A Hypothesis Concerning the Genesis of Orebodies in the Coeur d'Alene Mining District, Idaho

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by

Earl H. Bennett[1]

ABSTRACT

The origin of the ore deposits in the Coeur d'Alene mining district, Idaho, has been a topic of controversy since the first lode claims were staked in 1884. Almost all of the ore produced from the district's mines is from veins that occur in fractures in the rocks of the Belt Supergroup. Several mines also contain noncommercial disseminated mineralization. The two types of mineralization have been used to support the two familiar arguments of magmatic hydrothermal versus syngenetic (stratabound/stratiform) origin.

The veins and the disseminated mineralization are localized in three stratigraphic horizons in the Belt metasediments. One is the Middle Prichard quartzite; another is the Prichard-Burke transition zone; and the third, and most important, is the Revett-St. Regis transition zone. The deposits in each of the three horizons are characterized by their own metal content and mineralogy.

This paper presents the hypothesis that the three groups of deposits originated from the mobilization of stratabound deposits in the three favorable horizons. Each of the stratabound deposits formed in its own restricted area. Models for these orebodies include the synsedimentary Sullivan mine at Kimberley, British Columbia, and the Troy project and other similar stratabound copper-silver deposits in the Revett quartzite.

If the hypothesis is correct, then the ore deposits in the Coeur d'Alene district are unique because of the extensive mobilization of the stratabound ore into veins. Other deposits assumed to be stratabound do not exhibit this mobilization phenomenon on the scale of the Coeur d'Alene mines, although some deposits, such as Broken Hill and Mount Isa

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in Australia, have been equally or more severely deformed than the Coeur d'Alene deposits.

INTRODUCTION

The Coeur d'Alene mining district in northern Idaho (Figure 1a) is one of the premier silver-producing areas in the world. Since the beginning of lode mining in 1884, the district's mines produced by 1982 963,544,000 ounces of silver, 7,751,071 tons of lead, 3,099,975 tons of zinc, and minor quantities of other metals including antimony, cadmium, copper, and gold, for a value of over $4.2 billion (Springer, 1983). The origin of these valuable deposits has been a controversial subject of debate among scientists, and the argument presented in this paper will prove to be no less so. Most of the paper views the district as it appeared prior to major movements along the Osburn and Dobson Pass faults. The reader is referred to Bennett and Venkatakrishnan (1982) for details concerning the palinspastic reconstruction of the district and for a general review of the literature.

DESCRIPTION OF THE COEUR D'ALENE MINING DISTRICT

The Coeur d'Alene mining district is approximately centered on the town of Wallace (Figure 1a). The mines are in rocks of the Belt Supergroup of Precambrian age. A description of the stratigraphic units in the Belt Supergroup is given in Gott and Cathrall (1980) based on data from Hobbs and others (1965). The total thickness of the Belt Supergroup in the district is estimated to be at least 6,400 meters by Hobbs and others (1965), although the base of the Prichard Formation is not exposed and part of the upper Belt has been removed by erosion. This thick sequence of Belt rocks is still only a relatively thin skin on a much thicker continental crystalline basement. The thin skin has been complexly affected above a decollement (Harrison and others, 1980). Intrusive rocks include the Gem and Dago Peak stocks of Cretaceous age, and diabase

and lamprophyre dikes that are exposed in both surface outcrops and mine workings.

The Coeur d'Alene district lies within the Lewis and Clark shear zone. The zone is a belt of separate faults that together form a major intracontinental plate boundary in the northwestern United States (Reynolds and Kleinkopf, 1977). It has been suggested that soft sediment deformation in the Prichard Formation and other Belt sediments indicates that structures in the shear zone were active early in the history of the Belt basin (Webster, 1981; Chevillon, 1977).

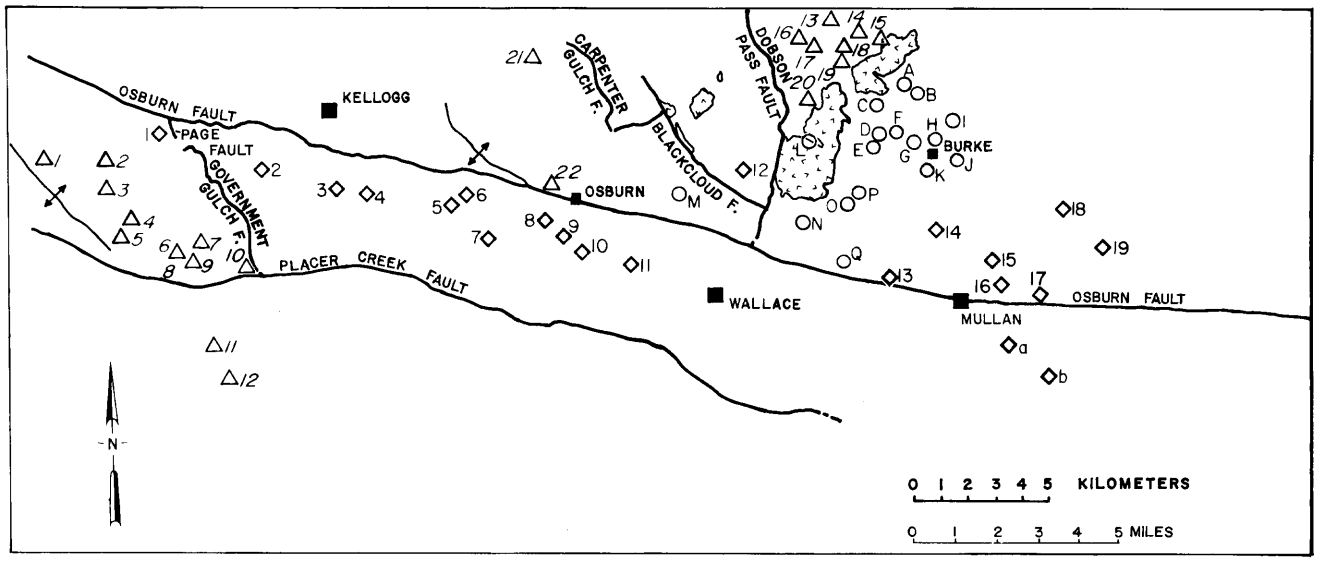
The deformation of Belt metasediments within the Lewis and Clark zone is much more intense than elsewhere in the Belt basin, and folding and faulting are more intense in the Coeur d'Alene mining district than elsewhere in northern Idaho. It must be more than coincidence that the most highly deformed parts of the basin contain major mineralization. Folding in the district has been attributed to the Kootenay orogeny (White, 1959; Harrison and others, 1974).

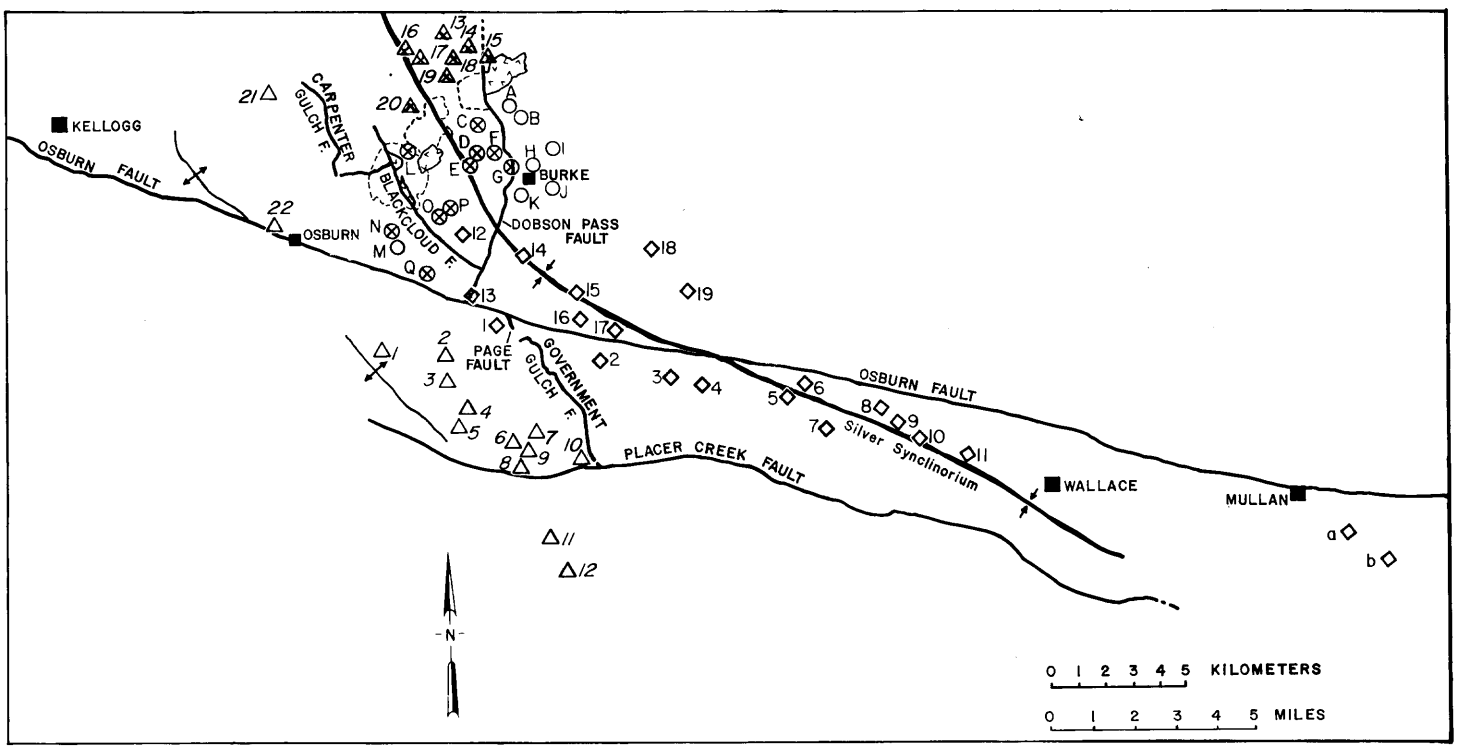
Long and others (1960) noted that lead isotope ages from the district's mines averaged about 1.4 b.y. They suggested that the Precambrian ores had been locally remobilized by Cretaceous intrusions.

