New tricks for an old elephant: Revising concepts of Coeur d'Alene geology

The Coeur d'Alene Mining District of northern Idaho is remarkable for its number of large ore bodies and for the amount of its historical production of lead, zinc and silver (Fig. 1).

Since veins were first discovered in 1884, more than 127 Mt (140 million st) of ore have been produced from narrow, high-grade veins. Mining continues at the Lucky Friday, Galena and Sunshine mines (Fig. 2). All have been in production for decades. At these mines, more efficient mining and exploration techniques have reduced costs while adding significant new reserves. Even the old Bunker Hill Mine, where ore was first found in 1875, continues operation on a limited basis, partly involving production of world-class pyromorphite specimens. Until recently, the Coeur Mine was also a profitable silver producer. Other large producers have included the Star-Morning, Hecla, Page, Standard-Mammoth, Hercules and Gold Hunter mines (Fig. 2).

The first deposits were discovered by prospectors who spilled over from the Murray gold mining district, 24 km (15 miles) to the north. The Bunker Hill Mine was founded the year after the first veins were discovered. Bunker Hill has now operated for more than 100 years. Production includes 2.3 Mt (2.6 million st) of lead, 1.1 Mt (1.2 million st) of zinc and 4.1 kt (132 million oz) of silver.

Total district production through 1996 (Springer, 1997) amounted to 7.3 Mt (8.1 million st) of lead, 3 Mt (3.3 million st) of zinc, and 34.5 kt (1.109 billion oz) of silver. This record establishes the district as the largest recorded producer of silver in the world, while also yielding major quantities of lead and zinc. Only Potosi, Bolivia, may have produced more silver, although records are unclear.

Despite the district's longevity, historic production and current activity, the published literature on the district lags behind with regard to recent concepts of district geology. The most recent comprehensive US Geological Survey (USGS) bulletins (Hobbs et al., 1965; Fryklund, 1964) are dated. Much research in the last half century has been short-lived or geographically restricted because the district is large and its geology is complex — and even this research tends to remain unpublished. Thus, it has been difficult for in-

Despite an extensive history of deep mining, the flat core hole being drilled here in the Silver Belt suggests reasonable expectation for new discoveries at shallow depths. The drill is a Hagby Onram 1000, a model that is used extensively in district mines. Photo by Lars Edling, Hagby, USA.

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FIG. 1

Coeur d'Alene Mining District in North America.

terested parties to get a good overall picture of the geology and geologic history of the district.

The Coeur d'Alene district has a reputation for being exotic, one of a kind and so complex as to be beyond reasonable comprehension. However, much has been learned in the past 30 to 40 years since the last major USGS reports were published.

Geologic framework of the Coeur d'Alene district

The Coeur d'Alene Mining District is one of three world-class mining districts in this part of North America. Others are Butte, MT, and the Sullivan massive-sulfide deposit in British Columbia. All three districts lie within a region underlain by Proterozoic sedimentary strata of the Belt Supergroup (Fig. 3). Belt strata are characterized by thick, uniform sequences of slightly metamorphosed, predominantly fine-grained sediments.

The Coeur d'Alene district lies in the Lewis and Clark line (Fig. 3). This is a major tectonic and topographic lineament defined by subparallel normal faults, reverse faults and strike-slip faults. Rapid facies and thickness changes suggest that the line was active during Belt sedimentation (Harrison, 1972; Winston, 1986). Successive development of the other tectonic structures indicates that the line was recurrently active in response to various stresses (White, in press). Thus, the line appears to represent a deep-seated basement structure that formed in Precambrian time. Reverse faults that appear to be part of the vein-forming tectonic event (White, in press) partially define the line. This suggests that the Coeur d'Alene district exists partly because of the Lewis and Clark line.

The district is located north of the Idaho batholith (Fig. 3). The northern lobe of the batholith and its associated regional metamorphism are aligned parallel to the Lewis and Clark line, as well as to many structures in the Coeur d'Alene district. This alignment may be coincidental but could also have bearing on the genesis of the district.

Belt strata have been folded on a large scale and abundantly faulted. Belt terrane is also found in the Laramide overthrust belt (Harrison et al., 1980). Some of these thrust faults have been mapped as extending into the district from the north (Harrison, 1986).

The lower half of the Belt strata exposed in the district (more than 4,000 m or 13,000 ft) is characterized by pyritic black argillite of the Pritchard Formation and reflects deep-water sedimentation. Younger formations reflect shallow-water sedimentation and are slightly coarser grained (Fig. 4).

