Ore Deposits of the Coeur d'Alene District Shoshone County, Idaho

GEOLOGICAL SURVEY PROFESSIONAL PAPER 445

Ore Deposits of the Coeur d'Alene District Shoshone County, Idaho

By VERNE C. FRYKLUND, JR.

With a section on THE BLEACHED ROCK IN THE COEUR D'ALENE DISTRICT

By PAUL L. WEIS

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Part of a comprehensive study of the Coeur d'Alene mining district, Idaho

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ORE DEPOSITS OF THE COEUR D'ALENE DISTRICT, SHOSHONE COUNTY, IDAHO

By Verne C. Fryklund, Jr.

ABSTRACT

The Coeur d'Alene district of this report is that area in northern Idaho between the Montana State line and longitude 116°17′, and between latitudes 47°26′15″ and 47°33′45″.

The country rock of the area consists of the Prichard, Burke, Revett, St. Regis, Wallace, and Striped Peak Formations of the Precambrian Belt Series. These formations are composed of fine-grained quartz-rich rocks that have been mildly regionally metamorphosed and which, in consequence now belong to the green schist facies. The ubiquitous sericite was oriented during the folding and metamorphism and the rocks now consist of quartzose slate, sericite phyllite, sericite quartzite, and in a few areas, schistose quartzite and sericite schist.

Igneous rocks of the area include monzonite stocks and related monzonite dikes, which were probably intruded at the same time as the Idaho batholith, and biotite lamprophyre, diabase, and porphyritic hornblende-augite-olivine-dikes, the latter perhaps varieties of the diabase dikes. The two stocks are part of a line of northeastward-striking intrusives that apparently lie along a major fracture. This fracture is probably one of the controlling factors in the origin of the Coeur d'Alene district.

Several sets of faults can be recognized; there is no certainty that any are older than the shear zones that contain ore deposits, but the great strike-slip faults—the Osburn and Placer Creek faults—have offset mineral belts.

Idaho, within which the Coeur d'Alene district is the only important mining area, has ranked second in lead and in zinc production for many years. The first recorded production from the Coeur d'Alene district proper was in 1884; through 1957, 572,295,521 ounces of silver, 88,532 tons of copper, 6,316,326 tons of lead, and 1,945,172 tons of zinc have been produced. The total value through 1957 is $1,703,195,505.

The Coeur d'Alene district is the ore-bearing part of the Great Coeur d'Alene mineral belt of Idaho and Montana. This mineral belt is about 95 miles long and extends from the vicinity of Coeur d'Alene, Idaho, to the vicinity of Superior, Mont. It is a part of the Lewis and Clark line of Billingsley and Locke.

The main period veins are clustered in two groups: One is centered around the towns of Burke and Mullan, north of the Osburn fault; the other lies south of the Osburn fault and centers around Kellogg but extends eastward almost to Wallace. The productive veins, with two minor exceptions, lie in belts of slight disturbance or shearing, which have been designated as mineral belts. The mineral belts north of the Osburn fault are: Sunset, Carlisle-Hercules, Tamarack-Marsh subbelt, Rex-Snowstorm, Success subbelt, Gem-Gold Hunter, Dayrock subbelt, and Golconda-Lucky Friday. All, except the Golconda-Lucky Friday, strike about N. 65° W. Mineral belts south of the Osburn fault are: Page-Galena, Moe-Reindeer Queen, and Pine Creek belts, and Douglas subbelt. The Page-Galena belt is parallel to the Golconda-Lucky Friday belt. The Moe-Reindeer Queen and Pine Creek belts parallel the other belts north of the Osburn fault. Reconstruction of the major anticline of the district as it existed before movement on the Osburn, Placer Creek, and Dobson Pass faults brings the two groups of mineral belts together.

The ore deposits of the district are replacement veins of simple mineralogy. Six periods of mineralization, ranging from Precambrian to Tertiary in age, are recognized. The oldest mineral deposits are zones of disseminated arsenopyrite; they are older than uraninite-bearing veins that have been dated as Precambrian. Uraninite-pyrite veins have been discovered in most of the mines of the Page-Galena mineral belt, but there has been no uraninite production. The productive galena-sphalerite- and tetrahedrite-bearing veins of the district are younger than the monzonite stocks that have been dated as Late Cretaceous in age. These veins formed during what has been designated as the main period of mineralization. As demonstrated by crosscutting relationships, there was a younger, almost nonproductive, period of base metal mineralization that was probably Tertiary in age. A second Teritiary period of mineralization is represented by stibnite veins; in addition, a single mine contains scheelite-stibnite veins. The second Tertiary period veins are older than the diabase dikes. A third Tertiary period of mineralization is represented by dolomite-arsenopyrite-gold veins that are younger than the diabase dikes.

The main period veins formed in stages, though generally not all stages are represented in any one vein. The silicate stages are the oldest and probably formed at the highest temperatures; biotite, garnet, and amphiboles, principally grunerite, were formed in that order. During a succeeding carbonate stage, siderite and then ankerite were deposited. In some mines a small amount of barite was deposited, probably after the carbonates; in some nonproductive veins, barite is a major mineral. Minerals of the iron oxide stages were deposited next. Specular hematite is a minor constituent of productive veins; the later magnetite is a major constituent of many of the veins north of the Osburn fault. Sulfide stages followed in the normal sequence, and structural adjustments demonstrably followed the deposition of minerals of particular stages. Pyrrhotite was the first abundant sulfide to be deposited; it is a major gangue mineral in some mines of all the mineral belts except the Golconda-Lucky Friday, Page-Galena, and Moe-Reindeer Queen. Sphalerite, tetrahedrite, and galena, deposited in that order, are present in almost all the productive veins but in widely varying proportions. Lead-antimony and silver-antimony sulfides, both in minor amounts, were the last sulfides deposited in the main period of mineralization.

Distribution patterns for gangue minerals and ore metals have been plotted. Orderly distribution patterns can be recognized

for minerals of the various stages. Though it would seem that new terms might be justifiable, it would be most simple to designate all orderly distribution patterns as zoned (or zoning), using a prefix to indicate the pattern and perhaps the degree of order involved. In the Coeur d'Alene district, concentric zoning (the classic zoning pattern), linear zoning, and asymmetric planar zoning can be recognized. Districtwide, there is compound zoning. The silicates within the veins are zoned concentrically around the stocks, and they extend well beyond the metamorphic aureoles of the stocks. Magnetite is also zoned concentrically around the stocks, but the older hematite has a pattern not related to the stocks. Within one mineral belt the carbonates have a linear zoning pattern, and regionally also they have a linear pattern. The ore metals in several of the mineral belts have linear zoning patterns. Asymmetric planar zoning of the ore metals can be recognized in the two groups of mines north and south of the Osburn fault. The two asymmetric planar patterns merge when the pre-Osburn fault situation is reconstructed.

The distribution patterns of the vein minerals suggest that material now in the veins came from three different sources. The silicates and the magnetite are zoned concentrically around the Gem stocks, and these minerals probably came from the roots of the exposed stocks. This source has been designated in this paper the "shallow point" source. The Great Coeur d'Alene mineral belt is characterized by veins that contain massive carbonate, specular hematite, and barite. It is suggested that all these veins were fed from the same source. This source has here been designated the "deep linear" source, and though it may be the top of a cooling batholith, it appears to be distinctly different from the shallow point source.

Commercial concentrations of sulfides in this great mineral belt are largely restricted to the Coeur d'Alene district, where there is one of the world's great concentrations of base metals. The sulfides obviously did not come from the deep linear source, for elsewhere at best it provided only small amounts of sulfides, and the asymmetric planar zoning of the ore metals within the district has no discernible relationship to the monzonite stocks.

Umpleby and Jones (1923) believed that the location of the Coeur d'Alene district is controlled by the intersection of the great mineral belt and a fracture now indicated by the line of stocks. A "deep point" source, not magmatic in nature, probably was tapped at the intersection of the two lines. Geologic evidence shows that the main period veins are younger than the stocks, which are Cretaceous. The isotopic composition of the galena lead is that of "ancient" lead, which could not have been derived from an igneous source in Cretaceous time. A possible explanation is that the lead, and the other ore metals, came from a deep sulfide-rich and uranium- and thorium-poor level of the earth's mantle in Cretaceous time; an alternative, and less acceptable, explanation is that the lead was separated from a normal magmatic source in Precambrian time but was not brought into the upper part of the crust until Cretaceous time.

The main period, and other, veins were formed by a series of replacements. Valuable sulfide minerals may have directly replaced country rock or may have been the last of a long series of replacements. The ore sulfides, in a very restricted volume, may have replaced a silicate, a carbonate, magnetite, and other sulfides.

Primary mineral variation (zoning) can be demonstrated conclusively in only one ore shoot, in the Tony vein of the Page mine. Here there is a change from galena dominance at the top to sphalerite dominance at the bottom, but even here a galena root extends to the lowest level of the mine. The Hercules vein may show a change from pyrite dominance at the top to pyrrhotite dominance at the bottom. Examples of vertical zoning mentioned by Ransome and Calkins (1908) were not substantiated by Umpleby and Jones (1923) or during this study.

In one ore shoot, in the Star mine, the iron content of sphalerite in the upper part is higher than in the lower part. Two ore shoots of the Highland-Surprise mine appear to show reversed relations. Where determined, minor elements showed no variation in amount with position in the ore shoots.

No criteria can be presented that will permit a prediction as to where an ore shoot will bottom.

Bleaching is a common and widespread form of wallrock alteration in the Coeur d'Alene district. Bleached rock, characterized by notably lighter colors as compared with adjacent unbleached rock, are associated with ore deposits in many places and have been used as a guide to prospecting since about 1936. The exact nature of the bleaching process has been variously described as sericitization and as alteration involving removal or change of pigmenting minerals.

Petrographic study of bleached and unbleached rocks shows abundant sericite in both rocks. Evidence of potassium metasomatism is absent. Rather, the principal difference between bleached and unbleached rocks is in the amounts of pigmenting minerals—chiefly hematite and green chlorite—present. Hydrothermal solutions with a pH of 6 to 8 and a temperature of 130° to 175°C could have produced the alteration of the bleached zones without necessarily adding or subtracting any significant quantity of any element. These solutions are, however, very different from those envisioned as the transporting fluids that created the ore deposits. No explanation of this difference can be offered at present.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Coeur d'Alene mining region centers around the towns of Kellogg, Wallace, Burke, and Mullan in Shoshone County in the panhandle of northern Idaho (fig. 1). The nearest large city is Spokane, Wash., 75 miles west of Kellogg by U.S. Highway 10. The area is served from the west by a branch of the Union Pacific Railroad, which terminates at Burke, and from the east by a branch of the Northern Pacific Railway, which terminates at Wallace. The various parts of the area are linked by all-weather roads.

Most of the mining regions of the Western States are composed of legal entities called mining districts. The Coeur d'Alene mining region includes several of these districts, but the Coeur d'Alene mining district proper lies outside the area discussed in this report. Inasmuch the Coeur d'Alene mining region is larger than the area discussed in this report, the area under discussion should be designated simply as the "Coeur d'Alene district"; this usage conforms to local custom.

The Coeur d'Alene district consists of the area shown on the Smelterville and vicinity, Kellogg and vicinity, Wallace and vicinity, Mullan and vicinity, and Pottsville and vicinity quadrangle maps. This area includes

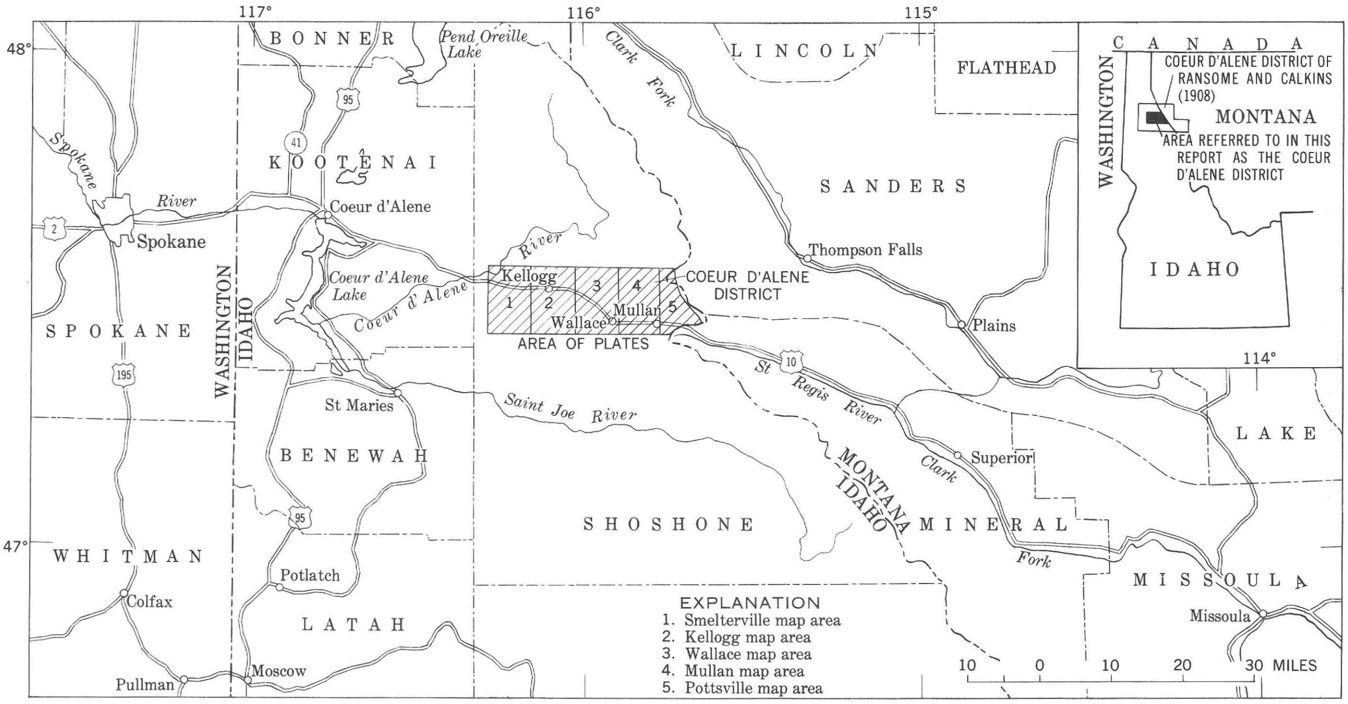

FIGURE 1.—Map showing the location of the Coeur d'Alene district, Shoshone County, Idaho.

parts of the Beaver, Hunter, Lelande, Placer Center, and Yreka mining districts.

SCOPE AND WORK

This report is a part of a comprehensive study by the U.S. Geological Survey of the Coeur d'Alene district. The general geology of the district and its regional setting will be described by S. W. Hobbs and others, in a report currently being prepared. The present report is concerned with the mineralogy of the ores, stages in the formation of the veins, distribution patterns of the various minerals, origin of the veins, wall-rock alteration, and the grosser structural controls of the ore deposits.

I began work on the ore deposits on a half-time basis in 1952. From July 1953 to July 1954 work was on a full-time basis. Work continued from July 1956 to May 1959, though fieldwork was halted in September 1958. P. L. Weis worked on the bleached rock from September 1958 to May 1959.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the wholehearted cooperation of all the mining companies in the Coeur d'Alene district. A list of individuals who have been of help would include the managers, superintendents, geologists, foremen, and many shift bosses and miners.

I am especially indebted to the geologists, engineers, and superintendents who accompanied me underground as guides, instructors, and, not infrequently, as opponents in debate. These men are: Rollin Farmin, Garth Crosby, Robert Miller, and Phillip Miller of Day Mines, Inc.; Robert Sorenson, Murl Hutchinson, and Herbert Harper of the Hecla Mining Co.; Philip Conley, Norman Keston, Robert Sargent, Donald Springer, Troy Tower, and Norman Visness of the American Smelting and Refining Co.; Robert O'Brien and Tibor Klobusicky of the Highland-Surprise Consolidated Mining Co.; Ray Lomas of Sunset Mines, Inc.; Ben Dickerson, Sidney Mining Co.; Alvin Lenz, Donald Long, James Younger, Robert Mize, and Robert Muhs of the Bunker Hill Co.; and James Coulson, James Talmadge, and Glen Phillips of the Sunshine Mining Co.

In addition, I would like to thank Henry L. Day of Day Mines, Inc., for the loan of polished surfaces and thin sections.

HISTORICAL SUMMARY AND PRODUCTION RECORD

The history of the Coeur d'Alene mining region prior to 1905 is summarized from the account of Ransome and Calkins (1908, p. 78 ff.).

The first known prospecting in the region was done by Thomas Irwin; in 1878 he located a quartz claim in Gold Run gulch just west of Mullan. In 1882, gold placers were discovered in the Murray district. Widely separated lead-silver veins had been recognized in the Coeur d'Alene district proper by 1884 and exploitation of what became the Hecla, Tiger-Poorman, and Polaris

TABLE 1.—*Production of silver, copper, lead, and zinc from the Coeur d'Alene district, Idaho, between 1886 and 1957*

[1886–1903, Ransome and Calkins (1908); 1904–23, U.S. Geological Survey Mineral Resources of the United States (annual volumes); 1924–31, U.S. Bureau of Mines Mineral Resources of the United States (annual volumes); 1932–57, U.S. Bureau of Mines Minerals Yearbooks. Total entries are from U.S. Bureau of Mines Minerals Yearbook for 1957; they include subsequent changes of yearly summaries and are not necessarily the total of the column above; totals for silver, lead, and total value include production for 1884 and 1885]

Year	Producers	Ore	Silver	Copper	Lead	Zinc	Total value
		Short tons	*Ounces*	*Pounds*	*Tons*	*Pounds*	
1886			116,246		1,500		$436,335
1887			340,000		5,980		1,022,996
1888			554,000		8,000		1,438,227
1889			1,095,265		17,500		2,532,978
1890			1,499,663		27,500		4,132,506
1891			1,825,765		33,000		4,868,356
1892			1,195,904		27,839		3,538,684
1893			1,963,561		29,563		4,258,621
1894			2,343,314		30,000		3,816,026
1895			2,471,300		31,000		4,016,049
1896			3,163,657		37,250		4,703,971
1897			3,756.212		57,777		6,764,010
1898			3,521,982		56,339		6,565,287
1899			2,737,218		50,006		6,263,404
1900			5,261,417		81,535		10,588,707
1901			4,339,296		68,953		8,731,662
1902			5,033,928		74,739		8,847,552
1903			5,471,620		103,691		11,885,078
1904	27	1,410,245	6,143,001	1,424,400	112,584		13,592,014
1905	37	1,526,927	7,292,986	5,225,606	126,928	144,000	17,198,856
1906	36	1,622,975	7,944,338	6,393,940	126,011	2,054,998	21,133,963
1907	33	1,541,670	7,266,862	7,199,648	114,721	6,948,655	18,888,203
1908	43	1,551,680	6,364,552	9,042 876	102,069		13,220,853
1909	41	1,569,332	6,201,157	8,906,944	106,779	1,280,000	13,724,065
1910	39	1,639,781	6,703,080	6,018,688	109,879	5,526,717	14,416,910
1911	50	2,004,487	7,383,899	2,926,551	127,419	8,310,435	16,306,680
1912	52	2,108,037	7,558,314	4,386,403	123,276	13,800,181	18,313,604
1913	48	2,289,226	9,337,109	5,097,894	148,370	21,415,565	20,767,410
1914	38	2,152,268	12,178,194	4,242,662	169,849	41,523,383	22,728,903
1915	52	2,255,475	11,158,955	1,941,296	164,199	69,685,003	30,119,424
1916	63	2,516,325	11,639,841	2,370,610	178,117	86,238,283	44,424,716
1917	66	2,522,127	11,241,126	2,876,911	186,004	77,724,221	50,054,297
1918	52	1,918,052	8,447,219	2,706,535	139,307	43,661,314	33,115,903
1919	38	1,308,063	4,815,200	1,474,642	83,833	15,994,229	15,900,815
1920	39	1,822,488	6,386,663	571,119	118,105	27,932,326	28,347,791
					Pounds		
1921	31	1,379,178	4,986,263	404,615	189,086,518	33,463	13,720,730
1922	36	1,249,536	4,690,097	341,141	182,432,281	4,065,810	15,147,542
1923	38	1,553,011	6,117,621	599,555	228,852,538	27,952,749	23,297.547
1924	35	1,596,280	6,695,830	655,706	236,653,990	15,307,617	24,677,235
1925	48	1,714,159	6,701,747	620,444	241,711,973	31,155,037	28,272,585
1926	58	1,850,519	6,952,074	962,447	257,667,986	52,533,485	29,097,421
1927	49	1,919,309	8.256,126	1,306,773	283,896,615	52,262,188	26,091,273
1928	42	1,949,980	8,513,048	1,044,105	278,551.953	47,329,671	24,792,445
1929	44	1,971,580	8,776,726	1,320,700	283,115,336	86,092,294	28,439,351
1930	38	1,794,929	8,831,461	1,569,882	258,621,960	66,290,478	19,728,887
1931	30	1,239,592	7,003,541	1,044,885	195,541,151	37,868,650	10,809,561
1932	21	912,664	6,547,674	1,129,952	143,010,500	20,502,267	6,831,168
1933	?	1,052,889	6,762,537	1,544,343	147,851,459	41,916,167	9,729,460
1934	24	1,071,059	7,062,640	1,472,275	140,662,811	49,597,628	12,159,340
1935	26	1,227,889	9,894,300	1,975,546	156,627,454	62,107,700	16,369,235
1936	25	1,454,987	13,740,222	2,629,511	173,267,391	88,620,840	23,370,963
1937	49	1,731,801	18,457,726	3,888,157	193,010,644	94,140,000	32,382,311
1938	43	1,514,278	17,325,379	3,765,795	164,547,979	63,874,125	22,346,313
1939	34	1,611,068	15,204,934	4,136,115	163,397,979	80,129,962	22,805,024
1940	49	1,917,235	15,616,852	5,359,000	191,218,460	125,896,000	29,444,265
1941	58	2,051,390	14,678,356	5,957,000	191,057,000	136,642,000	32,398,932
1942	49	2,327,417	12,977,287	5,986,000	212,947,000	156,625,000	38,880,253
1943	47	2,270,385	10,302,840	3,974,000	179,626,000	159,268,000	38,594,728
1944	47	2,765,483	8,669,371	2,578,000	153,625,000	170,454,000	38,307,297
1945	49	2,794,208	7,115,646	2,036,000	126,860,000	156,059,000	34,258,050
1946	56	2,559,636	5,655,672	1,619,000	113,096,000	134,858,000	33,673,731
1947	61	2,957,143	9,234,906	2,624,000	146,120,000	158,502,000	49,226,932
1948	65	3,165,780	10,598,338	2,775,000	165,174,000	167,601,000	62,168,955
1949	61,	2,282,614	9,146,146	2,341,000	148,304,000	148,739,200	50,699,924
1950	57	2,542,169	15,056,131	3,791,000	189,394,000	172,205,000	64,555,947
1951	67	2,393,939	13,639,808	3,748,000	141,140,000	149,978,000	65,058,887
				Tons	*Tons*	*Tons*	
1952	58	2,327,536	13,752,081	1,862	67,330	70,316	58,459,368
1953	43	1,788,426	13,636,680	2,100	69,885	68,650	47,729,814
1954	37	1,630,250	14,898,699	2,566	64,812	58,736	45,515,124
1955	41	1,637,121	12,984,323	2,637	59,820	50,527	44,036,867
1956	36	1.674,781	12,663,214	2,889	60,221	46,738	45,729,474
1957	31	1,701,442	14,397,771	3,473	67,125	54,825	47,117,496
Total		101,332,344	572,295,521	[1] 88,532	[1] 6,316,326	[1] 1,945,172	1,703,195,505

[1] Tons.

mines had started. In 1885 the Bunker Hill deposit was discovered. Production from the district has been continuous since that time.

In 1905 the Success Mining Co. built a 150-ton jig mill to recover sphalerite. The first flotation plant was installed in 1911 at the Morning mine (Bell, 1912, p. 108). Production of lead and zinc reached new highs during World War I, and stibnite veins also were mined. According to Shenon and McConnel (1939, p. 2), production from sideirte-tetrahedrite veins of the Page-Galena mineral belt began in 1904 and continued on an increasing scale until 1937, when the great tetrahedrite ore shoot of the Sunshine vein came into production. The discovery of this ore shoot started intensive exploration for tetrahedrite veins that continues to the present time. Since 1937, the Coeur d'Alene district has been the major silver-producing district in the United States.

Production records, first kept in 1904, show the district has produced over a million tons of ore each year since, and during periods of war and just after World War II production exceeded two million tons of ore annually. Many mines have been exhausted, but production has remained at high levels because of the discovery of new deposits and of new veins and ore shoots in old mines.

Future extensive exploration in the district probably will continue to be on permissive targets rather than on outcropping veins. The size of permissive targets that have been inadequately or not at all explored suggests that new deposits will continue to be discovered. Subject to the influence of economic factors, production from the Coeur d'Alene district should continue to be over a million tons of ore per year for many years.

Production totals of silver, copper, lead, and zinc from 1886 through 1957 are given in table 1; a small part of the production of these metals has come from the Murray district. Figures for gold production are not given because production from the Murray district is not separated from that of the Coeur d'Alene district in available tabulations.

RÉSUMÉ OF THE GENERAL GEOLOGY

For the résumé I have drawn on the reports of Ransome and Calkins (1908), Umpleby and Jones (1923), and the following geologic maps placed on open file by the Geological Survey: the Twin Crags quadrangle, by Good and Campbell, 1950; the Smelterville and vicinity quadrangle, by Campbell, 1953; the Kellogg and vicinity quadrangle by Campbell and others, 1953; the Wallace and vincinity quadrangle, by Bowyer, Rainey, and others, 1954; the Mullan and vicinity quadrangle, by Griggs and others, 1953; and the Pottsville and vicinity quadrangle, by Wallace and others 1952. Petrographic observations and synthesis of the data are my own.

The rocks of the Coeur d'Alene district consist of formations of the Precambrian Belt Series, of monzonite stocks and related dikes of Cretaceous age, and of lamprophyre and diabase dikes of probable Tertiary age. In the Coeur d'Alene district the Belt Series is subdivided (Ransome and Calkins, 1908, p. 23 ff.) into, from bottom to top, the Prichard, Burke, Revett, St. Regis, Wallace, and Striped Peak Formations. These formations have been regionally metamorphosed and are in the green schist facies. Petrographically these rocks are rather similar and consist, in order of abundance, of quartz, sericite, rock fragments, feldspars, and heavy accessory minerals. Exceptions are parts of the Wallace Formation that contain sedimentary carbonate minerals. In isolated areas, regional metamorphic chlorite and biotite exist in the other formations. The characteristics of the Belt Series are shown in table 2.

In Late Cretaceous time, stocks and related dike rocks intruded the Belt Series. Petrographically the stocks vary from quartz syenite to quartz monzonite; it is not clear whether the bulk of the stocks is granodiorite or quartz monzonite.

The other dike rocks of the district have been classed as lamprophyres and diabases. Age relations of the two rock types are not known, although A. L. Anderson

TABLE 2.—*Characteristics of Belt Series, Coeur d'Alene district, Idaho*

Formation	Mineral composition (in order of abundance)	Rock type (in order of abundance)	Ore-bearing	Color
Striped Peak	Not studied	Not studied	No	Dominantly purple red.
Wallace	Quartz, sericite, carbonate, rock fragments, feldspar, magnetite, heavy accessories.	Slate, sericite phyllite, calcareous slate and phyllite, sericite quartzite.	Yes, but limited	Light yellow gray to dark gray.
St. Regis	Quartz, sericite, rock fragments, carbonate, hematite, feldspar, magnetite, heavy accessories.	Quartzose slate, sericite phyllite, sericite quartzite.	Yes	Dominantly purple red.
Revett	Quartz, rock fragments, sericite, feldspar, magnetite, heavy accessories.	Sericite quartzite, quartzose slate, sericite phyllite, quartzite.	Yes	Light gray to white.
Burke	Not studied. Apparently similar to Revett	Quartzose slate, sericite quartzite	Yes	Light yellow gray to medium gray.
Prichard	Quartz, sericite, rock fragments, feldspar, magnetite, heavy accessories, fine-grained sulfides and graphite(?).	Quartzose slate, sericite quartzite, sericite phyllite, quartzite.	Yes	Light gray to dark gray.

(1940, p. 24) has suggested that similar dikes west of the district are genetically related. Both dike types contain olivine or pseudomorphs after olivine, and these dikes may have come from the same magma as the Columbia River Basalt which come within 10 miles of the district. Diabases have been intruded along the Osburn and Placer Creek faults, among others.

The dominant structural feature of the district is the curved and faulted southward extension of the Trout Creek anticline (Gibson and others, 1941, pl. 1). Most of the mines of the district lie on the east flank of this anticline.

There are several sets of faults of considerable magnitude and, of course, a very large number of sets of lesser magnitude. The gradational nature of all formation contacts, the almost complete lack of key beds within formations, and the thickness of the formations make interpretations of the nature and amount of movement along these faults very difficult.

The few cross cutting relations exposed indicate that the fractures that controlled bleaching and main period vein formation are the oldest in the district.

The old fractures are grouped in belts. Displacement along these fractures in general has been small, although a few, such as the Chester, Alhambra, and Silver Syndicate, may have had significant postmineral movement. (For location of these structures, see Sorenson, 1951, and Shenon and McConnel, 1939.) The other faults appear to be postmineral in age. The oldest are N. 20° W.-striking, west-dipping reverse faults, such as the Page and the Carpenter Gulch faults. A group of normal faults that strike between N. 10° W. and N. 20° E. are probably the next younger faults, but they do not intersect the older reverse faults. Next younger is a set of N. 60° to 70° W.-striking faults that include both normal and reverse faults. The majority of the veins also strike approximately in this direction, and determining the relative ages of these faults and the veins is generally impossible because of a lack of intersections of the veins and the faults; however, where such intersections have been exposed, postmineral movement can be determined.

The next to youngest group of faults are the Osburn, Placer Creek, and the related faults, such as the Spring (for location, see Campbell, 1953), White Ledge, and Paymaster (for location, see Wallace and others, 1952) that strike west to N. 80° W. Strike-slip movement on the Osburn fault is about 17 miles and that on the Placer Creek is about 1½ miles. The youngest fault with major movement is the Dobson Pass fault, a north-striking low-angle normal fault that may have formed in the later stages of movement along the Osburn fault.

GREAT COEUR d'ALENE MINERAL BELT

The Great Coeur d'Alene mineral belt lies along the Lewis and Clark line of Billingsley and Locke (1941, p. 57). As shown on plate 1, it extends from the vicinity of Coeur d'Alene, Idaho, on the west to the vicinity of Superior, Mont., on the east. The belt strikes about N. 60° W. and is about 95 miles long; it is outlined on plate 1 by the positions of mines and prospects. The Montana part of the belt is shown on Missouri Basin Studies map 16 (Chace, 1947), though it is not named there. The belt can also be considered as a great shear zone, because, in addition to the minor shear zones along which the veins have formed, the belt is traversed by a group of strike-slip faults of considerable displacement, such as the Osburn, the Placer Creek, and the Boyd Mountain; the latter fault is shown on plate 48 of Wallace and Hosterman (1956).

The great mineral belt includes smaller units that have also been designated as mineral belts. The Coeur d'Alene district includes several of these smaller mineral belts.

MINERAL BELTS

The great bulk of production from the Coeur d'Alene district has come from a north area that centers around the towns of Burke and Mullan and a south area that centers around the town of Kellogg. These two areas have one outstanding feature in common: the important productive veins in each are in well-defined, nearly straight parallel or subparallel mineral belts that, with two exceptions, trend about N. 65° W. Twelve such mineral belts and subbelts are shown on plate 2A. Lindgren (1904, p. 111) recognized three of the mineral belts that lie north of the Osburn fault; Emmons (1940, fig. 56, p. 64) showed all the mineral belts north of the Osburn fault except for the Golconda-Lucky Friday belt and the subbelts, but did not mention mineral belts in his text. My colleagues on the Coeur d'Alene project—S. W. Hobbs, A. B. Griggs, A. B. Campbell, and R.E. Wallace—had recognized most of the other mineral belts by 1951. The Moe-Reindeer Queen mineral belt and the subbelts have been recognized since that time.

The mineral belts are structural features. They consist of veins, productive and nonproductive, that formed along fracture systems or shear zones, and their positions and attitudes, except possibly for those of the success subbelt, are not greatly affected by local geology. Exploration over the years has shown that the belts have limited widths, though they may be wider than the outcropping productive veins indicate. Plate 3 shows part of a mineral belt that is delineated by the productive veins of the Amazon, the Interstate-Callahan, and the Hercules mines. The long crosscuts north and south from the mineral belt show no veins outside the mineral belt.

As shown on plate 3, the mineral belts are primarily defined by the ore shoots of productive veins. Except for the Page-Galena and the Golconda-Lucky Friday mineral belts, all are apparently as straight as, and possibly even narrower than, they are shown on plate 2*A*, although widths along each belt vary considerably. The Page-Galena belt is actually slightly sinuous as indicated by the ore shoots, though if all the ore shoots, here shown at many different elevations, were projected to a common plane, the east part of the belt would become straighter and narrower. The width of the Golconda-Lucky Friday mineral belt could be reduced in the same manner.

The mineral belts are subparallel; they are not affected by local trends of fold axes. The origin of the fracture systems of the mineral belts should not be ascribed, therefore, to joint systems produced in either the folding or the flexing of the Pine Creek-Moon Creek anticline.

The mere fact that these fracture systems are in part loci of replacement by introduced material argues for extension of the fractures to depth. The major movement along the Osburn fault is comparatively recent; however, this fault is paralleled along much of its length by older mineralized fractures. Fracture systems of the Coeur d'Alene district apparently are the result of lateral movement along deeper structures of the Lewis and Clark line and do not differ in origin from the similar fracture systems that can be traced from Coeur d'Alene Lake in Idaho at least 95 miles to the vicinity of Superior, Mont. As noted on page 49, the Coeur d'Alene district fracture systems do differ somewhat from the others in that they tapped a major reservoir of sulfides.

To summarize, the most significant facts concerning Coeur d'Alene mineral belts are:

1. Five of the belts are nearly parallel. The Sunset, Carlisle-Hercules, Rex-Snowstorm, and Gem-Gold Hunter belts are north of the Osburn fault; the Pine Creek belt lies south of the fault. Three other belts, one north and two south of the Osburn fault, are parallel to each other and at least subparallel to the other belts. The Douglas subbelt strikes at an angle of about 25° to the majority of the belts.
2. Most of the individual veins strike very nearly parallel to the long axes of their corresponding mineral belts.
3. Perhaps most significant is the fact that, though the mineral belts are parallel, they cut local fold axes at widely differing angles. The clear implication is that neither major nor local flexures have greatly influenced the attitude of the mineral belts.
4. With minor exceptions, the productive veins of the main period of mineralization are apparently confined to mineral belts unless displaced by obvious faults.

BELTS IN NORTH AREA

Sunset mineral belt.—The Sunset mineral belt (pl. 2A) strikes about N. 65° W. and is about 1,000 feet wide and 16,000 feet long. The belt cuts, almost at right angles, the general strike of the beds on the west flank of the Burke anticline (see Griggs and others, 1953, for location), and it also cuts the north Gem stock. The belt as defined consists of a group of alined ore bodies, prospects, fractures, and shear zones that are only weakly mineralized. Two prospects, which contain lead and zinc, are in the stock. Rather intensive exploration has shown that the north and south borders of the belt are well defined.

Carlisle-Hercules mineral belt.—The Carlisle-Hercules mineral belt strikes about N. 65° W. and is about 2,000 feet wide and about 28,000 feet long. East and west of the north Gem stock the belt cuts at right angles the beds of the west flank of the Burke anticline (see Griggs and others, 1953, for location). No prospects are known in the stock, though soil samples I collected in two traverses across the strike of the belt in the stock had lead and zinc contents of twice background. The part of the belt west of the stock contains the greater number of mineralized structures.

Rex-Snowstorm mineral belt and Tamarack-Marsh mineral subbelt.—The Rex-Snowstorm mineral belt strikes about N. 65° W. and is approximately 48,000 feet long. The Tamarack-Marsh subbelt is a split that strikes about N. 60° W. and is about 12,000 feet long; it is one of the more productive mineral belts of the district. The main belt and the subbelt appear to merge east of the Hecla ore body at the town of Burke.

Most of the Rex-Snowstorm belt strikes at right angles to the trend of the fold axes; however, fold axes east of Burke are cut more and more obliquely until at the Snowstorm mine the local fold axes are parallel to the overall strike of the belt. Again, no prospects are known in the stocks.

The Tamarack-Marsh subbelt strikes at right angles to fold axes. It is very well defined by mineralized structures and was recognized by Lindgren in 1899 (Lindgren, 1904). The subbelt is perhaps 1,500 feet wide. Parallel ore bodies are known in several areas; for example, the Tamarack mine has 10 different ore shoots on as many subparallel veins.

Gem-Gold Hunter mineral belt, and Success mineral subbelt.—The Gem-Gold Hunter mineral belt strikes about N. 65° W. and extends from the east edge of the south Gem stock southeast about 30,000 feet, where it appears to merge with the Golconda-Lucky Friday mineral belt. In the Gem mine, and on the 1600 level of the Frisco mine, the veins penetrated the borders of the stock. In the Gem mine area the belt strikes at right angles to fold axes; in the Gold Hunter mine area the belt is parallel to local fold axes. The individual veins in general again parallel the strike of the belt.

The Success subbelt strikes about N. 65° W. and is about 6,000 feet long. It is well defined and contains the Success mine and the American prospect, both of which lie partially in monzonite. The subbelt cuts the local fold axes at right angles. There is no apparent connection with the Gem-Gold Hunter belt, but I consider that the Success is part of that belt.

Dayrock mineral subbelt.—the Dayrock subbelt is a less well-defined unit than the others, and its strike, N. 70° W., can be determined only from the strike of its veins in the Dayrock and California mines. The Dayrock veins have been brought to their present location by movement of the hanging-wall block of the Dobson Pass fault. The subbelt extends from the Dobson Pass fault to and probably under the Blackcloud fault. It is almost parallel to the fold axes of the area.

Golconda-Lucky Friday mineral belt.—This mineral belt strikes about N. 85° W. and has been traced for about 32,000 feet. It is cut on the west end by the Dobson Pass fault, and on the east end it may be cut by the Osburn fault or may merge with the Gem-Gold Hunter belt. This belt is more diffuse and less distinct than the other belts. Only three mines are present, and the mines and prospects are spread over a width of some 3,000 feet, though this width could be reduced by projecting the veins updip to a common horizontal plane.

The west part of the belt cuts fold axes almost at right angles, but to the east the belt is nearly parallel to the fold axes of the area. The individual veins strike parallel to the belt.

BELTS IN SOUTH AREA

Page-Galena mineral belt.—The Page-Galena is the largest and the most productive of the mineral belts of the district. The overall strike is about N. 75° W. and the belt is about 67,000 feet long. The trend of the known mineralized ground is somewhat sinuous and the strike of the belt is much more idealized than that for the other belts, although the trend would be more regular if all the veins were projected updip to a common horizontal plane. The belt is terminated on the west end by the Page fault (the stibnite ore body of the Coeur d'Alene and Pine Creek antimony mine is considered to be much younger than the main period mineral belt); its termination on the east end is placed at the Galena mine. On the west end the Page-Galena belt is subparallel to the fold axes. From the Crescent mine eastward the veins parallel the fold axes.

Moe-Reindeer Queen mineral belt.—The Moe-Reindeer Queen mineral belt strikes about N. 70° W., and can be traced for about 40,000 feet eastward, part of it being in Montana. The belt is not considered to be an extension of the Page-Galena belt, for it has a slightly different strike and if prolonged further west than shown on plate 2*A* would be cut by the Osburn fault east of Wallace. The belt seems typical of some farther east in Montana that also contain large carbonate veins but which generally lack significant amounts of sulfides. The belt is parallel to the local fold axes.

Pine Creek mineral belt and Douglas mineral subbelt.—The Pine Creek mineral belt is well-defined and strikes about N. 65° W. It is about 1,500 feet wide and 33,000 feet long. The Hypotheek mine is considered to mark the west end of the belt, although the Hypotheek ore body may be much younger than the other ore bodies of the belt. On the east end the belt is cut by the Placer Creek fault (for location, see Campbell, 1953), where the Highland ore shoot of the Highland-Surprise mine is truncated by the fault. The belt cuts the axis of the Pine Creek anticline at a moderate angle.

The Douglas mineral subbelt strikes N. 40° W. and is about 15,000 feet long. It apparently terminates to the northwest at the Placer Creek fault, but has not been traced southeast of the Constitution mine. The beds in this area are irregularly contorted; in places the belt is parallel to and at others is at right angles to fold axes. This subbelt may be the offset segment of the Pine Creek belt, though the abrupt change in strike cannot be explained by any known tilting of the fault blocks south of the Placer Creek fault.

ORE DEPOSITS NOT IN MINERAL BELTS

Veins of several different ages occur in the Coeur d'Alene district, but one should not necessarily expect veins other than those of the main period to lie in the mineral belts, though the known uraninite veins, which are not of the main period, do lie in the belts. However, very few productive veins lie outside the mineral belts. The most important of these exceptions are the Dayrock and California mines of the Dayrock subbelt.

These two mines are in the hanging-wall block of the Dobson Pass fault, which is known to cut the Ohio vein of the Dayrock mine. This block was probably moved several miles from the east, and the small stocks west of the Dayrock mine are probably cupolas sliced off the top of the larger monzonite stocks. A plausible reconstruction of the prefault situation places the Dayrock and California mines in the Gem-Gold Hunter mineral belt.

The Formosa vein is between the Gem-Gold Hunter and Golconda-Lucky Friday mineral belts, and the Western Union vein is betwen the Dayrock subbelt and the Osburn fault, but it is uncertain whether they should be classed as main period or later veins. On the other hand, Sherman and other prospects south of the Pine Creek mineral belt are mineralogically identical with the productive veins of the Pine Creek belt.

A number of other prospects lie outside the belts, and the mineralogy of some of these suggests that they are younger than the main period veins. The stibnite veins do not fall in the belts either, and are considered to be younger than any of the base-metal veins.

PREFAULT RECONSTRUCTION

The geology of the Coeur d'Alene district before the major movement along the Osburn, Placer Creek, and Dobson Pass faults has been described by S. W. Hobbs and others (written communication, 1959) and a brief review is given here; plate 2*B* is a reconstruction of the prefault situation.

If the quartzite beds of the lower part of the Prichard Formation north of the fault are assumed to be correlated with those south of the fault, the amount of strike-slip movement on the Placer Creek fault is about 1.5 miles and the north side has moved east. Because two separate horizons can be matched on either side of the fault and the horizontal offset is about the same for each pair, the assumed 1.5 miles of movement seems to be a reasonable figure for the horizontal component. The axial trace of the Pine Creek anticline, however, cannot be recognized with any certainty south of the Placer Creek fault because of widespread faulting south of the fault, but the general form of the anticline is obvious.

The Dobson Pass fault strikes roughly north and dips about 30° west. It is postmineral in age, as shown by the relation of fault and vein in the Dayrock mine, and it cuts the south Gem stock. Reconstruction of the fault movement involves superimposing the small intrusives near the Dayrock mineral subbelt upon the south Gem stock in such a way as to bring the Ruth fault (for location, see Bowyer and others, 1954) parallel to and updip from the Mexican-San Jose fault (for location, see Griggs and others, 1953). This procedure superimposes the California and Dayrock mines onto the Gem-Gold Hunter mineral belt, to the west of the Star mine.

The amount of strike-slip movement on the Osburn fault, in the reconstruction, has been determined by matching the traces of the axial planes of the Pine Creek and Moon Creek anticlines. The correlation is such that a precision of plus or minus half a mile is about as good as can be achieved for any reconstruction, especially as no account is taken of possible dip-slip movement. The postulated magnitude of movement, about 17 miles, is almost the same as that proposed by Hershey (1916, p. 4), although he used other criteria.

The reconstruction shown in plate 2*B* brings the mineral belts north of the Osburn fault opposite the Pine Creek mineral belt and opposite the west end of the Page-Galena mineral belt. The remainder of the Page-Galena mineral belt now serves as a tail to the district and the Moe-Reindeer Queen mineral belt does not enter into the picture at all. Plate 2*B* also shows that the subparallel fracture systems that define the mineral belts are superimposed on a major anticline that was flexed before the fracture systems formed.

MINERALOGY

HYPOGENE VEIN MINERALS

The present knowledge of all hypogene vein minerals reported from the Coeur d'Alene district is summarized. The minerals are listed in the order used by Palache and others (1944; 1951) except for the silicates, for which the arrangement of Dana (Dana and Ford, 1926) is followed.

GOLD

Very small amounts of gold (Au) are in the galena and sphalerite deposits, as shown by production figures (not available for publication) of individual base-metal mines, but neither native gold nor other gold minerals have been recognized in studies of such ores. Minor amounts of gold occur in the stibnite-bearing veins of the district (Shannon, 1926, p. 78), and in the present study gold was recognized in a single polished surface of ore from the Stanley mine. The very late quartz-carbonate-arsenopyrite veins of the General Mines prospect type also contain gold, and small amounts of gold probably were introduced into veins during all periods of mineralization.

ARGENTITE

Shannon (1926, p. 87) reported grains of argentite (Ag_2S) disseminated in quartz in the Big Creek mine (upper workings of the Sunshine mine?) but he did not state whether he believed it to be of hypogene or supergene origin. Waldschmidt (1925, p. 583) tentatively identified argentite inclusions in galena from the Morning mine. Argentite was not recognized in the present study.

GALENA

Galena (PbS) is the most important ore mineral of the district, and its occurrences have been described by Ransome and Calkins (1908), Umpleby and Jones (1923), Waldschmidt (1925), Shannon (1926), Warren (1934), and R. J. Anderson (1940).

The Coeur d'Alene galena is medium to fine grained, and very little of it is euhedral. Most galena grains are less than 5 mm on an edge, and in many mines most of the galena is probably less than 1 mm on an edge. Cleavage masses "several centimeters broad" were noted by Shannon (1926, p. 100), and similar material, now in the National Museum, was collected by Ransome from the Hercules mine, but such material is rare. A few crystals reaching 2 cm on an edge were found in vugs in the Sunset Minerals mine. Schistose galena produced by postmineral fault movement can be seen in most mines, though not in every exposure, and in some mines steel galena produced by more intense movement is present. (Steel galena is very fine grained, to the eye, and resembles the fractured surface of a metal; thus the name.)

Most galena masses contain varying amounts of country rock and unreplaced remnants of earlier formed vein minerals. Preparation of sufficiently pure galena concentrates is particularly difficult from the ores of the Pine Creek mineral belt because of the fine-grained nature of the ore and the incomplete replacement of the early formed minerals by galena.

The major elements of galena are lead and sulfur, but other elements may be present in small quantities in lead and sulfur positions in the galena structure (Fleischer, 1955, p. 975 ff.). A study of the minor elements in Coeur d'Alene galena has not been done. A single galena crystal from a vug was analyzed spectrographically, and the results are shown in table 3. All the metals found in the semiquantitative analysis, except bismuth, antimony, and silver, are probably present in inclusions of other minerals. Guild (1917, p. 305) and Warren (1934, p. 693) have demonstrated that Coeur d'Alene district galena probably contains very little silver in the lead positions. Examination of polished surfaces in this study has shown that where ores have high silver:lead ratios the amount of silver-bearing minerals is high, and vice versa.

Galena was introduced during at least two periods of mineralization (see page 44); however, only one generation of galena was recognized in any one vein, though Ransome and Calkins (1908, p. 112) and Waldschmidt (1925, p. 582) believed more than one generation was present in some veins.

TABLE 3.—*Spectrographic analysis of a galena crystal from a vug, 800 level, Sunset Minerals mine, Coeur d'Alene district, Idaho*

[Field sample VCF-377a-53. Analyst, Janet D. Fletcher, U.S. Geological Survey]

Looked for but not found: Au, Pt, Pd, Ir, Hg, Mo, W, As, Tl, Sn, Ni, Cr, Sc, Y, Yb, La, U, Nb, Ta, Zr, Be, Sr, Ba, P, B, V]

Constituent	Percent	Constituent	Percent
Quantitative analysis			
Fe	0.007	Cd	0
Cu	.0006	In	0
Ge	0	Mn	.0006
Pb	Major	Ga	0
Ag	.12	Co	0
Semiquantitative analysis			
Pb	X0	Zn	0.0X
	X	Fe, Mg, Ca	.00X
Bi, Sb, Ag	.X	Ti, Cu, Mn	.000X

H. G. Thode and Jan Monster, who made isotopic analyses of sulfur from three galena samples from the Star mine (table 4), noted (written communication, 1956) that the ratios are "quite near the value found for meteoritic sulfides: S^{32}: S^{34}=22.225", and suggested the probability of a magmatic origin for the sulfide ore.

Isotopic analyses of lead in galena from the Coeur d'Alene district have been made by Farquhar and Cummings (1954, p. 12), Russell and Farquhar (1957, p. 558), L. R. Stieff and T. W. Stern (written communication, 1959), and Long and others (1959, p. 1114).

Galena from main period veins from both north and south of the Osburn fault is almost identical in isotopic composition, as was first noted by Arnold Silverman (written communication, 1958). In addition, all investigators have demonstrated that galena from the main period veins has an "ancient" composition. "Ancient" lead is thus present in veins that are younger than stocks of Cretaceous age. The problem of reconciling this geologic paradox is discussed on pages 31 to 36.

Galena from the Sunrise No. 3 vein, which is also younger than the stocks, contains "modern" lead (Arnold Silverman, written communication, 1958; L. R.

TABLE 4.—*Isotope ratios of sulfur from galena from the Star mine Coeur d'Alene district, Idaho*

[Analysts, H. G. Thode and Jan Monster, McMaster University, Ontario, Canada]

Field sample	Mine level	S^{32}: S^{34}
VCF-20a-53	1,200	22.210
VCF-84a-53	2,100	22.215
VCF-186a-53	4,700	22.207

Stieff and T. W. Stern, written communication, 1959). This vein probably belongs to the first Tertiary period of mineralization.

CLAUSTHALITE

Shannon (1926, p. 104) reported clausthalite (PbSe) in the Hypotheek mine but did not see the specimens. No other occurrences have been reported.

SPHALERITE

Sphalerite ((Zn,Fe)S) is second in abundance to galena in the district, and is probably present in at least small amounts in all the veins except for the uranium-bearing veins and a few tetrahedrite-siderite veins, such as the Silver vein of the Galena mine. There have probably been three, and possibly four, periods of mineralization (see p. 44 to 45). The discussion that follows is concerned primarily with sphalerite of the main period of mineralization.

The largest sphalerite crystal seen came from a vug in the Sunset Minerals mine and measured about 1.5 cm on an edge. The material with the next largest grains came from the Success mine where polyhedral grains were seen that were 3 and 4 mm in diameter. Most of the sphalerite grains of the Coeur d'Alene district are less than 1 mm in diameter and are anhedral.

TABLE 5.—*Variation in color of selected samples of sphalerite with combined iron and manganese content*

[Munsell color-chip designations. Determined visually using a desk lamp with one white and one daylight fluorescent bulb, the light 1 foot above the streak plate]

Field sample	Fe+Mn (percent)	Color
VCF-27a-53	[1] 6.78	10 YR 5/3
VCF-40a-53	[1] 5.83	10 YR 5/4
VCF-34a-53	[1] 5.77	10 YR 5/3
VCF-73a-53	[1] 5.21	10 YR 6/3
ABG-62-50	[2] 4.14	10 YR 4/4
VCF-61a-53	[1] 4.07	10 YR 6/3
VCF-195g-52	[2] 3.23	10 YR 6/4
VCF-185g-52	[3] 2.96	10 YR 6/4
VCF-185j-52	[2] 2.76	10 YR 6/4.5
VCF-185i-52	[3] 0.58	10 YR 7/2
VCF-185h-52	[2] 0.42	10 YR 7/3
VCF-140-52	[2] 0.34	10 YR 9/1

[1] Quantitative spectrographic analysis by Harry Bastron, U.S. Geological Survey.
[2] Quantitative spectrographic analysis by Janet D. Fletcher, U.S. Geological Survey.
[3] Chemical analysis by Leonard Shapiro, U.S. Geological Survey.

The streak color of sphalerite crystals ranges from very pale lemon yellow to chocolate brown, but most are yellow-brown. These color designations are qualitative, and the color of the streak can be designated more exactly by comparison with Munsell color chips as suggested by Simons (1955, p. 404). Table 5 shows the Munsell color designations for a selected series of analyzed sphalerite samples. The color and intensity vary directly with the variations in combined iron and manganese content to as much as about 5 percent iron; above that percentage the eye cannot make useful distinctions, although a photocell probably could.

The composition of 64 specimens of sphalerite is shown in table 6. Main period sphalerite ranges in iron content from 0.42 to 11 percent. Because most of the specimens came from the Star mine ore body, a mean composition for the entire district cannot be given. The streak colors certainly indicate that most of the sphalerite contains more than 2 percent iron, but probably not much of it is marmatitic (that is, over 10 percent iron).

Analyzed specimens of sphalerite from veins younger than the main period contained less than 1 percent iron, and the streak colors suggest that probably none of the younger sphalerite contains as much as 2 percent iron.

Sphalerite commonly contains small amounts of other elements that occupy zinc positions in the sphalerite structure. The only minor elements of consequence in Coeur d'Alene sphalerite are germanium, cadmium, indium, manganese, gallium, cobalt, and mercury. Quantitative spectrographic analyses of sphalerite for these elements are given in table 6. The lead and copper analyses were made as a check on the purity of the samples, though some of the copper may be in the sphalerite structure.

Semiquantitative analyses of selected sphalerite for some minor elements are presented in table 7; it is doubtful that any but the above-named elements, and nickel, actually are in the sphalerite structure in any significant amount.

Fryklund and Fletcher (1956, p. 237) compared the minor element content of Coeur d'Alene sphalerite with those of sphalerite from several districts in Europe. The average cadmium content of Coeur d'Alene sphalerite is relatively high; the gallium, indium, germanium, and cobalt contents are relatively low. Mercury has not been looked for in analyses in most other studies, and only 14 samples were analyzed for mercury in this work; no comparison was made with mercury content of samples from other districts. Quantitative spectrographic analyses for mercury, requiring development of new and quite sensitive techniques by Janet D. Fletcher (Fryklund and Fletcher, 1956, p. 232), show a content range from 0.005 to 0.02 percent, and average 0.0095 percent.

The relation of temperature of formation to occurrence and abundance of minor elements of sphalerite was considered in Fryklund and Fletcher (1956). The conclusion was (p. 246), "The minor elements in sphalerite, other than Mn (Fe should be considered a major element), cannot be indicators of formation temperature because equilibrium concentrations are rarely, if ever, obtained."