Zartman and Stacey (1971) determined from lead isotopes that the age of the Coeur d'Alene deposits ranged from 1.2 to 1.5 b.y. They concluded that the deposits are Precambrian and are unrelated to the Gem stocks. Sericite from the Tallon orebody in the Bunker Hill mine has been dated by potassium-argon methods at 829 m.y., as reported by Landis and Leach (1983). This may be close to the time of vein formation.

The mines in the district exploit oreshoots in steeply dipping veins that are classified as tabular replacement veins by Hobbs and Fryklund (1968). Some geologists have described the veins as open-space fillings. The veins range from several centimeters to meters in width and may be up to several hundred meters in length and several times their strike length in depth. Most of the veins occupy one of three stratigraphic horizons (Figure 1a). These are veins proximally located near the middle quartzite in the Prichard Formation, the Prichard-Burke transition zone, and the Revett-St. Regis transition zone.

The primary economic minerals in the district include galena,





B

Figure 1. Location of ore deposits in the Coeur d'Alene district before and after movement on the Osburn and Dobson Pass faults. (**A**) Present location of mines in the Coeur d'Alene district grouped by stratigraphic position. (**B**) Location of mines in the Coeur d'Alene district grouped by stratigraphic position as they were positioned prior to movement along the Dobson Pass and Osburn faults (Bennett and Venkatakrishnan, 1982). Middle Prichard deposits are shown as △, Prichard-Burke deposits as ○, and Revett-St. Regis deposits as ◇. Mines below the Dobson Pass fault are shown by these symbols: ⊗ ⟁ . The Gem stocks are shown by a barbed pattern.

Figure 1. Continued.

MIDDLE PRICHARD DEPOSITS

Pine Creek Area
1. Hypotheek
2. Bobby Anderson
3. Amy Matchless
4. Sunset (Liberal King)
5. Lookout Mountain
6. Nabob
7. Sidney
8. Hilarity
9. Little Pittsburg
10. Highland Surprise
11. Douglas
12. Constitution

Upper Ninemile Creek and Sunset Peak Area
13. Idora, Tuscumbia, and Tough Nut
14. Silver Tip
15. Sunset Lease
16. Carlisle
17. Amazon-Monitor
18. Nepsic
19. Interstate-Callahan
20. Rex (16 to 1)

Evolution District
21. Charles Dickens
22. Evolution

PRICHARD-BURKE DEPOSITS

A. Ambergris, Guelph, and Honolulu
B. Hercules
C. Tamarack
D. Union
E. Standard-Mammoth
F. Sherman
G. Hummingbird, Fairview, and Wide West
H. Tiger-Poorman
I. Ajax
J. Marsh
K. Hecla
L. Success (Granite)
M. Western Union
N. Canyon Silver (Formosa)
O. Helena-Frisco
P. Black Bear
Q. Golconda

ATLAS BLOCK
a. Atlas (Carbonate Hill)
b. Reindeer Queen

REVETT-ST. REGIS DEPOSITS

1. Page
2. Bunker Hill
3. Alhambra

"Silver Belt"
4. Crescent
5. Sunshine
6. Polaris
7. Consolidated Silver (Silver Summit)
8. Coeur d'Alene (Mineral Point)
9. Coeur
10. Rainbow
11. Galena

Other Revett-St. Regis Deposits
12. Dayrock
13. Alice
14. Star-Morning
15. Gold Hunter
16. Lucky Friday
17. Vindicator

Stratabound Disseminated Copper-Silver Deposits
18. National
19. Snowstorm

sphalerite, and tetrahedrite. Gangue minerals include quartz, siderite, pyrite, and pyrrhotite. Fryklund (1964) and Hobbs and Fryklund (1968) discuss the paragenesis of the mineralization.

PREVIOUS IDEAS ON THE ORIGIN OF THE DEPOSITS

The various theories on the origin of the Coeur d'Alene deposits can be separated into two groups. The division is based on the familiar arguments of a magmatic hydrothermal origin (with several versions) and of a mobilized sediment-hosted stratiform or stratabound origin (also in several versions). In recent works it is often difficult to separate the two ideas, because hydrothermal mechanisms are blended with stratiform or stratabound origins via metamorphism and diagenesis.

The original description of the geology and deposits in the district was by Ransome and Calkins (1908). They proposed a classical magmatic hydrothermal model where the veins in the district were related to igneous activity associated with the Gem stocks. Later workers, such as Umpleby (1917), Umpleby and Jones (1923), Anderson (1949), Fryklund (1964), Hobbs and Fryklund (1968), and Juras (1979b), also supported some type of hydrothermal model.

A major problem with the magmatic hydrothermal theory is in explaining how hydrothermal veins can exist to such great depths with essentially no change in vein mineralogy, and in fact with only slight changes in the metal content of the minerals (Sorenson, 1968). The Star-Morning vein system, for example, is 2,225 meters from top to bottom and was still in mineralization when closed by the Hecla Mining Company in 1982. The Sunshine, Bunker Hill, Lucky Friday, and Galena mines are all over 1.5 kilometers deep and are still in mineralization, with the same mineralogy over the vertical range of veins and with only minor changes in mineral chemistry. Both chemistry and mineralogy have changed laterally along the strike of some of the veins, the best example being the Star-Morning mine that is zinc-rich in the western part of the vein (Star mine) and lead-rich and silver-rich to the east (Morning mine). The Page mine also shows this type of zoning. Another problem with the

hydrothermal theory is in the three kinds of ore assemblages in the three stratigraphic horizons. Why would this happen in a typical hydrothermal system?

The great Bunker Hill Company geologist, Oscar H. Hershey, in 1916 thought that the metals originated in the sediments. He wrote: "I submit that the facts point to invisible diffused mineralization in the upper portion of the Upper Prichard strata as the source of nearly all the lead and zinc in the deposits of the district." Other supporters of a sediment-hosted stratiform or stratabound model for the origins of the metals included Sorenson (1968) and Ramalingaswamy and Cheney (1982).

The mobilized syngenetic-stratabound theories also have problems. Many stratiform theorists on the district believe that the metals were mobilized from the Prichard Formation, described as a metalliferous garbage basket. Explaining the differences between the three kinds of ore mineral assemblages occurring in three separate stratigraphic horizons poses problems for bringing all of the metals out of a common source area. Much attention is given to localities in the district that display disseminated ore or stratiform ore (or what is interpreted as stratiform) because these are interesting geologic areas. Stratiform ore occurrences are known in most of the mines in the Revett-St. Regis group, including the Lucky Friday ("blue rock"), Morning, Dayrock, Galena (in core), Bunker Hill, and Snowstorm. Radford (1982) pointed out, however, that stratiform ore is rare in the district in comparison to ore in veins. Lateral secretion is a difficult concept to apply to the district, because it seems improbable that the ore in the veins was squeezed out of the wall rocks with so little evidence that such mobilization happened. In the Lucky Friday mine brecciated fragments of unaltered "blue rock" were observed within the vein, indicating that the vein crosscuts the disseminated ore and is younger. In fact, some of the "stratiform" ore in the Bunker Hill mine may be disseminated ore that moved out of the veins and into the wall rocks (Reid, 1982). Major differences are also apparent in the chemistry of the disseminated ore and the veins, as shown in the "blue rock" (disseminated ore) and the vein mineralogy in the Lucky Friday mine (Hauntz, 1982a and 1982b).

Other geologists have suggested that metamorphism might be a

mechanism for mobilizing metal from the sediments into veins. Crosby (1973) noted: "Ample evidence is accumulating to accommodate the theory that metals have mobilized from the parent rocks into present ore bodies through a combination of metamorphism and hydrothermal processes." Bijak and Norman (1982) suggested that water in fluid inclusions in samples of sphalerite and quartz from the Bunker Hill mine was derived from the Belt Supergroup sediments. Landis and Leach (1983a and 1983b) believed that mineralization was coincident with greenschist-grade metamorphism accompanied by intense structural deformation.

Metamorphism is appealing in that it solves the big problem of the lack of mineral zoning in the deep veins. Bijak and Norman (1982) noted that temperatures based on fluid inclusion studies ranged from 320°C to 350°C in sphalerite and from 250°C to 320°C in quartz in samples from the Bunker Hill mine. Leach and Hofstra (1983) presented similar temperatures for other deposits in the district.