Strata equivalent to the deeper, unseen Prichard Formation are host rocks for the Sullivan massive sulfide deposit. Where they are exposed in western Montana, they are also known to locally contain anomalous lead and zinc. The younger, generally siltier and sandier strata above the Prichard Formation include the Burke, Revett, St. Regis and Wallace formations. These sedimentary rocks have been intruded by several stocks, primarily the Gem stocks.

Strata in most mines have been tightly folded on a large scale, creating steep bedding dips. These folds are, in turn, cut by strike-slip, normal, reverse and thrust faults of various orientations, probably representing separate tectonic episodes (White, in press). The Osburn Fault is a major right-lateral, strike- slip fault. It has separated two parts of the district by about 25 km (16 miles).

Lindgren (1933) classified veins of the Coeur d'Alene district as

FIG. 2

Mines in the Coeur d'Alene Mining District.

mesothermal ore deposits. The veins consist of highly variable proportions of sphalerite, galena and argentiferous tetrahedrite in a gangue dominated by either quartz or siderite.

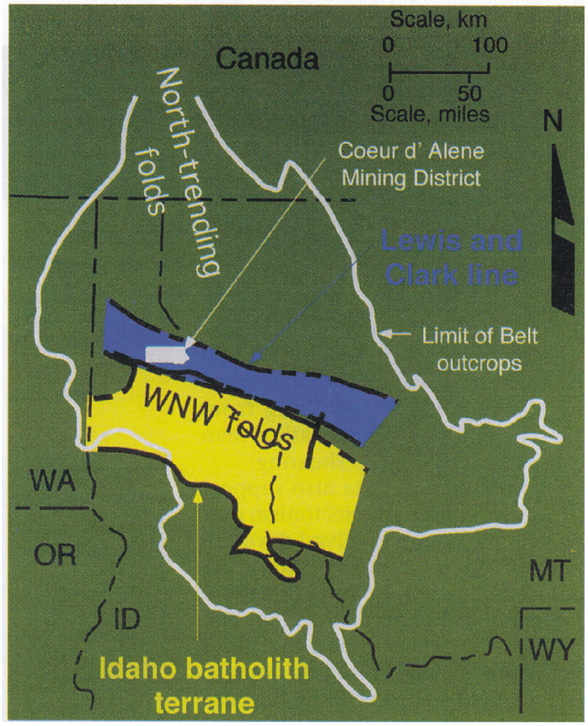
The ore bodies are remarkable in their number and, in many cases, in their large physical dimensions and tonnages. Strike lengths frequently exceed 300 m (985 ft), dip lengths 1,000 m (3,300 ft) and thicknesses several meters. The larger ore bodies have produced from 3.6 to 23 Mt (4 to 25 million st) of ore. Ore grades commonly run in the range of 685 to 857 g/t (20 to 25 oz/st) silver, 7% to 14% lead and 4% to 8% zinc. Average grades of mined ore for all mines (Mitchell and Bennett, 1983) are 240 g/t (7 oz silver), 5.7% lead and 2.3% zinc. Average grades, however, are not representative because many veins are composed primarily of any one of these metals.

The ore bodies lie in west-trending linear clusters known as mineral belts (Fig. 2). Most veins strike westerly, parallel to their mineral belts. Others strike northeasterly and some change from westerly to northeasterly in plan, forming S-shapes.

Most silver production has come from a mineral belt south of the Osburn Fault, the eastern part of which is known as the Silver Belt (Fig. 2). Other mineral belts have primarily contributed lead or zinc, with lesser production of silver. Disseminated copper-silver deposits at the east ends of some of the mineral belts in the northeast part of the district have occasionally been identified as part of a separate, northwest-trending mineral belt called the Copper Belt. This zone is defined by the upturned edge of Revett strata that contains stratiform copper-silver deposits. This is the southwesternmost occurrence of this type of mineralization and is unrelated to Coeur d'Alene-type veins.

FIG. 3

Regional geology surrounding the Coeur d'Alene Mining District (Modified after Harrison, 1972; Hyndman et al., 1988; and Griggs, 1973).



Current ideas of district geology

Nearly all aspects of the geology of the Coeur d'Alene district have been reexamined since the works of Fryklund (1964) and Hobbs et al. (1965). In some cases, well-known and once highly regarded ideas have been significantly modified or replaced. A few old ideas have received new emphasis. In the following sections, some of the more significant and better-known ideas about the district are reviewed and updated.