TABLE 6.—*Spectrographic analyses, in percent, of sphalerite from the Coeur d'Alene district, Idaho*

[Analyst, Janet D. Fletcher, U.S. Geological Survey, unless otherwise noted]

Analysis	Fe	Cu	Ge	Pb	Cd	In	Mn	Ga	Co	Hg	Mine level
53-2020SW [1]	6.2	0.013	0.0015	0.12	0.46	0	0.58	0.0014	0.004	----------	Star 1,700.
53-2021SW [1]	5.5	.016	.0017	.08	.37	0	.27	.0004	.004	----------	Star 2,700.
53-2022SW [1]	5.5	.012	.0046	.29	.42	0	.33	.0014	.004	----------	Star 1,450.
53-2023SW [1]	3.9	.013	.0017	.06	.65	0	.17	.0013	.002	----------	Star 2,100.
53-2024SW [1]	6.2	.064	0	.42	.47	0	.32	.0010	.004	----------	Star 2,100.
53-2025SW [1]	5	.025	.0017	.21	.63	.004	.21	.0010	.003	----------	Star 1,450.
54-211S	4	.01	0	.23	.34	.003	.07	0	.003	----------	Star 2,700.
54-212S	11	.1	0	.84	.34	0	.96	.0006	.005	0.01	Star 4,900.
54-213S	9	.3	.004	.72	.52	0	.96	.004	.005	----------	Star 1,200.
54-214S	6	.008	.005	.18	.42	0	.24	.002	.004	.009	Star 2,300.
54-215S	8	.02	0	.74	.35	0	.17	.0005	.002	.007	Star 2,300.
54-216S	6	.1	.003	.80	.70	0	.42	.002	.003	----------	Star 2,700.
54-217S	6	.02	0	.38	.60	0	.22	.001	.004	.02	Star 2,700.
54-457S	4.7	.016	0	.09	.23	0	.58	0	.004	.007	Star 1,200.
54-458S	2.9	.011	.004	.70	.40	.004	.35	.001	.004	.005	Star 1,450.
54-459S	3.1	.022	0	.23	.44	.004	.58	.003	.003	.01	Star 1,450.
54-460S	3.4	.14	.003	1	.29	0	.26	.0009	.004	----------	Star 2,100.
54-461S	6.7	.17	0	1	.26	0	1.4	.001	.005	.007	Star 1,700.
54-462S	2.6	.014	0	.02	.36	.004	.04	0	.004	.008	Star 1,700.
54-463S	3.1	.15	.002	.01	.44	0	.33	.002	.003	----------	Star 1,700.
54-464S	3.1	.40	0	.19	.36	0	.21	.0007	.02	----------	Star 1,700.
54-615S	3.5	.25	0	1.6	.35	0	.51	.001	.004	----------	Star 5,500.
54-616S	3.5	.012	0	.004	.53	0	.28	.002	.005	----------	Star 5,500.
54-617S	2.8	.2	0	.08	.29	.005	.27	.0007	.006	.01	Star 1,200.
54-618S	2.2	.049	0	.2	.34	0	.21	.0004	.005	.005	Star 2,700.
54-619S	2.2	.4	0	.2	.53	0	.10	0	.006	.02	Morning 5,200.
54-620S	1.4	1	0	.24	.54	0	.24	.0004	.039	----------	Star 2,700.
54-621S	3.1	.024	0	.84	.49	0	.26	.0009	.004	----------	Star 4,900.
54-622S	4	.0048	0	.84	.34	0	.70	.0006	.005	----------	Star 4,900.
54-623S	2.8	.015	0	.25	.36	0	.35	.001	.004	.009	Star 4,900.
54-139038	4.5	.047	0	.22	.36	.003	.07	0	.008	----------	Star 1,000.
54-139039	5	.18	0	.15	.50	.004	.58	.001	.004	----------	Star 1,000.
54-139040	5	.088	0	.065	.48	.004	.58	.0008	.008	----------	Star 1,200.
54-139041	4.6	.11	.002	.11	.80	.004	.26	.003	.004	----------	Star 5,100.
54-139042	4.8	.076	0	.10	.40	.004	.48	.0007	.004	----------	Star 1,450.
54-139044	3.7	.13	0	.14	.36	0	.06	.0006	.008	----------	Star 4,700.
54-139045	4.6	.013	0	.002	.56	0	.06	0	.01	----------	Star 5,100.
54-139046	3.9	.014	0	.01	.52	0	.19	.003	.005	.006	Star 5,100.
54-139047	3.4	.012	0	.01	.60	0	.18	.003	.005	----------	Star 5,100.
54-139048	4.2	.054	0	.03	.46	0	.19	0	.008	----------	Star 5,100.
53-159S	.34	.01	0	.007	.41	0	.0009	0	0	----------	Idaho 200.
53-160S	[2] 2.90	.003	0	.004	.21	0	.06	.001	.003	----------	Success 1,100.
53-161S	.42	.006	0	.07	.20	0	.009	.001	.003	----------	Success 1,100.
53-162S	.58	.004	0	.04	.24	0	.007	.001	.003	----------	Success 1,100.
53-163S	2.70	.003	0	.005	.24	0	.06	.001	.003	----------	Success 1,100.
53-164S	3.2	.004	0	.05	.21	0	.03	.002	.009	----------	Tamarack 2,400.
53-165S	.72	.002	0	.009	.16	0	.002	0	0	----------	Big It adit.
53-166S	4.1	.002	0	.4	.15	0	.04	.0006	.007	----------	Amazon 2,000.
54-832S	9.2	.0070	0	.44	.19	0	.1	0	.0074	----------	Sidney 900.
54-833S	5.1	.013	.006	.004	.098	0	.07	.006	.010	----------	Idaho 300.
54-834S	4	.0086	.006	.097	.38	0	.1	.002	.0090	----------	Frisco 2,400.
54-835S	3.5	.011	.004	.01	.40	0	.06	.001	.002	----------	Page 2,100.
54-836S	3.2	.013	.004	.02	.34	0	.06	.002	.002	----------	Page 3,000.
54-837S	2.2	.0091	.002	.03	.45	0	.04	.002	.0072	----------	Page 2,700.
54-838S	2.1	.012	.002	.097	.40	0	.05	.002	.0066	----------	Page 2,700.
54-839S	4	.0044	0	0	.25	0	.01	0	.0059	----------	Sunset Mineral 800.
54-139049	5.5	.0068	.002	.096	.28	.004	.06	.0008	.0009	----------	Highland-Surprise No. 4 adit.
54-139050	4.8	.011	0	.11	.40	0	.32	.001	.003	----------	Frisco 1,400.
150448 [3]	1.8	.01	.001	----------	.6	.001	.02	.004	.005	----------	Page 2,565.
150449 [3]	3.8	.02	.001	----------	.6	.002	.1	.006	.004	----------	Page 3,030.
150450 [3]	3.0	.4	.001	----------	.8	0	.03	.004	.01	----------	Page 2,700.
150451 [3]	4.0	.02	.001	----------	.5	.002	.1	.005	.007	----------	Page 2,700.
150452 [3]	3.7	.3	.001	----------	.6	0	.04	.006	.003	----------	Page 2,565.
150453 [3]	2.7	.1	.001	----------	.6	0	.04	.007	.003	----------	Page 2,400.

[1] Spectrographic analysis by Harry Bastron, U.S. Geological Survey.
[2] Chemical analysis by Leonard Shapiro, U.S. Geological Survey.
[3] Spectrographic analysis by Sol Berman, U.S. Geological Survey.

Kullerud (1953) has shown that sphalerite which formed in equilibrium with pyrrhotite has an iron content determined by its formation temperature and pressure. Much of the Coeur d'Alene sphalerite probably formed in equilibrium with pyrrhotite, but unfortunately a reasonable estimate of the formation pressure cannot be made, and therefore it does not seem desirable to present possible formation temperatures.

Kullerud originally thought that equilibrium with pyrite was almost equivalent to equilibrium with pyrrhotite (Kullerud, 1953, p. 109). However, Barton and Kullerud (1957, p. 1699) have shown that the sit-

TABLE 7.—*Supplemental semiquantitative analyses for minor elements in sphalerite of the Coeur d'Alene district, Idaho*

[Only elements present in concentrations less than 1 percent are given. Not found in any samples: Au, Pt, Pd, Ir, Mo, W, As, Sb, Bi, Tl, Cr, Sc, Y, Yb, La, Th, U, Nb Ta, Be, P, B. All samples contained X percent Fe. Analyst, Janet D. Fletcher, U.S. Geological Survey]

Analysis	Constituent, in percent				Not found in sample	Mine
	0.X	0.0X	0.00X	0.000X		
53-2025SW	Cd, Pb, Mn	Ag, Cu, Ca	Hg, Ge, Sn, Co, Mg, In, Al, Ga	Ni, Ti	V, Zr, Ba, Sr	Star.
54-217SW	Cd, Pb, Mn	Cu, Ca, Ba, Mg, Al, Hg	Ag, Ga, Co		Ni, Ti, Zr, Ge, Sr, In	Do.
54-463SW	Cu, Cd, Mn	Pb, Mg, Ca	Hg, Ag, Ge, Co, Ga	Ti, Ba	Ni, V, Zr, Sr, In	Do.
54-464SW	Cu, Pb, Cd, Mn	Co, Mg, Ca	Hg, Ag, Ni, Ti, Ba	Ga	V, Zr, Ge, Sr, In	Do.
54-622SW	Pb, Cd, Mn, Mg	Ca, Ag	Hg, Cu, Co, Ni, Ti, Ba	Ga	V, Zr, Ge, Sr, In	Do.
54-623SW	Pb, Cd, Mn	Mg	Hg, Ag, Sn, Co, Ga, Cu	Ni	V, Zr, Ge, Sr, In, Ba	Do.
54-838SW	Cd	Hg, Cu, Ag, Pb, Mn, Mg	Ge, Co, Ga, Ti, Cu	Ni	V, Zr, In, Sr, Ba	Page.
54-839SW (single crystal)	Cd	Mn	Cu, Co, Ti, Mg, Ca		Ag, Hg, Ge, Pb, Ni, V, Zr, In, Sr, Ba.	Sunset Mineral.
54-139048	Cd, Mn	Cu, Ag, Pb, Mg, Ca	Hg, In, Co, Ni, V, Ti, Zr, Ba	Sr	Ge, Ga	Star.
54-139049	Cd	Pb, Mn	Ag, Ge, In, V, Ti, Zr, Mg, Ca	Co, Ga	Hg, Sr, Ba	Highland Surprise.
54-139050	Pb, Cd, Mn		Hg, Ag, Co, Ga, V, Ti, Zr, Mg, Ca.		Sr, Ge, Ni, Ba, In	Frisco.

uation is not that simple. Unless the partial pressure of sulfur vapor at the time of sphalerite formation is known, the iron content of sphalerite formed in equilibrium with pyrite can indicate only a minimum temperature of formation.

Fryklund and Fletcher (1956, p. 241 ff.) have shown that in Coeur d'Alene sphalerite the content of minor elements, with the exception of manganese, has no correlation with iron content.

The maganese and iron diadochy is such that, if an ore fluid has a constant manganese:iron ratio, the ratio in the sphalerite will reflect that of the fluid though, as pointed out by P. B. Barton, Jr., (written communication, 1960), the constant of proportionality is not one. The correlation of manganese with iron simply reflects the manganese:iron ratio of the ore fluid in this case.

Most of the Coeur d'Alene sphalerite probably formed in equilibrium with either pyrrhotite or pyrite. The iron variation in the Star ore body is discussed very briefly on p. 76.

CHALCOPYRITE

Minor amounts of chalcopyrite ($CuFeS_2$) can be found in most of the main period veins of the district, but it is most abundant in the tetrahedrite-siderite veins, in the Snowstorm and National mines where it is the chief hypogene ore mineral, and in the carbonate veins of the Amador type (Shannon, 1926, p. 234) which extend from the vicinity of Mullan eastward into Montana.

None of the chalcopyrite examined contained cubanite or other exsolution minerals. Whether chalcopyrite has or has not been exsolved from any of the sphalerite of the Coeur d'Alene district has not been satisfactorily determined. Chalcopyrite occurring as blebs within sphalerite and as small irregular veinlets that follow sphalerite grain boundaries could have been exsolved. Formation temperatures for much of the sphalerite were high enough that chalcopyrite would have exsolved when the sphalerite cooled if sufficient copper had been present, but whether sufficient copper actually was present in the sphalerite to produce exsolved chalcopyrite is not known. Trellis or lattice patterns of chalcopyrite, which most clearly demonstrate an exsolution origin, were not observed. Some chalcopyrite veinlets cut across sphalerite as well as grains of pyrrhotite, magnetite, carbonate minerals, and other grains, and thus are not of exsolution origin.

PYRRHOTITE

Pyrrhotite ($Fe_{1-x}S$) is a major gangue mineral in the Pine Creek mineral belt and in the veins around the stocks; it is a minor mineral in many veins in other areas of the district, except for the Page-Galena mineral belt where it appears to be absent. Most pyrrhotite grains are from 0.002 mm to 0.1 mm across; grains larger than 1.0 mm are rare. Much of the pyrrhotite, particularly in the Pine Creek mineral belt, is twinned, apparently as the result of slight deformation.

Some of the pyrrhotite is not homogeneous and in polished surfaces is clearly made up of two phases. The intergrowths are in general parallel and there is no development of grating textures. One phase is darker, but both have the same crystallographic orientation as shown by parallel extinction of the two phases. The distribution of two-phase pyrrhotite is erratic and it is not a characteristic of any vein or group of veins.

Nonhomogeneous pyrrhotite has long been recognized in other districts, and Ramdohr (1950, p. 408 ff.) has summarized various discussions of its origin; perhaps the best recent illustrations of nonhomogeneous pyrrhotite are those of Vokes (1957, pl. 9). Nonhomogeneous pyrrhotite may originate in several ways, but there appear to be no generally accepted explanations.

TABLE 8.—*Spectrographic analyses of pyrrhotite from the No. 1 ore shoot of the Surprise vein, Highland-Surprise mine, Coeur d'Alene district, Idaho*

[Analyst, R. S. Harner, U.S. Geological Survey. Looked for but not found: Ge, Sn, In, Ga, V (specifically requested)]

Analysis	Constituent, in percent			Level	Altitude (feet)
	Cu	Co	Ni		
52-2165SW	0.015	0	0.026	No. 4 tunnel	3,240
52-2166SW	.013	.0070	.0080	200	3,080
52-2167SW	.0064	0	.0062	300	2,980
52-2168SW	.014	.010	.011	700	2,560
52-2169SW	.0056	.0048	.0026	1000	2,250
52-2170SW	.030	.0032	.0034	1150	2,130
52-2171SW	.017	.0036	.0086	1150	2,130
52-2172SW	.014	.0054	.0084	1300	1,980
52-2173SW	.034	.0044	.0042	1300	1,980
52-2174SW	.016	.0032	.012	1450	1,850

Arnold (1956, p. 177) has shown that the mere presence of pyrrhotite has no particular temperature significance but simply indicates a sulfur deficiency, but that the composition of pyrrhotite formed in equilibrium with pyrite depends upon the formation temperature and thus, if formation pressure is known, can serve as a geothermometer.

Ten pyrrhotite samples from eight different levels on the No. 1 ore shoot of the Surprise vein of the Highland-Surprise mine were analyzed for cobalt and nickel (Fryklund and Harner, 1955) and for other elements that might be expected in pyrrhotite. The results of these spectrographic analyses are presented in table 8. The copper is present in minute inclusions of chalcopyrite. No inclusions of cobalt and nickel minerals were observed in polished surfaces, and the two elements are presumed to be in the pyrrhotite structure. There is no correlation of cobalt and nickel content with depth.

A semiquantitative spectrographic analyses for the other minor elements was made as shown below:

[Analyst, R. S. Harner, U.S. Geological Survey. Looked for but not found: Au, Hg Ru, Pd, Os, Ir, Pt, Mo, W, Re, As, Sb, Bi, Se, Te, Zn, Cd, Tl, Cr, Cs, Y, Yb, La Ce, Ti, Zr, Hf, Th, Nb, Ta, U, Be, Ca, Sr, P, B]

Constituent	*Percent in— 52-2165SW*	*52-2174SW*
Ag	0	0.00X
Pb	0	.X
Mn	.00X	.00X
Al	.0X	.X
Mg	.00X	.00X
Ba	0	.000X

Pyrite, marcasite, and possibly magnetite, which I consider to be the products of the hypogene alteration of pyrrhotite, are to be found in most of the pyrrhotite-bearing veins. The alteration of pyrrhotite to these minerals is common in other districts throughout the world (see Ramdohr, 1950, p. 411 ff., and Edwards, 1954, p. 122, for various examples). Ramdohr (1950, p. 412) considered such alteration to be supergene, and so it may be in many veins; however, the Coeur d'Alene material studied comes from deep levels (in the Star mine, for example, 5,000 feet below the surface) where the other vein minerals are unaffected by supergene processes. Edwards (1954, p. 122) considered that such alteration could be hypogene and that it was the result of a change in the acidity and temperature of residual mineralizing solutions that "* * * generally coincides with the appearance of hypogene carbonate deposition * * *" Because the main stage of carbonate deposition in the district is prepyrrhotite in age, I believe that, although the alteration of Coeur d'Alene pyrrhotite is hypogene, it did not take place when carbonate deposition began, except perhaps locally where late calcite veins are involved.

Examples of fine-grained mixtures of alteration pyrite and marcasite partially replacing pyrrhotite are shown in figure 2. In other examples the marcasite developed coarse lamellae such as that shown in figure 3. The partial replacement of marcasite blades by galena shows that the alteration of pyrrhotite was hypogene in nature, and dates such alteration as at least pregalena in age.[1]

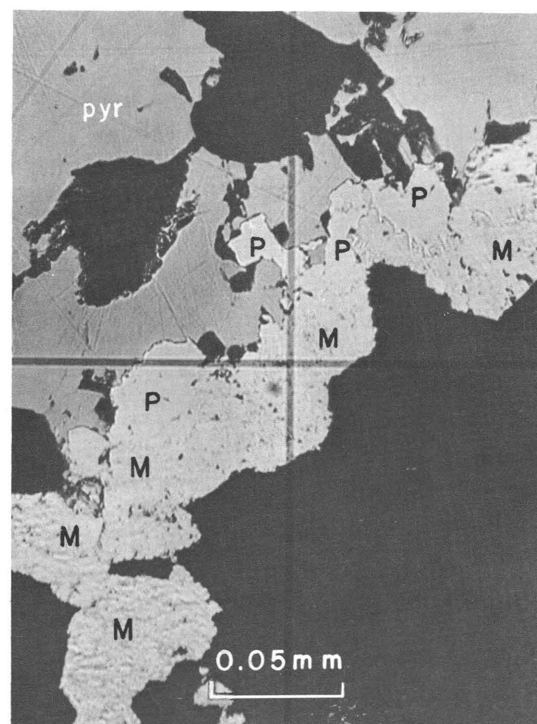

FIGURE 2.—Photomicrograph of pyrrhotite (light gray with low relief) partially altered to a mixture of marcasite and pyrite (white with high relief). Highland-Surprise mine, Coeur d'Alene district, Idaho. Plane-polarized light. P, pyrite; M, marcasite.

[1] After the two preceding paragraphs were written, Rhoden (1959) published a well-illustrated description of altered pyrrhotite from the Silver mines district, Erie; he presented strong evidence that the alteration is hypogene.

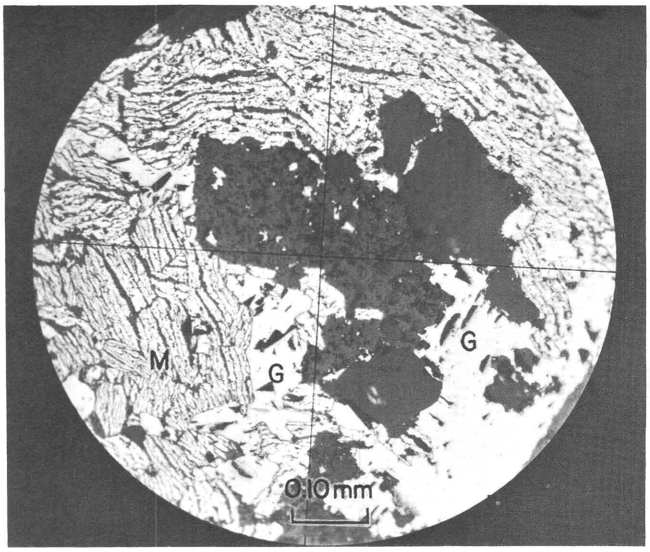

FIGURE 3.—Photomicrograph of lamellar marcasite partially replaced by galena (white with low relief), Marsh mine, Coeur d'Alene district, Idaho. Plane-polarized light. M, marcasite; G, galena.

The first stage in the alteration of pyrrhotite is the formation of aggregates of fine-grained (less than 0.001 mm in diameter) granular marcasite. In some areas alteration started along pyrrhotite grain boundaries; in other areas alteration started in the center of a grain, and where there is no visible fracture. In specimens from the Hercules mine, where nonhomogeneous pyrrhotite is common, the minor phase, the darker and harder of the two, seemed to be the preferred locus of alteration. In much of the granular marcasite, and also in alteration pyrite, there are specks of a darker gray material. These specks may be remnants of pyrrhotite or they may possibly be magnetite; an example of such magnetite has been figured by Ramdohr (1950, p. 413).

A second stage in the alteration process appears to be the recrystallization of granular to bladed or lamellar marcasite. The two types may be found grading into one another. Perhaps all lamellar marcasite of the district was originally granular.

Another possible second stage in the alteration process is the alteration of granular marcasite to euhedral pyrite, or at least to pyrite aggregates that are bounded by crystal faces. It is difficult to see how euhedral pyrite could be altered to granular marcasite if the marcasite did not retain the shape of the pyrite; thus it seems probable that the direction of alteration is consistently from marcasite to pyrite, though some pyrite may have formed directly from pyrrhotite.

The alteration in several of the veins can be dated by the fact that marcasite lamellae are cut and partially replaced by later sulfides. (See fig. 3, for example.) The alteration, if a single time interval is involved, is presphalerite in age.

STIBNITE

Stibnite (Sb_2S_3) occurs most frequently in a group of small properties along Pine Creek on the west fringe of the district, but most of the stibnite produced in the area has come from the Stanley mine at Burke, and the Houghland mine (Stibnite Hill mine?) (this mine is in unsurveyed sec. 19, T. 21 N., R. 31 W., Sanders County, Mont.) 8 miles northeast of Burke (Shannon, 1926, p. 80). Much of the stibnite that has been reported from mines in the district probably is actually one of the sulphosalts (Shannon, 1926, p. 80).

Some stibnite occurs in blades 3 to 4 cm long, but most is smeared and granulated by faulting.

The absolute age of the stibnite veins is not known but they are considered to be younger than the main period veins. (See p. 45.)

PYRITE

Pyrite (FeS_2) has been introduced during all the periods of mineralization and is probably a constituent of all the veins of the district; in addition there have been at least two subperiods of pyrite introduction during the main period of vein formation; some writers (Willard, 1941, p. 541) have recognized three periods of introduction in a single vein.

Massive pyrite is found mainly in the Highland-Surprise and Sidney mines and in the mines in the area around the stocks; large amounts of it are not at all common.

The most common mode of occurrence of pyrite is in disseminated euhedral to subhedral grains that range in size from 2 to 3 mm on an edge down presumably to the vanishing point. The replacement of silicates and magnetite by pyrite frequently produces irregular masses as long as veinlets. Poikilitic and skeletal crystals are quite common, and much that might be called corroded or partially replaced pyrite is actually younger than its groundmass. The poikilitic character of the pyrite is best recognized where the pyrite has partially replaced country rock in a vein. Similar textures also result where pyrite has replaced the older vein minerals. It is not always possible to tell whether the shape of a crystal results from corrosion and thus represents an older mineral or whether it is a skeletal crystal and thus indicates a younger mineral.

A very small amount of pyrite is recognizably colloform in structure; probably such pyrite was once fairly widespread in the Coeur d'Alene district and has been mostly obliterated by recrystallization. Colloform pyrite has been collected from the 1900, 2500, 3700, and

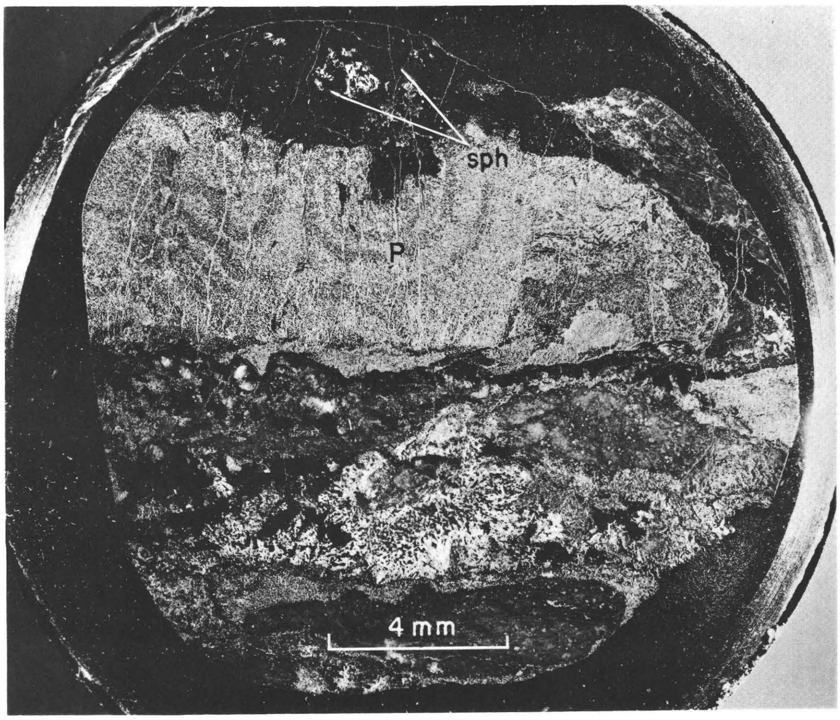

FIGURE 4.—Photomicrograph of colloform pyrite partially replaced by sphalerite (black), 1900 level, Star mine, Coeur d'Alene district, Idaho. Plane-polarized light.

4900 levels of the Star mine; from the Highland-Surprise mine, and from dumps of prospects in Terror Gulch. (See Bowyer and others, 1954, for location.) References to colloform pyrite from high-temperature deposits are apparently rare; the paper by Smitheringale (1928) contains the only one known to me.

The colloform texture of pyrite from the Star mine is shown in figure 4. The colloform masses obviously were once larger.

NICCOLITE

Stringham and others (1953, p. 1280) mentioned that niccolite (NiAs) has been reported from the Hercules mine. No niccolite was recognized during this study in material from the Hercules mine or from any other mine in the district.

GERSDORFFITE

Gersdorffite ((Ni,Fe,Co)AsS) was first recognized in the Coeur d'Alene district by Willard (1941, p. 542) on the basis of etch tests; X-ray analysis by J. M. Axelrod (written communication, 1953) has confirmed the identity of the material. The only known occurrence is in the siderite-tetrahedrite veins of the Page-Galena mineral belt, where it is considered (Fryklund and Hutchinson, 1954, p. 756) to be among the early ore-shoot sulfides, following siderite and pyrite but preceding tetrahedrite. Gersdorffite is generally a minor constituent of most of the siderite-tetrahedrite veins, but in the Silver Summit mine it was present in quantities large enough to constitute cobalt and nickel ore, though it was not recovered.

Grains of gersdorffite are rarely larger than 1 mm and most are less than 0.5 mm in diameter. They are anhedral and corroded. As is common elsewhere, the gersdorffite is zoned. Bulk composition, based on assay data, suggests an average of twice as much nickel as cobalt.

MARCASITE

The present study has established that minor amounts of marcasite (FeS_2) are fairly widespread in the main period veins that contain pyrrhotite.

Two modes of occurrence can be recognized, granular and bladed, though there seems little doubt that all the marcasite is an alteration product of pyrrhotite (see also p. 14). The greatest concentration of marcasite seen was in material from the Marsh mine dump, where it is recognizable in hand specimens; most of the other marcasite is recognizable only in polished surfaces. Both granular and bladed marcasite are present, but bladed marcasite probably formed largely by recrystallization of granular material. With the exception of that from the Marsh mine dump, all the marcasite-bearing material has come from deep levels where the veins are perfectly fresh, the marcasite therefore, must be hypogene. The time of hypogene alteration of pyrrhotite is uncertain. Chalcopyrite had partially replaced a marcasite blade in one specimen from the Highland-Surprise mine, and marcasite blades are cut by galena (fig. 3) and sphalerite in several mines; hence the alteration is older than the sphalerite and probably happened shortly after the pyrrhotite formed.

Remnants of granular marcasite within alteration pyrite which has partially replaced pyrrhotite provide evidence that marcasite alters to pyrite.

ARSENOPYRITE

Arsenopyrite (FeAsS) has a much more restricted geographical distribution than pyrite, though its distribution in time seems about the same.

The oldest arsenopyrite is disseminated, along with some pyrite, in elongate zones in the eastern part of the Page-Galena mineral belt. Such dissemination has not been recognized in other areas except at the Carbonate Hill (Atlas) mine, but it would not be readily recognizable in dark rocks such as the Prichard and Wallace formations. The arsenopyrite is fine grained and the length of crystals is mostly less than 0.10 mm.

Mitcham (1952, p. 439–442) considered that these zones were favorable indicators of tetrahedrite-bearing veins, but Kerr and Robinson (1953, p. 507) found arsenopyrite to be older than the uraninite wherever evidence of sequence was available, a conclusion with which I agree. In addition, several of these disseminated zones are now known to exist far from any veins, much less ore bodies.

Coarse-grained arsenopyrite, much of it over 0.5 mm long, occurs with coarser grained pyrite in the tetrahedrite-bearing veins of the Page-Galena mineral belt, and this arsenopyrite is younger than the uraninite of the same area. Similar arsenopyrite is common in the Pine Creek mineral belt veins. Arsenopyrite seems to be absent from most of the main period veins north of the Osburn fault.

Arsenopyrite is also present in the Hypotheek vein, which is considered to belong to a younger period of vein formation in the Big It scheelite-stibnite vein, in the other stibnite veins except the Stanley, and in the quartz-gold-arsenopyrite veins typified by those at the General Mines prospects.

No cobalt was found in arsenopyrite from the Silver Summit mine, where there are concentrations of gersdorffite, or from the Big It mine.

POLYBASITE

Polybasite ($(Ag,Cu)_{16}Sb_2S_{11}$) was present in vugs on the 3,000 level of the Silver Summit mine, some 4,500 feet below the surface. Identification was first made on the basis of micro-chemical tests and later confirmed by X-ray analysis (Fred A. Hildebrand, written communication, 1954). The great depth at which polybasite occurs appears to prove a primary origin.

PYRARGYRITE

Pyrargyrite (Ag_3SbS_3) is a rare mineral in the district. Shannon (1926, p. 158) reported its occurrence in the Yankee Boy and Polaris mines of the Silver belt (east part of the Page-Galena mineral belt) and on the 2,000 level of the Standard-Mammoth ore shoot. The mineral has been tentatively identified from ore on the 1,700 level of the Star mine. Occurrence of pyrargyrite at depth suggests that the mineral is primary.

PROUSTITE

A crystal collected by Ransome and Calkins (1908, p. 93) from the Yankee Boy mine (now upper workings of Sunshine mine) was identified by them as proustite (Ag_3AsS_3). Another crystal of the same lot was identified as pyrargyrite by X-ray methods (Fred A. Hildebrand, written communication, 1955). The original material was not proustite, and none has been identified by X-ray methods. Shannon (1926, p. 159) appears to have had no personal knowledge of the proustite he reported.

TETRAHEDRITE

Tetrahedrite ($((Cu,Fe,Zn,Ag)_{12}(Sb,As)_4S_{13})$, after galena and sphalerite, is third in abundance of the ore minerals, and the most recent of the three to be mined in quantity. It is the chief silver-bearing mineral in all the main period veins of the district, but is a major vein constituent only in the east part of the Page-Galena mineral belt (Silver belt).

The tetrahedrite is anhedral except for a few euhedral crystals in vugs, and grain boundaries in polished surfaces cannot be recognized without etching. It may occur in masses 10 feet or more in width, as minute veinlets, and as specks in other minerals such as galena.

According to Palache and others (1944, p. 375), there is a complete series from tetrahedrite (antimony dominant) to tennantite (arsenic dominant); however, tennantite has not been recognized in the district. Tetrahedrite is commercially valuable in the Coeur d'Alene district largely because of silver which substitutes for copper in the tetrahedrite structure. The available analyses of tetrahedrite are presented in table 9. Almost all tetrahedrite examined in polished surfaces contained inclusions of other minerals; most of these inclusions, with the exception of galena, have elements that are also present in the tetrahedrite structure. It has not been possible, during this work, to prepare any sample pure enough to warrant analysis.

TABLE 9.—*Analyses of tetrahedrite from the Coeur d'Alene district, Idaho*

Constituent	1	2	3	4	5
Cu	29.10	29.10	37.70	33.70	26.2
Fe	5.50	5.50	5.13	5.05	----------
Zn	5.09	3.56	3.87	----------	----------
Ag	3.95	6.15	Tr.	5.75	11.12
Bi	0	0	Tr.	0	----------
Pb	0	0	0	0.20	----------
Sb	22.36	22.36	26.81	25.90	26.1
As	10.13	8.59	Tr.	1.18	----------
S	24.16	24.44	26.49	24.10	----------
Total	100.29	99.70	100.0	95.88	----------

1: Sunshine mine (Warren, 1934, p. 694, analysis A).
2: Sunshine mine (Warren, 1934, p. 694, Analysis B).
3: Hypotheek mine (Shannon, 1926, p. 167).
4: Sunshine mine, C. A. Rasor 1934, Silver mineralization at the Sunshine mine: Idaho Univ. M.S. thesis.
5: Sunshine mine (Mitcham, 1952, p. 443).

Although not shown in any of the analyses in table 9, mercury is present in Sunshine mine ore in appreciable quantities (James Coulson, Chief Geologist, Sunshine mine, oral communication, 1958).

There is a distinct possibility that there are two different periods of tetrahedrite deposition, the younger being nonargentiferous. The nonargentiferous tetrahedrite appears to be restricted to the Hypotheek mine (analysis 3 of table 9), to a group of prospects in the Pine Creek area, and to a vein on the Wisconsin claim east of Kellogg (Shannon, 1926, p. 168). These veins, including the Hypotheek, are considered to be younger than those of the main period of vein formation and belong to the first Tertiary period of mineralization.

BOURNONITE

Bournonite ($PbCuSbS_3$) was first recognized in the district by C. A. Rasor [2] in ore from the Sunshine mine. The identification was made by etch and microchemical tests. R. J. Anderson (1940, p. 665) and Willard (1941, p. 545) both recognized bournonite on the basis of similar tests. Bournonite from the Galena mine was identified by X-ray methods during the present study. It is an uncommon mineral in the district.

R. J. Anderson (1940, p. 665) believed that bournonite is found only at contacts between galena and tetrahedrite and that it is a reaction product between the two. Actually, however, it also occurs as veinlets in galena away from tetrahedrite contacts.

MENEGHINITE

A single specimen of meneghinite ($Pb_{13}Sb_7S_{23}$), coating boulangerite, has been identified by X-ray methods (Charles Milton, written communication, 1957). The specimen came from the Lead vein on the 2800 level of the Galena mine. Without any doubt, material identified as bournonite or boulangerite by other than X-ray methods may include meneghinite and probably other as yet unrecognized lead-antimony minerals.

BOULANGERITE

Boulangerite ($Pb_5Sb_4S_{11}$) is probably the most abundant of the late sulphosalts in the Coeur d'Alene district. It has been identified in ores from several mines in the district; perhaps its most notable occurrence was at the Gold Hunter mine (Shannon, 1926, p. 154). Waldschmidt (1925, p. 577) identified the mineral in ore from the East Hecla mine, it has been recognized in the Tamarack mine by E. W. Bulla,[3] Willard (1941, p. 545) recognized it in the Chester vein (for location see Sorenson, 1951), and it has been recognized in a number of other Silver belt veins. Boulangerite probably has been mistaken for jamesonite and stibnite in a number of visual identifications.

Analyses of boulangerite from the Coeur d'Alene district and from Mineral County, Mont. (table 10), show little variation in composition. Palache and others (1944, p. 421) did not consider arsenic to be an essential constituent, even in small amounts.

TABLE 10.—*Composition of boulangerite from Idaho and from Montana*

[Analyses reduced to 88 atoms of sulfur. From Berry (1940) p. 17]

Constituent	1	2	3
Pb	40.2	39.4	40.1
Sb	32.0	31.4	31.6
As	.5	.5	1.3
S	88.0	88.0	88.0

1. Iron Mountain mine, Montana (Shannon, 1921).
2: Iron Mountain mine, Montana (Shannon, 1921).
3: Gold Hunter mine, Idaho (Shannon, 1921).

Boulangerite is younger than tetrahedrite and galena. A surface coating of meneghinite is younger than a boulangerite mass. The relation of boulangerite to bournonite and to the ruby silver is uncertain because of the scarcity of these minerals.

JAMESONITE

Jamesonite ($Pb_4FeSb_6S_{14}$) has been identified in ore from the Hercules mine (Stringham and others, 1953, p. 1280), but none was recognized in this study.

HEMATITE

Specular hematite (Fe_2O_3) is an uncommon vein mineral in a number of the productive veins in the mineral belts north of the Osburn fault. South of the Osburn fault it is a common constituent of carbinate

[2] Rasor, C. A., 1934, Silver mineralization at the Sunshine mine, Coeur d'Alene district, Idaho: Idaho Univ. M.S. thesis.

[3] Bulla, E. W., 1951, A mineragraphic study of ore from the Tamarack mine, Burke, Idaho: Idaho Univ. M.S. thesis.

and barite veins in the Moe-Reindeer Queen mineral belt, but the Yankee Girl vein (Sunshine mine, 3100 level) appears to be the only productive vein south of the Osburn fault that contains specular hematite. Small quartz-carbonate-specular hematite veins are common in the Silver belt part of the Page-Galena belt.

Specular hematite plates range from less than 1 mm to 2 cm in diameter. Most of the hematite is magnetic, presumably owing to magnetite inclusions. Magnetite pseudomorphous after hematite is common in all hematite-bearing veins.

Small amounts of very fine grained specular hematite form a halo around most of the uranium-bearing veins. This hematite was presumably deposited at the same time as the uranium.

URANINITE

Uraninite (UO_2) in uraninite-pyrite veins was first recognized in 1950 in the Sunshine mine (Thurlow and Wright, 1950, p. 401). Since then radioactive material, presumably containing uraninite, has also been found in the Page, Bunker Hill, Crescent, Coeur d'Alene Mines, and Galena mines, all of the Page-Galena mineral belt, and the Sherman and Hercules mines. The uraninite is Precambrian (Kerr and Kulp, 1952, p. 86–87).

MAGNETITE

North of the Osburn fault, magnetite (Fe_3O_4) is a major gangue mineral in the mines in the area around the stocks and is common in the Star mine. Euhedral magnetite is present, and magnetite pseudomorphous after specular hematite is abundant, in some of the veins of the Moe-Reindeer Queen mineral belt south of the Osburn fault. The Yankee Girl vein is the only productive vein south of the Osburn fault that contains magnetite.

The most common mode of occurrence in the area around the stocks is as a partial replacement of grunerite-rich veins. The individual magnetite grains are irregular in shape and range in size from grains just barely visible to those 1 to 2 mm long. Outside the grunerite areas the grains are euhedral, though when present in quantity they tend to merge into massive clumps and clusters. Isolated euhedral grains range in size from less than 0.01 mm to about 0.1 mm on an edge. In the same grunerite-rich veins there are magnetite grains that are pseudomorphous after specular hematite.

GAHNITE

The zinc spinel, gahnite ($ZnAl_2O_4$), was first identified by A. M. Piper [4] in material from the Success and Rex mines. Similar mineral grains were seen in thin sections of material from the Success mine, loaned by Day Mines, Inc. The isotropic grains range from less than 0.01 mm to 0.1 mm on an edge and are bright green. J. M. Axelrod was able to scan a single grain in a thin section by means of a curved crystal spectrograph, and he determined that "the green isotropic mineral grain is a zinc mineral probably with iron and definitely without major lead," (written communication, 1957). There seems little doubt that the mineral is gahnite.

The sphalerite rims on the ends of some gahnite grains indicate that gahnite is the older of the two. No other contacts of gahnite with sulfide minerals have been seen.

CALCITE

Calcite ($CaCO_3$) is a relatively unimportant mineral in the Coeur d'Alene district. At least four types can be recognized; types 1 and 2 are presulfide in age, the other two types are probably much younger than the main period productive stages.

Type 1, massive calcite, accompanies ankerite and siderite at the Dayrock mine. Similar massive calcite is common in the Atlas vein of the Carbonate Hill (Atlas) mine, and it is undoubtedly present in other veins of the Amador type (Shannon, 1926, p. 234) in the southeast part of the Coeur d'Alene district. Shannon (1926, p. 219) has noted "granular" calcite in the upper workings of the Sunshine mine and as a gangue mineral at the Hypotheek mine at the west end of the district.

Type 2 calcite is probably an exsolution mineral. Many ankerite analyses show excessive amounts of calcium for an ankerite structure, and Mitcham (1952, p. 434) has noted what is probably exsolved calcite in thin sections containing ankerite and siderite. Exsolved calcite might be of value in geothermometry.

Type 3 calcite is present in pyrite-calcite veins that reach a width of 1 foot. These veins appear to be most common in mines in the area around the stocks. The only ones that have been recognized lie in the productive structures, but others are undoubtedly present in unexplored ground. One vein on the Hercules mine 1600 level, about 3,500 feet below the surface, generally follows a sheared zone on the hanging wall of the Hercules vein, where it cuts the vein at slight angles. This calcite has replaced wallrock and vein minerals. Similar veins have been recognized on higher levels of the mine, and, as shown by dump material, they were common in many mines now shut down. Some of the white to cream-white calcite grains are 1 cm long but most are about half that length. Pyrite is later than the calcite. The veins are considered to be of hydrothermal origin.

[4] Piper, A. M., 1925, Paragenesis of some primary ores from the Rex and Success mines, Coeur d'Alene district, Idaho: Idaho Univ. M.S. thesis.

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Type 4 calcite occurs as euhedral crystals lining open spaces and is probably of supergene origin. It is generally confined to upper levels of mines; Shannon (1926, p. 219) has described several occurrences.

SIDERITE

Siderite ($FeCO_3$) is perhaps the dominant carbonate in the Coeur d'Alene district, and it probably occurs in at least microscopic amounts in all the veins of the main period of mineralization. Nevertheless, massive siderite is restricted in occurrence, and probably less than a third of the ore mined in the district has come from veins where massive siderite is the dominant gangue mineral. Massive siderite is confined to the central and east parts of the Page-Galena mineral belt, the east part of the Tamarack-Marsh mineral subbelt, the Standard-Mammoth mine, and parts of the Moe-Reindeer Queen mineral belt. Perhaps the smallest amounts of this nonmassive siderite are to be found in the veins of the Pine Creek mineral belt.

On fresh surfaces the massive siderite is creamy yellow to greenish yellow to buff. When exposed to the atmosphere, the surface becomes dark red brown within weeks. Siderite grains range in size from less than 1 mm to those with cleavage edges 3 inches long. Euhedral to subhedral grains are common but where siderite has replaced country rock and has not been recrystallized, the grains are anhedral and about the same size as the country-rock grains.

Analyses of seven siderite samples from the Sunshine vein of the Sunshine mine (table 11) indicate only slight variations in composition over a considerable vertical range of the vein. Analyses (Shaw, 1959, p. 1674) have shown that siderite from the Bunker Hill mine had a composition of $(Fe_{0.75-0.85}Mn_{0.08-0.10}Mg_{00.6-0.10}Ca_{0.02-0.06})\cdot CO_3$.

TABLE 11.—*Analyses of siderite from the Sunshine vein, Sunshine mine, Coeur d'Alene district, Idaho*

[Samples collected by P. J. Shenon. Analysts: R. K. Bailey (D710-380, 401, 607); R. E. Stevens (D785-616); F. S. Grimaldi (D1190-1, 2, 3)]

Constituent	D710-380	D710-401	D710-607	D785-616	D1190-1	D1190-2	D1190-3
Whole sample:							
SiO_2+insolubles	2.14	1.92	3.38	1.85	5.80	1.61	3.88
$FeCO_3$	85.38	85.62	83.85	86.72	82.27	86.38	84.43
$MnCO_3$	7.29	8.41	7.81	7.60	7.28	7.58	7.39
$CaCO_3$	.57	.57	.36	.41	.71	.68	.71
$MgCO_3$	4.83	3.49	4.14	3.75	4.28	4.20	3.96
Total	100.21	100.01	99.54	100.33	100.34	100.45	100.37
Recalculated after removing SiO_2+insolubles:							
$FeCO_3$	87.06	87.29	87.20	88.05	87.02	87.39	87.50
$MnCO_3$	7.43	8.57	8.12	7.72	7.70	7.67	7.66
$CaCO_3$	.58	.58	.37	.42	.75	.69	.74
$MgCO_3$	4.93	3.56	4.31	3.81	4.53	4.25	4.10
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

D710-380: Two sets below 1700 level, 38 ft west of Survey Station 1707.
D710-401: 700 level, North vein just west of Shaft Station.
D710-607: 2700 level.
D785-616: 2700 level, near east shaft.
D1190-1: 2700 level, east drift, 5 raise.
D1190-2: 3700 level, east drift 400 ft east of No. 4 winze.
D1190-3: 3100 level, 11 stope.

FERROAN DOLOMITE AND ANKERITE

Dolomite ($Ca(Mg,Fe)(CO_3)_2$) and ankerite ($Ca(Fe,Mg)(CO_3)_2$ of varying composition are common in veins of the Coeur d'Alene district proper and abundant or dominant in the Amador-type veins that lie within an area extending eastward into Montana. Shannon (1926, p. 223) was the first to recognize that much that had been called siderite was actually ankerite and dolomite, that both magnesian and ferroan dolomites are present, and that compositions vary greatly.

The present study has added little to an understanding of the mineralogy of these carbonates. Physical mixtures of calcite with dolomite and ankerite are known to exist in the Coeur d'Alene district, and many of the analyses are probably of such mixtures. Further, Shannon (1926, p. 223) stated, "There is represented a gradation from dolomite containing a small amount of iron, to ankerite containing relatively little magnesia, most of the specimens consisting of an intermediate mixture containing both iron and magnesia." Thus a particular analysis may be of a fine-grained mixture of carbonate minerals which, in addition, may have varied compositions. An interpretation of such an analysis must be only tentative.

There seems to be no present way to determine composition of Coeur d'Alene carbonate minerals within reasonable limits by either optical or X-ray methods, nor is it feasible to prepare sufficiently pure material for chemical analyses.

In this investigation, four carbonate minerals have been distinguished on the basis of the omega index of refraction. Carbonates with an omega index of refraction above 1.78 are called siderite. Carbonate minerals with an omega index below 1.66 are called calcite. The distinction between ferroan dolomite and ankerite depends upon whether the mineral has an omega index lower than 1.71 (ferroan dolomite) or higher (ankerite) (Palache and others, 1951, p. 211). During this work, no dolomite was recognized in main period veins, although it may well be present in the Amador-type veins (Shannon, 1926, p. 228). Available analyses indicate that the manganese content of all these carbonates is low, but if a high content of manganese calcite were present, the omega indices of the samples containing manganese calcite would have overlapped those of the ankerite samples (Frondel and Bauer, 1955, p. 752, 753) and the manganoan calcite would not be recognized. The work so far has not indicated that either ferroan dolomite or ankerite predominates in any area.

Ferroan dolomite and ankerite in productive veins is generally present in small stringers, or it is disseminated. Only three mines, the Star, Morning, and the Dayrock, contain approximately equal amounts of ankerite (including ferroan dolomite) and siderite. Of the accessible mines, the Page, the Lucky Friday, and all the mines of the Pine Creek mineral belt appear to contain the greatest amounts of ankerite and ferroan dolomite, and little or no siderite. Some ankerite and ferroan dolomite can be found in at least microscopic quantities in the other mines of the district. None of the descriptions of veins published before that of Shannon distinguished siderite from ankerite; due caution is needed, therefore, in reading the older literature.

No productive veins in the Coeur d'Alene district contain a gangue of massive ankerite or ferroan dolomite. Nonproductive veins of the Amador type containing massive ankerite and ferroan dolomite, sometimes accompanied by substantial amounts of siderite, are present in the southeast part of the district and in neighboring parts of Montana.

Available analyses of dolomite and ankerite are given in tables 12 and 13. Ankerite from the Bunker Hill mine had a composition of $Ca_{1.00-1.12}(Fe_{0.50-0.70}Mg_{0.20-0.26}Mn_{0.06-0.12})(CO_3)_2$ (Shaw, 1959, p. 1674).

BARITE

Barite ($BaSO_4$) occurs as a minor constituent in several of the productive veins and as a major constituent in barren veins that lie south of the Osburn fault. The greatest amount of barite is in barren barite-dominant veins that have some affiliations with the Amador type (ankerite-dominant veins). These veins, in the Coeur d'Alene district, all lie south of the Osburn fault and are known as far west as the Twin Crags Lookout in the Twin Crags quadrangle just southwest of the district. They are especially abundant in prospects in the south part of the Mullan and vicinity quadrangle. Unimportant amounts of barite, younger than the carbonate minerals and older than the base-metal sulfides, are found in the Silver Summit No. 3 vein and the Morning-Star vein. Considerably larger amounts of barite are present in the Gold Hunter veins (Ransome and Calkins, 1908, p. 170). This barite also is older than the ore sulfides. Barite is in the Standard-Mammoth vein (Ransome and Calkins, 1908, p. 103). According to Shannon (1926, p. 444) barite is also present in the Senator Stewart, Caledonia, Crown Point, and Silver King mines in the Bunker Hill area.

Quantitative spectrographic analyses of barite specimens were made for strontium and lead, which are known to replace barium in barite (Palache and others, 1951, p. 411), in order to determine any significant differences in composition between the barite of the productive veins and that of the nonproductive barite-dominant veins. As shown by the analyses (table 14), lead was not detected in two samples and is quite negligible in the other two. The strontium content was less than 1 percent and was nearly the same for each of the samples.

TABLE 12.—*Analyses of ferroan dolomite and ankerite from the Coeur d'Alene district, Idaho, and western Mineral County, Mont.*

[From Shannon (1926)]

Constituent	S-1	S-2	S-3	S-4	S-5	S-6
$FeCO_3$	9.96	8.11	6.73	10.79	26.81	31.32
$MnCO_3$	.66	.54	.45	.24	4.38	2.72
$MgCO_3$	30.80	33.32	28.77	28.23	18.29	17.12
$CaCO_3$	58.58	58.03	64.05	60.74	50.52	48.84
Total	100.00	100.00	100.00	100.00	100.00	100.00

S-1: Copper Age claim, southeast of Mullan, Idaho. This property is shown as the Copper Edge on plate 48 of Wallace and Hosterman (1956).
S-2: Monitor mine, Mineral County, Mont.
S-3: Monitor mine, Mineral County, Mont.
S-4: Manhattan prospect (now part of the Amazon mine), Beaver Creek area, Idaho.
S-5: Carney Copper prospect, Idaho.
S-6: Reindeer Queen prospect, Idaho.

TABLE 13.—*Analyses of ankerite from the Coeur d'Alene district, Idaho*

[Analyst, Norman Davidson, U.S. Geological Survey]

Constituent	F-9-3	F-9-4	F-9-6	F-9-8	F-9-9
Whole sample:					
Insolubles	2.33	18.95	13.28	7.26	27.73
FeO	20.43	12.14	12.74	17.81	12.31
MnO	3.12	1.54	1.95	2.76	2.15
MgO	4.05	8.36	7.19	5.05	5.68
CaO	28.70	23.19	27.01	27.29	20.47
CO_2 [1]	41.37	35.82	37.83	39.83	31.66
Total	100.00	100.00	100.00	100.00	100.00
n_ω [2]	1.732	1.717	1.715	1.735	1-725-1.730
Insolubles removed:					
FeO	20.92	14.98	14.69	19.20	17.04
MnO	3.19	1.90	2.25	2.98	2.97
MgO	4.15	10.31	8.29	5.44	7.86
CaO	29.38	28.61	31.15	29.43	28.32
CO_2	42.36	44.20	43.62	42.95	43.81
Total	100.00	100.00	100.00	100.00	100.00

[1] CO_2 by difference.
[2] Indices of refraction determined by Charles Milton, U.S. Geological Survey.

F-9-3: Sunshine nine, 3100 level, 45 ft south of survey station C-3131.
F-9-4: Coeur d'Alene mine, 1000 level, 15 ft north of survey station W1017.
F-9-6: Coeur d'Alene mine, No. 5 level, at survey station 1062.
F-9-8: Merger Mines prospect, adit level, 165 ft from portal.
F-9-9: Bunker Hill mine, 19 level, Pate ore body.

TABLE 14.—*Spectrographic analyses of barite from the Coeur d'Alene district, Idaho*

[Analyst, Janet D. Fletcher, U.S. Geological Survey]

Analysis	Quantitative analysis		Semiquantitative analysis				Location
	Pb	Sr	La	Ce	Y	Yb	
53-2457SC	0.02	0.6	0	0	0	0	Star mine.
53-2458SC	0	.5	0	0	0	0	Silver Summit mine.
53-2459SC	0	.6	0	0	0	0	Twin Crags Lookout.
53-2460SC	.004	.7	0	0	0	0	Carbonate Hill mine.

Lanthanum, cerium, yttrium, and ytterbium were looked for but not detected. As these "are among the most abundant and spectrographically sensitive rare earth elements" (Janet D. Fletcher, written communication, 1954), one may assume that no other rare earth elements are present. These analyses indicate close chemical similarity, if not identity, of the sources of the fluids that formed the barite. It should be noted in this respect that the Star mine is north of the Osburn fault, whereas the others are south of the fault.

SCHEELITE

In the Coeur d'Alene district proper, scheelite ($CaWO_4$) is found in a small group of veins centering around the Big It mine, in Trapper Creek just south of the East Fork of Pine Creek. Scheelite is also present in the south vein of the Silver Crescent mine in the East Fork of Moon Gulch and in the gold veins of the Murray district (Shenon, 1938, p. 18).

Scheelite probably was deposited during the second Tertiary period of vein formation.

QUARTZ

Most of the quartz (SiO_2) in the Coeur d'Alene veins was an original constituent of the country rock which was recrystallized in place, or had been moved negligible distances. Some quartz has been introduced, but the distance such quartz moved is uncertain.

Quartz recrystallization can be recognized in the veins of all of the productive mines that were studied. Clear glassy recrystallized quartz is much more common in the Pine Creek area and the veins of the Nine Mile-Canyon Creek area surrounding the stocks. Light-gray and milky recrystallized quartz is more common in the Star, Page, Bunker Hill, and Silver Belt mines.

When sericitic quartzite or quartzose slate recrystallizes to pure quartz, rock fragments and sericite are removed. Lindgren (1904, p. 109) appears to have first recognized that the sericite in Coeur d'Alene district rocks is physically moved away and may be segregated. Mitcham (1952, p. 434) observed the phenomenon of growing siderite sweeping sericite ahead of the siderite grains, and apparently he also recognized that sericite was segregated during the recrystallization of sericitic quartzite. The sericite segregations, the grains of which may also have been recrystallized, were recognized in material from the Dayrock, Page, Galena, Highland-Surprise, and other mines.

Additional periods of quartz grain recrystallization in very small amounts, are demonstrated by the presence in some veins of quartz blades oriented perpendicularly to the surfaces of sulfide and carbonate mineral grains. Recrystallized bladed quartz on opposite sides of a pyrite grain to form "pressure shadows" has been noted by Mitcham (1952, p. 438) in the Sunshine mine, and they also occur in the Galena mine and in thin sections of country rock from the Sunset Minerals mine.

Quartz that cuts vein minerals is believed to be introduced quartz. It can be recognized in many veins, but is very much less abundant than the early recrystallized quartz. The greatest amount of introduced quartz fills the nearly horizontal fractures that are commonly called tension cracks; it replaces country rock outward from these fractures. These tension-crack veins are most readily recognized where they leave the main vein and pass into country rock, but usually they can be traced to some extent in the main vein. The quartz that fills them is milky white and may merge with early white recrystallization quartz.

ADULARIA

Adularia ($KAlSi_3O_8$), low-temperature orthoclase, has been reported by Stringham and others (1953, p. 1280) "* * * in two specimens taken from the main Hercules fissure zone between two stoped areas where essentially no prominent sulphide mineralization was present." Stringham and his coworkers believed the adularia belonged to the silicate stage of vein formation. I collected no material from this part of the Hercules vein.

ALBITE

Shenon (1938, p. 20) has reported albite ($NaAlSi_3O_8$) from veins in the Murray area just north of the Coeur d'Alene district proper; it has not yet been recognized in any of the Coeur d'Alene district veins.

ANTHOPHYLLITE

Although mentioned by several investigators, anthophyllite probably does not exist in the Coeur d'Alene district; what has been called anthophyllite is probably actinolite.

ACTINOLITE

What was thought to be anthophyllite ($Ca_2(Mg,Fe)_5(Si_4O_{11})_2(OH)_2$) was first noted by Ransome and Calkins (1908, p. 99); Shannon (1926, p. 289) published an analysis and description of what he called "ferroanthophyllite." The original material was reexamined by Winchell (1931, p. 253) and determined to be actinolite. "It shows parallel extinction between crossed nicols of groups of fibers in any position and also of single fibers in the usual position, but V. E. Barnes reports that a single tiny fiber when turned on its axis to a suitable position shows an extinction angle of about 10°, although it shows parallel extinction in some positions."