As a mechanism, metamorphism does not explain how the deposits were separated into three stratigraphic horizons or how widely disseminated metals were mobilized into veins with so little evidence of any such mobilization. If the Prichard Formation is assumed to be the sole source of the metals, then the districtwide metal zoning pattern is a problem.

The mobilization of stratiform ores into veins from three separate stratigraphic horizons during metamorphism explains many characteristics of Coeur d'Alene deposits. This mechanism will be amplified in the following discussion.

THREE TYPES OF DEPOSITS IN THREE DIFFERENT STRATIGRAPHIC HORIZONS

The first mention of the idea that the ore deposits in the Coeur d'Alene district were in three stratigraphic horizons was by Simos and Droste (1961), as referenced by Sorenson (1968). Bennett and Venkatakrishnan (1982) adopted this classification instead of using the familiar "mineral belts" described by Fryklund (1964).

The three groups of deposits, one in the Middle Prichard, another in the Prichard-Burke transition zone, and the third in the Revett-St. Regis transition zone, are not only different in stratigraphic position, but also have different mineral assemblages and metal contents (Fryklund, 1964).

Understanding that all of the deposits are confined to the three stratigraphic horizons is a major key to the genesis of the deposits. This stratigraphic control of the deposits must be more than a coincidence, especially since these are not the most favorable horizons in the Belt for fracture generation during deformation of the Belt sequence. Massive quartzite in the nonmineralized Lower Revett and the Burke Formation would support a better developed fracture system, because these rocks are as competent, or more so, as any of the three mineralized horizons.

The three mineralized horizons indicate abrupt and major changes in the type of sediments that were filling the basin. Total time for Belt sedimentation may have extended from 1.5 b.y. to 800 m.y. (Kootenay orogeny). Harrison (1972) noted the monotonous sequence of sedimentary rocks that form each major unit in the Belt Supergroup. Given the amount of time involved for Belt sedimentation and the monotony of the individual units, the change in sedimentation that occurs at the mineralized horizons is indeed profound. For example, the change from black siltites and argillites in the Lower Prichard to the white quartzites in the Middle Prichard is dramatic and abrupt.

The changes in sedimentation between Belt units are probably related to changes in the tectonics of the basin or in the source area, or in both. Such changes in tectonics as recorded by the sediments are at the precise times that the ancestral Osburn fault or some other structure in the Lewis and Clark zone could have become active with outpourings of metal-rich brines into the basin area. The three mineralized horizons are the most dramatic breaks in the Belt sediments. The Burke-Revett transition is between more similar rocks than the breaks between other formations, and as noted there are no major deposits in this horizon. The more subtle change from Burke to Revett indicates a lack of major tectonism and associated mineralization.

An isometric drawing based on regional sections shows that the

thickest section of the Prichard Formation in this part of Idaho was in the district approximately beneath the town of Wallace (Hobbs and others, 1965). Harrison (1972) showed that the thickest part of the Revett Formation is also in the area of the Coeur d'Alene district, although he later cautioned against using his isopach maps too literally because much of the Belt is now believed to be allochthonous (Harrison and others, 1980). It does, however, appear that subbasins in the much larger Belt basin formed near the district. These subbasins received metals during tectonic activity along the Lewis and Clark line.

THE CURRENT HYPOTHESIS

Basically there are three different vein deposits in the Coeur d'Alene district: one in the Middle Prichard, one in the Prichard-Burke transition zone, and one in the Revett-St. Regis transition zone. The three deposits formed in three different sedimentary subbasins in the Belt basin. Each subbasin received a different sediment-hosted, synsedimentary mineralization from structures similar to the Osburn fault. The concentrated sulfide cores (which will be referred to as ore pods) of these deposits were later mobilized into vein structures during regional metamorphism. Differences in mineralogy and metal zoning in the original stratiform orebodies and overlaps of the three basins explain the differences observed in the various mines in the Coeur d'Alene district.

THE SULLIVAN MINE--A PROTOTYPE FOR THE PRICHARD-BURKE AND MIDDLE PRICHARD DEPOSITS

The sediment-hosted, synsedimentary orebody envisioned for the Coeur d'Alene deposits is similar to the one at the Sullivan mine operated by Cominco, Ltd., at Kimberley, British Columbia. The Sullivan mine has a core zone, typically greater than 45 meters thick, that is composed essentially of solid sulfides including pyrrhotite, pyrite, galena, and sphalerite (Hamilton and others, 1982). The upper part of the orebody

contains waste rock composed of silty argillite and argillaceous siltstones with occasional laminae of pyrrhotite. The metals probably filled a basin from a vent zone that is now represented by a brecciated pipe in the center of the orebody.

The massive sulfide core in the Sullivan mine is a key area because these metals could be moved into fractures without having to be separated from the enclosing sediments. It would be much more difficult to separate disseminated sulfides enclosing sediments than from the massive sulfide core. The mobilization of such a core into favorable structures could easily generate all of the Prichard-Burke vein deposits in the Coeur d'Alene district. A similar, but smaller, orebody (or orebodies) could account for the Middle Prichard deposits on Pine Creek, Upper Ninemile Creek, and the Sunset Peak area.

The Gem stocks (Figure 1) are surrounded by a contact metamorphic halo that contains magnetite and chlorite. This chlorite zone may in part be a relict of a central vent area, located just west of Burke, that would be analogous to the central vent area of the Sullivan mine. If this is true, then the main Gem stock intruded through this central vent area.

Lambert (1976) has compared the Sullivan with other stratiform deposits in the world, including McArthur River, Mount Isa, and Broken Hill in Australia. It seems reasonable that submarine exhalative fluids might account for massive sulfide deposits in the Coeur d'Alene district that could later be mobilized into the Prichard-Burke and Middle Prichard deposits.

The big difference between the Sullivan mine and the Coeur d'Alene district is the silver and related copper content of some of the ores, as in the "Silver Belt." Because the "Silver Belt" deposits are in the Revett-St. Regis group, they are quite different mineralogically from the Sullivan-type Prichard-Burke or Middle Prichard deposits.

THE TROY PROJECT--A PROTOTYPE FOR THE REVETT-ST. REGIS DEPOSITS

The Troy Project (Spar Lake) near Troy, Montana, was placed in operation by Asarco in 1982. This stratabound copper-silver deposit is in an 18-meter-thick zone, 2,256 meters long and 549 meters wide. The ore zone is 69 meters below the Revett-St. Regis contact and is nearly concordant to the shallow-dipping beds in the Revett. Ore minerals include bornite, chalcocite, chalcopyrite, tetrahedrite, digenite with minor amounts of galena, native silver, and native copper. The deposit is rimmed with a low-grade galena zone, 1 to 10 meters thick.

The Troy Project is the best-known deposit in a series of stratabound copper-silver occurrences in the Revett. The Rock Creek project near the Troy project is another deposit that is larger than Troy. Asarco plans to mine this deposit in the near future. The Snowstorm-National belt that forms the northeastern boundary of the Coeur d'Alene district is another one of these deposits, and was described as such by Huston (1910).

The Snowstorm-National belt is possibly the edge of a much larger copper-silver deposit, similar to the Sullivan massive sulfide deposit but composed of silver, lead, and copper instead of lead and zinc. Mobilization of the core of this deposit into favorable structures formed the rich "Silver Belt" of the Coeur d'Alene district in the Revett-St. Regis transition zone.

Although the massive sulfide core of the Sullivan orebody is a crude model for the Revett-St. Regis mobilized deposits in the Coeur d'Alene district, the two types of deposits probably formed by quite different processes. The Sullivan orebody formed in a deep marine environment in the Aldrich (Prichard) basin. Metals were supplied by hydrothermal solutions via a central conduit on the sea floor (Hamilton and others, 1982). A proposed mechanism for the development of these submarine, exhalative fluids is given by Hutchison (1982).

The Troy Project is in the Revett quartzite that was deposited in shallower water than the Prichard sediments. Harrison (1974) suggested that "copper was reconcentrated epigenetically in permeable strata of a structural-stratigraphic trap in the Revett prior to or during regional

metamorphism of the formation." He noted that the copper deposits in the Belt might be similar to red bed copper deposits in Africa and Australia. Gustafson and Williams (1982) included the deposit at Troy with the red bed-associated copper deposits, noting that the Revett, which does not contain apparent red beds, might be bleached due to alteration during metamorphism. White and Winston (1982) believed that such bleaching and alteration might also be due to diagenesis. Lange and Sherry (1983) suggested that the deposits in the Revett might have formed by upward migration of metal-bearing solutions along syndepositional, basement-controlled faults such as the East fault at Troy. Sulfides formed after sedimentation but prior to lithification.

One problem with the proposed model is in explaining how a massive sulfide core (ore pod) could form in the Revett-St. Regis zone from a disseminated Troy-type deposit. A Sullivan-type massive ore pod composed of silver and copper is, to my knowledge, unknown anywhere in the world. A clue to the solution of this problem may be found in the Snowstorm mine. Huston (1910) noted that the richest ore in this mine was near the Snowstorm fault, where the ore grade per ton was 4.5 percent copper and 6 to 8 ounces of silver. North of the fault, the silver grade dropped off to 1 ounce or less per ton. This compares with an average silver grade at Troy of 1.5 ounces per ton and 0.74 percent copper; however, near the East fault at Troy, copper grades increase to 4 percent. Metals are also more highly concentrated in bedding-plane faults at Troy. The reason for these grade increases near faults is speculative, but higher grade zones are in these deposits. It is possible that the largest Revett-St. Regis deposit lay along the axis of the "Silver Belt" and that very high silver and copper grades were present in this deposit, perhaps having formed in a similar fashion to the fault-controlled high grade zones in the smaller and more disseminated Snowstorm and Troy deposits. Such a mechanism for concentrating "Silver Belt" ores is appealing, because intense fracturing due to folding could concentrate original stratiform ore quite efficiently.