District tectonics. The interpretation of the basic tectonics of the Coeur d'Alene district by Hobbs et al. (1965) derived from the obvious patterns formed on geologic maps by tight, large-scale folds. They noted that northerly trending folds are prominent in the northern part of the district, while only westerly trending folds are obvious farther south (Fig. 5). They proposed that these were a single set of folds that had been bent to their present orientations by right-lateral transcurrent movements in the Lewis and Clark line. They inferred that the veins and various faults ultimately formed in response to these movements and that the folds were finally truncated and offset by the Osburn Fault. Following their work, several graduate students also interpreted local structures in district mines as being a reflection of transcurrent movements.

The author has mapped key areas where bending of the supposed original fold set had been thought to be most evident (shown in Fig. 5 as a heavy dashed line in the northeastern part of district). He found no evidence to support this interpretation. The evidence suggested that these are actually two separate fold sets (White, 1989, in press). This interpretation has also been expressed by Anderson (1970) and Juras (1982).

In the southern part of the district, the north-trending folds are evidenced by saddles and domes formed in the westerly trending folds. Northward, these westerly trending folds abruptly die out at the northern edge of the fold belt that they define (Fig. 5).

The westerly trending folds become tighter in the Lewis and Clark line, as if compressed against preexisting structures within the line. This is another indicator that the line is an old feature. It is reasonable to interpret both fold sets as representing regional fold sets that project toward the district from the north (Harrison, 1986), south (Wagner, 1949) and east (Harrison et al., 1974).

White (in press) also argues that various faults in the district represent separate episodes of reverse and normal faulting followed by strike-slip faulting. Thus, structures in the district are not mainly the result of transcurrent movements as Hobbs et al. (1965) believed. Instead, these structures reflect diverse kinds of movements, again demonstrating a complex tectonic history in the Lewis and Clark line.

Tectonics related to mineralization. The interpretation of the tectonic history of the district by Hobbs et al. led to a logical inference that the veins were also the product of transcurrent movements. However, a reinterpretation of the gross structure suggests that this may not be the case.

Recent papers (White, 1989, in press; Bond et al., 1992; Waura et al., 1994) show that movements during mineralization were dip-slip or nearly so. Evidence supporting this interpretation arises primarily from identification of a weak but pervasive shearing lineation found on weakly developed metamorphic foliation paralleling the veins. Certain vein-related textures and structural geometries are all parallel to the shearing lineation found in adjacent wall rocks. These include ore shoots, lineated mineral grains, ridges and grooves on the walls of veins, and intersection geometries of veins. Hobbs et al. (1965) described many of these features in detail. But they interpreted the lineation as the result of intersecting cleavage planes resulting from transcurrent movements, rather than as the result of dip-slip shearing.

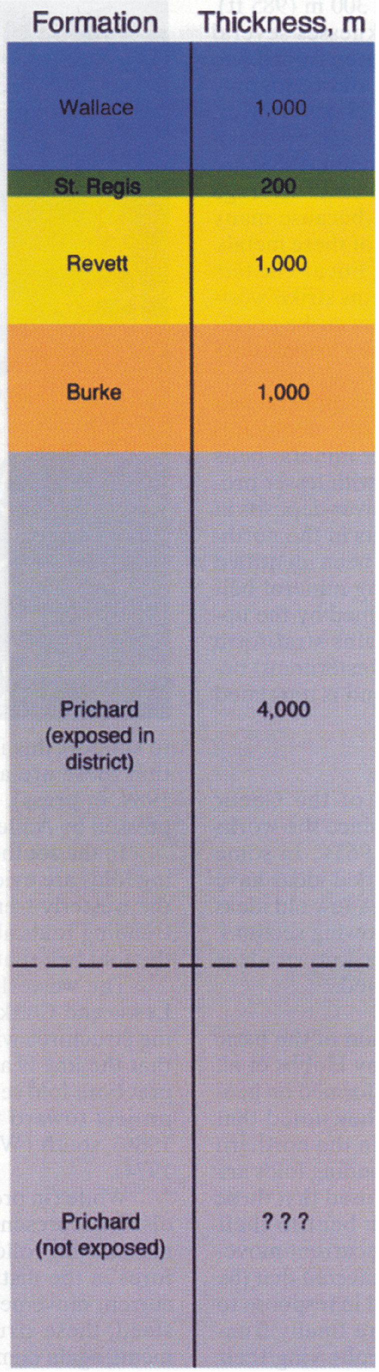
Some indirect data also support the interpretation that tectonism during vein formation involved development of the metamorphic foliation and its associated shearing lineation. For example, Landis et al. (1984) and Leach et al. (1988) noted that fluid inclusions in vein minerals contain certain light hydrocarbons that are best interpreted as products of metamorphism. In most parts of the district, the shear-lineated foliation is the only obvious evidence of metamorphism. This metamorphism suggests that the lineated foliation represents the metamorphism responsible for the metamorphic fluids found in fluid inclusions.