TABLE 15.—*Optical properties of grunerite from the Coeur d'Alene district, Idaho*

[Determined by P. L. Weis. 2V estimated]

Field sample	Mine	Refractive index of Z	Z∧C	2V	Comments
VCF-273a-53	Frisco	1.706–1.710±0.006	14°	Very large	
VCF-276-53	do	1.706–1.718±0.006	8°–10°	75°–85°(−)	Twinned.
VCF-278-53	do	1.697±0.004	5°		
VCF-278a-53	do	1.705±0.004	4°	80°–85°(+)	Twinning rare.
VCF-294-53	do	1.715±0.005	13°	75°±(−)	Weakly pleochroic, Z=pale yellow, X=colorless.
VCF-294a-53	do	1.708–1.711±0.006	8°–10°	Very large(−)	Twinning rare.
VCF-296-53	do	1.718±0.003			Twinning rare.
VCF-298-53	do	1.704±0.005	6°–10°	70°–75°(−)	Y=1.698–1.700; twinned.
VCF-444-7-53	do	1.705–1.718±0.005	1°	75°(−)	Y=1.699; Twinned.
VCF-23b-54	Hercules	1.718±0.003	0°–2°	85°±(−)	Twinning rare.
VCF-29b-54	Interstate-Callahan	1.718±0.003	10°	Large(−)	Twinned.
VCF-29j-54	do	1.718±0.003	10°	80°(−)	Twinning very rare.
VCF-29L-54	do	1.718±0.003	Parallel	85°(−)	Distinct dispersion, v; twinned.
VCF-22-56	Hercules	1.718±0.003	9.5°–11°		

A short-fiber amphibole with parallel extinction is an uncommon constituent of the silicate-bearing veins, and all the occurrences of an amphibole with parallel extinction are probably of actinolite rather than anthophyllite. This mineral has been recognized only in thin section and no X-ray analyses have been made.

In thin section the individual needles or fibers are generally 0.1 mm or less long.

GRUNERITE

Grunerite ($(Fe, Mg)_7 (Si_4O_{11})_2(OH)_2$) is probably the most abundant gangue mineral in the veins surrounding the stocks; it was not identified in the district until 1953 (Stringham and others, 1953, p. 1280).

The grunerite generally occurs as needles less than 0.1 mm long. In a few thin sections there is a rough orientation of the needles, but most commonly they form a tough feltlike mass. The indices of refraction show the mineral to be almost pure iron grunerite, though within a particular vein the indices may vary and presumably also the iron content. The optical properties of grunerite from three mines are given in table 15. Grunerite is younger than green biotite and hornblende and older than siderite.

HORNBLENDE

Hornblende (complex silicate of Ca, Mg, Fe, Al) is much less abundant than grunerite. It appears to be most abundant in material from the Hercules mine,. but this apparent abundance may be due to inadequate sampling of the other veins.

Most hornblende grains are about 0.1 to 0.2 mm long, and the maximum grain size is about 1.0 mm. P. L. Weis found that hornblende from a single specimen had rather widely varying optical properties. They were Z∧C=15°–29°; (−)2V=70°; X=1.656–1.658; Y=1.672–1.688; Z=as low as 1.687; X=light yellow green; Y=yellow green; Z=blue green. Similar variations in optics of vein hornblende were found by Ross (1935, p. 65) in the copper veins of the Ducktown district, Tennessee.

GARNET

Garnet (complex silicate of Al, Fe, Ca, Mg, and Mn) is a minor constituent of the silicate-bearing veins because in large part, it has been replaced by masses of grunerite. It is most noticeable, with biotite, as a selvage along veins, but it may also be found in specimens containing sulfides. The color is generally salmon pink. Euhedral gains range from about 0.02 to about 3.0 mm in diameter; they are restricted to areas where the grains grew in biotite. Where the garnet directly replaced country rock, or recrystallized country rock, the grains are anhedral and frequently poikilitic; grain size of this material ranges from less than 0.01 to about 0.2 mm.

Ransome and Calkins (1908, p. 99) described the garnet but did not attempt to determine its composition. They erroneously described it as being a constituent of the contact zone of the stocks as well as a constituent of the veins. Stringham and others (1953, p. 1279) called the garnet from the Hercules mine andradite. G. W. Leo, U.S. Geological Survey, found that the refractive index of Hercules mine garnet ranged from 1.785 to 1.793: the unit cell size of a single measured grain was 11.71±0.01 A. An analysis of a number of grains from a single specimen is given in table 16. This garnet obviously is not andradite, but a simple name is not possible. The analyzed material contained about 2 percent impurities, mainly quartz (G. W. Leo, written communication, 1959).

TABLE 16.—*Analysis of garnet from the Hercules mine, Coeur d'Alene district, Idaho*

[Analyst, M. K. Carron, U.S. Geological Survey. Analysis 153820, field sample VCF-7-55]

SiO_2	36.99	MnO	12.13
Al_2O_3	19.95	BaO	1.08
Fe_2O_3	1.69	H_2O^-	.00
FeO	11.22	TiO_2	.53
CaO	12.13		
MgO	4.64		100.36

TOURMALINE

Tourmaline (complex silicate of B, Al, Fe, Mg) appears to be a rare constituent of some of the silicate-bearing veins. Tourmaline that may be part of the vein seems most abundant in samples from the Frisco vein of the Frisco mine where it was recognized in fragments of unreplaced quartzite. Here it is pleochroic in green and olive green, two to three times the length of the detrital quartz grains (which are 0.02±mm in diameter), and cuts across quartz grains. The tourmaline grains have diverse orientations.

MUSCOVITE

Muscovite (sericite) ($K\ Al_2(AlSi_3O_{10})(OH)_2$) is present in veins as a constituent of unreplaced country rock and as recrystallized material that formed at the same time as the recrystallized grains of country rock quartz that are so common in the veins. Muscovite from the Lead vein of the Galena mine reached 2 mm in diameter, but most muscovite is rarely more than 1 mm in diameter.

BIOTITE

Green to olive-brown biotite ($K_2(Mg, Fe_2)(AlSi_3O_{10})(OH)_2$) was first recognized by Ransome and Calkins (1908, p. 101) as a constituent of all the silicate-bearing veins of the district. The present study has shown that two other biotites are also present in these veins. (No two of the biotites were deposited at the same time.) A distinctive feature of the green biotite is a platelike shape. The grains usually range from 0.01 to 0.05 mm in diameter, although some were about 0.3 mm in diameter. Optical properties of green biotite differ even in the same hand specimen, and no composition or range of compositions seems characteristic of any one vein. Optical properties of six samples of green biotite are shown in table 17, and a chemical analysis of one of the samples is given in table 18. The analysis shows a high ferrous iron content and an unusual chlorine content.

TABLE 18.—*Analysis of green biotite from the Interstate-Callahan mine dump, Coeur d'Alene district, Idaho*

[Analyst, M. K. Carron; alkalies (Na_2O, K_2O) determined by flame photometer by Paul D. Elmore; fluorine determined by S. M. Berthold; all of the U.S. Geological Survey. Lab. sample 153819, field sample VCF-29K-54]

SiO_2	31.56
Al_2O_3	15.98
Fe_2O_3	2.75
FeO	32.12
CaO	.58
MgO	3.43
MnO	1.02
BaO	.33
Na_2O	.15
K_2O	6.47
H_2O^+	3.98
H_2O^-	.02
TiO_2	1.20
F	.35
Cl	.24
	100.18
Less $O \rightleftharpoons F_2$	.15
	100.03
Less $O \rightleftharpoons Cl_2$	.05
	99.98

The biotite of this sample is annite; probably all the green biotite is annite. The green biotite is the first mineral to form, after quartz recrystallization, in the silicate-bearing veins.

Brown biotite having an elongate, shredlike habit occurs in the Rex mine in veinlets that cut green biotite, as well as chlorite that replaces garnet. The biotite is strongly pleochroic with X=light yellow brown and Z=very dark brown, almost black; the β index of this

TABLE 17.—*Optical properties of green biotite, Coeur d'Alene district, Idaho*

[Determined by P. L. Weis. 2V estimated]

Field sample	Mine	Refractive index of Z	2V	Comments
VCF-269a-53	Frisco	1.658±0.004	Small (−)	Y=Z=dark green to greenish brown.
VCF-274-53	do	1.657±0.003	0°-4°(−)	X=light greenish yellow, Y=Z=dark forest green.
VCF-276-53	do	1.620-1.625±0.008	5°-20°(−)	Range of several grains.
VCF-290-53	do	1.620-1.625±0.007	0°-5°(−)	X=yellowish brown, Y=Z=dark brown. Range of several grains.
VCF-291-53	do	1.590-1.600±0.010		Range of several grains. Y and Z in individuals=dark brown or olive brown.
VCF-29K-54	Interstate-Callahan	1,653-1,658 (most 1,656±0.005)	0°(−)	Range of several grains. X=light olive green, Z=Y=dark greenish olive.

TABLE 19.—*Optical properties of brown biotite from the Coeur d'Alene district, Idaho*

[Determined by P. L. Weis. 2V estimated]

Field sample	Mine	Refractive index of Z	2V	Comments
VCF-270a-53	Frisco	1.588–1.593 ±0.005	0°(−)	Range of several grains. X=1.564–1.572. In one grain 2V=10°(−) X=yellow brown, Y=Z=very dark brown.
VCF-276-53	do	1.64±0.008	0°–5°(−)	
VCF-287a-53	do	1.663–1.665 ±0.004	0°(−)	Range of several grains. X=light brown, Y=Z=dark brown.
VCF-22-56	Hercules	1.654–1.662 ±0.005	2°–10°(−)	Y=Z=dark yellowish brown.
ABG-3-49	Rex	1.660±.0005	0°–5°(−)	Y=Z=dark yellowish brown.
W-6-58	Hercules	1.675±0.005	Very small (−).	X=pale yellow, Y=Z=dark brown or greenish brown.

mineral was 1.595. Brown biotite grains may reach 0.2 mm in length. Very small amounts of a similar biotite were recognized in thin sections of veins from the Herculese, Tamarack, and Frisco mines. Optical properties of some brown biotite samples are shown in table 19. This biotite is younger than garnet, and probably younger than the amphiboles, but its age with respect to the other vein minerals is not known.

A third type of biotite, possibly related to the brown biotite described above, can be recognized in thin sections of carbonate minerals that have been partially replaced by magnetite. The mica is shredlike in habit and occurs either in veinlets that cut carbonate or as individual shreds that lie in a carbonate groundmass near the oxides. The color of this mica varies considerably even in the same thin section, but X is generally colorless and Z may range from a very faint yellow to a rather dark mulberry brown. If color is indicative, there must be a wide range in composition.

CHLORITE

Hydrothermal chlorite (complex silicate of Al, Mg, Fe) is present in many veins and it has been deposited in the country rock on a large scale. The composition of the varieties of chlorite has not been correlated with distribution and occurrence because of the lack of material suitable for chemical analysis; correlation of the composition of chlorite with the optical properties is not possible.

Several varieties of chlorite may occur in the same vein, and, as pointed out by Ransome and Calkins (1908, p. 101), some are not readily distinguishable from green biotite.

Mitcham (1952, p. 444 ff.) classified the chlorite according to mode of occurrence and indicated some of the optical variation to be expected. In this report, however, we are only concerned with the hydrothermal chlorite of which there appears to be a bewildering number of varieties and it seems best to follow Mitcham (1952, p. 449) and classify these varieties simply as early or late.

Early hydrothermal chlorite is best formed in the Carbonate Hill (Atlas) mine area where there is an extensive zone of chloritic alteration. This chlorite is possibly the same as the vein chlorite so conspicuous in the magnetite-chlorite veins on the Carbonate Hill (Atlas) mine 2400 level and in the veins of the Gem State prospect. The two modes of occurrence are quite distinct, but the two varieties are otherwise identical.

Several varieties of chlorite can be recognized in the silicate-bearing veins. Some occur in veinlets that cut biotite and carbonate minerals; others have replaced, or might be considered to be alteration products of garnet, biotite, and the amphiboles. Whether all this chlorite was formed at various times or at single time is not known. The range in color, absorption intensity, and interference colors suggest formation at different times, but crosscutting relations seem absent. I am inclined to believe that most of the chlorite is postcarbonate in age and came into the veins about the time the iron oxides were deposited. This would imply that the iron oxides are approximately the same age as the chlorite in the Carbonate Hill (Atlas) mine.

Late hydrothermal chlorite also is present as coatings on fracture surfaces that cut sulfides in some veins; and, as suggested by Mitcham (1952, p. 445), some chlorite that coats fracture surfaces in the country rock is also probably postsulfide in age.

The only chemical analysis available of Coeur d'Alene chlorite is of postcarbonate presulfide chlorite from the Sherman mine. The analysis by Shannon, which assumes all iron to be ferrous, is shown in table 20.

According to Shannon (1926, p. 381), the chlorite is apparently biaxial with 2V nearly 0°; pleochroism is not marked, X=pale green, Y and Z=bluish green; and refractive indices are about 1.640 to 1.645.

P. L. Weis has found that the optical properties of hydrothermal chlorite have a wide range even in the

TABLE 20.—*Analysis of chlorite from the Sherman mine, Coeur d'Alene district, Idaho*

[From Shannon (1926)]

SiO_2	21.56
Al_2O_3	20.44
FeO	39.40
CaO	Tr.
MgO	8.62
H_2O	9.88
	99.90

TABLE 21.—*Optical properties of some samples of vein chlorite from the Coeur d'Alene district, Idaho*

[Determined by P. L. Weis. 2V estimated]

Field sample	Mine	Indices of refraction	2V	Comments
VCF-179c-52	National	Y variable, 1.560–1.590±0.006	0° (–)	Birefringence 0.006(?); yellow-green. Range for several grains.
VCF-270a-53	Frisco	Z,Y=1.656–1.658±0.005	0° (–)	Birefringence=0.004–0.008; grass green. Range for several grains.
VCF-276-53	Frisco	Z=1.641–1.61±0.006	0–5° (–)	Range for several grains; green.
VCF-290-53	Frisco	Z=1.592±0.004	0–5° (–)	
VCF-291-53	Frisco	Y,Z=1.587±0.003; X=±1.56	(–)	X=nearly colorless; Y=Z=medium green.
VCF-407-53	Atlas	Y,Z=1.648±0.004	(–)	Birefringence=0.004.
VCF-424-53	Atlas	Z=1.565 to 1.58+ ±0.005		Range for several grains. Z=Y=medium green.
VCF-16b-54	Silver Summit	Y,Z=1.649±0.003	10° (–)	Birefringence=0.006.
VCF-22-56	Hercules	Some Z=1.649±0.004 Some Z=1.640±0.004		
VCF-100-57	Gem State	X=1.641–1.640±0.003; Y,Z=1.649±0.003	Small (–)	
VCF-116-57	Gem State	X=1.651; Y,Z=1.653–1.654±0.003	5° (–)	X=light yellow brown, Y=Z=clear deep green.
ABG-180-49	Frisco	Z=1.647–1.652±0.003		Range for several grains.
W-6-58	Hercules	X=1.588–1.6(?) Y,Z=1.649–1.660±0.003	Small 0°–4° (–)	

same vein; as yet no composition pattern distinctive of particular veins can be recognized. The optical properties of some samples of vein chlorite are shown in table 21.

SUPERGENE VEIN MINERALS

Supergene minerals were not studied during the present investigation because most of the oxidized ores have long since been mined out. The oxidized ores were unusual, and native lead was present among other rare minerals. Most of these minerals have been described by Shannon (1926); an incomplete listing is given by Ransome and Calkins (1908, p. 90 ff.).

MINOR ELEMENTS

Many elements of actual or potential economic interest are present in Coeur d'Alene ores only as minor constituents of various ore minerals.

Cadmium, germanium, gallium, mercury, and indium are among the minor constituents of district sphalerite (table 6). The average cadmium content is 0.41 percent; the average germanium content is 0.001 percent; the average gallium content is 0.0015 percent; the average mercury content is 0.009 percent.

Cadmium is recovered from zinc concentrates from the Coeur d'Alene district (Lansche, 1955, p. 261), and cobalt is stockpiled as a byproduct of the Bunker Hill Co. zinc smelter (Davis and Buck, 1958, p. 390).

If the market price warranted, germanium, gallium, and indium could also be recovered. The mercury content of analyzed sphalerite is particularly interesting in view of the large amounts of sphalerite mined. In 1957, production of zinc was 54,825 short tons and in the period 1884–1957 was 1,945,172 short tons (Baber and others, 1959, p. 378). Thus it is apparent that since 1911, when substantial amounts of sphalerite were first recovered in the Coeur d'Alene district, considerable amounts of mercury have been dissipated and that geochemically, at least, the Coeur d'Alene district ranks as an important center of mercury deposition. Any recovery of mercury as a zinc smelter byproduct might have considerable impact on traditional producers.

The selenium content of six samples of sphalerite from the Page mine was determined (table 22). If these samples are representative, the district sphalerite would not be a significant source of this element. No other sulfides were analyzed for selenium.

Analyses for minor elements of tetrahedrite were not made because of the difficult seperation problem, though

TABLE 22.—*Analyses showing selenium content of sphalerite from the Page mine, Coeur d'Alene district, Idaho*

[Analyst, Esma Campbell, U.S. Geological Survey]

Field sample	Analysis	Se (percent)
VCF-313-53	150448	0.0006
VCF-315-53	150449	<.0008
VCF-336-53	150450	.0008
VCF-340-53	150451	.0006
VCF-367-53	150452	<.0008
VCF-371-53	150453	<.0008

it is known that bismuth and mercury are present in probably significant amounts. A large tonnage of tetrahedrite is mined each year, and substantial amounts of bismuth probably could be recovered.

ORE DEPOSITS

GENERAL FEATURES

The ore deposits of the Coeur d'Alene district are replacement veins that appear to be characterized by simple structural controls and, though the list of hypogene vein minerals is reasonably long, the individual veins have a simple mineral makeup.

The oldest veins of the district contain uraninite of Precambrian age (Kerr and Kulp 1952, p. 86; Eckelmann and Kulp 1957, p. 1130). Zones of disseminated arsenopyrite are older than the uraninite veins (Kerr and Robinson, 1953, p. 507). The main period of bleaching probably antedates the uraninite veins.

The productive veins of galena, sphalerite, and tetrahedrite, all considered to belong to the same period of mineralization, are younger than monzonitic stocks that have been dated as Late Cretaceous in age (Larsen and others, 1958, p. 51). These main period veins, as they are designated, lie in 12 mineral belts and subbelts (pl. 2A). The mineral belts cut the country rock without regard for fold attitudes or lithology; they appear to have originated as zones of fracturing and shearing that extended to great depths, although the individual fractures probably had only slight to moderate movement. The fractures have served as the channels from which replacement of the country rock started.

The main period of mineralization was accomplished in several episodes or stages. "It would seem, therefore, that movement concurrent with deposition, so that lodes of different systems were reopened at different times, is a sufficient explanation of preponderant galena and siderite in the Bunker Hill area, quartz and galena in the Jersey area, a mixture of the four predominant minerals of the region in the Blue Bird lodes, quartz and galena in the Hecla, sphalerite, quartz, and siderite in the Interstate-Callahan, and quartz and pyrite in the gold area near Murray" (Umpleby and Jones, 1923, p. 132).

An apparent chaotic distribution of ore and gangue minerals has resulted because the fractures were open and accessible during part of the main period of mineralization and closed during other parts. However, if the distribution pattern of minerals formed during different stages of the main period of mineralization are considered separately, fairly orderly zoning of concentric, linear, and planar patterns can be demonstrated. Furthermore, the distribution of minerals in the veins of the main period suggests derivation from three different sources.

The sources of the main period veins are believed to be: (1) the roots of the monzonitic stocks, (2) a deep-linear source, over 95 miles long, that may have tapped the top of a cooling batholith, and (3) a deep-point source that may be nonmagmatic in nature. Inasmuch as the oldest source appears to be Late Cretaceous in age, the main period veins are also considered to be of that age.

Most of the main period veins strike N. 60° to 70° W. and dip 65° to 85° S., but there are many exceptions. Many of the ore shoots are of considerable size. The largest ore shoot is in the Morning-Star vein, where a near-vertical ore shoot has been mined, or explored in ore, over a vertical length of 6,700 feet, a horizontal length of 4,000 feet, and a maximum width of 50 feet. Most ore shoots are much smaller, but strike lengths and vertical extents of 1,000 feet are common. Stope widths vary but are commonly 6 to 10 ft. Individual veins vary greatly in appearance, and a simple descriptions is impossible. The veins probably were formed by a series of replacements of the quartzose slate and quartzite country rock working out from what must have been quite unimportant-appearing fractures. Initial replacement of the country rock is commonly incomplete and the replacement of older by younger minerals is also usually incomplete. Introduced gangue minerals are virtually absent in some veins whose ore consists of lenses, stringers, and disseminations of galena and sphalerite in a country rock gangue. In other veins earlier amphibole, siderite, or pyrrhotite, all containing a few remnants of country rock, have been replaced more or less completely by the ore sulfides.

Several groups of veins are considered to be younger than the main period veins and probably are of Tertiary age. Veins of what are called the first Tertiary period contain galena, yellow sphalerite, and nonargentiferous tetrahedrite. Only two of these veins are known to cut a main-period vein. Veins of what is called the second Tertiary period have been mined for stibnite, and one also contained mineable quantities of scheelite. The gold-scheelite veins of the Murray district also are probably of this age. Veins of what is called the third Tertiary period have been recognized only where they cut diabase dikes; they contain dolomite, quartz, arsenopyrite, and a small amount of gold. A group of large, almost barren quartz veins, the only large quartz veins in the district, have been explored for gold with little success. These veins may well be of Tertiary age, but there is no reason to group them with any of the other Tertiary veins. The final group of veins includes the calcite-pyrite veins that cut main-period veins in the area surrounding the stocks; they are also probably Tertiary in age.

AGES OF SOME GEOLOGIC EVENTS

The geologic events of greatest interest in a discussion of the veins are the folding of the Belt Series rocks and the intrusion of the monzonitic rocks and of the lamprophyre and diabase dikes.

The uraninite-bearing veins cut folded and regionally metamorphosed sediments. The uraninite is Precambrian in age; hence the major period of folding and metamorphism must also be Precambrian in age.

The monzonite stocks have been dated as Late Cretaceous in age (Larsen and others, 1958, p. 54) by the lead-alpha method. Lead in feldspar from the south stock has an isotopic constitution concordant with the lead-alpha age (data from L. R. Stieff, written communication, 1959).

I believe there is fairly strong chemical evidence that the minette lamprophyre dikes are different from the olivine-augite-hornblende-plagioclase dikes, and that the latter are genetically related to the late diabase dikes and to the Columbia River Basalt and are therefore Tertiary in age. This point of view is not accepted by my colleagues (S. W. Hobbs and others, written communication, 1959).

The late diabase dikes are younger than the monzonite stocks, as are the lamprophyre dikes. No crosscutting relations are known between the lamprophyre dikes and the diabase dikes.

CLASSIFICATION OF THE VEINS

Ransome and Calkins (1908, p. 84) stated only that the "mineral resources of the Coeur d'Alene district, in the order of their present importance, are (1) lead-silver ores, (2) copper ores, (3) gold ores." Umpleby and Jones (1923, p. 24) used the following classification:

- Deposits in igneous rocks
- Deposits in sedimentary rocks:
  - Disseminated deposits:
    - Copper deposits
    - Sphalerite and galena deposits
    - Pyrite deposits
    - Siderite deposits
  - Contact-metamorphic deposits
  - Replacement deposits along fissures and fracture zones:
    - Lead-silver deposits
    - Zinc deposits
    - Copper deposits
    - Antimony deposits
    - Siderite deposits
  - Fissure fillings:
    - Gold veins
    - Tungsten veins

The work of Shannon (1926) demonstrating two periods of galena-vein formation, that of Shenon (1938) demonstrating that the gold-scheelite veins of the Murray district (and inferentially the scheelite-bearing veins of the Coeur d'Alene district) are younger than galena veins of the main period, and the discovery of the uranium-bearing veins (Thurlow and Wright, 1950) necessitate a new classification of the veins.

Such a new classification should recognize the various periods of vein formation as well as the various types of veins formed during those periods. It is possible to categorize with some simplicity the products of the oldest and of the younger periods of mineralization. Veins of the main period of mineralization cannot be treated in this simple manner. A single main-period vein may contain minerals formed during several stages of deposition and from material that came from more than one source; a simple nomenclature is impossible. It is neither desirable nor correct to classify a galena vein as hypothermal or a sphalerite vein as mesothermal because the terms "hypothermal" and "mesothermal" have no meaning as applied to most of the main period veins. The Hercules vein of the Hercules mine, for example, might be described as a hypothermal biotitie-garnet-amphibole-mesothermal siderite-mesothermal iron oxide-mesothermal sphalerite-galena vein, or the Lucky Friday vein as a mesothermal siderite-epithermal sphalerite-galena vein, but, though descriptive, these designations are cumbersome.

In this report no formal classification is made of the main period veins, and only the important stages of mineral deposition, which indicate the range in major mineralogy to be found in a main-period vein, are listed. The following classification is used:

- Precambrian mineral deposits:
  - Disseminated arsenopyrite and pyrite
  - Bleached rocks
  - Uranium-bearing veins
- Stages of the Main period of mineralization (Late Cretaceous):
  - Country rock recrystallization
  - Silicate stages (biotite, garnet, amphiboles)
  - Carbonate stage
  - Barite stage
  - Iron oxide stages (hematite, magnetite)
- Sulfide stages:
  - Pyrite stage
  - Arsenopyrite stage
  - Pyrrhotite stage
  - Sphalerite stage
  - Tetrahedrite-chalcopyrite stage
  - Galena stage
  - Late sulfosalt stage
- Tertiary mineral deposits:
  - Veins formed during the first Tertiary period of mineralization:
    - Sphalerite-galena veins
  - Veins formed during the second Tertiary period of mineralization (quartz, carbonate, scheelite, and sulfide stages can be recognized):
    - Stibnite veins
    - Stibnite-scheelite veins
    - Scheelite-gold veins
  - Veins formed during the third Teritary period of mineralization:
    - Quartz-dolomite-arsenopyrite-gold veins
  - Veins formed during other Tertiary periods of mineralization:
    - Quartz veins
    - Calcite-pyrite veins

Under the above classification, the Ohio vein of the Dayrock mine would be referred to as a galena vein, the mineralogically more complex Hercules vein would be described as a silicate-iron oxide-pyrrhotite-sphalerite-galena vein, the Sunshine vein of the Sunshine mine as a siderite-tetrahedrite vein, the Sherman vein as a siderite-magnetite-pyrrhotite-galena vein, and so on.

CRITERIA OF PARAGENESIS

The general criteria used in determining paragenetic sequences of vein minerals have been described in several publications (Bastin and others, 1931; Bastin, 1950; Edwards, 1954;), but the subjective aspects of paragenetic determinations make desirable a brief discussion of the criteria used in any particular study. Criteria used during this study are:

1. Crosscutting relations:
    - (a) Veinlets of one or more minerals that cut other mineral masses. The veinlet may or may not completely traverse the mineral mass.
    - (b) Prongs of one mineral mass that penetrate a second mineral mass. (The term "prong" is meant to connote a protuberance whose length is greater than its width at the base. The contacts of the two minerals involved may be relatively straight elsewhere. The chief distinction between a prong and a veinlet is perhaps, first, the greater length of a veinlet and, second, the fact that the parent mass of the prong is readily visible.)
2. Inclusions:
    - (a) Inclusions that are uniformly optically oriented. (These inclusions being older than the host, they are considered diagnostic. Due regard must be given to the possibility that optically oriented inclusions are exsolved phases. This criterion can be used only with anisotropic minerals. Conversely, if closely grouped inclusions of anisotropic minerals are not uniformly optically oriented, they are considered to replace the host mineral.)
    - (b) "Trains" (inclusions that are aligned and closely spaced. The trains are actually incomplete veinlets and might well be included in the crosscutting relations criteria).

The crosscutting relations appear to be the only criteria generally considered diagnostic of age relations among both isotropic and anisotropic minerals; however, even they must be used with care, inasmuch as veinlets that antedate their host mineral (antecedent veinlets) have been recognized in other districts. No attempt was made in this study to determine the relative age of inclusions of isotropic minerals.

Caries and rounded-grain textures are considered of little or no diagnostic value. (Caries were described by Schwartz (1951, p. 582) as "scalloplike contacts or smooth concave and convex boundaries"; they are distinguished from prongs in that their penetration is no greater than the width of the base.) In ores of the Coeur d'Alene district, caries texture has been particularly misleading in determining relative ages of garnet, pyrite, arsenopyrite, and magnetite minerals that tend to have euhedral shapes but which readily form skeletal grains.

Rounded mineral grains have been interpreted, on occasion, as being partially replaced, or corroded, by the surrounding material. If a mineral has no tendency to form euhedral grains, no interpretation of rounded corners can be made safely. Rounded corners on minerals that tend to have euhedral shapes may have some, but not diagnostic, value, but again only if the possibility is excluded that the grains are poikilitic or skeletal.

Because there are so few diagnostic criteria, a paragenetic interpretation of all textures in an ore is often attempted; however, there are more indeterminate than determinate situations to be seen in polished surfaces and thin sections, and it is neither worthwhile nor possible to interpret every contact that is seen between two minerals.

In considering simultaneous deposition, the discussion and usage of Bastin and others (1931, p. 563) have been followed, "substances being considered to be simultaneous only if their precipitation from solution begins and ends at the same time." To quote further, "It is recognized that under natural conditions simultaneous deposition, as so limited, is probably comparatively rare. It is recognized also that overlap is partial simultaneity and that the evidence of overlap consists, in the last analysis, of evidence of simultaneous deposition in one part of the specimen and of successive deposition in an adjacent part * * *. Positive evidence of simultaneous deposition or contemporaneity is in general difficult to secure, and in most cases simultaneity has been doubtfully and tentatively inferred from the absence of any evidences of age diversity."

The following are criteria of simultaneous deposition as listed in the literature:

1. Exsolution intergrowths (Bastin and others, 1931, p. 566).

2. The association of different minerals in zonal intergrowths of definite gel origin (Edwards, 1954, p. 133).
3. Narrow, rapidly alternating crustified banded textures (Edwards, 1954, p. 133).
4. Partial automorphism of Bastin (1950, p. 61).
5. A eutectic (Bastin and others, 1931, p. 565).

Edwards (1954, p. 133) suggested, "Minerals crystallizing simultaneously, but not in solid solution, also develop 'mutual boundaries.' However, this texture, while suggestive of contemporaneous formation, is not a reliable criterion, because such textures can as readily develop from replacement." I agree with Edwards' opinion.

Examples of the generally accepted criteria of simultaneous deposition either do not occur in Coeur d'Alene ores or they have not been recognized. Without any useful evidence for simultaneous deposition, it is impossible to demonstrate overlap in deposition; consequently only successive deposition can be demonstrated in the veins of the districts, although several minerals may occur in two generations or in veins belonging to entirely different periods.

PRECAMBRIAN MINERAL DEPOSITS

DISSEMINATED ARSENOPYRITE AND PYRITE

Zones containing fine-grained disseminated arsenopyrite and pyrite are apparently restricted to parts of the Page-Galena and Moe-Reindeer Queen mineral belts. This apparent restriction may be because of the difficulty in recognizing such mineral deposits in the darker country rock of the Prichard and Wallace Formations. Mitcham (1952, p. 439) first recognized the existence, size, and extent of these zones; he considered that they were indicators of nearby tetahedrite ore bodies. Further exploration has shown that zones of disseminated arsenopyrite and pyrite exist in the parts of the Page-Galena mineral belt where siderite-tetrahedrite veins are absent; the association of the disseminated arsenopyrite with tetrahedrite at the Sunshine mine now seems to be fortutitous.

Kerr and Robinson (1953, p. 507) thought that disseminated arsenopyrite was earlier than uraninite, and I agree. They concluded also that disseminated arsenopyrite is an indicator of uraninite rather than of tetrahedrite. Results of recent exploration, however, suggest that disseminated arsenopyrite does not indicate either uraninite or tetrahedrite.

The uraninite is Precambrian in age. The disseminated arsenopyrite and pyrite then is also Precambrian in age and is the oldest of the introduced minerals.

The zones of disseminated arsenopyrite and pyrite have not been recognized on the surface, but underground they can be recognized in bleached rocks and in unbleached rock of the Revett Quartzite by their darker shades of gray, the darker the gray the more abundant the sulfides. The lengths of the zones are uncertain, but individual zones have been traced for more than 1000 feet; widths vary greatly, 10 to 50 feet apparently being more common and 100 feet not unusual. The individual arsenopyrite grains are euhedral, lack a common orientation, and range from about 0.005 to about 1.0 mm in length; most grains are less than 0.10 mm in length. Pyrite is much less abundant and forms euhedral grains of about the same size. Arsenopyrite and pyrite of the siderite-tetrahedrite veins of the same area are much more coarse grained.

BLEACHED ROCKS

"Bleaching" is the term applied to hydrothermal alteration of widespread zones of Belt Series rock within the district. Because it is discussed more fully in a later section (p. 83 to 95), only a brief summary is given here. The nature of the bleaching depends on the original mineral content of the bleached rock and may be due to the alteration of hematite, presumably to goethite, or to softening in (or loss of) color of regional metamorphic chlorite. A ubiquitous concomitant change, which contributes little to the change in color, is the alteration of magnetite of regional metamorphic origin to goethite(?). Chemical differences between bleached and unbleached rock cannot be detected with certainty, and apparently no material other than water was introduced. Although a large volume of water apparently did pass through these rocks, the temperature must have been low because the detrital plagioclase grains of the country rock are unaltered.

The bleaching stage is probably Precambrian in age. The existence in bleached St. Regis rocks of hemotite formed during the period of uraninite deposition suggests that bleaching possibly predates the period of uraninite deposition. The color change of the St. Regis is due primarily to alteration of hematite quite similar in grain size to the hematite around the uraninite veins; it would seem, therefore, that the hematite accompanying the uraninite veins is younger than the bleaching. The bleaching may be, although it is not necessarily closely related to the zones of disseminated arsenopyrite and pyrite.

URANINITE-BEARING VEINS

The uraninite period of mineralization consists of a single stage of pyrite-quartz-uraninite vein formation of Precambrian age. Uraninite-bearing veins are known in the Bunker Hill, Crescent, Sunshine, Coeur d'Alene Mines, and Galena mines, all in the Page-Galena mineral belt. Anomalous radioactivity, probably caused by minute uraninite veinlets, has been recognized in the Page mine of the Page-Galena mineral belt, the Sherman mine of the Tamarack-Marsh mineral subbelt, and the Hercules mine of the Carlisle-Hercules mineral belt. The most complete description of the occurrence in the Sunshine mine is by Kerr and Robinson (1953, p. 495ff.); all the other known occurrences are apparently similar. The uraninite veins characteristically are in country rock that has been stained by disseminated hematite.

The uraninite veins have a simple mineral makeup, but where they have replaced disseminated arsenopyrite (Sunshine mine) or have been replaced by siderite-tetrahedrite veins (Sunshine and Galena mines) or galena-sphalerite veins (Galena and Bunker Hill mines), their mineralogy may be complex.

Perhaps the field relations are most indicative of the relative age of the uraninite and the later veins. On a gross scale, the uraninite zone in the Sunshine mine is crosscut by the Sunshine A and B veins, a relation that can only be shown on the level map (see Kerr and Robinson, 1953, fig. 3, for example); in the same mine uraninite stringers are cut by siderite stringers. The uraninite stringers in the south wall of the Silver vein, on the 3100 level of the Galena mine, were cut by siderite of the Silver vein.

My observations are in accord with the general picture presented by Kerr and Robinson (1953), who concluded that the uraninite veins in the Sunshine mine had been partially replaced by younger veins.

MAIN PERIOD OF MINERALIZATION

AGE OF THE MAIN PERIOD

The age of the main period of mineralization is of particular interest because of the isotopic composition of the lead in the galena. If an age were given to such an isotopic composition, it would be called Precambrian. If it can be established that the main-period veins are younger than the monzonitic rocks, which are Late Cretaceous in age, changes will be necessary in our thinking about the sources of ore metals. It is believed that the evidence presented below demonstrates that the main-period veins are younger than the monzonitic rocks.

The age relation of the main-period veins to the monzonitic rocks is discussed below under four headings. First, the isotopic evidence and the evidence that vein lead in one other major ore district is much less radiogenic than the feldspar lead of the wall rock, a situation analogous to that in the Coeur d'Alene district, is discussed; second, the direct geologic evidence is presented; third, evidence is given that, though the mineralogy of some of the main period veins is unusual, the Coeur d'Alene district is by no means unique; last, the criteria for the recognition of remobilized veins are considered. The age relation of the main-period veins to the dike rocks is discussed under a fifth heading.

THE LEAD-ISOTOPE EVIDENCE

Ahrens (1956) and Rankama (1954) gave summary reports on the use of lead isotopes in dating. Russell and others (1954) were the first to publish suggestions that lead-isotope data could be used for dating galena. "It is well known that the variations in the isotopic abundances of ore leads cover a much greater range than could possibly be explained by simple isotopic fractionation during any natural physical or chemical process. The observed abundances can be explained by additions of different quantities of those lead isotopes produced by the radioactive decay of uranium and thorium. It is here assumed that variations of the lead isotopes found in galenas are due entirely to this effect" (Russell and others, 1954, p. 301).

Implicit in any postulation that the isotopic constitution of galena lead can be used to date the formation of an ore deposit are the assumptions that (1) all hydrothermal ore deposits are derived from a single type of rock that originally contained uniform amounts of uranium and thorium, regardless of its geographic distribution, and (2) the time of withdrawal from radiogenic contamination is the time of galena formation.

The most generally accepted theory of the origin of hydrothermal ore deposits is that the ore-forming fluids are derived from consolidating intrusions of granitic magma. All the granitic rocks may reasonably be considered as representing a single rock type. One can see readily that, because uranium and thorium disintegrate to produce lead isotopes in the source material, the the most recently formed ore deposits will contain the greatest amount of radiogenic lead. In many ore districts of the world, the isotopic data is in agreement with the geologic evidence. Russell and others (1954, p. 301), however, recognized two classes of common lead, "ordinary" and "anomalous." The "ordinary" lead fits the geologic evidence; methods of calculation necessarily give negative ages to the "anomalous" lead.

It is, of course, not possible to derive this anomalous lead from normal granitic magma because the radiogenic lead isotopes are greatly in excess of the amount that could be generated to this point in the earth's history. Quite obviously, either our knowledge of the thorium and uranium contents of granitic rocks is faulty and extremely wide variations in thorium and uranium content are actually present, or the "anomalous" lead is not derived from granitic magma in the first place.

The main-period veins contain lead isotopes for which Long and others (1959, p. 1114) gave an age of 1,250 million years, and they concluded that the age of the mineralization is also Precambrian, a conclusion not necessarily valid.

Cahen and others (1958, p. 136) had already described as B-type lead that which has an isotopic composition older than the host rock, and of course this relation exists in the Coeur d'Alene district where main period veins cut monzonitic rocks. Murthy (1959, p. 1650) has shown that at Butte, Mont., "The lead in the quartz monzonite is distinctly more radiogenic than the lead in the ore." All the wallrock at Butte is igneous; here is the first known unequivocal evidence in a major ore district that vein lead is isotopically "older" than its wallrock. This relation at Butte, however, is simply a more striking example of that in the Coeur d'Alene district.

I have hesitated to use the term "B-type" for the Coeur d'Alene lead because the deposits originally so designated are bedded replacements. Nevertheless, Murthy and Patterson (1961, p. 59) have applied the term to Butte lead, and the Coeur d'Alene lead may as well also be so designated.

There seems little doubt that a third major class of common lead exists and it only remains to explain the geologic occurrence of such lead. Cahen and others (1958, p. 148) concluded that their B-type lead was rejuvenated from older deposits, though they present no evidence to substantiate this conclusion, and the mechanism of rejuvenation was not stated. Murthy and Patterson are noncommittal as to the source of the lead, only stating, "the ore metals probably were concentrated and isolated in several nonshallow locations" (written communication, 1960). The use of the word "nonshallow" does not suggest that they believed the source of the lead was an old ore deposit. Lastly, Long and others in a later paper (1960, p. 655) concluded, from a small sample I sent them, that "although the deposition of the commercial ore bodies of the Coeur d'Alene district occurred about 1,400 million years ago in Precambrian time, local reheating occasioned by Laramide intrusives caused minor amounts of this sulfide to be remobilized."

The crosscutting relations between main period veins and monzonitic rocks are not as trivial in number or in size as indicated by Long and others (1960). The geologic relations are summarized below and brief consideration is given to remobilization. A discussion of the source of the main period lead is on page 50.

DIRECT GEOLOGIC EVIDENCE

The geologic evidence can be divided into four parts: (1) Evidence that there has been only one period of monzonite intrusion, (2) evidence that main-period veins cut the contact aureole of the stocks, (3) evidence that main-period veins cut monzonite rock, and (4) the negative evidence that ore bodies are absent from the stocks.

Only two writers familiar with the geology of the Coeur d'Alene district, Hershey (1916; 1917) and Crosby (1959), have questioned the age relation of the main-period veins to any part of the monzonite rock; their suggestions will be considered at appropriate places (p. 32).

MONZONITE INTRUSION

Only one period of monzonite intrusion was recognized either by Ransome and Calkins (1908) or by Griggs (1952) who undertook detailed mapping of the stocks and environs. Thus, to the present, no mapping has shown that the Gem stocks are composed of intrusives of different ages. Several rock types are represented but contacts between rock types are gradational. Though no one has drifted along a monzonite dike back to the parent mass, these dikes, which are common along the flanks of the two stocks, are known to be composed of rocks similar to the border phases of the stocks.

It is important to note that neither Hershey nor Crosby advocates two periods of monzonite intrusion. Hershey (1916, p. 20) wrote, "It appears that at the Granite mine, after the intrusion of the acidic dikes, the monzonite magma continued to rise, metamorphosed the sedimentary rocks in advance of it, formed the Granite vein, and then largely destroyed the vein and the contact-metamorphic zone." (The Granite mine is now called the Success mine.) Crosby came to much the same conclusion. Crosby wrote (1959, p. 700), "Because ore in the Success mine is seen to be later than the main mass of the monzonite in some places and earlier in other places, it is considered to be very closely related in time to the monzonite." Such an interpretation simply implies overlap of intrusion and vein formation and gives little encouragement to those who wish to consider the main-period veins to be much older than any of the monzonite rocks of the Coeur d'Alene district.

RELATION OF MAIN-PERIOD VEINS TO THE CONTACT AUREOLE OF THE STOCKS

The Gem stocks have metamorphosed their wallrocks. The metamorphic zone of the Gem stocks that contains new minerals is only a hundred or so feet wide, though in the Hercules mine this zone seems to be missing. The metamorphic zone containing recrystallized country rock minerals extends only some 1,000 to 1,500 feet from the contact, and bedding is recognizable throughout the zone.

Main-period veins in the vicinity of the stocks contain the same minerals and, most important, the same silicate minerals, whether the veins are in the zone containing contact metamorphic minerals as at the Rex mine, whether they lie entirely within the zone of recrystallization as at the Frisco and Sunset Lease mines, lie partly within and partly without the zone of recrystallization as at the Hercules mine, or lie entirely outside the zone of recrystallization as at the Tamarack, Amazon, Interstate-Callahan, Idora, and so on.

These veins are younger than the contact metamorphism, and, of course, younger than the stocks. The silicate minerals in these veins were not formed by thermal metamorphism of preexisting vein minerals.

MAIN-PERIOD VEINS THAT CUT MONZONITE

Inasmuch as there seem to be no students of the district who deny that at least some monzonite rock is cut by main-period veins it seems necessary to present only brief summaries of the evidence where crosscutting relations can be seen. It should be noted at this point that veins belonging to the First Tertiary period of mineralization also cut monzonite. Main-period veins cut monzonite at the following mines:

1. The Success mine, which was not examined in any detail during this study, though in any case little could be added that would change the conclusions of Umpleby (1917) and Piper,[5] who believed all the monzonitic rock was older than the veins, and of Hershey (1916, 1917) and Crosby (1959), who believed only part of the monzonitic rock to be older than the vein. A photograph of a vein in monzonite from the Success mine is shown in figure 5.
2. The main workings of the Interstate-Callahan mine, just west of the north monzonite stock, and a single monzonite dike as much as 50 feet wide which is cut in the main workings. The dike is cut by the Interstate vein on several levels. These relations have been described by Umpleby and Jones (1923, p. 94), W. H. Weed (as quoted by Spurr, 1924, p. 559), and McKinstry and Svendsen (1942, p. 229).
3. The Frisco mine. According to Umpleby and Jones (1923, p. 25), "The Frisco lode extends westward nearly to the igneous contact, and although the main lodes does not reach the monzonite on levels that were accessible in 1916, veinlets of sphalerite together with much disseminated pyrite and less sphalerite were observed in the main monzonite mass on the 1,600-foot level west." Umpleby and Jones are obviously referring to the Gem part of the Frisco 1600 level.
4. At the Sunset lease (sometimes called the "Clarke mine"). Both Umpleby and Jones (1923, p. 25) and Hershey (1916, p. 20) refer to sulfides, including sphalerite, in the monzonite.
5. The American prospect, just west of the Success mine. Quartz and galena veinlets cut monzonite (Umpleby and Jones, 1923, p. 25).
6. The Tamarack mine. A. B. Griggs (written communication, 1959) has noted that the Murphy vein cuts across an apophysis of the monzonite on the No. 5 tunnel level. At this point the vein narrowed and consisted largely of silicate minerals.
7. The Hercules mine, where monzonite dike rocks are in contact at several places with vein material and where veins that cut the border of the stock were intersected in diamond-drill holes on the west end of the 1600 level. On the 1900 level, the Rambler vein (a westward continuation of the Hercules structure) is in contact with a dike 12 feet wide, a leucocratic phase of the monzonite. The dike appears to cut the vein, but, on both walls of the dike, irregular veinlets of galena and sphalerite penetrate the dike for as much as 6 inches from the main contact. In addition, minute veinlets of grunerite cut the margin of the dike. Crosby (1959, p. 700), who showed a map of the exposure, wrote, "the short sulfide prongs are interpreted as postsulfide adjustments." The sulfides show no sign of crushing or smearing as might be expected had they been injected plastically into the dike, rather they occur in a delicate network that seems no different from other replacement veinlets. Sphalerite veinlets in monzonite at this contact are shown in figure 6.

   A porphyritic monzonite dike also exposed on the 1600 level of the Hercules mine has the same relation to the vein as the larger monzonite dike on the 1900 level. This dike also appears to cut the vein, but again sulfide stringers, including pyrrhotite and galena, penetrate the dike; Stringham and others (1953, p. 1278) also noted that small stringers of vein minerals penetrated this dike.

   The core from DDH 1604 (1600 level) well illustrates the relation of veins to stock. A vein between 141.6 and 142.3 feet cuts monzonite, and a thin section across one contact shows the vein to consist of silicate and carbonate minerals, as well as magnetite, pyrite, and pyrrhotite. At the contact the feldspar of the monzonite is largely al-

[5] Piper, A. M., 1925, Paragenesis of some primary ores from the Rex and Success mines, Coeur d'Alene district, Idaho: Idaho Univ. M.S. Thesis.

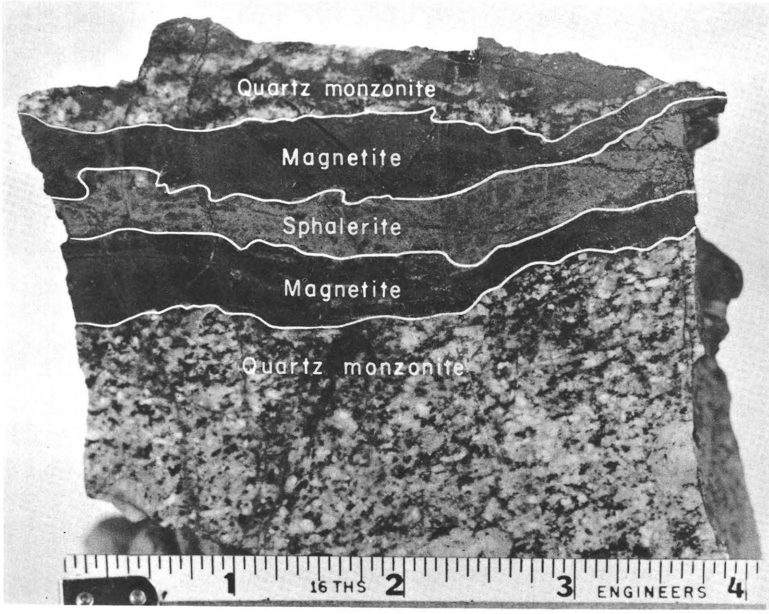

FIGURE 5.—Magnetite-sphalerite vein cutting monzonite, Success mine, Coeur d'Alene district, Idaho.

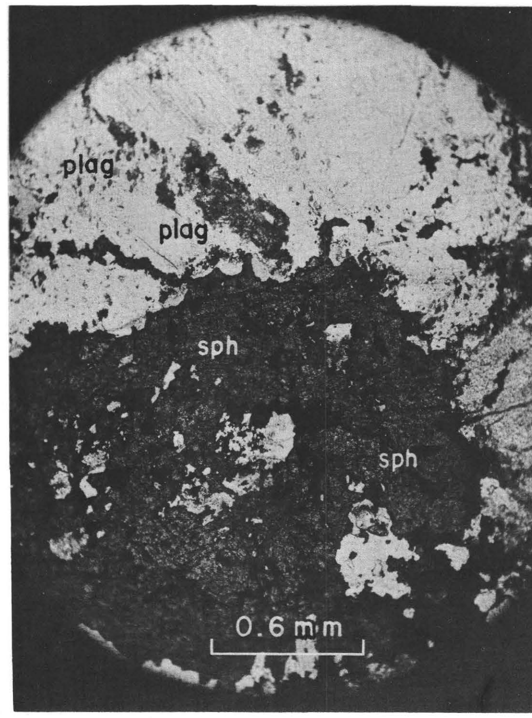

FIGURE 6.—Photomicrograph of sphalerite (gray) cutting porphyritic quartz monzonite, Hercules mine, Coeur d'Alene district, Idaho. plag, plagioclase; sph, sphalerite. Plane-polarized light.

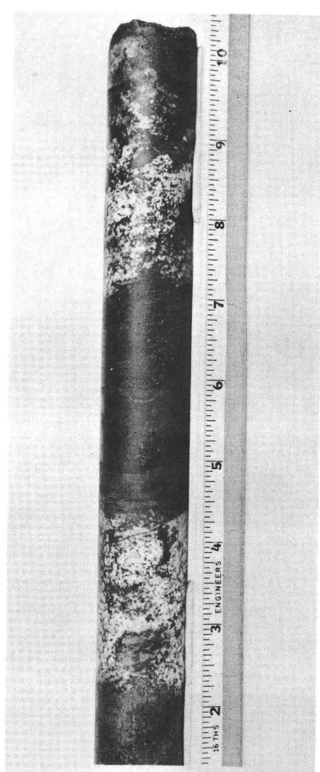

FIGURE 7.—Silicate-magnetite-sulfide veins cutting quartz monzonite, DDH 1604, Hercules mine, Coeur d'Alene district, Idaho.

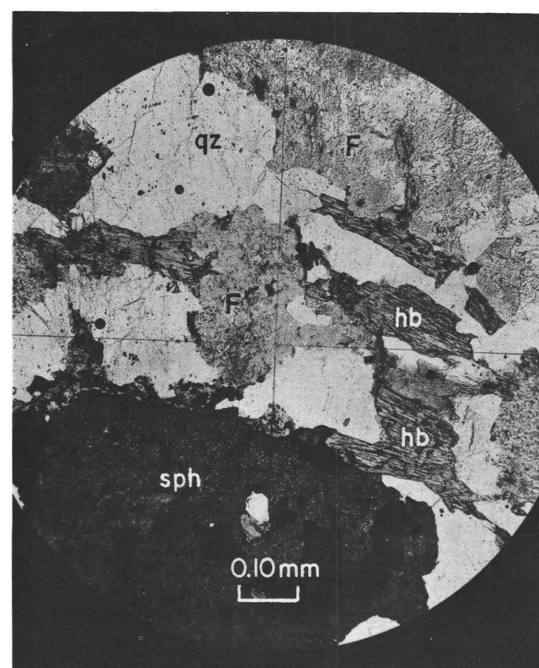

FIGURE 8.—Photomicrograph of hornblende quartz monzonite, partially replaced by sphalerite, Rex mine, Coeur d'Alene district, Idaho. qz, quartz; hb, hornblende; F altered feldspar; Sph, sphalerite. Plane polarized light.

tered to aggregates of chlorite or of sericite cut by chlorite veinlets. From 156 feet to 157 feet, biotite-rich monzonite is cut by several veinlets containing silicates, magnetite, and pyrite. From 175 feet to 176.7 feet, three larger veinlets cut monzonite as shown in figure 7. Another vein was cut at 178.5 feet; the orthoclase feldspar of the monzonite is completely replaced by chlorite for as much as 2.5 cm. from the vein wall, and beyond that distance the feldspar is strongly sericitized.

8. A single quartz monzonite specimen from the upper dump of the Rex mine contained a vein composed of green biotite, garnet, sphalerite, and galena. A photomicrograph of monzonite partially replaced by sphalerite is shown in figure 8.

There is then considerable evidence that veins containing silicates, carbonates, magnetite, and sulfides cut the various phases of the monzonitic stocks and related dikes.

REASON FOR THE ABSENCE OF ORE BODIES IN THE MONZONITE STOCKS

As shown on plate 2*A*, no mines lie entirely in the stocks, and of the three prospects shown in the stocks at least one, and probably two, belongs to the first Tertiary period of mineralization. There is very little evidence of even barren veins in the monzonite where a mineral belt lies on both sides of a stock. I know of no prospects in the stock between the Rex and Tamarack mines. A soil-sample traverse between the Interstate-Callahan and Hercules mines showed anomalies of only twice background.

The most probable explanation of the absence of ore bodies in the monzonite stocks is that the main monzonite bodies did not break in the same manner as the Belt Series rocks. The margins of the stocks were hard enough to permit fracturing, as demonstrated at the Hercules, Gem, and Success mines, but the central parts of the stocks were still plastic; fractures either did not form or were healed before mineral-forming solutions were available. The dike in the Tamarack mine did not fracture in the same maner as the adjacent country rock, and it is suggested that this is the reason the two dikes in the Hercules mine are only insignificantly replaced by the veins.

COMPARISON WITH VEINS IN OTHER DISTRICTS

The silicate-bearing veins of the Coeur d'Alene district are unusual but they are not unique. As far as I could tell from hand specimens and from only one day's examination underground, the Sullivan mine (British Columbia) ore body is mineralogically similar to the silicate-bearing veins of the Coeur d'Alene district. This observation was first made by Schofield (1915, p. 113–115), who devoted a section of his report to a comparison of the Sullivan and Coeur d'Alene ores. He showed several photomicrographs of silicates partially replaced by magnetite and sulfides. Though grunerite was not mentioned by Schofield, it was by Rice (1937, p. 43). The similarity extends to the isotopic constitution of the galena lead. The North Star mine, 2 miles west of the Sullivan mine, and the Stemwinder mine, 1 mile west of the Sullivan mine, contain ore identical with the Sullivan ore (Schofield, 1915, p. 133–135). The ore of the Kootenay King mine, 16 miles east of the Sullivan mine is also identical with that of the Sullivan ore (Rice, 1937, p. 45). The St. Eugene mine near Moyie, British Columbia, contains magnetite, garnet, and actinolite that are in part replaced by sulfides (Schofield, 1915, p. 123). Schofield (1915, p. 115) noted the similarity of the Sullivan ore to that of the Snowstorm (formerly B and B) and Big Eight mines near Troy, Mont. Ore from these two mines was described by Gibson (1948, p. 97 ff.).

The best known of several silicate-bearing veins in the Hoodoo district, Latah County, Idaho, is the Mizpah. As described by Anderson (1941, p. 646 ff.), the silicate minerals of this mine include diopside, tremolite, actinolite, biotite, epidote, tourmaline, microcline, and muscovite. The silicates were partially replaced by dolomite. The sulfide-stage minerals are pyrrhotite, arsenopyrite, chalcopyrite, and cubanite. Anderson concluded (1941, p. 656), "However, the field relations show that the deposit is not pyrometasomatic, but, like the deposits of the Ducktown type, is a replacement of noncalcareous rock."