THE DEVELOPMENT OF THE THREE BASIN MODEL

The formation of one of the three sediment-hosted orebodies as envisioned for the Coeur d'Alene district is shown in cartoon form in Figure 2. The idea that disseminated sulfides occur around a massive sulfide core or pod (and possibly above and below the core as well), as is the case in the Sullivan orebody, is important. These disseminated zones, in the present model, form the "blue rock" in the Lucky Friday and Morning mines as well as the deposits in the Snowstorm-National copper belt and other mines in the Revett-St. Regis group. Other examples of stratiform ore in the Bunker Hill mine may be those shown by Ramalingaswamy and Cheney (1982).

The approximate outline of the three subbasins is shown in Figure 3. The geography in these drawings is based on the palinspastic reconstruction of Bennett and Venkatakrishnan (1982) and presents the district as it appeared before faulting, and is therefore generalized. The outline of the Middle Prichard subbasin is shown in Figure 3a, the Prichard-Burke subbasin in Figure 3b, and the Revett-St. Regis subbasin in Figure 3c. The overlap of the three basins is shown in Figure 3d. It is important to remember that the sulfide deposits in each basin have a distinct metal content and mineralogy.

DEFORMATION OF THE THREE BASINS AND MOBILIZATION OF THE ORE--A GENERAL MODEL

With the close of Belt sedimentation, the Coeur d'Alene mining district contained three separate sediment-hosted stratabound orebodies (Figure 3a-d). Most geologists attribute subsequent folding and metamorphism of the district to the Kootenay orogeny (Sorenson, 1968; Juras, 1982) that occurred 700 to 800 m.y. ago (Harrison, 1972).

Several ideas exist about the style of the deformation in the district. Hobbs and others (1965) believed that all of the major folds were formed by a single fold event that produced north- to south-trending folds. The north-south folds were reoriented to a northwest

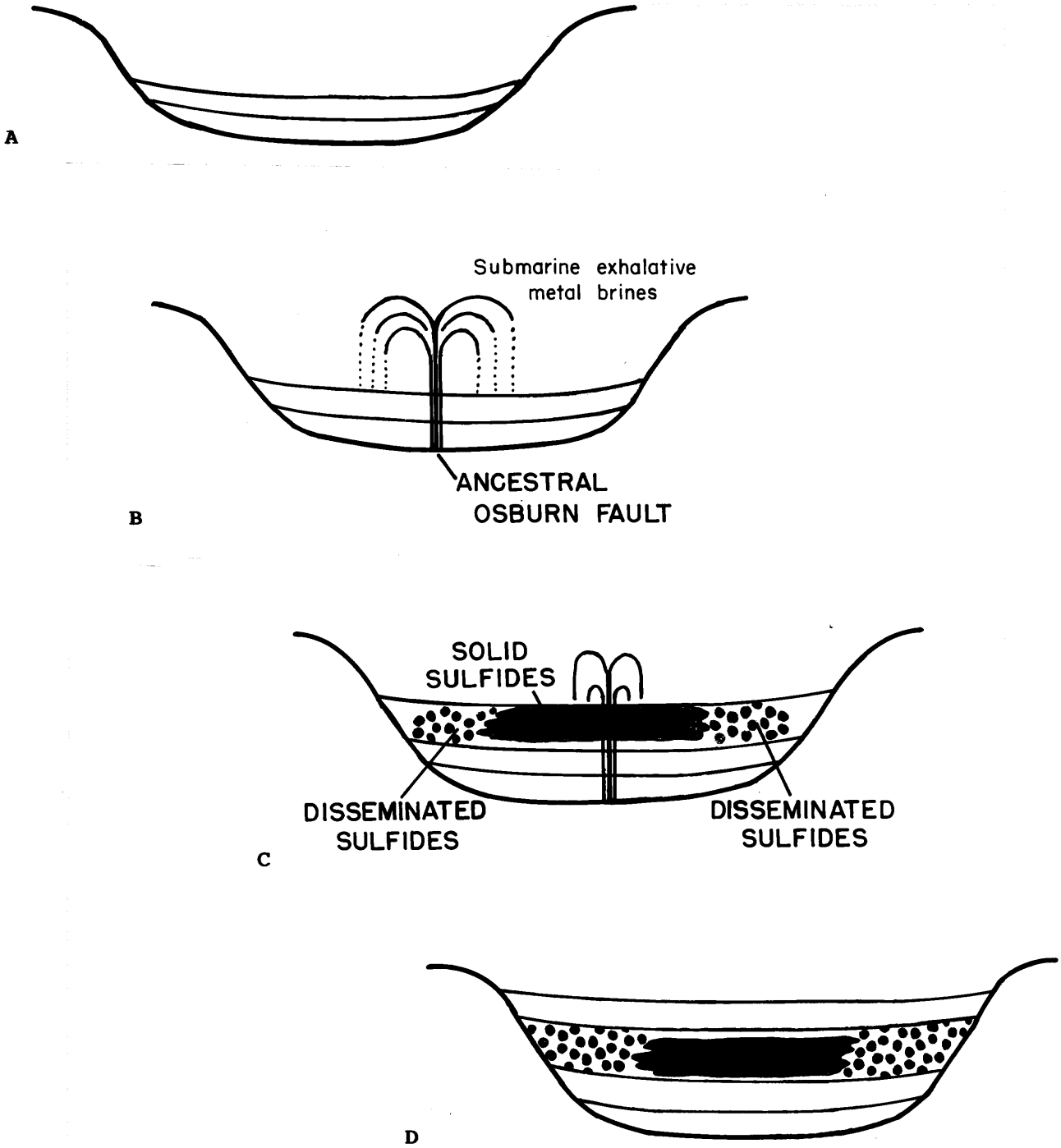


Figure 2. Generalized model of stratiform ore deposition. (**A**) Basin forms. (**B**) Metals are introduced into the basin via central conduits. Vents are active during tectonic change in the basin or source area, indicated by a change in basin sedimentation. (**C**) Metal pod forms, with disseminated ore on the edges of the basin and probably above and below the central ore pod as well. The pod may form directly as at the Sullivan mine in British Columbia, or over a period of time via mechanisms such as diagenesis and metamorphism as at the Troy mine in Montana. (**D**) Sedimentation continues as tectonics in the basin stabilize and metallization ceases. A stratabound metal pod and disseminated ore are now ready to be mobilized during a later tectonic event.