The lineated metamorphic foliation associated with the veins is not always conspicuous. However, the foliation is easiest to find in the known mineral belts and is less conspicuous or nonexistent outside the mineral belts. This distribution suggests that the mineral belts represent very low-grade metamorphic shear zones and provides an explanation for clustering of the veins within these linear trends.

Recognition that ore shoots parallel the steep shearing direction was partially responsible for Hecla Mining's discovery of major new ore reserves at the old Gold Hunter Mine. Prior exploration beneath the exhausted deposits high in the mine had always been done vertically beneath the old slopes to a depth of 1,230 m (4,050 ft). Recognizing that the shear lineation at the Gold Hunter actually rakes 75° west, Hecla drilled exploratory holes west of the down-dip projection of the old ore bodies on the 1,230-m (4,050-ft) level of the Lucky Friday Mine. This resulted in the discovery of a major new ore body that approximates the width, length and grade of the famous Lucky Friday vein.

FIG. 4

Relative thickness of Belt strata in Coeur d'Alene Mining District (Modified from Hobbs et al., 1965).



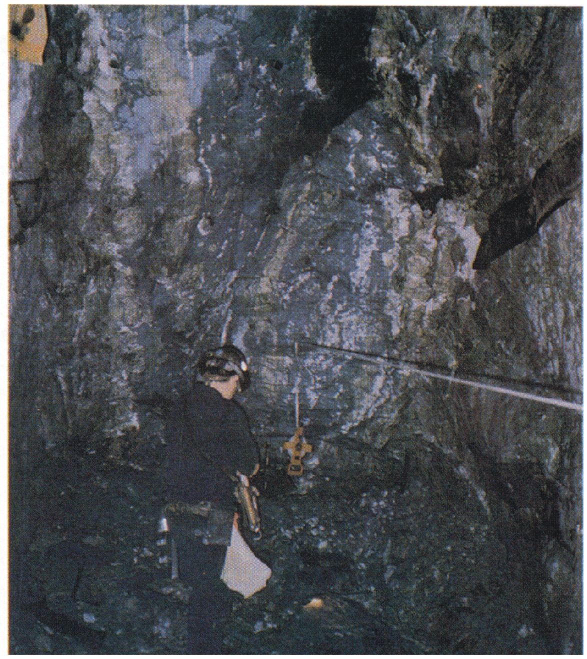
The Gold Hunter deposit provides good examples of textures and fabrics common to shear-zone-hosted gold deposits (Sibson and Poulsen, 1988). These include the metamorphic foliation, steeply raking shear lineations and veins and veinlets that either parallel foliation or are perpendicular to foliation and the lineation (White, unpublished data). The nearly horizontal veinlets at the Gold Hunter Mine are of the crack-seal variety in which quartz fibers parallel the shearing lineation just as found in the shear-zone-associated gold deposits. At other mines in the district, these flat veinlets are more commonly represented by "ladder quartz" veins that crosscut primary veins.

Stratigraphic control of ore. Certain strata have been known to be more favorable for ore than others. For the most part, ore is associated with sandier strata, now metamorphosed to quartzite. About 75% of the total district ore production has come from the Revett Formation (Mitchell and Bennett, 1983). This formation is particularly characterized by the presence of thick-bedded quartzite. An additional 19% of production has come from quartzitic strata that span the Burke-Prichard contact. All current production is associated with the Revett or the immediately overlying St. Regis Formation.

Beginning with work at the Bunker Hill Mine during the 1970s (White and Winston, 1982), it has become evident that ore bodies are particularly associated with limited thicknesses of specific quartzitic strata. At the Bunker Hill Mine, for example, many ore bodies confined to about 30-m- (100-ft-) thick quartzites pinch out where the vein structure intersects thick, argillitic strata. At mines such as the Sunshine Mine, most of the favorable strata are simply siltier than the unfavorable argillitic strata, where the ore bodies abruptly end (White, unpublished data).

During the past several years, identification and mapping of specific, productive strata have led to the discovery of significant new ore reserves, particularly in Silver Belt mines. Once these favorable strata have been identified and mapped at individual mines, a productive means of exploration has been to locate and then explore favorable structures where they pass through these strata.

Wall-rock alteration. Except for hydrothermal bleaching that was once thought to characterize Coeur d'Alene ore deposits, alteration of wall rocks surrounding the ore bodies has been regarded as subtle or nonexistent. However, it has been found that several types of wall rock alteration do surround ore bodies and clusters of ore bodies. Some features of the alteration halos provide evidence concerning the development of the ore bodies.