Silicate-bearing veins are well represented in the general region. There is no need to consider that the Coeur d'Alene veins are unusual or that they are products of contact metamorphism.

Outside the general region the best-known examples of silicate-bearing veins, in the United States, are those of the Ducktown district, Tennessee (Ross, 1935).

THE POSSIBILITY OF REMOBILIZATION

In view of the evidence already presented, remobilization of the ingredients of preexisting veins does not seem either a necessary or likely process in the Coeur d'Alene district. Furthermore, to my knowledge no one has listed any criteria for recognizing remobilized vein minerals.

Long and others (1960, p. 655) stated only that "local reheating occasioned by Laramide intrusives caused minor amounts of this sulfide to be remobilized." The mechanism would appear to be volatilization, but the temperatures needed simply to melt or volatilize the sulfides are well in excess of that expected for the crystallization temperature of a monzonitic intrusive.

Leaching of a vein with hot water and redeposition of its minerals elsewhere appears to be a more likely way of remobilizing vein material, particularly if transporation to any great distance is involved. If the vein mineral, silicates, oxides, and sulfides, could be taken into solution in the first place, which does not seem likely if the event takes place rapidly, the final product should differ from a normal vein only in having simultaneous-deposition textures rather than stage-by-stage replacement textures. Textures resulting from simultaneous deposition of reconstituted minerals have not been recognized in veins adjacent to stocks or in veins in monzonite.

Plastic deformation and extrusion is also a possible process of remobilization, but it is difficult to understand how such material could be transported any great distance. Steel and gneissic galena would certainly be a product of such extrusion, but galena in the Hercules mine dike shows no signs of such deformation. Recrystallization, however, would tend to obliterate such deformation.

Proponents of remobilization must explain how it is done and how the final product is to be recognized.

AGE RELATION OF THE MAIN-PERIOD VEINS TO THE DIKE ROCKS

All workers agree that the main-period veins are older than the minette and hornblende-augite-olivine dikes (Ransome and Calkins, 1908; Hershey, 1916; Shannon, 1920; Umpleby and Jones, 1923; Fryklund and Fletcher, 1956).

The large diabase dikes occur mostly in the west-striking faults, including the Osburn and Placer Creek faults, of the post main period of mineralization. Because these faults roughly parallel the mineral belts, contacts between main period veins and the diabase dikes are rare. Most of those who have expressed an opinion on the matter (Hershey, 1916, p. 13; Jones, 1920, p. 18; Forrester and Nelson, 1945, p. 8) have concluded that the main period veins are older than the diabase dikes; the only exceptions are Shenon and McConnel (1939, p. 6). They stated "Some of the diabase dikes contain secondary quartz, carbonates, and sulphides; for example, the highly altered dike along the Osburn fault contains quartz, calcite, pyrrhotite, pyrite, chalcopyrite, sphalerite, and galena, and the one exposed on the intermediate level of the Merger Mines Corporation contains quartz, calcite, and chalcopyrite." Most of these minerals could have been deposited during some of the Tertiary periods of mineralization, and, with the exception of pyrrhotite, the assemblage is not diagnostic. Pyrrhotite, however, seems to be found only in main-period veins.

The Osburn fault occurrence referred to is near the portal of the Silver Dollar crosscut (Shenon, written communication, 1938). In 1958, exposures in that part of the crosscut were much less accessible than when Shenon and McConnel were there, and the exposures they saw were less extensive than those existing when the crosscut was mapped earlier by R. E. Sorenson. Exposures of the diabase dike in 1958 were limited to a continuous strip about 1 foot wide between the drainage ditch and the lagging; nowhere along this strip were sulfides found. Sorenson's field sheet, dated 1937, was made available by Herbert Harper, Chief Geologist of Hecla Mining Co. The important fact is that sulfide-bearing veins are present but are entirely confined to quartzite of the Prichard Formation, which at this point forms the footwall of the Osburn fault. According to Sorenson (written communication, 1940), "In some places along the footwall of this dike there is a small amount of lead-zinc mineralization associated with a more quartzy bed of the Prichard and with vein quartz."

The most conclusive evidence that a diabase dike is younger than a main-period vein is in the Highland-Surprise mine: The Highland ore shoot is cut by the Placer Creek fault, which has been intruded by a diabase dike.

STAGES OF MAIN-PERIOD MINERALIZATION

The use of the word "stage" as in "stage of deposition" and "stage of mineralization" is common in the literature of ore deposition (Nolan, 1935, p. 108 ff.; Loughlin and Koschmann, 1942, p. 111 ff.; Lovering, 1949, p. 16; Kutina, 1957, p. 316) and is used in this report to mean a step, or a discrete interval of deposition, in the development of a vein. The main-period veins appear to have formed during a series of stages in which the vein-forming fluids were of different compositions, that is, they were produced "by more or less distinct pulses" (Umpleby and Jones, 1923, p. 134). The thesis will be developed that, for example, the siderite stage of deposition took place throughout the district during an interval of time when the vein-forming fluids were of one composition, the galena stage during another interval of time when the fluids were of a different composition, and so on. There is no evidence that siderite or silicate was being deposited at one point while, because of declining temperatures, galena was being deposited simultaneously at another point. Nor is there any evidence that a single isolated body of fluid deposited a group of minerals in a fissure because of declining temperatures.

It seems probable that material in the main-period veins came from at least three different sources and that even during sulfide deposition, when all the sulfides came from the same source, there were appreciable periods when vein-forming solutions did not exist, at least at the levels now exposed.

COUNTRY ROCK RECRYSTALLIZATION

Recrystallization of some country-rock quartz was the first event in the formation of most of the veins. The several steps of recrystallization are still apparent in a large number of places, and probably all the coarse-grained clear gray and white quartz that is cut by silicate or carbonate minerals is recrystallized country-rock quartz. A typical example of the relations that permit the identification of quartz recrystallized from country rock is shown in figure 9. Unrecrystallized country-rock quartz grains are at the top of the photograph; a small shear plane that permitted entrance of the recrystallizing solutions is at the bottom of the photograph. Recrystallization has proceeded up from the shear plane, and the large quartz grains have grown perpendicularly to the plane. The bases of the large crystals are homogeneous; the middle parts contain a few "shadow" grains that have not been completely reoriented crystallographically although they have been incorporated into the large crystals. The upper parts contain grains that have undergone little growth and but slight crystallographic reorientation. In this example and others, the sericitic matrix of the country rock has been

FIGURE 9.—Photomicrograph of partially recrystallized country rock, Tamarack mine, Coeur d'Alene district, Idaho. Crossed nicols.

removed and some quartz has been moved so as to fill the resulting voids, but the amount of quartz thus "introduced" is small and the amount of transport of quartz probably equally so.

The solutions that deposited the vein minerals did not recrystallize the country rock, for country rock remnants are common in the veins and vein walls are generally unrecrystallized.

SILICATE STAGES

The early silicate gangue minerals are present only in the veins surrounding the stocks. However, the assumption of Ransome and Calkins (1908, p. 185) that the silicates were of "contact-metamorphic" origin is not in accord with the conclusion of later investigators (Griggs, 1952, p. 102; Stringham and others, 1953, p. 1279), who consider these silicates to be hydrothermal in origin. Mines where the early silicate minerals are present are shown on plate 5A.

Ransome and Calkins were aware only of the garnet and green biotite; they stated (1908, p. 99), "In the course of the present investigation no garnet has been found in ore bodies lying outside of the recognizable range of contact metamorphism due to monzonitic intrusions." However, in several mines, vein silicate minerals exist well beyond the contact aureole of the stocks. An intermediate step in the transformation of thought about the origin of the vein silicates is the statement of Umpleby and Jones (1923, p. 32), "Contact-metamorphic replacement deposits are not well developed in Shoshone County, although a number of the lodes fulfill part of the criteria of contact metamorphism and evidently were formed under comparable conditions of temperature and pressure."

The first published recognition that the green biotite and garnet in the veins near the stocks belonged to the general hydrothermal sequence was by Griggs (1952, p. 102). His paper was followed by that on the Hercules ore by Stringham and others (1953), who published the first detailed description of the hydrothermal silicate stages and the first recognition of the occurrence of grunerite in the Coeur d'Alene district. The concentric zonal arrangement of the silicate-bearing veins around the stocks strongly suggests a genetic relationship between the two. I consider that the source of the silicates lies in the lower part of the stocks. This source was presumably small, and though it may have served as a source of some of the later iron oxides, it was not the source of either the carbonates or the sulfides of the district. This source will be referred to as the "shallow point" source—"shallow," by comparison with the other sources, and "point," because geologically it is small enough to be so designated.

BIOTITE STAGE

The biotite stage is the oldest of the stages in the veins immediately surrounding the stocks. Biotite occurs in veins, in veinlets, and as disseminations that may extend 50 to 100 feet from a major vein into the wallrock. The green to olive-brown biotite is restricted to the mineral belts. As indicated by unreplaced remnants in veins of grunerite and sulfide, some of the biotite veins must have been about 10 feet wide. The veins are very dark green, almost black. Such veins are almost entirely composed of biotite grains, though hornblende and unreplaced quartz grains or even quartzite remnants may be present. The individual grains of biotite may be unoriented or may be in layers where the plates are oriented. Individual grains are small and in the grain-size range of the country rock.

Underground, the contacts of biotite veins with country rock are sharp and mappable, for the concentration may change over a distance of only 4 to 5 mm from almost 100 percent biotite in the veins to perhaps 10 percent in the country rock. Biotite in diminishing amounts may extend 50 or even 100 feet from the larger veins out into the country rock, but only millimeters out from biotite veinlets.

The biotitite has completely or partially replaced what is usually a quartzose slate or a sericitic quartzite. Replacement of the country rock started along quartz-grain boundaries, and there is no indication that sericite grains served as centers of nucleation. The pattern of partial replacement of country rock is linear and obviously is controlled by minor fractures, though these may be recognizable only in thin section. The presence of unreplaced remnants of country rock in biotite masses suggests there must be very effective barriers to movement of fluids outside microchannels. The presence of sericite grains crosscut by biotite grains is equally suggestive that solutions could not move far from microfractures.

The work of Eugster (1957) on ferrous biotite (annite) should permit an estimation of the formation temperature of the biotite stage; however, the stability field of pure annite is fairly large. It should be realized (1) that Eugster is concerned with pure annite (the analysis of table 18A shows significant amounts of Fe_2O_3, MgO, and MnO), (2) that decreasing partial pressure of oxygen significantly decreases the formation temperature, and finally (3) that formation temperature will vary directly with total pressure of the whole system. It should be noted that the total pressure will have considerably less influence on the formation temperature than the partial pressure of the oxygen alone. The formation of annite in the quartz-rich rocks of the Prichard Formation suggests then, on the basis of figure 12 of Eugster (1957, p. 162), a maximum temperature of formation of about 660°C and the possibility that the actual temperature was 100° to 200° lower.

GARNET STAGE

As far as can be determined, garnet is found in the same parts of mineral belts as biotite and amphiboles. The distribution of garnet is intermediate in extent between that of biotite and amphibole. Garnet is commonly associated with biotite, but short garnet veinlets also cut country rock away from green biotite. Garnet veinlets also crosscut biotite veinlets, but I have not seen garnet veinlets cutting across the larger biotite veins, probably because fractures would not persist in biotite masses.

The most characteristic mode of occurrence of garnet is as euhedral grains in biotite. The garnets may have symmetrical cross sections if only a few grains are present, or asymmetrical cross sections if many grains have interfered with each other's growth. Biotite grains have been pushed aside by the growing garnet and are now wrapped around garnet grains; this phenomenon is presumably exactly the same as that of garnet growth in metamorphic rocks.

Garnet is disseminated in wall rock adjacent to the larger veins, but the disseminated zone, 25 to 30 feet in maximum width, is always considerably narrower than the accompanying zone of disseminated biotite. The disseminated garnet is poikilitic or anhedral in habit and the grains are rarely more than two to three times as large as the country-rock quartz grains.

AMPHIBOLE STAGE

Amphiboles are the most abundant of the silicate minerals and probably are second in abundance only to siderite among the presulfide gangue minerals. They are the most abundant gangue minerals in all the silicate-bearing veins shown on plate 5A.

Grunerite and gruneritelike amphiboles, hornblende, and actinolite are present and in that order of decreasing abundance. Very commonly, a grunerite-rich vein has a border 1 to 2 inches wide on either or both walls composed of unreplaced green biotite and garnet, though the grunerite mass may also contain unreplaced remnants of the two minerals. In the Hercules mine, the Hercules structure, which consists of several individual veins, contains grunerite veins that are over 3 feet wide. On the 1600 level of the mine the crosscut from the shaft intersected two veins of almost pure grunerite each 2.5 feet thick, and did not reach a third of similar size that was cut in a drill hole. Several other grunerite veins over an inch thick are exposed in the crosscut. In the Hercules structure, the grunerite veins have been traced over a strike length of at least

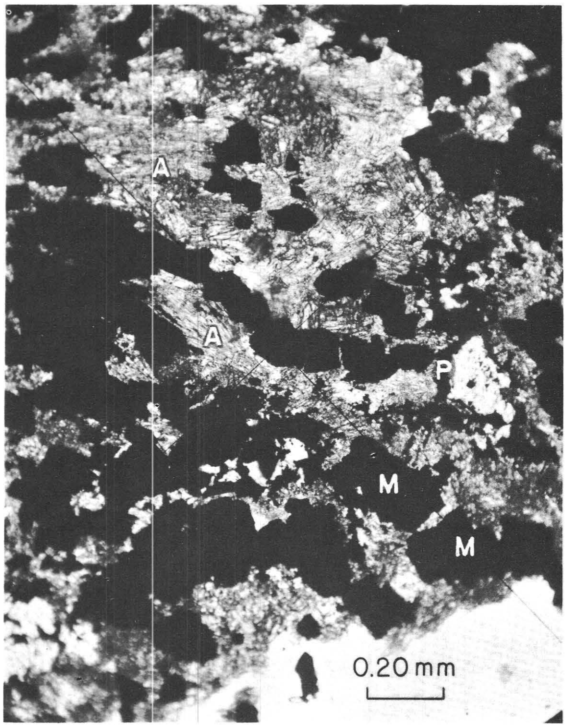

FIGURE 10.—Photomicrograph of an amphibole mass, mainly grunerite, partially replaced by magnetite and sulfides, Hercules mine, Coeur d'Alene district, Idaho. A, amphibole; P, pyrrhotite; M, magnetite. Plane-polarized light.

3,400 feet, and the east end of the vein has not been reached.

The former presence of abundant grunerite can be demonstrated by its common occurrence as inclusions in ore; in many places grunerite veins must have reached 10 feet in width.

The amphibole veins have sharp contacts with the country rock, and grunerite in contrast to biotite and garnet, is rarely or never disseminated beyond the vein walls.

The general age of the amphiboles is postgarnet and precarbonate and magnetite. Hornblende may be older than grunerite. The relation of anthophyllite to grunerite is indeterminate, and contacts between hornblende and actinolite have not been recognized. A typical amphibole mass, partially replaced by magnetite and sulfides, is shown in figure 10.

The lack of disseminated grunerite in the wallrock suggests that the fluid that transported the grunerite components lacked the penetrating power of the fluid that transported the components of the biotite and garnet.

CARBONATE STAGE

The Great Coeur d'Alene mineral belt (pl. 1) roughly paralleling the Osburn fault line, can be traced from the vicinity of Coeur d'Alene, Idaho, at least to the vicinity of Superior, Mont., a distance of about 95 miles; the Coeur d'Alene district occupies a central part of this belt. Many veins of this belt are characterized by abundant carbonates (Calkins and Jones, 1914; Shannon, 1926; A. L. Anderson, 1940; Wallace and Hosterman, 1956). Two types of carbonate-rich veins have been distinguished: (a) the massive ankerite-dominant veins, called the Amador type by Shannon (1926, p. 234), and (b) the massive siderite-dominant type, originally designated as the Yankee Girl type by Shannon (1926, p. 234) but which may now be designated more appropriately the Sunshine type. So far, the only significantly productive carbonate-rich veins of the mineral belt are the siderite-rich veins, which apparently occur mostly in the Coeur d'Alene district proper.

The carbonate minerals of the area are siderite, ankerite, ferroan and magnesian dolomite, and calcite. Three types of occurrences, all of hydrothermal origin, are to be distinguished: (1) massive veins composed entirely of carbonate or that were originally entirely of carbonate, (2) disseminated carbonate, or stringers and veinlets of carbonate in a vein structure where the gangue is mainly country rock or silicates, and (3) carbonate disseminated in the wallrock. Calcite has not yet been recognized as disseminated in the country rock; otherwise all the carbonates are represented in the three modes of occurrence.

Siderite is the most abundant carbonate mineral, and ankerite ($n_\omega > 1.70$) is next most abundant. Dolomite and ferroan dolomite are present, but their relative abundance is not known; in the remaining discussions the two minerals will be grouped with ankerite because of the lack of detailed knowledge about their distribution. Calcite is probably the least abundant of the carbonates.

Massive siderite is the prinicpal gangue of productive veins in the central and east parts of the Page-Galena mineral belt, the east part of the Tamarack-Marsh mineral subbelt, the Standard-Mammoth and East Hecla veins of the Rex-Snowstorm mineral belt, and the west part of the Moe-Reindeer Queen mineral belt. These veins are shown in figure 5B, some reached widths of 15 to 20 feet.

The only massive ankerite veins are in the east part of the Moe-Reindeer Queen mineral belt; none are now productive (December 1958) and past production has been small.

In contrast to the limited distribution of massive carbonate veins, veinlets and disseminated carbonate minerals occur in all the other main-period veins of the district, though the abundance varies greatly. Ankerite and siderite occur together in these veins, and their relative abundance varies greatly. Siderite is much less abundant than ankerite in the Pine Creek mineral belt; on the other hand, ankerite is uncommon in the veins around the stocks, and siderite is the dominant carbonate, though not abundant. Ankerite and siderite are about equally abundant in the Morning-Star vein. Type 1 calcite (see p. 19) occurs in significant amounts in a productive vein only at the Dayrock mine, where ankerite and siderite are about as abundant.

Both siderite and ankerite are known to be disseminated in the country rock of the Coeur d'Alene district, but the precise manner in which the two are distributed is not known.

Where crosscutting relations are present, siderite is older than ankerite. The relative age of the small amount of type 1 calcite has not been determined, even in the Dayrock mine where it is most abundant. Mitcham (1952, p. 434) has recognized calcite intergrowths with ankerite and siderite in some of the Silver Belt veins, but he indicated only that calcite is later than siderite. The relation to barite is not certain, but barite was probably introduced during and also after the carbonate stage. As shown by crosscutting relationships all the carbonates are younger than the silicates, except for the late brown biotite and the chlorite.

The age of the carbonates with respect to the first main-period pyrite is confusing. In the Sherman and Hercules mines, where specular hematite and magnetite are younger than siderite, pyrite is younger than siderite. Thus, although the available evidence suggests that no pyrite preceded carbonate minerals in the veins in the area around the stocks, this relation does not exist in the massive siderite veins in the Page-Galena mineral belt and elsewhere. Some coarse-grained pyrite (and arsenopyrite) in the Silver Summit mine and also at the Star mine appears to be older than siderite.

Perhaps the most noteworthy fact is that hematite and magnetite are generally younger than the carbonates. The relations of carbonate to the iron oxides are described at more length in the discussion of the hematite-magnetite stage (p. 41).

In the general area of the Great Coeur d'Alene mineral belt, only the Wallace Formation is carbonate-rich; it physically overlies many of the siderite veins of the Page-Galena mineral belt. Thus the possibility that the carbonate was derived from any of the exposed formations in the district is slight. The occurrence of carbonate veins throughout a belt 95 miles long suggests that we are not dealing with the same source of vein-forming material that supplied the sulfides or, still less, the vein silicates. This source is here designated the "deep linear source."

BARITE STAGE

The barite stage could be considered as the last part of the carbonate stage. A regional spatial relation exists between the massive ankerite veins and the massive barite veins, and gradations between the two types have been found. Within the Coeur d'Alene district proper (pl. 5*E*), however, barite has a spotty distribution.

The barite veins in the district are most numerous in the Moe-Reindeer Queen mineral belt. Here veins of barite accompanied by older ankerite and younger specular hematite reach widths of at least 4 feet (Calkins and Jones, 1914, p. 202), and prospect pits on the other barite veins of the same general area indicate strike lengths of several hundred feet.

Except in the Gold Hunter mine, barite is a very unimportant constitutent of the main period productive veins, where it is present at all. Some scattered barite occurs in the Silver Summit mine, the Morning-Star vein, and, according to Shannon (1926, p. 444), in some of the veins of the Bunker Hill area, although none was recognized in collections from the Bunker Hill mine. Where age relations could be determined, barite is younger than the carbonates and older than the iron oxides and the sulfides.

The similar regional spatial distribution certainly suggests that barite came from the same source as the carbonate.

IRON OXIDE STAGES

The two iron oxide stages present an unusual situation in that specular hematite and magnetite are younger than the carbonates and barite. This phenomenon is region wide; Anderson, (1940, p. 40, 43) noted that hematite was younger than the carbonates and barite in veins in Kootenai County to the west, and similar material on dumps at many prospects to the east of the district in Mineral County, Mont., show the same relation.

Specular hematite was formed during the first iron oxide stage. The greatest amount of hematite is in the barren carbonate and barite veins of the Moe-Reindeer Queen mineral belt (pl. 5*C*). In the mines surrounding the monzonite stocks, both unaltered and altered specular hematite are common. Hematite was collected from the Yankee Girl vein, which is a siderite-tetrahedrite vein, and small veins of quartz-carbonate and hematite have been cut in workings outside the productive veins in the Page-Galena mineral belt.

The deposition of hematite implies a lack of both carbonate and sulfur in the transporting solutions. We may assume, following Posnjak and Merwin (1922, p. 1972), that the hematite formed above 130° C, otherwise goethite would have formed. Smith and Kidd,

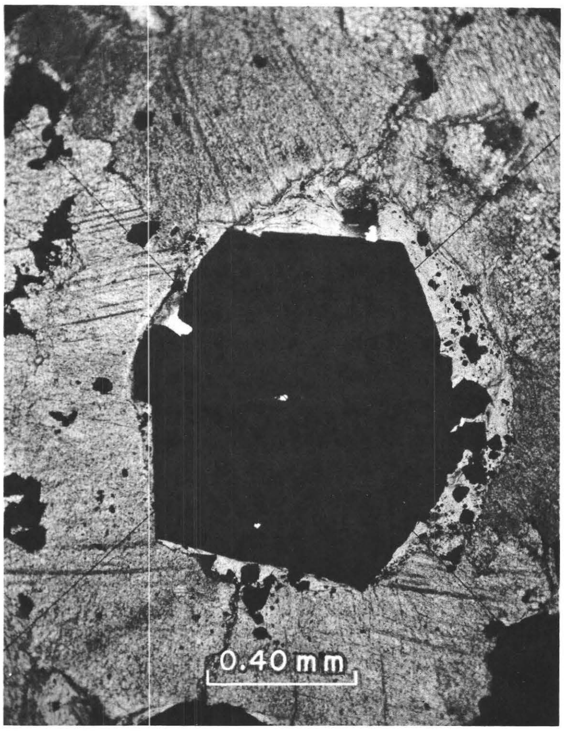

FIGURE 11.—Photomicrograph of magnetite grain fringed by pale brown biotite in siderite, Hercules mine, Coeur d'Alene district, Idaho. Plane-polarized light.

1949, p. 412, gave a decomposition temperature for goethite in "normal" hydrothermal solutions as 150°±20° C. Schmalz, 1959, p. 577, fig. 3, showed that the hematite-goethite phase boundary would be about at 175° C at 1,000 bars pressure.

Most of the hematite is magnetic or visibly altered to magnetite. Hypogene alteration of hematite to magnetite is fairly common (see Palache and others, 1944, p. 532), and presumably reflects a variation in the partial pressure of oxygen after the hematite was formed. The alteration has taken place in all lithologic environments—silicate, carbonate, barite, and country rock—and obviously does not depend on the contiguous minerals.

The second iron oxide stage is marked by the formation of euhedral magnetite. The age relationship is clear, for magnetite grains cut across magnetite pseudomorphous after hematite and in a few places they cut blades of unaltered hematite.

Magnetite is abundant in veins in the vicinity of the stocks, for instance in the Hercules, Tamarack, and Frisco mines. At a somewhat greater distance from the stocks, lesser amounts of magnetite replace massive siderite in veins of the Sherman mine and probably also in the adjacent Tiger-Poorman mine.

Euhedral magnetite replaces ankerite on the 2400 level of the Carbonate Hill (Atlas) mine and siderite at the Gem State prospect, both of which are in the Moe-Reindeer Queen mineral belt.

Brown biotite commonly borders many magnetite grains that are in carbonate. Inasmuch as considerable vein material now containing magnetite and biotite obviously was originally solid carbonate, it seems necessary to assume that the ingredients of this biotite were brought from depth as were the ingredients of the early green biotite. Figure 11 shows an example of magnetite fringed by biotite. The role of the magnetite in the formation of this mica is not clear; it is probably simply a matter of the two minerals being deposited at about the same time. In some areas the amount of mica is much greater than the amount of magnetite. Figure 12 shows a sample of brown biotite in which, though magnetite is present, a much larger volume of mica has largely replaced siderite.

The iron oxides of the two stages appear to have come from separate sources. Within the great mineral belt along the Osburn fault, carbonate veins, in which specular hematite is a common mineral, are characteristic. On the other hand, primary magnetite is very abundant only in the Coeur d'Alene district and, more specifically, only in the veins surrounding the stocks. If the carbonate in the Greater Coeur d'Alene mineral belt came from a source different from that of the silicate min-

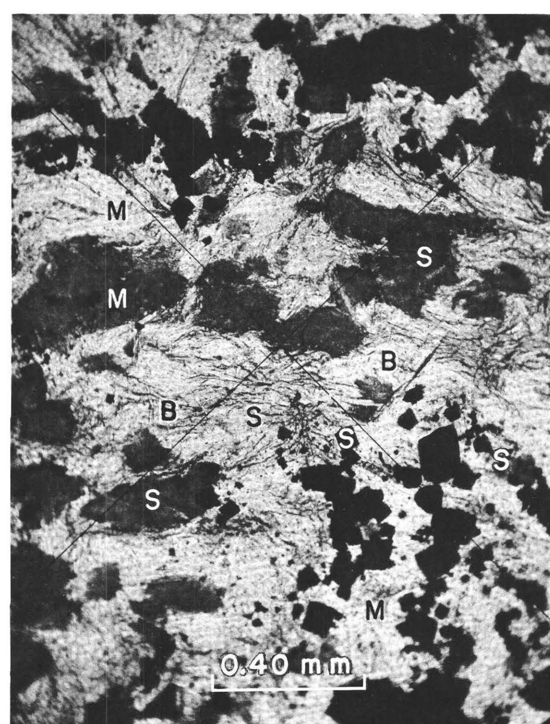

FIGURE 12.—Photomicrograph of pale brown biotite that contains remnants of siderite, Hercules mine, Coeur d'Alene district, Idaho. M, magnetite; S, siderite; B, biotite. Plane-polarized light.

erals, the hematite could logically be assumed to have come from the same source. In contrast, the localized nature of abundant magnetite suggests that it was the final contribution of a sulfur-poor magma of limited extent. If such has been the sequence of events, a time interval represented by the carbonate and the hematite stages must have separated the amphibole and the magnetite stages. Such a thesis seems more logical than an explanation of the hematite-magnetite sequence as due to the changing partial pressures of oxygen in a common source of the two minerals; that explanation might be valid if the evidence used was solely that found within the Coeur d'Alene district.

On the other hand, P. B. Barton, Jr. (written communication, 1960) suggested the possibility that, though the iron may have come from a single source, magmatic gases from the stocks may have produced a reducing environment and so, locally around the stocks, magnetite rather than hematite formed. This postulation would mean that, after hematite deposition had started, faulting or jostling would have permitted magmatic gases to reach the veins and then mixing of the two fluids would have resulted in the deposition of magnetite. This hypothesis invites further study.

SULFIDE STAGES

The sulfide stages are the final events of the main period of mineralization, except for the formation of some minor quartz and carbonate veinlets and possibly some chlorite.

The sulfides are not concentrically zoned around the stocks and apparently had a source different from that postulated for the silicate minerals. The mineral belt contains significant amounts of sulfides at, geologically speaking, only a single point believed to have been fed from a deep source. (See p. 50.)

It is unlikely that the vein-forming fluid issued from its source in a constant stream and changed composition abruptly. A time interval between, for instance, the arrivals of pyrrhotite-depositing fluid and of sphalerite-depositing fluid seems more likely; otherwise explanation is difficult of anomalous situations such as that in the Nabob mine, for example, where a vein containing both pyrrhotite and sphalerite is parallel to a vein (or veins) containing only pyrrhotite. Such anomalies are most readily explained by a spurt of vein-forming fluid of one composition, perhaps followed by a dry interval during which channel ways may be closed or opened, followed by another spurt of vein-forming fluid of another composition.

In the east end of the Page-Galena mineral belt, siderite-tetrahedrite veins are the characteristic mineral deposits. Galena also occurs in this part of the belt, but its distribution is erratic. At the Sunshine mine, the siderite-tetrahedrite veins contain notable amounts of galena. However, in the veins of the Silver Summit mine just to the east, galena is scarce, and it also appears to be very rare in the newly discovered deep ore bodies in the Crescent mine just to the west of the Sunshine mine. At the Galena mine at the east end of the belt, galena is present in the Silver vein in an ore shoot within the larger tetrahedrite shoot, but some 700 feet in the footwall of the Silver vein are a group of major galena veins. These associations again suggest that a period of structural adjustment intervened between the spurts of vein-forming fluids that first deposited tetrahedrite and then galena.

The distribution pattern of the veins in the Coeur d'Alene district, therefore, is most readily explained by differentiation of the fluid in the sulfide source, expulsion of differentiated fluids, and deposition of the individual sulfides throughout the district during separate and succeeding intervals.

PYRITE STAGE

Pyrite is a ubiquitous vein mineral, and in the main-period veins more than one generation can be recognized, though only that deposited early in any one vein seems to be abundant. However, pyrite is a volumetrically unimportant constituent of most veins except for some of the veins of the Pine Creek mineral belt and possibly some of the veins around the stocks. Within ore shoots, most of the pyrite has been replaced by younger sulfides; noticeable concentrations of pyrite occur most commonly, therefore, on the edges of the ore shoots or within relatively barren parts of the veins. In only a few areas does pyrite appear to be older than carbonate. The general association shows that pyrite is the first of the sulfide minerals and that the sulfides are younger than the minerals of the silicate, carbonate, and iron oxide stages.

ARSENOPYRITE STAGE

The relative ages of the pyrite and arsenopyrite in the main-period veins are uncertain. The two minerals probably did not form at the same time, and the arsenopyrite is probably the younger. Arsenopyrite of the main period has a restricted occurrence, but where found is always older than the base-metal sulfides and tetrahedrite. The relative ages of the arsenopyrite and the carbonate minerals is also uncertain. Most of the arsenopyrite is probably younger than the siderite but some at the Silver Summit mine, for example, is probably older than siderite. Although some arsenopyrite is present in some of the veins north of the Osburn fault, many more veins south of the Osburn fault contain arsenopyrite.

PYRRHOTITE STAGE

The pyrrhotite stage is the first of the major sulfide stages. Pyrrhotite is one of the principal gangue minerals, and ranks in abundance perhaps only after grunerite, siderite, and magnetite. The formation of pyrrhotite rather than pyrite apparently reflects a low partial pressure of S_2 rather than any particular formation temperature (Arnold, 1956, p. 177). Pyrrhotite is found in all but the Page-Galena and Moe-Reindeer Queen mineral belts (pl. 5*D*); a period of sulfur deficiency must have existed over nearly the entire region. Pyrrhotite from the Highland-Surprise mine formed above 450°C (R. Arnold, written communication, 1960), and it is probably still to be accepted as indicating mesothermal conditions in the veins. Pyrrhotite, except for a very small amount of second-generation pyrrhotite in the Hercules vein, is consistently older than sphalerite, and it is younger than the carbonate minerals and the first generation of pyrite.

SPHALERITE STAGE

Sphalerite is second only to galena as the most abundant ore mineral in the district. At least minor amounts of it have been found in all the productive main period veins examined in this study, with the exception of the Silver Summit veins and the Silver vein of the Galena mine. In many mines, however, sphalerite is not abundant enough to recover.

Variations in the iron content of sphalerite are discussed in the sections on mineralogy and ore shoots (p. 63). A single source of sphalerite seems adequate to explain its distribution in the main-period veins.

Sphalerite is younger than pyrrhotite and older than tetrahedrite, chalcopyrite, and galena.

TETRAHEDRITE-CHALCOPYRITE STAGE

Tetrahedrite and chalcopyrite are treated as minerals of a single stage, although they may represent two separate stages, inasmuch as some veins notably deficient in tetrahedrite contain significant amounts of chalcopyrite. The two minerals are probably present in all the main-period veins, but their actual and relative abundances vary greatly. In the east part of the Page-Galena mineral belt, from the Crescent mine to the Galena mine (the Silver Belt) the dominant ore mineral is tetrahedrite; chalcopyrite is the second most abundant ore mineral in the veins of these mines, and the overall proportion of tetrahedrite to chalcopyrite ranges perhaps from 10:1 to 20:1. The mines in the west part of the Page-Galena belt also contain important amounts of tetrahedrite, as do the veins of the Dayrock mine and the Lucky Friday mine, but galena is the dominant ore mineral. The other veins of the district usually contain only very small amounts of tetrahedrite. The greatest concentration of chalcopyrite is in the siderite-tetrahedrite veins. In the Snowstorm and National mines, at the east end of the Rex-Snowstorm mineral belt, chalcopyrite is the chief primary mineral and is accompanied by only small amounts of tetrahedrite. In all other main-period veins, chalcopyrite is at least an accessory mineral.

The siderite-tetrahedrite veins are unusual, but one can recognize many gradations with other veins in the district. For example, the galena-rich March ore shoot of the Bunker Hill mine, just to the west of the tetrahedrite ore bodies, is in a vein of massive siderite. Important amounts of tetrahedrite, though in no sense comparable to the amounts in the tetrahedrite ore bodies, partially replaced siderite. Then both siderite and tetrahedrite were replaced by a great flood of galena.

The change from an antimony-rich to an antimony-poor ore fluid appears to be sharp, and presumably indicates exhaustion of a great antimony concentration, though antimony minerals were also formed after the galena stage.

Where the paragenesis can be determined, tetrahedrite is uniformly younger than sphalerite and older than galena. This sequence is found not only in the tetrahedrite-siderite veins but also in the galena and sphalerite veins. Where comparatively large amounts of tetrahedrite are present in galena-dominant veins, as at the Page, Dayrock, and Lucky Friday mines, there are enough gradations between tetrahedrite partially replaced by galena and galena containing only specks of tetrahedrite to suggest that all tetrahedrite specks in galena in other mines are remnants of larger tetrahedrite masses that have been replaced by galena.

Tetrahedrite is older than chalcopyrite. Both minerals are younger than sphalerite and older than galena, although a small amount of a second generation of chalcopyrite, younger than galena, is present in ore from the Lucky Friday mine and in some ore from the Bunker Hill mine.

GALENA STAGE

Galena is the most abundant ore mineral of the district, and, except for the Silver Summit veins, it is present in all the veins of the main period. Galena is not a major ore mineral in the tetrahedrite veins of the east part of the Page-Galena mineral belt and in the chalcopyrite-bearing veins of the east part of the Rex-Snowstorm mineral belt.

The galena in any one vein is younger than the sphalerite in that vein, and the lead-antimony and silver-antimony sulfides found have been younger than galena.

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LATE SULFOSALT STAGE

The minerals of the last stage consist of the silver-antimony sulfides, polybasite and pyrargyrite, and the lead-antimony sulfides, bournonite, boulangerite, and meneghinite.

Significant amounts of the late sulfosalts are to be found only in the Galena mine, south of the Osburn fault, and in the Lucky Friday, Gold Hunter, and Marsh mines, north of the Osburn fault. Again the control for their concentration seems to be structural. At the Galena mine, the Silver vein (siderite-tetrahedrite) lacks these late sulfosalts, but the nearby lead veins have notable concentrations of them.

PARAGENESIS OF THE MAIN-PERIOD VEINS

The paragenesis of the main-period veins is indicated by the order in which the stages were described. Figure 13 gives a generalized paragenetic sequence for

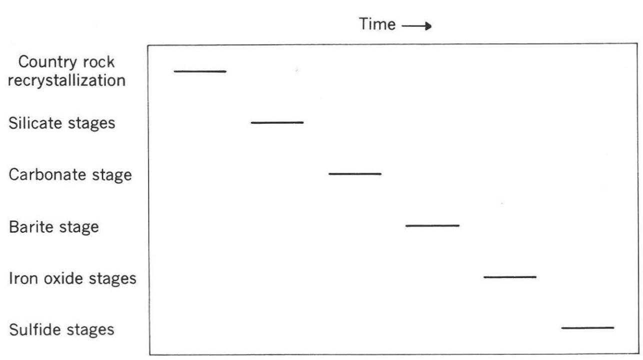

FIGURE 13.—Generalized paragenetic sequence of the main period of mineralization.

the main-period veins. More detailed paragenetic sequences for particular veins are given in the last section of the report describing individual veins.

TERTIARY MINERAL DEPOSITS

The relative ages of the so-called Tertiary mineral deposits can be reasonably well established by geologic means, as discussed in the following section. The deposits are younger than the main-period veins, which are presumed to be of Late Cretaceous age, but I am not sure that all or any are actually of Tertiary age.

FIRST TERTIARY PERIOD OF MINERALIZATION

The first Tertiary period of mineralization is represented by veins of yellow sphalerite and galena. Recognition of the existence of the veins is based on three lines of evidence. The three lines of evidence are for three different groups of galena-sphalerite veins, so there remains a possibility that there were three Tertiary periods of galena-sphalerite deposition, but all will be discussed together here.

The existence of sphalerite-galena veins that are different from the main-period veins was first recognized by Shannon (1926, p. 100). He noted that "A small group of prospects differs from the majority of Pine Creek mines in that the ore consists of relatively clean granular galena with ankerite in white quartz. * * * The principal mines of this group are the Lookout Mountain, Hypotheek, Northern Light, and Carbonate." The main-period veins, the Pine Creek mineral belt, are characterized by pyrrhotite, but these Tertiary veins lack pyrrhotite. Furthermore, the tetrahedrite in these Tertiary veins is silver-free (Shannon, 1926, p. 167), but that in the main-period veins is silver rich.

Two examples of crosscutting relations between main-period veins and Tertiary lead-zinc veins are known. According to Shannon (1926, p. 168), "Similar silver-free tetrahedrite has also been noted in small amounts in the ore of the Wisconsin claim east of Kellogg, where it is later than the quartz-ankerite-pyrrhotite mineralization in which it fills seams." On the 300 level of the Idaho prospect, a typical main-period vein containing magnetite, pyrrhotite, and dark red-brown sphalerite is cut by a vein of quartz, ankerite, yellow sphalerite, and galena.

Galena from the Sunrise No. 3 vein, which cuts the north stock, contains lead that has a "modern" isotopic composition (Arnold Silverman, written communication, 1958; L. R. Stieff and T. W. Stern, written communication, 1959) in contrast to the main-period galena, whose lead has an "ancient" isotopic composition. Isotopic analyses of galena from any of the other so-called first Tertiary period veins are not available. The isotopic composition of the lead in the Sunrise No. 3 vein proves that it came from a source different from that of the main-period lead. Inasmuch as the isotopic composition of the Sunrise No. 3 lead is compatible with that of feldspar lead from the stocks (L. R. Stieff and T. W. Stern, written communication, 1959), a "modern" igneous source for the Sunrise No. 3 lead, and inferrentially the other ore metals, is possible. As noted elsewhere, (p. 50), a "modern" igneous source for the main-period lead is not possible.

As noted above, only two veins believed to be of the first Tertiary period are known to cut veins of the main period. Of these two, the vein at the Idaho prospect is in turn cut by an olivine-augite-hornblende-plagioclase dike. These are the only geologic associations that show the relative age of the first Tertiary period veins. Thus, these veins are younger than Late Cretaceous and most likely are older than middle Tertiary.

SECOND TERTIARY PERIOD OF MINERALIZATION

The veins of the second Tertiary period of mineralization are economically the second most important of the region, but even so are relatively insignificant. In the Coeur d'Alene district the most impoprtatnt representatives of this period are stibnite-bearing veins. Most of these veins are in the southwest corner of the district (pl. 4*c*), but two are near Burke and a small group of antimony veins are known in Montana east of Burke. A stibnite vein was cut in a drill hole in the Crescent mine.

Material from the stibnite veins has been described by Jones (1920, p. 31 ff.), Umpleby and Jones (1923, p. 121 ff.), and Shannon (1926, p. 78 ff.). The veins are characterized by stibnite, arsenopyrite, and yellow sphalerite in a gangue of white quartz and ankerite, although some veins are in country rock that contains no other gangue minerals.

The presence of minable amounts of scheelite in the stibnite veins of the Big It mine suggests a relation, albeit tenuous, with the scheelite-bearing south vein of the Silver Crescent prospect and with the gold-scheelite veins of the Murray district, which lies just north of the Coeur d'Alene district. Shenon (1938, p. 22, 23) has summarized the evidence and concluded that in the Murray district these gold-scheelite veins are younger than the pyrrhotite-sphalerite-galena veins of the main period.

Shenon (1938, p. 22) noted that the scheelite-gold veins of the Murray district, which are placed tentative in the second Tertiary period, were typically to be found along bedding-plane displacements, but the main-period veins formed along shear zones that cut bedding. It seems probable that a great deal of the overlying cover had been removed in the Murray district between the time main-period veins formed and the scheelite-gold veins formed, and for this reason movement occurred along preexisting discontinuities (that is, bedding planes), rather than shearing that crosscut bedding planes. The analogous structural features of the stibnite veins, which are dominantly along bedding planes, as compared with those of the known first Tertiary period veins, which are replacements along shear zones, is the principal line of evidence that this group of veins is younger than the first Tertiary period veins. This evidence and the presumed lower temperature nature of stibnite are the only criteria for the relative ages of the two periods of mineralization.

There is a possibility that the stibnite veins are post-Placer Creek fault in age. As shown in plate 4*c*, stibnite veins are clustered just west of Pine Creek, and one of these veins, the Great Dunkard, lies just north of the Placer Creek fault. The cluster does not appear to have been offset by the 1½ miles of displacement known to exist on the Placer Creek fault.

THIRD TERTIARY PERIOD OF MINERALIZATION

The third Tertiary period of mineralization is represented by the veins of the General Mines prospect. These are quartz-dolomite-arsenopyrite-gold veins in a diabase dike. Most such veins are small and contain only minute amounts of sulfides; however, the veins in the General Mines prospect contain notable amounts of arsenopyrite. The only other occurrence considered to be of this type is in the diabase dike of the Osburn fault at the Sisters prospect. Other veins of this age may be present away from the diabase dikes but they have not been identified. The Tertiary age assigned these veins is based upon the presumed Tertiary age of the dikes in which they lie.

OTHER TERTIARY PERIODS OF MINERALIZATION

Two other groups of veins, one consisting of barren white quartz and the other of calcite and pyrite, are more or less distinctive. Possibly each should be considered as the product of a separate period of mineralization.

The white quartz veins are the largest quartz veins in the district. They characteristically form prominent outcroppings, in which sulfides and iron-bearing carbonates are so scarce that the croppings are stained only lightly in a few places. One vein at the Enterprise prospect has been worked for gold. Their usual strike is N. 35°–40° W., which is in contrast to the N. 60°–70° W. strike of most of the main-period veins. Quite probably many of the hundreds of small barren quartz veins belong to this group, but it is not possible to distinguish them from similar veins that may have formed during other periods of mineralization.

The relative ages of these veins are not known.

DISTRIBUTION PATTERNS (ZONING) OF IMPORTANT VEIN CONSTITUENTS

The recent review of zoning by Park (1955) and the criticism of this review by Kutina (1957) demonstrate that any writer on the subject of mineral distribution patterns must explain the terms he uses. The "zonal theory" is defined in a glossary by the American Geological Institute (1957, p. 325) as "A theory of ore deposition which holds the the ores originate in a zone of differentation in the lower part of the zone of crystallization, where are formed the siliceous-aqueous-metalliferous residues, which in passing upward through faults and fractures deposit the ores in successive zones, each marked by its distinctive mineral associations."

This glossary defines "zoning" as, "In a mineral deposit the occurrence of successive minerals or elements outward from a common center." The term "district zoning," popular though it is amongst geologists, is not defined in the glossary. Park did not define his terms, but on the last page of his paper (1955, p. 246) there is this statement: "The center from which zoning has taken place is no longer by definition a center of known igneous activity. It may be a center of metamorphism, a fault, a shore line or other control." Bateman (1950, p. 314) wrote, "Zonal distribution of minerals about centers of igneous activity is another form of ore control, sometimes referred to as the zonal theory although zonal arrangement would be a better term."

The significant feature of these comments about zoning is the reference to a center or centers. Certainly the word "zoning" when applied to a mining district carries a connotation of symmetry, either about a point or by reflection across a plane, though the degree of symmetry may be low, as indicated by Loughlin and others (1936, p. 433). Consideration of distribution patterns in a district has for much too long a time hinged on the presence or absence of a pattern with recognizable symmetry. Instead, distribution patterns should be considered in the light of whether they are chaotic or orderly. A distribution pattern involving symmetry around a point (zoned, zoning) is only one of several possible orderly distribution patterns, and perhaps not even the most important of these patterns.

There is probably a need for a new term or terms, because use of "zoned" as the general term for a class rather than for a member of that class may be confusing unless the usage is defined by each writer.

However, orderly distribution patterns, whether they are concentric around a point or are planar and quite asymmetric, are commonly referred to as "zoning" by geologists. It is suggested, therefore, that "zoned" be used for the class of orderly distribution patterns and that it be prefixed by such descriptive terms as "concentric," "linear," "planar," or "composite" (as for the Coeur d'Alene district), and so on. Further, it might be well to indicate the degree of order involved.

Orderly distribution patterns can be recognized in the Coeur d'Alene district, considered either as a whole or as two subdistricts. The earliest gangue minerals, the silicates, are concentrically zoned around the stocks; later gangue minerals and most of the ore minerals are zoned in planar or linear patterns.

Very little has been published concerning distribution patterns in the district. The district has been described as "concentrically zoned" in two textbooks (Emmons, 1940, p. 415; Bateman, 1950, p. 538), and Lindgren (1933, p. 573) commented on possible zoning of gangue minerals. Of the workers who have studied the district as a whole, Ransome worked in the area before the zonal theory had been proposed, Hershey (1916, p. 22) explicitly rejected the idea and was able to convince E. V. Shannon (as quoted by Hershey, 1916, p. 23) that zoning was not present, and Umpleby and Jones (1923) did not consider the problem at all.

Hershey (1916) was the first to discuss Coeur d'Alene distribution patterns in the light of Spurr's (1907) zonal theory, and though he did not recognize any zonal distribution of lead and zinc it was not primarily, one may gather, because of the obvious distribution pattern of the deposits; Hershey's principal argument seems to be that the lead and zinc came from the Prichard Formation, not the stocks.

In the same paper, Hershey discussed the ideas of Shannon about zonal distribution. Shannon was thoroughly familiar with the Coeur d'Alene ore deposits, as demonstrated by his "Minerals of Idaho" (1926), but he published nothing on the ore deposits as such and Hershey's paper is the only source for his ideas about zoning. Shannon provided Hershey with a scheme of zonal distribution that involved five zones and two transitions; however, the highest temperatures were indicated by gold and scheelite in the Murray district, north of the Coeur d'Alene district proper and well to the northwest of the monzonite stocks. It was not surprising that "Since the publication of my last paper, Mr. Shannon concedes that his zones are related to the formations" (Hershey, 1916, p. 23).

This last comment brings us to Hershey's own two hypotheses for explaining the distribution of the deposits. He considered 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 ore deposits of the district" (Hershey 1916, p. 32). He also stated (p. 31), "A certain amount of the silver has come with the lead, but that which is present in tetrahedrite has probably had the same source as the copper, antimony, and gold. I am inclined to refer these minerals to the granite as a source, although I cannot give any conclusive evidence in support of this idea." It seems safe to say, however, that Hershey did not consider the silver, copper, antimony, and gold deposits to be symmetrically zoned around the monzonite stocks.

It should be pointed out that the group of mines in which concentric zoning of the silicate gangue minerals can be recognized were not accessible to Hershey and at that time other orderly distribution patterns were not being considered.

The most recent published statement on district zoning is that of Griggs (1952, p. 103), who was the first to recognize the concentric zoning of the earliest gangue minerals around the stocks.

MAIN-PERIOD ORE MINERALS AND METALS

A series of maps have been prepared to illustrate the present and original distribution of main-period minerals. These maps show all the mines that have produced at least 2,000 tons of ore; all the stibnite veins are shown regardless of amount of production. Only the ore-shoot parts of the veins are shown and where several closely spaced veins were mined, some simplification has been necessary. These maps also show the locations of important prospects; a prospect is so defined if a substantial-sized vein was explored even if ore bodies have not yet been found. Many workings in the Coeur d'Alene district are on quite unmineralized faults or on no structure whatsoever, and these have not been included.

The present distribution of the principal ore metals is shown on plate *4C*. Two facts standout: (1) The ore bodies lie along belts, except for the stibnite veins and some that have been moved by faults from their original positions, and (2) there are two concentrations of ore bodies, one north and one south of the Osburn fault, the north concentration being about 17 miles east of the south concentration.

With the exception of the National-Snowstorm part of the Rex-Snowstorm mineral belt, where chalcopyrite is dominant, galena and sphalerite are the dominant ore minerals of the belts that lie north of the Osburn fault. The northmost mineral belt (Sunset) contains sphalerite-dominant veins, galena-dominant ore bodies, and an ore body that contained equal amounts of galena and sphalerite (see pl. *4C*); there is no pattern in the belt. The mineral belt to the south (Carlisle-Hercules) has a linear distribution pattern: sphalerite ore bodies on the west and galena ore bodies on the east. The Tamarack-Marsh subbelt of the Rex-Snowstorm belt contains sphalerite ore bodies on the west end; the remainder of the belt contains galena ore bodies. The Rex-Snowstorm belt contains sphalerite ore bodies on the west end, galena ore bodies in the central part, and chalcopyrite ore bodies on the east end. The Success subbelt of the Gem-Gold Hunter belt contains sphalerite ore bodies. The Gem-Gold Hunter belt contains sphalerite ore bodies on the west end and galena ore bodies on the east end. The Golconda-Lucky Friday mineral belt contains only galena ore bodies. The Dayrock subbelt contains galena ore bodies.

The arrangement of the ore minerals, galena, sphalerite, and chalcopyrite, is apparently not concentric with respect to the monzonite stocks, to any structural feature of the area, or to each other. Except for the Sunset belt, which has no pattern, and the Golconda-Lucky Friday mineral belt, which contains only galena ore bodies, the individual belts have a linear distribution pattern (linear zoning). Viewed on a smaller scale, the entire area north of the Osburn fault would be described as having a planar pattern (planar zoning), zinc on the west, lead on the east. As shown on plate *4C*, the major anomaly to the planar pattern is the group of galena ore bodies just west of the Dobson Pass fault (Western Union, California, and Dayrock mines and Nine Mile prospect). A reconstruction of the pre-Dobson Pass fault situation, however, shows that these mines were displaced from positions just on the edge of the galena zone in the Gem-Gold Hunter mineral belt.

Three mineral belts and one subbelt can be recognized south of the Osburn fault. The northmost, Page-Galena belt, is sphalerite-rich on the extreme west end; the central part contains galena ore bodies, and the east part contains tetrahedrite-chalcopyrite ore bodies; at the very east end there also is a major lead ore body. Exploration in the Moe-Reindeer Queen mineral belt has not found any major ore bodies, but the prospects give a clear picture of linear zoning similar to the Rex-Snowstorm and Page-Galena mineral belts; the belt is sphalerite-rich on the west end, galena-rich in the central part, and chalcopyrite-rich on the east end. The Pine Creek mineral belt appears to have a galena ore body on the west end (Hypotheek mine), but because the ore body has none of the pyrrhotite to be expected in a vein in this location, it is placed with the first Tertiary period veins; the remainder of the belt contains sphalerite-dominant ore bodies. The Douglas subbelt also contains sphalerite-dominant ore bodies.

In summary, two of the mineral belts south of the Osburn fault have linear distribution patterns, two contain only sphalerite ore bodies. The two with linear patterns are similar to those of the mineral belts north of the Osburn fault; there is no concentric zoning with any structural feature, nor is any igneous mass known.

Stibnite veins, one containing commercial amounts of scheelite, are also shown on plate *4C*. These veins fall outside the mineral-belt pattern and they are considered to be much younger than the main-period veins.

Thus far, the north and south subdistricts have been discussed as though they were separate entities although some comparisons have been made that indicate similarities. I believe, however, that we are dealing not with two similar ore districts but rather with a single large district that has been cut by the Osburn fault and whose two parts are offset about 17 miles. This hypothesis was first proposed by Hershey (1916, p. 5); Umpleby and Jones (1923, p. 12) accepted it and pointed out additional conformatory stratigraphic and mineralogical evidence. However, the hypothesis apparently was not generally accepted among district geologists.

The most important indication of movement along the Osburn fault, the offset of the Pine Creek and Moon Creek anticlines, has already been discussed and it is only necessary now to show that the two productive areas are opposite each other when the pre-Osburn fault situation is reconstructed as shown on plates 2*B* and 4*A*. As shown on plate 4*A*, the reconstructed district has planar zoning, zinc on the west, lead in the center, and a small copper zone on the east.

MAIN-PERIOD GANGUE MINERALS

The distribution pattern of the vein silicate minerals is shown on plate 5. Veins containing green biotite, garnet, and amphiboles have been recognized only in the area north of the Osburn fault and around the stocks; all three silicates generally occur together, and the silicate-bearing veins are clustered about the stocks.

Carbonates and barite followed the silicates and preceded the iron oxide minerals. As previously noted (p. 39), the carbonate minerals may occur in massive veins or as disseminated grains or as stringers in the larger veins. The distribution pattern of the massive carbonate-bearing veins is shown on plate 5*A*. In the area north of the Osburn fault, parts of two mineral belts contain massive carbonate, and some disseminated and stringer carbonate can be found in all the veins. The St. Joe group of prospects 5 miles west of Dobson Pass also contains massive siderite veins; before movement on the Dobson Pass fault this group of prospects was probably at the west end of the Gem-Gold Hunter mineral belt.

South of the Osburn fault, massive siderite veins are characteristic of the Page-Galena mineral belt between the Bunker Hill deep veins and the Galena mine. In the Moe-Reindeer Queen mineral belt, massive siderite is present in the west part of the belt; massive ankerite and some siderite are present in the east part of the belt. Only stringers and disseminations of carbonate are present in the Pine Creek belt and the Douglas subbelt.

As shown on plate 1, west of the Coeur d'Alene district massive ankerite veins can be traced to the vicinity of Lake Coeur d'Alene, and east of the productive part of the district massive ankerite veins can be traced many miles into Montana. In the productive part of the district the only massive carbonate is siderite. On a regional basis, however, this long line of massive carbonate veins has a linear zoning pattern; massive siderite veins in the central part are flanked by massive ankerite veins.

The veins that contain specular hematite and magnetite are shown on plate 5*C*. North of the Osburn fault, magnetite is distributed around the monzonite stocks. South of the Osburn fault, primary magnetite is found only in the Moe-Reindeer Queen mineral belt. North of the Osburn fault, specular hematite was recognized in many of the silicate-bearing veins, and it may be present in all these veins. However, specular hematite is also found in veins east of the silicate-bearing veins; its distribution pattern is not quite as symmetrical about the stock as that of magnetite. South of the Osburn fault, specular hematite is largely restricted to the veins of the Moe-Reindeer Queen belt. Except for the Yankee Girl vein of the Sunshine mine, where it is scarce, the productive siderite veins of the Page-Galena belt lack specular hematite. A few small quartz-carbonate-hematite veins occur outside the main vein zones.

Hematite is a constituent of the massive carbonate veins both east and west of the Coeur d'Alene district, and on a regional scale it has a linear distribution pattern.