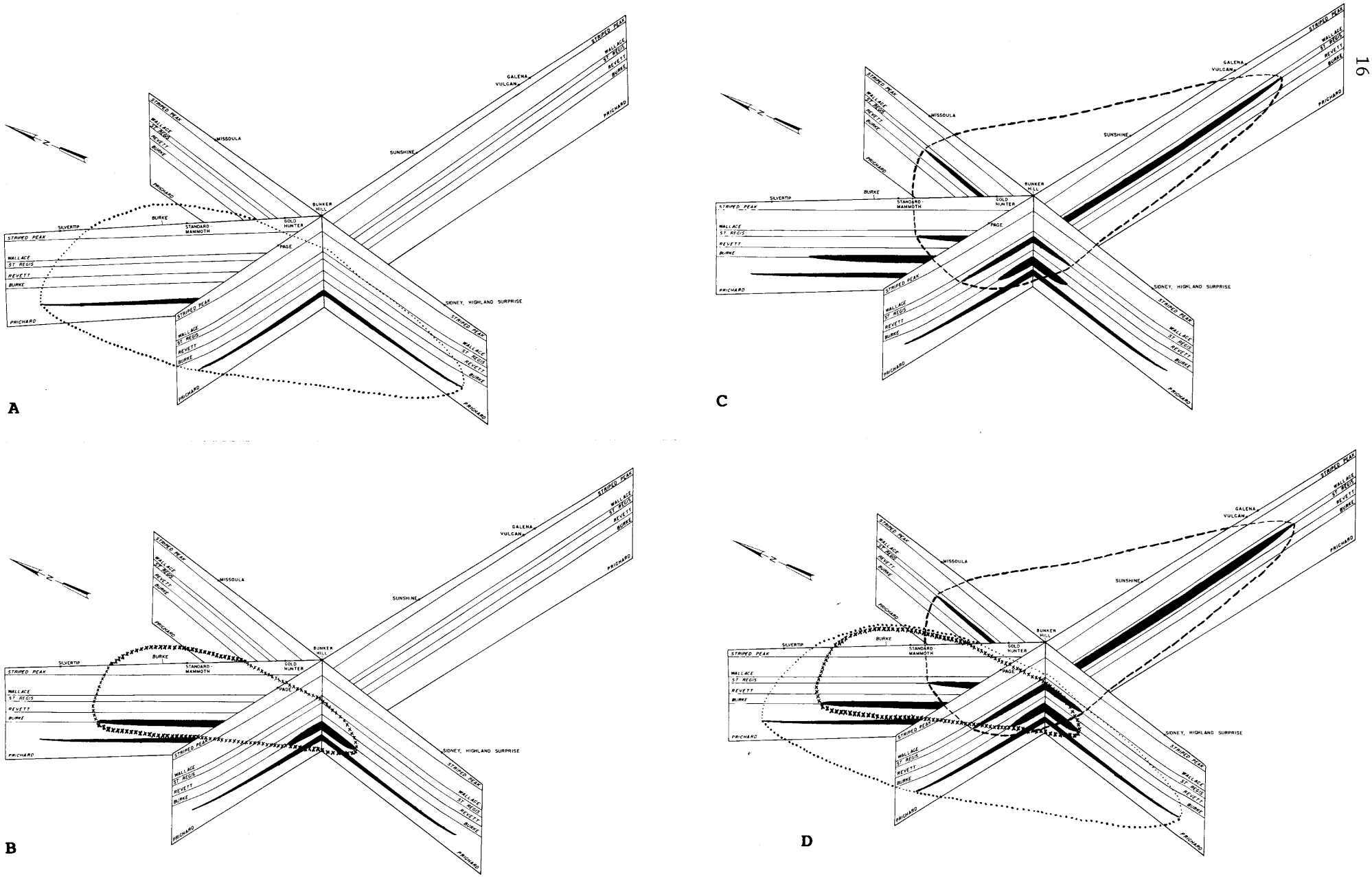


Figure 3. Formation of mineralized horizons in the Coeur d'Alene district. Mineralization shown in black. (**A**) Generalized outline of the Middle Prichard basin, prefolding and faulting. (**B**) Generalized outline of the Prichard-Burke basin, prefolding and faulting. (**C**) Generalized outline of the Revett-St. Regis basin, prefolding and faulting. (**D**) Generalized outline of the Middle Prichard, Prichard-Burke, and Revett-St. Regis basins, prefolding and faulting.

trend south of the Osburn fault by means of right lateral movement.

Anderson (1970) described two fold events in the district: the first deformation formed west-northwest trending folds, and the second event formed northwest and north-south folds. Juras (1982) presented evidence for two separate fold events, an earlier one forming north-south folds and a later one producing northwest-trending folds that were overprinted on the north-south folds throughout the district. Juras' two fold events are in the reverse order of Anderson's (1970).

A combination of both Juras' (1982) and Hobbs and others' (1965) ideas is possible. Complex folds generated by the two deformations were further deformed during movement along the Osburn and related faults. The north-south folds are best developed north of the Osburn fault, and the northwest folds are best developed south of the Osburn fault, but there is interference between the two fold sets just north and south of the fault. The original configuration of the Prichard-Burke subbasin and the Revett-St. Regis subbasin probably influenced the two fold domains. Postfolding fractures that are now veins were, in part, controlled by the orientation of the two fold sets.

How the ore moved into the veins is shown in Figure 4a-d. The stratiform ores are localized in the central, deepest part of the sedimentary basin that is folded into a major syncline called the Silver synclinorium by Bennett and Venkatakrishnan (1982). Postfolding fractures tap the infolded concentrated core (ore pod) of the stratiform orebody, and sulfides from the core fill the fractures via hydrothermal-metamorphic solutions, or possibly in some places by squeezing the sulfides directly into the fractures. Note in Figure 4c that the filled fracture now passes through the disseminated zone of the original stratiform orebody. This disseminated ore is the "blue rock" and other examples of disseminated ore described earlier.

Two ingredients are necessary to generate a Coeur d'Alene vein as outlined above: first, an ore pod, and second, a fracture. The complexities in the Coeur d'Alene district exist because we are dealing with three separate basins in three different stratigraphic horizons, each with its own mineralogically distinct ore pod. In places these basins overlap and in others they do not. There are also several sets of fractures,

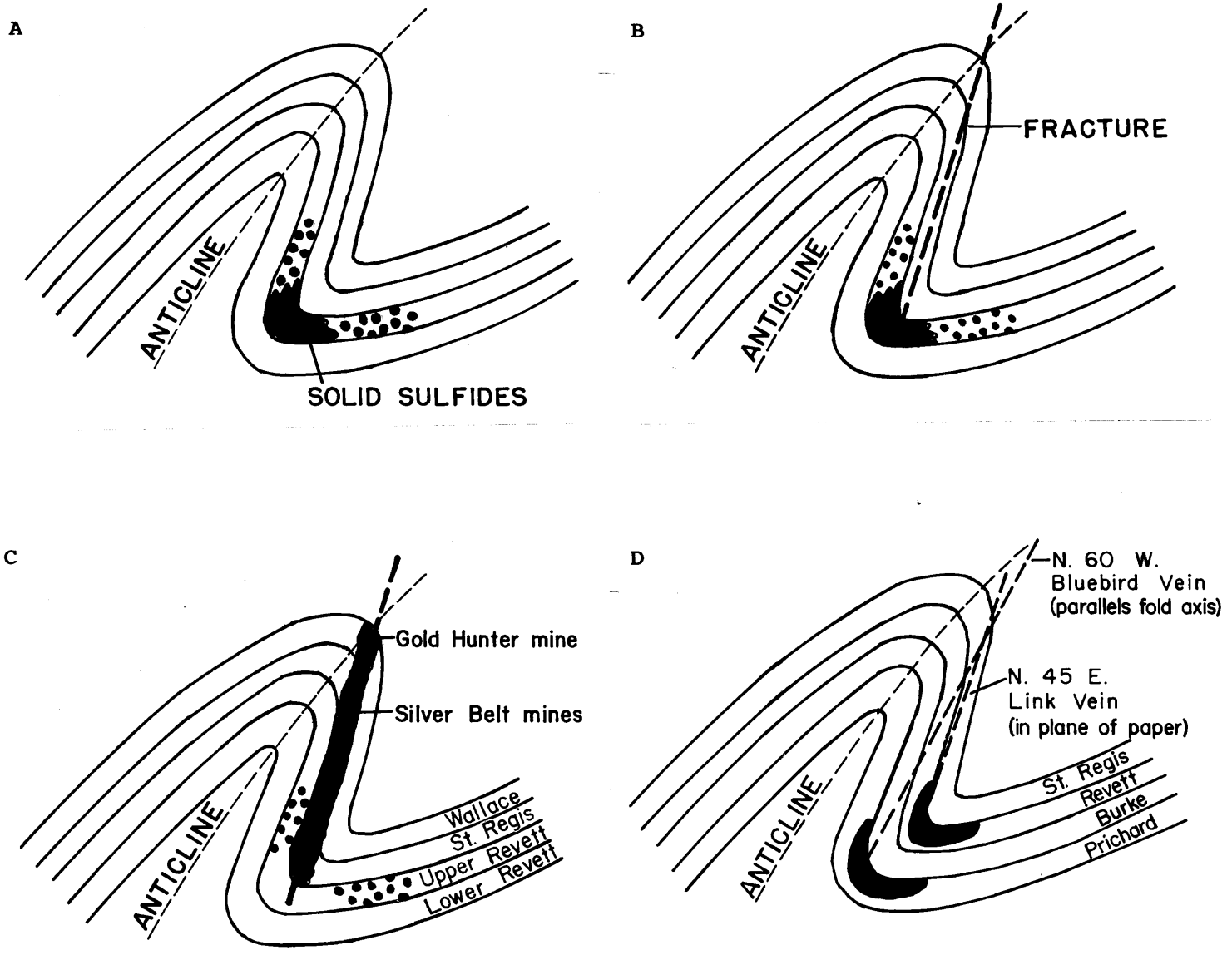


Figure 4. Mobilization of stratiform ore into veins. (**A**) Fold the basin, formed in Figure 2D. (**B**) Generate the vein fractures, postfolding. (**C**) Mobilize the ore from sulfide pod into vein fracture. Where the vein fracture is parallel to bedding, disseminated ore is preserved as "Blue-rock." If vein fracture crosscuts bedding at a sharp angle, no disseminated ore will be preserved along the veins, as only the massive sulfide ore pod is mobilized. Where fracture intersects the Wallace Formation, Gold Hunter type ore is found. (**D**) If two sets of fractures tap overlapping basins (two ore pods), a "double" orebody results, as at the Bunker Hill mine.

each capable of producing a vein if it is properly located to tap one, two, or all three of the complexly folded basins.

Five combinations of fractures and ore pods explain all of the deposits in the Coeur d'Alene district:

(1) Fractures that tap the Middle Prichard basin. These include the Pine Creek, Upper Ninemile Creek, and Sunset Peak deposits.

(2) Fractures that tap the Prichard-Burke basin. These are the Canyon Creek deposits.

(3) Fractures that tap the Revett-St. Regis basin. These are the "Silver Belt" deposits and a few other important mines.

(4) Fractures that tap both the Prichard-Burke and Revett-St. Regis basins where they overlap. This is how the deposits of the Bunker Hill mine and other mines near Wardner formed.

(5) Fractures that tap both the Prichard-Burke and Revett-St. Regis basins where the basins are adjoining but not overlapping. This is how the deposits at the Star-Morning mine formed.