A Hecla Mining Co. geologist prepares to sample a stope face in the newly developed Gold Hunter silver-lead ore body. Photo: Brian White, NIOSH.

Hydrothermal bleaching. Hydrothermal bleaching in the Coeur d'Alene district was first described by Rasor (1934) at the Sunshine Mine. The bleaching sometimes extended far beyond known ore bodies. It was thought to provide a rough exploration guide, so that bleached strata became the focus of much subsequent exploration and study (Weis, in Fryklund, 1960). In time, investigators began to realize that much of the presumed bleached strata extended far beyond the bounds of the Coeur d'Alene district. This indicated that the perception of the importance of hydrothermal bleaching had been exaggerated.

At the Sunshine Mine, where hydrothermal bleaching was first recognized, purplish, hematitic strata are more prominent in the upper Revett Formation and lower St. Regis Formation than in most of the remainder of the district (personal observation). In this purplish rock, hydrothermal bleaching typically extends 10 to 30 m (33 to 100 ft) out from ore bodies. A 0.5-m- (1.6-ft-) wide zone of coarse, euhedral pyrite occurs at the edge of the bleached zone along the redox boundary (Mitcham, 1952; reaffirmed by Sunshine Mine geologists). Thus, hydrothermal bleaching is prominent only in a limited part of the district where mineralizing structures intersect hematitic strata.

Carbonate zoning. The earliest reports on district geology (Ransome and Calkins, 1908) commented on the presence of disseminated siderite near veins. But the existence of other carbonates in the wall rocks has not been considered diagnostic of Coeur d'Alene veins. Shaw (1959) was apparently the first to identify a distal carbonate zone containing ankerite and calcite around ore bodies at the Bunker Hill Mine.

This discovery should have been immediately applied in exploration. But the practical problem of readily distinguishing small amounts of disseminated ankerite, calcite and siderite underground and in drill core prevented these minerals from attracting attention.

Since then, Goers (unpublished progress reports to Hecla Mining, 1969) identified similar zones around the Star-Morning, Standard Mammoth and Lucky Friday mines. Gitlin (1986) further investigated carbonate zones about the Lucky Friday vein. With the application of field-usable carbonate stains in the early 1980s, identification of wall rock carbonates became integrated into exploration efforts at all active mines.

The zone of disseminated siderite, tens to hundreds of meters wide that surrounds the veins, grades out into a siderite-ankerite zone a few meters or tens of meters wide. This zone is, in turn, surrounded by a zone up to hundreds of meters wide containing both ankerite and calcite. Out from the calcite-ankerite zone, disseminated ankerite extends beyond the mineral belts and the district. This indicates that carbonate is an original constituent of the sediments, probably diagenetic in origin. A likely explanation for the concentric arrangement of these carbonate zones is that the calcite component of ankerite was dissolved and displaced out from the siderite zone.

At the Lucky Friday Mine, the distribution of car-

FIG. 5

Major geologic features of the Coeur d'Alene Mining District.

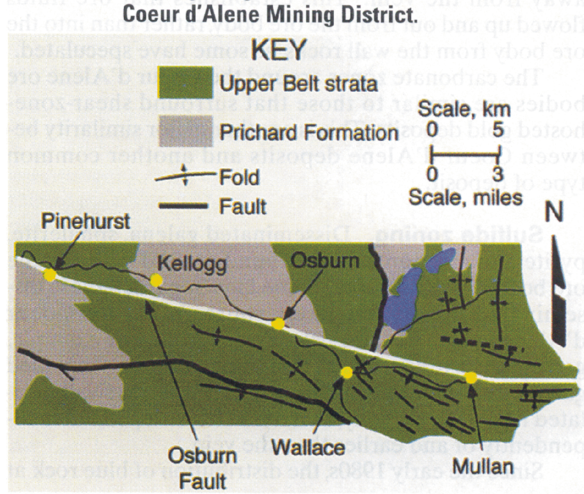
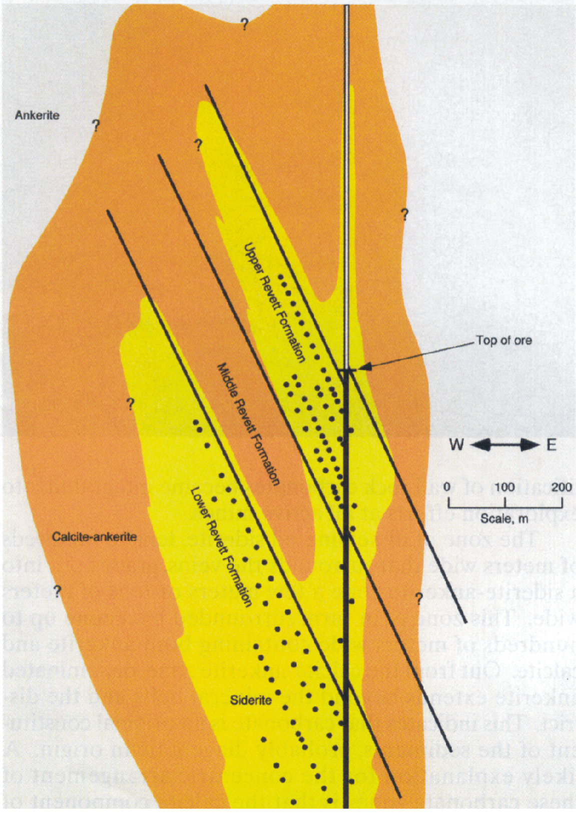