Pyrite is present in all the veins of the district, but is scarce in many veins; it is probably most abundant in those veins that contain large amounts of pyrrhotite. Inasmuch as pyrite is ubiquitous, there is no need to illustrate its distribution.

The distribution of pyrrhotite is shown on plate 5*D*. North of the Osburn fault, pyrrhotite appears to be zoned concentrically around the stocks. South of the Osburn fault, pyrrhotite is found only in the Pine Creek belt, the Douglas subbelt, and adjacent prospects. If the pre-Osburn fault situation is reconstructed, as shown on plate 4*B*, pyrrhotite lies in two groups, the southmost separated from the stocks by the Page-Galena mineral belt. Though the veins of the north group are concentric around the stocks, the 4.5-mile gap between the two groups suggests that the stocks were not the source of the pyrrhotite-bearing fluids.

Neither arsenopyrite nor barite is abundant in the district, though arsenopyrite is common in some mines south of the Osburn fault (pl. 5*E*). Significant amounts of barite can be found on both sides of the Osburn fault but north of it only the Gold Hunter vein contains large amounts of barite.

The distribution pattern of gangue minerals as just described is that of the present. North of the Osburn fault, the silicates, iron oxides, and perhaps pyrrhotite are concentrically zoned around the stocks but the carbonates do not have this pattern. South of the Osburn fault, silicates are not present and the other minerals do not have concentric distribution patterns. An orderly distribution pattern of the ore minerals could be shown on a reconstruction of the pre-Osburn fault situation, but not of the various gangue minerals. The prefaulting distribution of pyrrhotite, massive siderite, and massive ankerite is shown on plate 4*B*.

Inasmuch as possible vertical movements on the Osburn and Placer Creek faults were not considered in the reconstruction of plate 4*A*, *B*, the distribution patterns shown on these figures may be due in part to exposure at different levels. However, south of the Osburn fault, surface patterns persist to depths of as much as 5,000 feet.

To summarize, the Coeur d'Alene district is zoned in the sense that orderly distribution patterns exist and patterns of concentric, linear, and planar zoning can be recognized. No single overall pattern exists; the Coeur d'Alene district has a composite zoning pattern and so probably do many other mining districts. The composite pattern exists because the vein minerals were introduced in surges or pulses and, as shown in a following section (p. 49), from more than a single source.

VEINS OF THE LATER PERIODS OF MINERALIZATION

The distribution of mines and prospects containing veins belonging to the Tertiary periods of mineralization is shown on plate 4*D*. The information on which the map is based is incomplete, and additional veins probably belong to these groups. The source of these late veins can not be determined, though the clustering of stibnite-bearing veins of the second Tertiary period suggests that stibnite may have had the same deep source as the sulfides of the main-period veins.

SOURCES OF THE VEIN MINERALS

The main-period veins of the Coeur d'Alene district are normal hydrothermal veins in appearance; however, several features suggest that not all the material which forms them has been derived from what might be termed "normal magmatic sources." To me a "normal magmatic source" is a cooling intrusive.

Ransome and Calkins (1908), Hershey (1916), and Umpleby and Jones (1923) all gave much thought to the sources of the vein material and their conclusions are noteworthy.

According to Ransome and Calkins (1908, p. 137), "It is not supposed that the ores were derived from the comparatively small bodies of monzonite now exposed in the district. * * * The source of the ores is thought to lie in the underlying batholith from which the exposed masses are probably offshoots." According to Hershey (1916, p. 14), "I submit that the facts point strongly to an origin of the lead and zinc in diffused mineralization in the sediments at some horizon above the Middle Prichard. My idea is that where the strata became greatly disturbed and highly tilted, the solutions set into active circulation by the monzonite intrusion dissolved minerals from the sediments and deposited them higher in the veins. In earlier papers I have tentatively traced the lead and zinc to the Upper Prichard. The iron for the pyrrhotite, pyrite, and siderite probably came partly from the monzonite, but chiefly from the sediments. The copper and gold in the copper-gold veins near Kellogg probably came from the monzonite, though there is no conclusive evidence of it." Umpleby and Jones (1923, p. 149) wrote, "In conclusion the marked concentration of mineralization near the intersection of an elevated axis of igneous intrusion and a zone of tremendous faulting, the gradation of the several types of lodes, the local development of contact-metamorphic deposits, and the definite sequences of mineral deposition in all the deposits of the county lead the writers to conclude that the ores are of magmatic derivation and that their source lies in the granitic intrusive which is exposed locally in the region and which in depth is doubtless continuous with the great Idaho batholith."

The conclusions of this report embody some of the elements of the conclusions of Ransome and Calkins and of Umpleby and Jones, but not those of Hershey. The principal inovation is that a "shallow point" source, a "deep linear" source, and a "deep point" source are postulated for material now in the main-period veins. The shallow-point source, or the source of early silicates and magnetite, is that suggested by Umpleby and Jones—the deeper parts of the exposed monzonite stocks. The deep-linear source, the source of the carbonates, barite, and specular hematite, is perhaps the hidden parent batholith suggested by Ransome and Calkins as the source of all the vein matter. The idea of a deep-point source for the sulfides is certainly contained in the statement of Gregory (1928, p. 108) quoted below, but the expression of the idea in this form is mine. My general hypothesis is admittedly eclectic, but such rare phenomena as major mining districts very likely owe their existence to the fortuitous juxtaposition of several features.

The features of greatest significance were recognized by Umpleby and Jones: They consist of a major northwest-striking fracture zone defined by the Great Coeur d'Alene mineral belt and its generally barren veins, and a major northeast-striking fracture zone indicated by the line of the stocks. It surely is no mere coincidence that the Coeur d'Alene district and its great sulfide ore deposits lie at the intersection of these two fracture zones.

SHALLOW-POINT SOURCE

The shallow-point source is suggested by the concentric zoning of the early silicates and magnetite around the monzonite stocks. The silicate-bearing veins are not just "local contact metamorphic deposits" as postulated by Umpleby and Jones, but the genetic connection between stocks and silicate veins, which they suggested (1923, p. 148), does seem probable. Silicate veins cut the monzonite and demonstrate that the now visible parts of the intrusion were solid when the veins were formed, so the actual source of the vein material must lie below the present surface.

The minerals attributable to the shallow-point source are all apparently iron-rich: green biotite, garnet, amphiboles (particularly grunerite), and magnetite. The source seems to have been iron-rich and also deficient in sulfur.

DEEP LINEAR SOURCE

There is reason to believe that such a batholith as Ransome and Calkins (1908, p. 137) postulated for the source of the ores does underlie the district, though probably at considerable depth. The Osburn fault zone, from the Washington State line to the Montana State line, is between the Idaho batholith on the south and the Loon Lake batholith on the north (Ross and Forrester, 1947) and the stocks in the area suggest a connection between the two batholiths. As already noted (p. 6), however, the Coeur d'Alene district is only a part of a great mineral belt, about 95 miles long, and it seems necessary to account for the material that is in all these veins.

If an underlying hidden batholith was the source of the veins along the great mineral belt, it was not productive of valuable concentrations of metals. Massive ankerite and siderite were first formed in the veins of the great mineral belt and then specular hematite. Except for barite which is widespread, sulfur-bearing minerals are scarce outside of the Coeur d'Alene district. Sulfides are present in all these veins, but except in the Coeur d'Alene district, they are rarely present in commercial amounts. Though some of the minor deposits of sulfides may have come from the linear source, a different origin is postulated for the great concentration of sulfide minerals—a deep point source, as discussed below. The deep linear source, of course, may be nonmagmatic, but, lacking evidence for such a source, and in keeping with tradition, a magmatic source is suggested.

DEEP-POINT SOURCE

The position of the Coeur d'Alene district along the Great Coeur d'Alene mineral belt is at the intersection of the belt with a line of stocks, and, as noted by Umpleby and Jones (1923, p. 149), this structural relationship is probably crucial to the existence of the Coeur d'Alene district.

The only significant concentration of sulfides along the mineral belt is found at the only intersection of this kind. Because the source of the Coeur d'Alene sulfides lies at depth along the intersection, it might be assumed that a cooling intrusive was tapped at a point instead of along a line. The evidence, on the contrary, suggests that a cooling intrusive was not the source of the galena nor, by inference, of the other sulfides.

To review briefly, galena with a lead isotope constitution indicating a Precambrian age is in veins that cut igneous rocks dated as Cretaceous in age. If the lead had the same source as the other base metals, it seems doubtful that the base metals could have come from a cooling intrusive of Cretaceous age, because (1) isotopic constitution of lead in the local intrusive is commensurate with lead-alpha ages and with the geologic probability that the stocks are outliers of the Idaho batholith, and (2) lead derived from a cooling intrusive of Cretaceous age, which had originally contained normal amounts of uranium and thorium, would of necessity contain a markedly greater amount of radiogenic lead than does the lead in the galena of the main-period veins.

The possibility still remains, however, that the sulfides came from a magma of Cretaceous age, that contained abnormally small amounts of uranium and thorium and their radiogenic daughter products. Though such a magma is not an impossibility, it would be different from the magmas that produced the Gem stocks and the Idaho batholith because these intrusive bodies appear to contain normal amounts of uranium- and thorium-bearing accessory minerals. The similarity between the isotopic compositions of galena from the Sullivan mine, British Columbia, and galena from the Coeur d'Alene district, about 160 miles distant, hardly suggests that some hidden local intrusive is the source of the Coeur d'Alene lead.

It seems most likely that the deep-point source lies in some relatively uranium- and thorium-free and sulfide-rich zone below the magmatic zone in the mantle. This conclusion about the Coeur d'Alene ores was anticipated, but on other grounds, by Gregory (1928, p. 108, and as quoted by Holmes, 1937, p. 766), who wrote, "The ores at Coeur d'Alene in Idaho and Leadville in Colorado, for example, are remarkably alike, in spite of the differences in structure between the two fields. This similarity indicates that the ores are not derived from either the adjacent sedimentary on intrusive rocks, but come from an ore-zone beneath the igneous rocks of the crust." Holmes (1938, p. 867) suggested "that ore-lead may be derived directly from lead-rich portions of the substratum when these are tapped by shear fractures of the kind inferred from the records of deep earthquakes." Holmes "retreated from his former hypothesis and concluded that granitic rocks and their sedimentary and metamorphic derivatives are the most probable source of lead ores" (Rankama, 1954, p. 397); however, the previous ideas of Holmes still seem worthy of consideration in relation to the Coeur d'Alene veins.

REPLACEMENT

The veins of the Coeur d'Alene district were formed by an extensive series of replacements. What has happened in the veins can be described, but how it happened and under what conditions is not fully understood. The study of the vein material, however, is the first step in determining the conditions of replacement, and certainly such study can at least indicate some of the limiting conditions of the replacement process.

Lead-zinc replacement ore bodies are commonly thought of as simple assemblages of minerals that have replaced limestone and dolomite. Such assemblages occur in many of the Coeur d'Alene veins, but instead of carbonate rock, the replaced material is principally sericitic quartzite and quartzose slate. Nevertheless, despite the difference in host rocks, at least some of the limiting conditions for the formation of the Coeur d'Alene ore bodies may also be limiting conditions for the formation of, for example, the Tri-State ore bodies.

The discussion of replacement is presented in five parts: brief comment on the geologic environment during replacement, petrography of the veins, voids and their significance, movement of host rock during replacement, and theoretical considerations.

GEOLOGIC ENVIRONMENT DURING REPLACEMENT

The greatest known vertical range of ore in the Coeur d'Alene district, 7,400 feet, is north of the Osburn fault. Veins containing silicates now crop out at altitudes as high as 6,300 feet; the lowest explored level of the Morning mine (5200 level) was in ore at 1,050 feet below sea level. Ore is known at greater depth south of the Osburn fault but the vertical range is less.

Geologic evidence, local or regional, does not permit even a tentative estimate of the cover at the time of vein formation. The silicate veins suggest deep burial—that the highest outcrops were covered by more than 10,000 feet of rock. Geomorphic evidence, such as Miocene lava flows that fill valleys cut in the erosion surface at which the silicate veins crop out, suggests that the estimate of 10,000 feet of cover is perhaps excessive. Because some figure is needed for pressure calculations, a cover 10,000 feet thick over the highest outcrops is arbitrarily assumed during main-period vein formation. On this basis, the ore on the 5200 level of the Morning mine would have formed at a depth of 17,400 feet.

Such a depth implies that at the time of vein formation the rock pressure at what is now the 5200 level of the Morning mine was about 1,300 atmospheres, 76 atmospheres being assumed for each 1,000 feet of cover. If the hydraulic system was open to the surface, a much lower hydraulic pressure may have been involved; on the other hand, if the hydraulic system had restricted access to the surface, this pressure might have been higher than the rock pressure. There seems to be no practical way of determining the actual pressure during any of the various stages of mineralization. However, the Tertiary periods of mineralization probably took place at pressures and temperatures very much lower than did the stages of the main period of mineralization.

The rock temperature at the time of vein formation cannot be estimated. If a temperature gradient of 1°C per 100 feet is assumed, the temperature at a depth of 17,400 feet below the surface would be at least 174°C.

PETROGRAPHY OF THE VEINS

As an introduction to the study of replacement in the Coeur d'Alene district, it would be difficult to improve on the descriptions of Lindgren and Ransome and Calkins; two are given below. The first is from Lindgren (1904, p. 109), who was apparently describing ore from the Frisco mine:

> The greenish-gray fine-grained quartzite which constitutes the prevailing country rock contains no sulphides when fresh. It is composed of small, rounded, or subangular quartz grains, closely packed—often, indeed, jointing closely, as in a normal quartzite. Usually, however, a little sericite, in bunches of small fibers, is present as cementing material between the grains. There are few other minerals, except a little feldspar in clastic grains, small prisms of tourmaline, and some grains of calcite. Near the veins minute specks of siderite, zincblende, pyrite, and galena appear in this quartzite; and these scattered grains gradually merge into bodies of merchantable ore. The thin sections show how the rock near the veins is filled with small grains of branching and irregular form, which consist of siderite, developed by attack first upon the groundmass and then upon the grains of clastic quartz. Accompanying the siderite are small grains of zincblende, cubes of pyrite and irregularly wiry masses of galena. All these sulphides appear not only in or near the siderite, but also in the cementing sericite, and in the apparently perfectly fresh quartz grains.
>
> At a more advanced stage these areas of siderite extend until they join, and thus completely replace the rock. In the resulting ore lie scattered many small quartz grains, representing remanants of the clastic constituents of the quartzite. Occasionally larger masses of zincblende appear to form directly in the quartzite by metasomatic replacement of the quartz. The sericite in the quartz then disappears, though once in a while small foils of it may be detected. During the transition stage, seams and narrow veinlets in the altering rock are filled with sericite, apparently segregated there, when driven out from the main mass.

Ransome and Calkins (1908, p. 108) in describing ore from the Bunker Hill mine said:

> In the richest ore the galena predominates and forms irregular and ill-defined bunches. These grade into massive siderite in

which the galena forms countless small reticulating veinlets. Although many of the veinlets are of microscopic width, the absence of definite walls to the little fissures is noticeable and it is evident, without the use of the microscope, that the galena has not merely filled the cracks but has been deposited metasomatically at the expense of the siderite. At the intersections of the cracks the galena has gathered in little bunches. In a more advanced stage of replacement the veinlets are wider and more irregular, the bunches of galena at the intersections are larger, and the final stage of the process is a mass of nearly solid galena with perhaps here and there a small shadowy remnant of siderite. In the other direction, from the center of a rich mass outward, the siderite with its network of stringers and bunches of galena passes into material in which the lead sulphide is less abundant and in which residual masses of sericitic quartzite appear. This is turn grades into the ordinary quartzitic country rock, containing irregular veinlets, ill-defined bunches, and scattered microscopic crystals of siderite with finely disseminated pyrite and in some places veinlets of white quartz carrying a little valueless pyrite.

It thus appears * * * that although this ore in general is a metasomatic replacement of quartzite by siderite and galena the process is actually more complex than that statement would imply, and has taken place in at least two steps. The siderite has first replaced the quartzite and the galena has then attacked the siderite. That galena, however, can under some conditions directly replace the sericitic quartzites of the region is amply illustrated in these same Wardner mines, as well as in those of other parts of the district.

The process can become very complex, and in the following paragraphs attention will be given to monomineralic replacement of monomineralic aggregates before the more complex relationships are considered.

The petrography of rocks of the Prichard, Revett, and St. Regis Formations is described in the section on the bleached rocks (p. 85). At the time this study was made, parts of veins in rocks of the Burke and Wallace Formations were no longer accessible, and consequently no work was done on these rocks. The Burke Formation, which contained important ore bodies, is apparently similar to Revett Quartzite.

Generally, the first mineral introduced in any of the veins has replaced either quartzose slate or sericitic quartzite. An example of perhaps the simplest type of replacement is shown in figure 14. The detrital grains of the quartzite are now in contact with each other, but the texture is not sutured. The small amount of galena seems to be about evenly divided between obvious veinlets and small masses that lie at the intersections of several quartz grains. At this stage in the replacement process the influence of grain boundaries is marked; nevertheless quartz has been attacked, as is most noticeable at the center and upper right of the illustration. Examples of most, if not all, of the vein minerals replacing quartzite could be similarly shown.

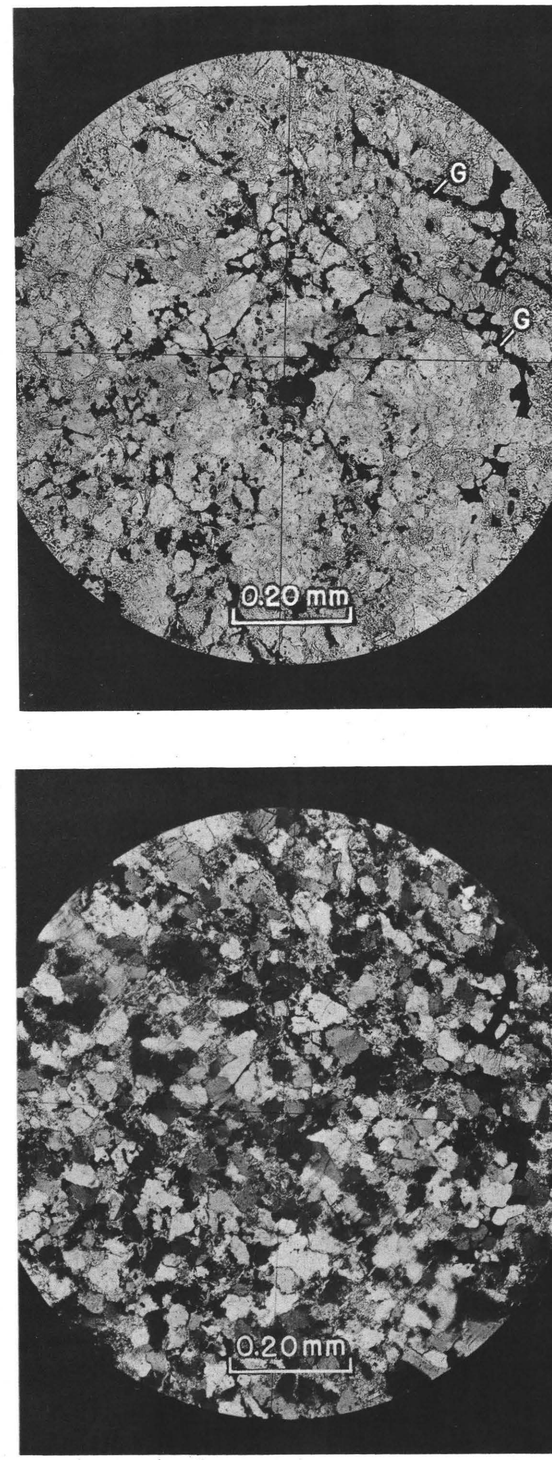

FIGURE 14.—Photomicrographs of Revett Quartzite partly replaced by galena (black), Dayrock mine, Coeur d'Alene district, Idaho. Top, plane-polarized light; bottom, crossed nicols.

The product of more complete replacement of almost unrecrystallized quartzite of the Prichard Formation is shown in figure 15. The individual quartz grains in the remains of a quartzite area are just barely recognizable

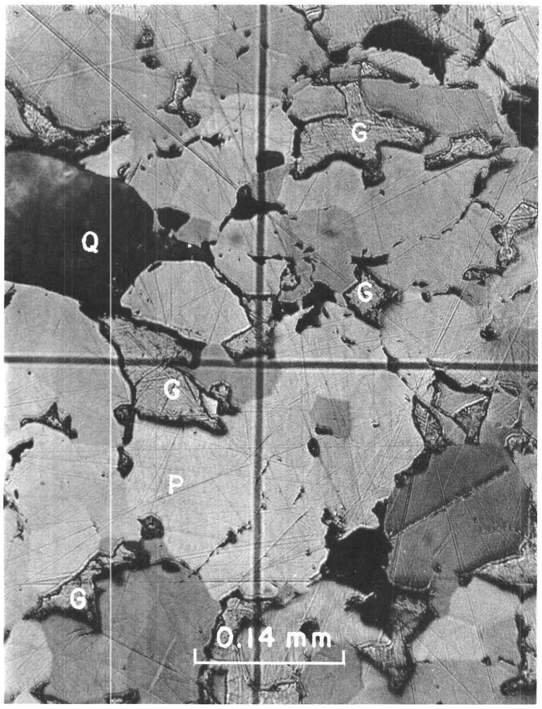

FIGURE 15.—Photomicrograph of a granular aggregate of pyrrhotite, the product of replacement of quartzite of the Prichard Formation. Note the partial replacement of pyrrhotite by galena at the intersections of pyrrhotite grains. Highland-Surprise mine, Coeur d'Alene district, Idaho. Q, quartzite remnant; G, galena. Partly crossed nicols.

in the upper left quadrant of the photomicrograph. Penetration of the quartzite along grain boundaries is evident, but the important feature is the texture of the pyrrhotite aggregate. The aggregate is composed of pyrrhotite grains that are anhedral in shape and that are all of about the same size as the quartzite grains. Figure 16 shows Revett Quartzite largely replaced by siderite; the unreplaced quartzite remnant is in the upper left corner. The sideriate grains are anhedral in shape and about the same size as the unreplaced quartz grains. The textures shown in figures 33 and 34 are typical of most of the pyrrhotite and much of the carbonate that has replaced unrecrystallized or only slightly recrystallized quartzite; similar replacement textures where biotite and sphalerite have replaced quartzite could be illustrated. The isotropic and opaque sulfides present a problem in observation, but etching has shown a similar fine-grain texture in a few samples of galena from the Page mine.

The intersections of three and four quartz grains, which have a rather regular distribution, are preferred points for the initiation of replacement, that is, of nucleation. The regular distribution of these points of nucleation has resulted in fairly uniform-sized polyhedra of pyrrhotite, siderite, sphalerite, and other minerals as the crystals have mutually interfered during their growth. The individual grains of the new aggregate are, therefore, about the same size as the detrital grains of country rock, but their intersections are at about the positions of the centers of the replaced grains.

A first step in the formation of many of the veins has been the recrystallization of greater or lesser amounts of the country-rock quartz. Such recrystallization may vary from what might be called incipient to a degree that quartz grains several millimeters in length have formed.

The replacement of strongly recrystallized quartzite is also primarily controlled by grain boundaries, but the number of grain boundaries in a given volume of recrystallized quartzite may be very much less than in unrecrystallized quartzite and the centers of nucleation farther apart and more irregularly distributed. The result is that a monomineralic aggregate which has replaced recrystallized quartzite will consist of large grains having a considerable range in size and shape. The distinction between vein material recrystallized after deposition and material that has replaced recrystallized quartzite can be made only when unreplaced remnants of quartzite are present.

Figure 17 is a photomicrograph of siderite replacing recrystallized quartz grains of the Revett Quartzite.

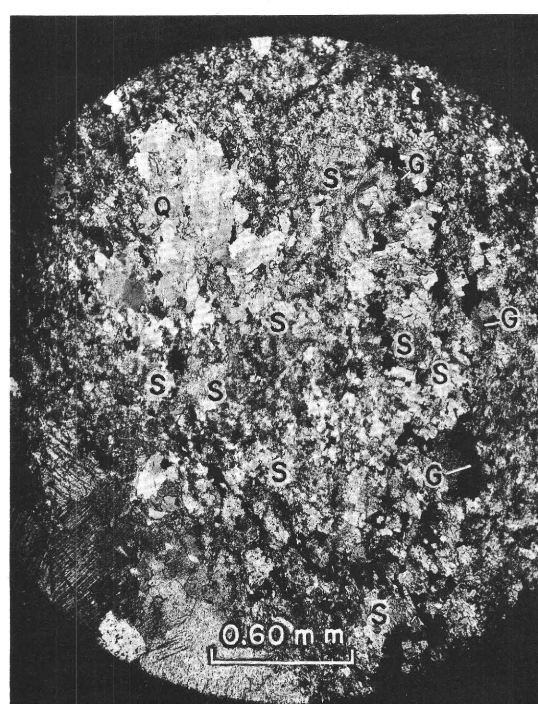

FIGURE 16.—Photomicrograph of Revett Quartzite largely replaced by fine-grained siderite, Star mine, Coeur d'Alene district, Idaho. Q, quartzite remnant; G, galena; S, siderite. Crossed nicols.

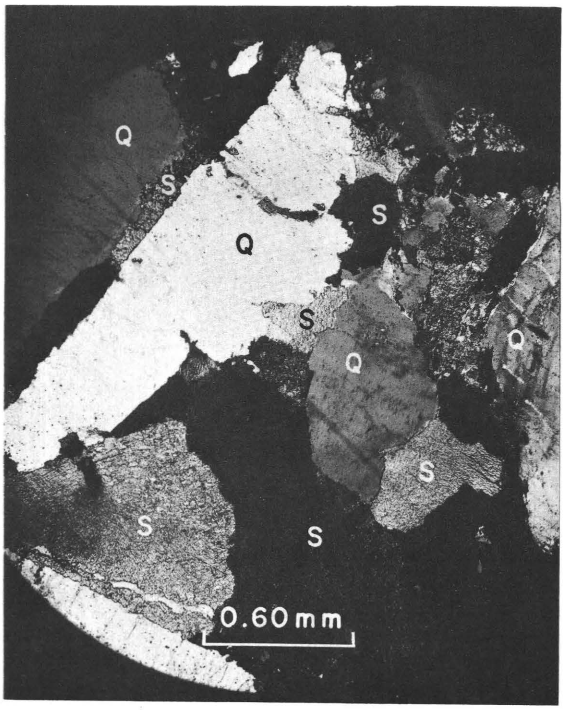

FIGURE 17.—Photomicrograph of recrystallized quartz grains of the Revett Quartzite partially replaced by siderite, Galena mine, Coeur d'Alene district, Idaho. Q, quartz; S, siderite. Crossed nicols.

Relict quartz grains are recognizable in the larger quartz grains, particularly toward the right of the photomicrograph. Most of the siderite grains are confined to positions along grain boundaries and, in contrast to the grains shown in figure 16, are relatively large, although a considerable range in size is represented. Even coarse-grained recrystallized quartzite and siderite are present in this and other mines. Figure 18 is a photomicrograph that shows recrystallized quartzite of the Revett Quartzite partially replaced by tetrahedrite. With the possible exception of a single veinlet, replacement has been controlled by grain boundaries. It is, of course, impossible to determine the size of the individual tetrahedrite grains without etching. Similar photographs could be shown of coarse-grained pyrrhotite or coarse-grained sphalerite replacing coarse-grained quartz and so on. In general, quartz grain boundaries are the controlling structures.

To imply that megascopically visible fractures are of little importance in permitting access of fluids in the replacement process would be incorrect, but these fractures, though most readily visible in the field, are not likely to show up in the thin sections, as do grain boundaries. Furthermore, in the Coeur d'Alene district, brecciation, including microbrecciation, is generally absent and entry into a volume of quartzite seems mainly dependent on grain boundaries and on a very few fractures. It also seems that even the grain boundaries must be disturbed, or jostled, before they can serve as entry ways.

Veins of replacement origin have two general types of contacts with wall rock, sharp and gradational. The designation of one or the other of these types depends to some extent on the scale of the phenomena under consideration. In general, walls of veins and veinlets in the Coeur d'Alene district are sharp. This conclusion may seem to be somewhat at variance with parts of the comments of Lindgren and of Ransome and Calkins quoted above, but the apparent disagreement is largely due to the scales involved. There are exceptions, naturally, where veins have halos of sulfides, and stope walls must be determined by careful inspection or sampling, but the structural or lithologic control of these exceptions is also obvious. The Tony vein of the Page mine is a good example. The wall rock is relatively coarse grained and the beds are at right angles to the vein walls, and hence the ore fluids were able to move out from the main vein fractures along bedding planes and thence along grain boundaries.

The examples of replacement previously illustrated are of rather incompletely replaced rock or of the nearly completely replaced rock from centers of veins. Figure 19 shows the boundary between quartzite and a galena veinlet that has almost completely replaced quartzite. Most of the contact shown in figure 19 is

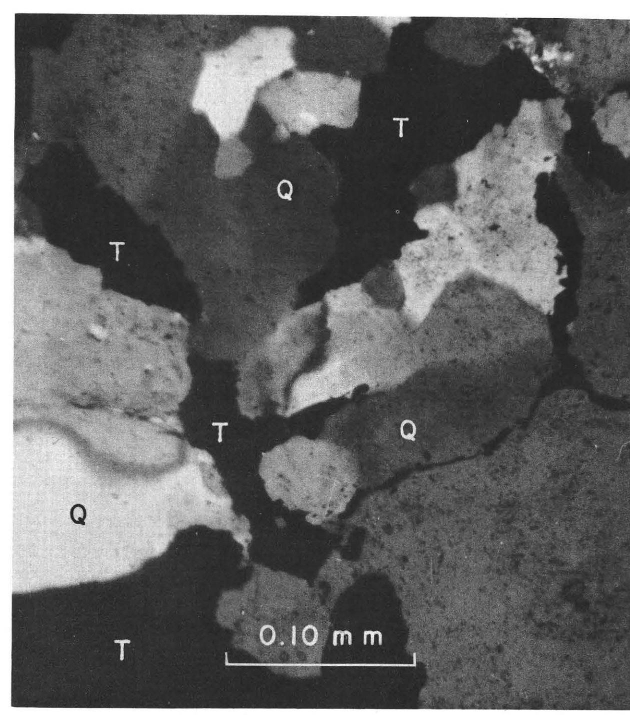

FIGURE 18.—Photomicrograph of recrystallized quartzite of the Revett Quartzite partially replaced by tetrahedrite (black), Galena mine, Coeur d'Alene district, Idaho. Q, quartz; T, tetrahedrite. Crossed nicols.

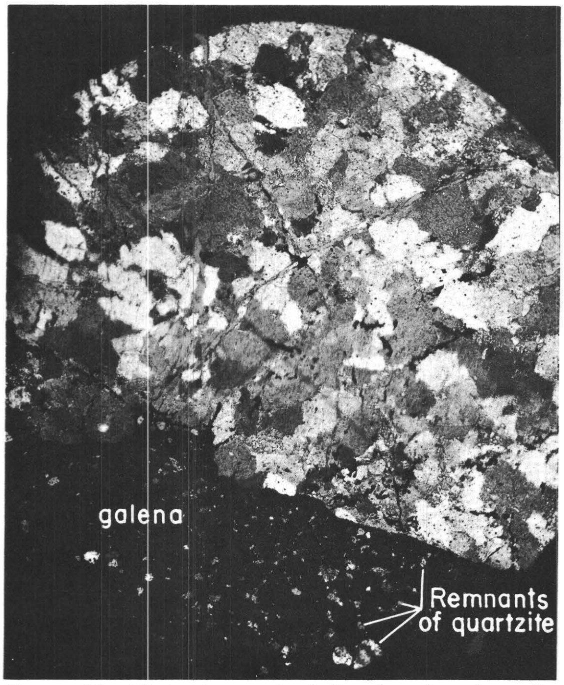

FIGURE 19.—Photomicrograph of the sharp boundary of a galena veinlet that has replaced quartzite, Dayrock mine, Coeur d'Alene district, Idaho. Crossed nicols.

knife-sharp and cuts across the interiors of quartz grains, though at one point galena embays the quartzite and extends slightly along grain boundaries. In the quartzite further out from the contact there are a few areas of galena, as usual controlled by grain boundaries. The illustrated example is not unusual; walls of veins and veinlets are generally of this nature. There is no zone of disseminated galena in the quartz grains along the wall of the vein, as might be expected if diffusion through the quartz grains, either through the quartz structure or along submicroscopic opening of any kind, had played any appreciable role in the formation of the vein. Instead, the quartz grains are perfectly clear, though there are some scattered galena veinlets farther out from the main vein that are controlled by minute fractures and grain boundaries. As a generalization, the microscope provides no evidence that diffusion has been important in the formation of any of the Coeur d'Alene veins.

Once unrecrystallized, or strongly recrystallized, quartzite has undergone monomineralic replacement, any further replacement may result in a wide diversity of textures; however, the more complete the later replacement, the greater the likelihood that the texture will be massive.

Most vein minerals owe their shapes and sizes to some physical property of the replaced material, unless, of course, there has been recrystallization subsequent to their formation, though a few minerals tend to be euhedral. The shape and size of a new mineral may be controlled by the texture or kind of aggregation of the replaced grains, or by the texture or structure of individual grains.

The replacement of granular material, whether it be quartzite or pyrrhotite or siderite, may be expected to produce an aggregate that is of similar grain size, provided the replacement is sufficiently complete. The formation of fine-grained granular aggregates of sphalerite as a replacement of equally fine grained aggregates of pyrrhotite is a common feature of ores from the Pine Creek mineral belt and the veins around the stocks; probably some galena ores are fine grained because the galena has in turn replaced fine-grained granular sphalerite.

A very common type of ore, which forms in the early stages of the replacement of granular aggregates, is one in which the youngest mineral is disseminated in triangular-shaped grains (in three dimensions these are rods). These textures are much more common along the edges of ore shoots where replacement of early gangue minerals by later ore minerals is less complete, but such material is also common in the ore shoots. The triangular shape of the newly introduced material is the result of replacement that began at the intersections of three or more grains of the host material. The triangularity is much more pronounced where the host rock is a granular mass of sulfides than where it is quartzite, because the sulfide grains are in actual contact with each other but the quartz grains are generally separated by some interstitial material. In figure 20, the galena has started to replace pyrrhotite almost entirely at intersections only of pyrrhotite grains. Figure 21 shows a granular aggregate of sphalerite partially replaced by galena. The galena grains tend to have triangular outlines where replacement is very incomplete, and in these areas the texture is similar to that in figure 20. The replacement shown in both figures is quite incomplete, and a number of grain intersections in both examples are not occupied. Figure 22, of the same polished surface as figure 21, shows the contacts between sphalerite and galena at a higher magnification. Figure 23 shows granular pyrrhotite which was first partially replaced by sphalerite; later galena has partially replaced the remaining pyrrhotite and some of the sphalerite. This bleb or granular texture composed of three or more minerals is common in the ores of the Pine Creek mineral belt and the veins around the stocks. Obviously, recrystallization after any of these stages would tend to obliterate the texture. These textures present a problem in determining the paragenesis, but fortunately material is available showing the various steps as well as crosscutting relations.

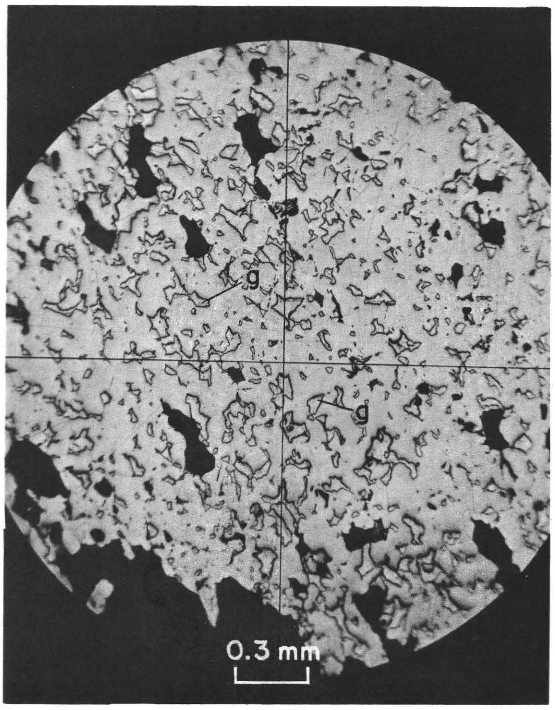

FIGURE 20.—Photomicrograph showing partial replacement of a granular aggregate of pyrrhotite (light gray, smooth) by galena (white), Highland-Surprise mine, Coeur d'Alene district, Idaho. The galena G has started replacement almost entirely at intersections only of pyrrhotite grains. Plane-polarized light.

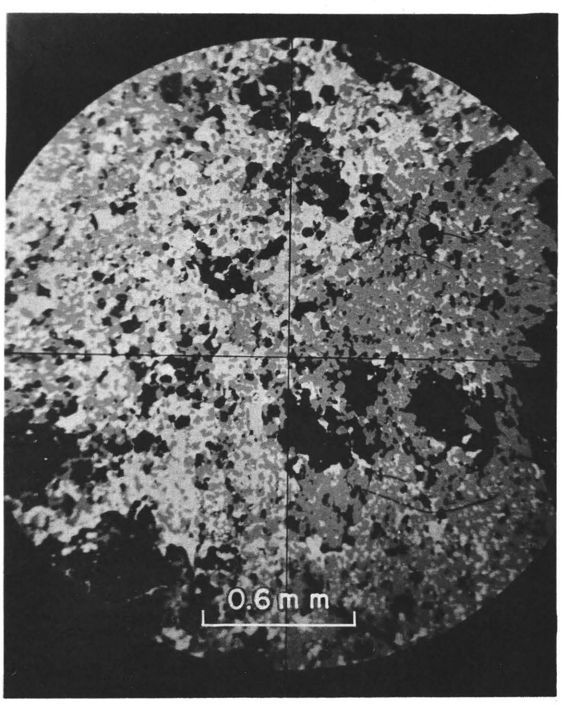

FIGURE 21.—Photomicrograph of granular aggregate of sphalerite (gray) partially replaced by galena (white). Replacement has begun at the intersections of sphalerite grains, as shown to the right of the crosshair where the "triangular" texture is still present. Highland-Surprise mine, Coeur d'Alene district, Idaho. Plane-polarized light.

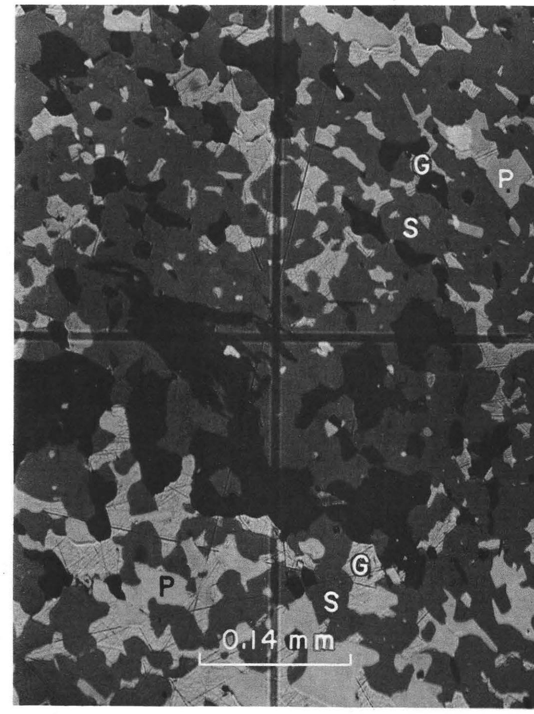

FIGURE 22.—Photomicrograph of sphalerite (dark gray, S) partially replaced by galena (light gray, rough surface, G) along grain boundaries. Some pyrrhotite (smooth, medium gray, P) is also present. Highland-Surprise mine, Coeur d'Alene district, Idaho. Plane-polarized light.

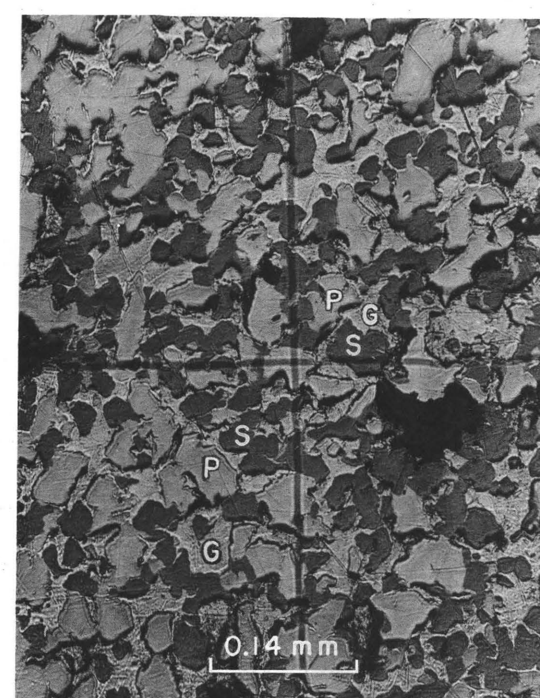

FIGURE 23.—Photomicrograph of granular pyrrhotite (light gray, P, moderate relief against galena) partially replaced by sphalerite (medium gray, S); both are replaced by later galena (white, G). Sidney mine, Coeur d'Alene district, Idaho. Plane-polarized light.

As replacement continues along grain boundaries, grains of the replacing mineral may coalesce to form a network. The strands of the net then increase in width until only small remnants of the original grains remain, or until replacement is complete. All steps may be seen in the same polished surface. Figure 24 shows a moderately advanced stage in the replacement of sphalerite by galena; a small amount of pyrrhotite remains in the sphalerite, but it is imperceptible in the illustration. Concentrating such material presents a considerable problem to the millman. Figure 25 shows all stages in the replacement of granular sphalerite by galena. Triangular blebs of galena are present in the massive sphalerite; the network of galena is present in various stages of development, and in the lower part of the photomicrograph only blebs of sphalerite remain in the galena.

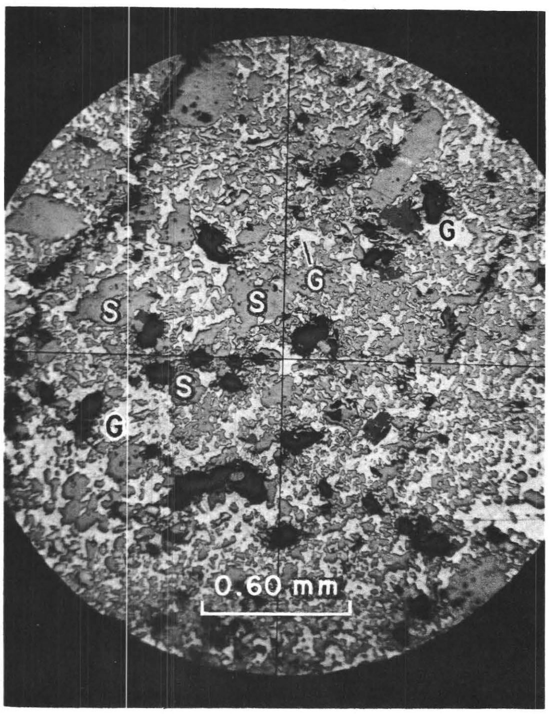

FIGURE 24.—Photomicrograph of granular sphalerite (medium gray, S) partially replaced by galena (white, G). Many sphalerite grains are almost entirely replaced by the network of galena. Sidney mine, Coeur d'Alene district, Idaho. Plane-polarized light.

The formation of delicate fine-grained networks is of course not restricted to the replacement of sulfides by sulfides, for similar textures are formed where country rock is replaced by sulfides and where other fine-grained materials such as carbonates are replaced. Figure 26 shows fine-grained siderite that has been partially replaced by a network of galena. Cleavage

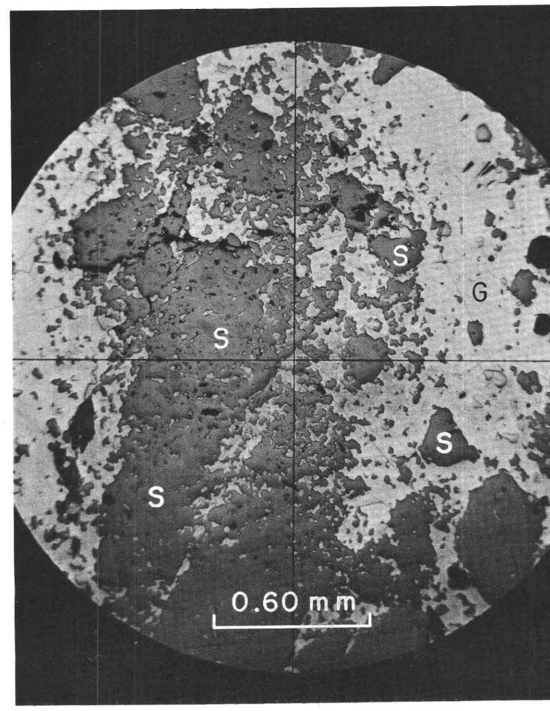

FIGURE 25.—Photomicrograph of a network of galena (white, G) partially replacing granular sphalerite (medium gray, S); all stages in the process are present. Highland-Surprise mine, Coeur d'Alene district, Idaho. Plane-polarized light.

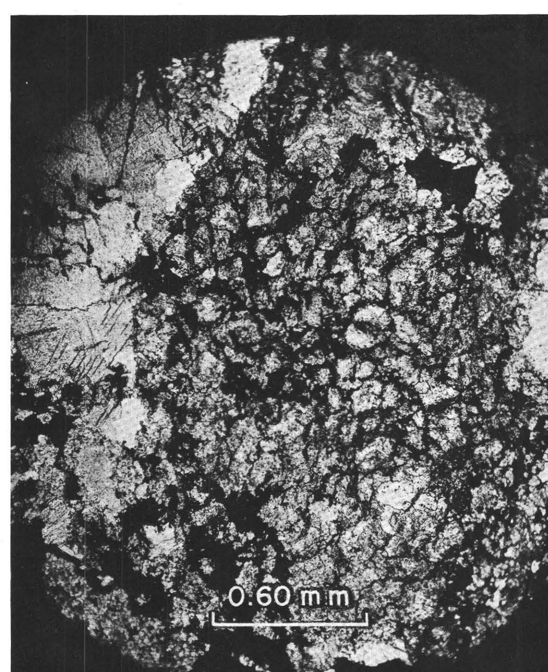

FIGURE 26.—Photomicrograph of fine-grained siderite partially replaced by a network of galena (black). Star mine, Coeur d'Alene district, Idaho. Plane-polarized light.

is poorly developed in such siderite grains and the replacement is almost entirely along grain boundaries. Cleavage control of replacement is shown in the larger carbonate grains, probably ankerite, in the upper left corner of the illustration. Similar but more irregular textures arise where feltlike masses of amphibole are replaced by magnetite and sulfides.

The replacement of coarse-grained monomineralic aggregates gives, on a gross scale, patterns not greatly different from those of the replacement of fine-grained aggregates, but the influence of grain intersections and boundaries is less important for a given volume of rock. In addition, characteristics of the replaced grains such as cleavage become more important. Coarse-grained carbonate, as contrasted with the fine-grained carbonate discussed above, furnishes the best examples of the influence of individual grains on the course of replacement.

The replacement of coarse-grained siderite by a sulfide is largely controlled in the earliest stages by grain boundaries, but even during these stages penetration of the siderite along cleavage cracks is noticeable. Where replacement is far advanced, it becomes obvious that cleavage cracks have been the dominant control.

A more subtle influence of cleavage on replacement and grain boundaries is illustrated in figure 27, which shows pyrrhotite replacing siderite. Although the contacts between the two minerals tend to be straight, many little prongs of pyrrhotite penetrate a short distance into the siderite along cleavage; the blocky appearance of the pyrrhotite is entirely controlled by the siderite cleavage.

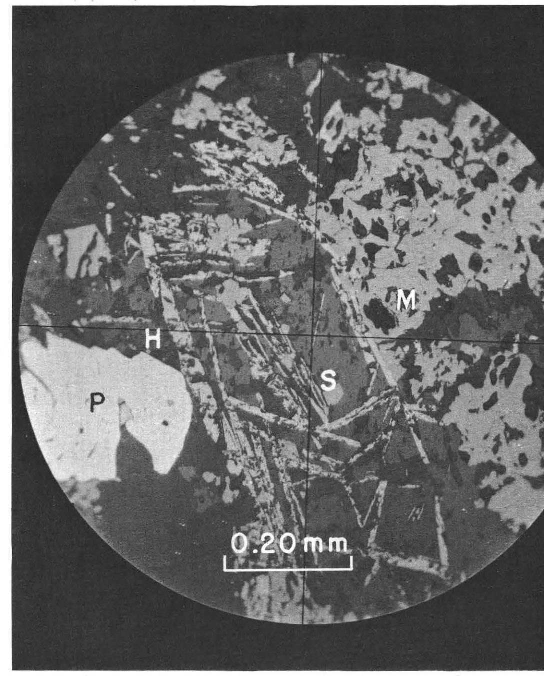

FIGURE 28.—Photomicrograph of siderite (medium gray) partially replaced by specular hematite (white blades), Sherman mine, Coeur d'Alene district, Idaho. S, siderite; H, hematite; M, magnetite; P, pyrite. Plane-polarized light.

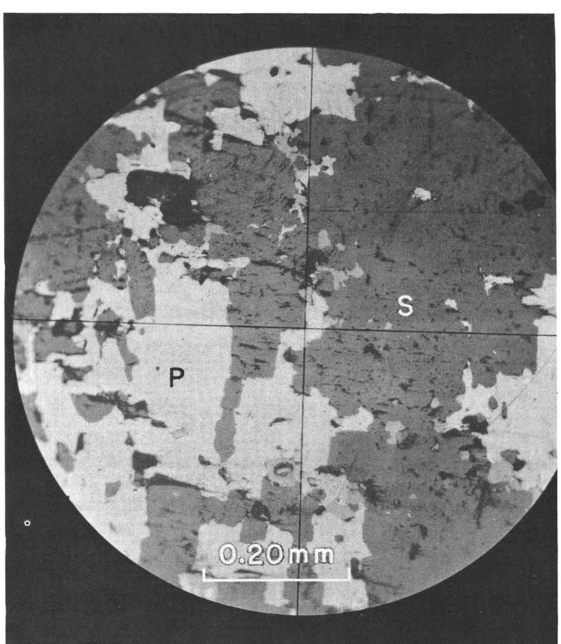

FIGURE 27.—Photomicrograph of a siderite grain (medium gray, S) partially replaced by pyrrhotite (white, P). Most of the siderite is in a single large grain centering around the crosshair. Hercules mine, Coeur d'Alene district, Idaho. Plane-polarized light.

Neither pyrrhotite nor tetrahedrite has a strong tendency to form euhedral crystals and their textures in partially replaced carbonate are irregular. However, minerals that tend to be euhedral also may be significantly controlled by the siderite cleavage. Figure 28 shows coarse-grained siderite partially replaced by specular hematite. Control of the orientation of the euhedral hematite by the siderite cleavage is obvious.

Strong cleavage or parting control may be expected if the host mineral is cleavable or has parting (fig. 29). Similar textures may be interpreted perhaps too readily as indicating an origin by exsolution where two sulfides are involved.

Pyrite has a strong tendency to form euhedral grains, but this tendency can be greatly affected by the nature of the host, and the resulting grain may seem to be corroded. Pyrite that replaces quartzite generally is euhedral, but skeleton grains of pyrite and poikilitic pyrite containing abundant quartz grains can be found from place to place. The replacement of massive green biotite by pyrite, as shown in figure 30,

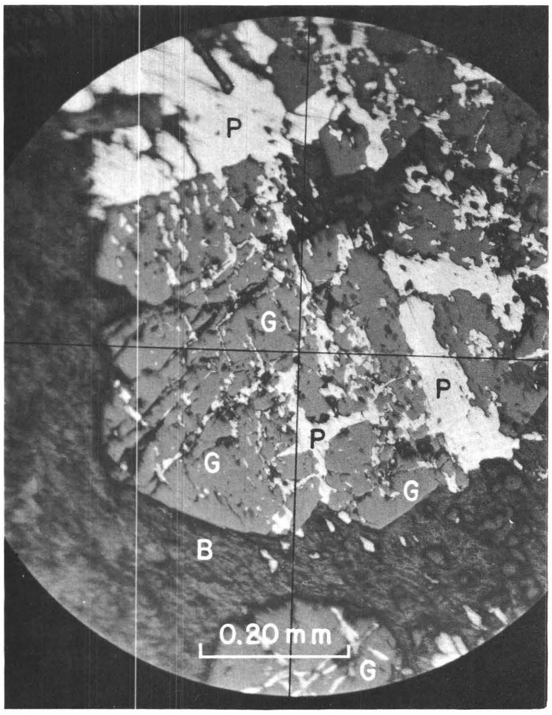

FIGURE 29.—Photomicrograph of garnet crystal (medium gray) partially replaced by pyrrhotite (white), Hercules mine, Coeur d'Alene district, Idaho. G, garnet; P, pyrrhotite; B, green biotite. Plane-polarized light.

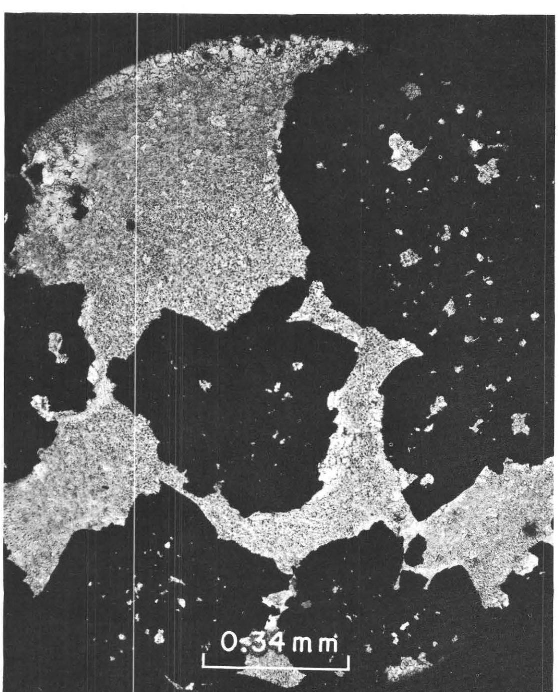

FIGURE 30.—Photomicrograph of green biotite partially replaced by pyrite (black), Idora mine, Coeur d'Alene district, Idaho. Plane-polarized light.

frequently results in skeleton grains of pyrite that might be confused with corroded grains. The pyrite contacts may appear irregular at first glance, but they are along a series of steplike straight lines, particulaly around the central grain. These steps are, of course, crystal faces, and the edges and corners of the pyrite are not corroded. Abundant inclusions of biotite in the pyrite grains also indicate that pyrite is the younger. The biotite aggregate does not seem to have been deformed as it was replaced by pyrite. Zoning of the pyrite parallel to the present contacts, visible under the microscope but not in figure 30, indicates that the shapes of the grains are determined by deposition not solution.

The replacement of magnetite by pyrite rarely results in the formation of euhedral pyrite. Perhaps the most regular forms to be found under such circumstances are similar to those shown in figure 31. This pyrite could at best be called subhedral, and at low magnification the pyrite appears to be badly corroded. However, the edges and corners of the pyrite are not rounded but are steplike, and the pyrite is not corroded by the magnetite. Most of the pyrite that replaces magnetite has irregular shaped grains similar to the daggerlike shape in the lower left corner of the upper right quadrant of figure 31. In almost all other circumstances, where pyrite replaces a softer mineral, single grains are, or were, euhedral.

