line, and the Coeur d'Alene Mining District.

offsets on various faults and also indicate that the LCL is definitely not a major left-lateral shear zone, as has been inferred from the distribution of Cretaceous batholiths (Hyndman et al., 1988). Tectonism associated with formation of the veins has been interpreted as involving reverse faulting and dip-slip movements within associated metamorphic shear zones (Wavra et al., 1994; White, 1989, 1994, 1998a, 1998b). Many faults have been reactivated with different senses of slip.

Based on these considerations, it is apparent that the LCL is the product of diverse, recurrent tectonism, probably controlled by some underlying, crustal-scale structure at least as old as the Belt rocks themselves. Muehlberger (1986, p. 76) considered the LCL an example of a "major fault that never dies," and noted that, "[such faults] will move again in whatever direction is necessary to accommodate the new stresses that are being imposed." Evidence for this conclusion is now even stronger, and we will see some of the evidence on this field trip.

Although the structures of the LCL associated with the veins characterize much of the west-central part of the line between Missoula and the Coeur d'Alene district, the district occupies only a short section of the line. This suggests there was a control on localization of the veins in addition to the LCL.

NOXON LINE

A possible explanation for the concentration of ore bodies in the Coeur d'Alene district is that the metal sources were controlled by a separate, north-trending, regional tectonic lineament that intersects the LCL in the district (White and Appelgate, 1999) (Figure 1). White and Appelgate (1999) noted various features that define the proposed, north-trending structure. These features include an elongate region where the Revett Formation is notably thinned with respect to surrounding Revett strata (Figures 2, 3), a rapid facies change in upper Revett-St. Regis strata that follows the west side of the "thin spot" (Figure 3), and major reverse and normal faults that extend along the axis of the thin spot from the eastern Coeur d'Alene district to Canada (Harrison et al., 1992).[2] Isopachs of various stratigraphic units in the Prichard Formation (Cressman, 1989) also define this structure and establish its existence during earlier Belt sedimentation.

This north-trending feature centers on Noxon, Montana, so it is here called the Noxon line. A structural high that can be inferred to have caused the thinning of Belt strata associated with the Noxon line is here referred to as the Noxon arch.

Revett thicknesses average about 570 m in the central part of the Noxon arch (White and Appelgate, unpublished data) and increase to about 800 m or more both east and west of the arch (Ryan and Buckley, 1998). This elongate area of thinned Revett Formation and the facies change adjacent to it probably reflect growth faulting that deepened the Belt basin on both sides of the arch during sedimentation, although the location of such faulting is not everywhere clear. The major Cretaceous-Tertiary age normal and reverse faults that extend along the axis of the thin spot may represent reactivation of an early, basement-controlled fault zone, as has been interpreted in British Columbia, Canada (Turner et al., 1997).

Based on facies changes and increases in thickness evident in various Belt strata west of the Noxon arch (primarily from my unpublished stratigraphic compilations from various district mines) (Figure 3), I speculate that, at times, the Noxon arch divided the Belt basin into two separate subbasins. Information is currently being collected by various workers that may better define the western subbasin, which must lie primarily in northern Idaho and northeastern Washington. Although evidence for the Noxon line and the Noxon arch will not be viewed directly on this field trip, evidence for the western subbasin will be seen.

The thinning of the Revett Formation that partially defines the Noxon arch diminishes or ends at the LCL approximately at the Osburn fault (Figure 2). This thinning is

[2]Harrison (1972) also described the Missoula Group as thinning in this area. However, Winston (personal communication, 1999) believes the Missoula Group data were flawed and that this interpretation is unsubstantiated.