MIDDLE PRICHARD DEPOSITS

(Pine Creek-Upper Ninemile Creek,
Sunset Peak, and Evolution District)

The Middle Prichard deposits are represented by mines on Pine Creek, Upper Ninemile Creek, Sunset Peak, and by small deposits in the Evolution district. The Pine Creek deposits are along Pine Creek and the East Fork of Pine Creek (Figure 1a). These mines, with the exception of the Douglas and Constitution, are spatially associated with the Middle Prichard quartzite. These deposits account for only 5 percent of the total tonnage produced in the Coeur d'Alene district, but for 10 percent of the zinc; hence their classsification as zinc mines (Table 1).

The Middle Prichard quartzite indicates a tectonic disturbance in the Belt basin. Based on the relatively limited thickness of the middle quartzite units, this disturbance was probably of shorter duration than the one at the major stratigraphic change of the Prichard-Burke transition. The fractures supplying sulfides to the Middle Prichard subbasin may have provided lesser amounts and operated for a shorter period than

Table 1. Percentage of total production through 1980 in the Coeur d'Alene mining district by stratigraphic group (Mitchell and Bennett, 1983).

Stratigraphic Group[1]	Tonnage	Silver	Lead	Zinc
Middle Prichard (includes Evolution district)	5%	1%	2%	10%
Revett-St. Regis (without Star, Bluebird, and hybrid veins)	75% (61%)	84% (80%)	76% (75%)	80% (47%)
Prichard-Burke (with Star, Bluebird, and 1/3 hybrid veins[2])	19% (33%)	14% (18%)	25% (25%)	7% (41%)
TOTALS (with Star, Bluebird, and hybrid veins)	99%	99%	103%	97%
TOTALS (without Star, Bluebird, and hybrid veins)	(99%)	(99%)	(102%)	(98%)

[1] See Figure 1 for the location of the individual mines in each group.

[2] Star, Bluebird, and one-third of the hybrid veins in the Bunker Hill mine are added to the Prichard-Burke percentages.

fractures active during the Prichard-Burke transition time. There may also have been several vents in the larger Middle Prichard subbasin, each responsible for a small ore pod. This would explain why the Pine Creek, Ninemile Creek, and Sunset Peak deposits are smaller and have a different mineralogy than the Prichard-Burke deposits.

When the Coeur d'Alene district is palinspastically reconstructed, the Pine Creek deposits and the upper Ninemile Creek-Sunset Peak deposits are brought into a north-south alignment (Figure 1b). This reconstruction is probably close to defining the Middle Prichard sediment-hosted stratiform ore zone in the original subbasin, because unfolding the relatively gently warped Pine Creek-Moon Creek anticline and the adjacent open north end of the Silver synclinorium would not separate the two areas significantly from their positions shown in the reconstruction.

Most of the veins in the Upper Ninemile Creek and Sunset Peak areas crosscut bedding at some angle, whereas veins on Pine Creek are more parallel to bedding. The mineralogy and metal content of both areas are similar, implying that regardless of vein orientation, fractures tapped a similar source and now contain similar orebodies.

With the exception of the Denver vein near the Sidney mine, all silver grades in the Middle Prichard deposits are below 2.0 ounces per ton. The low silver credit and relatively high zinc values, the spatial association with the Middle Prichard quartzite, and the relatively small size of the deposits are the main differences between these deposits and the Prichard-Burke deposits. Both the Prichard-Burke and Middle Prichard deposits contain pyrrhotite that is absent in the "Silver Belt" ores.

PRICHARD-BURKE DEPOSITS

The mines classified as Prichard-Burke transition zone deposits are in the vicinity of Burke on Canyon Creek (Figure 1a). The general trend of veins in the Prichard-Burke deposits is to the northwest. These mines were developed and some were worked out before production started from mines in the "Silver Belt" where the favorable Revett-St. Regis zone was buried much deeper. There is virtually no mention of any

stratiform ore occurring in the Prichard-Burke deposits in the early literature. The lack of any disseminated ore was undoubtedly a reason why the deposits were thought to be magmatic-hydrothermal.

Stratiform ore is lacking in the Prichard-Burke deposits because the veins in all of these deposits crosscut bedding (as do the Upper Ninemile Creek and Sunset Peak veins in the Middle Prichard). The general trend of bedding and folds, such as the Burke anticline, is north-south. The veins trend northwest, crosscutting the bedding. The vein material represents the massive sulfide core of the Sullivan-type orebody (or orebodies) that lay below this area. As shown in Figure 4c, the stratiform ore is only preserved where the veins are parallel to the bedding, as in the "Silver Belt" and in some of the Pine Creek deposits. Veins that crosscut the bedding, as in the Prichard-Burke deposits, are filled with metals from the massive core, but the stratiform ore remains in the bedding far below the veins.

The distribution of metals in the Prichard-Burke basin is crudely reflected by the production records of the mines in this group (Mitchell and Bennett, 1983). The Hercules, Standard-Mammoth, Greenhill-Cleveland (an extension of the Standard-Mammoth), Hecla, and Sherman mines had the highest silver production and probably represent a silver core of the zoned massive sulfide deposited in the basin. The Tamarack-Custer, Helena Frisco, Success, and Golconda mines contained more zinc than the other mines in this group and probably are closer to the edge of the basin. The Star mine and the Bluebird veins in the Bunker Hill, although in the Revett-St. Regis group, also represent the zinc zone of the Prichard-Burke basin.

The zinc values, although high for the Prichard-Burke deposits, are low when compared with the Middle Prichard deposits. On the other hand silver and to a lesser degree lead are more plentiful in the Prichard-Burke mines than in the Middle Prichard mines.

REVETT-ST. REGIS DEPOSITS

The Revett-St. Regis group of deposits is the most important in the district, having produced 75 percent of the tonnage, 84 percent of the

silver, 71 percent of the lead, and 80 percent of the zinc for the entire district (Table 1).

The locations of the Revett-St. Regis deposits are shown in Figure 1a. The deposits are obviously spatially related and form a single belt 18 miles long and about 3 miles across at the widest part. This is also quite likely the trace of the axis of the Revett-St. Regis subbasin prior to folding. The center of the basin is believed to have been below the Sunshine mine for the simple reason that the Sunshine has produced nearly 300 million ounces of silver, or almost one-third of the district's production.

"SILVER BELT" MINES

All of the major mines in the "Silver Belt," from the Crescent on Big Creek to the Galena mine just west of Wallace, are on the overturned north limb of the Big Creek anticline. Bennett and Venkatakrishnan (1982) noted that mineralized areas were separated by barren ground along the "Silver Belt," but were unable to explain this peridocity. The idea of deriving the vein deposits from a core zone of concentrated silver-copper mineralization, coupled with information about the Polaris fault system provided by Don Long, chief geologist for the Sunshine Mining Company, and Stan Huff, chief geologist for Asarco's Coeur d'Alene operations, may provide a partial answer.

The Polaris fault (mineralized at the Galena mine) parallels the axis of the Big Creek anticline and hence the "Silver Belt" throughout its length (Figure 5). The Silver Syndicate fault (mineralized at the Sunshine mine) may be a part of the Polaris system, as may other mineralized vein structures in other mines in the "Silver Belt." If this is true, then the northwest-trending veins in the "Silver Belt" deposits have formed in a manner depicted in Figure 4c and the Polaris fault system is the main vein-forming structure.

The axis of the Big Creek anticline is not straight, but curves with a convex bend to the north in the vicinity of the Coeur d'Alene (Mineral Point) mine. Production from this mine was relatively minor. The Coeur d'Alene mine production was small because the Polaris fault (or a related structure) cuts closer to the axis of the Big Creek anticline