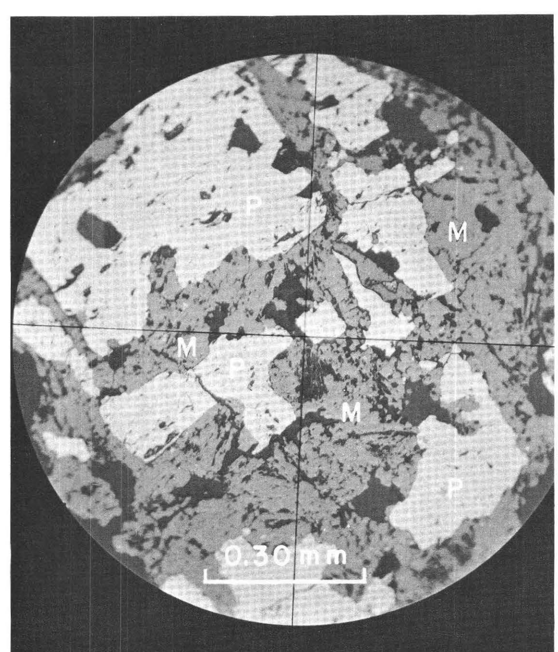

FIGURE 31.—Photomicrograph of magnetite (medium gray, M) partially replaced by pyrite (light gray, P), Sherman mine, Coeur d'Alene district, Idaho. Plane-polarized light.

The textures that may be produced by several stages of partial replacement tend to be complicated. Description of the resulting textures would be involved and no new principles would be introduced.

In summary, replacement in the Coeur d'Alene ore deposits appears to be controlled largely by the physical or structural features of the host material.

VOIDS AND THEIR SIGNIFICANCE

Replacement is customarily considered to be a volume-for-volume process and the agent that removes the host material to be responsible for the deposition of new material. That volume-for-volume replacement is not always the rule, and that voids may form and then persist throughout the remainder of the vein-forming process was recognized by Lindgren (1912, p. 531–532). Where vugs exist, the conclusion immediately follows that the agent of removal is not always the same as the agent of deposition, and a question may then be raised as to the time interval between removal and deposition in other parts of the vein. A related matter is that of recognizable transport of the host material in the replacement process; the host material at some places can be shown to be not all removed from a particular area by solution or by comminution followed by flushing.

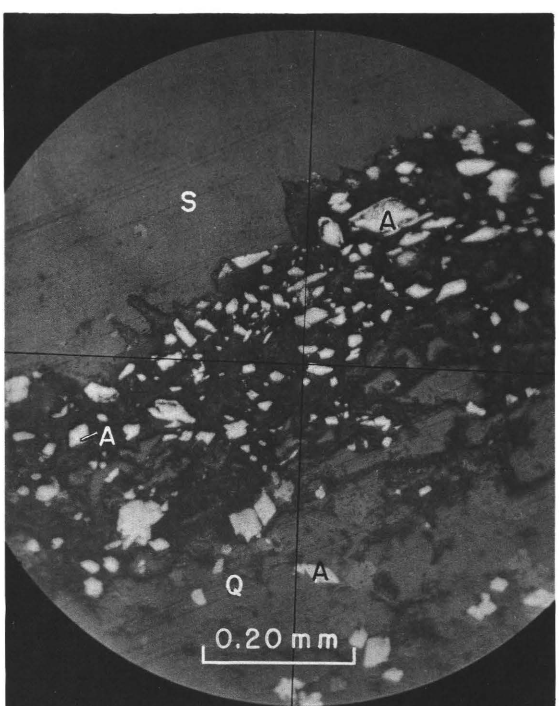

FIGURE 32.—Photomicrograph showing sulfides, mainly arsenopyrite (white, A), accumulated at edge of siderite veinlet (smooth, medium gray, S) replacing quartzite (rough, medium gray, Q), Silver Summit mine, Coeur d'Alene district, Idaho. Normal density of sulfide distribution in country rock is shown at bottom of photomicrograph. Plane-polarized light.

Vugs are not common in the veins, but they have been found in many of the mines. Vugs are most common in the Silver Summit and Galena mines, where coarsely recrystallized quartzite contains vugs variously lined with euhedral quartz, siderite, tetrahedrite, chalcopyrite, and silver-antimony sulfides. (In Fryklund and Hutchinson, 1954, p. 757, I erroneously considered this quartz to be younger rather than older than the main depositionary stages and the minerals of the vugs to belong to late generations.) Similar vugs exist in siderite. The mere existence of these vugs, some reaching lengths of 2 feet and widths of 3 to 4 inches, is of interest, because many are now more than 4,000 feet below the present surface and undoubtedly were much deeper when the veins formed.

A vug may be explained by saying that dissolution exceeded deposition at any one point or that deposition did not fill all the available voids. One may then ask just how extensive were the voids throughout the vein before a particular stage of deposition began. Gradations from networks of minute veinlets in country rock to vein material containing only minor remnants of country rock, or just quartz grains, are to be found in all the veins, and voids similar in size to the ones now visible seem never to have been common.

MOVEMENT OF HOST MATERIAL

Examples of recognizable transport or movement of host material are not common in the district. Lindgren (1904, p. 109) recognized sericite that had apparently been segregated during replacement of quartzite. Mitcham (1952, p. 434) wrote, "Some recrystallization and accompanying limited migration of most wall rock minerals are noted. Resistant tourmaline is occasionally found in accumulations along siderite crystal interfaces, as if swept on an advancing crystal front as other wall-rock minerals were dissolved." The replacement by siderite of quartzite containing disseminated arsenopyrite and pyrite may result in the accumulation of sulfide grains at the replacing front, as shown in figure 32. The edge of the siderite vein in figure 32 is where the dark rougher material is in contact with the quartzite; the siderite at the edge is darker and rough appearing because only the harder sulfides were polished. The arsenopyrite and pyrite concentrated at the edge of the siderite vein appear to have been actually pushed outward as the vein formed. The siderite veinlet was almost vertical, and it does not seem possible that at any time there was an open cavity crusted by arsenopyrite grains. A similar concentration of arsenopyrite and pyrite is present on the opposite wall of the

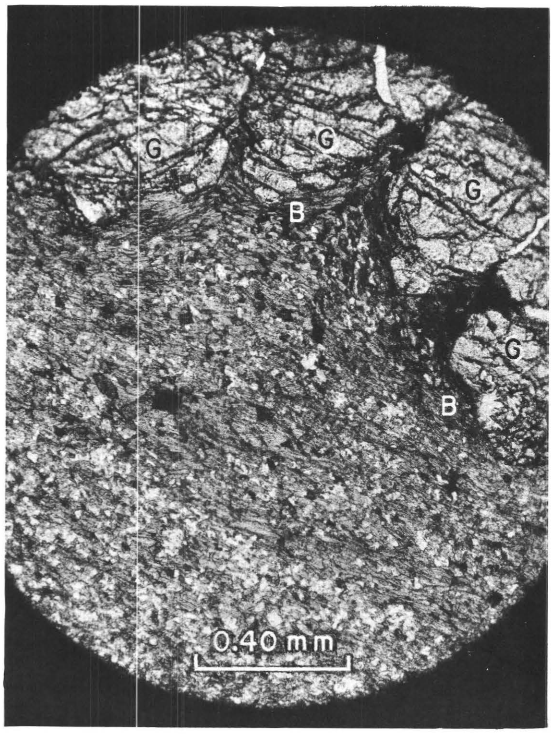

FIGURE 33.—Photomicrograph of biotite aggregate (B) deformed by garnet (G), Hercules mine, Coeur d'Alene district, Idaho. Plane-polarized light.

siderite vein. Any open spaces no doubt were small and, though the quartz and sericite were removed, the residual sulfide probably was simply pushed on ahead.

Similar examples of accumulations of pyrite grains at the edges of sphalerite masses probably formed in the same way. The analogous deformation of masses of green biotite by garnet, as shown in figure 33, can be seen in the silicate-bearing veins.

THEORETICAL CONSIDERATIONS

The literature on replacement is voluminous and a comprehensive review is needed; in its absence the reader is referred to Garrels and Dreyer (1952) and Holser (1947). Garrels and Dreyer (1952, p. 329) epitomized the problem as follows, "From the wide range of opinion expressed concerning the relative importance of mass movement of solution down a pressure gradient (permeability), versus movement of ions down a concentration gradient (diffusion), it is clear that an understanding of the replacement processes cannot evolve until the relative importance of these two mechanisms of material transport can be assessed."

Lindgren (1933, p. 177) considered that ore solutions moved through open spaces and that "Diffusion is incompetent to originate mineral deposits; it must be supplemented by the movement of the solution on fractures or other open spaces." Others (see Holser, 1947, for a concise summary) have given consideration to grain boundary and intralattice diffusion.

The evidence presented so far, and particularly the relations shown in the photomicrographs, do not suggest any significant role for diffusion in the replacement process; rather it suggests that the ore minerals were deposited in open spaces, small, or even submicroscopic, though these open spaces may have been.

There seems no reason to believe that the open spaces were not formed by solution, though the exact nature of the fluid must be, for the present, a matter of conjecture. The reader should consult, for example, the review article by Morey (1957).

GENERAL FEATURES OF ORE SHOOTS

"Ore deposits are rarely equally rich throughout. Generally, the valuable primary minerals tend to be concentrated in certain sections called ore shoots, which contrast with lean or barren portions of the deposits. * * * An ore shoot may differ from the lean portions of a deposit by the presence of only as little as 0.0004 percent gold or 1 percent copper, or there may be readily detectable mineralogical differences, such as the presence of galena in the ore shoot and its absence from the barren portion" (Bateman, 1950, p. 158). The ore shoots of the Coeur d'Alene district are of the latter type.

Because the veins of the district have considerable extents, both horizontal and vertical, many of the ore shoots are large; most are in steeply dipping veins, and their dip length is usually several times the strike length. Most ore shoots rake between 70° and 90° in the plane of the vein. The largest known ore shoot in the district is on the Morning-Star vein. This ore shoot cropped out at an altitude of 5,675 feet and has been partially explored (in ore) at an altitude of −1,050 feet; and has not been bottomed. Inasmuch as the vein is approximately vertical, the dip length of the shoot is 6,725 feet and the rake is 90°. Sizes of other ore shoots are given in tables 23–33.

The principal aims of a study of ore shoots in a district would include the prediction of their existence, their location, their variation of metal content with depth, and their vertical extent and the recognition of blind ore shoots in veins that are barren at the outcrop.

Productive veins are probably more numerous than large barren ones in the mineral belts of the district; if a large barren vein is discovered, the chances are better than even, therefore, that an ore shoot is present somewhere along it. Nevertheless, at present the only way to find an ore shoot is by thorough and comprehensive physical exploration, and such exploration may be very expensive. The ore shoot controls that have been suggested for the Coeur d'Alene deposits do not seem to be reflections of any fundamental geologic factors.

PRIMARY MINERALOGIC VARIATIONS WITHIN ORE SHOOTS

Whether the primary mineral constituents of Coeur d'Alene ore shoots change with depth was first considered in the literature by Ransome and Calkins (1908, p. 130), but it is safe to say that the topic was much debated at the very start of lode mining in the region, and the discussion continues to the present. Ransome and Calkins listed the Tiger-Poorman, Standard-Mammoth, Helena-Frisco, and Gold Hunter as mines whose ores changed in composition with depth, but these examples are poorly documented and the changes noted are hardly striking.

Umpleby and Jones (1923) did not discuss in detail the problem of primary variations, but the comments scattered through their report indicate that they were skeptical about reported variations with depth. They specifically (1923, p. 81) took issue with Ransome and Calkins with respect to supposed variations in depth in the Tiger-Poorman, Standard-Mammoth, and Helena-Frisco mines. The first two mines mentioned are inaccessible, but the Frisco was examined during this study and vertical variations are not apparent.

Few ore shoots are ever as accessible to the visiting geologist as he would like and even if the old drifts are still open, most of the ore has been removed and the rest is generally obscured by timber. Vein matter in the ore shoots usually is exposed only in today's working faces, which are always limited in number. Production records are rarely, if ever, kept on a level basis, and if top, middle, and bottom of an ore shoot have been mined simultaneously for years, as in the Star mine, the yearly production records will have no meaning. In many cases, of course, production figures over a number of years reasonably well reflect the composition of ore from increasingly deeper levels. Systematic face sampling of new drifts is not universal in the Coeur d'Alene district, and records of old mines are no longer available. A further handicap in the use of old production records is that sphalerite was not recovered from the ores until 1905, and recovery in the first few subsequent years can hardly be considered as representative of the ore body being mined, in view of the milling and marketing problems then reigning. Primary variations in the gangue minerals are not reflected in production figures, and secondhand and hearsay information may be actually misleading. With these reservations in mind, the following comments are to be considered summaries of information and evidence.

1. The ore bodies of the Sunset mineral belt have relatively short strike lengths and extensions in depth. No primary variations are known.
2. Of the veins in the Carlisle-Hercules mineral belt, only the Interstate and Hercules veins have been described as zoned. The Interstate vein contained sphalerite from top to bottom, but the sphalerite ore body has been described as having a fringe of galena on the top, bottom, and sides (McKinistry and Svendsen, 1942, p. 226). The Hercules vein contains two ore shoots: the main Hercules ore shoot which was lead-rich, and the Rambler ore shoot to the west, which is zinc-rich in all the explored parts. Stringham and others (1953, p. 1280) found that a line could be drawn in the Hercules ore shoot separating areas where pyrite is dominant from areas where pyrrhotite is dominant. The line is horizontal on the west end of the 200 level and becomes vertical on the 400 level east of the shaft. Stringham and others considered all the pyrite to be younger than pyrrhotite; they did not recognize that the pyrite younger than pyrrhotite is an alteration product of pyrrhotite and that important amounts of older pyrite are also present in the vein. Their statement may, therefore, apply only to vertical zoning with respect to alteration pyrite rather than to any primary zoning of pyrite and pyrrhotite.
3. Among veins of the Tamarack-Marsh mineral subbelt, only the Tiger-Poorman has been described as having mineral variations with depth (Ransome and Calkins, 1908, p. 130), and Umpleby and Jones 1923, p. 81) did not agree. I have no first-hand knowledge of the Tiger-Poorman mine, and there is insufficient data on the other mines in this belt.
4. Of the veins in the Rex-Snowstorm mineral belt, only the Standard-Mammoth was described by Ransome and Calkins (1908, p. 130) as showing variations with depth, and Umpleby and Jones (1923, p. 80) again specifically disagreed.
5. From the Gem-Gold Hunter mineral belt and the Success mineral subbelt, Ransome and Calkins (1908, p. 130) described the Frisco and Gold Hunter veins as showing variations with depth. Umpleby and Jones (1923, p. 81) disagreed with Ransome and Calkins with respect to the Frisco, as I do. The supposedly abrupt decrease in the silver tenor of the Gold Hunter ore from the surface to

depth probably was not due to secondary enrichment, because the ore mineral near the surface was also tetrahedrite. Obviously, Ransome and Calkins (1908, p. 130) were uncertain as to the accuracy of their information and it is doubtful that the mine had important mineralogic changes at depth.

The Morning-Star vein is zoned laterally, the eastern part—almost a fringe area—being galena-rich and the remainder sphalerite-rich. The sphalerite in the Star segment of the ore shoot shows an iron-concentration gradient, that is, more iron in sphalerite toward the top (Fryklund and Fletcher, 1956, p. 239).

6. The veins of the Golconda-Lucky Friday mineral belt are not known to be zoned. The shape of the Lucky Friday ore shoot has changed with depth, but the mineral composition and silver tenor of the ore apparently have not changed. There are no lateral changes in the lower levels of the mine.
7. Two of the veins of the Page-Galena mineral belt show primary variations. The Tony vein of the Page mine has a striking zoning pattern. The upper part of the ore shoot, which has been truncated by the Page fault, is galena-rich, but the lower part is sphalerite-rich. The line separating galena-rich ore from sphalerite-rich ore is between the 1800 and 1600 levels on the west end of the ore body; eastward the line slopes downward to about 500 feet from the end of the ore shoot on the 2100 level, from which point it is more or less vertical to the bottom of the mine.

   The scanty data available on the great ore shoots of the upper part of the Bunker Hill mine do not suggest zoning. Fairly closely spaced samples indicate no mineral zoning in the Mac, Emery, and Truman-Ike veins in the lower part of the mine. The upper veins had massive siderite gangue, however, and the lower veins contain only disseminated siderite and siderite stringers, but different vein systems are involved.

   Nothing is known about primary variations in the upper ore shoots of the Crescent mine, and the lower ore bodies are insufficiently exposed for study.

   The Sunshine vein supposedly contained more galena in the upper than in the lower segments of the ore body. Yearly production figures, which fairly well reflect the composition of ore from successively deeper levels, show a direct correlation between the amount of lead and the tonnage of ore mined each year; thus, the amount of galena per volume of rock did not change with depth of the ore shoot. The amount of tetrahedrite tremendously increased below the 1700 level, but this increase reflects the dramatic change in the size of the ore shoot rather than in its composition.

   The Silver vein of the Galena mine was sampled between the 2200 and 3400 levels, and the galena in this tetrahedrite ore shoot was found to be largely restricted to an S-shaped body in the center of the ore shoot.

   There are insufficient data for comment on the other ore bodies of the Silver Belt.
8. No primary mineral variations have been recognized in the veins of the Pine Creek mineral belt, though chemical variation of sphalerite, described in the following section, exists in the Highland-Surprise mine, the only mine studied in such detail.

In summary, only two ore shoots appear to show primary variations in mineralogy with depth, and for one of these the evidence is not clearcut. The Tony vein of the Page mine shows the classic zoning pattern from galena at the top to sphalerite at the bottom, though it should be pointed out that a vertical galena root in the east part of the ore body will probably extend to the bottom of the ore shoot. The Hercules ore shoot may well have more pyrrhotite than pyrite at depth, but vein material on the Nos. 2–4 dumps contains abundant pyrrhotite, as well as all the silicate minerals.

The greatest primary variation in mineral content of an ore shoot at depth is, of course, the inevitable diminishing of the volume of ore minerals per given volume of rock to the point where economical mining of the ore body is no longer possible. Many veins in the Coeur d'Alene district already have been mined to this depth. In other words, the decrease in the proportion of ore minerals to gangue at depth reflects not a true mineral zoning but rather only a difference in the degree of replacement of gangue by ore.

Primary mineralogic variations within an ore shoot may involve not only the presence or absence of certain minerals vertically and laterally, but also composition variations of particular minerals.

Vertical variations have been found in sphalerites, and such variations may be found for other minerals, though vertical variations in ore assemblages are rare.

Fryklund and Fletcher (1956, p. 239) have demonstrated that sphalerite from the upper parts of the very large ore body at the Star mine has a higher iron content than sphalerite from the lower part of the same ore body. On the other hand, work in progress in March

1959 indicated that sphalerite from the Nos. 1 and 2 ore shoots on the Surprise vein, Highland-Surprise mine, has less iron at the tops of the ore shoots than at the bottoms. The variation in the iron content of pyrrhotite from the two ore shoots was also being investigated, but no information was yet available.

Fryklund and Harner (1955) showed that minor-element variation in pyrrhotite from the Surprise No. 1 ore shoot was erratic. They concluded (1955, p. 344) that the cobalt and nickel content of the pyrrhotite lacked systematic variation, "probably due to the fact that the Co and Ni contents did not reach equilibrium concentrations for the temperatures and pressures involved." Fryklund and Fletcher (1956, p. 246) reached similar conclusions about the minor element content—cadmium, indium, gallium, germanium, cobalt—of sphalerite from the Star mine.

BOTTOMING OF ORE SHOOTS AND VEINS

Bottoming of ore shoots and veins is a topic of both scientific and economic interest. Although it is possible to describe the apparent conditions below many bottomed ore shoots, and even veins, no sound method seems to exist for predicting where an ore shoot will bottom, nor is there any really good explanation for nondeposition. I am indebted to A. B. Campbell, U.S. Geological Survey, for discussions from which part of the following material is derived. In considering the comments that follow, the reader should be reminded that ore is something that can be mined at a profit.

The various reasons for the bottoming of ore shoots in the Coeur d'Alene district, and probably elsewhere, are outlined below:

1. The ore shoot can no longer be mined profitably, although (a) the grade of vein changed only slightly, or (b) the grade remained constant.
2. The ore shoot is faulted and its extension beyond the fault has not been found.
3. The content of ore minerals decreased abruptly.
4. The entire vein pinched.
5. The vein horsetailed.

The examples described below are to be considered only as illustrative of each category:

1. (a) In a broad economic sense, an ore shoot bottoms at the point where it ceases to be profitably minable, but a more restricted meaning is intended. Some ore bodies are only marginal in value at best, and a slight decrease in grade of ore may cause mining to stop. These small changes are, of course, particularly important where higher costs of mining at greater and greater depths are involved. A change in the market price will have the same effect. Several mines in the district probably provide examples of this sort of bottoming.

   (b) The grade and volume of ore may remain constant, but the increased cost of mining from deeper and deeper levels may change ore into waste. The Morning part of the Morning-Star ore shoot bottomed for this reason.
2. Faulted ore shoots are rare in the district. The Highland ore shoot of the Highland-Surprise mine was cut off by the Placer Creek fault. Inasmuch as the strike-slip movement on this fault is large, about 1.5 miles, and the dip-slip movement is unknown, search for the offset segment does not seem worthwhile. The Ohio vein of the Dayrock mine is cut by the Dobson Pass fault, and the offset footwall segment probably cannot be found.
3. Many ore shoots bottom as a result of an abrupt downward change from ore to gangue. Certainly most of the ore shoots now accessible have bottomed in this manner, as apparently did most of those previously accessible.

   Changes in composition of wallrock do not appear to have caused bottoming of any ore shoots in the Coeur d'Alene district, although this explanation has been invoked from time to time.

   Bottoming because of changes in attitudes of of beds has not been postulated for any of the ore bodies, and there appears to be no place where bottoming is accompanied by such changes. A change from ore to gangue with a change in dip of the vein can be established in a few places. The Sunset vein of the Sunset Minerals mine contains an ore shoot in the flattest part of the vein, but the Surprise ore shoot of the Highland-Surprise mine is in the steep part of the vein. The Sunset ore shoot is in the thickest part of the vein, where widths are 5 to 10 times greater than widths below the ore shoot; on the other hand, the pyrrhotite-rich vein below the Surprise ore shoot has about the same width as the ore. It is doubtful if either ore shoot bottomed because of a change in the dip of the vein.

   The ore shoots that bottom where no changes in country rock or in vein attitude are discernible are probably in the majority. Examples that were observed are to be found in the Tamarack mine, the Sherman veins, the Hercules and Rambler ore shoots of the Hercules mine, and the Sunset Lease veins of the Sunset mineral belt.

In these and other examples, the strong vein below the ore shoot indicates that vein-forming activity continued at much greater depths and consequently that another ore shoot may exist at depth. Exploration directly downdip from bottomed ore shoots has proved fruitless. Possibly such exploration, nowhere extending for as much as 1,000 feet, has not gone far enough. The Hercules vein was tested 600 feet below the Hercules ore shoot by drifting and diamond drilling, and a few other veins have been similarly tested. However, experience certainly indicates that exploration directly downdip from an exhausted ore shoot is not worthwhile, though some additional ore shoots along the strike and at deeper levels are known.

4. Some ore shoots have bottomed as a result of narrowing or pinching out of the vein. These include shoots on the Interstate vein, the Silver Summit veins, the Golconda vein, and the Dayrock vein.
5. Bottoming by horsetailing is difficult to establish without extensive exploration and it is highly possible that some veins that seem to have pinched out may have horsetailed instead. Perhaps the best example is the Sunshine "B" vein. This vein contained an ore shoot below the 1900 level that bottomed just below the 3100 level. The bottoming occurred where the vein passed from thin-bedded sericite quartzite and quartzose slate into thicker bedded sericite quartzite. There is some indication that the single large strand broke into a number of smaller strands that occupied a larger volume of rock. The main strand as exposed on the 3700 level contains some siderite and scattered sulfides; it has not yet completely pinched out. Another possible example is the Mac vein of the Bunker Hill mine.

TOPS OF ORE SHOOTS

Criteria by which the presence or absence of an ore shoot below a barren outcrop or at depth within a barren vein could be predicted are very desirable. No such criteria are at hand, but there are some features about tops of ore shoots that are of interest.

Though most of the veins mined in the Coeur d'Alene district cropped out, and probably most of the ore bodies on these veins also cropped out, the outcrop of some ore bodies gave little indication of their great size at depth; there also are ore bodies on these veins that apexed below present erosion levels; in addition, there are entire veins and vein systems that apex a thousand feet or more below the surface.

The following ore shoots did crop out, but the near-surface parts were much smaller than the lower parts.

1. The Lucky Friday mine is the most recently discovered example of this category. The vein cropped out and a flattened pipe, with strike lengths of 30 to 50 feet, was stoped for several hundred feet down the dip of the vein, but only after exploration on the 1400 level was it obvious that a major ore body was involved. The strike length at and near the surface was modest, but the grade of the ore was always encouraging.
2. The North and South veins of the Sunshine mine merged near the 1300 level to become the Sunshine "A" vein. These veins cropped out at the ridge crest and were stoped for hundreds of feet downdip over strike lengths of only 100 feet or so. The grade was excellent although the veins were narrow. Below the 1700 foot level, the strike length of the "A" vein increased to over 2,000 feet, vein widths reached 25 feet, and the grade of the ore improved.

The following are examples of ore bodies that did not crop out though they are on veins that did: (1) Rambler ore shoot on Hercules vein, (2) several of the Tamarack mine veins, (3) North vein of Frisco mine, (4) lower ore shoots on Alhambra vein in the Crescent mine, (5) Silver Syndicate ore shoot of the Sunshine mine, (6) several small ore shoots on the Yankee Girl vein, Sunshine mine, (7) Silver Summit mine ore shoots, (8) No. 2 ore shoot of the Surprise vein, Highland-Surprise mine.

The first three are north of the Osburn fault; the others are south of the fault. All but the Silver Summit and Silver Syndicate ore shoots were found during exploration subsequent to the mining of ore shoots that did crop out.

Exploration of the Silver Summit veins began on the upper tunnel level at an altitude of 3,344 feet where "Some of the veins were entirely barren quartz or quartz and carbonate veins containing carbonate of light color and others contained some siderite" (Sorenson, 1951, p. 611). The veins were again cut on the lower tunnel level (altitude 2,663 ft) where the strike length of the veins was longer and valuable sulfides were abundant; however, no ore was present. Shaft sinking began from the lower tunnel, and the veins were explored for only short distances on the 600 and 1500 levels because the grade was consistently low. The ore bodies were finally cut on the 3000 level (alt −339 ft). Exploration on, for instance, the 2500 level instead of the 3000 level would have found the veins just as barren as on the upper levels, for the ore bodies are now known to apex at about the 2800 level and to bottom below the 3400 level. Such an example demonstrates the difficulty of formulating reliable geologic guides for mine exploration.

The following ore shoots are on veins that have no known surface expression; it is probably significant that they are all south of the Osburn fault: (1) The Mac, Francis, Barr, Truman, and Emery veins (among others) of the Bunker Hill mine, (2) the Polaris veins in the east part of the Sunshine mine, (3) the silver vein of the Galena mine, (4) the Sunset vein of the Sunset Minerals mine.

All these veins except those of the Bunker Hill mine are post-World War II discoveries.

EXPLORATION IN THE COEUR d'ALENE DISTRICT

Though development of many more mines in the district through the discovery of outcropping veins is doubtful, many exploration targets do remain. Four kinds of exploration targets can be recognized: lateral and depth extensions of known productive veins, unknown parallel veins in existing mines, inadequately explored or totally unexplored parts of the mineral belts, and faulted segments of productive veins.

Unexplored parts of the mineral belts hold the greatest promise for the discovery of new mines. Plate 4 shows that not all parts of the mineral belts are known to contain productive veins, but it does not indicate whether the blank areas have been adequately explored. Exploration of a block of ground in the Coeur d'Alene district can be considered adequate only if the ground is explored at least as deep as sea level, and on enough levels that the entire height and width of the block has been probed. Work in several mines has shown that ore may extend more than a thousand feet below sea level. Such exploration should not depend upon the presence of surface mineralization. The only exempted areas might be those where the Wallace formation will extend to the bottom of the block to be explored.

Such exploration is permissive. Apparently ore deposits of significant magnitude are confined to the mineral belts, but there are no geologic criteria that would rule out any of the spaces within these belts shown as blank on plate 4.

The most important of the secondary exploration targets are the lateral extensions of known productive veins. More than one ore shoot can exist on the same vein. The example of the Sidney mine, where the west ore shoot was almost mined out before the east ore shoot (separated from the west by only 100 to 200 ft of barren vein) was discovered, should be incentive enough to drift to the ends of a vein. Even though assay values outside a known ore shoot may be low, only continued drifting can determine whether another ore shoot is beyond the face.

Several veins terminate at faults, and it is generally believed, though I do not, that these faults probably predate the ore and acted as dams to the ore-forming fluids. However, some or all of these faults may be postore, and faulted segments of veins may be found on the other sides. The evidence of relations of veins to faults is inconclusive, or even conflicting, at most places, but experience at the Tony fault in the Page mine, should prove that thorough testing of the opposite sides of these faults is necessary. This fault was long considered to predate the ore, but beyond it an extension of the ore shoot was found.

The mineral belts may reach widths of 3,000 feet, and parallel veins may be overlooked if the walls beyond productive veins are not adequately probed. In particular, the walls must be tested on closely spaced centers, to make sure that an unimportant-appearing stringer does not open into an ore shoot a short distance from a drill hole. Parallel veins must, of course, be probed at all altitudes, not just from one level.

INDIVIDUAL ORE SHOOTS

All available information on the significant features of most of the ore shoots, whether worked out or active, is summarized below. This information is presented in tabular form; additional detailed comments are made about the ores of some of the larger mines. More formal descriptions are given of four ore shoots that are typical of those accessible during this study. All ore shoots of a mineral belt are grouped together, and the westmost is described first.

SUNSET MINERAL BELT

The only operating property in the Sunset mineral belt in 1958 was the Sunset Lease mine (pls. 2, 4, 21). The only ore studied in detail came from the Idora dump. All the ore shoots of this belt contain silicates, carbonate, and iron oxides in addition to sulfides. The Sunrise and St. James prospects are in the monzonite, and no silicates are present in the dump material; however, the former prospect, and perhaps the latter, is considered to belong to the first Tertiary period of mineralization. Pertinent features of the ore shoots are given in table 23.

TABLE 23.—*Characteristics of ore shoots of mines in the mineral belts of the Coeur d'Alene district, Idaho (data as of December 1958)*

Mine	Ore shoot								Remarks
	Name	Strike	Dip	Strike length (feet)	Depth range (altitude, in feet)		Formation	Mineralogy and paragenesis (major minerals)	
					Top	Bottom			
Sunset belt									
Toughnut		N. 55° W.	South	150	4,575	4,625	Prichard	Silicates, carbonate, magnetite, pyrite, pyrrhotite, sphalerite, and galena.	G. M. Crosby (oral communication, 1958).
Idora		N. 65° W.	75° S.	300	5,050	4,670	do	Silicates, siderite, specular hematite, magnetite, pyrite, pyrrhotite, sphalerite, chalcopyrite, and galena; some chlorite.	Umpleby and Jones (1923, p. 83); A. B. Griggs (1952).
Tuscumbia		N. 80° E.	70° S.	180	5,070	4,950	do	do	No sphalerite production. G. M. Crosby (oral communication, 1958), Griggs (1952).
Parrott		N. 65° W.	75° S.	220	5,450	5,300	do	do	G. M. Crosby (oral communication, 1958).
Silver Tip	North vein	N. 73° W.	85° S.	300	500		do	do	
	South vein	N. 78° W.	South	300	500		do	do	South vein is extension of Sunset lease South vein. G. M. Crosby (oral communication, 1958).
Sunset lease	North vein	N. 60° W.	80° S.	750	6,200	4,550	Prichard, Burke.	do	Umpleby and Jones (1923, p. 83) recognized the silicates, except grunerite, and classified them as high temperature veins instead of contact deposits. G. M. Crosby (oral communication, 1958).
	South vein	N. 60° W.	80° S.	750	5,875	5,400	do	do	
Carlisle-Hercules belt									
Carlisle	Carlisle	N. 20° W.	75° W.	200	3,475	3,090	Prichard	Ankerite, pyrite, pyrrhotite, sphalerite, and galena.	Griggs (1952). Apparently no silicates or magnetite, but sampling is inadequate.
Amazon	Manhattan	N. 65° W.	70° S.	700	4,850	3,320	do	Silicates, siderite, magnetite, pyrite, pyrrhotite, sphalerite, and galena.	Griggs (1952). Sampling is inadequate.
Blue Grouse	Blue Grouse	N. 70° W.	80° S.	230	4,440	4,240	do	do	Griggs (1952).
Mountain Goat	Mountain Goat.						do	do	Sampling is inadequate.
Interstate-Callahan.	Interstate	W.-N. 40° W.	75° N.	1,700	5,320	3,920	do	Silicates, siderite, ankerite, magnetite, pyrite, pyrrhotite, sphalerite, chalcopyrite, and galena.	Ransome and Calkins (1908); Umpleby and Jones (1923); Spurr (1924); McKinstry and Svendsen (1942); Griggs (1952). The writer studied material only from the east end of the Interstate vein.
	Callahan West.			400					
	Callahan East.	N. 60° W.	85° S.	250	5,500	3,400	do	Probably the same as Interstate.	
	South	N. 70° W.	85° S.	200	5,110	4,810	do	do	
Hercules	Hercules	N. 65° W.	70° S.	1,500	6,075	2,660	Burke, Prichard.	Silicates, siderite, hematite, magnetite, pyrite, pyrrhotite, sphalerite, chalcopyrite, and galena. (Minor minerals include arsenopyrite, tetrahedrite, marcasite, and bournonite.)	Stringham and others (1953); Griggs (1952).
	Rambler	W.-S. 45° W.	60°-80° S.	400	Being (1958).	explored	Prichard		
Ambergris	Ambergris	N. 65° W.	70° S.	200+	5,745	3,900	Burke, Prichard.	do	Griggs (1952).
Ajax	Ajax	West	Steep (south).	200±	5,300(?)	5,100(?)	do	White quartz, ankerite, sphalerite, and galena.	Griggs (1952). The vein may belong to the first Tertiary period of mineralization.
Tamarack-Marsh subbelt									
Tamarack	Custer	N. 73° W.	70° S.		6,000	5,550	Burke	Unknown, but probably like the South vein ore shoot.	Griggs (1952) E. W. Bulla [1]; G. M. Crosby (oral communication, 1958).
	Nelson	N. 40° W.	70° W.		3,650	3,000	Burke, Prichard.	Silicates, siderite, hematite, magnetite, pyrite, pyrrhotite, sphalerite, chalcopyrite, galena, and boulangerite.	
	South	W.-N. 45° W.	90°	1,400	5,325	3,475	do	Same as South vein.	
	North	West	90°	1,000	5,350	3,400	do	do	
	Monroe	West	90°	500	5,470	4,700	Burke	do	
	Murphy	West	90°	500	4,950	3,500	Burke, Prichard.	do	
	Wet	N. 10° W.	70° E.	200	4,800	4,600	Burke	do	
	Chesapeake	N. 45° W.	65° N.	600	4,000	2,850	Prichard	do	
	Chesapeake No. 2 split.	N. 50° W.	80° N.	300	3,600	3,100	Burke	do	
	Thomas	N. 45° W.	65° N.	400	3,850	2,175	Prichard	do	
	Watson	N. 45° W.	65° N.	620	3,020	1,865	do	do	
	A Cross	N. 30° E.	50° E.	100	3,830	3,300	Burke	do	

[1] Bulla, E. W., 1951, A mineragraphic study of ore from the Tamarack mine, Burke, Idaho: Idaho Univ. M.S. thesis.

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TABLE 23.—*Characteristics of ore shoots of mines in the mineral belts of the Coeur d'Alene district, Idaho (data as of December 1958)*—Con.

Mine	Ore shoot								Remarks
	Name	Strike	Dip	Strike length (feet)	Depth range (altitude, in feet)		Formation	Mineralogy and paragenesis (major minerals)	
					Top	Bottom			
Tamarack-Marsh subbelt—Continued									
Sherman	Sherman	N. 70° W.	75° S.	1,000	5,400	4,450	do.	Green biotite, massive siderite, hematite, magnetite, pyrite, pyrrhotite, sphalerite, chalcopyrite, and galena.	A. B. Griggs (1952). The pyrrhotite has been extensively altered to pyrite and marcasite.
	Leary	N. 60° W.	70° S.	1,100	5,575	4,775	do.	do.	
Hummingbird	Hummingbird.	N. 70° W.	70° S.	100	4,600	3,060	Burke, Prichard.	No information about the ore.	Griggs (1952).
Union	Union	N. 60° W.	70° S.	500			Burke	No information; probably similar to the Sherman vein.	
Tiger-Poorman		N. 60° W.	80° S.	1,800	4,050	1,500	Burke, Prichard.	Not studied; apparently similar to Sherman mine ore.	Ransome and Calkins (1908); Umpleby and Jones (1923); Shannon (1926); Griggs (1952).
Marsh	Marsh	N. 75° W.	70° S.	200	3,950	3,000	Prichard	Massive siderite, pyrite, marcasite (pseudomorphous after pyrrhotite), sphalerite, galena and bournonite.	Griggs (1952). Unusual amounts of marcasite are present; bournonite was a major ore mineral.
Rex-Snowstorm belt									
Silver Crescent							Prichard	Ore not studied. Dump samples contain pyrite, pyrrhotite, sphalerite and galena.	
Rex	North	N. 65° W.	60°–80° N.	100			do.	Silicates, siderite, hematite, magnetite, pyrite, pyrrhotite, sphalerite, and galena.	Griggs (1952); Ransome and Calkins (1908); Umpleby and Jones (1923); A.M. Piper [2]. Sulfides cut monzonite rock. Pyrrhotite not altered to pyrite and marcasite.
	Rex	N. 75° W.	55°–65° N.	150			do.	do.	
	Okanogan	N. 75° W.	60° N.	100			do.	do.	
Standard-Mammoth.	Standard-Mammoth.	N. 83° W.	80° N.	2,000	5,100	1,370	Burke, Prichard.	Ore not studied. Massive siderite, magnetite (and probably hematite), pyrite, pyrrhotite, sphalerite, tetrahedrite, chalcopyrite, galena, and pyrargyrite.	Ransome and Calkins (1908); Shannon (1926); Griggs (1952). Barium was present in analysed ore.
Hecla	Hecla	N. 45° W.	80° N.	1,300	4,330	205	do.	Ore not studied. According to Ransome and Calkins (1908, p. 175 ff.), siderite (disseminated) pyrite, sphalerite, and galena. High Ag assays indicate tetrahedrite.	Ransome and Calkins (1908); Umpleby and Jones (1923); Griggs (1952).
	Hecla B	N. 45° W.	80° N.	500	2,865	2,015	Prichard	do.	The gangue was mainly country rock.
	Ore-or-no-go	N. 65° W.	75° N.	300	4,050	2,510	Burke	do.	Do.
	Magazine			260	4,190	3,488	do.	do.	Do.
	East Hecla	N. 80° W.		250	3,810	2,065		do.	Do.
	East Hecla 74.	N. 75° W.	75° S.	600	4,880	2,720	Burke, Prichard.	Ore not studied. According to Waldschmidt (1925, p. 581 ff), siderite, pyrite, pyrrhotite, sphalerite, tetrahedrite, chalcopyrite, and galena.	Waldschmidt (1925); Griggs (1952). The mineralogy suggests that these two veins were similar to those in the Marsh and Sherman mines.
Copper King		N. 50° W.	55–60° S.	300			St. Regis	Ore not studied in detail. Pyrite, sphalerite, tetrahedrite, chalcopyrite, and galena; carbonate is not common, abundant white quartz gangue.	This ore is similar to that of the Lucky Friday mine.
National	National	N. 80° W.	80° S.	350	4,980(?)	4,000(?)	Revett	Ore not studied in detail. Pyrite, chalcopyrite, tetrahedrite, and galena. The chalcopyrite in the enriched zone has been altered to chalcocite and bornite.	Calkins and Jones (1914); Umpleby and Jones (1923). The greatest part of the ore body consisted of disseminated sulfides surrounding the vein.
Snowstorm	Snowstorm	N. 60° W.	65° S.	700	5,550	4,650 ?	do.	Ore not studied. Pyrite, chalcopyrite, tetrahedrite, chalcocite, bornite, cuprite, and malachite.	Ransome and Calkins (1908); Calkins and Jones (1914); Umpleby and Jones (1923). Sulfides disseminated in a quartzite bed.
Gem-Gold Hunter belt									
Gem	Lead	N. 60°E.	90°	500	3,835	3,135	Prichard	Not studied. Probably same as adjacent Frisco vein.	Ransome and Calkins (1908); Umpleby and Jones (1923); Griggs (1952). The main monzonite was cut by pyrite and sphalerite veins on deep levels.
	Zinc	N. 55°E.	90°	550	3,600	2,825	Prichard	do.	
	Fraction	West	85° S.	175	4,035	3,035	Prichard	do.	
	Hanging	N. 75°W.	85° S.	140	3,835	2,835	Prichard	do.	

[2] Piper, A. M., 1925, Paragenesis of some primary ores from the Rex and Success mines, Coeur d'Alene district, Idaho: Idaho Univ. M.S. thesis.

TABLE 23.—*Characteristics of ore shoots of mines in the mineral belts of the Coeur d'Alene district, Idaho (data as of December 1958)*—Con.

Mine	Ore shoot								Remarks
	Name	Strike	Dip	Strike length (feet)	Depth range (altitude, in feet)		Formation	Mineralogy and paragenesis (major minerals)	
					Top	Bottom			
Gem-Gold Hunter belt—Continued									
Frisco	Frisco	N. 67°W	80° S.–85° N	900	4,035	1,325	Burke, Prichard.	Silicates, siderite, ankerite, magnetite, pyrite, pyrrhotite (partially altered to pyrite and marcasite), sphalerite, chalcopyrite, and galena.	Ransome and Calkins (1908); Umpleby and Jones (1923); Griggs (1952).
	North	N. 72°E	80° S	450	3,865	2,050	do	The vein lacks silicates; otherwise it is the same as the Frisco vein.	The North and Middle veins are splits off the Frisco vein that were opened after the minerals of the silicate stages were deposited.
	Middle	West	80° S	300	3,865	2,050	do	Same as the North vein.	
Black Bear	West	West	90°–85° N	330	4,100	3,060	Burke	do	Ransome and Calkins (1908); Umpleby and Jones (1923) Griggs (1952).
	East	West	80° N	200	4,385	3,305	do	do	
Black Bear Fraction.	West	N. 70° W	75° S	200(?)	3,875(?)	3,475(?)	do	Ore not studied. Probably like veins of the Black Bear mine.	Griggs (1952).
	East	N. 70° W	78° S	300	4,675	3,475	do		
Star and Morning mines.	Morning-Star	N. 70° W	85° N	4,000	5,675	−1,050	St. Regis, Revett.	Siderite, ankerite, magnetite, pyrite, sphalerite, chalcopyrite, and galena.	Ransome and Calkins (1908); Umpleby and Jones (1923); Fryklund and Fletcher (1956).
	You-like	N. 65° W	85° N	700	5,580		St. Regis	Not studied. Same as Morning-Star vein.	
Gold Hunter	North	N. 85° W	Steep South	900	4,775	2,800	Wallace	Not studied. Siderite, barite, pyrite, Sphalerite, tetrahedrite, chalcopyrite, galena, and boulangerite.	Ransome and Calkins (1908) Calkins and Jones (1914); Umpleby and Jones (1923). G. M. Crosby (Oral communication, 1958). The Gold Hunter is the only mine in the district where barite was a major gangue mineral.
	Middle	W.–S. 80° W.	do	240	4,330	3,820	do		
	South	W.–S. 80° W.	do	250	4,015	2,800	do		
Success and Dayrock subbelts									
Success	Main	Irregular (northwest).	Steep (south).	700	4,450	2,750	Prichard	Silicates, hematite, magnetite, pyrite, pyrrhotite, sphalerite, chalcopyrite, and galena.	Ransome and Calkins (1908); Umpleby and Jones (1923); Hershey (1917); Umpleby (1917); Griggs (1952).
Dayrock	Dayrock	W.–N. 70° W.	90°–65° S	1,900	3,200	2,700	St. Regis, Revett.	Siderite, ankerite, calcite, pyrite, sphalerite, tetrahedrite, chalcopyrite, and galena.	The main gangue is country rock. An unusual amount of sulfides is disseminated in vein walls.
	Ohio	N. 55° W	South	2,000+	3,200	2,120	do	do	
	Dora	N. 65° W	South	650	2,970	2,710	do	do	
California		N. 75° W	75° N	600	3,750	3,250	St. Regis	Not studied. Dump material looks like Dayrock ore.	
Western Union		West (?)					Prichard	do	
Golconda-Lucky Friday belt									
Golconda	Main	West	50°–75° S	520	3,260	2,500	Burke, Prichard.	Not studied	Probably similar to Lucky Friday ore.
	East	West	50°–75° S	260	3,100	2,670	Burke	do	
Alice	Alice						Revett	Not studied. Dump material looks like disseminated ore from the Lucky Friday mine.	Calkins and Jones (1914); Ransome and Calkins (1908).
	Mary J	N. 60° E.?	80° S	100			do		
	Mud Tunnel						do		
Lucky Friday	Main	N. 65° E. (main part).	75° S	1,200	3,800±	915	St. Regis, Revett.	Siderite, pyrite, arsenopyrite (rare), sphalerite, tetrahedrite, chalcopyrite, galena, and a ruby silver.	W. T. Folwell (oral communication, 1958). The bottom of the ore shoot had not been reached in December 1958.
Formosa	Main	N. 80° E	Steep (south).	200			Burke	Not studied. The dump has been contaminated by the dump of a custom mill.	This mine lies north of the mineral belt.
Page-Galena belt									
Page	Tony	S. 60° W	50°–80° S	2,300	2,880	390	St. Regis, Revett.	Pyrite, ankerite, sphalerite, tetrahedrite, chalcopyrite, and galena.	This is a vertically zoned ore shoot.
	Curlew	S. 85° W	50° S	500	2,600(?)	1,800	St. Regis	Not studied.	

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TABLE 23.—*Characteristics of ore shoots of mines in the mineral belts of the Coeur d'Alene district, Idaho (data as of December 1958)*—Con.

Mine	Ore shoot								Remarks
	Name	Strike	Dip	Strike length (feet)	Depth range (altitude, in feet)		Formation	Mineralogy and paragenesis (major minerals)	
					Top	Bottom			
				Page-Galena belt—Continued					
Crescent	Upper Alhambra.	N. 75° W	80° S	750	4,200	2,700	do	Not studied. Apparently a typical siderite-tetrahedrite vein.	P. J. Shenon (written communication, 1938).
	Hanging wall.	N. 75° W	80°±S	500	3,600	3,080	do	Not studied. Apparently a galena-rich tetrahedrite vein.	
	Lower Alhambra.	N. 80° W	80° S	Discovered on deep levels; dimensions and formation not known (December 1958).				Typical siderite-tetrahedrite vein. Galena and sphalerite are very rare or absent.	First discovered 400 feet below sea level: exploration is incomplete.
Bunker Hill	Stanley	N. 49° W	48° S	500	3,430	2,122	St. Regis, Revett.	Not studied. Same as other veins in the mine.	Bunker Hill co. records.
	March	N. 16° W	42° W	675	3,418	573	St. Regis	Not studied in detail. Siderite, pyrite, sphalerite, tetrahedrite, chalcopyrite, and galena.	Bunker Hill Co. records. The gangue is massive siderite.
	Mac	N. 38° E	35° E	425	840	−793	St. Regis, Revett.	Siderite, ankerite, pyrite, sphalerite, tetrahedrite, galena.	Bunker Hill Co. records. Bottom of ore body not known. Chalcopyrite is rare; most of it is younger than galena.
	Francis	N. 78° E	58° S	697	2,164	401	do	Not studied. Same as Mac vein.	Bunker Hill Co. records.
	Emery	N. 45° E	52° S	875	378	−1,192	do	Same as Mac vein	Bunker Hill Co. records. Bottom of ore body is not known.
	Truman	N. 67° E	48° S	451	865	−1,190	do	do	Bunker Hill Co. records. Bottom of ore is not known. Sulfantimonides are relatively common.
	Caledonia	N. 51° E	37° S	297	3,240	2,680	St. Regis	Not studied. Same as Mac vein.	Bunker Hill Co. records. Umpleby and Jones (1923, p. 118) noted unusual amounts of tetrahedrite in the vein.
	Stewart	N. 40° E	34° E	934	3,020	2,420	do	Not studied. Probably same as Mac vein.	Bunker Hill Co. records. Umpleby and Jones (1923, p. 58) placed the vein among the Jersey-type veins (here typified by the Mac vein).
Sunshine	North Yankee Boy.	N. 75°–85° W.	70° S	1,300	3,800 (?)	1,450	Wallace, St. Regis.	Not studied. Siderite, pyrite, arsenopyrite, sphalerite, tetrahedrite, chalcopyrite, galena, and lead-antimony sulfides.	P. J. Shenon (written communication, 1938); R. J. Anderson (1940).
	South Yankee B.	N. 75°–85° W.	70° S	1,000(?)	3,800(?)	1,650	do	do	
	Sunshine A	N. 85° W	70° S	1,500	1,450	830	St. Regis	do	
	Sunshine B	West	60°–70° S	2,200	830	−800	St. Regis Revett.	do	
	Silver syndicate.	N. 70° W	70° S	300	−530	−1,300	St. Regis	Not studied. The ore shoot is galena-rich; siderite and tetrahedrite are present but not abundant.	
	Yankee Girl	West	70° S	Several small stopes.	--------	--------	St. Regis, Revett.	Not studied. Typical siderite-tetrahedrite vein.	
	Polaris	N. 85° E	65° S	950	3,180	1,600	St. Regis	do	The Polaris ore shoot is on the Sunshine B vein. Willard (1941).
	Polaris Veins (including the Chester vein).	Diverse	S	--------	380	−1,600	St. Regis, Revett.	Siderite, pyrite, arsenopyrite, sphalerite, tetrahedrite, chalcopyrite, galena, and lead-antimony sulfides.	This network of west- to north-striking veins links the Chester and Sunshine B veins. A number of separate ore shoots are present.
Mineral Mountain.	--------	N. 40° E.(?)	E	--------	--------	--------	Wallace(?)	Not studied. Apparently siderite-tetrahedrite vein.	
Silver Dollar	Chester	N. 70° W	50°–65° S	--------	--------	--------	Wallace	Not studied. Siderite, pyrite, arsenopyrite, sphalerite, tetrahedrite, chalcopyrite, and galena.	P. J. Shenon (written communication, 1938). Production has come from small scattered stopes.
Silver Summit	No. 3 Vein East.	N. 75° W	70° S	700	−100	−700 (?)	St. Regis	Pyrite, arsenopyrite, siderite, gersdorffite, tetrahedrite, and chalcopyrite.	
	No. 3 Vein West.	N. 75° W	70° S	400	−200	−700 (?)	do	--------	
	Several smaller ore shoots present.	--------	--------	--------	--------	--------	--------	--------	
Metropolitan	Main	West	45°–60° S	--------	--------	--------	Wallace, St. Regis.	Not studied. Ankerite, pyrite, sphalerite, tetrahedrite, and galena.	P. J. Shenon (written communication, 1938). Tetrahedrite was the main ore mineral; some was disseminated in quartzite.
Coeur d'Alene Mines.	Main	N. 65° E	Steep (south).	500	2,400	200 (?)	St. Regis	Not studied. Siderite-tetrahedrite vein.	
Argentine	Main	N. 80° E	55°–65° S	--------	--------	--------	do	do	P. J. Shenon (written communication, 1938).

TABLE 23.—*Characteristics of ore shoots of mines in the mineral belts of the Coeur d'Alene district, Idaho (data as of December 1958)*—Con.

Mine	Ore shoot								Remarks
	Name	Strike	Dip	Strike length (feet)	Depth range (altitude, in feet)		Formation	Mineralogy and paragenesis (major minerals)	
					Top	Bottom			
Page-Galena belt—Continued									
Galena	Winze	N. 60° W	65° S	200	2,400	1,400	Wallace	Not studied. Production figures show that main ore mineral was galena. Ore was probably similar to that of the Lead vein.	P. J. Shenon (written communication, 1938). The Winze and 600 E. No. 2 ore shoots lie north of the Polaris fault (See Shenon and McConnel, 1939, for location of this fault). The Lead vein lies just south of the Polaris fault but at a much greater depth. Probably only a slight offset of a single mineralized zone is involved.
	600 E. No. 2	N. 60° W	65° S	50	3,100	2,400	do		
	Lead	N. 70° W	Steep (south).	1,800±	Not stoped		Revett	Arsenopyrite, pyrite, siderite, sphalerite, tetrahedrite, chalcopyrite, galena, and lead-antimony sulfides. A typical siderite-tetrahedrite vein.	
	Silver	S. 70° W	70° S	800	850+	−300	do	Typical siderite-tetrahedrite vein. Pyrite, arsenopyrite, siderite, tetrahedrite, chalcopyrite, and galena.	
Pine Creek belt									
Hypotheek	Main vein	N. 70° W	70° S	400	----	----	Prichard	Dump specimens studied. Ankerite, pyrite, arsenopyrite, sphalerite, tetrahedrite, chalcopyrite, and galena.	Jones (1920); Shannon (1926). This vein probably belongs to the first Tertiary period of mineralization. The tetrahedrite contains no silver.
Amy-Matchless	Main vein	N. 50° W	Steep (south).	200(?)	----	----	do	Not studied. Two types of veins are present; the productive vein is pyrrhotite-bearing.	Jones (1920); P. J. Shenon (written communication 1943).
Sunset Minerals	Sunset	N. 45° W	5°–50° S	500	1,820(?)	1,270	do	Ankerite, pyrite, arsenopyrite, pyrrhotite (which contains alteration pyrite and marcasite), sphalerite, chalcopyrite, and galena.	Outcrop of vein not known. Tetrahedrite is present.
Nabob	Nabob	N. 65° W	70° S	120	----	----	do	Not studied. Vein gangue is country rock and pyrrhotite. Probably similar to Sidney mine ore.	Jones (1920); Forrester and Nelson (1945).
Sidney	Denver	N. 60° W	70° S	820	3,920	3,350	do	do	Jones (1920); Forrester and McKnight (1944); Forrester and Nelson (1945). Tetrahedrite is present.
	D-5	N. 65° W	65°–85° S	475	----	----	do	do	
	West	N. 60° W	70° S	700	4,200	3,250	do	Ankerite, pyrite, arsenopyrite, pyrrhotite (partially altered to pyrite and marcasite), sphalerite, chalcopyrite, and galena.	
	East	N. 65° W	70° S	1,070	4,260	2,900	do	do	
Little Pittsburgh.	Main vein	N. 30° W	60°–70° W	400	----	3,210	do	Not studied. Apparently the same as the Sidney ore.	Jones (1920); Forrester (1945d); Forrester and Nelson (1945).
Highland Surprise.	Surprise No. 1	N. 65° W	60° S–90°	300	3,470	1,780	do	Ankerite, pyrite, arsenopyrite, pyrrhotite (partially altered to pyrite and marcasite), sphalerite, tetrahedrite, chalcopyrite, and galena.	Jones (1920); Umpleby and Jones (1923); Forrester (1945c); Forrester and Nelson (1945); Fryklund and Harner (1955).
	Surprise No. 2	N. 65° W	60° S–90°	230	2,850	2,250	do	do	
	Highland	N. 70° W	60° S	600	3,720	2,820	do	do	
Douglas subbelt									
Douglas	East	N. 80° W	50°–70° S	550(?)	3,100(?)	2,700	Prichard	Not studied. Same as Highland-Surprise ore. Ore is fine-grained.	Jones (1920); Forester (1945b); Forrester and Nelson (1945).
	West	N. 80° W	50°–70° S	630	----	----	do	do	
Constitution	Constitution	N. 30° W	85°–90° W	1,200	3,430	2,280	do	Not studied same as Douglas ore. Ore is fine-grained.	Jones (1920); Forrester (1945a); Forrester and Nelson (1945).
Moe-Reindeer Queen belt									
Moe	----	W	75° S	----	----	----	St. Regis	Not studied. A massive siderite vein with galena as the chief ore mineral. Hematite is present.	
Carbonate Hill (Atlas).	----	N. 70° W	South	200(?)	4,800(?)	----	do	Not studied. Siderite, ankerite, barite, magnetite, pyrite, sphalerite, chalcopyrite, and galena.	Calkins and Jones (1914, p. 201). The main ore mineral was galena but important amounts of yellow sphalerite were present.