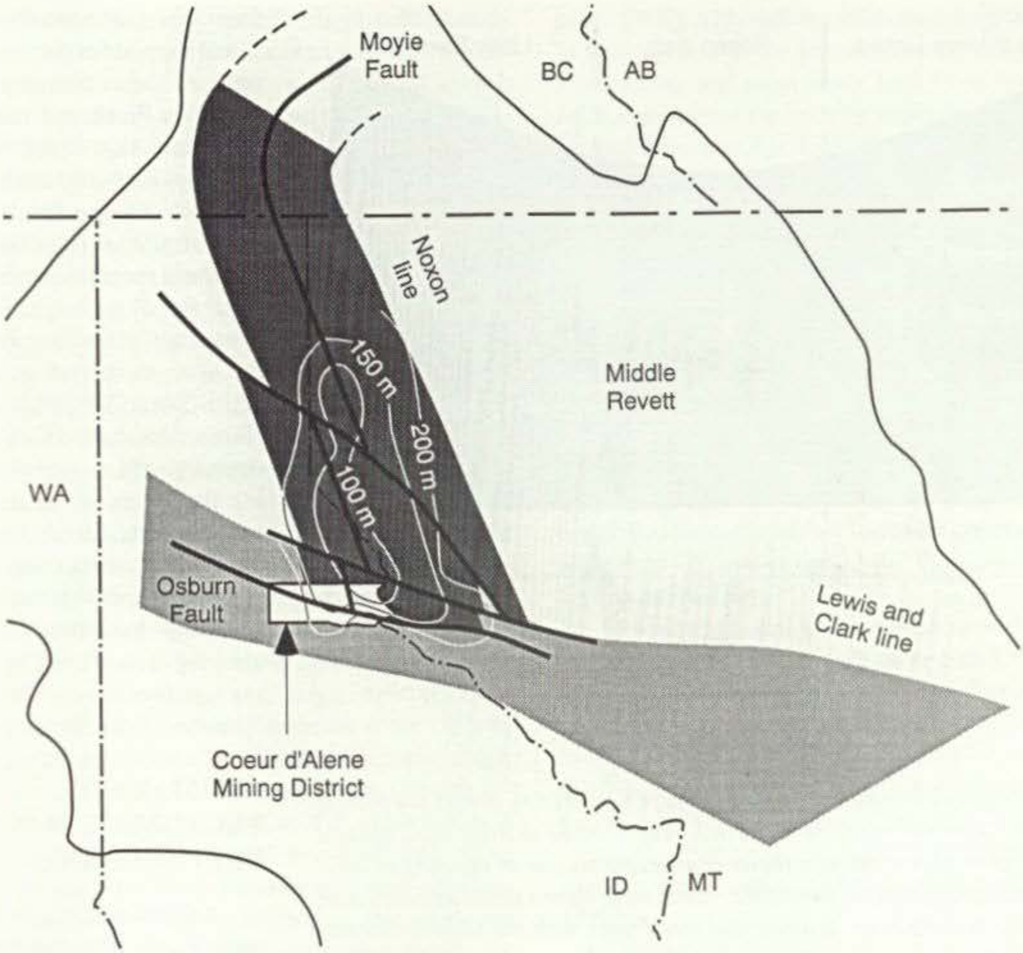

Figure 2. Isopachs for the middle member of the Revett Formation and Noxon and Lewis and Clark lines (author's unpublished data). Note that the thinned area elongates and terminates along the Lewis and Clark line, suggesting that this line was also active during middle Revett sedimentation.

the best evidence that the LCL or some particular structure within the line (e.g., Winston, this volume) was active during Belt sedimentation.

The Moyie fault, a major Cretaceous reverse fault (Harrison et al., 1992), follows the axis of the Noxon arch northward into British Columbia. In Canada, the fault curves northeast and follows an inferred growth fault that reflects tectonism associated with formation of the nearby Sullivan syngenetic zinc-lead-silver ore deposit (Turner et al., 1997). Here, the Moyie fault was evidently localized by the underlying growth fault. Southward, the Moyie fault may reflect synsedimentary faulting associated with formation of the Noxon arch. Consequently, faults that formed the arch could have localized syngenetic metal deposits in appropriate Belt strata.

Although Sullivan-type mineralized zones are not known southward along the Noxon line, zinc-lead-silver veins closely associated with the Moyie fault may indicate the presence of such deposits at depth. These veins contain galena that is isotopically similar to galena found in both the Sullivan deposit and veins of the Coeur d'Alene district (Zartman and Stacey, 1971) and their distribution along the Noxon line forms a continuous belt between these two mining districts. Thus, galena occurrences along the line provide a mineralogic and isotopic tie between these two deposit types.