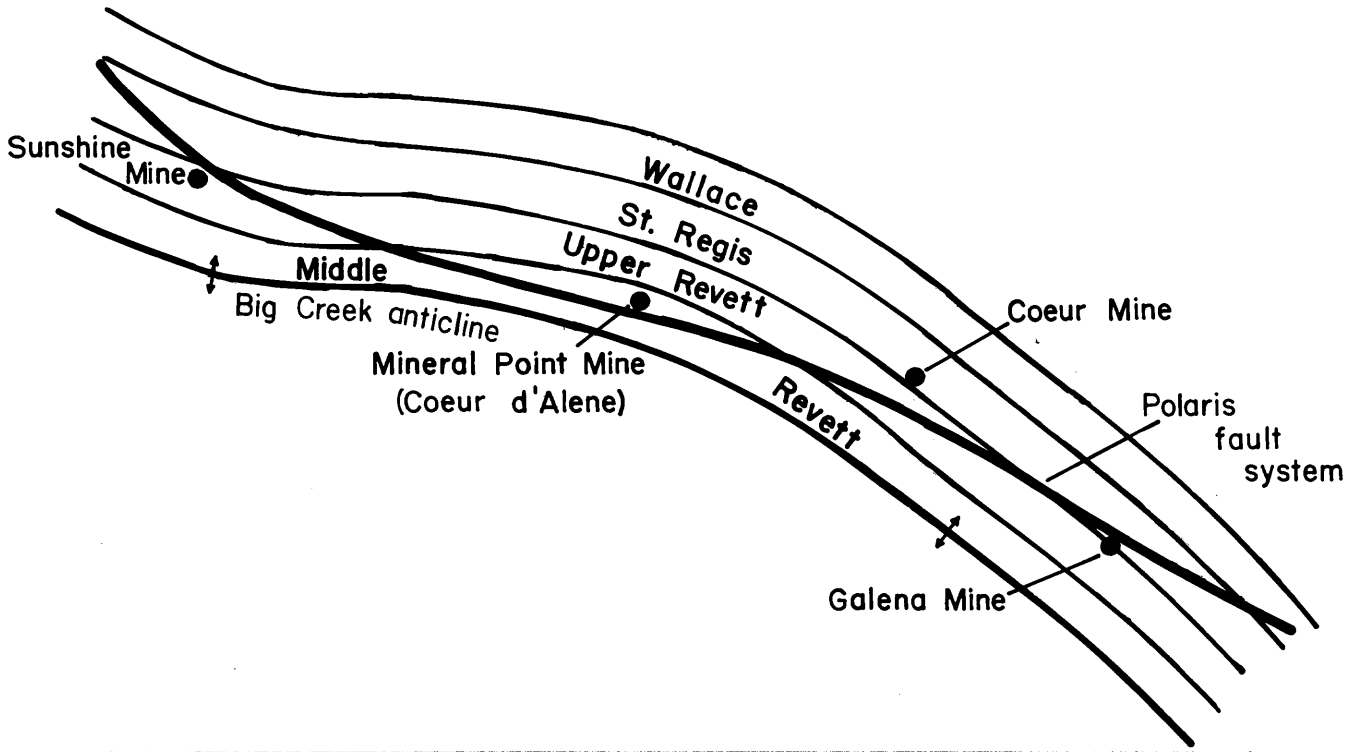


Figure 5. Generalized plan showing the axis of the Big Creek anticline, the Polaris fault system, and the location of mines on the overturned north limb of the Big Creek anticline. Note the location of major deposits where the Polaris fault intercepts the upper Revett-St. Regis horizon.

at this point than elsewhere. The Polaris fault, being closer to the anticline's axis at the Mineral Point mine, does not intercept the favorable Revett-St. Regis horizon but is below this horizon. The Polaris and related faults at the Sunshine, Coeur, and Galena mines are farther to the north of the axis of the Big Creek anticline and will intercept the favorable horizon that contains the massive ore pod. The generalized schematic for this model is shown in Figure 5. Once again, the two key elements needed for a deposit are noted: a *structure* (the Polaris fault) that intersects the *favorable horizon* (Revett-St. Regis ore pod). The Polaris fault by itself is not enough.

The Mineral Point mine is also poorly positioned for the development of northeast-trending fractures that are possibly A-C joints developed on the Big Creek anticline. Such veins are the economic heart of the Galena mine.

THE STAR-MORNING MINE (An Example of a Double Orebody Formed Across Adjacent Basins)

The Star-Morning mine is actually two mines, the Morning mine and the Star mine. Veins parallel to the Star-Morning veins were mined to the east of the main vein along the Morning East fault. A series of mineralized fractures (splits) depart from the south wall of the Morning East fault (Leep, 1982). These veins contained some of the highest silver values in the Star-Morning mine. The Morning mine produced more silver and lead than the Star, which was primarily a zinc mine.

The change from high silver and lead in the eastern part of the Morning mine to high zinc/low silver in the Star reflects the change from the Revett-St. Regis deposits in the east to the Prichard-Burke in the west. The two basins along the Star-Morning vein must be adjacent to each other (Figure 6), unlike the Bunker Hill mine where the two basins are overlapped (Figure 7). The Star fault crossed the two adjacent basins, producing the main vein system as we see it today. The split veins on the east end of the Morning mine may be tension fractures formed between the Star fault and the Commander fault, although they never reached the Commander fault (Leep, 1983, personal communication). The split vein may also be related to A-C joints. In any event, these

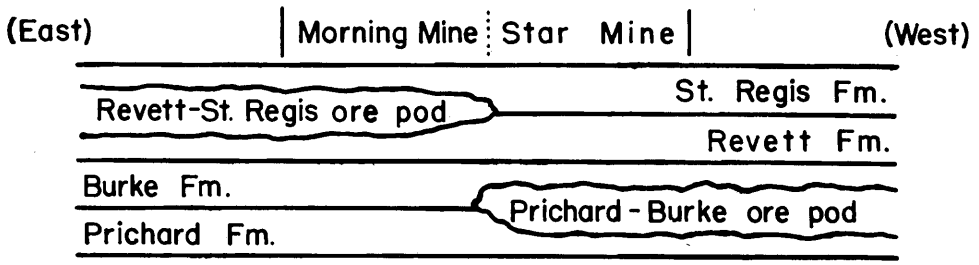


Figure 6. Generalized longitudinal section looking south, showing adjacent basins in the vicinity of the Star-Morning mine. Section is prefolding and faulting.

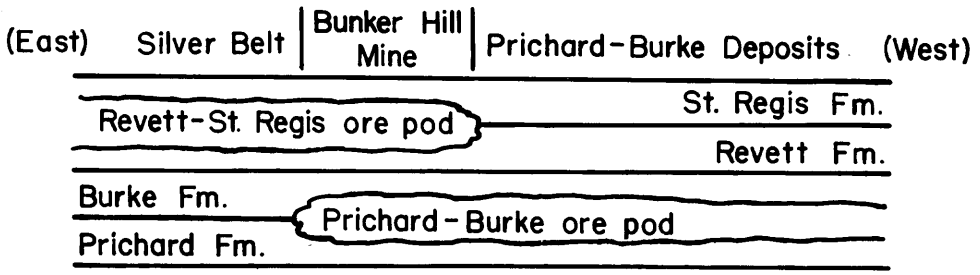


Figure 7. Generalized longitudinal section looking south, showing basin overlap in the vicinity of the Bunker Hill mine. Section is prefolding and faulting. See Figure 4D for mobilization of the two basins into two fault systems, one trending northeast (Link veins, A-C joints), and the other trending northwest (Bluebird veins, parallel to northwest axes).

split veins that produced the most silver tapped ore from further east in the Revett-St. Regis basin than the main Star-Morning vein did. The relatively high lead values in the Morning mine fit a general overall metal zoning exhibited by the Revett-St. Regis deposits that will be described later. Similarly, the high zinc content of the Star mine relates to metal zoning in the Prichard-Burke basin as previously described.

THE BUNKER HILL MINE, WARDNER DISTRICT (An Example of a Double Orebody Formed in Overlapping Basins)

The Bunker Hill mine, discovered in 1885, is the largest lead-zinc mine in the United States. There are two types of veins in the Bunker Hill mine: a northwest-trending siderite-sphalerite-pyrite vein system called the Bluebird veins, and a northeast-trending quartz-galena vein system called the Link veins. Both sets were recognized by Hershey (1916), but the understanding of how a mixture of these two types of veins relates to most of the ore in the Bunker Hill mine is more recent (Juras, 1979a, 1982).

The interrelationship between the two vein sets is that much of the lead and silver from the Bunker Hill mine is associated with the Link veins (Juras, 1979). Bluebird veins, crossed by the Link veins, produce hybrid ore consisting of lead and silver from the Link veins and zinc from the Bluebird veins (Juras, 1979).

The two types of veins in the Bunker Hill mine accommodate the mobilized stratabound concept very well. The northwest-trending Bluebird veins are similar to the Prichard-Burke deposits, having a similar northwest trend, mineralogy, and metal content (high zinc, lower lead and silver). The Link veins, on the other hand, with their high silver and lead content, are similar to the Revett-St. Regis deposits. I believe that deep-seated northwest fractures tapped the Prichard-Burke ore zone, generating the Bluebird veins (Figure 4d). These fractures extend through the entire stratigraphic section to the Revett-St. Regis horizon. The Link veins developed in A-C joints as described by Foster (1982). These fractures were shallower, and tapped the Revett-St. Regis ore zone only. The main requirement for this concept is that the Prichard-Burke basin is overlapped by the Revett-St. Regis basin, as shown in Figure 7.

The Galena mine at the southeast end of the "Silver Belt" contains two vein sets, analogous to the Bluebird veins (lead zone in the Galena) and the Link veins (silver veins in the Galena). The two vein sets at the Galena only tap the Revett-St. Regis basin and exhibit a zoning pattern expected from the metal distribution in this basin. No zinc occurs in the lead zone veins because there was no Prichard-Burke basin in this area to feed the veins.

The Bunker Hill mine is a double orebody, which explains the high silver, lead, and zinc production and large ore tonnage. The largest orebody in the Bunker Hill mine is the March. This orebody may be a good example of mixing between the two ore types because large blocks of tetrahedrite-bearing ore (Revett-St. Regis type from the Link veins) were found in the middle of massive galena and sphalerite veins (Prichard-Burke, Bluebird veins), according to Don Long, chief geologist for Sunshine Mining Company (personal communication, 1982). The tetrahedrite blocks may represent the actual mechanical mixing of Prichard-Burke and Revett-St. Regis ores on a massive scale.

OTHER REVETT-ST. REGIS DEPOSITS

The other mines in the Revett-St. Regis group with substantial production include the Lucky Friday, Page, and Dayrock. These three deposits contain important clues to the origin of the Coeur d'Alene district.

The Page mine contains two main veins, the Tony and the Curlew, with most of the production coming from the Tony vein. According to Kesten (1963), the economic minerals are sphalerite and galena with a minor gangue of quartz and ankerite. The orebody is more zinc-rich to the west and more lead-rich to the east. The relatively high zinc content of the ore suggests that the Page mine has an ore similar to the Prichard-Burke deposits, but the mine is in the Revett-St. Regis zone similar to the Star mine. It may represent another mixed orebody.