FIG. 6

A Cross section of the Lucky Friday vein showing the distribution of disseminated carbonates and galena in wall rocks. A narrow ankerite-siderite zone at the boundary between the siderite and calcite-ankerite is not distinguished. Large dot represents disseminated galena.



bonates is controlled by lithology and by the orientation of bedding with respect to the Lucky Friday ore body (Fig. 6). The siderite zone extends farther out in quartzitic strata than in argillitic strata and also extends farther into strata that dip into the vein than in strata that dip away from the vein. This establishes that ore fluids flowed up and out from the ore body, rather than into the ore body from the wall rocks, as some have speculated.

The carbonate zones around the Coeur d'Alene ore bodies are similar to those that surround shear-zone-hosted gold deposits. This is another major similarity between Coeur d'Alene deposits and another common type of deposit.

Sulfide zoning. Disseminated galena, sphalerite, pyrite and arsenopyrite are found around many of the ore bodies in the district. Some have regarded these disseminated deposits as likely source rocks for Coeur d'Alene veins. At the Lucky Friday Mine, for example, geologists have speculated that some of the disseminated galena, known locally as "blue rock," was physically isolated from the ore body, as if it had been deposited independently of and earlier than the vein.

Since the early 1980s, the distribution of blue rock at the Lucky Friday Mine has become well established as a result of diamond drilling and additional development (White, unpublished data). Disseminated galena extends out from the vein along selected bedding units for tens to hundreds of meters on the side of the vein where strata dip into the vein. But it extends only 1 to 3 m (3.3 to 10 ft) on the side of the vein where strata dip away from the vein (Fig. 6). This pattern mimics that of the carbonate zones. It suggests that these sulfides came from the vein, traveling up and out along available, permeable bedding planes, not the reverse.

At other mines, disseminated sulfides are found only near veins containing the same metal sulfides. Exploration throughout the district has rarely discovered sulfides that cannot be explained by proximity to a nearby vein that contains the same metal. The relationship is consistent and frequent enough to provide evidence that all of these wall rock sulfides came out of the veins and represent alteration.

Vein zoning. Although Ransome and Calkins (1908) and Mitcham (1952) thought they saw metal zoning in some individual ore bodies, Fryklund (1960) recognized only one vein that appeared to be zoned. However, continued consideration of metal ratios in many Cocur d'Alene veins suggests that upward zonation of sulfide minerals does exist.

Mitcham (1952) presented evidence that the Sunshine ore body contains increasing amounts of lead relative to silver higher in the vein. Since then, similar patterns have been identified in other Silver Belt ore bodies, including in the Sunshine and the Galena mines. Thus, upward grading of tetrahedrite into galena in Silver Belt mines now seems to be an established pattern.

Outside of the Silver Belt, other consistent patterns of metal zoning in veins have also been established. Production statistics from the Lucky Friday vein, mined over a vertical range of 1,500 m (4,920 ft), indicate that silver and lead decrease slightly with depth, while the zinc content increases (Devoe, 1995, personal communication). This pattern duplicates the zoning that Fryklund (1964) recognized in the Tony ore shoot of the Page Mine.

Crosby (unpublished Hecla Mining data) compiled production statistics for the Star-Morning and Tamarack mines, nonSilver Belt mines that show similar trends. Crosby (1989, personal communication) noted that silver-to-zinc and lead-to-zinc ratios varied widely from level to level in these mines. He speculated that geologists who worked at these large mines for only a few years may not have become aware of systematic changes in metal ratios with depth.