During the early deep-water phase of Belt sedimentation represented by the Prichard Formation (Aldridge Formation in Canada), thickness changes in these strata (Cressman, 1989) provide the first indication of the proposed Noxon arch and Noxon line. Basement faulting that may have been responsible for such thickness changes could have localized Sullivan-type, syngenetic zinc-lead-silver deposits along the length of the line (White and Appelgate, 1999). The unradiogenic galena veins present along the Noxon line and various occurrences of Sullivan-type alteration zones found in the lower Prichard Formation exposed in the northern parts of the Noxon line (Beaty et al., 1988) are reasonable evidence of the presence of syngenetic deposits within the Noxon line, even though the favorable lower Prichard strata are mostly covered by younger Belt strata farther south around the Coeur d'Alene district.

Epigenetic, stratabound copper-silver deposits in the Revett Formation are also concentrated in a north-trending belt (Harrison, 1972) that corresponds to the Noxon line (White and Appelgate, 1999). This cluster of deposits de-

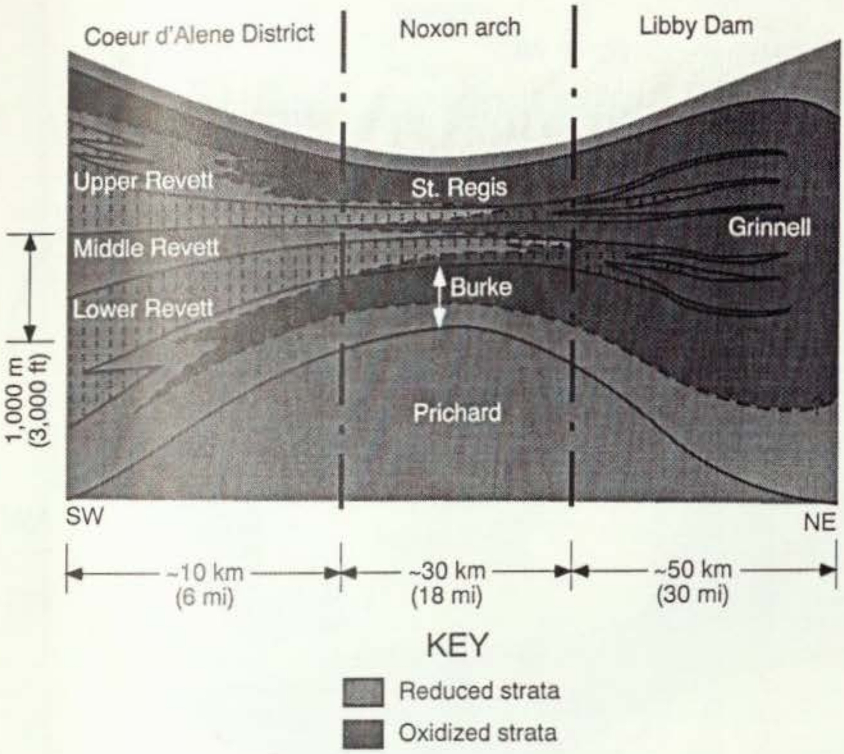

Figure 3. Southwest-northeast stratigraphic cross section across the Noxon arch. Revett Formation of the western Coeur d'Alene district thins toward the arch, partly as a result of a facies change, partly due to thinning of individual lithologic packages. East of the Noxon arch, Revett strata again thicken as they also become finer grained and interfinger with the Grinell Formation. Also shown is a redox boundary that interfingers across this region. This boundary is important with respect to the location of stratabound silver-copper deposits (White and others, this volume). (Cross section constructed from author's unpublished stratigraphic sections.)

fines the Revett copper belt, which extends into or close to the silver-copper-rich northeastern and eastern parts of the Coeur d'Alene district.