The Lucky Friday mine is north of the Bunker Hill mine on the reconstruction because the galena-quartz veins in the Lucky Friday are similar to the Link veins in the Bunker Hill mine (Figure 1b). The Lucky Friday is a substantial silver producer.

The Dayrock mine marks the northwest limit of the Revett-St. Regis subbasin in this study, although it is possible that the basin continued further to the northwest towards the Capitol Hill area that is known to contain disseminated "blue rock." Garth Crosby (1982) described the veins in the Dayrock that changed from disseminated ore to vein material along strike.

The veins in the Dayrock parallel the bedding in the Revett-St. Regis rocks, but dip opposite at a steep angle. The veins are in the north limb of a large overturned west-northwest fold (Farmin, 1961) and are cut off at depth by the Dobson Pass fault. The major fold that contains the Dayrock may also be an extension of the Big Creek anticline, and the disseminated ore described by Crosby above may represent another example of "blue rock" or minerals that are near where they were deposited at the northwest edge of the original Revett-St. Regis basin.

The veins in the Revett-St. Regis deposits have a variety of attitudes and mineralogies. The major difference between these veins and the Prichard-Burke veins is their low zinc content and lack of pyrrhotite. Four of the idiosyncrasies of the Revett-St. Regis deposits are explained as follows.

First, all of the Revett-St. Regis deposits originated from a relatively confined basin, the axis of which parallels present northwest-trending folds from the Dayrock mine to the Galena mine. This basin may be more confined than previously thought because the northwest-trending zinc veins in the Bunker Hill mine (Bluebird veins) and the high zinc content of the Page mine indicate that these veins did not tap the Revett-St. Regis ore pod. This means that the edge of the Revett-St. Regis basin was in the vicinity of these properties.

Second, the original Revett-St. Regis ore pod was zoned similarly to the Troy project, but with a higher metal content. The Morning (east end), Dayrock, Page, Bunker Hill (Link veins), and Lucky Friday mines all contain higher lead values than the "Silver Belt" mines. As noted, the Galena mine contains a series of galena veins, the "lead zone," that is not presently mined. This suggests that a lead halo surrounded the Revett-St. Regis ore pod that is now concentrated in veins located at the periphery of the basin (that is, the northwest and southeast ends of

the basin). These lead zones also correlate in part with the area of disseminated "blue rock" that would also be near the edge of the basin. A considerable lead component must have been in the northwest part of the basin to account for all of the lead in the Link veins and the Dayrock, Lucky Friday, and Morning mines; the mines in this part of the basin can probably be considered a subgroup of the Revett-St. Regis deposits.

Third, lead is not the only indication of metal zoning. The high values for silver start at the Dayrock mine and extend to the southeast through the "Silver Belt" where copper-silver mineralization is more important than lead-silver mineralization. Likewise, the split veins at the east end of the Morning mine were the richest in silver, again indicating that the silver-rich part of the original basin lies in this direction.

Finally, all of the Revett-St. Regis deposits either are in northwest-trending structures related to northwest-trending folds or are in northeast-trending veins. The northwest-trending veins have the same strike as the enclosing sediments although different dips. The northeast veins are probably related to A-C joints that are at right angles to the fold axes (Foster, 1982) or are the result of interference patterns between two fold sets (Juras, 1983). Mines with northwest-trending veins include the Dayrock, Star-Morning, Gold Hunter (although in the Wallace), Sunshine, Coeur, and Galena (lead zone). Examples of veins that trend northeast include the Link veins (Bunker Hill), the Lucky Friday vein, the Split veins in the east end of the Morning, and the Silver vein at the Galena. The veins in the Coeur, although apparently northeast-trending, may be due to refraction of the vein as it crosses from argillite (northwest trend) to quartzite (northeast trend) and back to argillite (northwest trend).

THE GOLD HUNTER PROBLEM

The Gold Hunter mine is generally passed over quickly in a discussion of the Coeur d'Alene district, because all production from this mine is

from the Wallace Formation and the mine therefore does not fit into anyone's classification. Shenon and Full (1948) described the ore occurrences as follows:

> *The ore at the Gold Hunter is in ill-defined and ramified lenses that lie within an extensive zone of mineralization. The mineralized zone is over 2,000 feet long and, in places, is 250 feet wide, whereas the ore bodies contained in it range from very small discontinuous stringers to shoots more than 300 feet long and 40 feet wide. The mineralized zone and the ore bodies strike nearly east-west and have essentially vertical dips. The enclosing Wallace beds have nearly the same attitudes, although the ore in places can be seen cutting across bedding.*

The above description is similar to ore pods in the Wallace Formation above the Sunshine mine that were mined by the original discoverers.

The ore occurrences in the Wallace Formation are explained by the present model. The pods are probably in vertical extensions of the vein fractures that are heavily mineralized in the more favorable Revett-St. Regis horizon (Figure 4c). The Wallace is incompetent in comparison with the Revett. Any tectonic movement would quickly seal off the fractures in the easily deformed Wallace, leaving isolated ore pods without any sign of a feeder system.

SUMMARY OF EVENTS LEADING TO THE FORMATION OF THE COEUR D'ALENE MINING DISTRICT

The debate over the sequence of events in the formation of the Coeur d'Alene deposits and the timing of these events is as controversial as most other aspects of the district's origin. In keeping with the practice of other geologists who have grappled with the district's problems, the following scenario is presented as a possibility, with the understanding that it will change as new data become available.

(1) Coeur d'Alene mineralization began with the initiation of Belt sedimentation. The first sediments deposited were the deep-water, lower Prichard argillites and siltites.

(2) A change in the tectonics of the Prichard basin or source area is indicated by the abrupt change to the Middle Prichard quartzite. Outpourings of metals (submarine exhalations) into

subbasins in the Belt basin occurred from vents associated with the ancestral Lewis and Clark line, a major intracontinental rift system. Several vents may have operated at various times, giving rise to more than one mineralized area.

(3) Following metal deposition, the basin returned to quiescent, deep-water turbidite sedimentation of upper Prichard argillite and siltite.

(4) A dramatic change in basin or source tectonics is recorded by the major change from Prichard sedimentation to Burke. Major outpouring of metals into a subbasin developed a Sullivan-type orebody centered near present-day Burke. The magnetite-chlorite halo around the Gem stocks may mark the vent area for this deposit. If so, then this vent was intruded by the main Gem stock.

(5) Sedimentation continued with the depositions of the Burke and Revett Formations with an obvious change from deep-water sediments in Prichard time to a shallower water environment.

(6) The Revett-St. Regis type of mineralization developed. The source of the metals is debatable; however, the metals could have come from the Revett, the St. Regis, an outside source area, or from some type of submarine exhalative system. Deposits were probably altered and in part concentrated by diagenesis. The center of the largest deposit was located below the Sunshine mine.

(7) Deposition of the St. Regis Formation and other younger Belt units continued. Belt sedimentation closed with the onset of the Kootenay orogeny at about 800 m.y.

(8) Belt sediments were folded into broad north-south oriented anticlines and synclines (Juras, 1982). Ore pods are infolded as well. The major domain of north-south folds is centered on Burke, and these folds may have inherited the north-south trend from the shape of the original Prichard-Burke basin.

(9) Belt sediments were then folded into tight northwest-trending anticlines and synclines that folded earlier north-south folds (Juras, 1982). The northwest folds are more highly developed

south and just north of the Osburn fault. The northwest folds may have inherited the northwest trend from the shape of the original Revett-St. Regis subbasin. Most intense deformation is now localized in the Silver Synclinorium that also contains both the Revett-St. Regis and Prichard-Burke ore pods. The synclinorium is folded very tightly between the Bunker Hill mine and the National and Snowstorm mines to the northeast. It is possible that 16 kilometers or more of the Wallace Formation is now infolded in the most intensely deformed core of this synclinorium that is now only 5 kilometers wide. The synclinorium opens to the northwest and to the southeast from this deformed central area. The unique structural setting of the Coeur d'Alene district as compared with the rest of the Belt basin is essentially complete.

(10) At the close of northwest folding, major reverse faults such as the Big Creek-Alhambra-White Ledge-Black Cloud fault system formed as a result of compression. These faults are not the structures that are now veins.

(11) Further movement within the Lewis and Clark zone starts the complex chain of events that generate the Placer Creek, Osburn, and Thompson Pass strike-slip faults. Normal faults generated by these movements are described by Bennett and Venkatakrishnan (1982). Northwest-trending fractures were in part controlled by northwest folds. Northeast fractures (exploiting A-C joints) were a result of brittle deformation as the original folds reoriented along the Osburn fault (Foster, 1983). Some northeast fractures may have formed in response to interference patterns of the two fold sets (Juras, 1979).

(12) The northwest and northeast fractures filled with sulfides where these fractures tapped the infolded ore pods. Variations in the types of orebodies are described in this paper. The veins were probably filled during a period of high heat flow when hydrothermal systems would operate. The required heat flow was related to regional metamorphism.

Emplacement of the veins during metamorphism as suggested by Leach and Hofstra (1983) and Landis and Leach (1983a and 1983b) eliminates many of the problems in explaining the lack of mineral zoning over the great vertical extent of the veins.

(13) Postmineral faulting such as the Dobson Pass fault and others complicates the picture. Final right lateral movement along the Osburn fault separates the areas north and south of the fault by 30 kilometers.

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