In smaller veins, systematic zoning may not have been evident at all. However, over the 2,600-m (8,530-ft) vertical range of the Star-Morning vein, the trend is unmistakable and shows increased zinc and decreasing lead and silver with depth. In this same ore body, Hutchinson (1984, personal communication) noted that pyrite was more abundant with depth along the vein's west end. Some mine geologists consider that the veins of the Silver Belt also become pyritic or chalcopyrite-rich with depth.

These observations establish that vein zoning is present and widespread in the Coeur d'Alene district, although not always obvious. The zoning patterns mostly reflect the familiar sequences of sulfide minerals seen in ore bodies around the world. Thus, although the quantity of metal in Coeur d'Alene veins is unusual, the processes that formed the ore bodies appear to be no different from the common ones that have formed ore bodies elsewhere.

Metamorphism and genesis

Earlier writers speculated that Coeur d'Alene metals came from intrusive magmas, from the immediate wall rock or deeper strata, or from a subcrustal source. But an origin involving metamorphism of sediments now seems likely.

Some papers describing Belt strata have commented that the metamorphic grade of these rocks is low, but that it increases toward the Idaho batholith. However, it is actually only in the immediate border zone of the batholith (Fig. 3) that metamorphism increases notably. Elsewhere, burial metamorphism before development of the batholith reached its highest grade in the deeper, more central part of the Belt sedimentary basin northeast of the district in Montana. As a result of these separate areas of elevated metamorphism, the district sits in a regional metamorphic low, where most strata had not reached greenschist facies metamorphism before the ore deposits formed.

Many authors describe wall rocks of the district as being greenschist or upper greenschist in metamorphic grade. This view, however, is not supported by field observations. Except locally, such as at the Atlas Mine, no greenschist minerals associated with mineralization are present.

Gitlin (1986) determined that diagenetic sericite in Revett strata outside of mineral belts contains appreciable iron and magnesium. This suggests that burial metamorphism had not brought these rocks to greenschist grade before formation of the Coeur d'Alene ore bodies.

In contrast, at the Lucky Friday Mine, Gitlin found that mica from equivalent strata contains significantly less iron and magnesium and thus approaches a pure muscovite. Her work suggests that mineralization was superimposed onto subgreenschist-facies strata and that conditions associated with mineralization approached those of greenschist metamorphism.

The low-to-nonexistent burial metamorphism in the district before the veins formed probably had consequences that contributed to the formation of the ore bodies. First, these sediments were probably not so extensively dewatered as higher-grade rocks would have been. So even the low-grade metamorphism associated with the formation of the veins could have exploited this water as ore fluids. Second, the lack of burial metamorphism in the district left the pyrite in the thick, black-shale Prichard Formation instead of the pyrrhotite that characterizes this formation in the region surrounding the Coeur d'Alene district.

Metamorphism of pyrite to pyrrhotite at depth within the metamorphic shear zones would have involved the liberation of sulfur. This liberation could have mobilized metals in the form of bisulfide complexes that, in turn, could have solubilized the anomalous metals that are found locally in the lower Prichard Formation. The metals could then have been transported up in the shear zones in the metamorphic waters. This hypothesis has not been widely discussed and its feasibility has not been assessed. However, the presence of the thick, pyritic, locally metal-anomalous Prichard Formation at depth is one of the more unique features of the district and could help explain the unusual wealth of its ore deposits.

Age

Interpretation of the age of the Coeur d'Alene ore bodies has varied widely. Ransome and Calkins (1908) thought the veins were related to an underlying batholith that also formed the Mesozoic Gem stocks. Fryklund (1964) and Hobbs et al. (1965) were once convinced that the veins postdated the stocks. But Hobbs (Hobbs and Fryklund, 1968) reconsidered this view in the face of persuasive arguments by USGS coworkers Gott and Zartman (whose ideas involved the Precambrian isotopic composition of Coeur d'Alene lead and new evidence that the stocks postdated the veins). Consequently, Hobbs became convinced (Hobbs and Fryklund, 1968) that a Precambrian date for origin of the veins was more logical than a much younger date.

Uranium-lead dating of uraninite veins that postdate folding but predate Silver Belt tetrahedrite ore bodies at the Sunshine Mine (Eckelmann and Kulp, 1957) once seemed to indicate that the uraninite veins and the folding that predates them are Precambrian. More recently (Zortman and Smith, 1995), new and more reliable U-Pb dates indicate that these veins are 136 ga or Mesozoic.