CARLISLE-HERCULES MINERAL BELT

All but the eastmost (Ajax, pls. 2, 4) and westmost (Carlisle) ore bodies of the Carlisle-Hercules mineral belt contain silicates and magnetite. The Ajax ore body contains ankerite, sphalerite, and galena in a quartz gangue; the mineral content is strikingly different from that of the Hercules vein, half a mile away, and the vein may have formed during the first Tertiary period of mineralization. No silicates or magnetite were found in material from the Carlisle vein, but it does contain pyrrhotite; it probably belongs with the main-period veins. The characteristics of these ore bodies are given in table 23.

TAMARACK-MARSH MINERAL SUBBELT

The ore bodies of the Tamarack-Marsh mineral subbelt (pls. 2, 4) are now inaccessible, except those of the Tamarack mine, but the collections of Day Mines, Inc., dump material and the brief descriptions by Ransome and Calkins (1908) and Shannon (1926) show that this mineral belt has perhaps the most unusual mineralogical makeup of the district. The veins of the Tamarack mine contain the high-temperature silicates, specular hematite, and magnetite; siderite is present, but only as disseminations and veinlets. The other veins of the belt, like the siderite veins of the Page-Galena mineral belt, have as their chief gangue massive siderite. The massive siderite has been partially replaced by specular hematite, magnetite, and pyrrhotite, and in this respect the veins are quite different from the other massive siderite veins of the district. Dump material indicates that the Marsh ore body may have contained the richest concentration of bournonite, and probably other late sulfosalts, in the district.

The characteristics of the various ore shoots are given in table 23.

REX-SNOWSTORM MINERAL BELT

The location and size of the Rex-Snowstorm mineral belt is shown on plate 2. All the mines were closed in 1958 and none of the ore bodies except those of the Rex mine,[6] were studied in detail. The characteristics of the ore bodies of this belt are given in table 23.

GEM-GOLD HUNTER MINERAL BELT

The Gem-Gold Hunter mineral belt is shown on plate 2. The ore bodies of this mineral belt differ greatly in mineralogy; the veins of the Gem mine and the Frisco vein of the Frisco mine contain the high-temperature silicates; the gangue of the Morning-Star and the You-Like veins is principally country rock; and the gangue of the Gold Hunter veins is primarily country rock containing large amounts of barite. The characteristics of the ore shoots are given in table 23. The ore shoots of the Frisco and Morning-Star veins are described in more detail in following sections.

FRISCO ORE SHOOT OF THE FRISCO MINE

The geology of the Frisco mine (pl. 4) has been described by Lindgren (1904, p. 109 ff.), Ransome and Calkins (1908, p. 181), and Umpleby and Jones (1923, p. 100 ff.). The development of the mine had been completed largely before 1942, when the mine was reopened, and only the 2400, 2500, and 2560 levels were driven before the mine closed again in 1956.

The Frisco vein has an average strike of N. 67° W., though on the lowest levels the strike was about N. 85° W., dips range from 80° S. to 85° N. The Frisco vein is cut on the west by the Fraction fault and on the east by the Frisco fault; these two faults did not cut the Frisco ore shoot. The offset segment on the west is the Gem vein; the offset segment on the east has not been located. Two footwall splits (the North and Middle veins) off the Frisco vein, also contained ore shoots. The vein cropped out in mildly thermally metamorphosed rock of the Burke Formation, however, the greater part of the mine is in the upper part of the Prichard Formation. The beds strike a little east of north and dip moderately to the east; thus the vein cuts the beds almost at right angles.

The Frisco ore shoot, to the 2200 level, is shown on figure 7 of Umpleby and Jones (1923, p. 76). The ore shoot has a rake of 90°. Ore extended from the surface to the 2560 level, a distance of about 2,700 feet, and the ore shoot had a maximum stope length of 900 feet.

Though the general appearance is of rude banding, the appearance of the ore varies greatly within short distances. All the stages of the main period of mineralization are represented, except that of barite, and there is the impression that the Frisco vein formed more by coalescence of a number of smaller veins than by having a single large mass of the oldest mineral incompletely replaced by younger minerals. The amphiboles appear to have been present originally in separate smaller veins rather than in the 6-ft-wide grunerite veins of the Hercules mine; the wider pyrrhotite bands seem to have formed as separate veins rather than in a single large vein as at the Highland-Surprise and other mines.

The valuable sulfides are in veins that cut and replace the older vein minerals; however, in many places the valuable sulfides simply replaced unrecrystallized country rock. Where the grade of the ore is low, the vein is more likely to be coarsely banded. High-grade

[6] Piper, A. M., 1925, Paragenesis of some primary ores from the Rex and Success mines, Coeur d'Alene district, Idaho: Idaho Univ., M.S. thesis, Moscow, Idaho.

ore may be finely banded or it may be as fine grained and massive in appearance as that found in some mines of the Pine Creek mineral belt.

The first episode in the formation of the Frisco vein was the fairly extensive recrystallization of country-rock quartz grains to clear gray and white quartz. The introduced minerals of the Frisco vein, in their approximate order of formation are: green biotite, dark-brown biotite, garnet, hornblende, actinolite and grunerite, siderite and ankerite, magnetite, chlorite, pyrite, arsenopyrite, pyrrhotite (partially altered to pyrite and marcasite), sphalerite, chalcopyrite, and galena. There are some late quartz and carbonate veinlets.

The green biotite is very fine grained, 0.001± mm in diameter, and much smaller than the green biotite in the Hercules mine, for example. As shown in table 17, the optical properties of this biotite vary considerably. Green biotite veins reach a width of 1 foot, and may contain less than 1 percent of unreplaced country rock. The biotite masses can be recognized in all stages of replacement by later minerals. As at the Hercules mine, some dark-brown biotite is present but its age is uncertain. This biotite is shreddy in habit, and grains may be 0.1 mm long; optical properties of some grains are shown in table 19.

The garnet has not been determined though in appearance it is similar to the garnet at the Hercules mine (see table 16). Garnet is best developed in biotite masses where it tends to form euhedral grains 0.5 mm in diameter. Garnet disseminated in the wallrock is not euhedral, and the anhedral and poikilitic grains are rarely larger than 0.2 mm long.

The dominant amphibole is grunerite, though blue-green hornblende is common; actinolite is rare. Grunerite is an important gangue mineral in the Frisco vein, and the grunerite veins, composed of feltlike masses of grunerite needles only a 0.5 mm or less long, reached widths of at least 2 feet though they are now extensively replaced. The optical properties of some grunerite are shown in table 15. Most of the hornblende occurs as grains no larger than 0.04 mm long that form veinlets no more than 2 to 3 mm wide.

Minor amounts of both siderite and ankerite are present, but only rarely are they megascopically visible; ankerite appears to be the more abundant. Age relationships between the two could not be determined.

Magnetite is abundant. It may be present in euhedral grains, anhedral grains, or larger irregular-shaped masses 1.0 to 2.0 mm in diameter; a typical occurrence is as a partial replacement of grunerite. Pseudomorphs after specular hematite were not recognized. Magnetite contacts with carbonate are rare, and the age with respect to carbonate could not be determined; probably magnetite is the younger of the two minerals, as it is in other veins.

Postmagnetite chlorite is present in veinlets and masses, and garnet and amphibole are partially altered to chlorite.

Pyrite is not abundant and is younger than siderite. It is rarely euhedral; small rounded grains are common, as are skeleton grains that may reach 2 to 3 mm on an edge. No evidence suggests any difference in age between the pyrite of these two modes of occurrence. There is a small amount of alteration pyrite in some pyrrhotite. Arsenopyrite occurs in a few specimens as scattered euhedral or brecciated and corroded grains in pyrrhotite. It is older than the pyrrhotite and probably came in with the pyrite.

Pyrrhotite was present in all the polished surfaces examined, although selected ore may contain only a minor amount of pyrrhotite. Individual grains range from 0.001 to 0.1 mm in diameter; the smaller grains are inclusions in galena and sphalerite. Pyrite is present as an alteration product of pyrrhotite but is not common. The small amount of marcasite in the ore is probably an alteration product of pyrrhotite.

Sphalerite is the chief ore mineral. All the sphalerite is relatively low in iron. One sample from the 1400 level contained 4.8 percent iron and another from the 2400 level contained 4.0 percent iron; the sphalerite had opportunity to form in equilibrium with pyrrhotite, and a low temperature of formation, perhaps about 260°C (adjusted for effects of pressure), is indicated. The sphalerite from this mine is comparatively coarse grained and much of it is 1 mm or so in length; however, galena may have minute inclusions of sphalerite.

Chalcopyrite occurs as blebs in sphalerite and in veinlets that cut sphalerite as well as other minerals; it is not an abundant vein mineral.

Coarse-grained galena is an important ore mineral; grains 2 and 3 mm on an edge are common. It occurs in stringers that cut all the other vein minerals, and inclusions of magnetite, pyrrhotite, and sphalerite are abundant.

Late quartz and carbonate veinlets were recognized in thin sections.

The North and Middle veins, opened after biotite, garnet, and amphiboles had been introduced into the Frisco vein. On the 2400 level the intersection of the Middle vein with the Frisco vein had not been explored, and the Middle vein drift is about 100 feet from the Frisco vein. The only biotite and garnet in and near the Middle vein is in the vein walls or in unreplaced inclusions of country rock. Amphiboles are prominent in the Frisco vein but there are none in the Middle vein, and thus it seems that the fractures that localized the Middle vein were not opened until after the amphibole stage. Ore of the North vein also lacks the early silicates.

The appearance of the Middle vein on the 2400 level fits Lindgren's (1904, p. 111) description of Frisco vein ore. The gangue of the Middle vein is mainly country rock that is cut by stringers of sulfides; magnetite and pyrrhotite are not present in the great quantities characteristic of the Frisco vein. In addition, minor amounts of chalcocite and covellite were recognized in one sample from the Middle vein on the 1200 level. The chalcocite was an alteration of chalcopyrite; covellite rimmed some pyrite and marcasite and also cut galena in tiny veinlets. The sample showed no evidence of oxidation, and the two minerals probablу formed under hydrothermal conditions. A little pyrargyrite(?) also was recognized.

The Black Bear vein, in the adjoining Black Bear mine, was considered by Lindgren (1904, p. 111) to be the offset segment of the Frisco vein, east of the Frisco fault. Ransome and Calkins (1908, p. 180) disagreed with this interpretation because of the difference in character, largely meaning difference in mineralogy, between the Frisco and Black Bear veins. The mineralogy of the Black Bear vein is identical to that of the North vein, and I suggest that the Black Bear vein is the offset segment not of the Frisco vein, but of the North vein and that the offset segment of the Frisco vein has not yet been recognized.

MORNING-STAR ORE SHOOT

The Morning-Star ore shoot is a large shoot on the Morning-Star vein (pl. 4). The east part was mined by the Federal Mining and Smelting Co. as the Morning mine, and the west part was mined by the Hecla Mining Co. as the Star mine. Work on the west part did not begin until the 1920's, so there is no mention of the Star mine in the descriptions of the Morning mine by Ransome and Calkins (1908, p. 164–168) and Umpleby and Joes (1923, p. 102–103).

The Morning-Star vein has an average strike of N. 75° W. on the Star 4000-Morning 2250 level, but it is sinuous and a part strikes west on that level. On the Star 1700-Morning No. 5 level, the Morning part of the vein strikes about N. 65° W. and the Star part strikes about N. 85° W. The overall dip is about 85° N. At the property line in the middle of the ore shoot, the vein is vertical, from the surface to an altitude of 4,300 feet; from 4,300 to 4,000 feet it dips 77° N. From 4,000 to 3,750 feet the dip is about 85° N., from 3,750 to 3,600 feet 80° S.; the main vein dips 77° N. from that point to about 2,900 feet. The vein is vertical from 2,900 to 2,700 feet; from 2,700 to 2,000 feet it dips 85° N., and from there to 650 feet it is vertical. The pronounced bend in both strike and dip suggests that there was little movement on the original fault.

The Star mine is entirely in rocks of the Revett Quartzite. The top of the Morning mine is in St. Regis Formation; but, because the contact between the Revett Quartzite and St. Regis Formation dips steeply eastward, most of the Morning mine levels are in both formations, except the lowest levels, which are entirely in Revett Quartzite. Beds in the mine area generally strike a little west of north, so the vein cuts the beds at high angles.

A monzonitic dike is exposed in the top levels of the Star mine, but I have no information as to its relation to the vein. Aphanitic dikes with andesine, hornblende, and olivine phenocrysts cut the vein in the Star mine; these dikes strike north. The largest dike reaches a width of 70 feet and at the time of my work was known to extend from the top of the mine to the 5500 level. It is accompanied by a halo of disseminated chlorite that may be 50 or more feet wide on either side of the dike. The chlorite is so abundant that chloritized quartzite can be distinguished, in hand specimen, from dike only with difficulty.

The Star fault cuts the vein at a slight angle and offsets the large dike. Faults in the vein also offset the dike; on the Star 2300 level the horizontal component of movement is about 270 feet and the north side has moved east. These postmineral and postdike faults have formed thick gouge seams in the vein and along the hanging wall and the footwall.

The Morning-Star ore shoot is the largest in the Coeur d'Alene district. The maximum stope length is 4,000 feet; in the Morning mine the vein was stoped from an altitude of about 5,675 feet above to 1,050 feet below sea level, where the vein still contained ore. The ore shoot, which probably has the shape of a shield, has not been mined to that depth in the Star mine.

Within the ore shoot, and especially in the Morning mine part, the vein is split by large horses of country rock and as much as 50 to 60 feet of waste may lie between two strands of the vein. The vein splits merge along both strike and dip, and at points of mergence vein widths have reached 50 feet. The average vein width is perhaps 10 feet.

Except for the two bottom levels I have no personal knowledge of the Morning mine; the following remarks apply largely to the Star side of the ore shoot.

As in all the mines, the appearance of the ore varies depending on the part of the mine from which it comes. The chief gangue of the ore is country rock, so the appearance of the ore depends upon the amount of sphalerite, the dominant ore mineral. In lean ore the near-vertical veinlets and stringers of sphalerite contrast sharply with the light gray of the country rock to give a picture of brown and white irregular banding. Postmineral faulting has crushed the sphalerite in many of the stringers. In some areas enough siderite is disseminated in the country rock that a stope face, in lean ore, has tan and brown bands. In richer ore, the country-rock bands have been largely replaced and the ore is more massive in appearance. In places the more massive ore has also been crushed into an incoherent yellow-brown mass. A moderate amount of white recrystallized country rock adds some variety to the appearance of the ore in a few areas. Galena is an important, and visible, constituent of the vein only on the very east edge of the ore shoot.

The minerals of the Morning-Star vein, in their approximate order of formation, are siderite, ankerite, barite, specular hematite (rare), magnetite, pyrite, pyrrhotite (very rare), marcasite (rare), sphalerite, tetrahedrite (very rare), chalcopyrite, galena, polybasite(?), and quartz and calcite. Chlorite and biotite, which accompany the large dike, have been introduced into a part of the vein.

Virtually unrecrystallized country rock is the chief gangue of the vein, and the many places where white quartz can be seen to grade into unrecrystallized country rock indicate that practically all the visible quartz in the vein, including that in the "tension crack" veins, is recrystallized country rock. The recrystallization of the quartz grains has resulted in the segregation and recrystallization of the country-rock sericite, and bands rich in this mineral are common in and near the areas of white quartz. As is usual, recrystallization of the quartz took place before the introduction of the carbonates.

The first mineral to be introduced was siderite. Its most common mode of occurrence is as sparse to abundant disseminations in the country-rock gangue of the vein: massive siderite is absent, and even megascopically recognizable siderite is not common. Where the country rock contains abundant disseminated siderite, it has a yellow-brown color but the carbonate grains cannot be recognized except in thin section. The disseminated siderite consists of irregular-shaped grains of a fairly uniform size, approximately that of the country-rock quartz grains (fig. 16). Coarse-grained siderite may form either by recrystallization of fine-grained siderite, as some of the larger grains shown in figure 16 seem to have done, or by replacement of the coarser grained white quartz.

That ankerite is younger than siderite is shown by the partial replacement of siderite by ankerite. The ankerite grains are consistently larger than the fine-grained siderite (about 1.0 to 2.0 mm long on a cleavage edge). Probably siderite is more abundant than ankerite in the mine.

Barite is not common; the crosscutting veinlets show it is younger than ankerite, and it is older than sphalerite. Probably barite of the Star mine is older than any of the sulfide minerals, as it is in other veins where the relationships with sulfides can be determined.

Specular hematite is rare, and unaltered specular hematite was recognized in only one sample taken from the 1000 level. A very few pseudomorphs of magnetite after specular hematite were recognized. The specularite was in carbonate, a relationship common in many others of the veins in the district. The alteration of the specular hematite to magnetite probably occurred when formation of euhedral magnetite began.

Magnetite is a common, though not abundant, constituent of the vein. Most of it occurs as euhedral- to subhedral-shaped grains that rarely exceed 1 to 2 mm on an edge and generally are less than 0.5 mm. Except for the rare pseudomorphs after hematite, the magnetite occurs as minute inclusions in the later formed minerals. The distribution pattern of magnetite in the vein is not known. The two oxides are younger than the siderite and are probably also younger than the ankerite and barite.

Pyrite is common though not abundant in the vein. There were at least two periods of pyrite introduction, but the second, recognizable principally as minute veinlets traversing sphalerite, is very unimportant. Megascopically visible pyrite is present in most parts of the mine, but the quantity is always small. The most common mode of occurrence is as euhedral to anhedral grains; some reach 1 to 2 mm on an edge but most are probably smaller than 0.5 mm. In some areas, "atoll" shapes of partially replaced grains suggest some zoning of the grains.

Perhaps the most unusual mode of occurrence of pyrite is in masses that have a colloform texture. The general problem of colloform pyrite has been discussed (p. 15), and it is sufficient here to point out that colloform pyrite is older than sphalerite and is recognizable in samples from the 1200 to the 4900 level of the mine. The individual pyrite grains are visible to the eye as a result of recrystallization, but the colloform texture is distinct and striking in several specimens (fig. 4). A barely perceptible amount of pyrite is present as an alteration product of quite rare pyrrhotite.

Pyrrhotite is an insignificant constituent of perhaps half a dozen polished surfaces of material from all parts of the mine. The largest amount seen was 0.2 mm long and half that wide. A few such masses are quite free of alteration, but others are partially altered to pyrite and granular marcasite. The pyrrhotite, following the normal district sequence, is older than sphalerite and younger than magnetite, and probably younger than pyrite.

The occurrence of marcasite as an alteration product of pyrrhotite probably explains the scattered amounts of granular and lamellar or bladed marcasite to be seen in polished surfaces of this ore. Some such masses approach 1 cm in length; they are irregular in shape and are cut and embayed by younger minerals, usually sphalerite. Inasmuch as marcasite blades are truncated and embayed, the alteration of pyrrhotite to marcasite was complete by the time sphalerite was introduced.

The dominant mineral of the vein is sphalerite. Two ages or generations of sphalerite have been recognized. The youngest sphalerite is present in veinlets that are generally about 0.1 mm wide, although one veinlet about 15 mm long had a maximum width of 1.5 mm. The veinlets can be recognized only on sawed surfaces or in thin section. The largest veinlet was light buff, lighter than analyzed sphalerite that contained 0.34 percent iron, and the veinlets are white in thin section. These veinlets contain a small amount of anisotropic material. The veinlets of white sphalerite are largely restricted to masses of darker sphalerite, although a veinlet may terminate outside of darker sphalerite. The white veinlets are distributed in rectilinear patterns in the dark sphalerite and are cut by galena veinlets. The suggestion is, then, that white sphalerite is simply the last surge of the sphalerite stage rather than a late introduction. Most areas of the mine apparently lack white sphalerite, but the sampling is inadequate to demonstrate any distribution pattern. Any white sphalerite recognized was eliminated from the sphalerite samples that were analyzed, and, although some was undoubtedly present in analyzed material, there could have been no appreciable dilution of iron values.

The dark sphalerite ranges in iron content from 0.5 to 11 percent. The distribution pattern of iron in sphalerite from different positions in the mine is shown in figure 2 of Fryklund and Fletcher (1956, p. 239). Sphalerite of lower iron content is concentrated in the lower part of the ore shoot.

The grain size is generally less than 1.0 mm; most uncrushed grains are in the 0.1 to 0.5 mm range. Many grains adjacent to postmineral gouge seams are crushed.

Galena, or, more properly, what appears to be galena, occurs as a black dust along the fringes of some sphalerite. This dust gives a darker appearance to some sphalerite when examined in thin section, but this aspect does not appear to be recognizable in polished surfaces. The galena dust (or possibly native lead?) was probably brought in as an impurity near the end of the sphalerite formation and before the main stage of galena introduction. These dusty areas are cut in places by galena veins, but many other areas containing dust are not. These areas are also cut by veinlets of white sphalerite, which are older than the veinlets of galena.

Chalcopyrite veinlets cut sphalerite, carbonate, and pyrite. These veinlets are in turn cut by galena veinlets. Chalcopyrite is much less abundant in the Star mine than in many other mines of the district.

A minor amount of tetrahedrite accompanies chalcopyrite in a few polished surfaces. Contacts with chalcopyrite were mutual, but on the basis of the relationships known to exist in other mines the chalcopyrite is probably the younger.

The main stage of introduction of galena began after the white sphalerite had formed. Most of the galena is fine grained, less than 1.0 mm on an edge, though at a few places grains reached 3 to 4 mm on an edge. Postmineral, and postdike, strike-slip faulting along the Star vein has produced some sheared and steel galena. Galena formed principally as a replacement of sphalerite.

Small amounts of what is probably a silver mineral are recognizable in the galena. The mineral is in specks, the largest being 0.04 to 0.05 mm in diameter. The identity of the material is not known, but it is similar to material from other mines that has been identified by X-ray analysis as polybasite. Age relationships with galena are indeterminate, but the material is probably younger.

Rare veinlets of quartz about 0.05 to 0.1 mm wide cut most of the other minerals. There are also some late calcite veinlets.

In the vein adjacent to the dike there is chlorite of various shades of green. In places, segregations of sericite have altered along borders to chlorite; in other places the original sericite composition can only be suspected. Green and brown biotite are also present; in one thin section a veinlet of brown biotite accompanied by carbonate cut across all other minerals present.

SUCCESS AND DAYROCK MINERAL SUBBELTS

Ore from the Success mine is similar to ore from the Gem and Frisco mines. The Success mine (see p. 8) is considered to be related to the Gem-Gold Hunter mineral belt.

The ore of the Dayrock mine is very different from that of the Success mine and from that of any of the other mines as close to the stocks (pl. 2). It is now known that the Dobson Pass fault cuts the Ohio vein and that the proximity of the Dayrock veins to the stock is due to fault movement.

The California mine (table 23) is in the Dayrock subbelt and its ore is similar to Dayrock ore. The Western Union mine (table 23) is not in the Dayrock subbelt, and even after reconstruction of the pre-Dobson fault situation the mine does not lie in a mineral belt. The ore is apparently similar to that of the Dayrock mine.

GOLCONDA-LUCKY FRIDAY MINERAL BELT

The ores of the Golconda-Lucky Friday mineral belt (pl. 2) are lead- and silver-rich and the gangue is mainly country rock. The presence of low-iron sphalerite and of more than usual amounts of late silver minerals suggests that these veins had low temperatures of formation. The only exception is the Sisters prospect, where the vein apparently contained silicates, magnetite, and pyrrhotite. Characteristics of the ore shoots are given in table 23.

PAGE-GALENA MINERAL BELT

The Page-Galena is the largest and, in February 1959, the most productive mineral belt in the Coeur d'Alene district (pl. 2). Characteristics of most of the ore shoots in this mineral belt are shown in table 23; the listing of the Bunker Hill mine veins is not complete—additional productive veins are known to exist—and no data are available for ore shoots of the Crown and Blackhawk mines. Ore from the Bunker Hill mine veins was described by Ransome and Calkins (1908, p. 162) and by Umpleby and Jones (1923, p. 52 ff.); R. J. Anderson (1940) and Kerr and Robinson (1953) described the ore from the Sunshine mine; Willard (1941) described the ore from the Polaris mine, and Fryklund and Hutchinson (1954) that from the Silver Summit mine. Sorenson (1951) gave a valuable report of the exploration of some of the siderite-tetrahedrite veins. The general geology and more particularly the wallrock petrography and vein mineralogy of the siderite-tetrahedrite veins were described by Mitcham (1952).

The Tony ore shoot of the Page mine, the ore from the Bunker Hill mine, and the Silver and Lead ore shoots of the Galena mine are described in detail below.

TONY ORE SHOOT OF THE PAGE MINE

The Tony ore shoot is on the Tony vein of the Page mine (pl. 4). The vein on the 600 level strikes west, on the 2100 level the overall strike is S. 60° W. The vein dips about 50° S. on the upper levels and 65° to 70° S. on the lower levels.

The country rock of the vein in the upper levels is St. Regis Formation; the contact with rocks of the Revett Quartzite is above the 1800 level but this part of the mine was inaccessible during my visits. On the surface, beds strike approximately N. 70° to 80° W.; they are overturned and dip about 70° S. Underground, beds have a great variety of strikes, but in the vicinity of the Tony vein the directions of strikes are nearly at right angles to that of the vein; dips near the vein range from 30° to 75° NE.

At least two sets of postore faults, not including the Page fault, can be recognized: Faults of the oldest set strike about N. 75° W. and dip south; faults of the other set strike a little west or east of north, and most of them dip west. The north striking faults usually displace the vein only a few feet, but their abundance greatly complicate mining. The most important of the oldest set is the Tony fault which dips 65° S. It offset the Tony vein about 50 feet. This fault was long considered to be a preore fault which had served as a dam when the Tony vein was being formed, and it was many years before its true nature was recognized and the offset segment of the Tony vein located.

Even though the discussion of the Page mine is restricted to consideration of the Tony ore shoot, it is necessary to describe the Page fault and its age relative to the Tony vein. The Page fault strikes about N. 20° W. and dips about 60° W.; it is a reverse fault and has at least 4,000 feet of movement. The Tony ore shoot has the shape of a shield whose upper left corner is missing. I think the best interpretation is that the Page fault truncated the Tony ore shoot. This conclusion is not that of S. W. Hobbs and others (written communication, 1959). The pertinent levels were inaccessible at the time of this study; no personnel of the U.S. Geological Survey Coeur d'Alene project have seen any intersections of the Tony vein and the Page fault. According to Mr. Troy Tower, mine superintendent of the Page mine, the contact of the ore with the fault was knifelike; he considers the Page fault to be postore in age, as does Philip I. Conley, Chief Geologist, Northwest District, American Smelting and Refining Co. (oral communication, 1959), who mapped some of the critical levels.

Proponents of preore faulting suggest the fault actually acted as a dam but I think this an unlikely interpretation. The Page fault now serves as a roof over most of the strike length of the ore shoot and at slightly higher altitudes than the present surface lay over the entire Tony vein. Gouge seams are relatively minor in any of the Coeur d'Alene faults, and the large faults I have seen have crushed and sheared zones on either side of a central gouge. Faults are not impervious to water today and there is no reason to believe they were in the past. If the Page were a preore fault roofing the Tony vein and if any central gouge had served as a dam, the ore-forming solutions should have moved out from the Tony vein along the fractures of the footwall to form a great plate-shaped ore deposit paralleling the undersigned of the Page fault. Such a deposit does not exit.

I believe that the large number of north-striking minor postore faults in the mine, which parallel the Page fault, formed at the same time as the Page fault and confirm its postore age. These faults are particularly significant; I know of no other ore shoot in the district that has been offset by so many small faults.

The Tony ore shoot has an unusual shape as compared to others in the Coeur d'Alene district. It can be best visualized as a shield, most of whose left side and top have been removed. Below the 1800 level the ore shoot does not reach the Page fault, though the vein does, and the ore shoot has the 90° rake common to Coeur d'Alene ore shoots. On the 300 level the strike length of the ore shoot is about 400 feet; on the 1800 level the strike is about 2,300 feet. Ore extends from near the surface at an altitude of about 2,880 feet to the 3030 level at an altitude of 390 feet. There is no indication that the ore shoot is approaching bottom.

The Tony ore shoot is the only one in the district in which the valuable sulfides are unquestionably vertically zoned. The zoning pattern was described on page 63.

The chief gangue of the vein is country rock, some of which has been recrystallized to white quartz. Only a small amount of megascopically visible ankerite is present so that the amount and kind of the valuable sulfides determines the appearance of the ore. Ore from the galena-rich part of the ore shoot appears different from and richer than sphalerite ore. The sphalerite ore is similar to ore from the Star mine, that is, lean ore is darker and light banded owing to steeply dipping stringers and veinlets of sphalerite, and rich ore is dull brown and contains white masses and ribs of unreplaced country rock. The galena ore is also banded. If the galena is fine grained, as most of it is, the bands are dark gray; in places, however, the galena is coarse grained and the ore has a rich metallic appearance.

The Tony ore shoot is one of the few in the Coeur d'Alene district in which the ore is bounded by a zone of disseminated sulfides. This zone is irregular in shape and probably does not extend more than 10 to 20 feet from the vein. The white wallrock may be only slightly peppered with specks of the sulfides, or the rock may be all shades of gray. Even the darkest gray rocks will not assay much more than 3 percent lead.

Mineralogically the ore of the Tony ore shoot is simple; pyrite, ankerite, sphalerite, tetrahedrite, chalcopyrite, galena, and pyrargyrite(?) were deposited in approximately that order. The main gangue of the vein is country rock, though recrystallization of some country rock has formed white quartz. Sericite bands, remnants from the country rock, are in the ore.

Pyrite is not common; most of it occurs in grains less than 1 mm on an edge. Ankerite is not abundant and most of it is disseminated in the country-rock gangue.

Much of the sphalerite and galena occurs as a partial replacement of country rock, and their grain sizes are largely controlled by the grain size of the country rock (0.04 to 0.1 mm in diameter). In some areas, however, both sphalerite and galena grains may reach 2 to 3 mm on an edge. The Tony vein is cut by numerous faults, and schistose and steel galena and granulated sphalerite are generally present adjacent to these faults.

The iron content of the sphalerite ranges from 1.8 to 4.0 percent (table 6).

Tetrahedrite and pyrargyrite(?) are largely, but not exclusively, confined to the galena-rich part of the ore body. The distribution of chalcopyrite is erratic and if closer spaced samples were available, several chalcopyrite-rich shoots could be outlined in both the galena- and sphalerite-rich parts of the ore body.

A little introduced quartz is present in minor veinlets.

BUNKER HILL MINE ORE

The Bunker Hill mine (pl. 4) is the largest in the district. Most of the currently productive veins (as of August 1958) in the lower part of the mine were sampled. Most of the veins in the upper part of the mine are no longer accessible; however, samples were taken from parts of the Motor vein and from an intricate network of minor veins still accessible in the Sweeney adit; in addition, some samples were taken from the March ore shoot on the Bunker Hill 10 level.

All the veins have a very simple and similar mineralogy; however, the chief gangue in the upper part of most of the mine is massive siderite, whereas in the deep veins it is country rock (Revett Quartzite) and siderite is little more than an accessory mineral.

Umpleby and Jones (1923, p. 60 ff.) recognized three types of ore and a similar division still seems warranted. Ore of the Bunker Hill type consists of massive siderite that has been partially replaced by sulfides, principally galena. Ore of the Blue Bird type is found in veins of a different system, and though siderite is abundant it is not massive but is in stringers; ore bodies on these veins were much smaller than those on the Bunker Hill veins. The third type was designated the Jersey type.

According to Umpleby and Jones (1923, p. 60), quartz is the dominant gangue of the Jersey type veins, and though the exposures they saw are no longer accessible, there is little doubt that the quartz they refer to is country rock, albeit at places recrystallized. The deep veins of the Bunker Hill mine, from which most of the production now comes, are apparently all of the Jersey type.

This classification simply reflects the amount of siderite present in the different veins, though different vein systems are involved. In all the veins, galena is the dominant ore mineral; the other sulfides, with the exception of sphalerite, are merely accessory minerals. All gradations between the three types undoubtedly existed, and the Blue Bird type is simply a transition from the Bunker Hill type to the Jersey type. The controlling factor appears to have been structure; the Bunker Hill veins opened first and remained accessible to siderite-forming solutions during the entire period of siderite deposition, but the others opened later and therefore were not accessible during the entire period of siderite formation.

The Motor vein is now perhaps the best exposed Bunker Hill-type vein in the mine. The vein has dips as low as 15°, and because it was mined without any filling, it is still possible to walk through many of the old stopes and examine stope edges and pillars. The vein minerals in their order of formation are siderite, pyrite (and rare arsenopyrite), sphalerite, tetrahedrite, chalcopyrite, galena, and bournonite(?).

Little recrystallized country-rock quartz is now visible, and it does not seem likely that any great amount of recrystallized quartzite was ever present. Massive siderite is the chief gangue mineral; it apparently was the first mineral to be introduced. Siderite grains are anhedral and range in diameter from a few hundredths of a milimeter to as much as 3 cm. The average grain is about 1 to 3 mm in diameter. Massive siderite reaches widths of at least 25 feet in the Motor vein, and Ransome and Calkins (1908, p. 159) noted widths of 100 feet in this same area of the mine. Below the Bunker Hill 9 level the Motor vein is barren and contains little more than siderite and pyrite; however, above that level, ore bodies attributed by Umpleby and Jones (1923, p. 57) to ore solutions that were diverted from the steeper dipping Blue Bird veins were formed. If this paragenesis is correct, as is probable, then the Motor vein must have formed in stages.

Pyrite was the first sulfide to be deposited in the vein. The Motor vein appears to have more and larger pyrite masses than the deep veins that were sampled, but even here pyrite is only a minor constituent. Grains are generally small, less than 1 mm across, but aggregates of such grains may form fist-sized masses. In one specimen a finer grained pyrite aggregate had an indistinct colloform texture. Only one sample contained a small amount of brecciated arsenopyrite—a considerable contrast to the common occurrence of arsenopyrite in the siderite veins farther east in the mineral belt.

Sphalerite is fairly abundant in places, though this apparent abundance reflects the fact that where sphalerite was present in quantity it was left in pillars. No analyses were made, but the sphalerite is similar in color to that of low-iron sphalerite from the adjacent Page mine (table 6). Except for a single sample, the sphalerite was free of chalcopyrite, but much of it contains rather abundant pyrite.

A very small amount of chalcopyrite is present; it is older than galena.

Galena is the dominant ore mineral, and old reports and the evidence remaining in pillars indicate that much of the ore consisted of little more than massive galena. Most galena grains are 1 to 2 mm in diameter though some grains are twice that size. Galena with gneissic structure is to be found; it indicates mild postore deformation, but no badly crushed or steel galena was noticed.

Bournonite(?), so identified by comparison with bournonite determined by X-ray methods, has a very spotty distribution; it forms perhaps 1 percent of a very few polished surfaces and is absent from the rest. The most common mode of occurrence is as elongate blebs in galena and along galena grain boundaries, though a few minute veinlets are present in galena.

The siderite-galena ore from veins in the Sweeney Tunnel area is megascopically identical with material from the Motor vein. Bournonite(?) is present in most of the polished surfaces from the tunnel area, and tetrahedrite is virtually absent.

The Jersey-type veins that were sampled in some detail include the Mac, Emery, and Truman veins. The mineralogy of these veins is the same as that of the Bunker Hill-type veins. Siderite is the dominant carbonate; it occurs disseminated in the country-rock gangue of the vein or as quite minor stringers and veinlets. The disseminated siderite is very fine grained, the grains being about the same size as the country-rock detrital grains that it has replaced. Ankerite is present but is much less abundant than siderite.

Barite was reported by Shannon (1926, p. 444) from what are believed to be examples of the Jersey-type veins but was not recognized in any material studied.

Pyrite is the oldest sulfide. It occurs as anhedral and euhedral grains that range from a small fraction of a millimeter to 4 mm in diameter. Most of the pyrite is visible only with a hand lens or under the microscope, and the fist-sized masses to be found in the Bunker Hill-type veins are apparently rare. A single grain of arsenopyrite was recognized in a sample from a 19-level part of the Truman vein.

Sphalerite was the third sulfide to be deposited; it is present in all three veins. Its occurrence is spotty but sphalerite ore shoots could be outlined in the three veins. The sphalerite is similar in appearance to that of the Page mine; most is quite free of chalcopyrite but it usually contains abundant pyrite inclusions.

Tetrahedrite is much more abundant than in the Bunker Hill-type veins. The occurrence of tetrahedrite also is spotty, however, and in a few samples no tetrahedrite could be recognized. The most common mode of occurrence is as irregular-shaped inclusions in galena. In some polished surfaces, perhaps 5 percent of a galena mass consists of tetrahedrite. Veinlets of tetrahedrite cut sphalerite.

Chalcopyrite is a common constituent in many Jersey-type veins where tetrahedrite is also abundant, in contrast to the Bunker Hill-type veins, which never contain much chalcopyrite. It is less abundant than tetrahedrite and most of it is younger than galena and is apparently associated with bournomite(?).

The chief ore mineral in all the veins of the Bunker Hill mine is galena, and in the Jersey-type veins examined it is also the chief vein mineral, and commonly so by a large percentage. In this respect, these veins are very similar to the veins of the Dayrock and Lucky Friday mines and to the galena-rich part of the Tony vein of the adjacent Page mine. Ore textures and galena grain sizes vary considerably depending on the extent of replacement of country rock and of subsequent recrystallization. Most of the galena is fine grained, apparently reflecting the grain size of the replaced country rock, which is mainly Revett Quartzite. In some areas, however, galena grains may reach 2 to 3 mm on an edge. Apparently nowhere in these deep veins are there the great thick masses of relatively coarse-grained galena that characterized the ore shoots of the Bunker Hill-type veins.

The final stage in formation of the Mac, Emery, and Truman veins consisted of deposition of the late chalcopyrite and of bournomite(?). Bournonite(?) is most abundant in polished surfaces of material from the Truman vein, and least abundant in material from the Emery vein. Megascopic amounts of bournonite(?) were not recognized.

A very small amount of covellite(?) is present in tetrahedrite from the 23½-level of the Truman vein and is probably hypogene in origin.

The Bunker Hill mine contains the greatest concentration of sulfides in the district, and the greatest number of veins. The ore shoots extend from about 4,200 feet above sea level to more than 1,000 feet below sea level. None of the individual veins, however, has this range in depth, and none shows any primary zoning with depth. The three types of veins overlap with depth, and it would be incorrect to state that depth zoning exists with respect to carbonate in the Bunker Hill mine as a whole. The mine is simply an outstanding example of what can happen if repeated fracturing occurs during a single stage of mineral deposition, in this case siderite.

SILVER AND LEAD ORE SHOOTS OF THE GALENA MINE

The Silver and Lead veins of the Galena mine (pl. 4) are only 600 feet apart at one point, yet ore from the two ore shoots differs greatly in content and appearance. Massive siderite is the chief gangue in the Silver vein and a minor constituent of the Lead ore shoot; the dominant sulfide in the Silver vein is tetrahedrite and in the Lead vein is galena.

The Silver vein does not crop out; it has an irregular strike, but the longitudinal mine section is along the line S. 70° W. The vein dips about 70° S. and is slightly offset on the east and west ends by north-striking faults. The west end of the vein, though not the ore shoot, cuts a disseminated arsenopyrite-pyrite zone. The country rock is Revett Quartzite. The general strike of the beds in the Silver vein area is N. 50° to 55° W.; dips are 65° to 80° N.

The ore shoot, in 1957, had been explored between the 2200 and 3400 levels. At that time, its shape was that of an inverted shield and the ore shoot had a 90° rake. The maximum stope length is about 800 feet; stope widths reach 20 feet and average perhaps 6 feet.

The ore is typical of the siderite-tetrahedrite veins of the Page-Galena mineral belt, though no part of the ore shoot is as rich in tetrahedrite as parts of the Sunshine ore shoot of the Sunshine mine. Lean ore consists of a solid mass of siderite cut by veinlets of dark-brown tetrahedrite. The tetrahedrite has entered the vein along fractures parallel to the vein walls; replacement of the siderite out from these fractures has produced an appearance of rough striping. Siderite fractures readily along cleavage and a fine reticulate network of terahedrite veinlets extends out from the larger tetrahedrite veins. Minor amounts of unreplaced country rock and white quartz may be found in both lean and rich ore. On the fringes of the ore shoot, ribs of unreplaced country rock may be as abundant as the larger siderite stringers. Gouge seams in and along the hanging walls and footwalls of the vein are nowhere as common or wide as in most other ore shoots in the Coeur d'Alene district. In rich ore, massive siderite is cut by one or more tetrahedrite veins that may reach a width of 6 inches, and several 1- to 2-inch-wide veins may be present; all are connected by tetrahedrite veinlets. The overall picture is of rough banding. Visible chalcopyrite and pyrite are not common and visible galena is rare.

The minerals of the ore shoot, in their approximate order of formation, are: siderite, pyrite and arsenopyrite, tetrahedrite, chalcopyrite, galena, and bournonite(?). The vein on its west end has cut a zone of disseminated arsenopyrite and pyrite, so in places two ages of arsenopyrite and pyrite can be recognized; the older is consistently the finer grained of the two. The white quartz, older than siderite, is recrystallized country rock.

The abundance of the ore minerals is of interest because the abundance in the Silver vein is so different from that in the Lead vein. Siderite is the most abundant mineral by several times. Tetrahedrite is next in abundance. Minute chalcopyrite veinlets are present in all polished surfaces but it is much less abundant than tetrahedrite. Visible galena is rare and the existence of an S-shaped concentration of galena in the ore shoot was determined by inspection of polished surfaces. Bournonite(?) is rare.

The Lead vein is actually a zone as much as 300 feet wide that is cut by many galena-rich veins and stringers. Several of these veins are 6 to 8 feet wide and could be mined individually. The vein strikes about N. 70° W. and dips steeply south. The explored part of the vein is about 1,800 feet long; the vertical dimensions of the Lead vein and its ore shoot are not yet known.

The country rock of the vein belongs to the Revett Quartzite. The beds strike N. 60° to 70° W. and dip 70° to 80° N.; they almost parallel the vein in strike, and the two dips intersect at low angles.

Unrecrystallized country rock and gray and white quartz are the principal gangue. Disseminated siderite is abundant in the zone, especially in and along the high-grade veins, but siderite stringers are not common; massive siderite is absent. The most abundant sulfide are galena and pyrite, and the gray and white banded ore is totally unlike that of the adjacent Silver ore shoot. The Lead vein is an interesting example of transition between siderite-tetrahedrite veins that are galena-rich, such as the Polaris veins of the Sunshine mine, and the galena veins that contain only disseminated carbonate in the country-rock gangue, such as those in the lower part of the Bunker Hill mine and the galena-rich part of the Page mine Tony vein.

The minerals of the Lead vein in their approximate order of introduction are: pyrite and arsenopyrite, siderite, sphalerite, tetrahedrite, chalcopyrite, galena, bournonite, meneghinite, and an unidentified ruby silver.

Arsenopyrite and pyrite grains each contain large corroded inclusions of the other mineral. Pyrite is abundant, much of it in masses that reach 4 inches in diameter. Sphalerite is uncommon and the color of its streak indicates it contains less than 1 percent iron. Tetrahedrite though not abundant contributes significantly to the value of the ore. The Lead vein contains one of the largest concentrations of the late sulfosalts in the Coeur d'Alene district. Although several different sulfosalts (other than tetrahedrite) have been reported from the Lead vein, all X-ray patterns were of bournonite or meneghinite.

PINE CREEK MINERAL BELT AND DOUGLAS MINERAL SUBBELT

The veins of the Pine Creek mineral belt (pl. 2) are sphalerite-rich, and the gangue consists of pyrrhotite and country rock; some of the latter is recrystallized. The principal carbonate is ankerite which is present as minor stringers or is disseminated in the country-rock remnants. Ore from the various mines is similar in appearance to that of the pyrrhotite-bearing veins around the monzonitic stocks, but the silicate minerals and magnetite are absent. Characteristics of the ore shoots of the mineral belt are given in table 23. A description of the Surprise No. 1 ore shoot of the Highland-Surprise mine is given below.

Ore from the Douglas and Constitution mines, the only two in the Douglas subbelt, has not been studied but appears to be identical with that of the ore bodies of the Pine Creek mineral belt. Characteristics of the ore shoots of the mineral subbelt are given in table 23.

SURPRISE NO. 1 ORE SHOOT, HIGHLAND-SURPRISE MINE

The Surprise vein in the Surprise part (west part) of the Highland-Surprise mine (pl. 4) strikes about N. 65° W. In the upper part of the mine, dips are vertical or very steep to the south; below the 1650 level the dip is 60° S. The Surprise No. 1 ore shoot is the largest of three mined on this vein.

The vein is entirely within rocks of the Prichard Formation. In the west end of the mine the strike of the beds is generally at least subparallel to the strike of the vein. However, a number of minor folds whose axial planes strike east are present, and beds dip from 50° to 85° both to the north and the south.

The ribbonlike ore shoot has a maximum stope length of about 300 feet and a dip length of 1,720 feet. The ore shoot rakes 75°. It cropped out at an altitude of

3,470 feet and bottomed at an altitude of 1,780 feet. Inasmuch as the adjacent Highland ore shoot crops out at an altitude of 3,720 feet and the nearby Sidney vein crops out at an altitude of 4,200 feet, between 500 and 1,000 feet of the ore shoot may have been removed by erosion.

The chief ore mineral is sphalerite. Fine-grained ore having a granular texture is common, but most of the ore was relatively coarse grained; the sphalerite grains were 0.5 to 2.0 mm long. The ore usually contains abundant unreplaced pyrrhotite either as small inclusions in vein minerals or as larger unreplaced masses. The edges of ore shoots, along strike particularly, are commonly composed of exceedingly fine grained pyrrhotite (0.01 to 0.05 mm in diameter) that contains abundant fragments of unreplaced quartzite. Massive pyrite is also common in the ore and fringing the ore shoots, but the vein is typified by the pyrrhotite content.

Glassy quartz formed by the recrystallization of the country rock is an important gangue mineral, although relatively unrecrystallized country rock is also present in the vein; most of the country rock has been replaced by introduced minerals.

The vein minerals, in their approximate order of formation, are pyrite, arsenopyrite, siderite and ankerite, pyrrhotite (partially altered to pyrite and marcasite), sphalerite, tetrahedrite, chalcopyrite, galena, quartz, and calcite; chlorite in the vein was probably introduced at a much later time.

Pyrite and arsenopyrite appear to be the oldest sulfide minerals. Most of the pyrite is euhedral to anhedral in shape, although massive pyrite is present and in at least one place such pyrite retains evidence of an original colloform texture. Most of the arsenopyrite is euhedral; individual grains reach 0.5 mm in length but most are smaller. Many of the larger grains that appear euhedral are actually aggregates of three or four individuals. Some grains are brecciated and have a floating-ice texture.

Pyrite and arsenopyrite and carbonates are not abundant and contacts between the minerals are few; the carbonate may be younger than the two sulfides. Small amounts of both siderite and ankerite are disseminated in unreplaced country rock, and a few veinlets of both are present. Ankerite is probably the more abundant.

Pyrrhotite is perhaps the most abundant vein mineral. In places the vein is composed almost entirely of pyrrhotite. Widths of massive pyrrhotite over 6 feet are common, and in places, at the east end of the 1300 level for example, pyrrhotite is 10 feet wide. In the ore shoot, unreplaced pyrrhotite can be found in all the younger sulfides.

Marcasite and pyrite as alteration products of pyrrhotite are common (fig. 2). Alteration pyrite and marcasite were recognized in material from all parts of the mine. In most of the polished surfaces, only a few pyrrhotite grains are altered and even in these grains the alteration is generally less complete than the pyrrhotite alteration at the Hercules mine.

Following sphalerite, the most abundant ore mineral, small amounts of both tetrahedrite and chalcopyrite were introduced. Tetrahedrite is very rare and even if argentiferous undoubtedly contributes only slightly to the silver content of the ore. A single example of a chalcopyrite veinlet cutting tetrahedrite was recognized. Chalcopyrite is not abundant; the zinc to copper ratio of the ore is 71 to 1, and the lead to copper ratio is 24 to 1. Nevertheless, ore of the Highland-Surprise mine contains more copper relative to the other base metals than does the ore of other mines in the Pine Creek mineral belt. Megascopically visible chalcopyrite is rare; most of it occurs as irregular-shaped masses which are less than 0.05 mm long.

Galena, the second most abundant ore mineral, occurs almost exactly as does sphalerite; the zinc to lead ratio is 3 to 1. Triangles of very fine grained galena occur at grain boundary intersections in quartzite-, pyrrhotite-, and sphalerite-dominant areas, and all gradations in the replacement of the three dominant hosts can be found. The coarsest galena reaches 2 to 3 mm on an edge, but such galena is uncommon.

A very small amount of a very fine grained anisotropic mineral forms veinlets 0.03 mm long in galena. The color and strong anisotropism suggest a sulfosalt, but the mineral's identity was not determined.

Sphalerite is the dominant ore mineral and its iron content, estimated on the basis of color, is about 4 to 6 percent. The single analyzed sample, from the Surprise ore shoot on the No. 4 adit level, contained 5.5 percent iron. The sphalerite grain size is variable and is controlled largely by the type of material replaced by the sphalerite and by the completeness of the replacement.

A few late veinlets of quartz and carbonate cut sulfides.

The chlorite present in the veins as films cutting sulfides is also in the country rock; such chlorite is not considered to belong to the vein-forming sequence.

MOE-REINDEER QUEEN MINERAL BELT

The Moe-Reindeer Queen mineral belt (pl. 2) contains only two mines though there has been extensive exploration of prospects. Production from the Moe mine has consisted largely of galena from massive siderite veins. Probably tetrahedrite and chalcopyrite

TABLE 24.—*Characteristics of stibnite veins in the Coeur d'Alene district, Idaho*
[For locations see pl. 4]

Mine or prospect	Strike, dip of vein	Formation	Mineralogy	Remarks
Coeur d'Alene and Pine Creek antimony.	Irregularly N. 35°–60° W.	Prichard	Quartz, pyrite, sphalerite, gold, stibnite.	Shannon (1926, p. 78).
Great Dunkard (Pearson)	N. 40° E., vertical	do	Sphalerite, stibnite, calcite	Jones (1920, p. 33).
Blue Bird (Hannibal)	N. 10° E., 60° W	do	Stibnite	Jones (1920, p. 34). Vein is cut by an unidentified dike.
Star antimony	E., 25°–60°S	do	Quartz, pyrite, arsenopyrite, sphalerite, stibnite, gold.	Jones (1920, p. 33).
Big It	E., 40°–60°S	do	Quartz, ankerite, pyrite, arsenopyrite, scheelite, sphalerite, stibnite, gold, calcite.	Relative age of the scheelite is not known. Analysed sphalerite contained 0.72 percent iron. Vein was mined for scheelite.
Stanley	N.5°W to N.10°E., 70°E	Burke	Quartz, arsenopyrite, stibnite, cinnabar(?), gold.	Gold was visible in polished surfaces. A red antimony oxide is present, as is a small amount of red material that gave a microchemical test for mercury.
Benton	E., 60°S	do	Probably same as Stanley	

were also present, and the veins are apparently the eastmost representatives of the productive siderite veins. According to Calkins and Jones (1914, p. 201), the Carbonate Hill, or Atlas vein in the Carbonate Hill (Atlas) mine, contained massive siderite and ankerite, though the vein now exposed on the Atlas adit level consists largely of ankerite. This vein is the westmost of a group of massive ankerite veins east of the district in Montana; it is the only productive example in the Coeur d'Alene district.

Characteristics of the ore shoots are given in table 23.

URANINITE VEINS

The uraninite veins were not examined during the early phases of this work; at the time of my study, most of the sublevels had caved and the available openings were either timbered or badly oxidized.

The uraninite veins are concentrated in the Page-Galena mineral belt. Uraninite, or anomalous radioactivity, has been recognized in all the large mines of the belt with the exception of the Silver Summit mine. Anomalous radioactivity has been noted in material from the Sherman mine in the Tamarack-Marsh mineral subbelt, and a single uranium-bearing stringer was noted in the Hercules mine of the Carlisle-Hercules mineral belt (G. M. Crosby, Chief Geologist, Day Mines, Inc., oral communication).

The largest, and most thoroughly explored, uraninite occurrence is in the Sunshine mine (Kerr and Robinson, 1953). Uranite occurs in quartz-pyrite-uraninite veins and veinlets, and the vein walls generally contain very fine grained disseminated hematite. The various occurrences are generally complicated by later emplacement of veins belonging to the main period of mineralization.

STIBNITE VEINS OF THE SECOND TERTIARY PERIOD OF MINERALIZATION

The stibnite veins have been described by Jones (1920, p. 31 ff.) and Shannon (1926, p. 78). They are found principally in two groups: the largest number of veins is in the Pine Creek drainage in the southwest part of the district south of the Osburn fault; a lesser number are near the town of Burke north of the Osburn fault; other prospects are northeast of Burke in Montana. Veins in both areas were productive during World War I.

The stibnite veins are outside the mineral belts of the main-period veins (pls. 2, 4), and the individual veins have diverse strikes that do not fit the pattern of the main-period veins. The prevalence of veins along bedding-plane fractures suggests that these veins formed at less depth than the main-period veins.

The mineralogy of the veins is simple. The gangue consists either of country rock or of white quartz that has formed by the recrystallization of country rock. Yellow sphalerite and arsenopyrite are the most common accessory minerals. An unusual mineral association for the district and the region is that of scheelite and stibnite at the Big It mine. The association of stibnite and scheelite is not unusual in Idaho, however, for the two are the chief ore minerals at Yellow Pine (Cooper, 1951). The characteristics of the stibnite veins are given in table 24.

BLEACHED ROCK IN THE COEUR d'ALENE DISTRICT

By PAUL L. WEIS

INTRODUCTION

Bleached rock has been used as a general guide to prospecting in parts of the Coeur d'Alene district since about 1936. Several of the largest and richest mines in the district lie wholly or partly within bleached zones, among them the Sunshine, Bunker Hill, Page, Star, and Morning mines. Bleached rock is found in all mines of the Page-Galena mineral belt, in part of the Moe-Reindeer Queen belt, Dayrock subbelt, in the Gem-Gold Hunter belt, especially the east part, and in the east parts of the Golconda-Lucky Friday and Rex-Snowstorm belts. Widespread bleaching has affected parts of the Wallace, St. Regis, and Revett Formations; it is somewhat less common in the Burke Formation, and only very small bleached areas are known in the Prichard and Striped Peak Formations. Although some rock outside known mineral belts is bleached, most of the bleaching is in mineral belts.

Bleaching alteration in the district was first noted by Rasor [7] in 1934, and was referred to in more or less detail by several later workers: H. S. Gale, unpublished data; Shenon and McConnel (1939), Willard (1941), Anderson (1949), Sorenson (1951), Mitcham (1952), A. H. Sorenson.[8] Two contrasting views have been expressed as to the nature of the bleaching process. One explanation attributes the bleaching to sericitization (or locally, to a combination of sericitization and silicification), that is, the addition of significant amount of potassium or potassium and silica to the bleached rocks. The alternative explanation is that the change in color is solely the result of changes in, or removal of, pigmenting minerals, chiefly some of the minerals that contain a significant percentage of iron. Both explanations presume that the bleaching took place as a result of the action of hydrothermal solutions. A close relation, in both time and space, between these solutions and those that deposited the ore has been commonly assumed.

The present study was undertaken to determine the nature of the bleaching process; a necessary preliminary was the study of the petrography of the rocks of the Belt Series in the Coeur d'Alene district.

The ore bodies of the Coeur d'Alene district are replacement deposits. During the main period of mineralization a variety of minerals were emplaced to form the ore deposits: the silicates (biotite, amphiboles, chlorite, garnet, and sericite(?) and the carbonates (calcite, dolomite, ankerite, and siderite); quartz may also have been introduced in some of the deposits. However, except for a zone of chlorite alteration in the Moe-Reindeer Queen belt, none of these minerals appear to have been introduced for more than a few feet into the vein walls. They are in fact as much a part of the mineral deposits as the sulfides themselves and, like the sulfides, are confined to relatively narrow zones, despite their gradational contacts with the vein walls. The bleached zones, in marked contrast, are large broad, more or less continuous zones that may partly or completely envelop not only single veins, but a whole vein system, or even several vein systems. In parts of the Page-Galena mineral belt, bleached zones are more than 2,000 feet wide; some of the bleached rock lies as much as 1,000 feet from the nearest known vein (Sorenson, 1951, fig. 2). It is this relatively broad areal distribution that constitutes the important difference between the bleaching alteration and the replacement process that resulted in the formation of narrow mineralized zones made up of introduced minerals, and it is the widespread distribution of the bleached rock, in general around ore deposits, that has made it a more attractive guide to prospecting than the restricted zones that contain gangue minerals characteristic of the ore deposits themselves.