METALS SOURCES FOR COEUR D'ALENE VEINS

Geologic conditions that were favorable for localization of both Sullivan- and Revett-type deposits can reasonably be inferred to underlie ore bodies of the Coeur d'Alene district, making remobilization of metals from these sources a plausible explanation for the origin of district ore bodies. Concentrations of these source deposits within the Noxon line may explain the occurrence of the district at the intersection of this line with the LCL, while also accounting for the richness of the district as the result of contributions from multiple, preconcentrated sources. Such an interpretation gains support from a recent discovery that tetrahedrite in district veins contains a small amount of radiogenic young lead (Leach et al., 1998), in stark contrast to the unradiogenic Precambrian lead found in galena. Hence, both a separate source for tetrahedrite and relatively recent mobilization from this source are required. Additional support for the conclusion that the ore bodies are young was provided by Fleck and others (1991), who note that siderite in Coeur d'Alene veins contains highly radiogenic strontium, which could only have originated from Belt strata at a relatively recent (Cretaceous or Tertiary) time. I also argue that the veins are young, since they cut folds that are best interpreted as Late Cretaceous (White, 1998b). Known and inferred distributions of preexisting deposits with respect to the ore bodies, the young age of the veins, and isotopic evidence that the galena and tetrahedrite were derived from separate sources provide tangible support for earlier hypotheses that the metals were remobilized from preexisting concentrations in Belt strata (Hershey, 1916; Bennett, 1984).

SUMMARY OF TECTONISM IN WESTERN BELT TERRANE

A series of relatively discrete tectonic events affected the LCL and western Belt terrane. Evidence for many of them will be viewed on the field trip (White et al., this volume). Although the LCL is expressed primarily by fault-controlled physiography, the line is also indicated by the distribution of prominent northwest- to west-trending, large-scale folds of the eastern border zone fold and thrust belt (Hyndman et al., 1988) (elsewhere referred to as the western Montana fold and thrust belt; for example, by White et al., this volume). The folds of this belt lie north and northeast of the Idaho batholith and terminate within the LCL. They reflect the earliest tectonism affecting Belt strata that may be readily identified on geologic maps (White, 1998b). Along much of the length of the LCL, the folds trend northwest. In the Coeur d'Alene district, the folds have swung around to a west-northwest trend, about parallel to the LCL. Folds within the entire belt become tighter and overturned near their northern limit within the LCL. The folds particularly tighten in the district in an 8 km-wide belt that dies out several kilometers north of the Osburn fault. White (1998b) referred to this belt of tight folds as the "Coeur d'Alene fold belt" and suggested that it extends at least 80 km east of the district.

The termination and intensification of the west-to-northwest-trending folds in the LCL suggest buttressing of the folds against a preexisting obstacle (Harrison et al., 1974), which requires the existence of the obstacle prior to folding. Current knowledge of Belt terrane suggests two possibilities for the origin of such an obstacle as the result of yet-earlier tectonism: (1) the LCL (Harrison et al., 1974) or a specific structural element within or adjacent to the LCL (Winston, 1986a, b, and this volume) was present and active during Belt sedimentation, or (2) block faulting occurred within the line that postdated Belt sedimentation but predated deposition of the Cambrian Flathead sandstone (preserved at scattered locations in western Belt terrane) (Harrison et al., 1974). Many agree that structures within the LCL were active during Belt sedimentation (e.g., Winston, this volume). However, although post-Belt, pre-Flathead tectonism is recognized locally in Belt terrane, there is no clear evidence that such tectonism affected the LCL.

The folds of the eastern border zone fold and thrust belt involve strata as young as Late Cretaceous 80 km east of Missoula and Cambrian 50 to 100 km west of Missoula. It has been suggested that these folds formed during the Late Cretaceous and resulted either from emplacement of the Idaho batholith (Harrison et al., 1974) or from pre-intrusive mobilization of the batholithic terrane (White, 1998b).

A separate north-trending set of large, tight, regional folds intersects the more westerly trending folds (White, 1998b). These are folds of the Purcell anticlinorium, which includes much of western Belt terrane. White (1998b) interprets the folds as postdating the Coeur d'Alene fold belt and deforming folds of the latter belt into doubly plunging structures. Formerly, the north-trending and west-trending folds were interpreted as having originated as a single set that was subsequently bent into contrasting trends by transcurrent movement within the LCL (Hobbs et al., 1965). This idea was the basis for a long-standing interpretation of the tectonics of the district and the LCL as the product of right-lateral strike-slip.

Involvement of Cambrian strata in the north-trending folds of the Purcell anticlinorium (Harrison et al., 1992) documents their age of formation as also being Phanerozoic. White's (1998b) conclusion that, in the Coeur d'Alene district, these folds postdate the folds of the eastern border zone fold and thrust belt reinforces this interpretation.