Fleck et al. (1991) analyzed strontium isotope compositions from siderite veins. They concluded that strontium in the veins is too radiogenic to have possibly formed in the Precambrian and must be no older than Mesozoic. Leach (1998) reported that siderite and Silver Belt tetrahedrite contain a trace amount radiogenic Pb. This is in sharp contrast to the nonradiogenic, Precambrian Pb contained in Coeur d'Alene galena. Thus, evidence is accumulating that Silver Belt tetrahedrite veins, at least, formed in the Mesozoic. However, based on the nonradiogenic character of galena Pb and on Ar-Ar dates from sericite found in some veins in the district, Leach and others (1998) propose that, while the galena and sphalerite components of Coeur d'Alene veins were emplaced in the Precambrian, the tetrahedrite was

Sunshine Mine geologists now differentiate hydrothermally bleached, green colored rock from similarly appearing, diagenetically reduced strata by the presence of pyrite at hydrothermal redox boundaries. Photo: Bob Doler, Sunshine Mining Co.

emplaced much later. An alternative to isotopic and radiometric approaches may be available through conventional relative dating of some of the structures found in the district. For example, all parties agree that veins postdate the large, tight folds of the district. But no such folds dated as Precambrian have been identified in the surrounding region.

On the other hand, two younger sets of folds do exist and feature geometries and orientations coincident with district folds. These folds are datable as Phanerozoic by virtue of their involvement with Cambrian strata northeast (Harrison and Cressman, 1993) and east (Harrison et al., 1974) of the district and Mesozoic by their development in the higher grade metamorphic zone adjacent to the Idaho batholith (Harrison, 1986; Hyndman et al., 1988). Confirmation that these are the same sets of folds found in the district would require that the veins be Mesozoic or younger.

The Longyear 44 is commonly used for surface exploration diamond drill holes. Photo: Lisa Hardy, Sunshine Mining Co.

Relative dating may be able to more precisely identify the timing of vein formation. Two sets of folds occur in the border zone of the Idaho batholith with geometries (Harrison, 1986) that make them likely to be the folds that occur in the district. These folds evidently formed while metamorphism related to formation of the batholith was taking place but were intruded by the batholith (Hietenan, 1984). The veins of the district are locally cut by thrust faults that logically correspond to Laramide thrusts (Harrison et al., 1980). These apparently developed most extensively in the early Tertiary (White, 1978). Thus, veins formed after extensive metamorphism around the batholith had begun, but before completion of the overthrust belt. This would bracket the age of the veins as about equal to the time of the intrusion of the batholith, that is, late Cretaceous.

This scenario suggests that the batholith played a role in generation of the dynamic metamorphism that characterizes Coeur d'Alene veins and mineral belts. Criss and Fleck (1990) support this interpretation. They showed that oxygen isotopes found in Belt argillite are found in zones in the northern part of the Idaho batholith in an area extending all the way into the Coeur d'Alene district. They suggest that heat from the batholith influenced fluid flow in the Coeur d'Alene district and contributed to formation of the veins.

Conclusions

As old ideas about the Coeur d'Alene Mining District are discarded, modified or given new emphasis, it is becoming evident that as more is learned about the district, the less unique and exotic its deposits are from other deposits around the world. Advances in understanding Coeur d'Alene ore deposits have aided the discovery of new reserves. But these advances make it clear that Coeur d'Alene ore bodies are more elusive than had been first appreciated. Many past discoveries resulted more from perserverance and good fortune than from comprehension of the geology. As a result, it is certain that many good ore bodies remain undiscovered.

As is true of ore deposits everywhere, the ore bodies of the Coeur d'Alene Mining District resulted from locally unusual circumstances. In this case, those circumstances were extraordinary. However, the basic processes that operated during the formation of the ore bodies and the general evolution of the district are common to mining districts everywhere. As a result, the Coeur d'Alene district is an outstanding laboratory for discovering new things about ore bodies and also about the tectonics and geologic history of the region. However, much remains to be learned. The ideas discussed in this article are also subject to modification and/or replacement. ■

Acknowledgments

The geologic studies discussed here are part of ongoing work by personnel of the Spokane Research Laboratory of the National Institute for Occupational Safety and Health (NIOSH). These studies would not have been possible without the continuing cooperation of many mines in the Coeur d'Alene Mining District, including those owned or operated by Bunker Hill, Day Mines, Hecla, Sunshine, Coeur, Asarco and Silver Valley Resources. The goal of this work is to better understand the role of various geologic factors in the generation of rock bursts and other ground-control hazards in mining. Through these efforts, NIOSH is continuing the commitment of the former US Bureau of Mines to improving the health and safety of the nation's miners.

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