Because of the possibility of confusing near-vein mineralization directly related to vein formation with the changes due solely to bleaching, a particular effort was made in the present study to consider only those rocks that were a few tens of feet or more from known veins.

[7] Rasor, C. M., 1934, Silver mineralization at the Sunshine mine, Coeur d'Alene district, Idaho: Idaho Univ. M.S. thesis.

[8] Sorenson, A. H., 1958, Wall rock alteration in the Silver Summit mine, Shoshone County, Idaho: Paper presented at the Pacific Northwest Regional Conference, Am. Inst. Min. Pet. Eng., Spokane, Wash., 11 p.

METHOD OF STUDY

The U.S. Geological Survey began an extensive investigation of the Coeur d'Alene district and some adjacent areas in 1948, and fieldwork continued until the fall of 1958. During the course of the work, several people devoted at least some attention to the bleached rocks and their significance, but it was not until October 1958 that I was assigned to the specific study of the petrography of bleached rocks and started the work described in this report. During the preceding 10 years, other workers on the project had collected a great deal of data and a large number of surface and underground samples, which were available for study during the present work. Many of these samples, especially among those taken underground, were pertinent to the bleaching problem. The collections and data were supplemented by a few surface and underground samples collected by me, and altogether provided a reasonably representative suite of rocks for the work.

The petrography of some of the formations is described on pages 85 to 89. Enough specimens of St. Regis, Revett, and Prichard Formations were available to provide representative sampling of these formations. Other formations mentioned or described in this report may or may not be typified by the samples that were available. Particular attention was directed toward samples of Revett and St. Regis that contained both bleached and unbleached parts of single beds.

The present report is primarily petrographic in scope. It is based mainly on the examination of hand specimens and thin sections, but is supplemented to some degree by chemical analyses, brief visits to a few of the mines, study of the literature, and by the extensive backlog of information, both general and specific, gathered by other members of the project.

DEFINITION OF TERMS

Some of the confusion and disagreement on the nature of the bleaching process is the result of misunderstanding the meaning of terms used in discussing the process. Several terms that have previously been used with more than one connotation appear in this report. Those that are used here in a special or restricted sense are defined below. The reader should note that no redefinition of terms is intended, but only a clarification of the sense in which they are used in this section of the present report.

Sericitization.—The process of sericitization, in the strictest sense, requires only the formation of sericite in a rock. As used in the following discussion, however, the term is restricted in meaning to refer only to that hydrothermal process that involves the addition of potassium and the resultant conversion of preexisting minerals to sericite.

Metamorphism.—None of the rock specimens described in this report were near enough to igneous intrusives to show the effects of contact metamorphism. All, however, were slightly metamorphosed during folding and deformation. One of the most common changes that took place during deformation was the conversion of the clay-sized fraction of the original sediments to fine-grained muscovite. Although the formation of this mica might properly be called sericitization, it is called metamorphism in the present paper, in order to distinguish it from the process whereby potassium- and aluminum-bearing hydrothermal solutions convert other preexisting minerals to sericite.

Silicification.—In the present paper, silicification is the term applied to the process whereby silica is added to the rock, either as a replacement of preexisting minerals, or as a cementing agent, or as both. Recrystallization of quartz already present is not included.

Bleaching, hydrothermal alteration.—These two terms are used interchangeably in this section of the present report. They refer to the process that produced lighter colors in some of the rocks in the Coeur d'Alene district. The rock is called bleached rock or altered rock. No specific hydrothermal process is implied.

Sericite, muscovite.—Muscovite mica occurs in two characteristic forms in the rocks of the Coeur d'Alene district. One is as sparse, relatively large grains, generally oriented with their long axes parallel to bedding. They are believed to represent detrital grains and are termed muscovite. The second form is represented by abundant small thin, irregular-shaped grains. These grains probably formed after deposition and consolidation of the original rocks; they are referred to as sericite.

Hydrothermal solution.—The term "hydrothermal solution" as used in this report, refers to any aqueous solution with a temperature above 25°C, without any connotation as to source. It implies movement of the solutions through a significant volume of rock.

PETROGRAPHY OF UNBLEACHED ROCKS

The formations that make up the Belt Series in the Coeur d'Alene district are remarkably similar in gross petrography, despite their extreme heterogeneity on a small scale. Their overall composition is such that probably only the Wallace and Revett Formations could be distinguished by bulk composition alone. The rocks are to a large extent thin bedded; they have marked differences in composition and considerable differences in appearance from bed to bed, but the range in composition and appearance is mainly due to differences in grain size and in the ratio of quartz to sericite. Most of the major and minor mineral constituents can be found in almost every thin section of each formation.

The rocks are for the most part so fine grained that accurate point counts or similar quantitative determinations of mineralogy are difficult. Mitcham (1952, p. 423) listed the approximate abundance of minerals in the principal rock types and I am in general agreement with those figures. Mitcham's percentages represent the sparser end members, however, rather than the more abundant mixtures. All gradations in rock composition exist between these major end members, and rocks of intermediate composition make up the bulk of the Belt Series in the district.

PRICHARD FORMATION

Within the Coeur d'Alene district, the oldest rock exposed is the Prichard Formation. Its base does not crop out, but the formation is at least 12,000 feet thick there (Shenon and McConnel, 1939, p. 3) and consists principally of slate and phyllite. The Prichard contains numerous quartzite layers and abundant material of all gradations of composition from slate to quartzose slate to quartzite; it is generally thin bedded and has well-developed bedding-plane and axial-plane cleavage. Sericite-rich layers show also moderately to well developed slaty cleavage. Colors are mostly darker shades of gray, greenish gray, and bluish gray. Shades recognized by comparison with the National Research Council rock-color chart, (Goddard, and others 1948) are N2 to N5, 5B4/1, and 5GY3/1, 4/1, and 3/2 for slaty layers, and 5GY2/1, 3/1, 5/1, 3/2, 5BG2/1, 5Y2/1, and N2 for quartz-rich layers.

Grain size ranges from fine (less than about 0.5 mm) in the quartz-rich layers to very fine (less than 0.005

mm) in slaty layers. Graded bedding is common, as are alternate beds of quartz-rich and sericite- or chlorite-rich material.

The mineralogy of the Prichard Formation is simple. Minerals identified are quartz, sericite, muscovite, carbonates (calcite, dolomite, ankerite), plagioclase feldspar, potassium feldspar, tourmaline, pyrite, pyrrhotite, zircon, rutile, magnetite(?), ilmenite(?), "leucoxene," carbonaceous material(?), and rock fragments.

Quartz makes up as much as 90 percent of some of the quartzitic layers and less than 10 percent of some of the fine-grained slaty layers. The grains in the quartz-rich layers are generally coarser than those of the sericite-rich layers, and in most specimens of quartzitic rock the quartz exhibits mosaic texture and occasional oriented overgrowths. The original outline of the grains has been little changed; they are typically irregular to subrounded. Those grains that have oriented overgrowths generally have a band of fine particles showing their original borders. Quartz grains in the fine-grained sericite-rich layers are generally irregular, but whether this shape is the original one is not known. Few quartz grains, of any size or shape, show strain shadows.

Detrital muscovite is not abundant. It generally occurs as large plates oriented parallel to the bedding. Most of the mica in the Prichard Formation is sericite. It is in very fine grained thin irregular flakes, interstitial to quartz in the coarser grained quartzitic rocks but making up 75 to 80 percent of some of the finest grained slaty layers. The sericite is typically well oriented parallel to the cleavage. In some specimens it reflects additional cleavage planes by showing more than one direction of preferred orientation. Its distribution in coarser facies and its relative abundance in fine-grained rock, suggest that most of it was derived from clay minerals that were present in the original sediment.

Chlorite is common in all the lithologic types that make up the Prichard Formation, but, like sericite, is more abundant in fine-grained rocks. Locally it appears to make up as much as 5 percent of the rock, although accurate determination of the chlorite content is difficult. Its appearance is very similar to that of the sericite—thin, fine-grained, irregular platelets, generally oriented parallel to cleavage. Most of the chlorite is pale to medium green; in thin sections the pale-green variety, which is commonly intergrown with fine-grained sericite, may readily be overlooked or maybe mistaken for sericite. Oil-immersion determinations of refractive index and 2V establish its identity as daphnite and aphrosiderite (Hey, 1954). Much of it appears to have formed from the finest-grained parts of the original sediment. It is the chief pigmenting mineral, along with exceedingly fine-grained opaque material, in much of the Prichard. All the chlorite seen in the thin sections studied appeared to have formed during metamorphism.

Feldspars are common accessory minerals, especially in the coarser, quartz-rich facies. Both plagioclase and potassium feldspars were seen. Plagioclase ranged from about An_8 to An_{28}. Locally feldspar makes up as much as 2 percent of the rock. It is typically in irregular or elongate grains, and shows no alteration whatever. The size, distribution, shape, and range in composition of the feldspar indicate that it is entirely detrital in origin.

Tourmaline is present in almost all facies of the Prichard, but nowhere makes up more than a fraction of a percent of the rock. Most grains are relatively large, elongate, dark olive-green in color, and strongly dichroic. Some show excellent pyramidal terminations. Many grains have yellowish or brownish rounded cores and dark-green prismatic outer parts; the core undoubtedly represents a detrital grain, and the outer part represents later overgrowth.

Zircon, as widely scattered euhedral to subrounded grains, is present in most rock types, but appears slightly more abundant in the quartzitic rocks. It is commonly found scattered along individual bedding planes. Grain size generally corresponds closely to that of adjacent quartz grains. Most grains are colorless, but a few are pale yellow or pale yellowish brown. No evidence of recrystallization or growth since deposition was noted. It appears to be entirely of detrital origin.

Carbonates, including calcite, dolomite, ferrodolomite, ankerite, and siderite, but principally calcite and dolomite, are most abundant in rocks that contain more than about 50 percent quartz, particularly the coarse grained facies. Locally, 10 to 20 percent of the rock is carbonate. Most of it is recrystallized to some degree. Grain boundaries of coarser grains are typically irregular; fine-grained crystals are mostly sharp, smooth rhombohedrons. Many carbonate grains appear to have partly replaced quartz or sericite. The amount of detrital carbonate present, and the degree of recrystallization or redistribution, is difficult to estimate, but the concentration of carbonate in individual beds and the range in composition suggest that at least part of it is syngenetic. The scarcity of calcite in vein zones (Fryklund, oral communication, 1959) is further evidence that some of the carbonate is detrital. Locally, carbonates contribute significantly to the color of the rock.

Opaque minerals are widely distributed through all facies of the Prichard. Some, like pyrite and pyrrhotite, are readily recognized in thin sections, but the identity of others is uncertain. Black irregular grains, which may be magnetite, ilmenite, or possibly carbonaceous material, are present in many specimens. Pyrite and pyrrhotite are generally present as large scattered grains that contribute little to the color of the rock. In some specimens, however, the black opaque minerals are very finegrained and contribute significantly to the color of the rocks. The origin of the opaque minerals is not known; some, perhaps including some of the pyrite, are probably syngenetic.

Rutile is widely scattered through most facies of the Prichard Formation. It occurs in extremely small stubby rectangular prisms that have slightly rounded terminations. The rutile is clear and colorless; none appears to be detrital.

Many thin sections contain irregular opaque blobs of whitish material, scattered at random through the rock. In a few specimens the blobs appear to be more abundant in fine-grained beds. The material is tentatively designated as leucoxene, goethite, or both. Larger blobs may be altered (titaniferous?) magnetite. The magnetite is not abundant enough to contribute significantly to the color of the rock as a whole.

Rock fragments were recognized in all but the finest-grained layers in the Prichard Formation. They generally make up less than 3 percent of the formation, although some beds were seen that contained an estimated 5 percent by volume, and a few contain more than 10 percent. The fragments are angular to subrounded, or locally elongate, and are commonly about the same size as associated quartz grains. Most appear to be extremely fine grained aggregates of sericite, chlorite, and quartz.

REVETT QUARTZITE

The Revett Quartzite is about 1,200 feet thick in the east part of the district (Ransome and Calkins, 1908, p. 35), and 3,400 feet thick in the Kellogg quadrangle (Shenon and McConnel, 1939, p. 4). A. B. Campbell (oral communication, 1961) measured a thickness of about 1,800 feet in the Twin Craggs quadrangle; it has gradational contacts with the underlying Burke Formation and the overlying St. Regis Formation, and the lower and upper approximate thirds of the Revett somewhat resemble the Burke and St. Regis Formations, respectively. The central third of the Revett is a distinctive quartzite (Hershey, 1912). All the Revett is more dominantly siliceous than other formations in the Coeur d'Alene district; it contains much less sericite, and highly slaty or micaceous beds are very sparse.

Colors range from light neutral gray in the purest quartzite beds to shades of greenish gray in impure quartzites (N5–N7; 5GY5/1–5/2). Near the top the quartzite may be a delicate pink. Cleavage is not conspicuous in the purer quartzites; in less pure beds, cleavage is the same as in other formations. The average grain size is somewhat coarser than in other formations in the district, but none of the Revett is coarse grained. Crossbedding and ripple marks are present in all parts, but ripple marks are not characteristic of the middle third. In many places the Revett contains tiny scattered euhedral crystals of magnetite, which weather to small brown spots at the surface. Locally, the weathering of scattered grains of siderite or ankerite causes similar brownish spots on weathered surfaces.

The Revett is bleached in places, but bleaching is less striking in the Revett than in some of the St. Regis Formation because of the relatively pale color typical of most of the normal, unbleached Revitt.

The mineralogy of the Revett Quartzite is almost identical with the mineralogy of the Prichard Formation. The principal difference is in the greater proportion of quartz and rock fragments, and smaller proportion of sericite in the Revett Quartzite. In many places, and particularly in the massive light-colored quartzite that makes up most of the middle third of the Revett, quartz constitutes 65 to 90 percent of some of the beds, and quartz plus rock fragments more than 90 percent of almost all beds. These detrital quartz grains are generally coarser than those in the other formations; mosaic texture is common. Sericite is the next most abundant mineral, and generally makes up from 8 to 20 percent of the rock. In some beds, most of the sericite is in rock fragments, and only 1 to 2 percent is interstitial. Rock fragments commonly make up more than 5 percent by volume, and locally as much as 20 percent. Many of the rock fragments came from an older slate and are composed largely of sericite. Detrital muscovite, which indicates the bedding, is sparse but widespread. Detrital feldspar (including orthoclase, perthite, microcline, a variety of plagioclase feldspar, and even a few grains of granophyre) is common and locally makes up as much as 5 percent of the rock. All the feldspar is fresh. Chlorite is present in a few places. Magnetite, zircon, tourmaline, carbonates (calcite, dolomite, ankerite, siderite), leucoxene(?), goethite(?), pyrite, and rutile are also present. Locally, carbonates make up as much as 10 percent of the rock.

Sericite as small irregular grains that occupy most of the spaces between quartz grains probably represents what was originally interstitial mud. In places it shows one or more directions of preferred orientation, but in specimens where interstitial sericite is less than about 3 percent of the rock, perferred orientation cannot be recognized, unless a large field is examined under low magnification.

Tourmaline appears as scattered, irregular to nearly euhedral elongate olive-green prisms of random orientation. Many grains that contain rounded cores of a different color may have been detrital grains that served as a seed for later growth. Tourmaline is never more than a small fraction of a percent of the rock.

Carbonates are abundant in some specimens and totally lacking in others. They have been completely recrystallized and now occur either as large irregular grains or as tiny euhedral rhombohedrons. Some of the carbonate may have been introduced after regional metamorphism, but the range in composition and especially the presence of calcite suggest that some at least may be syngenetic, either as recrystallized detrital grains or as chemical precipitates.

Chlorite is present in a few specimens. It commonly forms tiny irregular pale-green grains, intergrown with sericite. In places it is present as large irregular, deeper green aggregates.

Small white to brownish irregular opaque masses are scattered through some of the beds. They are believed to be leucoxene, goethite, or perhaps, in places, mixtures of both.

ST. REGIS FORMATION

The St. Regis Formation conformably overlies the Revett Quartzite and is about 1,400 to 2,000 feet thick (S. W. Hobbs and others, written communication, 1959). Its texture, fabric, and composition are similar to those of the Prichard Formation—that is, it consists of thin-bedded material that was originally largely mud and silt, but has some individual beds or groups of beds containing a large proportion of very fine sand- or silt-size quartz fragments. Individual beds contain as much as 90 percent or a little as 10 percent detrital quartz, and there are all gradations between these extremes. Low-grade regional metamorphism has converted most of the St. Regis to quartzitic, slaty, or even phyllitic rock. Fine-grained layers have moderately to well developed cleavage.

The colors of the St. Regis are various shades of green and purple, the shades of purple predominating. Colors noted by comparison with the rock-color chart are darker shades of neutral gray, reddish, brownish, olive, and greenish gray (N2–N6; 5R3/1; 5R3/2; 5YR 3/1; 5GY2/2; 5GY3/2; 5GY4/1). In general, facies containing significant amounts of hematite are reddish to brownish, and facies that contain no hematite are dark greenish or olive gray. Bleached St. Regis Formation has shades of grayish yellow green (5GY4/2–7/2).

The St. Regis is strongly bleached in some areas. Fresh material showing both bleached and unbleached parts of single beds was found in the Rock Creek tunnel, about 3 miles east of Wallace, and at the Carbonate Hill (Atlas) mine, about 1½ miles southeast of Mullan.

The most abundant minerals in the St. Regis Formation are quartz, sericite, chlorite, carbonates, and hematite. Other minerals observed are magnetite, muscovite, plagioclase and potassium feldspar, tourmaline, zircon, rutile, goethite(?), leucoxene(?), pyrite, sphene, and rock fragments. The chief differences between the St. Regis and the Prichard are the presence of hematite and the greater abundance of beds that are notably sericite-rich and, to a lesser extent, notably sericite-poor in the St. Regis.

Much of the petrographic description of the Prichard applies equally well to the St. Regis. Quartz is typically mosaic textured, and locally exhibits oriented overgrowths. Detrital muscovite is sparse, but is readily recognizable by its size and orientation parallel to bedding planes. Sericite abundance varies inversely with the average grain size of the individual beds. The grains are small, thin, irregular, and oriented parallel to cleavage planes. Tourmaline is greenish blue or olive green, randomly oriented, and appears to be largely authigenic or metamorphic, although a few crystals contain rounded brownish cores that must represent detrital grains. Most of the chlorite, like sericite, occurs as small thin irregular flakes that are oriented parallel to cleavage planes. Much of the chlorite is pale green, although some from the Carbonate Hill (Atlas) mine is somewhat deeper green and, unlike chlorite seen elsewhere, locally forms aggregates. Sorenson (1951, p. 608) stated that this deeper green chlorite was introduced. Feldspars are in fresh irregular fragments. Zircon is found as scattered, euhedral or subrounded grains. Some of the magnetite is euhedral, but some is present as irregular, somewhat skeletal grains. Pyrite occurs as large euhedral to subhedral scattered crystals. Sphene is present as very sparse subrounded detrital grains. Small whitish to yellowish irregular spongy masses scattered through the formation are tentatively identified as either leucoxene or goethite, or possibly mixtures of both.

Hematite is widely distributed in the St. Regis Formation and is the chief pigment in the purple facies. It occurs mostly as abundant, very tiny bright-red to orange hexagonal platelets, uniformly distributed through some of the beds. In some places it forms irregular spongy masses that appear completely opaque except on the thinnest edges. The spongy irregular masses apparently resent ferric oxide that was once distributed more uniformly, but which has been segregated into incompletely crystallized clumps. The tiny hexagonal grains appear to have crystallized, or recrystallized, in place. Both types are believed to have formed during regional metamorphism. In places, chlorite and magnetite are also important as pigmenting minerals.

BLEACHING

Bleaching of the rocks of the Coeur d'Alene district produced striking changes in color, from shades of dark green, dark reddish gray, and dark grayish purple to white, light gray, and pale green.

Careful study of adjacent bleached and unbleached parts of individual beds in the St. Regis Formation shows that hematite, magnetite, carbonaceous material(?), chlorite, and sericite largely determine the color of the unbleached parts. The relative abundance and grain size of hematite determines whether the unbleached rocks exhibit shades of red, brown, or purple; where hematite is absent, the relative abundance of magnetite, carbonaceous material(?), chlorite, and sericite determines whether the unbleached rocks are dark greenish or shades of neutral gray. In the adjacent bleached parts of the beds, hematite, carbonaceous material(?), and magnetite are absent. Green chlorite is apparently also absent. The bleached chlorite has the same relief, texture, and interference colors as unbleached chlorite but is not colored; the grains are presumably simply colorless chlorite. Sericite apparently remains completely unchanged; the only difference noted seems to be more apparent than real—some specimens appear to contain more sericite because when most of the opaque minerals are gone, more sericite is visible. In some places, there may actually be some residual enrichment. In a few specimens, pyrite appears in both bleached and unbleached rock; in others, pyrite is present only in unbleached rock. Possibly in some places the bleaching solutions attacked other iron-bearing minerals more readily than pyrite; elsewhere some of the pyrite may have been introduced after the bleaching was complete, or some of the iron formerly in other iron-bearing minerals may have been changed to pyrite.

THE QUESTION OF SERICITIZATION

Before deciding whether the bleached rocks of the Coeur d'Alene district have been sericitized, it is worthwhile to review the criteria that may be used to demonstrate sericitization. Among the features acceptable as evidence for sericitization are the following:

1. A recognizable quantitative increase in sericite content in altered rocks as compared with unaltered rocks (though this increase could be achieved in a feldspar-rich rock, for example, without the addition of potassium or aluminum).
2. Chemical analyses showing higher potassium content in sericitized rock than in unaltered rock, without concomitant increase in other potassium-bearing minerals.
3. Veinlets of sericite cutting the rock.
4. Pseudomorphs of sericite after detrital or metamorphic mineral grains, especially after feldspar.
5. Textures showing sericite partially replacing other minerals.
6. Absence of fresh feldspar, especially fresh plagioclase, in sericitized rocks.
7. Random orientation of introduced sericite, in contrast to the oriented sericite developed under stress during regional metamorphism.
8. Enlargement of preexisting sericite. If enlargement is significant, sericitized rock should be recognizable by its coarser texture.
9. Concentration gradients—that is, progressive, systematic differences in the amount of sericite from place to place, especially where the relation of concentrations to structural features indicates distances from sources of altering fluids.
10. Association, at least in part, of ore bodies and zones of sericite-rich rock.

Additional indications of sericitization, such as changes in color or hardness, might be used as evidence, but are omitted here principally because they normally serve more to call the observer's attention to the presence of alteration than to identify its nature.

Not all the above features can be used with equal confidence to demonstrate sericitization. Any one or more of the first five points listed would probably be accepted as very good evidence; any one or more of the last five might be considered as good supporting evidence. In rocks that have been notably sericitized, most of the features listed should be commonplace and readily recognizable.

None of the above features was recognized in the bleached rocks of the Coeur d'Alene district.

The criteria will be considered in the following discussion in the same order as they were listed above.

The most obvious feature of sericitized rock should be a noticeable increase in sericite content over adjacent otherwise similar, unaltered rock. In homogeneous igneous rock, such differences are easily demonstrated. The problem is more difficult in the rocks of the Coeur d'Alene district, however, because of their marked small-scale inhomogeneity. Most of the Belt rocks in the Coeur d'Alene district are characterized by thin beds, and by a wide range in original composition from bed to bed, the quartz-sericite ratios ranging from about

1:10 to 10:1 (Mitcham, 1952; Ransome and Calkins, 1908). Differences in composition of this order of magnitude are not uncommon in adjacent beds (figs. 34, 35), whether in altered or in unaltered rocks.

In order to demonstrate that there is more sericite in the altered rock, it is necessary to consider an individual bed and to determine its sericite content on both sides of the contact between altered and unaltered rock. Available exposures do not permit this determination on a large scale; single beds commonly can be traced only a few feet or a few tens of feet. In some places, however, exposures can be found that show a very sharp line and a marked difference in color between bleached and unbleached parts of single beds. If the alteration is sericitization, specimens of the two colors of rocks from these beds, at least, should show some difference in their sericite content. Examples were found in some specimens of St. Regis formation from the Carbonate Hill (Atlas) mine and the Rock Creek Tunnel (in NW¼ sec. 32, T. 48 N., R. 5 E.). Study of these specimens shows that although pigmenting material, principally hematite, masks the color of sericite in the unbleached part of the hand specimen, examination under the microscope reveals as much sericite in the unbleached part of the bed as in the bleached part (figs. 36–40).

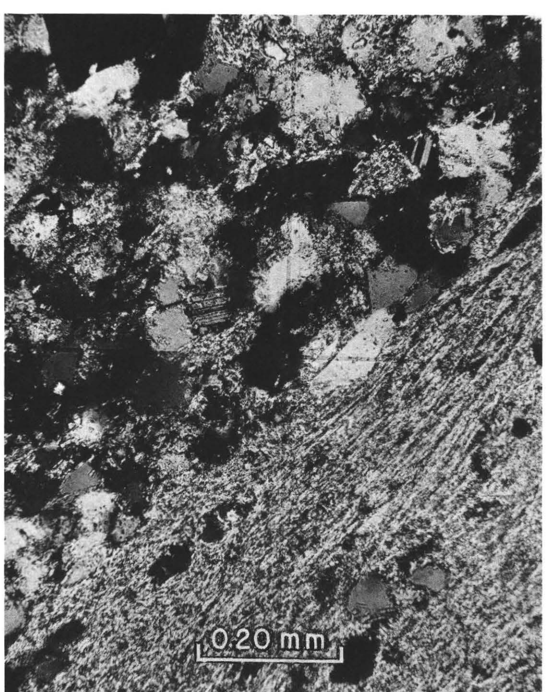

FIGURE 34.—Unaltered St. Regis Formation, Carbonate Hill (Atlas) mine. Note wide range in sericite content between adjacent beds. Coarse-grained bed contains quartz, plagioclase feldspar, interstitial sericite, rock fragments, pyrite. Crossed nicols.

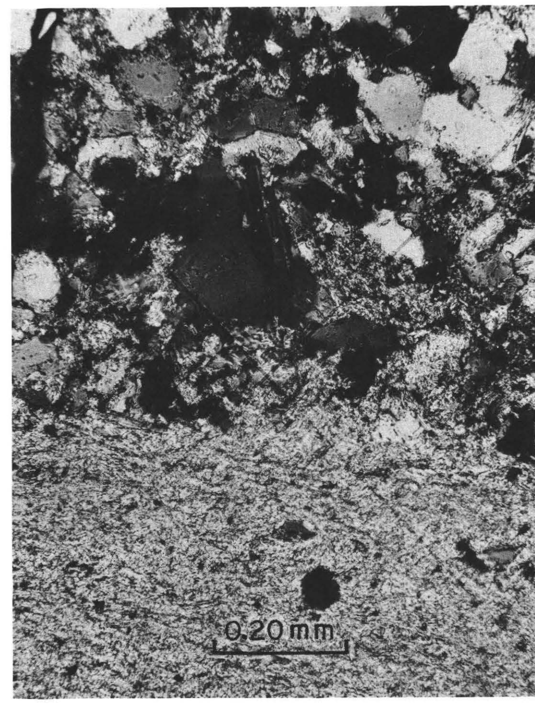

FIGURE 35.—Bleached St. Regis Formation, Carbonate Hill (Atlas) mine. Note wide range in sericite content between adjacent beds. Coarse-grained bed contains quartz, plagioclase feldspar, interstitial sericite, rock fragments. Crossed nicols.

Color difference between bleached and unbleached rock is the chief basis for recognizing bleached zones in the Coeur d'Alene district—a fact so obvious as to appear unworthy of mention. A critical aspect of this fact, however, may well be the most important single reason that some workers call the bleached rocks sericitized rocks. In general, the sericite-rich beds are the more intensely pigmented beds in unaltered rock (Mitcham, 1952, p. 423, table) (figs. 36–38). Consequently, their sericite content is easily overlooked in

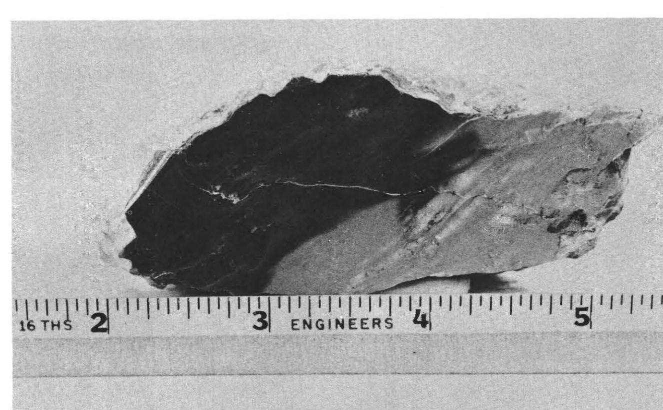

FIGURE 36.—St. Regis Formation, Rock Creek Tunnel. Dark-colored rock is dark purple and unaltered, and contains abundant fine-grained hematite. Light-colored rock is pale green, bleached.

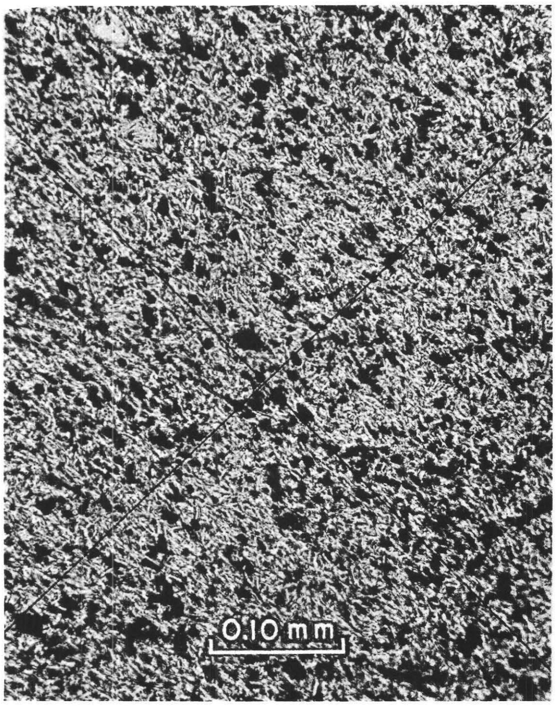

FIGURE 37.—Photomicrograph of dark purple unaltered part of the darkest bed visible in the specimen shown in figure 34. Opaque grains are hematite; almost all the rest of the rock is sericite. Plane-polarized light.

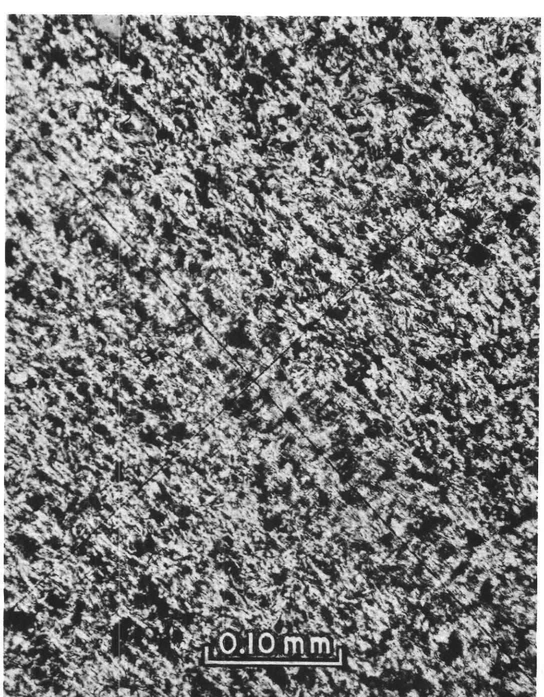

FIGURE 38.—Same as 37, crossed nicols. Note alinement of sericite.

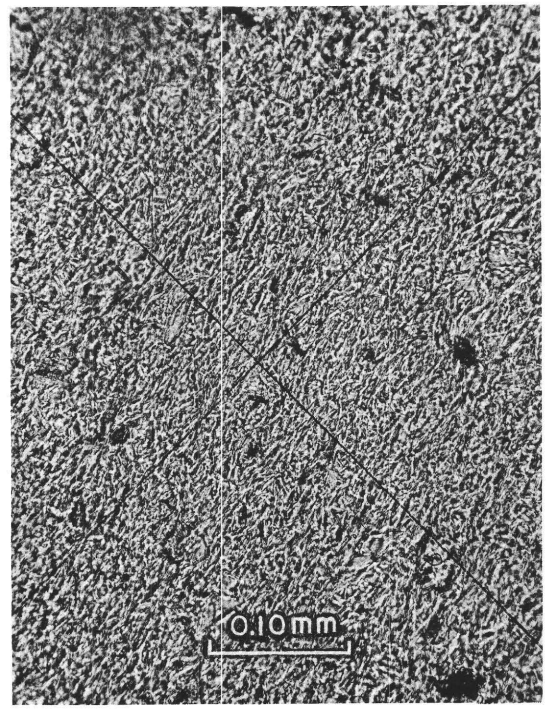

FIGURE 39.—Photomicrograph of bleached rock approximately 75 mm from the area shown in figure 37, showing a part of the same bed. Note absence of hematite. Plane-polarized light.

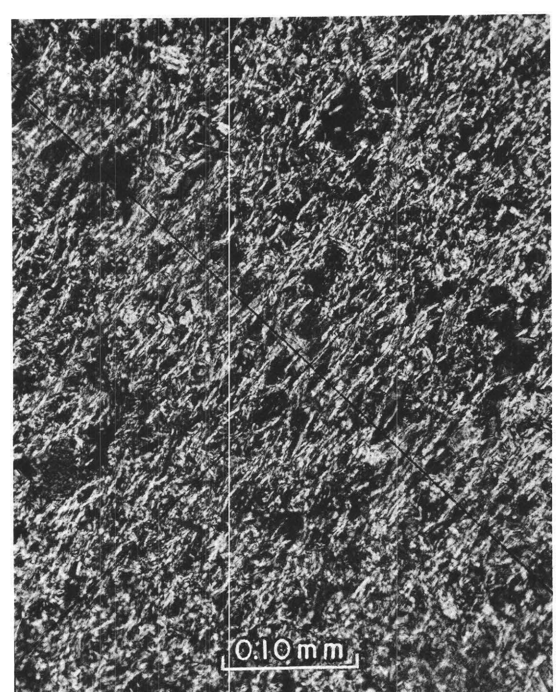

FIGURE 40.—Same as figure 39, crossed nicols.

outcrop or hand specimen. Where these same beds are bleached, on the other hand, the characteristic greasy luster and pale yellow-green color of sericite are strikingly apparent. Without microscopic examination of both bleached and unbleached facies of the same beds, it is understandably easy to conclude that the bleached rocks were sericitized, whereas in fact the sericite content was not changed at all. Sericite is the most abundant constituent of the fine-grained beds of the Belt rocks, regardless of their proximity to bleached zones, but it is only in the bleached zones that the sericite content is obvious.

Extensive sericitization of a quartz-rich rock will increase the amount of potassium in the rock. Chemical analyses of sericitized and unsericitized rocks should therefore show a higher potassium content in the altered rock. Chemical analyses of bleached and unbleached facies of the Belt rocks from the Coeur d'Alene district in themselves provide little evidence for sericitization. The great range in quartz and sericite content of individual beds and the impossibility of tracing a given bed for any considerable distance make sampling difficult. Analyses of single samples of altered rock, or of altered-unaltered pairs taken too far apart to permit recognition of single beds, merely indicate whether the particular samples are sericite-rich or sericite-poor—in effect, whether the bed sampled is slaty or quartzitic. A few analyses have been made from adjacent bleached and unbleached parts of individual beds. Two such pairs of analyses, of samples of Revett, Quartzite (figs. 41–43) collected by Fryklund at the 4500-foot point of the National mine tunnel, are shown in table 25.

TABLE 25.—*Chemical analyses of unaltered and altered quartzite of the Revett Quartzite, adit level, National mine, Coeur d'Alene district, Idaho*

[Members of each pair from same bed. Analyst, Lucille M. Kehl, U.S. Geological Survey]

Constituent	VF-179a-52		VF-180c-52	
	Unaltered	Altered	Unaltered	Altered
SiO_2	81.48	81.06	80.47	78.35
Al_2O_3	8.64	9.04	9.67	11.91
Fe_2O_3	.47	.42	.65	.64
FeO	1.25	.98	1.23	.70
MgO	.33	.28	.34	.25
CaO	.81	1.15	.54	.36
Na_2O	1.08	.13	.83	.06
K_2O	3.21	3.28	3.64	4.55
H_2O-	.18	.11	.20	.09
H_2O+	.91	1.55	1.12	1.79
TiO_2	.31	.38	.28	.53
CO_2	1.10	1.41	.72	.39
P_2O_5	.03	.03	.03	.03
S	.00	.03	.00	.02
MnO	.04	.04	.03	.01
BaO	.07	.07	.07	.07
	99.91	99.96	99.82	99.75
Less O for S	----------	.02	----------	.01
Total	99.91	99.94	99.82	99.74

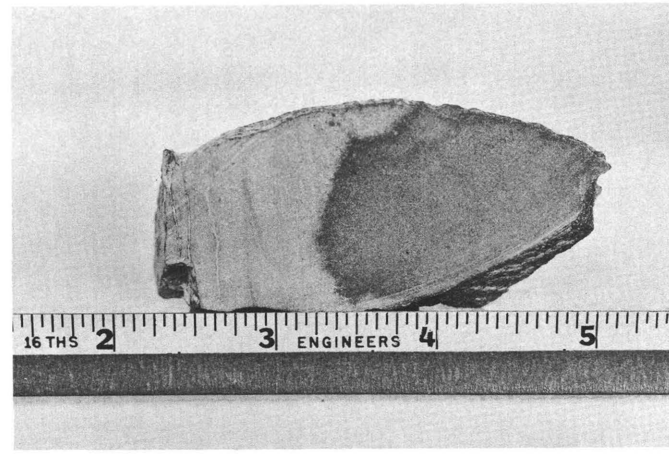

FIGURE 41.—Revett Quartzite, National mine. Darker part on right is unaltered; light gray part on left is bleached. Note bedding planes (vertical in photograph).

Little information is available to indicate how much variation in composition may be expected in a single bed. The two pairs of samples listed above are from closely spaced places in one bed and probably represent the closest spacing possible for minimum composition differences. Nevertheless, the difference in potassium oxide content between the two altered pairs is 1.27 percent and between the two unaltered pairs is 0.43 percent, but the differences between the two altered-unaltered pairs is 0.07 percent and 0.91 percent, respectively. Evidently, local variation in potassium content, even in two closely spaced samples from a single bed, is so great that chemical analyses must be interpreted with extreme caution. Differences in the potassium content of either altered or unaltered rock as great as those shown above clearly demonstrate that proof of sericitization through chemical analysis is, at least in these examples, almost impossible.

A bleached-unbleached pair of samples from a single bed in the Prichard Formation was collected by Fryklund on the 2400 level of the Frisco mine. Chemical analyses of these samples are shown in table 26.

As with the preceding pairs of samples, it is difficult to demonstrate sericitization on the basis of these chemical analyses.

Veinlets of sericite cutting altered rock would constitute evidence for the introduction of sericite. No such veinlets were found during the present study, and no such occurrences have been reported from wall rocks of the Coeur d'Alene district by other workers.

Pseudomorphs of sericite after preexisting minerals together with replacement textures showing partial replacement of other minerals by sericite should be considered as good evidence in support of sericitization. The recognition of possible pseudomorphs is made diffi-

TABLE 26.—*Chemical analyses of unaltered and altered rocks from the Prichard Formation, 2400 level, Frisco mine, Coeur d'Alene district, Idaho*

[Analyst, L. D. Trumbull, U.S. Geological Survey]

Constituent	VCF-286U-53 (unaltered)	VCF-286A-53 (altered)
SiO_2	83.63	84.47
Al_2O_3	8.78	7.90
Fe_2O_3	.42	.36
FeO	1.97	1.77
MgO	.28	.25
CaO	.00	.00
Na_2O	.13	.07
K_2O	2.61	2.43
H_2O-	.04	.03
H_2O+	1.14	.98
TiO_2	.45	.40
CO_2	.16	.91
P_2O_5	.03	.03
MnO	.17	.16
Total	99.81	99.76

cult because of the presence and local abundance of rock fragments and interstitial mud; much of the latter was converted to sericite during regional metamorphism. Two features assist in distinguishing rock fragments from partly or completely sericitized mineral grains of other types: (1) the close association of such material with fresh, completely unaltered feldspars in both altered and unaltered rocks (figs. 34, 35, 44–47) and (2) the preferred orientation of the sericite in what was originally mud or fine-grained rock fragments (figs. 34, 35). If the sericite in the rock fragments formed through hydrothermal sericitization, it should be distinguishable from sericite formed during regional metamorphism by virtue of its random orientation. And if sericite were introduced during a period of hydrothermal alteration, detrital feldspar, especially plagioclase feldspar, should show at least some degree of alteration (Schwartz, 1947, p. 347, 348). Rock fragments in Belt rocks contain oriented sericite, some of which is oriented parallel to the interstitial sericite scattered through the rocks, and sericite-rich rock fragments can be found side by side with completely unaltered feldspar in both bleached and unbleached rocks (figs. 34, 35, 44–46). In fact, all the feldspar seen in the rocks is remarkable for its freshness.

The rock fragments could have been mistaken for sericitized feldspar in the past; they have rounded, irregular, or blocky shapes that might readily be mistaken for detrital grains of individual minerals, except for their characteristically dirty appearance (figs. 34, 35, 44–46). Feldspars are generally comparatively uncommon constituents of the rocks, and orthoclase, particularly, may easily be overlooked; the likelihood is thus increased that sericite-rich rock fragments be mistaken for sericitized feldspar.

The preferred orientation of the sericite in the Coeur d'Alene rocks requires further comment. The rocks typically have well-developed axial plane cleavage, a

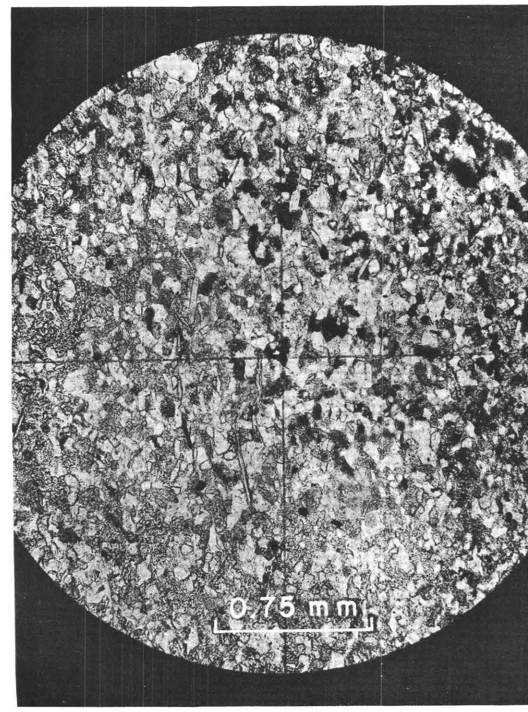

FIGURE 42.—Contact between bleached (left) and unbleached (right) parts of the specimen shown in figure 41. Pigmenting mineral in unbleached part is chlorite. Note elongate detrital muscovite grains, whose long axes indicate bedding. Plane-polarized light.

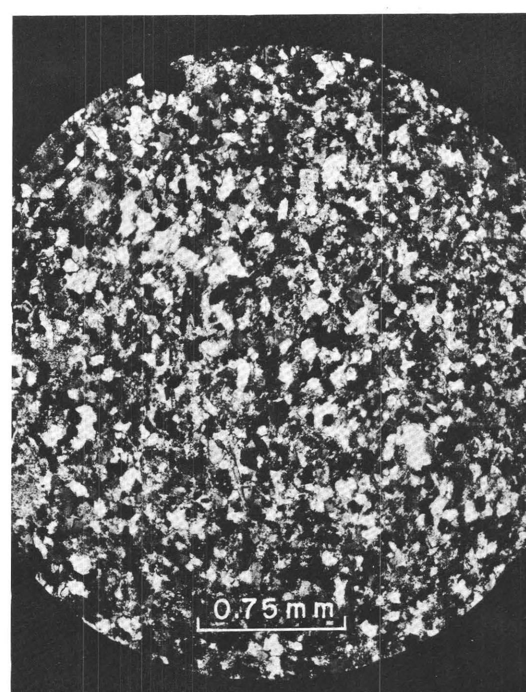

FIGURE 43.—Same as figure 42, crossed nicols.

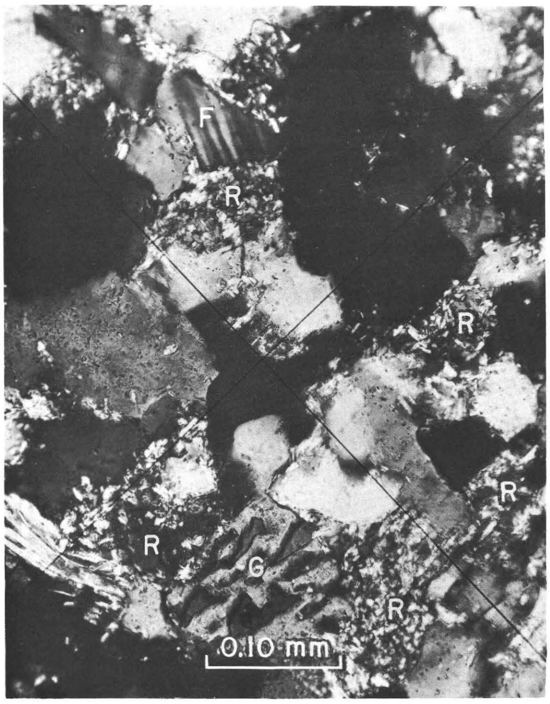

FIGURE 44.—Unaltered Revett Quartzite (same specimen as shown in figs. 41–43. Note plagioclase, F; granophyre grains, G; rock fragments, R. Crossed nicols.

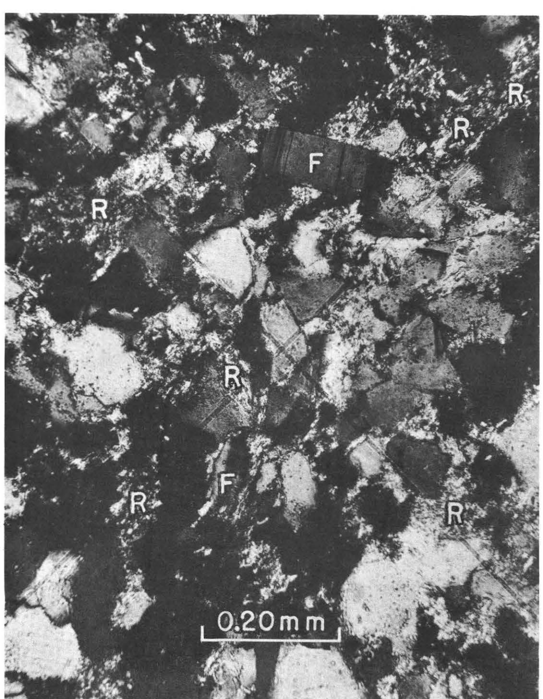

FIGURE 45.—Altered Revett Quartzite. Field shown in photograph is less than 1 cm from the field shown in fig. 44. Note plagioclase, F; rock fragments, R. Crossed nicols.

macroscopic reflection of the preferred orientation of the sericite observed in thin section (figs. 34, 38, 40, 46, 47). Many specimens have more than one direction of preferred orientation (fig. 46). Inasmuch as the cleavage and sericite orientation are related to the major and minor folds of the district, the sericite must have formed at the same time as the folds, and must be included among the metamorphic minerals that are typical of the Belt rocks. Conversion of silt, clay, and mudstone to sericite is a common process in low-grade regional metamorphism, and the presence of sericite in low-grade metamorphic rocks is a very characteristic feature. Later sericite, introduced into a stress-free environment, would be expected to form with random orientation. The absence of randomly oriented sericite is further evidence that none was introduced after metamorphism.

Enlargement of preexisting sericite might be expected in sericitized rocks. Although little is known about the degree of enlargement that might take place, the presence of coarse sericite, or of a generally coarser texture in altered rock, and the recognition of oriented overgrowths on sericite grains could certainly be taken as evidence supporting sericitization. No such features were found.

A conspicuous feature in many mining districts where sericitization is recognized as an important form of hydrothermal alteration is the existence of pronounced intensity gradients—differences in the intensity of alteration and in the sericite content—which are commonly related to well-defined structural features and often to concentrations of ore (Schwartz, 1947, p. 347–348; 1955, p. 302–304). Although zones of most intense sericitization may not always surround the richest ore, in many districts this relation is found. In any district where sericitization is important, concentration gradients should normally exist and they should show a relation to structural features that acted as channelways. No systematic relation of sericite content to structural features (other than bedding, which reflects original compositional differences) are known to exist in the Coeur d'Alene district. Furthermore, Mitcham (1952, p. 424) showed an inverse relation of sericite content of wallrock to richness of ore in at least one mine.

Although it is reasonable to expect that critical examination of altered rock might fail to show all the features listed as criteria for sericitization, the failure to find any one of them can mean only one thing: The alteration is not sericitization. The same type of criteria convinces me that silicification, too, must be eliminated from consideration as the agent responsible for bleaching.

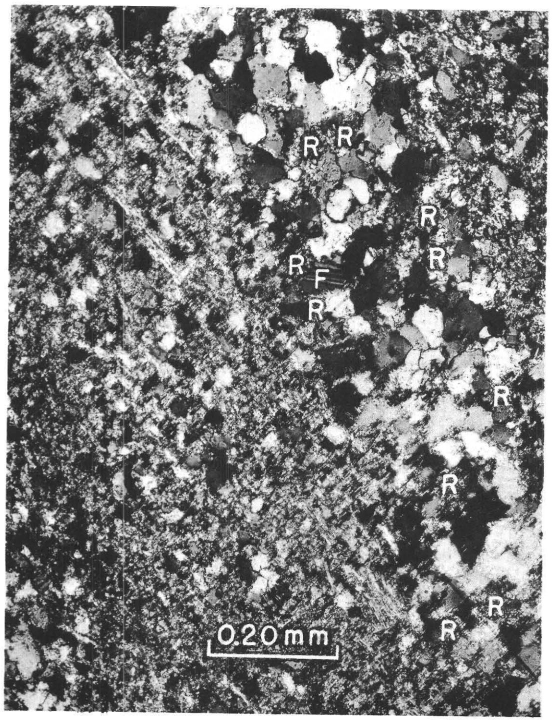

FIGURE 46.—Altered St. Regis Formation. Carbonate Hill (Atlas) mine. Note plagioclase grain, F; and rock fragments, R, in coarse bed, and two directions of preferred orientation of sericite. Crossed nicols.

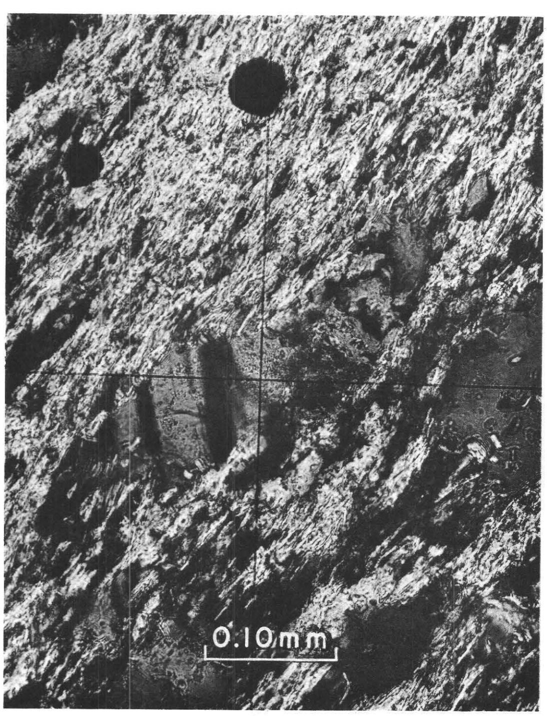

FIGURE 47.—Altered St. Regis Formation, Carbonate Hill (Atlas) mine at higher magnification. Note pronounced orientation of sericite and the fresh plagioclase grain. Crossed nicols.

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CAUSE OF BLEACHING

Consideration of the alteration process in terms of what it is not, provides few clues as to what it is. The bleached rocks have obviously been altered, as shown by striking differences in color. The relation of the bleaching to a variety of both large- and small-scale structural features, to differences in intensity of bleaching, and to general association of bleaching and ore deposits all point to some form of hydrothermal process. An examination of the mineralogical differences between bleached and unbleached rocks helps to show something of the nature of the hydrothermal solutions that caused the alteration.

The typical unbleached rocks of the Coeur d'Alene district may contain some or all of the following minerals:

Quartz	Tourmaline	Pyrite
Sericite	Hematite	Leucoxene
Feldspars	Magnetite	Carbonaceous material(?)
Carbonates	Zircon	
Chlorite	Rutile	

The bleached rocks, in general, contain all the above minerals except hematite, green chlorite, and carbonaceous material(?), and locally they may also lack pyrite or magnetite, or both. Goethite and leucoxene are present in most of the bleached rock, and also in some of the unbleached rock—though in the unbleached rock the goethite is an alteration, partial or complete, of magnetite. The composition, temperature, and pH of any hydrothermal solution causing bleaching must therefore be such that the potentially easily altered minerals (carbonates and feldspars, for example) are left unaffected, yet the hematite and chlorite must be unstable. The solution may have varied sufficiently in composition that magnetite, pyrite, leucoxene, and goethite were stable in some places and unstable in others. Finally, the solution must not have added significant amounts of new material— carbonate, sulfide, potassium, silica—to replace other minerals or to change the bulk composition of the rock by simple addition.

The precise composition, temperature, and acidity of such a solution cannot be stated. However, data from a variety of sources serve to outline some of the limits of the solution.

The Eh-pH stability field of hematite (following Huber and Garrels, 1953, p. 352) covers a rather wide range of Eh and pH values; however, there is also a wide range of Eh and pH values under which hematite is not stable. The solutions may well have been nearly neutral. The work of Posnjak and Merwin (1919; 1922), Smith and Kidd (1949), and Schmalz (1959) suggests that with pure water, or water containing only small amounts of various salts, hematite will alter to goethite in the temperature range of 130° C to 175° C, depending on the pressure. Goethite pseudomorphs after the minute hematite plates have not been recognized, but this absence is not surprising for the minute amounts of goethite probably were dispersed by the altering solutions. (Such pseudomorphs after the much larger magnetite grains are common.)

The loss of color of the chlorite probably reflects the loss of a small amount of iron, but the amount of degradation of the chlorite is not known.

The loss of the so-called carbonaceous(?) material in the bleaching process strongly suggests that it is not graphite.

If hydrothermal solutions destroyed, or degraded in the case of chlorite, some of the iron-bearing minerals, what happened to the iron? Several possibilities exist: The iron may have (1) been carried out in solution, (2) combined as part of the carbonates, (3) reacted with hydrogen sulfide to form pyrite, or (4) aggregated into larger grains, perhaps of goethite. At any one place, any one or more of these processes may have been in operation, but it was not possible to recognize which process was in operation at any one place. The iron of the pigmenting minerals makes up only a small fraction of the total iron in most of the rocks, and chemical analyses have revealed no significant change in iron content between bleached and unbleached rock. All that can be said with assurance is that the minerals that gave the unbleached rocks their colors are absent in bleached rock. Further studies, requiring many samples and chemical analyses, would be required to determine the fate of the iron with assurance.

The present study has succeeded, I believe, in demonstrating that the bleaching in the Coeur d'Alene district was a hydrothermal process that affected only a few minerals in the rocks, and which accomplished the alteration without the addition of significant amounts of new material—and perhaps without removing a significant amount of material, either. However, much remains to be learned of the process. The presence of many ore bodies within bleached zones implies a relation of channelways of bleaching solutions to channelways of ore solutions. This relation does not hold throughout the district, however, or even throughout the area of bleaching. Apparently the bleaching and ore deposition were sufficiently separated in time to allow the development of some new structural features and the sealing of some of the old ones, after the one process was completed and before the other process began. Fryklund (p. 30) suggests that bleaching may be older than the time of uraninite-vein formation.

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