The veins postdate the two major folding events and are regarded as forming in minor reverse faults created during the tectonism that also formed major reverse faults and dip-slip, metamorphic shear zones within the LCL (White, 1998b). The major reverse faults formed during this tectonism are characterized by intensified development of metamorphic shear foliation in their immediate walls, as well as by the rare presence of vein mineralization within the faults. The dynamic metamorphic fabrics seen in the veins and their immediate host strata are comparable to fabrics associated with mesothermal gold veins found in other parts of the world (e.g., Sibson and Poulsen, 1988). Thus, this style of tectonism seems particularly capable of mobilizing metals.

Relative dating of Coeur d'Alene veins with respect to the folds provides an opportunity to estimate the timing of vein formation. The veins clearly postdate the folds (Hobbs et al., 1965). Although the veins have long been considered to have formed in the Precambrian (Leach et al., 1988), a Phanerozoic and most likely Late Cretaceous age for the folds requires that the veins be young also. The original basis for the inference that folds in the Coeur d'Alene district formed in the Precambrian came from determinations of the isotopic composition of lead in galena veins. This unradiogenic lead yields model ages in the range of 1300 to 1.5 Ga (Leach et al., 1988), approximately equal to the age of Belt strata. The most obvious interpretation of such lead is that the veins — and, hence, the folds that predate the veins — formed in the Precambrian, soon after Belt sedimentation ended. However, the major proponents of a Precambrian age for these structures (see especially Zartman and Stacey, 1971) have all noted the possibility that the unradiogenic lead could also have resulted from remobilization of lead that had been concentrated in some other type of deposit during the Precambrian. This is the view promoted here.

Several additional tectonic events affected Belt terrane and the LCL. North-trending reverse and thrust faults that probably formed in the very Late Cretaceous and early Tertiary (Harrison et al., 1980) truncate some of the ore bodies of the district, further limiting the relative age of the veins. Such timing is reasonably coincident with emplacement of the Idaho batholith, suggesting that batholithic intrusion may reflect the tectonism that formed the reverse faults, metamorphic shear zones, and veins within the LCL (White, 1998b).

Extensional tectonism within the LCL subsequently formed major normal faults and reactivated preexisting reverse faults and also caused extensive development of horizontal-axis kink folds in steeply dipping strata and foliation (White, 1998b). These kink folds developed locally on a megascale, thereby creating interesting mapping problems in parts of the Coeur d'Alene district (White, unpublished maps for Hecla Mining Company and Silver Valley Resources). Extensional tectonism may be responsible for some of the block tilting seen in the LCL, such as that which affected the Tertiary sediments that fill the Nine Mile Valley near Missoula.

Strike-slip faults within the LCL developed late and involved up to 26 km of right-lateral slip (Osburn fault), cutting across all other structures and again reactivating some preexisting faults. Additional extensional tectonism may postdate strike-slip faulting, but this part of the record is less clear. Reactivation of earlier formed faults during later tectonism is a characteristic of the LCL.

I interpret north- to northwest-trending normal and reverse faults mapped in the eastern part of the district as partial products of the Noxon line. Followed far northward (and offset by two major strike-slip faults), these faults trend approximately into the Moyie fault (Harrison et al., 1980). The evidence of both ancient and Cretaceous tectonism along the Moyie fault and projection of this structure southward along the Noxon line suggest that the north-trending faults in the northeast part of the district may have been localized along a controlling structure of the Noxon arch.

SUMMARY

Recurrent episodes of tectonism were localized within the LCL by periodic reactivation of the crustal-scale faults responsible for the line. A particular style of tectonism, characterized by formation of reverse faults and metamorphic shear zones, generated conditions that resulted directly in the formation of veins. However, the concentration of lead, zinc, and silver veins that forms the heart of the Coeur d'Alene Mining District required the existence of localized, preconcentrated source deposits in this part of the LCL. The most obvious possibilities for such deposits are lower Belt syngenetic zinc-lead-silver deposits (like the Sullivan ore body) and younger epigenetic, stratabound silver-copper deposits, such as are found extensively along the northeast edge of the mining district in the Revett Formation. Redistribution of metals from two Belt sources into veins during Late Cretaceous tectonism provides a plausible explanation for the concentration of ore bodies and the particular abundance of silver as a result of contributions from both sources.

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